REPUBLIC OF KENYA

LEARNING GUIDE

FOR

CIVIL ENGINEERING TECHNOLOGY

LEVEL 6

TVET CDACC
P.O. BOX 15745-00100
NAIROBI

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FOREWORD

The provision of quality education and training is fundamental to the Government's overall strategy for social economic development. Quality education and training will contribute to achievement of Kenya's development blueprint and sustainable development goals.

Reforms in the education sector are necessary for the achievement of Kenya Vision 2030 and meeting the provisions of the Constitution of Kenya 2010. The education sector had to be aligned to the Constitution and this resulted to the formulation of the Policy Framework for Reforming Education and Training (Sectional Paper No. 4 of 2016). A key feature of this policy is the radical change in the design and delivery of the TVET training. This policy document requires that training in TVET be competency based, curriculum development be industry led, certification be based on demonstration of competence and mode of delivery allows for multiple entry and exit in TVET programmes.

These reforms demand that Industry takes a leading role in curriculum development to ensure the curriculum addresses its competence needs. It is against this background that this curriculum has been developed.

It is my conviction that this curriculum will play a great role towards development of competent human resource for the construction sector.

PRINCIPAL SECRETARY, VOCATIONAL AND TECHNICAL TRAINING
MINISTRY OF EDUCATION

PREFACE

Kenya Vision 2030 aims to transform the country into a newly industrializing, “middle-income country providing a high-quality life to all its citizens by the year 2030”. Kenya intends to create a globally competitive and adaptive human resource base to meet the requirements of a rapidly industrializing economy through life-long education and training. TVET has a responsibility of facilitating the process of inculcating knowledge, skills and attitudes necessary for catapulting the nation to a globally competitive country, hence the paradigm shift to embrace Competency Based Education and Training (CBET).

The Technical and Vocational Education and Training Act No. 29 of 2013 and Sectional Paper No. 4 of 2016 on Reforming Education and Training in Kenya, emphasized the need to reform curriculum development, assessment and certification. This called for a shift to CBET in order to address the mismatch between skills acquired through training and skills needed by industry as well as increase the global competitiveness of Kenyan labour force.

TVET Curriculum Development, Assessment and Certification Council (TVET CDACC) in conjunction with Construction Sector Skills Advisory Committee (SSAC) have developed this curriculum.

This curriculum is designed and organized with an outline of learning outcomes; suggested delivery methods, training/learning resources and methods of assessing the trainee’s achievement. The curriculum is competency-based and allows multiple entry and exit to the course.

I am grateful to the Council members, Council Secretariat, Construction SSAC, expert workers and all those who participated in the development of this curriculum.

Prof. CHARLES M. M. ONDIEKI, PhD, FIET (K), Con. EngTech.
CHAIRMAN, TVET CDACC

ACKNOWLEDGEMENT

This curriculum has been designed for competency-based training and has independent units of learning that allow the trainee flexibility in entry and exit. In developing the curriculum, significant involvement and support was received from various organizations.

I recognize with appreciation the role of Construction Sector Skills Advisory Committee (SSAC) members for their contribution to the development of this curriculum.
I also thank all stakeholders in the construction sector for their valuable input and all those who participated in the process of developing this curriculum.
I am convinced that this curriculum will go a long way in ensuring that workers in the Construction industry acquire competencies that will enable them to perform their work more efficiently.

Dr. LAWRENCE GUANTAI M'ITONGA, PhD
COUNCIL SECRETARY/CEO

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CHAPTER 1: INTRODUCTION

1.1 Background Information

This learning guide has been developed in line with the functions of TVET CDACC as stipulated in Article 45 (1a) of the Technical and Vocational Education and Training (TVET) Act No. 29 of 2013 and the Sessional Paper No. 2 of 2015 that embraces Competency Based Education and Training (CBET) system. It is, therefore, the sole intent of this document to provide guidelines for a Competency-Based Civil engineering curriculum for level 6.

Civil engineering level 6 qualifications consist of competencies that an individual must achieve to create visual concepts either using a computer software or by hand, communicate ideas that inform, captivate or inspire others via digital media, creative publishing of advertisements, magazines, corporate reports and brochures. This learning guide consists of interactive learning activities, content, further reading, self-assessment, relevant and related references that enhance implemention of Civil engineering Level 6 qualification. It enables the trainee to acquire the competencies that enables him/her to undertake the various processes in Civil engineering. The guide further provides illustrations, web links, case studies, examples and resources on how to implement all the learning outcomes/elements described in the Curriculum and Occupational Standards with a particular focus on the trainee.

1.2 The Purpose of Developing the Learning Guide

Civil engineering Level 6 curriculum development process was initiated using the DACUM methodology where jobs/occupations were identified. Further, job analysis charts and occupational standards were generated in collabouration with the industry players under the guidance of TVET CDACC (Curriculum Development Assessment and Certification Council). The result of the process was Civil engineering Level 6 Occupational Standard (OS) and Curriculum. The Curriculum was further broken down into units of learning. To effectively implement Civil engineering Level 6 Occupational standard and Curriculum, learning guides are required to provide training content, guide the learners and trainers on the learning process aimed at imparting the relevant knowledge, requisite skills and the right work behaviour/attitude to the industry. Learning guides are part of the training materials.

1.3 Layout of the learning guide

The learning guide is organized as per chapters. Chapter one presents the background information and purpose of developing the trainee guide. Each of the units of learning/unit of competency is presented as a chapter on its own. Each chapter presents the introduction of the unit of learning/unit of competency, performance standard and list of the learning outcomes/elements in the occupational standards.

1.4 Learning Activities

For each learning outcome, the learning activities are presented by covering the performance criteria statements and trainee's demonstration of knowledge in relation to the range in the occupational standard and content in the curriculum.

1.5 Information Sheet

The information sheet is a section under each learning outcome that provides the subject matter in relation to definition of key terms, methods, processes/procedures/guidelines, content, illustrations (photographs, pictures, video, charts, plans, digital content, and simulation) and case studies.

1.6 Self-Assessment

Self-assessment is linked to the performance criteria, required knowledge, skills and the range as stated in the occupational standards. This section further provides questions and assignments in which trainees demonstrate that they have acquired the required competences and an opportunity to reflect on what they have acquired. It is expected that the trainer keeps a record of their plans, their progress and the problems they encountered which will go in trainee's portfolio. A portfolio assessment consists of a selection of evidence that meets the pre-defined requirements of complexity, authenticity and reliability. The portfolio starts at the beginning of the training and will be the evidence for the development and acquisition of the competence (summative and formative) by the trainee. It is important to note that Portfolio assessment is highly emphasized in the learning guide.

Finally, the guide presents tools, equipment, supplies and materials for each learning outcome as guided by the performance criteria in the occupational standards and content in the curriculum. References, relevant links and addendums are provided for further study. The units of competency comprising this qualification include the following common and core units of learning:

Common units of learning

Unit of Learning Code	Unit of Learning Title	Duration in Hours	Credit Factor
ENG/CU/CET/CC/01/6/A	Applied Mathematics	80	8
ENG/CU/CET/CC/02/6/A	Technical Drawing	60	6
ENG/CU/CET/CC/03/6/A	Structural design and analysis	70	7
ENG/CU/CET/CC/04/6/A	Material Science	90	9
ENG/CU/CET/CC/05/6/A	Workshop technology practices	130	13
ENG/CU/CET/CC/06/6/A	Measurement of works and cost estimation	80	8
ENG/CU/CET/CC/07/6/A	Water and wastewater technology	120	12
ENG/CU/CET/CC/08/6/A	Water resources, water services and sanitation management principles	120	12
Total		**750**	**75**

Core units of learning

Unit of Learning Code	Unit of Learning Title	Duration in Hours	Credit Factor
ENG/CU/CET/CR/01/6/A	Material Testing	150	15
ENG/CU/CET/CR/02/6/A	Highway Survey	190	19
ENG/CU/CET/CR/03/6/A	Designing pavement structures	120	12
ENG/CU/CET/CR/04/6/A	Road construction works	150	15
ENG/CU/CET/CR/05/6/A	Design of engineering structures	220	22
ENG/CU/CET/CR/06/6/A	Building drawings	200	20
ENG/CU/CET/CR/07/6/A	Building works	200	20
ENG/CU/CET/CR/08/6/A	Water resource quality management	60	6
ENG/CU/CET/CR/09/6/A	Design of wastewater collection and treatment infrastructure	200	20
ENG/CU/CET/CR/10/6/A	Construction of wastewater infrastructure	180	18
ENG/CU/CET/CR/11/6/A	Designing onsite sanitation facilities	80	8

ENG/CU/CET/CR/12/6/A	Construction of onsite sanitation facilities	80	8
ENG/CU/CET/CR/13/6/A	Civil engineering project management	120	12
	Industrial Attachment	480	48
Total		**2430**	**243**
Grand Total		**3540**	**354**

The total duration of the course is. **3,540** Hours

Entry Requirements

An individual entering this course should have any of the following minimum requirements:

a) Civil Engineering craft certificate Level 5

Or

b) Kenya Certificate of Secondary Education (KCSE) C- (C Minus)

Or

c) Equivalent qualifications as determined by Kenya National Qualifications Authority (KNQA)

Assessment

The course will be assessed at two levels: internally and externally. Internal assessment is continuous and is conducted by the trainer who is monitored by an accredited internal verifier while external assessment is conducted by accredited external assessors appointed by TVET CDACC.

Certification

A candidate will be issued with a National Certificate of competency on demonstration of competence in a unit of competency. To attain the National Civil engineering Diploma Level 6, the candidate must demonstrate competence in all the units of competency as given in qualification pack. These certificates will be issued by TVET CDACC in conjunction with training provider.

CHAPTER 2: ENGINEERING MATHEMATICS

2.1 Introduction

This unit describes the competencies required by a technician in order to apply a wide range of mathematical skills in their work; apply ratios, rates and proportions to solve problems; estimate, carry out measurement; collect, organize and interpret statistical data; use common formulae and algebraic expressions to solve problems.

2.2 Performance Standard

The trainee will apply algebra, trigonometry and hyperbolic functions, complex numbers, coordinate geometry, carryout binomial expansion, calculus ordinary differential equations, Laplace transforms, power series, statistics Fourier series, vector theory, matrix and numerical methods in solving engineering problems.

2.3 Learning Outcomes

2.3.1 List of learning outcomes

a) Apply algebra
b) Apply trigonometry and hyperbolic functions
c) Apply complex numbers
d) Apply coordinate geometry
e) Carry out binomial expansion
f) Apply calculus
g) Solve ordinary differential equations
h) Carry out mensuration
i) Apply power series
j) Apply statistics
k) Apply numerical methods
l) Apply vector theory
m) Apply matrix

2.3.2 Learning Outcome No 1: Apply Algebra

2.3.2.1 Learning Activities

Learning Outcome No 1: Apply Algebra	
Learning Activities	**Special Instructions**
1.1 Perform calculations involving Indices 1.2 Perform calculations involving Logarithms 1.3 Use scientific calculator to solve mathematical problems 1.4 Perform simultaneous equations 1.5 Calculate quadratic equations	• Group assignments

2.3.2.2 Information Sheet No2/LO 1: Apply Algebra

Introduction

This learning outcome covers algebra and the learner should be able to: perform calculations involving Indices as per the concept; perform calculations involving Logarithms as per the concept; use scientific calculator is used mathematical problems in line with manufacturer's manual; perform simultaneous equations as per the rules. Algebra is used throughout engineering, but it is most commonly used in mechanical, electrical, and civil branches due to the variety of obstacles they face. Engineers need to find dimensions, slopes, and ways to efficiently create any structure or object.

Definition of key terms

Algebra is the study of mathematical symbols and the rules for manipulating these symbols; it is a unifying thread of almost all of mathematics. It includes everything from elementary equation solving to the study of abstractions such as groups, rings, and fields.

Content/Procedures/Methods/Illustrations

1.1 Calculations involving Indices are performed as per the concept

Indices

An i**ndex** number is a number which is raised to a power. The power, also known as the index, tells you how many times you have to multiply the number by itself. For example, 2^5 means that you have to multiply 2 by itself five times $= 2 \times 2 \times 2 \times 2 \times 2 = 32$

Laws of indices

(i) $x^0 = 1$

(ii) $x^{-n} = \frac{1}{x^n}$

(iii) $x^n . x^m = x^{n+m}$

(iv) $x^n - x^m = x^{n-m}$

(v) $(x^n)^m = x^{m.n}$

(vi) $x^{\frac{n}{m}} = \sqrt[m]{x^n}$

Application of rules of indices in solving algebraic problems

a) y^a x $y^b = y^{a+b}$

Examples:

2^4 x $2^8 = 2^{12}$

5^4 x $5^{-2} = 5^2$

b) $y^a \div y^b = a - b$

Examples

$5^4 \div 5^8 = 5^{-4}$

$7^4 \div 7^{-2} = 7^6$

c) $ym/n = (n\sqrt{y})m$

Examples

$16^{1/2} = \sqrt{16} = 4$

$8^{2/3} = (\sqrt[3]{8})^2 = 4$

d) $(y^n)^m = y^{nm}$

Example

$2^5 + 8^4$

$= 25 + (2^3)^4$

$= 2^5 + 2^{12}$

e) $y^0 = 1$

Example

$5^0 = 1$

1.2 Calculations involving Logarithms are performed as per the concept

If **a** is a positive real number other than 1, then the logarithm of **x** with base **a** is defined By:

$$y = \log_a x \quad \text{or } x = a^y$$

Laws of logarithms

(i) $\log_a(xy) = \log_a x + \log_a y$

(ii) $\log_a\left(\frac{x}{y}\right) = \log_a x - \log_a y$

(iii) $\log_a(x^n) = n\log_a x$ for every real number

1.3 Scientific calculator is used in solving mathematical problems

Use the scientific calculator manufacturer's manual on the steps to be followed in doing so.

1.4 Simultaneous equations are performed as per the rules

Simultaneous equations are equations which have to be solved concurrently to find the unique values of the unknown quantities which are time for each of the equations. Two common methods of solving simultaneous equations analytically are:

(i) By substitution

(ii) By elimination

Simultaneous equations with three unknowns

Examples

Solve the following simultaneous equation by substitution methods

$3x - 2y + = 1 \dots\dots\dots..(i)$

$x - 3y + 2z = 13 \dots\dots.(ii)$

$4x - 2y + 3z = 17 \dots\dots\dots(iii)$

From equation (ii) $x = 13 + 3y - 2z$

Substituting these expression $(13 + 3y - 2z$ for x gives)

$3(13 + 3y - \ \ 2z) + 2y + z = 1$

$39 + 9y - 6z + 2y + x = 1$

$11y - 5z = \ -38 \dots\dots\dots\dots\dots..(iv)$

$4(13 + 3y - 2z) + 3z - 2y = 17$

$52 + 12y - 8z + 3z - 2y = 17$

$10y - 5z = -35 \dots..(v)$

Solve equation (iv) and (v) in the usual way,

From equations (iv) $5z = 11y + 38; z = \frac{11y+38}{5}$

Substituting this in equation (v) gives:

$10y - 5\left(\frac{11y+38}{5}\right) = -35$

$10y - 11y - 38 = -35$

$-y = -35 + 38 = 3$

$y = -3$

$$z = \frac{11y + 38}{5} = \frac{-33 + 38}{5} = \frac{5}{5} = 1$$

But $x = 13 + 3y - 2z$

$x = 13 + 3(-3) - 2(1)$

$=13 - 9 - 2$

$=2$

Therefore, $x = 2$, $y = -3$ and $z = 1$ is the required solution

For more worked examples on substitution and elimination method refer to Engineering Mathematics by A.K Stroud.

1.5 Quadratic equations are calculated as per the concept

Quadratic Equations

Quadratic equation is one in which the highest power of the unknown quantity is 2. For example, $2x^2 - 3x - 5 = 0$ is a quadratic equation.

The general form of a quadratic equation is $ax^2 + bx + c = 0$, where a, b and c are constants and $a \neq 0$ of solving quadratic equations.

1) By factorization (where possible)
2) By completing the square
3) By using quadratic formula
4) Graphically

Example

Solve the quadratic equation $x^2 - 4x + 4 = 0$ by factorization method

Solution

$x^2 - 4x + 4 = 0$

$x^2 - 2x - 2x + 4 = 0$

$x(x - 2) - 2(x - 2) = 0$

$(x - 2)(x - 2) = 0$

i.e. $x - 2 = 0$ or $x - 2 = 0$

$x = 2$ or $x = 2$

I.e. the solution is $x = 2$ (twice)

For more worked examples on how to solve quadratic equations using, factorization, completing the square, quadratic formula refers to basic engineering mathematics by J.O Bird, Engineering mathematical by K.A strand, etc.

Conclusion

The learning outcome covered or equipped the learner with knowledge, skills and attitude to perform calculations involving Indices as per the concept; perform calculations involving Logarithms as per the concept; use scientific calculator in mathematical problems in line with manufacturer's manual; perform simultaneous equations as per the rules.

Further Reading

1. Stroud, A.K. (n.d.). Engineering Mathematics

2.3.2.3 Self-Assessment

Written Assessment

1. Solve the following by factorization
    a) $x^2 + 8x + 7 = 0$
    b) $x^2 - 2x + 1 = 0$
2. Solve by completing the square the following quadratic equations
    a) $2x^2 + 3x - 6$
    b) $3x^2 - x - 6 = 0$
3. Simplify as far as possible
    a) $\log(x^2 + 4x - 3) - \log(x + 1)$
    b) $2\log(x - 1) - \log(x^2 - 1)$
4. Solve the following simultaneous equations by the method of substitution
    a) $x + 3y - z = 2$
    b) $2x - 2y + 2z = 2$
    c) $4x - 3y + 5z = 5$

5. Simplify the following

$$F = (2_{x}^{\frac{1}{2}}y^{\frac{1}{4}})^4 \div \sqrt{\frac{1}{9}x^2y^6} \text{ x } (4\sqrt{x^2y^4})^{-1/2}$$

Oral Assessment

What is your understanding of algebra?

2.3.2.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Dice
- Computers with internet connection

2.3.2.5 References

Khuri, A. I. (2003). Advanced calculus with applications in statistics (No. 04; QA303. 2, K4 2003.). Hoboken, NJ: Wiley-Interscience.

Stoer, J., &Bulirsch, R. (2013). Introduction to numerical analysis (Vol. 12). Springer Science & Business Media.

Zill, D., Wright, W. S., & Cullen, M. R. (2011). Advanced engineering mathematics. Jones & Bartlett Learning.

2.3.3 Learning Outcome No 2: Apply Trigonometry and Hyperbolic Functions

2.3.3.1 Learning Activities

Learning Outcome No 2: Apply Trigonometry and Hyperbolic Functions	
Learning Activities	**Special Instructions**
2.1 Perform calculations using trigonometric rules 2.2 Perform calculations using hyperbolic functions	

2.3.3.2 Information Sheet No2/LO2: Apply Trigonometry and Hyperbolic Functions

Introduction

This learning outcome equips the learner with knowledge and skills to perform calculations using trigonometric rules and hyperbolic functions.

Definition of key terms

Trigonometry: This is a branch of mathematics which deals with the measurement of sides and angles of triangles and their relationship with each other. Two common units used for measuring angles are degrees and radians.

Content/Procedures/Methods/Illustrations

2.1 Calculations are performed using trigonometric rules

Trigonometric ratios

The three trigonometric ratios derived from a right-angled triangle are the sine, cosine and tangent functions. Refer to basic engineering mathematics by J.0 Bird to read move about trigonometry ratios.

Solution for right angled triangles

To solve a triangle means to find the unknown sides and angles; this is achieved by using the theorem of Pythagoras and or using trigonometric ratios.

Example

Express $3\,\text{Sin}\,\theta + 4\,\text{Cos}\theta$ in the general form $R\,\text{Sin}(\theta + \alpha)$

Let $3\,\text{Sin}\,\theta + 4\,\text{Cos}\,\theta = R\,\text{Sin}\,(\theta + \alpha)$

Expanding the right-hand side using the compound angle formulae gives

$3\,\text{Sin}\,\theta + 4\,\text{Cos}\,\theta = R\,[\text{Sin}\theta\,\text{Cos}\alpha + \text{Cos}\,\theta\,\text{Sin}\alpha\,]$

$= R\,\cos\alpha\,\text{Sin}\,\theta + R\,\text{Sin}\,\alpha\,\text{Cos}\,\theta$

Equating the coefficient of:

$\text{Cos}\theta: = \text{R Sin}\,\alpha$ i.e $\text{Sin}\,\alpha = \dfrac{4}{\text{R}}$

$\text{Sin}\,\theta: \quad 3 = \text{R Cos}\,\alpha$ i.e $\text{Cos}\,\alpha = \frac{3}{\text{R}}$

These values of R and α can be evaluated.

$\text{R} = \sqrt{4^2 + 3^2 = 5}$

$\alpha = \tan^{-1}\dfrac{4}{3} = 53.13^0 \text{or } 233.13^0$

Since both Sin α and Cos α are positive, r lies in the first quadrant where all are positive, hence 233.13^0 is neglected.

Hence

$3\ \text{Sin}\theta + 4\ \text{Cos}\ \theta = 5\ \text{Sin}\ (\theta + 53.13^0)$

Example

Solve the equation $3\ \text{Sin}\ \theta + 4\ \text{Cos}\ \theta = 2$ for values of θ between 0^0 and 360^0 inclusive

Solution

From the example above

$3\ \text{Sin}\theta + 4\ \text{Cos}\ \theta = 5\ \text{Sin}\ (\theta + 53.13^0)$

Thus

$5\ \text{Sin}(\alpha + 53.13^0) = 2$

$\text{Sin}(\theta + 53.13^0) = \dfrac{2}{5}$

$\theta + 53.13^0 = \text{Sin}^{-1}\ 2/5$

$\theta + 53.13^0 = 23.58^0 \text{or } 156.42^0$

$\theta = 23.58^0 - 53.13^0 = -29.55^0$

$=330.45^0$

OR $\theta = 156.42^0 - 53.13^0$

$=103.29^0$

Therefore, the roots of the above equation are 103.29^0 or 330.45^0

For more worked examples refer to Technician mathematics book 3 by J.) Bird.

Double/multiple angles

For double and multiple angles refer to Technician mathematics by J.O Bird

Factor Formulae

For worked exampled refer to Technic mathematics book 3 by J. O Bird, Pure mathematics by backhouse and Engineering mathematics by KA Stroud.

Half-angle formulae

Refer to pure mathematics by backhouse and Engineering mathematics by K.A STROUD

2.2 Calculations are performed using hyperbolic functions

Hyperbolic functions

Definition of hyperbolic functions, Sinhx cosh x and tanh x

- Evaluation of hyperbolic functions
- |Hyperbolic identifies
- Osborne's Rule
- Solve hyperbolic equations of the form a $\cosh x + b\sinh x = C$

For all the above refer, to engineering mathematics by KA strand.

Conclusion

The learning outcome covered or equipped the learner with knowledge, skills and attitude to perform calculations using trigonometric rules and perform calculations using hyperbolic functions.

Further Reading

1. Stoer, J., &Bulirsch, R. (2013). Introduction to numerical analysis (Vol. 12). Springer Science & Business Media.

2.3.3.3 Self-Assessment

Written Assessment

1. A surveyor measures the angle of elevation of the top of a perpendicular building as19^0. He moves 120m nearer the building and measures the angle of elevation as47^0. Calculate the height of the building to the nearest meter.

2. Solve the equation $5\cos\theta + 4\,\mathrm{Sin}\theta = 3$ for values of θ between 0^0 and 360^0 Inclusive.
3. Prove their identifies
    a) $\mathrm{Cash}\ 2x = \mathrm{cash}^2 x + \mathrm{Sinh}^2 x$
    b) $\mathrm{Sinh}(x + y)\mathrm{SinhCoshy}\ + \mathrm{coshySinhx}$
4. Solve the equation
5. $3\ \mathrm{Sinhx} + 4\ \mathrm{Coshx} = 5$

2.3.3.4 Tools, Equipment, Supplies and Materials

- Scientific calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Dice
- Computers with internet connection

2.3.3.5 References

Khuri, A. I. (2003). Advanced calculus with applications in statistics (No. 04; QA303. 2, K4 2003.). Hoboken, NJ: Wiley-Interscience.
O'Neil, P. V. (2011). Advanced engineering mathematics. Cengage learning.
Stoer, J., &Bulirsch, R. (2013). Introduction to numerical analysis (Vol. 12). Springer Science & Business Media.

2.3.4 Learning Outcome No 3: Apply Complex Numbers

2.3.4.1 Learning Activities

Learning Outcome No3: Apply Complex Numbers	
Learning Activities	**Special Instructions**
3.1 Represent complex numbers are represented 3.2 Perform operations involving complex numbers are performed 3.3 Perform calculations involving complex numbers	

2.3.4.2 Information Sheet No2/LO3: Apply complex numbers

Introduction

This learning outcome covers an introduction to complex numbers, their representation in argand diagrams and calculations involving complex numbers using De Moivre's theorem

Definition of key terms

Argand diagram: A diagram on which complex numbers are represented geometrically using Cartesian axes; the horizontal coordinate representing the real part of the number and the vertical coordinate representing the imaginary part of the number, as depicted below

Content/Procedures/Methods/Illustration

A number of the form $a + ib$ is called complex number where a and b are real numbers and $i = \sqrt{-1}$ we call $'a'$ the real part and 'b' the imaginary part of the complex $a + ib$ if $a = o$ then ib is said to be purely imaginary, if $b = 0$ the number is real.
Pair of complex number $a + ib$ are said to be conjugate of each other.

Addition and subtraction of complex numbers

Addition and subtraction of complex numbers is achieved by adding or subtracting the real parts and the imaginary parts.

Example 1

$(4 + j5) + (3 - j2)$

$(4 + j5) + (3 - j2) = 4 + j5 + 3 - j2$

$= (4 + 3) + j(5 - 2)$

$= 7 + j3$

Example 2

$(4 + j7) - (2 - js) = 4 + j7 - 2 + js = (4 - 2) + j(7 + 5)$
$= 2\ + j12$

Multiplication of complex numbers

Example 1

$(3 + j4)(2 + j5)$
$6 + j8 + j15 + j^2 20$
$6 + j23 - 20\ (\text{since} j^2 = -1)$
$=-14 + j^{23}$

Examples 2

$(5 + j8)(5 - j8)$
$(5 + j8)(5 - j8) = 25 + j40 - j40 - j^2 64$
$= 25 + 64$ =89

A pair of complex numbers are called conjugate complex numbers and the product of two conjugate. Complex numbers is always entirely real.
$\cos\theta + j\sin\theta$

Argand diagram

Although we cannot evaluate a complex number as a real number, we can represent diagrammatically in an argand diagram. Refer to Engineering Mathematics by K.A Stroud to learn more on how to represent complex numbers on an argand diagram. Use the same back learn three forms of expressing a complex number.

Demoivre's Theorem

Demoivre's theorem states that $[r(\cos\theta + j\sin\theta)]^n = r^n(\cos n\theta + j\sin n\theta)$
It is used in finding powers and roots of complex numbers in polar

Example

Find the three cube roots of $z = 5(\cos 225^0 + j\sin 225^0)$

$$Z_1 = Z^{\frac{1}{3}}\left(\text{Cos}\frac{225^0}{3} + j\sin\frac{225^0}{3}\right)$$

$1.71\ (\cos 75^0 + j\sin 75^0$
$z_1 = 1.71\ (\cos 75^0 + j\text{Sin} 75^0)$

Cube roots are the same size (modules) i.e. 1.71 and separated at intervals of $\frac{360^0}{3}$, i.e 120^0

$z_{1=1.71} / 75^0$

$z_{2=1.71}$ cos $(195^0$+jSin195^0

z_s = 1.71 $(315^+$+j Sin$315^0)$

1.1 Complex numbers are represented using Argand diagrams

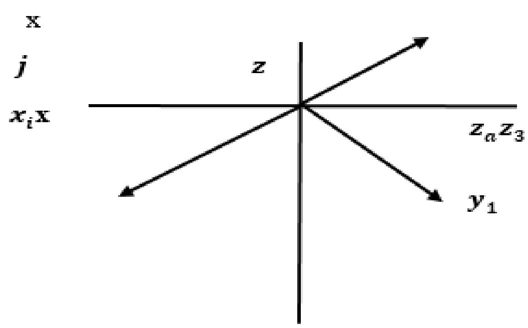


Figure 1: Sketched Argand diagram.

Refer to engineering mathematics by K.A Stroud and learn more on how to find the expansion of

$\cos^n\theta$And$\cos^n\theta$

1.2 Operations involving complex numbers are performed

LOCI problems

We sometimes required finding the locus of a point which moves in the Argand diagram according to some stated condition.

Examples

IfZ $= x + jy$, find the equation of the locus $\left[\frac{z+1}{z-1}\right] = 2$

$\sin\theta Z = x + jy.$

$\therefore \left(\frac{Z+1}{z-1}\right) = \frac{r_1}{r_2} = \left(\frac{z_1}{z_2}\right) = \frac{[(x+1)^2 + y^2]}{[(x-1)^2) + y^2]}$

$$\frac{[(x+1)^2 + y^2]}{(x-1)^2 + y^2}$$

$$\therefore \frac{(x+1)^2 + y^2}{(x-1)^2 + y^2} + 4$$

$\therefore (x+1)^2 + y^2 = 4\ ((x-1)^2 + y^2)$

$x^2 + 2x + 1 + y^2 = 4(x^2 - 2x + 1 + y^2)$

$=4x^2 - 8x + 4 + 4y^2$

$\therefore 3x^2$-10x+3+$3y^2 = 0$

Conclusion

The learning outcome covered or equipped the learner with knowledge, skills and attitude to represent complex numbers using Argand diagrams, perform operations involving complex numbers and Perform calculations involving complex numbers using De Moivre's theorem.

Further Reading

1. Atkinson, K. E. (2008). An introduction to numerical analysis. John Wiley & Sons.

2.3.4.3 Self-Assessment

Written Assessment

1. Find the fifth roots of $-3 + j3$ in polar form and in exponential form
2. Determine the three cube roots of $\frac{2-j}{2+j}$ giving the results in a modulus/ argument form.
3. Express the principal root in the form $a + jb$
4. If $z = x + jy$, where x and y are real, show that the locus $\left(\frac{Z-2}{z+2}\right) = 2$ is a circle and
5. Determine its center and radius.

Oral Assessment

1. Describe an Argand diagram according to your understanding.
2. What is a complex number?

Practical Assessment

1. Give an example of a complex number. Represent it in an Argand diagram
2. Find the root loci of the complex number above. Use De-Moivre's theorem

2.3.4.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Dice
- Computers with internet connection

2.3.4.5 References

Atkinson, K. E. (2008). An introduction to numerical analysis. John Wiley & Sons.

Stoer, J., & Bulirsch, R. (2013). Introduction to numerical analysis (Vol. 12). Springer Science & Business Media.

2.3.5 Learning Outcome No 4: Apply Coordinate Geometry

2.3.5.1 Learning Activities

Learning Outcome No 4: Apply Coordinate Geometry	
Learning Activities	**Special Instructions**
4.1 Calculate polar equations 4.2 Draw graphs of given polar equations 4.3 Determine normal and tangents	

2.3.5.2 Information Sheet No2/LO4: Apply Coordinate Geometry

Introduction

This learning outcome covers calculation of polar equations using coordinate geometry, drawing graphs of given polar equations using the Cartesian plane, determining normal and tangents using coordinate geometry.

Content/Procedures/Methods/Illustrations

The position of a point in a plane can be represented in two forms

i) Cartesian co-ordinate (x, y)

ii) Polar co-ordinate (r, θ)

The position of a point in the corresponding axis can therefore generate Cartesian and polar equations which can easily change into required form to fit the required result.

4.1 Polar equations are calculated using coordinate geometry

Example

Convert $r^2 = \sin\theta$ into Cartesian form.

$\cos\theta = \frac{x}{y} \quad \sin\theta = \frac{y}{x}$

Form Pythagoras theorem $r^2 = x^2 + y^2$

$r^2 = \sin\theta$

$(x^2 + y^2) = \frac{y}{x}$

$(x^2 + y^2)x = y$

$(x^2 + y^2)(x^2 + y^2)^{\frac{1}{2}} = y$

$(x^2 + y^2)^{\frac{3}{2}} = y$

Example 2

Find the Cartesian equation of

(i) $r = a(1 + 2\cos)$ (ii) $r\cos(\theta - \alpha) = p$

[The $\text{Cos}\theta$ suggest the relation$X = \text{COS}\theta$, so multiplying through by r}

$\therefore r^2 = a(r + 2r\cos\theta)$

$\therefore x^2 + y^2 = a\left(\sqrt{(x^2 + y^2)} + 2x\right)$

$\therefore x^2 + y^2 + 2x = a\sqrt{(x^2 + y^2)}$

Therefore, the Cartesian equation of $r = a(1 + 2\cos)$ is $(x^2 + y^2 - 2ax)^2 = a^2(x^2 + y^2)$

(ii) $r\cos(\theta - \alpha) = p$

$\cos(\theta - \alpha)$ May be expanded

$\therefore r\cos\theta\cos\alpha + r\sin\theta\sin\alpha = p$

(iii) Therefore, the Cartesian equation of $r\cos(\theta - \alpha) = p$ is $x\cos\alpha + y\sin\alpha = p$

Example 3

Find the polar equation of the circle whose Cartesian equation is $x^2 + y^2 = 4x$

$x^2 + y^2 = 4x$

Put $x = r\cos\theta, y = r\sin\theta$, then

$r^2\cos^2\theta + r^2\sin^2\theta = 4r\cos\theta$

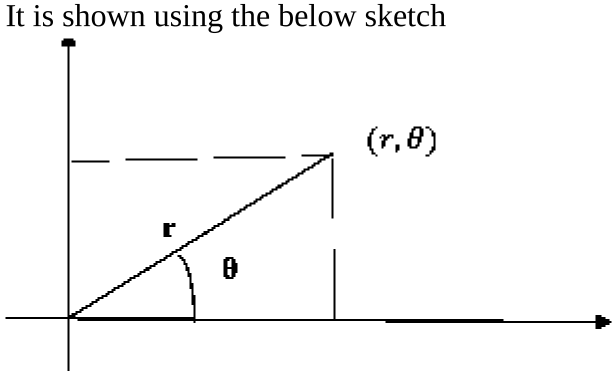
$\therefore r^2 = 4r\cos\theta$

Therefore, the polar equation of the circle is$r^2 = 4r\cos\theta$.

For more information on the conversion of Cartesian equation to polar equation and vice versa refer to pure mathematics by J.K Backhouse.

4.2 Draw graphs of given polar equations using the Cartesian plane

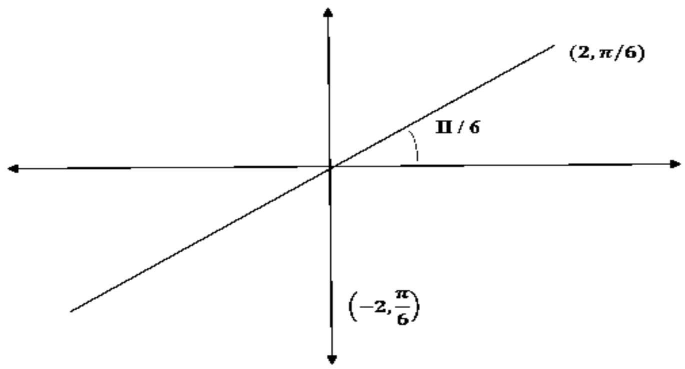
It is shown using the below sketch



Example:

Given points $\left(2, \frac{\pi}{6}\right)$ and $\left(-2, \frac{\pi}{6}\right)$

Sketch polar equation on the Cartesian plane



Example

Change $x = 3t + 1, y = 2t - 5$ to rectangular coordinates and then graph

$x = 3t + 1\ (equation\ 1)$

$y = 2t - 5\ (equation\ 2)$

From equation 1

$T = \frac{x-1}{3}$

Substitute to equation 2

We have:

$Y = 2((x-1)/3) - 5$

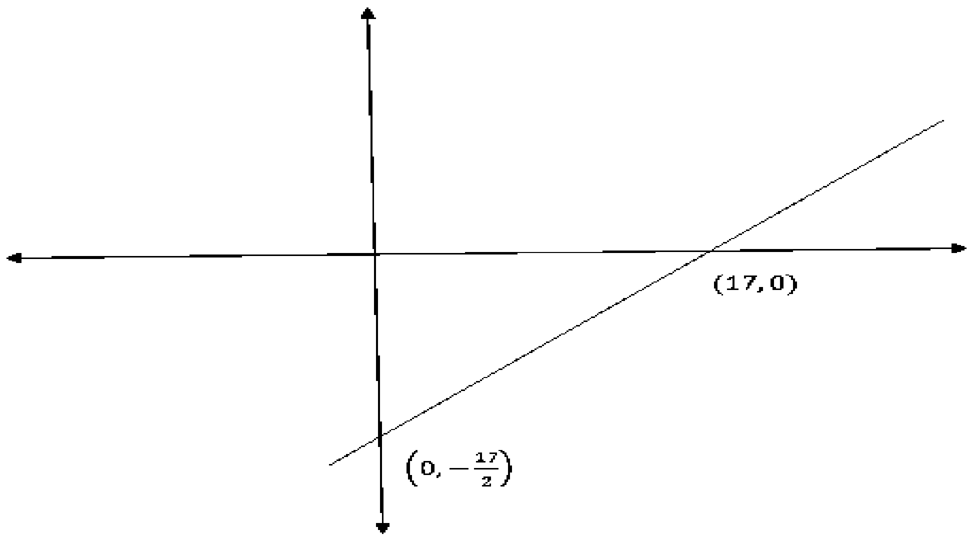
Simplifying

$3y - 2x + 17 = 0$

To graph, simply to intercept from

$\frac{X}{a} + \frac{y}{b} = 1$

$\frac{X}{\frac{17}{2}} + \frac{y}{-\frac{17}{2}}$



Example 1 Source (www Analysemath.com)
Graph the polar equation given by $R = 4 \cos t$ and identify the graph.

Solution

T	R
0	4
π / 6	3.5
π / 4	2.8
π / 3	2
π / 2	0
2 π / 3	-2
3 π / 4	-2.8
5 π / 6	-3.5
Π	4

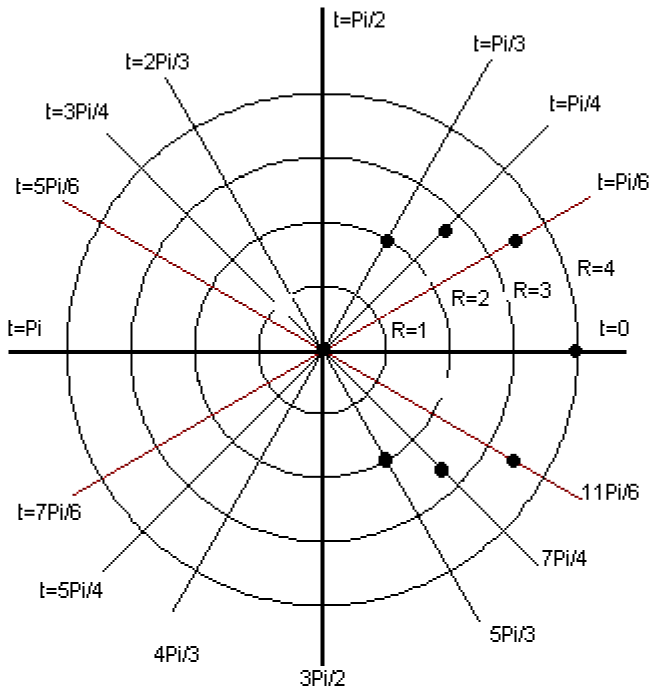
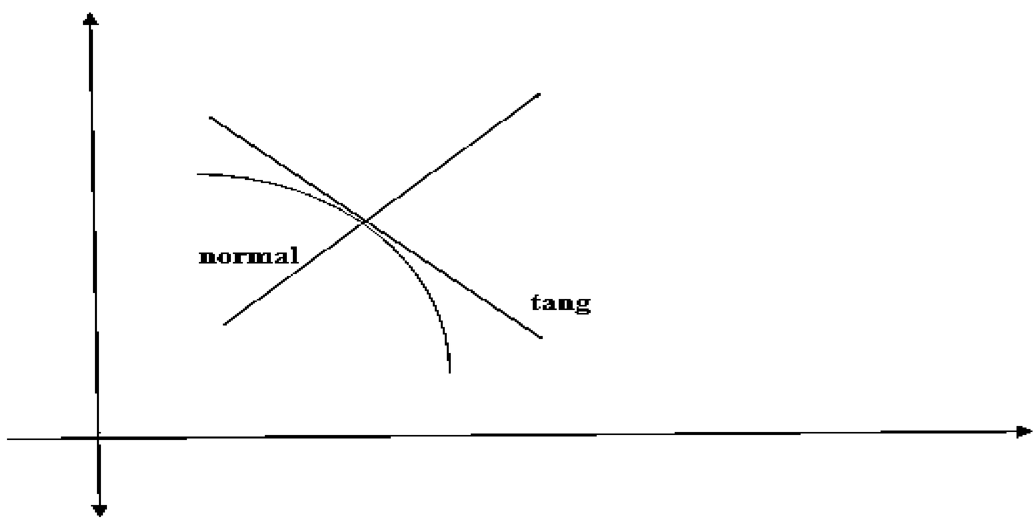


Figure 2: Solution on plotting polar equations.
Source www.analysemath.com

4.3 Determine normal and tangents using coordinate geometry

A tangent is a line that touches the curve. A normal is the perpendicular line to the tangent of the curve.



Note:

The tangent to a curve of any point will be parallel to $X - axis$ if $\theta = 0$ i.e. the derivative at the point will be zero.

i.e. $\left[\frac{dx}{dy}\right]$ at $(x, y) = 0$

The tangent at a point to the curve $y = f(x)$ will be parallel to $Y - axis$ if $\frac{dy}{dx} = 0$ at that point.

Example 1

Find the point on the curve $y = 3x^2 - 2x + 1$ at which the slope of the gradient is 4

$\frac{dy}{dx} = 6x - 2$

$6x - 2 = 4$

$6x = 6$

$x = 1, y = 2$, required point = $(1, 2)$

Example 3

Find the slope of tangent and normal to the curve $x^2 + x^3 + 3xy + y^2 = 5$ at (1, 1)

Solution:

The equation of the curve is

$x^2 + x^3 + 3xy + y^2 = 5$

Differentiating (1) w.r.t, we get

$2x + 3x^2 + 3\left(x\frac{dy}{dx} + y.1\right) + 2y\left(\frac{dy}{dx}\right) = 0$

Substituting$x = 1, y = 1$ in (2) we get

$2 \times 1 + 3 \times 1 + 3\left(\frac{dy}{dx} + 1\right) + 2\frac{dy}{dx} = 0$

∴ The slope of the tangent to the curve at $(1, 1)$ is $-\frac{8}{5}$

∴ The slope of normal to the curve at $(1, 1)$ is $\frac{5}{8}$

Point is a set of values that describes its position on a two- or three-dimensional plane.

Conclusion

The learning outcome covered or equipped the learner with knowledge, skills and attitude to calculate polar equations using coordinate geometry, draw graphs of given polar equations using the Cartesian plane, determine normal and tangents using coordinate geometry.

Further Reading

Kreyszig, E. (1999), Advanced Engineering Mathematics, 8th ed., John Wiley (New York).
O'Neil, P.V. (1995), Advanced Engineering Mathematics, 4th ed., PWS-Kent Pub. (Boston).

2.3.5.3 Self-Assessment

Written Assessment

1. Obtain the polar equation of the following loci
    a) $x^2 + y^2 = a^2$
    b) $x^2 - y^2 = a^2$
    c) $y = 0$
    d) $y^2 = 4a(a - x)$
    e) $x^2 + y^2 - 2y = 0$
    f) $xy = c^2$
2. Obtain the Cartesian equation of the following loci
    a) $r = 2$
    b) $a(1+\cos\theta)$
    c) $r = a\cos\theta$
    d) $r = a\tan\theta$
    e) $r = 2a(1 + \sin 2\theta)$
    f) $2r^2\sin 2\theta = c^2$
    g) $\frac{l}{r} = 1 + 8\cos\theta$
    h) $r = 4a\cot\theta\,\mathrm{cosec}\,\theta$

2.3.5.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Dice
- Computers with internet connection

2.3.5.5 References

Greenberg, M.D. (2000), Advanced Engineering Mathematics, 2nd ed., Prentice Hall (Upper Saddle River, N.J).

Hildebrand, F.B. (2002), Introduction to Numerical Analysis, 2nd ed., McGraw-Hill (New York).

Hildebrand, F.B. (2000), Advanced Calculus for Applications, 2nd ed., Prentice-Hall (Englewood Cliffs, NJ).

2.3.6 Learning Outcome No 5: Carry Out Binomial Expansion
2.3.6.1 Learning Activities

Learning Outcome No 5: Carry Out Binomial Expansion	
Learning Activities	Special Instructions
5.1 Determine roots of numbers using binomial theorem 5.2 Determine errors of small changes using binomial theorem	

2.3.6.2 Information Sheet No2/LO5: Carry Out Binomial Expansion

Introduction

This learning outcome seeks to equip the learner with knowledge and skills to determine the roots of numbers using binomial theorem and to determine errors of small changes using binomial theorem.

Content/Procedures/Methods/Illustrations

5.1 Carry out Binomial expansion

Binomial is a formula for raising a binomial expansion to any power without lengthy multiplication. It states that the general expansion of $(a+b)^n$ is given as

$$(a+b)^n = a^n b^0 + na^{n-1}n^1 + \frac{n(n-1)a^{n-2}b^2}{2!} + \frac{n(n-1)(n-2)a^{n-3}b^3}{3!} + \ldots$$

Where n can be a fraction, a decimal fraction, positive or negative integer.

Example 1

Use binomial theorem to expand $(2+x)^3$

Solution

$$(a+b)^n = a^n b^0 + na^{n-1}n^1 + \frac{n(n-1)a^{n-2}b^2}{2!} + \frac{n(n-1)(n-2)a^{n-3}b^3}{3!} + \ldots$$

$$A = 2, b = x \text{ and } n = 3$$

$$(2+x)^3 = 2^3x^0 + 3X2^2x^1 + \frac{3(3-1)2^1x^2}{2!} + \frac{3(3-1)(3-2)2^0x^3}{3!} + \ldots$$

$$= 8 + 12x + 6x^2 + x^3$$

For more examples on positive power refer to Technician Mathematic Book by J.O Bird.

Binomial theorem for any index

It has been shown that:

$$(1+x)^n = 1 + nx + \frac{n(n-1)}{2!}x^2 + \ldots.$$

The series may be continued indefinitely for any value of n provided $-1 < x < 1$

Example

Use the binomial theorem to expand $\frac{1}{1-x}$ in ascending power of x as far as the term in x^3.

Solution

Since $\frac{1}{1-x}$ may be written$(a-x+x)^{-1}$, the binomial theorem may be used. Thus

$(1-x)^{-1} = 1 + -1(-x) + \frac{-1(-2)}{2!}x^2 + \frac{-1(-2)(-3)}{3!} + \ldots$

$\frac{1}{1-x} = 1 + x + x^2 + x^3 + \cdots$

Provided $-1 < x < 1$

5.2 Practical application of binomial theorem

Example1

The radius of a cylinder is reduced by 4% and its height increased by 2%. Determine the appropriate percentage change in its volume neglecting products of small quantities.

Solution

Volume, $V = \pi r^2 h$

Let original values be, radius $= r$

Height $= h$

New values radius $= (1-0.04)r$

Height $= (1+0.02)h$

New volume $= \pi(1-0.004)^2 r^2 (1+0.02)h$

Using binomial theorem, $(1-0.04)^2 = 1 - 2(0.04) + (0.04)^2 = 1 - 0.08$

$= \pi r^2 h(1-0.08)(1.02) = \pi r^2 h(0.94)$

Percentage change $= \frac{(0.94-1)100\%}{1} = -6\%$

The new volume decreased by 6%

Conclusion

The learning outcome covered or equipped the learner with knowledge, skills and attitude to determine the roots of numbers using binomial theorem and to determine errors of small changes using binomial theorem.

Further Reading

1. Hoyland, A., Rausand, and M. (1994), System Reliability Theory: Models and Statistical Methods, John Wiley (New York).
2. Kaplan, W. (1984), Advanced Calculus, 3rd ed., Addison-Wesley (Cambridge, MA).
3. Kreyszig, E. (1999), Advanced Engineering Mathematics, 8th ed., John Wiley (New York).

2.3.6.3 Self-Assessment

Written Assessment

1. Expand as far as the third term and state the limits to which the expansions are valid.
    a) $\frac{1}{(1+2x)^3}$
    b) $\sqrt{4+x}$
2. Show that if higher powers of x are neglected,

$$\sqrt{\frac{1+x}{1-x}} = 1 + x + \frac{x^2}{2}$$

3. The second moment of area of a rectangular section through its centroid is given by $\frac{bl^3}{12}$. Determine the appropriate change in the second moment of area if b is increased by 3.5% and l is reduced by 2.5%.

2.3.6.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Dice
- Computers with internet connection

2.3.6.5 References

Greenberg, M.D. (1998), Advanced Engineering Mathematics, 2nd ed., Prentice Hall (Upper Saddle River, N.J).

Hildebrand, F.B. (1974), Introduction to Numerical Analysis, 2nd ed., McGraw-Hill (New York).

Hildebrand, F.B. (1976), Advanced Calculus for Applications, 2nd ed., Prentice-Hall (Englewood Cliffs, NJ).

2.3.7 Learning Outcome No 6: Apply Calculus

2.3.7.1 Learning Activities

Learning Outcome No 6: Apply Calculus	
Learning Activities	**Special Instructions**
6.1 Determine derivatives of functions 6.2 Determine derivatives of hyperbolic functions 6.3 Determine derivatives of inverse trigonometric functions 6.4 Determine rate of change and small change 6.5 Perform calculation involving stationery points of functions of two variables 6.6 Determine integrals of algebraic functions 6.7 Determine integrals of trigonometric functions 6.8 Determine integrals of logarithmic functions 6.9 Determine integrals of hyperbolic and inverse functions	

2.3.7.2 Information Sheet No2/LO6: Apply calculus

Introduction

This learning outcome equips the learner with relevant knowledge, skills and attitude so that they are able to: determine the derivatives of functions using differentiation; determine derivatives of hyperbolic functions using differentiation; determine derivatives of inverse trigonometric functions using differentiation; determine rate of change and small change using differentiation; perform calculation involving stationery points of functions of two variables using differentiation; determine integrals of algebraic functions using integration; determine integrals of trigonometric functions using integration; determine integrals of logarithmic functions using integration; determine integrals of hyperbolic and inverse functions using integration.

Definition of key terms

Calculus: It is a branch of mathematics involving calculations dealing with continuously varying functions. The subject falls into two parts namely differential calculus (differentiation) and integral calculus (integration).

Differentiation: The central problem of the differential calculus is the investigation of the rate of change of a function with respect to changes in the variables on which it depends.

Content/Procedures/Methods/Illustrations

6.1 Differentiation from first principles

To differentiate from first principles means to find $f'(x)$ using the expression.

$f'(x) = \lim_{\delta x \to 0} \left\{\frac{f(x+\delta x)}{\delta x}\right\}$

$\delta x \to \ 0, \left\{\frac{f(x+8x)-f(x)}{\delta x}\right\}$

$f(x) = x^2$

$f(x + \delta x) = (x + \delta x)^2 = x^2 + 2x\delta x + (\delta x)^2$

$f(x + \delta x) - f(x) = x^2 + 2\ x\delta x + (\delta x)^2 - x^2$

$=2x\delta x + (\delta x)^2$

$\frac{f(x+\delta x)-f(x)}{\delta x} = \frac{2x\delta x\ +(\delta x)^2}{\delta x}$

$=2x + \delta x$

As $\delta x \to 0,\ \frac{f(x+\delta x)-f(x)}{\delta x} \to 2x + 0$

$\therefore f'(x) = \lim_{\delta x \to 0} \left\{\frac{f(x+\delta x)-f(x)}{\delta x}\right\} = 2x$

At $x = 3$, the gradient of the curve i.e $f'(x) = 2(3) = 6$

Hence if $f(x) = x^2, f'(x) = 2x$. The gradient at $x = 3$ is 6

6.2 Methods of differentiation

There are several methods used to differentiate different functions which include:

(i) Product Rule
(ii) Quotient Rule
(iii) Chain Rule
(iv) Implicit Rule

Example

Determine ${}^{dy}/_{dx}$ given that

a) $y = x^2 \text{Sinx}$

Solution

From product rule: $uv(x) = u\frac{dv}{dx} + v\frac{du}{dx}$

$u = x^2 \text{and } v = \text{Sinx}$

$\frac{du}{dx} = 2x \quad \frac{dv}{dx} = \text{Cosx}$

$\therefore \frac{dy}{dx} = x^2(\text{Cosx}) + \text{Sinx}\ (2x)$

$= x^2 \text{Cos}\ x + 2x\ \text{Sin}\ x$

b) $y = \frac{x^2+1}{x-3}$

Solution. Using Quotient rule:

$$\frac{u(x)}{v(x)} = \frac{v\frac{du}{dx} - u\frac{dv}{dx}}{v^2}$$

$u = x^2+1 \qquad\qquad v = x - 3$

$\frac{du}{dx} = 2x \quad \frac{dv}{dx}=1$

$\therefore dy/dx= \frac{(x-3)(2x)-(x^2+1)(1)}{(x-3)^2}$

$$= \frac{2x^2 - 6x - x^2 - 1}{(x-3)^2}$$

$$= \frac{x^2 - 6x - 1}{(x-3)^2}$$

$$= \frac{x^2 - 6x - 1}{x^2 - 6x + 9}$$

For more examples on the cases of application of the other highlighted rates refer to Engineering Mathematics by K Stroud.

6.3 Applications of differentiation

Differentiation can be used to determine velocity and acceleration of a moving body. It can also be applied to determine maximum and minimum values.

Example: A rectangular area is formed using a piece of wire 36cm long. Find the length and breadth of the rectangle if it is to enclose the maximum possible area.

Solution.

Let the dimension a rectangle be x and y

Perimeter of rectangle = $2x + 2y = 36$

i.e. $x + y = 18$……………… (i)

Since it is the maximum area that is required, a formula for the area A must be obtained in terms of one variable only.

Area = $A = xy$

From equation (i), $y = 18 - x$

Hence $A = x(18 - x) = 18x - x^2$

Now that an expression for the area has been obtained in terms of one variable it can be differentiated with respect to that variable

$\frac{dA}{dx} = 18 - 2x$ for maximum or minimum value i.e. $x = 9$

$\frac{d^2A}{dx^2} = -2$, which is negative giving a maximum value

$y = 18 - x = 18 - 9 = 9$

Hence the length and breadth of the rectangle for maximum area are both 9 cm i.e. a square gives the maximum possible area for a given perimeter length When perimeter is 36cm, maximum area possible is 81cm^2.

6.4 Determine rate of change and small change using differentiation

We can always write the rate of change of one variable in terms of the other when the two are varying with respect to time. Both the functions will be differentiated with time. We therefore define $dx/_{dt}$ for the same function $f(x)$.

The solution of this problem is done using the following algorithm:

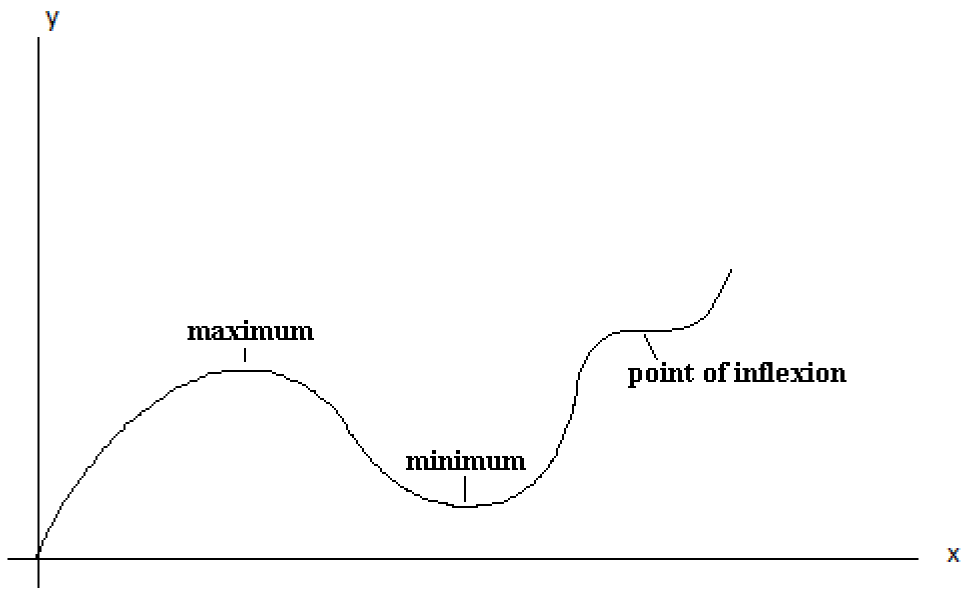
i. Sketch the problem
ii. Identify the constants and variables in the equation
iii. Identify independent and dependent variables
iv. Differentiate with respect to time.
v. Evaluate at a given point.

6.5 Perform calculation involving stationery points of functions of two variables using differentiation

A stationary point k is a point x is one at which $f'(x) = 0$. A point of a function $f(x)$ K is said to be maximum point if and only if $f(k) \geq f9x)$ for all the x in the f domain.

A point k of a function fx said to be a minimum point if and only if for all x in the f domain, $f(k) \leq f(x)$.

Local Maximum and minimum



The occurrence of local maximum or minimum is determined by the derivations of a given function.

Example

Find the turning points of $f(x) = 3x4 + 16x3 + 24x2$ and hence determine their nature.

Solution

$f(x) = 3x^4 + 16x^3 + 24x^2 + b$

$f'(x) = 12x^2 + 48x$

$= 12(x^3 + 4x^2 + 4x)$

$= 12x(x + 2)^2$

Solving the equation $f'(x) = 12x(x + 2)^2 = 0$

We get $x = 0$ or $x = -2$

$= x < -2\ , f'(x) < 0$

$-2 < x < 0,\ f'(x) < 0$

$x > 0,\ \ f'(x) > 0$

We can deduce that at $x = 0$ and $x = -2,$ we get stationary point.

Also, at $x = 0$ we have a minimum point and at $x = -2,$ is a point of inflexion.

6.6 Integrals of algebraic functions are determined using integration

Integration

Process of integration reverses the process of differentiation. In differentiation if $f(x) = x^2$, then $f'(x) = 2x$.

Since integration reverse the process of moving from f(x) to $f'(x)$, it follows that the integral of $2x$ is x^2 i.e it is the process of moving from $f'(x)$ to $f(x)$. Similarly if $y = x^3$ then $\frac{dy}{dx} = 3x^2$. Reversing this process shows that the integral of $3x^2$ is x^3.

Integration is also the process of summation or adding parts together and an elongated $'s'$ shown as $\int$ is used to replace the words 'integrated of'. Thus $\int 2x = x^2$ and $\int 3x^2 = x^3$

Refer to Engineering Mathematics by K.A Strand and learn those on definite and indefinite integrals.

6.7 Methods of integration and application of integration

The methods available are:

a) By using algebraic substitution
b) Using trigonometric identities and substitutions
c) Using partial fraction
d) Using $t = \tan\frac{\theta}{2}$ substitution
e) Using integration by parts

Refer to Engineering Mathematics by K. A. Strand and learn more about methods of integration,

Also use the above stated book to learn more on application of integration to find areas, volumes of revolutions, etc.

6.8 Determine integrals of logarithmic functions using integration

The natural logarithm function is always differentiable throughout is (0, 00) domain and

$ln(x) = \frac{1}{x}$ Also, in x increase $0, \infty)$

The rules of integrating logarithms functions are as follows:

f(x)	$\int \boldsymbol{fx(dx)}$
$ln(x)$	$xlnx - x + c$
$\log x$	$(xlnk - x)\ln(10) + c$
$log_a x$	$x(\log ax - \log\ ae) + c$

EXAMPLE:

Solve $\int e^{x2} 2x^2\, dx$

Solution

i. $f(x) = \int e^{x2} 2x^2\, dx$
ii. let $u = x^3$ and $du = 3x^2$
iii. The new function is now: $\int e^{x2} 3x^2 du = \int e^u$du
iv. According to laws of integration: $\int e^x dx = e^x + c$ thus $\int e^u du = e^u + c$
v. But $u = x^3$ *thus we have* $\int e^u du = \int e^{x3} dx = e^{x3} + c$

The answer is hence: $e^{x3} + C$

6.9 Determine integrals of hyperbolic and inverse functions using integration

There are six basic hyperbolic which are defined in section 6.2 above. The table below shows the integrals of hyperbolic function:

Function	Integral
$\sinh x$	$cosch\ x + c$
$cash\ x$	$\sinh x + c$
$\tanh x$	$ln/cosh/+C$
$\operatorname{csch} x$	$ln/\tanh\left(\frac{x}{2}\right)/+C$
$\operatorname{sech} x$	$\arctan(sinhx) + C = tan^{-1}(sinhx) + c)$
$cotch\ x$	$ln/sinhx + C$

The indefinite integral of one-to-one function is expresses as

$\int f^{-1}(x)dx = xf^{-1}(x) - \int f(u)du\,; u = f^{-1}(x)$

A definite integral is expressed as;

$\int_a^b f^{-1}(x) = bf^{-1}(b) - af^{-1}(a) - \int_{fy(a)}^{f-1(b)} f(u)du.$

Conclusion

The learning outcome covered or equipped the learner with knowledge, skills and attitude to determine the derivatives of functions using differentiation, determine derivatives of hyperbolic functions using differentiation, determine derivatives of inverse trigonometric functions using differentiation, determine the rate of change and small change using differentiation; perform calculation involving stationery points of functions of two variables using differentiation; determine integrals of algebraic functions using integration; determine integrals of trigonometric functions using integration; determine integrals of logarithmic functions using integration; determine integrals of hyperbolic and inverse functions using integration.

Further Reading

Read more on methods of integration.

2.3.7.3 Self-Assessment

Written Assessment

1. Find the co-coordinator, of the points on the curve

   $y = \frac{1/3(5-6x)}{3x^2+2}$

   Where the gradient is zero

2. If $y = \frac{4}{3x^3} - \frac{2}{x^2} + \frac{1}{3x} - \sqrt{x}$. Find $\frac{d^2y}{dx}$ and $\frac{d^3y}{dx}$

3. Find $\int \cos 6x \ \text{Sin}\ 2x \ dx$

4. Evaluate $\int_3^4 \frac{x^3 - x^2 - 5x}{x^2 - 2x + 2} dx$

Oral Assessment

1. What do you understand by differentiation and integration as applied in calculus?
2. How are they intertwined?
3. What are some of their practical applications?

2.3.7.4 Tools, Equipment, Supplies and Materials

- Scientific calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Computers with internet connection

2.3.7.5 References

Greenberg, M.D. (1998), Advanced Engineering Mathematics, 2nd ed., Prentice Hall (Upper Saddle River, N.J).

Hildebrand, F.B. (1974), Introduction to Numerical Analysis, 2nd ed., McGraw-Hill (New York).

Hildebrand, F.B. (1976), Advanced Calculus for Applications, 2nd ed., Prentice-Hall (Englewood Cliffs, NJ).

2.3.8 Learning Outcome No 7: Solve Ordinary Differential Equations
2.3.8.1 Learning Activities

Learning Outcome No 7: Solve Ordinary Differential Equations	
Learning Activities	**Special Instructions**
7.1. Solve first order and second order differential equations 7.2. Solve first order and second order differential equations from given boundary conditions	

2.3.8.2 Information Sheet No2/LO7: Solve Ordinary Differential Equations

Introduction

This learning outcome equips the learner with knowledge and skills to solve first order differential equations using the method of undetermined coefficients and also when given boundary conditions.

Content/Procedures/Methods/Illustrations

7.1. Solve first order and second order differential equations using the method of undetermined coefficients

An equation involves differential co-efficient is called a differential equation.

Examples

(i) $\frac{dy}{dx} = \frac{1+x^2}{1-y^2}$

(ii) $\frac{d^2y}{dx^2} + 2\frac{dy}{dx} - 8y = 0$

The order of a differential equation is the order of the highest differential coefficient present in the equation. Differential equations represent dynamic relationships i.e. quantities that change, and are thus frequently occurring in scientific and engineering problems.

Formation of a differential equation

Differential equations may be formed in practice from a consideration of the physical problem to which they refer. Mathematically, they can occur when arbitrary constants are eliminated from a given function.

Example

Consider $y = A\sin x + B\cos x$, where A and B are two arbitrary constants. If we differentiate, we get

$\frac{dy}{dx} = A\cos x - B\sin x$ and $\frac{d^2y}{dx^2} = -A\sin x - B\cos x = -(A\sin x + B\cos x)$

i.e. $\frac{d^2y}{dx^2} = -y$

$$\therefore \qquad \frac{d^2y}{dx^2} - y = 0$$

This is a differential equation of the second order.

Types of first order differential equations

a) By separating the variables
b) Homogeneous first order differential equations
c) Linear differential equations
d) Exact differential equations

Application of first order differential equations

Differential equations of the first order have many applications in Engineering and Science.

Example

The rate at which a body cools is given by the equations $\frac{d\theta}{dt} = -k\theta$ where θ the temperature of the body above the surroundings is and k is a constant. Solve the equation for θ given that $t = 0$,

$\theta = \theta_0$

Solution

$$\frac{d\theta}{dt} = -k\theta$$

Rearranging gives: $dt = \frac{-1}{k\theta}$

Integrating both sides gives: $\int dt = \frac{-1}{k}\int \frac{d\theta}{\theta}$

i.e.$t = \frac{-1}{k}\ln\theta + c$………………….. (i)

Substituting the boundary conditions $t = 0$, $\theta = \theta_0$ to find c gives

$$0 = \frac{-1}{k}\ln\theta_0 + c$$

$$\text{i.e. } c = \frac{1}{k}\ln\theta_0$$

Substituting $c = \frac{-1}{k}\ln\theta_0$ in equation (i) gives

$t = \frac{-1}{k}\ln\theta + \frac{1}{k}\ln\theta_0$

$t = \frac{1}{k}(\ln\theta_0 + \ln\theta) = \frac{1}{k}\ln\left(\frac{\theta_0}{\theta}\right)$

$kt = \ln\left(\frac{\theta_0}{\theta}\right)$

$e^{kt} = \frac{\theta_0}{\theta}$

$e^{-kt} = \frac{\theta}{\theta_0}$

Hence, $\theta = \theta_0 e^{-kt}$

7.2 First order and second order differential equations are solved using the method of undetermined coefficients

Formation of the second order differential equation

For formation of second order differential equations refer to Engineering Mathematics by K.A Strand, Technician 4 and 5 by J.O Bird.

Application of second order differential equations

Many applications in engineering give rise to the second order differential equations of the form $a\frac{d^2y}{dx^2} + b\frac{dy}{dx} + cy = f(x)$

Where a, b, c are constant coefficients and $f(x)$ is a given function of x.

Examples include:

(1) Bending of beams
(2) Vertical oscillations and displacements
(3) Damped forced vibrations

Conclusion

The learning outcome covered or equipped the learner with knowledge, skills and attitude to solve first order differential equations using the method of undetermined coefficients; and also when given boundary conditions.

2.3.8.3 Self-Assessment

Written Assessment

1. Solve the following equations:
   a) $x(y-3)\frac{dy}{dx}4y$
   b) $(xy + y^2) + (x^2 - xy)\frac{dy}{dx} = 0$
   c) $\frac{dy}{dx} + y\tan x = \sin x$

2. Show that the change, q, on a capacitor in an LCR circuit satisfies the second order differential equation

$$L\frac{d^2q}{dt^2} + b\frac{dq}{dt} + \frac{1}{c}q = E$$

3. Show that if $2L = cR^2$ the general solution of this equation is

$$q = e^{\frac{-t}{cR}}\left(A\cos\frac{1}{cR}t + B\sin\frac{1}{cR}t\right) + cE$$

4. If $i = \frac{dq}{dt} = 0$ and $q = 0$ when $t = 0$, show that the current in the circuit is

$$i = \frac{2E}{R}e^{\frac{-t}{cR}}\sin\frac{1}{cR}$$

Oral Assessment

1. Consider the following differential equation

   $x(y-3)\frac{dy}{dx} = 4y$. Is it of the first order or the second order?
2. Justify your answer above

2.3.8.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Dice
- Computers with internet connection

2.3.8.5 References

Greenberg, M.D. (1998), Advanced Engineering Mathematics, 2nd ed., Prentice Hall (Upper Saddle River, N.J).

Hildebrand, F.B. (1974), Introduction to Numerical Analysis, 2nd ed., McGraw-Hill (New York).

Hildebrand, F.B. (1976), Advanced Calculus for Applications, 2nd ed., Prentice-Hall (Englewood Cliffs, NJ).

2.3.9 Learning Outcome No 8: Carry Out Mensuration

2.3.9.1 Learning Activities

Learning Outcome No 8:Carry Out Mensuration	
Learning Activities	**Special Instructions**
8.1. Obtain perimeter and areas of figures 8.2. Obtain volume and surface area of solids 8.3. Obtain area of irregular figures 8.4. Obtain areas and volumes using Pappus theorem	

2.3.2.9.2 Information Sheet No2/LO8: Carry Out Mensuration

Introduction

This learning outcome covers perimeter and areas of figures, volume and surface area of solids, area of irregular figures and areas and volumes using Pappus theorem.

Definition of key terms

Area: Extent of part of a surface enclosed within a boundary.

Circumference: Distance around a circle.

Dimension: Measurable extent such as length, thickness and width.

Fraction: Number expressed as a quotient of two other numbers.

Mensuration: Act or art of measuring.

Perimeter: Bounding line or curve of a plain area.

Standard: Serves as a measure of reference.

Content/Procedures/Methods/Illustrations

8.1 Obtain perimeter and areas of figures

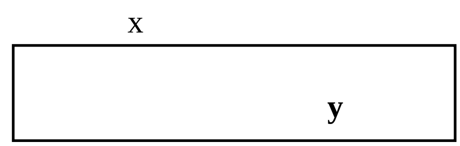
Perimeter

The perimeter is the length of the outline of a shape. To find the perimeter of a rectangle or square you have to add the lengths of all the four sides. x is in this case the length of the rectangle while y is the width of the rectangle.

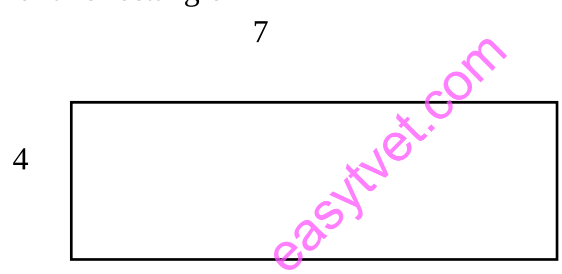
The perimeter, P, is:

$$P = x + x + y + y$$
$$P = 2x + 2y$$

$P=2(x+y)$



Find the perimeter of this rectangle



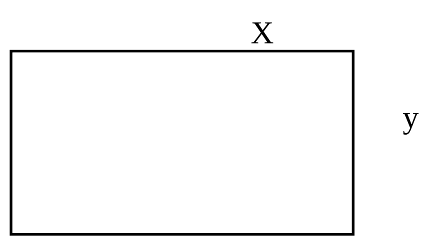
$$P = 7 + 7 + 4 + 4$$
$$P = 2 \cdot 7 + 2 \cdot 4$$
$$P = 2 \cdot (7 + 4)$$
$$P = 2 \cdot 11$$
$$P = 22\text{in}$$

Area

Area is the measurement of the surface of a shape. To find the area of a rectangle or a square you need to multiply the length and the width of a rectangle or a square.

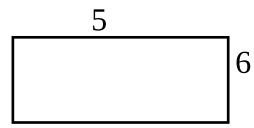
Area, A, is x times y.

$A=x\cdot y$



Examples

Find the area of this square.



$$A = x \cdot y$$
$$A = 5 \cdot 6$$
$$A = 30\text{in}^2$$

There are different units for perimeter and area. Perimeter has the same units as the length of the sides of rectangle or square whereas the area's unit is squared.

8.2 Obtain volume and surface area of solids

The surface area of a figure is defined as the sum of the areas of the exposed sides of an object.

The volume of an object is the amount of three-dimensional space an object takes up. It can be thought of as the number of cubes that are one unit by one unit by one unit that it takes to fill up an object.

Surface Area of a Rectangular Solid (Box)

$$SA = 2(lw + lh + wh)$$
$$l = \text{length of the base of the solid}$$
$$w = \text{width of the base of the solid}$$
$$h = \text{height of the solid}$$

Volume

Volume of a Solid with a Matching Base and Top

V=Ah

A = area of the base of the solid

h = height of the solid

Volume of a Rectangular Solid (specific type of solid with matching base and top)

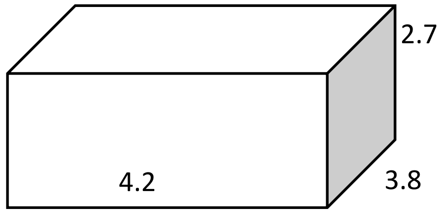
V=lwh

l = length of the base of the solid

w = width of the base of the solid

h = height of the solid

Examples



This figure is a box (officially called a rectangular prism). We are given the lengths of each of the length, width, and height of the box, thus we only need to plug into the formula. Based on the way our box is sitting, we can say that the length of the base is 4.2 m; the width of the base is 3.8 m; and the height of the solid is 2.7 m. Thus we can quickly find the volume of the box to be

$$V = lwh = 4.2 * 3.8 * 2.7 = 43.092m3$$

Although there is a formula that we can use to find the surface area of this box, you should notice that each of the six faces (outside surfaces) of the box is a rectangle. Thus, the surface area is the sum of the areas of each of these surfaces, and each of these areas is fairly straight-forward to calculate. We will use the formula in the problem

A cylinder

A cylinder is an object with straight sides and circular ends of the same size. The volume of a cylinder can be found in the same way you find the volume of a solid with a matching base and top. The surface area of a cylinder can be easily found when you realize that you have to find the area of the circular base and top and add that to the area of the sides. If you slice the side of the cylinder in a straight line from top to bottom and open it up, you will see that it makes a rectangle. The base of the rectangle is the circumference of the circular base, and the height of the rectangle is the height of the cylinder

Volume of a cylinder

V=Ah

A = the area of the base of the cylinder

h = the height of the cylinder

Surface Area of a Cylinder

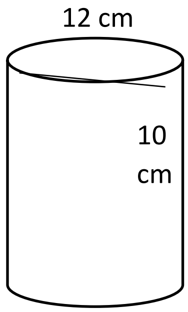
$SA=2(\pi r^2)+2\pi rh$

r = the radius of the circular base of the cylinder

h = the height of the cylinder

π = the number that is approximated by 3.141593

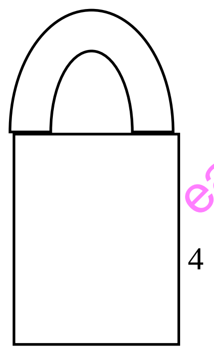
Find the area of the cylinder



$$SA = 2(\pi r2) + 2\pi rh$$
$$SA = 2(\pi.62) + 2\pi(6)(10) = 603.18579$$

8.3 Obtain Area of irregular figures

To find the area of irregular shapes, the first thing to do is to divide the irregular shape into regular shapes that you can recognize such as triangles, rectangles, circles, squares and so forth. Then, find the area of these individual shapes and add them up.



The figure above has two regular shapes. It has a square and half a circle. Find the area for each of those two shapes and add the results

Square

Area of square = s^2

Area of square = 4^2

Area of square = 16

Circle

Area of circle = pi × r^2

Notice that the radius of the circle is 4/2 = 2

Area of circle = 3.14 × $2^{2=}$3.14 × 4

Area of circle = 12.56

Since you only have half a circle, you have to multiply the result by 1/2
$1/2 \times 12.56 = 6.28$
Area of this shape = 16 + 6.28 = 22.28

Example
Circle
To get the area of the half circle, we need to know the diameter. Notice that the diameter is the hypotenuse of a right triangle, so use the Pythagorean Theorem to find the length of the diameter

$c^2 = a^2 + b^2$
$c^2 = 122 + 162$
$c^2 = 144 + 256$
$c^2 = 400$
$c = \sqrt{400}$
$c = 20$

Therefore, the diameter is 20. Since the diameter is 20, the radius is 10

Area of circle = pi × r^2
Area of circle = 3.14 × 10^2
Area of circle = 3.14 × 100
Area of circle = 314

Since you only have half a circle, you have to multiply the result by 1/2

$1/2 \times 314 = 157$

Area of this shape = $384 + 96 + 157 = 637$

8.4 Obtain Areas and volumes using Pappus theorem
Pappus' centroid theorems are results from geometry about the surface area and volume of solids of revolution. These quantities can be computed using the distance traveled by the centroids of the curve and region being revolved.

Theorem
Let CC be a curve in the plane. The area of the surface obtained when CC is revolved around an external axis is equal to the product of the arc length of CC and the distance traveled by the centroid of CC.

Let RR be a region in the plane. The volume of the solid obtained when RR is revolved around an external axis is equal to the product of the area of RR and the distance traveled by the centroid of RR.
Consider the cylinder obtained by revolving a rectangle with horizontal side r and vertical side h around one of its vertical sides (say its left side). The surface area of the cylinder, not including the top and bottom, can be computed from Pappus' theorem since the surface is obtained by revolving its right side around its left side. The arc length of its right side is h and the distance traveled by its centroid is simply 2\pi r, 2πr, so its area is 2 \pi r h, 2πrh.

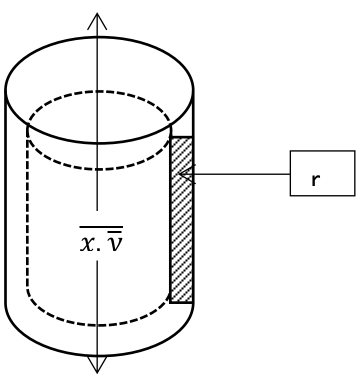
The volume of the cylinder is the area rh of the rectangle multiplied by the distance traveled by its centroid. The centroid of the rectangle is its center, which is a distance of r\2 from the axis of revolution. So it travels a distance of 2\pi\big (\frac r2\big) = \pi r2π (2r)=πr as it revolves. The volume of the cylinder is (rh) (\pi r) = \pi r^2 h= (rh)(πr)=πr^2h.

Example of volume of revolution

Theorem of Pappus

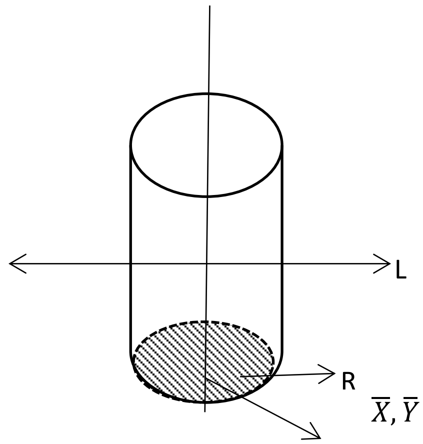
Let R be a region in a plane and let L be a line in the same plane such that L does not intersect the interior of R. If Ω is the distance between the centroid of R and the line, the volume of the solid of revolution R about the line is;

$V = 2\pi A$



$\mathbf{X}: (\mathbf{MY} =)/\mathbf{M}$

Using Pappus' theorem to find the volume of the solid of revolution, the turns formed by revolution the circle.



$X^2 + (y+5)^2 = 9$

About the x-axis.

$V = 2\pi \ rA$

V=2πrA

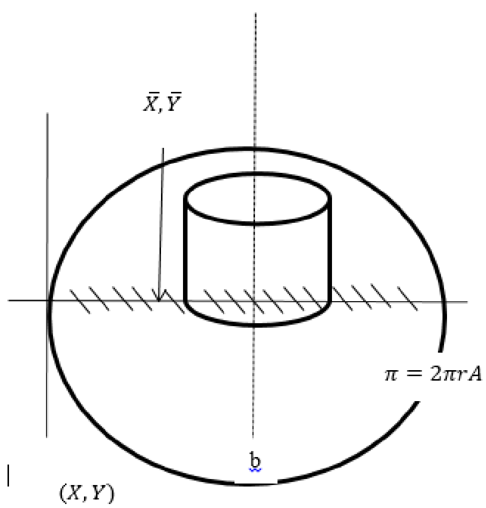
2(π)5(π(3)

90π

Example 2

Use the theorem of Pappus to find the volume of the solid of revolution formed by revolving the region bounded by the graph of:

Y=$\sqrt{X}$, $Y = 0$ and$x = 4$ about the line $x = 6$



$$\frac{\delta \int_a^b x[f(x)-g(x)]dx}{\delta \int_a^b x[f(x)-g(x)]dx} = \frac{my}{m} = \bar{x}$$

$$= \frac{\text{Moment about y-axis}}{\text{Mass of Lamina}}$$

Area of shaded region

A=$\int_{\theta}^{b}(x^{\frac{1}{3}} * dx$

$\left[\left[\frac{2}{3}\right] x^{-3}\right]$ -4 0

$\frac{2}{3}[4]^{\frac{3}{4}}$

$\frac{2}{3}[9]^{\frac{3}{4}}$

$\frac{2}{3}[8]^{\frac{3}{4}}$

$\frac{2}{3}(8) = \frac{16}{3}$

$= \ n = \frac{16}{3}, my = \frac{64}{5}$

$= \int_{\theta}^{4} x(x^{\frac{1}{3}})dx$

my=$\int_{\theta}^{4} x(x^{\frac{1}{2}})dx$

$= \int_{\theta}^{4} \left(x^{\frac{3}{2}}\right) dx$

$\left[\frac{2}{5} * \frac{5}{2}\right]$

=$\frac{2}{5}(4)^{\frac{5}{2}}$

=$\frac{2}{5} 4^{\frac{5}{2}} - \frac{2}{5}(0)^{\frac{5}{2}}$

=$\frac{2}{5}(2)^{5}$

=$\frac{64}{5}$

$v = 2\pi r A$=2π($\frac{18}{5}$)($\frac{16}{3}$)

$= \frac{567}{15}\pi$

Conclusion

The learning outcome covered or equipped the learner with knowledge, skills and attitude to obtain perimeter and areas of figures, volume and surface area of solids, area of irregular figures and areas and volumes using Pappus theorem.

Further Reading

1. Hoyland, A., Rausand, and M. (1994), System Reliability Theory: Models and Statistical Methods, John Wiley (New York).

2.3.9.3 Self-Assessment

Written Assessment

1. An equilateral triangle of side length rr in the first quadrant, one of whose sides lies on the xx-axis, is revolved around the line y= -r. y=-r. The volume of the resulting solid is c\pi r^3cπr3 for some real number c.c. What is c.c?
2. Consider the single rectangle in R^2 that passes through the points A = (1,2), B = (2,1), C = (4,3), D = (3,4) A rotating around x-axis in R^3. The volume of the surface of revolution obtained can be written as A3 Aπ unit3. Submit A
3. Revolving a right triangle with legs of length r and h around the leg of length h produces a cone. The surface of the cone (not including the circular base) is obtained by revolving the hypotenuse around that leg. The centroid of the hypotenuse is just the midpoint, located halfway up the side of the cone, which travels a distance $2\pi/2$ as it rotates. So, the surface area is $2\pi r\sqrt{R2 + H2}$
4. Consider the cylinder obtained by revolving a rectangle with horizontal side r and vertical side h around one of its vertical sides (say its left side). The surface area of the cylinder, not including the top and bottom, can be computed from Pappus's theorem since the surface is obtained by revolving its right side around its left side. The arc length of its right side is h and the distance travelled by its centroid is simply2π, 2πr, so its area is 2πr h. 2πrh.

2.3.9.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Computers with internet connection

2.3.9.5 References

Kaplan, W. (2000), Advanced Calculus, 3rd ed., Addison-Wesley (Cambridge, MA).
Kreyszig, E. (2004), Advanced Engineering Mathematics, 8th ed., John Wiley (New York).

2.3.10 Learning Outcome No 9: Apply Power Series
2.3.10.1 Learning Activities

Learning Outcome No 9: Apply Power Series	
Learning Activities	**Special Instructions**
9.1 Obtain power series using Taylor's Theorem 9.2 Obtain power series using McLaurin's theorem	

2.3.10.2 Information Sheet No2/LO9: Apply power series

Introduction

This learning outcome covers; derivation of power series using Taylor's Theorem and derivation of power series using McLaurin's theorem.

Content/Procedures/Methods/Illustrations

9.1 Obtain power series using Taylor's Theorem

The power series of McLaurin's theorem is different functions can be carried out using two theorems.

(i) Taylor's Theorem

(ii) Maclaurin's theorem

Taylor's series states that;

$f(x+h) = f(x) + hf'(x) + \frac{h^2}{2!}f''(x) + \frac{h^3}{3!}f'''(x) + \ ...$

Examples

Express $\text{Sin}(x+h)$ as a series of powers of h and hence evaluates $\text{Sin}\ 44^0$ correct to four decimal places.

Solution

$$f(x+h) = f(x) + hf'(x) + \frac{h^2}{2!}f''(x) + \frac{h^3}{3!}f'''(x) + \cdots$$

$f(x) = \text{Sin}x$

$f'(x) = \cos x$

$f''(x) = -\sin x$

$f'''(x) = -\cos x$

$f^{iv}(x) = \sin x$

$\therefore \text{Sin}(x + h) = \sin x + h\cos x - \frac{h^2}{2}\sin x - \frac{h^3}{6} \cos x ....$

$\text{Sin}44^0 = \sin(45^0 - 1^0)$
$= \text{Sin}(\pi/4) - 0.01745$
$= \sin \pi/4 + 0.01745 \cos\frac{\pi}{4} - \frac{0.01745^2}{2}\sin \pi/4 - \frac{0.0174s^3}{6} \cos \pi/4$

But $\sin 45 = \cos 45 = 0.707$
$= 0.707\ (1 - 0.01745 - 0.0001523 + 0.0000009)$
$= 0.707(0.982395)$
$= 0.69466$
$0.6947(4dp)$
For the use McLaurin's theorem refer to Engineering Mathematics by Strand.

9.2 Obtain power series using McLaurin's theorem

McLaurin's series is a special type of Taylor series where b is centred around where the variable x or y is zero. That is; from the Taylor series.
$f(x) = f(b) + (f^{\wedge\prime}(b)(x - b))/1! + (f''(b)(x - b)^2/2! + \cdots$ We obtain the following McLaurin's series:

f(x)= f(0)+ $f^1(0)(x) + \frac{f''(0)(x)^2}{2!} + \cdots$

How to find the McLaurin's series.

i. Get the derivatives of the given function until you notice a particular pattern

For example

$p(x) = sin\ x$
$p'(x) = cos\ x$
$p''(x) = -sin\ x$
$p'''(x) = -cos\ x$

$p'^{v}(x) = sin\ x$

Note that $p'(x) = p^{v}(x)$
$p''(x) = p^{vi}(x)$
$p'''(x) = p^{vii}(x)$ and so on

ii. Replace the variable in the first step with 0 as the input to get the McLaurin's series values.

That is;

$p(x) = p(0) + p'(0)x^1 + p''(0)\frac{x^2}{2!} + p'''(0)\frac{x^3}{3!} + \cdots$

$sin\ x = 0 + x + 0 - \frac{x^3}{3!} + 0 + \frac{x^5}{5!} + \cdots$

iii. Write what your get in step (ii) in sigma notation.
This is will enable one to obtain the final power series.
That is;

$x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} -$

$= \sum_{n=0}^{\infty} \frac{x^{2n+1}}{(2n+1)!}(-1)^n$

Example.

Obtain the McLaurin's series for $e^{5y.}$

$f(y)$=5$e^{5y.}$

f'(y)=5$e^{5y.}$

f''(y)=25$e^{5y.}$=$5^2 e^{5y.}$

f'''(y)=125$e^{5y.}$=$5^3 e^{5y.}$

$f(y)$=$e^{5(0).}$=1

f' (y)=5$e^{5(0)} = 5$

f''(y)=25$e^{5(0)} = 5^2$

f'''(y)=125$e^{5(0)} = 125 = 5^3$

$e^{5y} = 1 + \frac{5(y-0)}{1!} + \frac{5^2(y-0)^2}{2!} + \frac{5^3(y-0)^3}{3!}$

$= \sum_{n=0}^{\infty} 5^n \frac{y^n}{n!}$

Some common examples of the McLaurin's series include:

$f(x) = \frac{1}{1-x} = 1 + x + x^2 + x^3 + x^4 + \cdots$

$= \sum_{n=0}^{\infty} x^n$

$f(x) = e^x = 1 + x + \frac{1}{2^{x^2}} + \frac{1}{6^{x^3}} + \frac{1}{24^{x^4}} + \cdots$

$= \sum_{n=0}^{\infty} \frac{1}{n!} x^n$

Conditions for McLaurin's series.

- The derivative of the given function, say q(x) must exist for all n i.e $q^n(x) exists$ for all $n = 1,2 \ldots\ldots n$
- $f^n(0)$must be defined for all n $= 1,2 \ldots\ldots,$ n
- The series obtained should converge to the given function say q(x).

Conclusion

The learning outcome covered or equipped the learner with knowledge, skills and attitude to derive power series using Taylor's Theorem and power series using McLaurin's theorem.

Further Reading

1. Greenberg, M.D. (1998), Advanced Engineering Mathematics, 2nd ed., Prentice Hall (Upper Saddle River, N.J).
2. Hildebrand, F.B. (1974), Introduction to Numerical Analysis, 2nd ed., McGraw-Hill (New York).
3. Hildebrand, F.B. (1976), Advanced Calculus for Applications, 2nd ed., Prentice-Hall (Englewood Cliffs, NJ).

2.3.10.3 Self-Assessment

Written Assessment

1. Use McLaurin's theorem to expand $\ln(3x+1)$. Hence use the expansion to evaluate $\int_0^1 \frac{\ln(3x+1)}{x^2}dx$ to four decimal places.
2. Use Taylor's series to expand $\cos\left(\frac{\pi}{3}+h\right)$ in terms of h as far as h^3. Hence evaluate $\cos 68^0$ correct to four decimal places.

2.3.10.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Dice
- Computers with internet connection

2.3.10.5 References

Hoyland, A., Rausand, and M. (2005), System Reliability Theory: Models and Statistical Methods, John Wiley (New York).

Kaplan, W. (2003), Advanced Calculus, 3rd ed., Addison-Wesley (Cambridge, MA).

2.3.11 Learning Outcome No 10: Apply Statistics

2.3.11.1 Learning Activities

Learning Outcome No 10: Apply Statistics	
Learning Activities	**Special Instructions**
1.1 Perform identification, collection and organization of data. 1.2 Perform interpretation, analysis and presentation of data in appropriate format. 1.3 Obtain mean, median, mode and standard deviation from given data 1.4 Perform calculations based on laws of probability 1.5 Perform calculation involving probability distributions, mathematical expectation sampling distributions 1.6 Apply sampling distribution methods in data analysis 1.7 Perform calculations involving use of standard normal table, sampling distribution, t-distribution and estimation 1.8 Determine confidence intervals 1.9 Perform testing hypothesis using large samples and small samples 1.10 Do calculations involving correlation and regression 1.11 Do calculations involving rank correlation coefficient and equations of regression line	• Illustrations • Oral questioning • Written tests • Assignments • Supervised exercise

2.3.11.2 Information Sheet No2/LO10: Apply Statistics

Introduction

This learning outcome covers classification of data, grouped data, ungrouped data, data collection, tabulation of data, class intervals, class boundaries, frequency tables, diagrammatic and graphical presentation of data e.g. histograms, frequency polygons, bar charts and pie charts. It also covers cumulative frequency curves, measures of central tendency mean, mode and median, measures of dispersion, variance and standard deviation, definition of probability, laws of probability, expectation variance and S.D, types of distributions, mean, variance and SD of probability distributions, application of probability distributions, standard normal tables and sampling distributions and rank correlation coefficient.

Definition of key terms

Mode: This is the number which is the most repeated in a series.

Standard deviation: This is the amount of variation of a set of numbers. It is the square root variance.

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}}$$

$$\partial - \; Standard\ Deviation$$
$$\mu - \; Mean$$
$$x_1 - Each\ Value$$
$$N - Number\ of\ values$$

Variance: This is the mean of the aquared differences of the number from the mean.

$$\sigma^2 = \frac{\Sigma(\,x - \mu)^2}{N}$$

Where N – size of the number

$$\mu - Mean$$
$$x_i - Each\ value\ (Number)$$

Content/Procedures/Methods/Illustrations

1.1. Identification, Collection and Organization of data is performed

Data identification is described as the records that links the value to give more sensible information or database such as age. Data collection on the other hand is the process of acquiring information of the targeted variables in the system such as the ages of children in class while data organisation refers to way of classifying where there are two main type which grouped data and individual data.

1.2. Interpretation, analysis and presentation of Data in appropriate format is performed

Data interpretation

This means analysing of data to infer information which enables proper answering of the relevant question.

Data analysis
This means the process of cleaning and transforming the inspected data to model data with an objective to achieve.
Data presentation
This means the arrangement of data into graphs, tables and charts. The data can be classified as either grouped or ungrouped data.
Ungrouped data: It is the data (first data) gathered from a study or experiment.

Digrammatic and graphical presentation of Data
Histagram: IIt is an adequate representation of data and how it is distributed.
It is represented with a table which helps in showing the probability.

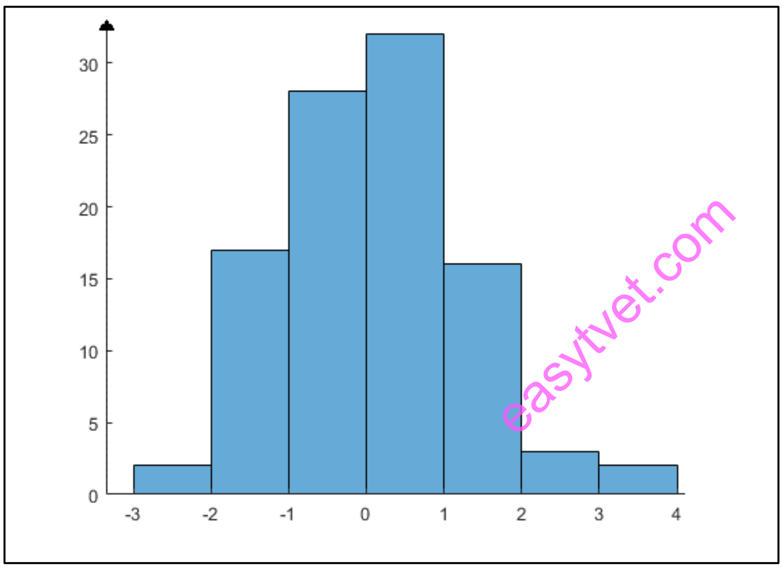


Figure 3: Histogram

Frequency polygon- This is a graph constructed by straight line passing on the midpoint of the class.
For example:

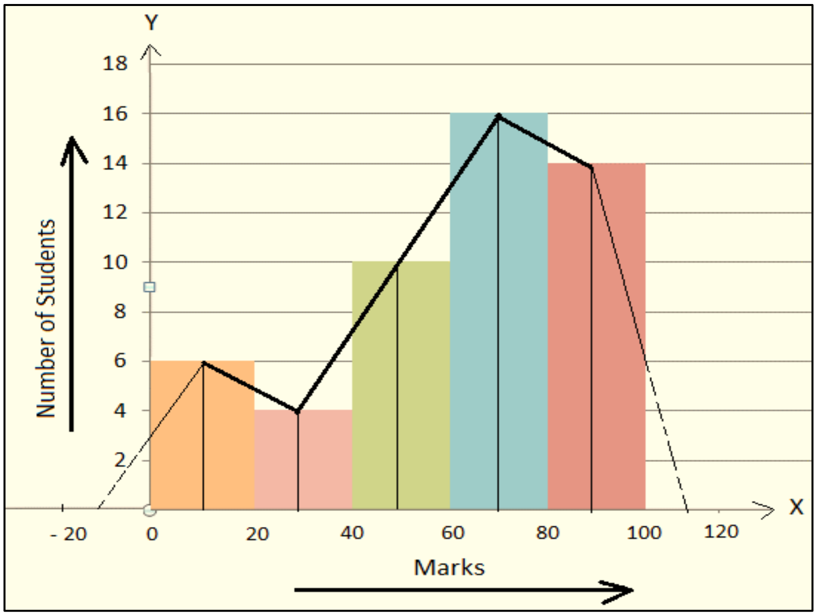


Figure 4: Frequency Polygon

Bar chart: It is a graph or chart that uses rectangles and their differences in heights or length to present data.

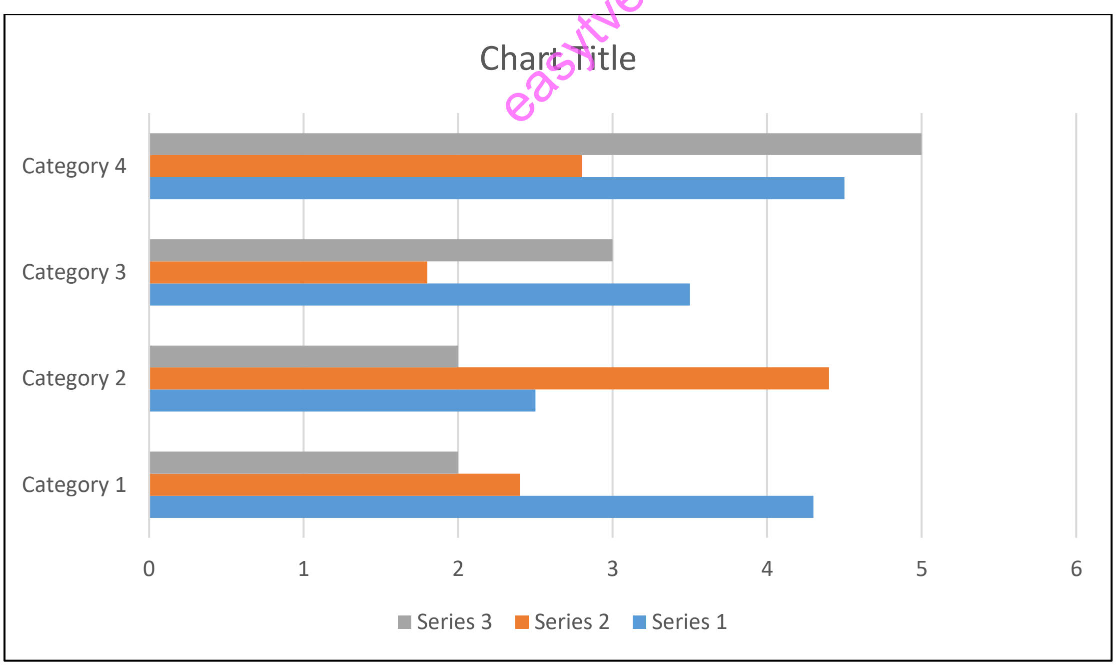


Figure 5: Bar Graph

Pie chart: This is a type of chart which represents data on a circle or pie where the pie is the total number.

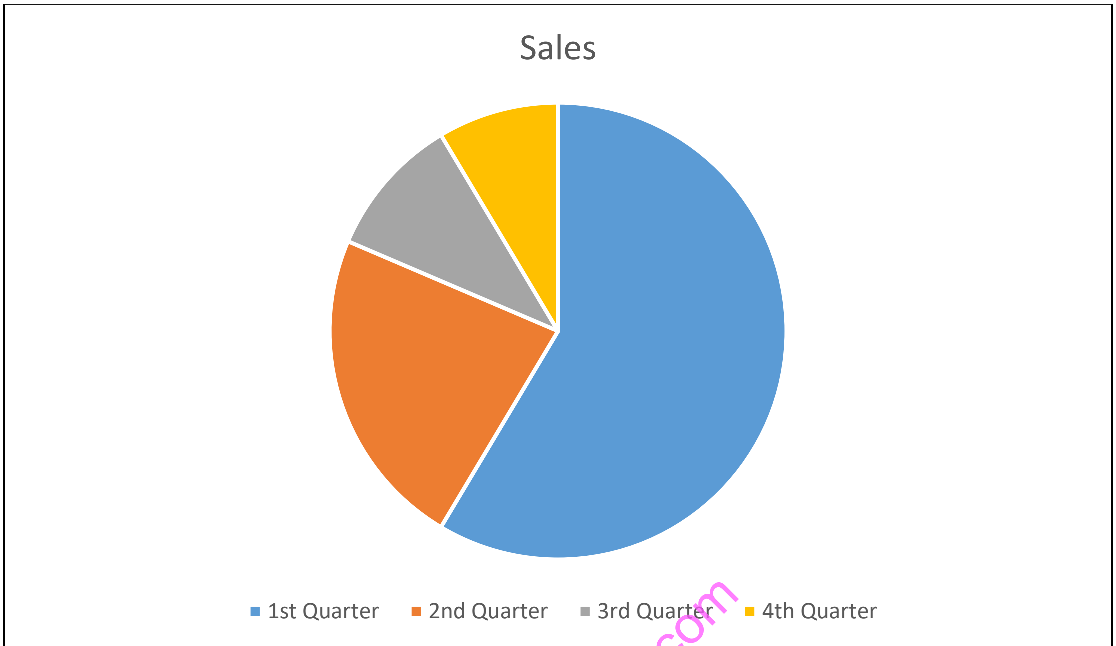


Figure 6: Pie Chart

Cumulative frequency curves: This is a curve which shows the cumulative frequency distribution of data mainly grouped data.

Data tabulation

Class intervals; this is the size of the individual group of data.

Class boundaries; these are the upper limit or the lower limit of grouped data.

Frequency table; it is a representation of frequency of various outcomes in a sample.

1.3. Median mode and Standard deviation are obtained from given data

Mean: It is also known as average therefore it is addition of the number divided by the number of the numbers.

$$Mean = \frac{\sum of\ numbers}{no\ of\ numbers}$$

Median: This is the number in the middle after being arranged from the lowest to the highest number; if they are two, find the mean.

Mode: This is the number which is the most repeated in a series.

Variance: This is the mean of the squared differences of the number from the mean.

$$Variance = \sum(x_{1-}\mu)^2/n$$

Standard deviation: This is the amount of variation of a set of numbers known as square-root variance.

1.4. Calculations are performed based on Laws of probability

Definition of probability; is a description of how likely an event or occasion to occur or how likely to happen or true.

Laws of probability

The Law of large numbers is the principle that the more trials you have in an experiment, the higher you get to the accurate value in probability. E.g a set of cards, probability to get black cards in two take is $1/52x2 = 1/26$

$$P(face)$$

Addition rule

Based on the next turn $P(AuB) = P(A) + P(B) - P(AnB)$

Multiplication Rule

It deals with the case in and of probabilities. It means the probability of two independent events.

$P(A \; and \; B) = P(A).P(B/A) = P(AnB)$

Example 2

A bag contains 3 pink candies and 7 green candles. 2 candies are taken out from the bag with replacement. Find the probability that both candies are pink.

Solution

Let A= event that 1st candy is pink and B= event that second candy is pink

$$p(A) = 3/10$$

$$A \; and \; B \; are \; independent$$

$$P(B/A) = P(B) = 3/10$$

Therefore, multiplication law we got

$P(AnB) = P(A)x \; P(B/A) \quad 3/10x3/10 = 9/100 = 0.09$

1.5. Calculation involving probability distributions, mathematical expectation sampling distributions are performed

Probability distribution is all the lekely and possible values that a random variable can take within the range. Also known as the 'bell curve'

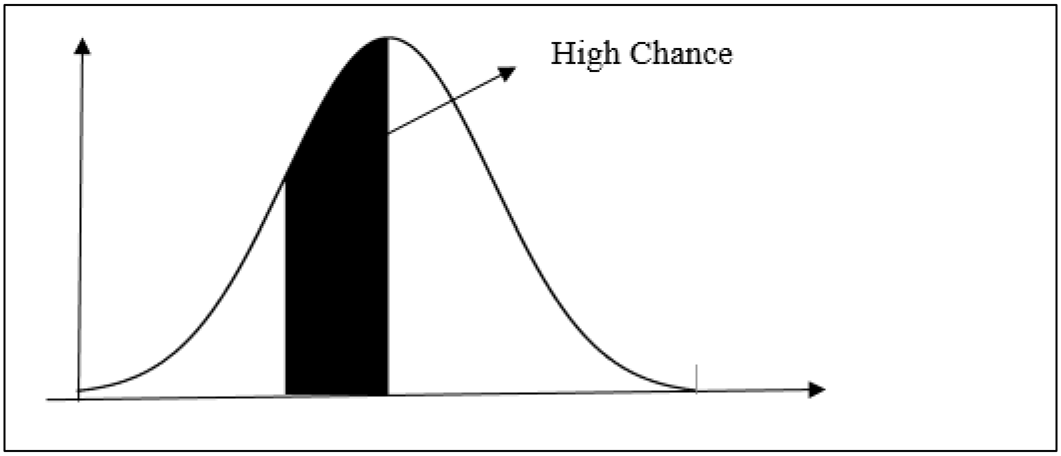


Figure 7: Probability Distribution

There are 4 common statistics in sampling distribution; the sample sum, the sample mean, the sample variance.

Sample sum is the sum of a random variables from the data

$$X_1 + \ X_2 \ldots, \ X_n$$

Sample mean is the average of the random variables:

$$M = (X_{1+}X_{2\ldots,X_n})/n$$

$$S^2 = ([(X_1 - M)^2 + (X_2 - M)^2 \ldots, ((X_n - M)^2])/(n-1)$$

Note square root estimates the standard deviation of a population.
Therefore the bell curve is from the standard deviation to the mean.

Example
Draw and show the bell curve if the mean is 30 and the standard deviation is 26.
The curve for the example is shown in the next page.

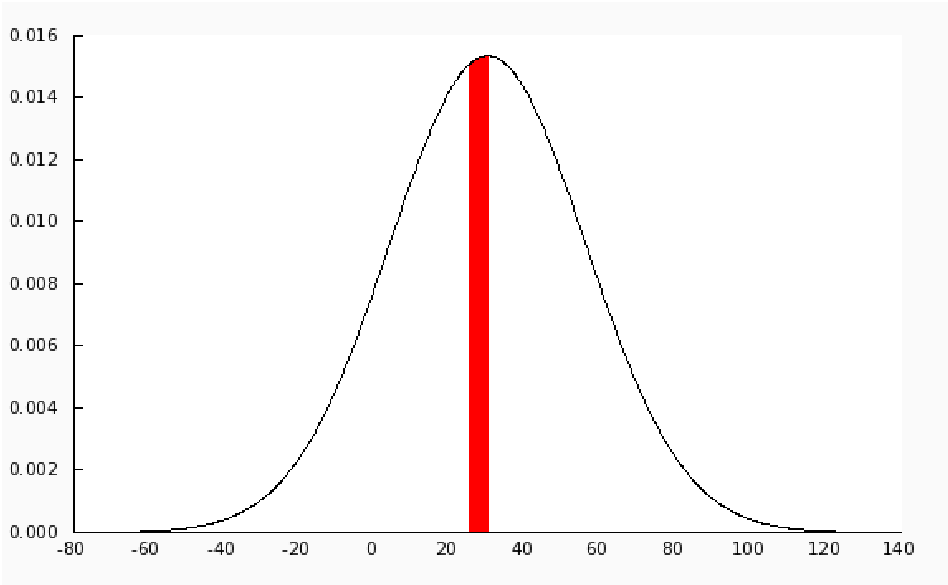


Figure 8: Bell curve

1.6 Sampling Distribution methods are applied in Data Analysis

There are three main types;

- **Normal distribution;** commonly used in investing, finance, science and engineering. It fully based on its mean and standard deviation.
- **Binomial distribution**: It is discrete, as opposed to continuous, since 1 or 0 / yes or no is a valid response.
- Chi-squared distribution
- Poisson distribution

NOTE: The first and second types are the most common used during data analysis in Kenya.

1.7 Calculations involving use of standard normal table, sampling Distribution, T-distribution and Estimation are done

Standard normal table (known Z table)

$$Z = \frac{x - \mu}{\alpha}$$

$$X = raw\ score$$

$$\mu = mean$$

$$\alpha \ = standard\ deviation$$

A Z found on the both table should be used on the table provided to known the percentile and therefore compare.

Note if it is a negative then a table for negative values is used.

Sampling distribution

It is also known as probability distribution and the standard deviation of this topic is known as standard error.

Samplig distribution mean is equal to the mean of the population.

$\mu_x = \mu$

Therefore standard error is:

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{n - 1}}$$

$$SE = \frac{\sigma}{\sqrt{n}}$$

SE Standard error

∂ =Standard deviation

μ=Size of population

n= size of sample

If $fpc = 1$ from factor$\sqrt{N - n)/N - 1)}$, therefore standard arror formula can be approximated by

$$\surd(\mathrm{x} = \alpha)/\surd n$$

Distribution

It is a type of distribution similar with the normal distribution curve but with a bit shorter and fatter tail. Therefore distribution is used because small size is small.

$$t = \frac{x - \mu}{(\frac{s}{\sqrt{n}})}$$

Where,

x̄ is the sample mean

μ is the population mean

s is the standard deviation

n is the size of the sample given

Estimation

This is the process of identifying a value by approximating due to a certain purpose. It can be done by rounding off to the nearest whole number.

1.8 Confidence intervals are determined

It is a type of estimate computed from the statistics of the observed data It is a range of value where a true value lies on.

Calculation

1) Find mean $\bar{x}$ and standard deviation s
2) Find 2 m table to find the percentile

$$Z=\overline{x-\mu/\alpha}$$

3) Using z un the formula for the confidence interval.

$$\overline{x} \pm z\left(\frac{s}{n}\right)$$

1.9 Testing hypothesis using large samples and small samples are performed

It is an act whereby an analyst test an assumption regarding a population parameter.

They are two types

a) Null hypothesis is equal to zero
b) Alternative hypothesis is not equal to zero

Steps of hypothesis testing

a) Analyse the state the 2 hypothesis so that only can be right.
b) Formulating an analysis plan, outline how the data will be evaluated.
c) Carry out the plan and physically Analyse the data.
d) Analyse the result either reject or accept if it is null hypothesis.

1.10 Calculations involving Correlation and regression are done

They are related because both deal with relationships among variable.

Where correlation is a measure of linear association between 2 variables while regression involves identifying the relationship between a dependent variable and one or more independent variable.

Calculation of correlation

$$r = \sum(x - \overline{x)(y - y/\sqrt{\{\sum(x-\bar{x})^2}})x^2(y-y)^2)$$

1.11 Calculations involving rank correlation coefficient and equations of regression line are done

Rank correlation coefficient: It is a tool to discover the strength of link between sets of data.

Method

a) Create a table
b) Rank the two data sets
c) Tied scores are given the mean rank
d) Square the differences

Linear regression

Formula

$$Y = a + bx$$
$$Y = explanatory\ value$$
$$X = dependent\ value$$
$$b = slope\ line$$
$$a = intercept$$

Conclusion

This learning outcome has covered classification of data, grouped data, ungrouped data, data collection, tabulation of data, class intervals, class boundaries, frequency tables, diagrammatic and graphical presentation of data e.g. histograms, frequency polygons, bar charts and pie charts. It also covered cumulative frequency curves, measures of central tendency mean, mode and median, measures of dispersion, variance and standard deviation, definition of probability, laws of probability, expectation variance and S.D, types of distributions, mean, variance and SD of probability distributions, application of probability distributions, standard normal tables and sampling distributions and rank correlation coefficient.

Further Reading

Read more on:

1. Correlation from the book Cox. D, Principles of applied statistics, (2011).
2. Confidence interval from the internet.

2.3.2.3 Self-Assessment

Written Assessment

1. Which of the following is NOT a way of presenting data?
    a) Figures
    b) Chart
    c) Graph
    d) Table
2. Suppose the covariance between Y and X is 12, the variance of Y is 25, and the variance of X is 36. The correlation coefficient, r, between Y and X is closest to:
    a) r = 0.000
    b) r = 0.013
    c) r = 0.160
    d) r = 0.400
3. The following represents age distribution of students in an elementary class. Find the mode of the values: 7, 9, 10, 13, 11, 7, 9, 19, 12, 11, 9, 7, 9, 10, 11.
    a) 7
    b) 9
    c) 10
    d) 11

4. Find the mean of 8, 5, 7, 10, 15, and 21
    a) 15
    b) 6
    c) 11
    d) 4
5. The standard deviation of a sample of 100 observations equals 64. The variance of the sample equals
    a) 8
    b) 10
    c) 6400
    d) 4096
6. Which of the following is not a measure of dispersion
    a) Range
    b) The 5^{th} percentile
    c) The standard deviation
    d) The interquartile range

7. In a certain game, players toss a coin and roll a dice. A player wins if the coin comes up heads, or the dice with a number greater than 4. In 20 games, how many times will a player win?

    a) 13
    b) 8
    c) 11
    d) 15

8. Justify the use of binomial distribution in Modern mathematics?
9. Classify the laws of probability?
10. A box contains 30 red, green and blue balls. The probability of drawing a red ball is twice the other colours due to its size. The number of green balls are 3 more than twice the number of blue balls, and blue are 5 less than the twice the red. What is the probability that 1st two balls drawn from the box randomly will be red?
11. There are 3 blue, 1 white and 4 red identical balls inside a bag. If it is aimed to take two balls out of the bag consecutively, what is the probability to have 1 blue and 1 white ball?
12. Kamau has two children and we know that she has a daughter. What is the probability that the other child is a girl as well? Describe the term rank correlation coefficient?

Oral Assessment

1. The average age of 6 persons living in a house is 23.5 years. Three of them are majors and their average age is 42 years. The difference in ages of the three minor children is same. What is the mean of the ages of minor children?
2. The arithmetic mean of a set of 10 numbers is 20. If each number is first multiplied by 2 and then increased by 5, then what is the mean of new numbers?

Practical Assessment

In a group analyses the data and form a table of the type of cars passed in the nearest road according to type.

2.3.11.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Computers with an internet connection

2.3.11.5 References

Bland, J. M., & Altman, D. G. (2010). Statistical methods for assessing agreement between two methods of clinical measurement. International Journal of Nursing Studies, 47(8), 931-936.

McCuen, R. H. (2002). Approach to confidence interval estimation for curve numbers. Journal of Hydrologic Engineering, 7(1), 43-48.

Torabi, H., & Behboodian, J. (2007). Likelihood ratio tests for fuzzy hypotheses testing. Statistical Papers, 48(3), 509.

2.3.12 Learning Outcome No 11: Apply numerical methods

2.3.12.1 Learning Activities

Learning Outcome No 11: Apply numerical methods	
Learning Activities	**Special Instructions**
1.1. Obtain roots of polynomials using iterative numerical methods (Newton Raphson and Gregory Newton)	

2.3.12.2 Information Sheet No2/LO11: Apply numerical methods

Introduction

This learning outcome covers Application of numerical methods, roots of polynomials, and performing interpolation and extrapolation using numerical methods.

Definition of key terms

Numerical methods: Are algorithms used for computing numeric data.

Content/Procedures/Methods/Illustrations

1.1 Obtain roots of polynomials using iterative numerical methods (Newton Raphson and Gregory Newton)

Numerical method is a complete and definite set of procedures for the solution of a problem, together with computable error estimates. The study and implementation of such methods is the province of numerical analysis.

Types of numerical methods

a) Bisection method
b) Newton Raphson method (Newton's Iteration method)
c) Iteration method
d) Newton's forward interpolation formula
e) Newton's backward interpolation formula
f) Gauss Seided method
g) Curve fitting

Applications

- Used in computer science for root algorithm
- Used to determine profit and loss in the company
- Solving practical technical problems using scientific and mathematical tools

- Used for multidimensional root finding
- Network simulation
- Train and traffic signal
- Weather prediction
- Build up an algorithm

Worked example

Construct a difference table to find polynomial of the data $(1,1), (2,8), (3,27), (4,64), (6,216), (7,343), 8,512)$.
Considering appropriate method find r, where (9,r) given.

Solution

We may construct anyone of forward backward and central difference tables. Since we also have to; Find r for x=9, which is nearer at the end of the set of given tabular values, so we will construct the backward difference table.

Table 1. The backward difference table of the data

X	Y	$\overline{\nabla}$	∇^{-2}	∇^3	∇^4
1	1	7	12	6	0
2	8	19	18	6	0
3	27	37	24	6	0
4	64	61	30	6	0
5	125	91	36	6	
6	216	127	42		
7	343	167			
8	512				

This the required difference table:
Here:
$X_n = 8, h = 1, Y_n = 512$
$\nabla^{-2}Yn = 42, \nabla^3 Yn = 6, \nabla^4 Yn = 0$
Therefore ; $P = \dfrac{x - xn}{n} = \dfrac{x - 8}{1} = (x - 8)$
By newtons backward formular;

$$Y(X) = Yn + p\nabla_{yn} + p\frac{(p+1)\nabla_{yn}}{2} + \frac{p(p+1)(p+2)\nabla_{yn}^{1}}{3!} \text{-------} + \frac{p(p+1)(p+n-1)\nabla_{yn}^{n}}{n!}$$

$$= 512 = 169\frac{(x-8) + (x-8)(x-8+1) * 42}{2!}$$

Conclusion

The learning outcome covered apply numerical methods, roots of polynomials, and perform interpolation and extrapolation using numerical methods.

Further Reading

2.3.12.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Dice
- Computers with internet connection

2.3.12.5 References

Greenberg, M.D. (1998), Advanced Engineering Mathematics, 2nd ed., Prentice Hall (Upper Saddle River, N.J).

Hildebrand, F.B. (2003), Introduction to Numerical Analysis, 2nd ed., McGraw-Hill (New York).

Hildebrand, F.B. (2002), Advanced Calculus for Applications, 2nd ed., Prentice-Hall (Englewood Cliffs, NJ).

2.3.13 Learning Outcome No12: Apply Vector Theory

2.3.13.1 Learning Activities

Learning Outcome No 12: Apply Vector Theory	
Learning Activities	**Special Instructions**
12.1 Obtain vectors and scalar quantities in two and three dimensions 12.2 Perform Operations (addition and subtraction) on vectors 12.3 Obtain position of vectors 12.4 Work out resolution of vectors	Encourage students to practice

2.3.13.2 Information Sheet No2/LO12: Apply Vector Theory

Introduction

This learning outcome covers vectors and scalar quantities in two and three dimensions, operations on vectors, and position and resolution of vectors.

Definition of key terms

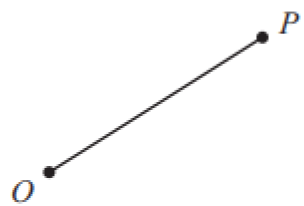
Vectors: A quantity having direction as well as magnitude, especially as determining the position of one point in space relative to another. A vector has both magnitude and direction, and both these properties must be given in order to specify it. A quantity with magnitude but no direction is called a scalar.

Content/Procedures/Methods/Illustrations

12.1 Apply Vector theory

Physical quantities can be divided into two main groups, scalar quantities and vector quantities. A Scalar quantity is one that is defined completely by a single number with appropriate units e.g. Lengths, area, volume, mass, time etc. A Vector quantity is defined completely when we know not only its magnitude but also the direction in which it operates, e.g. force, velocity, acceleration, etc.

Vector quantities are extremely useful in physics. The important characteristic of a vector quantity is that it has both a magnitude (and size) and a direction. Both of these properties must be given in order to specify a vector completely. An example of a vector quantity is a displacement. This tell us how far away we are from a fixed point, and it also tells us our direction relative to that point.



Another example of a **vector quantity** is **velocity**. This is speed, in a particular direction. An example of velocity might be 60 mph due north. A quantity with magnitude alone, but no direction, is not a vector. It is called a scalar instead. One example of a **scala**r is **distance**. This tells us how far we are from a fixed point, but does not give us any information about the direction. Another example of a scalar quantity is the mass of an object.

12.2 Representing vector quantities

Represent a vector by a line segment

This diagram shows two vectors.

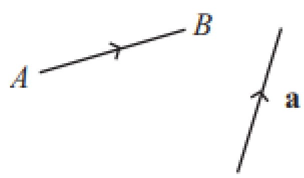
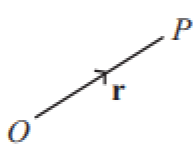


Figure 9. Vectors

The small arrow indicate that the first vector is pointing from A to B. A vector pointing from B to A would be going in the opposite direction.

Position vectors

Position vectors are referred to as fixed point, an origin. The position vector of a point P with respect to an origin O. In writing, might put OP for this vector. Alternatively, we could write it as **r**. These two expressions refer to the same vector.



Notation for vectors

What does it mean if, for two vectors, **a** = **b**? This means first that the length of **a** equals the length of **b**, so that the two vectors have the same magnitude. But it also means that **a** and **b** are in the same direction. How can we write this down more succinctly?

If two vectors are “in the same direction”, then they are parallel. We write this down as **a**//**b**.

For length, if we have a vector AB, we can write its length as AB without the bar. Alternatively, we can write it as |AB|. The two vertical lines give us the modulus, or size of, the vector. If we have a vector written as **a**, we can write its length as either |**a**| with two vertical lines, or as **a** in ordinary type (or without the bar). This is why it is very important to keep to the convention that has been adopted in order to distinguish between a vector and its length.

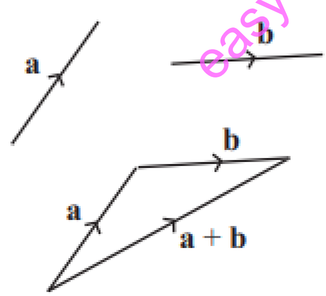
The length of a vector AB is written as **AB or |AB|,** and the length of a vector a is written as

a (in ordinary type, or without the bar) or as |**a**|

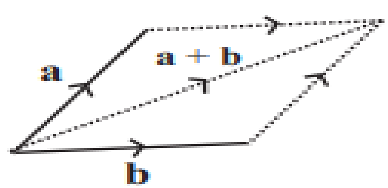
If two vectors **a** and **b** are parallel, we write **a//b**

12.3 Adding two vectors

In order to add two vectors, we think of them as displacements. We carry out the first displacement, and then the second. So, the second displacement must start where the first one finishes.



The sum of the vectors, a + b (or the resultant, as it is sometimes called) is what we get when we join up the triangle. This is called the triangle law for adding vectors. There is another way of adding two vectors. Instead of making the second vector start where the first one finishes, we make them both start at the same place, and complete a parallelogram. This is called the parallelogram law for adding vectors. It gives the same result as the triangle law, because one of the properties of a parallelogram is that opposite sides are equal and in the same direction, so that b is repeated at the top of the parallelogram.



Refer to Engineering mathematics by K. A Stroud to learn more on components of 0 Vector in terms of unit Vectors on page 368. Dot and cross product of vectors. The Scalar product of two vectors is denoted by $\bar{a}.\bar{\mathbf{b}}$ (sometimes called the 'dot product'.

The dot product of two vectors is defined as $\mathbf{a.b} = |\mathbf{a}||\mathbf{b}|\mathbf{cos\theta}$ where θ is the angle between **a** and **b**.

Refer to Technician mathematics 3 by J.O. Bird on page 297.

Examples

Solution

$\bar{\mathbf{a}} = \mathbf{2i + 3j + 5k}$ **And** $\bar{\mathbf{b}} = \mathbf{4i + j + 6k}$, $\bar{\mathbf{a}}.\bar{\mathbf{b}}$

$\bar{a}\,.\,\bar{b} = 2.4 + 3.1 + 5.6$

= 8 + 3+ 30

=41

A typical application of scalar products is that of determining the work done by a force when moving a body. The amount of work done is the product of the applied force and the distance moved in the direction of the applied force.

Example

Find the work done by a force F newtons acting at point A on a body, when A is displaced to point B, the coordinates of A and B being (3, 1, -2) and (4, -1, 0) metres respectively and when

$F = -i - 2j - k$ Newton's.

Solution

If a vector displacement from A to B is d, then the work done is F. d Newton Meters or joules. The position vector OA is $3i + j - 2k$ and OB is $4i - j$

$AB = d = OB - OA$

$= (4i - j) - (3i + j - 2k)$

$i - 2j + 2k.$

Work done $= F.d = (-1)/1) + (-2)(-2) + (-1)(2)$

$= -1 + 4 - 2$

=1 Nm or joule

For more worked examples refer to Technician mathematics 3 by J. O. Bird.

Cross Product

The vector or Cross product of two vectors $\bar{a}$ and $\bar{b}$ is C where the magnitude of C is $|\bar{a}||b|\text{Sin}\theta$ where θ is the angle between $\bar{a}$ and b.

For more information refer to Technician mathematics 3 by J.O Bird and Engineering mathematics by K. A Stroud.

Examples

$\bar{p} = 2i + 4j + 3k$ and $Q = i + 5j - 2k$ find $\overline{P} \times \overline{Q} = \begin{vmatrix} i & j & k \\ 2 & 4 & 3 \\ 1 & 5 & -2 \end{vmatrix}$

$=i\begin{vmatrix} 4 & 3 \\ 5 & -2 \end{vmatrix} - j\begin{vmatrix} 2 & 3 \\ 1 & -2 \end{vmatrix} + k\begin{vmatrix} 2 & 4 \\ 1 & 5 \end{vmatrix}$

$=-23i + 7j + 6k$

Typical applications of vector products are to moments and to angular velocity.

Refer to Technician mathematics. 3 by J.O Bird on page 308.

12.4 Vector field Theory

Refer to further Engineering mathematics by K.A Stroud to learn and also go through the worked examples and exercises on:

(i) Gradient

(ii) Divergence

(iii) Curl

Greens theorem: Learn how to perform vector calculations using Green's theorem by referring to further Engineer mathematics by KA. Stroud.

Stoke's Theorem: Refer to further Engineer Mathematics by K.A Stroud to learn how to perform vector calculations using Stroke's theorem.

Gauss's Theorem: Refer to the same book to learn how to determine line and surface integrals using Gauss's theorem.

Conclusion

This learning outcome covered vectors and scalar quantities in two and three dimensions, operations on vectors, and position and resolution of vectors.

Further Reading

1. Greenberg, M.D. (1998), Advanced Engineering Mathematics, 2nd ed., Prentice Hall (Upper Saddle River, N.J).

2.3.13.3 Self-Assessment

Written Assessment

1. If $\bar{a} = 2i - 3j + 4k$ and $\bar{b} = i + 2j + 5k$ determine
   (2́) $\bar{a} \cdot \bar{b}$
   (22́) $\bar{a} \times \bar{b}$
2. Find the work done by a force F Newtons acting at a point A on a body, when A is displaced to point B ,the coordinates of A and B being (5, 2, -4) and (3,-1,1) meters respectively , and when $F = -2i - 3j - 2k$ Newton's.

2.3.13.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Graph books
- Dice
- Computers with internet connection

2.3.13.5 References

Duffy, D. G. (2016). Advanced engineering mathematics with MATLAB. Chapman and Hall/CRC.

Jeffrey, A. (2001). Advanced engineering mathematics. Elsevier.

Zill, D., Wright, W. S., & Cullen, M. R. (2011). Advanced engineering mathematics. Jones & Bartlett Learning.

2.3.14 Learning Outcome No 13: Apply Matrix

2.3.14.1 Learning Activities

Learning Outcome No 11: Apply Matrix	
Learning Activities	**Special Instructions**
11.1 Obtain determinant and inverse of 3x3 matrix 11.2 Obtained Solutions of simultaneous equations in three unknowns are 11.3 Perform Calculation involving Eigen values and Eigen vectors	• Discussions • Projects • Demonstration by the trainer

2.3.14.2Information Sheet No 2/LO11 Apply Matrix

Introduction

This learning outcome covers; the determinant of a $3x3$ matrix, inverse of a $3x3$ matrix, solutions of three unknown simultaneous equations and the calculations on eigen values and eigen vectors.

Definition of key terms

Matrix: This is a set of real or complex numbers arranged in rows and columns to form a rectangular array and it is always denoted by capital letters.

Determinant: It is a physical quantity/value assigned to any square matrix. E.g. given $\begin{bmatrix} a & b \\ c & d \end{bmatrix} = ad - cd$

Inverse: The inverse of a matrix Q^{-1} is the matrix than when multiplied by the original matrix Q gives the identity matrix. i.e. $Q\ Q^{-1}=I$.

Content/Procedures/Methods/Illustrations

11.1 Determinant and inverse of 3x3 matrix are obtained as per the method.

A matrix with P rows and Q columns is called a $P \times Q$ matrix and is of order $P \times Q$. Square brackets [ ] or round brackets () are used when writing a matrix. For example, $\begin{bmatrix} 1 & 6 \\ 9 & 8 \end{bmatrix}$ or $\begin{pmatrix} 1 & 6 \\ 9 & 8 \end{pmatrix}$

Matrices are named by stating the number of rows followed by the number of columns. For example, $\begin{bmatrix} 1 & 9 & 7 \\ 6 & 5 & 4 \\ 2 & 3 & 6 \end{bmatrix}$ is a 3×3 matrix

. $\begin{bmatrix} 5 & 6 & 4 & 3 \\ 1 & 7 & 8 & 2 \\ 10 & 9 & 6 & 5 \end{bmatrix}$ is a 3×4 matrix

A line matrix (row matrix) consists of one row only e.g. $(5\ 6\ 4\ 3)$ while a column matrix consists of one column only e.g. $\begin{bmatrix} 5 \\ 1 \\ 10 \end{bmatrix}$

Double suffix notation

Each unit in a matrix can be defined by double suffixes. The first suffix is the row while the second is the column.

E.g. $\begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{pmatrix}$ Thus $P_{32}$is on the third row and the second column.

Addition and subtraction of matrices

For two or more matrices to be added or subtracted, they must be of the same order. The operation is done by adding or subtracting the corresponding elements.

Example:

$$\begin{pmatrix} 5 & 6 & 7 \\ 1 & 10 & 2 \\ 4 & 3 & 8 \end{pmatrix}+\begin{pmatrix} 12 & 9 & 8 \\ 6 & 5 & 3 \\ 9 & 7 & 2 \end{pmatrix}=\begin{pmatrix} 17 & 15 & 15 \\ 7 & 16 & 5 \\ 13 & 10 & 10 \end{pmatrix}$$

$$\begin{pmatrix} 4 & 5 & 1 \\ 2 & 7 & 8 \\ 3 & 6 & 9 \end{pmatrix} - \begin{pmatrix} 3 & 6 & 9 \\ 5 & 5 & 4 \\ 4 & 12 & 8 \end{pmatrix} = \begin{pmatrix} 1 & -1 & -8 \\ -3 & 2 & 4 \\ -1 & -6 & 1 \end{pmatrix}$$

Transposing a matrix

Example

Q=$\begin{pmatrix} 3 & 6 & 9 \\ 5 & 5 & 4 \\ 4 & 12 & 8 \end{pmatrix}$, $Q^T=\begin{pmatrix} 3 & 5 & 4 \\ 6 & 5 & 12 \\ 9 & 4 & 8 \end{pmatrix}$

Determinant of a 3x3 matrix

Suppose Q is a 3×3 matrix, the determinant of Q denoted by det Q or$|Q|$ is obtained by

$$\begin{pmatrix} q_{11} & q_{12} & q_{13} \\ q_{21} & q_{22} & q_{23} \\ q_{31} & q_{32} & q_{33} \end{pmatrix}$$

$$\det Q\ or|Q| = q_{11}\begin{vmatrix} q_{22} & q_{23} \\ q_{32} & q_{33} \end{vmatrix} - q_{12}\begin{vmatrix} q_{21} & q_{23} \\ q_{31} & q_{33} \end{vmatrix} + q_{13}\begin{vmatrix} q_{21} & q_{22} \\ q_{31} & q_{32} \end{vmatrix}$$

$$det\ Q = q_{11}(q_{22}q_{33} - q_{23}q_{32}) - q_{12}(q_{21}q_{33} - q_{31}q_{23}) + q_{13}(q_{21}q_{32} - q_{31}q_{22})$$

$$det\ Q = q_{11}q_{22}q_{33} - q_{11}q_{23}q_{32} - q_{12}q_{21}q_{33} + q_{12}q_{31}q_{23} + q_{13}q_{21}q_{32} - q_{13}q_{31}q_{22}$$

$$det\ Q = q_{11}q_{22}q_{33} + q_{12}q_{31}q_{23} + q_{13}q_{21}q_{32} - q_{13}q_{31}q_{22} - -q_{11}q_{23}q_{32} - q_{12}q_{21}q_{33}$$

Thus

$$\det Q = \begin{vmatrix} q_{11} & q_{12} & q_{13} \\ q_{21} & q_{22} & q_{23} \\ q_{31} & q_{32} & q_{33} \end{vmatrix}\begin{vmatrix} q_{11} & q_{12} & q_{13} \\ q_{21} & q_{22} & q_{23} \\ q_{31} & q_{32} & q_{33} \end{vmatrix}$$

Example

$$Q=\begin{pmatrix} 2 & 3 & 4 \\ 5 & 6 & 7 \\ 8 & 9 & 1 \end{pmatrix}$$

$$det\ Q = (2\times 6\times 1)+(3\times 4\times 8)+(4\times 5\times 9)-(2\times 7\times 9)-(3\times 5\times 1)-(4\times 6\times 8)$$

$$det\ Q = 27$$

Minors and cofactors of a 3x3 matrix

Suppose R is a 3×3 matrix, R=$r_{ij}$and S is 3×3 matrix obtained from R by deleting its i^{th} row and j^{th} column. Then the determinant of s_{ij} is called the minor of the element r_{ij} of R.

Cofactors are obtained by multiplying $(-1)^{i+j}$ by the submatrix of the matrix.

Example.

If $T=\begin{pmatrix} 5 & 3 & 8 \\ 1 & 10 & 2 \\ 4 & 6 & 7 \end{pmatrix}$ Minor of T $=\begin{pmatrix} 58 & -1 & -34 \\ -27 & 3 & 18 \\ -74 & 2 & 47 \end{pmatrix}$

Cofactors of T$=\begin{pmatrix} 58 & 1 & -34 \\ 27 & 3 & -18 \\ -74 & -2 & 47 \end{pmatrix}$

Adjoint of a 3x3 matrix

Adjoint is the transpose of the cofactors of a matrix denoted by $Adj\ T$.

$Thus$

Adj T$=\begin{pmatrix} 58 & 27 & -74 \\ 1 & 3 & -2 \\ -34 & -18 & 47 \end{pmatrix}$

Inverse of a 3x3 matrix

The inverse of T, i.e. T^{-1} is given by;

. $T^{-1} = \frac{adjT}{Det\ T}$

$\det T = 5(58)-3(-1)+8(-34) = 21$

$$T^{-1}=\frac{1}{21}\begin{pmatrix} 58 & 27 & -74 \\ 1 & 3 & -2 \\ -34 & -18 & 47 \end{pmatrix}=\begin{pmatrix} \frac{58}{21} & \frac{27}{21} & \frac{-74}{21} \\ \frac{1}{21} & \frac{3}{21} & \frac{-2}{21} \\ \frac{-34}{21} & \frac{-18}{21} & \frac{47}{21} \end{pmatrix}$$

11.2 Solutions of simultaneous equations in three unknowns are obtained as per the procedure

Consider 3 sets of linear equations

$r_{11}x + r_{12}y + r_{13}z = C_1$

$r_{21}x + r_{22}y + r_{23}z = C_2$

$r_{31}x + r_{32}y + r_{33}z = C_3$

Then the values x, y and Z are obtained by,

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix}^{-1} \begin{pmatrix} C_1 \\ C_2 \\ C_3 \end{pmatrix}$$

Example

Obtain the values $of\ p, q, r$ in the following system of simultaneous equations.

$3p + q + 2r = 5$

$5p + 3q + 2r = 7$

$9p + 8q + 7r = 3$

Solution

$$\begin{pmatrix} 3 & 1 & 2 \\ 5 & 3 & 2 \\ 9 & 8 & 7 \end{pmatrix} \begin{pmatrix} p \\ q \\ r \end{pmatrix} = \begin{pmatrix} 5 \\ 7 \\ 3 \end{pmatrix}$$

$$\begin{pmatrix} p \\ q \\ r \end{pmatrix} = \begin{pmatrix} 3 & 1 & 2 \\ 5 & 3 & 2 \\ 9 & 8 & 7 \end{pmatrix}^{-1} \begin{pmatrix} 5 \\ 7 \\ 3 \end{pmatrix}$$

$$\begin{pmatrix} 3 & 1 & 2 \\ 5 & 3 & 2 \\ 9 & 8 & 7 \end{pmatrix}^{-1} = \frac{1}{24}\begin{pmatrix} 5 & 9 & -4 \\ -17 & 3 & 4 \\ 13 & -15 & 4 \end{pmatrix} = \begin{pmatrix} \frac{5}{24} & \frac{3}{8} & \frac{-1}{6} \\ \frac{-17}{24} & \frac{1}{8} & \frac{1}{6} \\ \frac{13}{24} & \frac{-5}{8} & \frac{1}{6} \end{pmatrix}$$

Thus $\begin{pmatrix} p \\ q = \\ r \end{pmatrix} \begin{pmatrix} \frac{19}{6} \\ \frac{-13}{6} \\ \frac{-7}{6} \end{pmatrix}$

This implies that $p = \frac{19}{6}, q = \frac{-13}{6}, r = \frac{-7}{6}$

11.3 Calculation involving Eigen values and Eigen vectors are performed

If Q is a $m \times m$ matrix over some field N, then $\omega \varepsilon N$ is an eigen value of Q if some non-zero vector (column) rεN^m then $Qr = \omega r$. Thus, r is an eigen vector of Q which belong to the eigen value w.

Example

Find the eigen values and the eigen

Vectors associated with the matrix.

Q= $\begin{pmatrix} 3 & 1 & 0 \\ 0 & 1 & -1 \\ 0 & 2 & 4 \end{pmatrix}$

Solution

ω is an eigen value of Q is $|\omega I - Q|$=0 where I is the identity matrix.

$$|\omega I - Q| = \left| \begin{pmatrix} \omega & 0 & 0 \\ 0 & \omega & 0 \\ 0 & 0 & \omega \end{pmatrix} - \begin{pmatrix} 3 & 1 & 0 \\ 0 & 1 & -1 \\ 0 & 2 & 4 \end{pmatrix} \right| = 0$$

$$\begin{vmatrix} \omega - 3 & -1 & 0 \\ 0 & \omega - 1 & 1 \\ 0 & -2 & \omega - 4 \end{vmatrix} = 0$$

$$\omega - 3 \begin{vmatrix} \omega - 1 & 1 \\ -2 & \omega - 4 \end{vmatrix} = 0$$

$$\omega - 3[(\omega - 1)(\omega - 4) + 2\,] = 0$$

$$\omega - 3[(\omega - 2)(\omega - 3)] = 0 \qquad \omega = 3 \; or \; \omega = 2$$

Thus, the eigen values are $\omega = 3, 3 \; and \; \omega = 2.$

For eigen vectors, solve the equation $|\omega I - Q|$ r=0

When $\omega = 2$

$|\omega I - Q|$ r=0

$$\begin{pmatrix} -1 & -1 & 0 \\ 0 & 1 & 1 \\ 0 & -2 & -2 \end{pmatrix} \begin{pmatrix} p \\ s \\ t \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$$

$-p - s = 0$

$S + t = 0$

$-2s - 2t = 0 \qquad s = 0 \qquad t = 0 \qquad p = 0$

Example:

Find the eigen values and the eigen vectors associated with.

M= $\begin{pmatrix} 7 & 0 & 0 \\ 6 & 3 & 1 \\ 2 & 10 & 6 \end{pmatrix}$

Solution

Suppose ω is an eigen value of M, then $|\omega I - M|$=0

$$|\omega I - M| = \left| \begin{pmatrix} \omega & 0 & 0 \\ 0 & \omega & 0 \\ 0 & 0 & \omega \end{pmatrix} - \begin{pmatrix} 7 & 0 & 0 \\ 6 & 3 & 1 \\ 2 & 10 & 6 \end{pmatrix} \right| = 0$$

$$= \begin{vmatrix} \omega - 7 & 0 & 0 \\ -6 & \omega - 3 & -1 \\ -2 & -10 & \omega - 6 \end{vmatrix} = 0$$

$$\omega - 7 \begin{vmatrix} \omega - 3 & -1 \\ -10 & \omega - 6 \end{vmatrix}$$

$\omega - 7[(\omega - 3)(\omega - 6) - 5] = 0$

$\omega - 7[\omega^2 - 6\omega - 3\omega + 18 - 10] = 0$

$\omega - 7[\omega^2 - 9\omega + 8] = 0$

$(\omega - 7)(\omega - 1)(\omega - 8) = 0$

$\omega = 7,1 \; or \; 8$

Thus, the eigen values are 1, 7 and 8

For eigen vectors;

Take $|\omega I - Q|r = 0$

$$\begin{pmatrix} \omega - 7 & 0 & 0 \\ -6 & \omega - 3 & -1 \\ -2 & -10 & \omega - 6 \end{pmatrix} \begin{matrix} x \\ y = 0 \\ z \end{matrix}$$

When $\omega = 1$,

We have $\begin{pmatrix} -6 & 0 & - \\ -6 & -2 & -1 \\ -2 & 10 & -5 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = 0$

$-6x = 0 \quad thus \; x = 0$

$-6y - 2y - z = 0$

$-2x - 10y - 5z = 0$

$-2y - z = 0$

$-10y - 5z = 0$

$-10y - 10z = 0$

$-10y - 5z = 0$

$-5z = 0$

$Z = 0 \qquad y = 0$

When $\omega = 7$

We have $\begin{pmatrix} 0 & 0 & 0 \\ -6 & 4 & -1 \\ -2 & -10 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = 0$

$x = 0, \quad y = 0 \quad z = 0$

When $\omega = 8$

$$\begin{pmatrix} 1 & 0 & 0 \\ -6 & 5 & -1 \\ -2 & -10 & 2 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = 0$$

$x = 0 \qquad -6x + 5y - z = 0$

$-2x - 10y + 2z = 0$

$5y - z = 0$

$-10y + 2z = 0 \qquad y = z = 0$

Conclusion

This learning outcome covered the determinant of a $3x3$ matrix, solutions of three unknows simultaneous equation and the calculations Eigen values and Eigen vectors.

Further Reading

Read more on

1. Multiplication of two or more matrices. Matrix algebra useful for statistics by John Wiley and sons.
2. Eigen values and eigen values. Iterative methods for computing eigen values and eigen vectors by Panju M.

2.3.14.3Self-Assessment

Written Assessment

1.Find the determinant of the following matrix.

$$\begin{pmatrix} 4 & 3 & -1 \\ -17 & 7 & 9 \\ 13 & 25 & 1 \end{pmatrix}$$

a) 46
b) 48
c) 52
d) 64

2.Find the determinant of the following matrix.

$$\begin{pmatrix} 10 & 5 & 1 \\ 3 & 6 & 2 \\ 4 & 7 & 9 \end{pmatrix}$$

a) 300
b) 256
c) 272
d) 302

3.Find the inverse of the following matrices.

$$\begin{pmatrix} 3 & -5 & -2 \\ 2 & -2 & 4 \\ -3 & 8 & -5 \end{pmatrix}$$

a) $\begin{pmatrix} \frac{11}{38} & \frac{41}{76} & \frac{6}{19} \\ \frac{1}{38} & \frac{21}{76} & \frac{4}{19} \\ \frac{-5}{38} & \frac{9}{46} & \frac{-1}{19} \end{pmatrix}$

b) $\begin{pmatrix} \frac{76}{38} & \frac{65}{38} & \frac{11}{38} \\ \frac{21}{38} & \frac{23}{76} & \frac{9}{19} \\ \frac{-10}{19} & \frac{9}{76} & \frac{-1}{19} \end{pmatrix}$

c) $\begin{pmatrix} \frac{3}{38} & \frac{-5}{38} & \frac{-1}{19} \\ \frac{1}{19} & \frac{-1}{19} & \frac{2}{19} \\ \frac{-3}{38} & \frac{4}{9} & \frac{-5}{38} \end{pmatrix}$

d) $\begin{pmatrix} \frac{11}{19} & \frac{82}{76} & \frac{12}{19} \\ \frac{1}{19} & \frac{42}{76} & \frac{8}{19} \\ \frac{-5}{19} & \frac{9}{76} & \frac{-2}{19} \end{pmatrix}$

4.Find the inverse of the following matrix

$$\begin{pmatrix} 13 & 12 & 9 \\ 2 & 1 & 3 \\ 2 & -10 & 8 \end{pmatrix}$$

a) $\begin{pmatrix} \frac{19}{88} & \frac{-93}{88} & \frac{27}{176} \\ \frac{-5}{88} & \frac{43}{88} & \frac{-21}{176} \\ \frac{-1}{88} & \frac{7}{8} & \frac{-1}{16} \end{pmatrix}$

b) $\begin{pmatrix} \frac{11}{88} & \frac{-93}{88} & \frac{27}{176} \\ \frac{-3}{88} & \frac{43}{88} & \frac{-23}{176} \\ \frac{-1}{4} & \frac{7}{8} & \frac{-3}{16} \end{pmatrix}$

c) $\begin{pmatrix} \frac{21}{88} & \frac{-95}{88} & \frac{27}{176} \\ \frac{-3}{88} & \frac{47}{88} & \frac{-27}{176} \\ \frac{-5}{88} & \frac{7}{8} & \frac{-3}{16} \end{pmatrix}$

d) $\begin{pmatrix} \frac{3}{4} & \frac{-1}{6} & \frac{-2}{3} \\ \frac{1}{5} & \frac{1}{7} & \frac{2}{9} \\ \frac{3}{7} & \frac{5}{7} & 1 \end{pmatrix}$

5.Obtain the values p, q and r in the following equations.

$3p - 2r + 6q = 7$

$-7p + 4r - 8q = 15$

$9p - 3r + 17q = 3$

a) P=$\frac{31}{13}$ q= $\frac{15}{26}$ $r = \frac{23}{26}$
b) P=$\frac{-1}{3}$ $q = \frac{5}{26}$ $r = \frac{23}{26}$
c) P=$\frac{-131}{13}$ $q = \frac{-115}{26}$ $r = \frac{123}{26}$
d) P=$\frac{131}{26}$ $q = \frac{5}{16}$ $r = \frac{17}{19}$

6.Obtain the values of p, q and r in the following equation

$2p + 7r + 18q = 0$

$15p + 19r + 20q = 3$

$17p - 5r - 7q = -10$

a) $P = \frac{7}{8}$ $q = \frac{9}{10}$ $r = \frac{17}{823}$
b) $P = \frac{-1897}{4115}$ $q = \frac{652}{823}$ $r = \frac{-1057}{4115}$
c) $p = \frac{97}{115}$ $q = \frac{52}{23}$ $r = \frac{57}{15}$
d) $p = \frac{5}{6}$ $q = \frac{2}{3}$ $r = \frac{1}{5}$

7. Obtain the eigen values of $\begin{bmatrix} 2 & 1 & 0 \\ 0 & 1 & -1 \\ 0 & 2 & 4 \end{bmatrix}$

a) 3, 3, 4
b) 2, 2, 3
c) 2, 2, 2
d) 1, 2, 3

8. Evaluate how to obtain the determinant of matrix.
9. Compare between adjoint and inverse of a matrix.
10. Differentiate between minors and cofactors?

11. Justify whether an eigen value the same as an eigen vector.
12. Solve the following system of simultaneous equations.

$3p + q + 2r = 5$

$5p + 3q + 2r = 7$

$9p + 8q + 7r = 3$

Oral Assessment

1. Define an inverse of a matrix.
2. Discuss the process of finding the eigen vector.

Practical Assessment

In a given department, 3 lecturers may teach 3 units per week. The number of hours required on each unit to be examined are given in the table below. The department chairperson would like to assign the lecturers the units so that the number of hours is minimized. Find the specific unit that each lecturer should be assigned.

Lecturer	Math’s	Science	English
P	114	116	112
Q	19	228	109
R	113	600	110

2.3.14.4 Tools, Equipment, Supplies and Materials

- Scientific calculator
- 15 cm ruler
- Pen, pencil

2.3.14.5 References

Aitken, A.C (2017) Determinant and matrices Read Book Ltd.

Panju,M(2011) Iterative methods for computing eigen values and eigen vectors ar.xiv 11051185

Searle. S.R., & Khun, A.I. (2017) matrix algebra useful for statistics. John wiley & sons.

CHAPTER 3: TECHNICAL DRAWING

3.1 Introduction

This unit covers the competencies required to prepare and interpret technical drawings. It involves competencies to select, use and maintain drawing equipment and materials. It also involves producing plain geometry drawings, solid geometry drawings, pictorial and orthographic drawings and application of Computer Aided Design (CAD) packages.

3.2 Performance Standard

Use drawing equipment and materials according to task requirements, per workplace procedures and maintained as per manufacturer's instructions, waste materials are disposed in accordance with workplace procedures and environmental legislations, use personal protective equipment according to occupational safety and health regulations, produce plain geometry drawings, produce solid geometry drawings, produce pictorial and orthographic drawings of components and apply CAD packages in drawings according to standard drawing conventions and task requirements.

3.3 Learning Outcomes

3.3.1 List of learning outcomes

a) Use and maintain drawing equipment and materials
b) Produce plain geometry drawings
c) Produce solid geometry drawings
d) Produce pictorial and orthographic drawings of components
e) Apply CAD packages

3.3.2 Learning Outcome No 1: Use and Maintain Drawing Equipment and Materials

3.3.2.1 Learning Activities

Learning Outcome No 1: Use and Maintain Drawing Equipment and Materials	
Learning Activities	**Special Instructions**
1.1. Identify and gather drawing equipment 1.2. Use and maintain drawing equipment 1.3. Use drawing materials 1.4. Dispose waste materials 1.5. Use Personal Protective Equipment (dust coats, gloves and closed leather shoes)	• Demonstration • Group discussion

3.3.2.2 Information Sheet No3/LO1: Use and Maintain Drawing Equipment and Materials

Introduction

This learning outcome covers drawing equipment, drawing materials, maintenance of drawing equipment as per manufacturer's instructions as per workplace procedures. It also covers on how to dispose waste materials in accordance with workplace procedures and proper use of personal equipment. Use and maintain drawing equipment and materials.

Definition of key terms

Drawing: This is the use of lines, shapes, and sizes to construct objects or structures either in 2-dimesnional or 3-dimensional view.

Technical drawing: This is a precise detailed representation of an idea using symbols, lines, and signs in creating objects in the manufacturing of engineering articles.

Drafting: This is the act of producing a picture/sketch either in 2-dimesnional or 3-dimensional view and providing dimensions and notes. It is usually a quick sketch/ presentation with details and not to scale.

Designing: This is the act of producing drawings to clearly define the requirements for concepts or products in order to be in line with the expected outcome.

Maintenance: It is an excellent means of improving the performance and condition of equipment and facilities.

A maintenance program: It is a comprehensive list of maintenance and its incidents.

A maintenance schedule: It is a list allocating specific maintenance of an area, including equipment and tools to a specific period.

A maintenance checklist: It is a list of maintenance tasks (preventive or predictive) typically derived through some form of analysis, generated automatically as work orders at a predetermined frequency.

Content/Procedures/Methods/Illustrations

1.1 Use and maintain drawing equipment as per manufacturer's instructions

Maintenance is an excellent means of improving the performance and condition of equipment and facilities. An effective maintenance program identifies problems long before any equipment or facility breaks down or deteriorate. A good maintenance system presents the early discovery of problems, thus providing plenty of lead time for effective maintenance planning. The trainer has to value the importance of maintaining the training facilities, equipment and tools s/he is using or under his/her care if he values the presence and availability of these resources for effective training and learning processes. Training equipment is usually placed in the practical work area or the trainees' resource area. The sizes and uses of equipment vary in the different training qualifications and generally classified into five (5):

a) Large items of equipment; motor vehicles, industrial sewing machines
b) Small items of equipment
c) Simple equipment; electric fan, floor polisher
d) Complex equipment; plasma cutting machine, simulator (automotive)
e) Equipment with significant health and safety implications; duplicator machine

Reasons for maintenance

- To extend the useful life of physical facilities
- To assure the operational readiness of installed equipment and maximum possible return on investments
- To properly discard hazardous wastes
- To ensure the safety of personnel using the facilities, physical properties and the environment

Importance of maintenance

- Improved morale of human resources
- Reduced operational cost
- Increased production
- Prolonged life of facilities
- Prompt delivery of services/product
- Waste/garbage reduction
- Ensured safe environment

Ways of implementing a maintenance program

The question on how do we implement the maintenance program will centre on the 5Ms as follows:

- Manpower
- Money (financial resources)
- Methods and system
- Machines (facilities)
- Materials and supplies

Tools and equipment used in technical drawing

i. **Drafting Tables/board**

Draftsmen create technical drawings using a tilting table. Parallel rulers on each side of the drawing surface align the drawing paper and provide horizontal and vertical guides for drawing.

Figure 10. Drafting tables
Source: www.wayfair.com

ii. **Curve Templates and Compasses**

Draftsmen create curves using irregular curve templates made of clear rigid plastic. They draw circles and portions of circles called arcs with an adjustable compass and calculate angles from 1 degree to 180 degrees with clear plastic protractors.

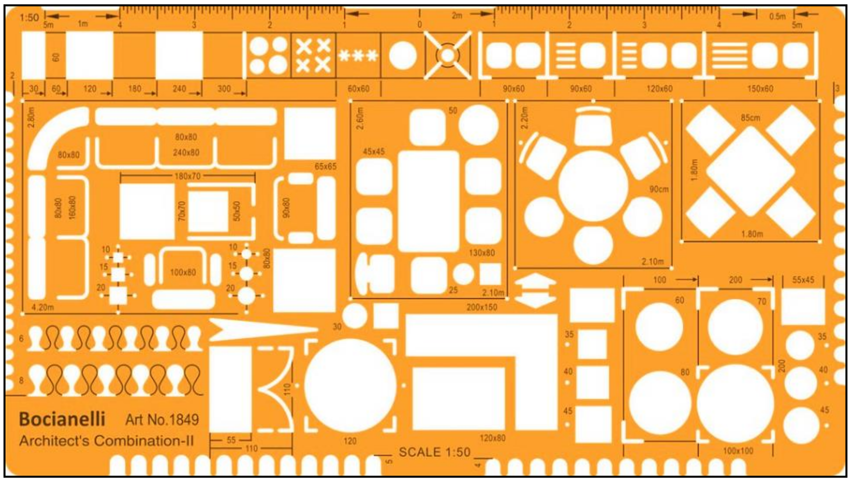


Figure 11.Drawing templates.
Source: www.bocianelli.com

Caliper and Vernier Scale

A caliper is a tool which is used for a measurement of some objects

Figure 12. Caliper and vernier scale
Source: www.amazon.com

Drawing Compass

A drawing compass is a tool for drawing circles on a specific material but also for navigational help and measuring distances

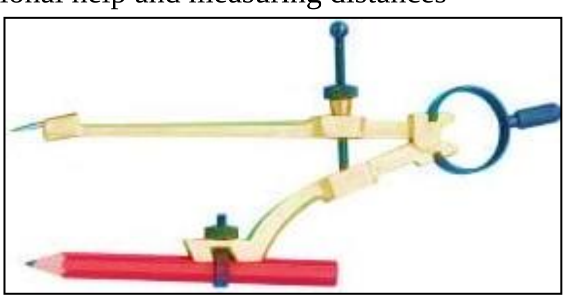


Figure 13. Drawing compass.
Source: www.amazon.com

Types of Drawing Compasses

Beam Compass

A beam compass is made of brass of wooden beam, and it is used for drawing circles that are larger than those made by regular compass.

Scribe Compass

This type of compass is the simplest by form. It is used by carpenters to scribe a circle instead of drawing it.

Loose Leg Divider

It is also used to scribe circles. Loose leg wing dividers also provide stepping off repetitive measurements with particular accuracy.

Figure 14. Loose leg divider
Source: www.amazon.com

Proportional Compass

It is a tool consisting of two rulers which are equal length and joined by a hinge.

iii. Lettering Guides

Lettering templates guide the draftsman in the execution of uniform lettering throughout the drawing. As a matter of common practice most creators of technical drawings hand letter in personally developed styles that identify their work as clearly as fingerprints.

iv. Drawing Pencils

Most draftsmen use sharp 2H and 4H pencils for drawing. Pencils may be wooden or mechanical pencils with replaceable leads. They utilize erasing shields and soft gum or nylon erasers to make corrections.

v. Inking Pens

Technical drawings created in pencil are usually over-traced with ink to render durable final drawings. Early inking pens consisted of a mechanical device with an adjustable nib. Modern disposable inking pens have built in ink reservoirs and are available in many point widths.

Pencils

Pencil is used to draw on the paper. Any type of pencil is not suitable for drawing. There are some limitations, the drawing appearance should be very neat and understandable. Every line of the drawing should indicate its importance. It depends upon the hardness of the pencil. Based on the hardness quality pencils are classified into 18 grades and they are as shown in the table below:

Table 2: Classification of pencils

Grade of Pencil	Hardness of Pencil
9H	Hardest
6H, 5H, 4H	Extremely Hard
3H	Very hard
2H	Hard
H	Moderately hard
F	Firm
HB	Medium hard
B	Moderately soft and black
2B	Soft and black
3B	Very soft and black
4B, 5B, 6B	Very soft and very black
7B	Softest

Out of the above 18 grades of pencils, the following grades are used in engineering drawings.

Table 3: Uses of engineering pencil grades

Grade of Pencil	Used to Draw
3H	Construction lines
2H	Dimension lines, center lines, sectional lines, hidden lines
H	Object lines, lettering
HB	Dimensioning, boundary lines

Figure 15: Pencil grades
Source: www.amazon.com

vi. Drafting Machines

Modern drafting machines combine horizontal and vertical rulers or scales and a protractor head that allows adjustment of the rulers to required angles for drawing. The device is permanently attached to the drawing board and uses a pair of connected arms to move freely around the drawing surface.

vii. CAD: Computer Aided Design

Drawings and designs using computer software drastically reduce hand and machine drafting, especially in the professional sectors. Lower drawing cost and greater degrees of accuracy dictate increasing use of CAD as a primary tool for creating technical drawings. Large computer screens for creating designs and plotters for printing large technical drawings are replacing traditional technical drawing tools. Colleges and trade schools offer CAD training to a growing number of specializing technicians who are replacing conventional draftsmen in the drafting room.

viii. Rulers and Squares

Using a T-square and clear plastic triangle, draftsmen create lines. Common triangles they use are an eight-inch triangle with forty-five- and ninety-degree sides and a ten-inch triangle with 30- and 60-degree sides. Draftsmen measure dimensions with triangular shaped rulers that have different scales on each of three surfaces.

A ruler is an instrument that can be used for measuring distances or to draw straight lines in printing, geometry, technical drawing and many other things.

Figure 16: Rulers and squares
Source: www.amazon.com

The protractor is an instrument used for measuring angles. It is usually made of transparent glass or transparent plastic

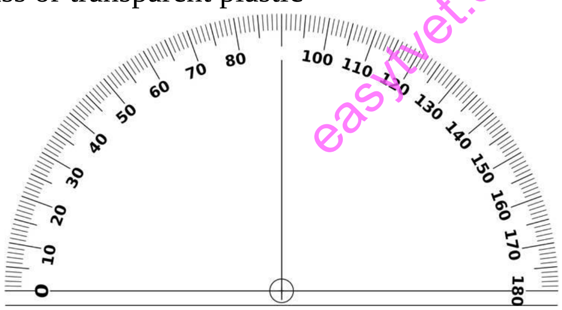


Figure 17: Protractor
Source: www.amazon.com

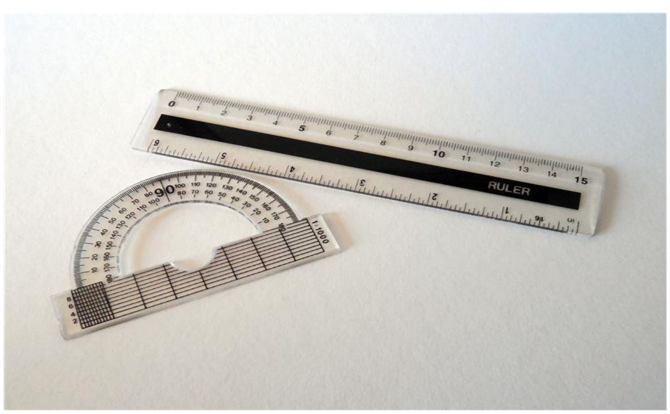


Figure 18: Protractor and a ruler
Source: www.amazon.com

Mini Drafter

Mini drafter is an instrument which can be used for multiple functions in drawing. It contains two arms which is adjustable to required angle and at the end of the lower arm a scale set is attached.

Figure 19: Mini drafter

Source: www.vectorstock.com

T-Square

A T-square is used to draw horizontal and vertical lines on drawing sheet. It is made of wood or plastic and in T shape. The vertical part of T is called as blade and horizontal part of T is called as head.

Figure 20: T-square

Source: www.amazon.com

Set Squares

Set squares are used to draw lines with an angle between them. In most of the structures, 30, 45, 60 and 90-degree lines are most common. So, set squares make the work easier for this type of drawings.

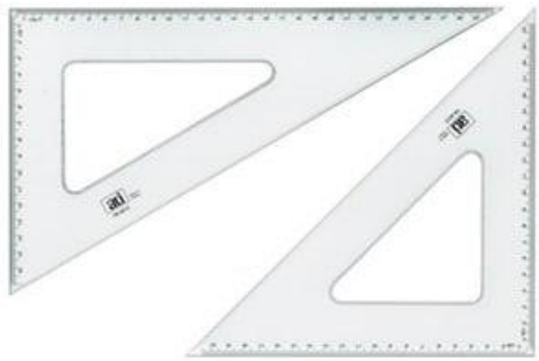


Figure 21: Set square
Source: www.vectorstock.com

French Curves
French curves are made of plastic and they are in irregular shapes. Sometimes the drawing requires irregular curves or shapes or arcs which cannot be drawn using compass. In that case French curves are suitable.

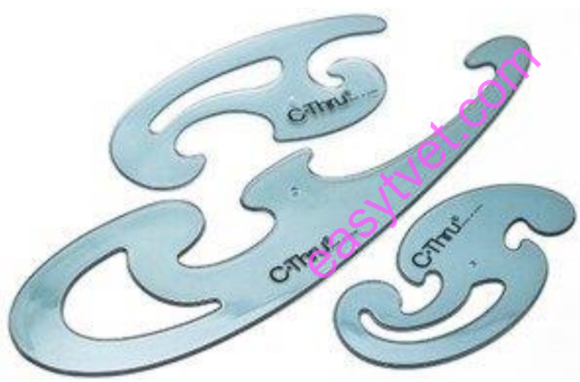


Figure 22: French curve
Source: www.goldstartool.com

Drawing Sheet
Drawing sheet is a white paper on which an object is drawn which is available in various sizes. The sheet used for engineering should be of good quality. It should be white in color with uniform thickness which must resist the easy torn of paper. The surface of sheet must be smooth.

Eraser
Eraser is used to remove the lines or spots which were drawn by mistake or with wrong measurements. The eraser used should be of good quality and soft. It should not damage the paper while erasing.

Figure 23: Eraser
Source: www.shutterstock.com

Paper Holders

When the drawing sheet is placed on the board it may not be in fixed position. To fix the drawing sheet to the board paper holders are used.

Figure 24: Paper holder
Source: www.shutterstock.com

Disposing of waste materials so as to prevent air pollution is a recent requirement in the history of waste disposal. Proper disposal of waste resulting from technical drawing must be followed. Degradable waste must be disposed separately with non-degraded waste. Broken compasses and rules must be disposed properly as they can cause harm to the trainee in the work place. Personal protective equipment, or PPE, is designed to protect you from hazards found on or off the job. The PPE prevent the draftsmen from hazards when they are working in the drawing rooms. These PPE include:

- Grooves
- Closed shoes
- Dust coat
- Helmets

Proper procedures must be observed and adhered to know when to put on the protective gears to minimize injuries during and after the exercise.

Conclusion

The learning outcome covered or equipped the learner with drawing equipment, drawing materials used and maintenance of drawing equipment, drawing materials, dispose of waste materials, and proper use of productive equipment in accordance with workplace procedures and environmental legislations.

Further Reading

1. Engineering drawing by K. Venugopal. Published by: New Age International (p) limited (2016).
2. Engineering drawing + Auto CAD. By: Venugopal. K PUBLISHED BY New Age International pvt ltd

3.3.2.3 Self-Assessment

Written Assessment

1. The accuracy of the drawing depends on ________.
2. Which of the following instrument is made of thin strips of wood arranged in a line to form a rectangle and on which, the drawing is made?
    a) Mini-drafter
    b) Drawing Board
    c) Protractor
    d) Scale
3. Which of the following tools is used to draw horizontal lines?
    a) Mini – drafter
    b) Protractor
    c) T – square
    d) French curve
4. Which of the following instruments can be used to draw accurate perpendicular lines, parallel lines and angular lines?
    a) Mini-drafter
    b) T-square
    c) Protractor
    d) Set square

5. According to the Indian Standard Institute (ISI), which among the following designation has the size 1000 x 700 (in mm)?
    a) B0
    b) B1
    c) B2
    d) B3
6. Which is the most common tool used for drawing circles?
    a) French curve
    b) Mini – drafter
    c) Divider
    d) Compass
7. For drawing circles with a large radius, which of the following tool is used?
    a) Bow compass
    b) Lengthening bar compass
    c) Divider
    d) Protractors
8. The preferred size of the drawing sheets is recommended by the ______
    a) B.I.S.
    b) ASME
    c) ASTM
    d) NIST
9. SP: 46 (2003) recommends the borders of _______ mm width for the sheet sizes A0 and A1, and _______ mm for the sizes A2, A3, A4 and A5.
    a) 10, 20
    b) 15, 20
    c) 20, 10
    d) 15, 10
10. The false statement regarding orientation mark.
    a) The orientation mark coincides with one of the centering marks
    b) Represents the direction to which sheet is placed
    c) Orientation mark can be used for the orientation of drawing sheet on the drawing board
    d) Facilitate positioning of the drawing for reproduction purpose
11. Select and apply different drawing paper holders
12. Discuss the best methods of drawing waste materials disposal which is environmentally friendly.
13. State three importance of drawing tools maintenance

Oral Assessment

1. State two uses of protractors in technical drawing
2. Give two types of pencils used to make faint lines

Practical Assessment

Make a sketch of a CAD design

3.3.2.4 Tools, Equipment, Supplies and Materials

- Drawing room
- Computer lab
- Drawing equipment and materials
- Computers
- CAD package
- Overhead projector

3.3.2.5 References

Hubka, V. (2015). Principles of engineering design. Elsevier.
Morling, K. (2010). Geometric and engineering drawing. Routledge.
Shrock, C. R. (2009). Advanced AutoCAD 2010 Exercise Workbook. Industrial Press Inc.

3.3.3 Learning Outcome No 2: Produce Plane Geometry Drawings
3.3.3.1 Learning Activities

Learning Outcome No 2: Produce Plain Geometry Drawings	
Learning Activities	**Special Instructions**
2.1 Identify different types of lines used in drawing and their meanings 2.2 Construct different types of geometric forms (circles, triangles, rectangles, parallelogram, polygons, pyramids, conic sections, prisms, loci) 2.3 Construct different types of angles 2.4 Measure different types of angles using appropriate measuring tools. 2.5 Bisect angles 2.6 Conduct freehand sketching of different types of geometric forms, tools, equipment and diagram.	• Use correct tools (drawing and measurement) • Demonstrations and group discussion • Use the correct dimensions

3.3.3.2 Information Sheet No3/LO2: Produce Plain Geometry Drawings

Introduction

This outcome covers a variety of plain geometry drawings that include lines, triangles, quadrilaterals, polygons, dimensioning and drawing rules, bisecting angles according to standard and measurement of different types of angles.

Definition of key terms

Drawing instruments: These are the tools/equipment that are essential in producing drawings.

Drawing materials: These are consumables that are utilized in technical drawing.

Plane geometry: This type of geometry involves production of drawings in two dimensions.

Solid geometry: Solid geometry involves production of drawings in three dimensions.

Content/Procedures/Methods/Illustrations

Plane geometry principle

A line projects as a true length when a view is taken looking perpendicular to the line. A line parallel to the vertical plane will appear as a true length in elevation. A line parallel to the horizontal plane will appear as a true length in plane. Parallel lines appear parallel in every orthographic view. If a line is parallel to any line on a plane, it is parallel to the plane. A line projects as a point when we look along its true length. A plane projects as an edge when any line on the plane projects as a point. The true shape of a plane is seen on a projection plane which is parallel to the plane. Two planes intersect in a line.

Line

A geometric primitive that has length and direction, but no thickness. It may be straight, curved or a combination of these. Lines also have important relationship or conditions, such as parallel, intersecting, and tangent. Specific length and non-specific length. Straight line that extends to infinity from a specified point.

Relationship of one line to another line or arc

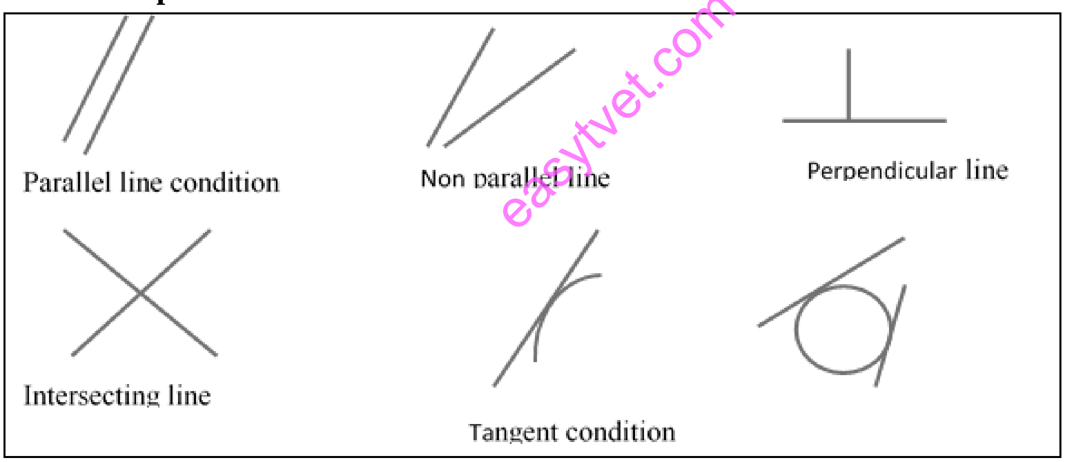


Figure 25: Lines

Bisecting a line

Steps

a) Preparing the Compass

i. Draw the line segment you need to bisect. If the line segment is not already given, you will need to make it using a straightedge.

Figure 26: Drawn line

ii. Choose an appropriately sized compass. If you open the compass completely, and its span is one-half the length of the line or less, you need to choose a bigger compass.

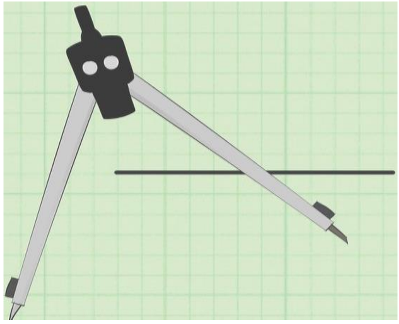


Figure 27: Open Compass
Source: alamy.com

iii. Position the compass on an endpoint. To do this, place the needle of the compass on either endpoint. Open the compass so that it spans a little more than half the length of the line

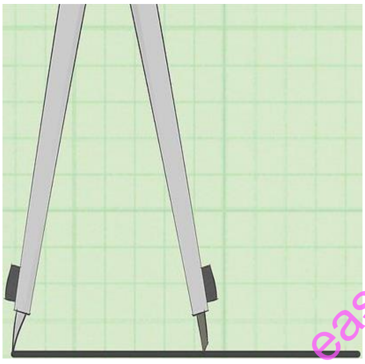


Figure 28: Compass Position
Source: www.alamy.com

a) Bisecting the Line

i. Draw an arc above and below the line segment. Make sure the needle stays on the endpoint, and that you do not adjust the compass setting. The length of the arcs does not matter.

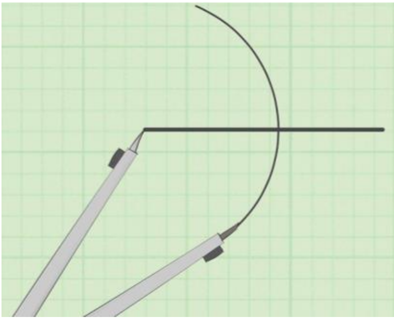


Figure 29: An arc
Source: www.alamy.com

ii. Reposition the compass on the other endpoint. Make sure you do not change the compass setting.

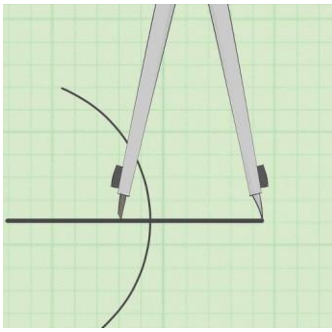


Figure 30: End point Position
Source: www.researchgate.com

iii. Draw another set of arcs, above and below the line segment. Make sure the needle stays on the endpoint, and that you do not adjust the compass setting. The two sets of arcs you've drawn should intersect.

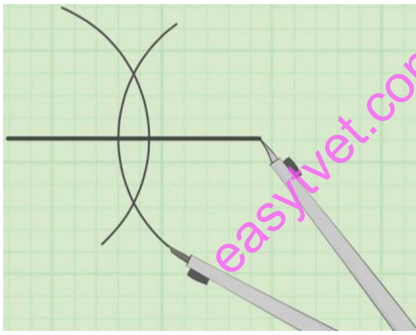


Figure 31: Arcs above and below line segment
Source: www.researchgate.com

iv. Connect the arc intersections. To do this, place your straightedge on the point where the arcs above the line intersect, and align it with the point where the arcs below the line intersect.

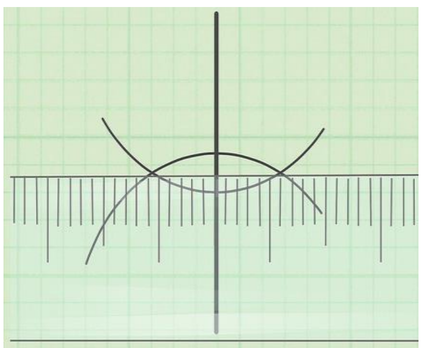


Figure 32: Connected arc intersections
Source: www.alamy.com

v. Draw your perpendicular bisector. The line you draw between the two arc intersections bisects the line at a ninety-degree angle.

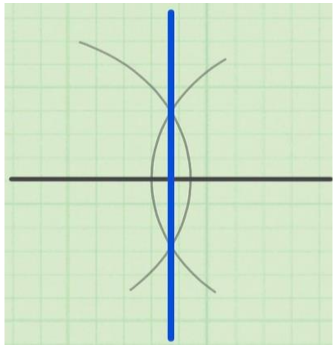


Figure 33: Perpendicular line
Source: www.shutterstock.com

vi. Understand why this works. You have used the compass to outline two congruent circles centered over either endpoint. The intersecting arcs represent the endpoint of a radii from the center of either circle. The length of the radii will be the same since the circles are of the same size.

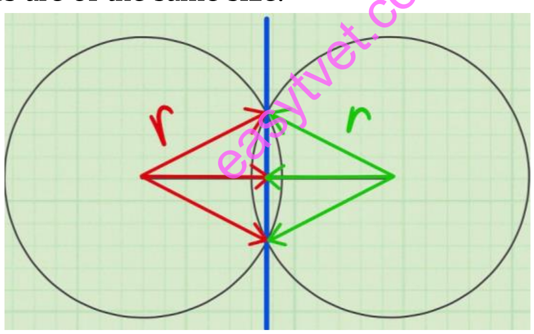


Figure 34: Completed Drawing
Source: www.alamy.com

Plane Geometry

Plane geometry can take various shapes.

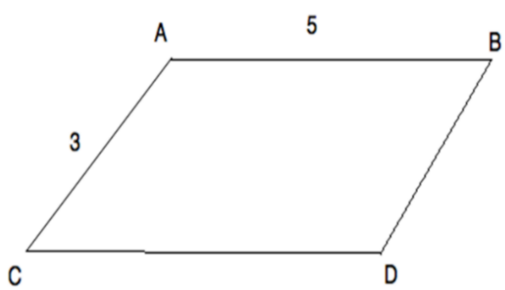


Figure 35: Plane Geometry
Source: www.earthslab.com

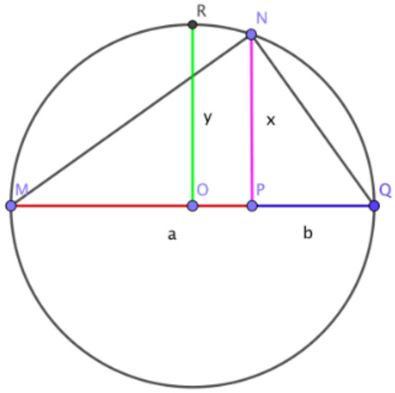


Figure 36: Plane Geometry
Source: www.earthslab.com

Conclusion

This outcome covered plane geometry drawings i.e. types of lines, polygons, triangles, quadrilaterals, dimensioning and drawing rules

Further Reading

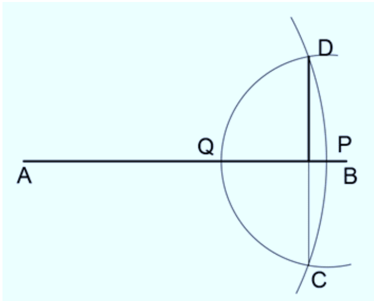
1. K Morling geometric and engineering drawing
2. Hubka,V.(2015)Principles of engineering design, Elserier
3. Davies, B. L., Robotham, A. J., & Yarwood, A. (1991). Computer-aided drawing and design. London: Chapman & Hall.

3.3.3.3 Self-Assessment

Written Assessment

1. While drawing a perpendicular to a line from a point within the line but nearer to the end of the line, all the arcs drawn in the process are of _______?
   a) Different radii
   b) Different radii but one
   c) Same radii but one
   d) Same radii

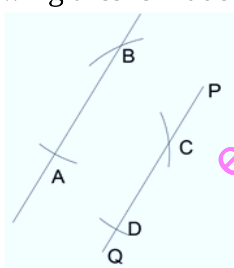
2. In the given figure which of the following construction line is drawn first?



a) Line AP
b) Arc DPC
c) Arc DQC
d) Line DC

3. For drawing parallel lines to a given line through a given point we make use of ____
a) Arcs
b) Triangles
c) Lines
d) Quadrilaterals

4. Which of the following arcs is made first to draw a parallel line to the given line PQ?

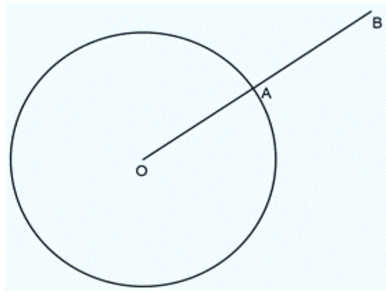


a) A
b) B
c) C
d) D

5. A tangent to a circle is a line which touches the circle at one and only one point.
a) True
b) False

6. The line perpendicular to a tangent and is passing through the point of contact is called _____
a) Perpendicular bisector
b) Angle bisector
c) Normal
d) Tangent

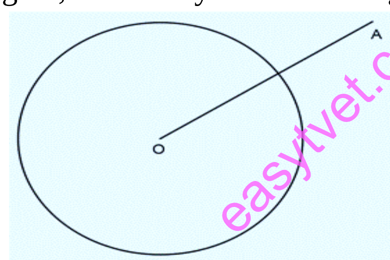
7. In the following figure, the tangent at point A can be drawn by _______



a) Angle bisector
b) Perpendicular bisector
c) Rectangle
d) Arc

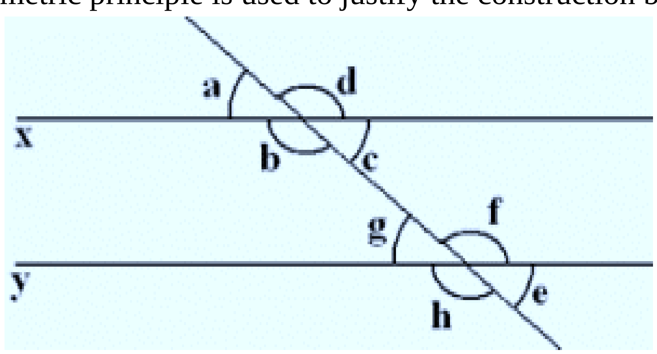
8. How many tangents can be drawn from a point outside a given circle?
    a) 4
    b) 3
    c) 2
    d) 1

9. In the following figure, how will you make a tangent from the point outside the circle?



    a) By drawing a semicircle with diameter as OA
    b) By drawing a perpendicular bisector
    c) By drawing an angle bisector
    d) By drawing circle with the same radius from A

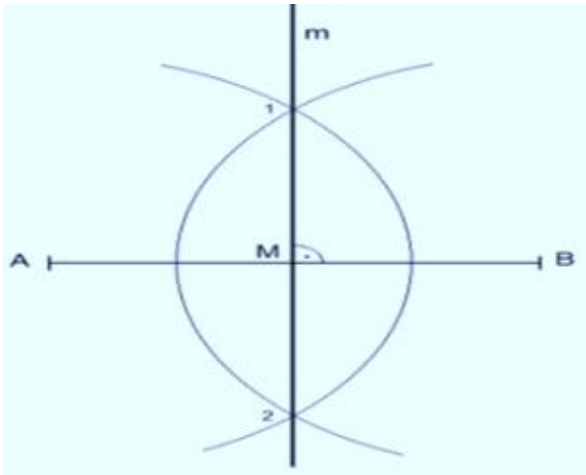
10. Which geometric principle is used to justify the construction below?



    a) A line perpendicular to one of two parallel lines is perpendicular to the other
    b) Two lines are perpendicular if they intersect to form congruent adjacent angles

c) When two lines are intersected by a transversal and alternate interior angle are congruent, the lines are parallel
d) When two lines are intersected by a transversal and the corresponding angles are congruent, the lines are parallel

11. The diagram below shows the construction of the perpendicular bisector of AB.



Which statement is not true?
a) AM=MB
b) MB=1/2AB
c) AM=2AB
d) AM+MB=AB

12. Construct an isosceles triangle given the perimeter and the altitude (perimeter 150mm and altitude 70mm).
13. Construct a rhombus given the diagonal and the length of the sides.
14. Construct a trapezium given the lengths of the parallel sides, the perpendicular distance between them and one angle.
15. Construct a regular octagon given the diameter, i.e. within a given square.

Oral Assessment
1. Which steps are followed when bisecting a line?

Practical Assessment
1. Construct an equilateral triangle, given one of the sides, AB = 100.
2. Construct a triangle given the base, the altitude and the vertical angle (base 100mm and vertical angle 65^0)
3. Construct a triangle similar to another triangle but with a different perimeter

3.3.3.4 Tools, Equipment, Supplies and Materials
- Drawing room
- Computer lab

- Drawing equipment and materials
- Computers
- CAD package
- Overhead projector

3.3.3.5 References

Childs, P. (2003). Mechanical design. Butterworth Heinemann.

Olkun, S. (2003). Making connections: Improving spatial abilities with engineering drawing activities. International journal of mathematics teaching and learning, 3(1), 1-10.

Shrock, C. R. (2009). Advanced AutoCAD 2010 Exercise Workbook. Industrial Press Inc.

Yamaguchi, F. (2012). Curves and surfaces in computer aided geometric design. Springer Science & Business Media.

3.3.4 Learning outcome No 3: Produce Solid Geometry

3.3.4.1 Learning Activities

Learning Outcome No 3: Produce Solid Geometry	
Learning Activities	**Special Instructions**
3.1 Interpret drawings of patterns 3.2 Develop patterns	• Demonstrations and group discussion • Use the correct dimensions

3.3.4.2 Information Sheet No3/LO3: Produce Solid Geometry

Introduction

In this outcome, the areas covered are interpretation of sketches and drawings of patterns, surface development of interpenetrating solids and truncated solids, and interpenetration of solids.

Definition of key terms

Straight line: It is a line such that, if any portion of it is placed with its ends in the line, the entire portion so placed will lie in the line, however it may be applied.

A plane surface (or plane): It is a surface of unlimited extent such that whatever two of its points are taken, a straight-line joining them will lie wholly in the surface.

A plane figure: It is a geometric figure all of whose points lie in one plane. Plane Geometry treats of plane figure.

Content/Procedures/Methods/Illustrations

Solid geometry: interpretation of sketches and drawings, surface development of prisms, cylinders, truncated prisms, cones and pyramids. Development of surfaces of interpenetration cylinders and truncated solids, and interpenetration of cylinder to cylinder and cylinder to prism or prism to prism of equal and unequal diameters.

Design elements

Solid geometry

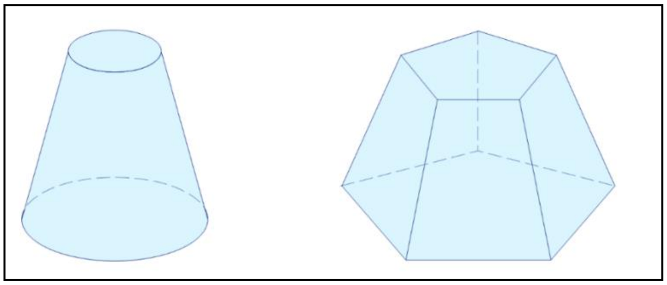


Figure 37: Shapes, Cone and Pentagonal pyramid with flat tops

Source: www.conceptdraw.com

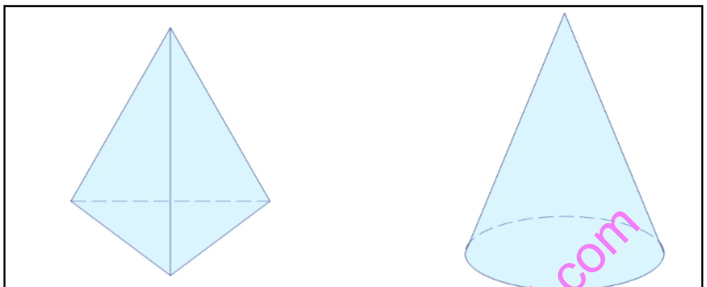


Figure 38: Cone and 4-sided pyramid

Source: www.conceptdraw.com

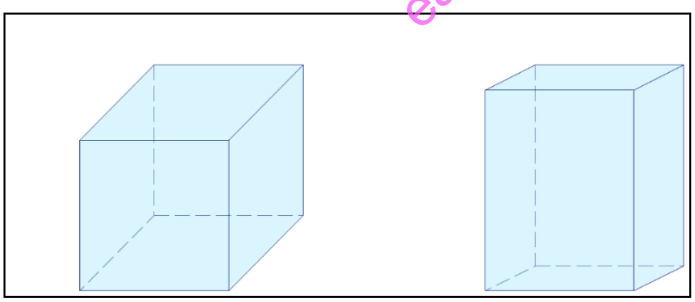


Figure 39: Cube and rectangular Box

Source: www.conceptdraw.com

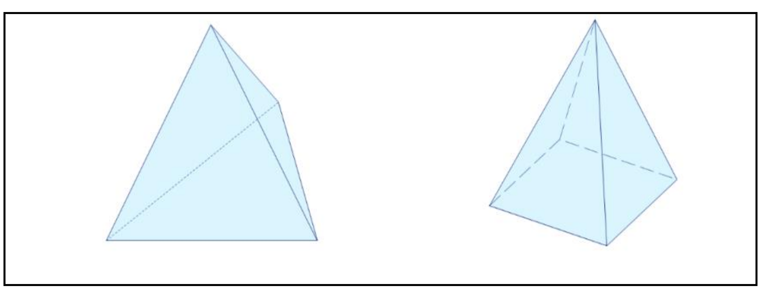


Figure 40: Tetrahedron and Pyramid

Source: www.conceptdraw.com

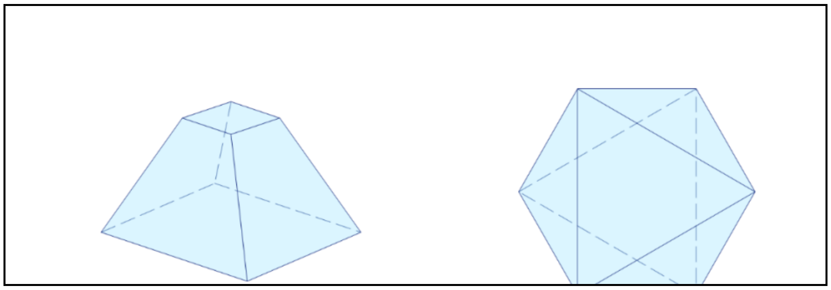


Figure 41: Pyramid with flat top and octahedron
Source: www.conceptdraw.com

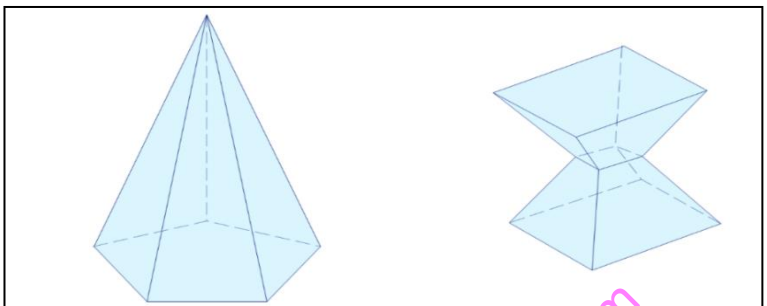


Figure 42: pentagonal Cone and Irregular polyhedron
Source: www.conceptdraw.com

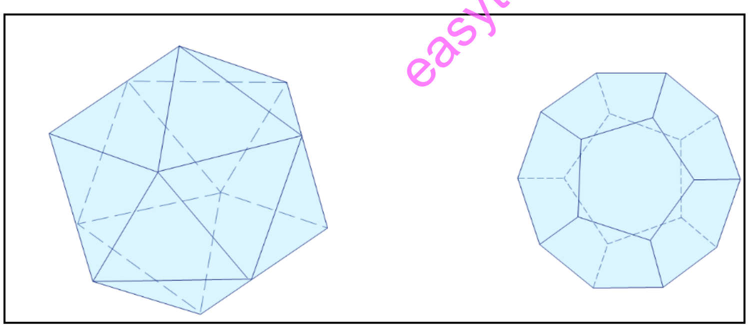


Figure 43: Icosahedron and decahedron
Source: www.conceptdraw.com

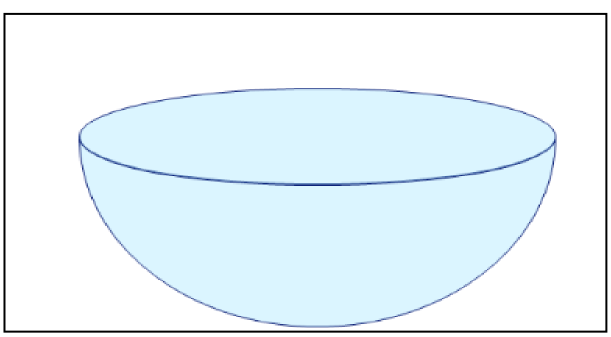


Figure 44: Half Sphere
Source: www.conceptdraw.com

Use these shapes to draw your geometrical diagrams and illustrations

1. The sides of the quadrilateral are in the ratio of 2:3:4:5. The triangle BCE is half the area of the quadrilateral.
    a) Draw the given figures showing clearly how the points C, D and E are obtained.
    b) Draw a square which shall have the same area as the figure ABCDE.

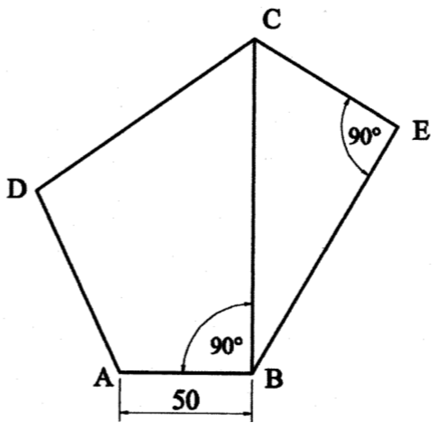


Figure 45: Plan and elevation of a sphere

2. The figure below shows the plan and elevation of a sphere with a point P on its surface. The elevation of a cone which is in contact with the sphere is also shown.
    a) Draw the plan and elevation of both solids and show the position of the point P in the plan.
    b) Draw the plan and elevation of another sphere, having a diameter of 40mm, which shall be in contact with the given sphere at point P.

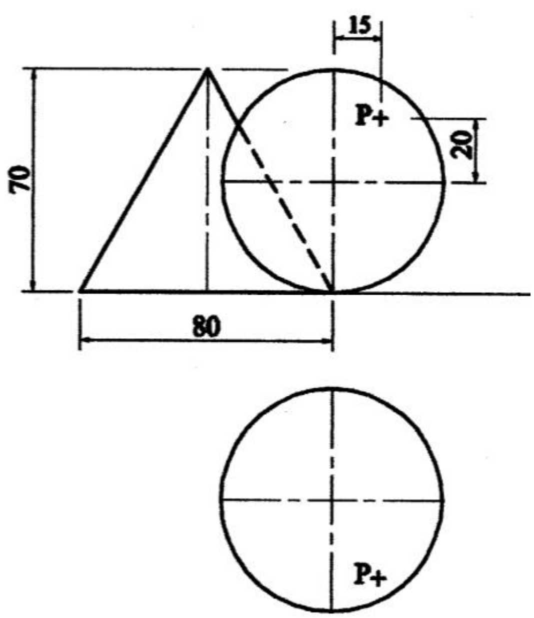


Figure 46: Plan and elevation of another sphere

Conclusion

This outcome covered interpretation of sketches and drawings, surface development of solids, and interpenetration of surfaces.

Further Reading

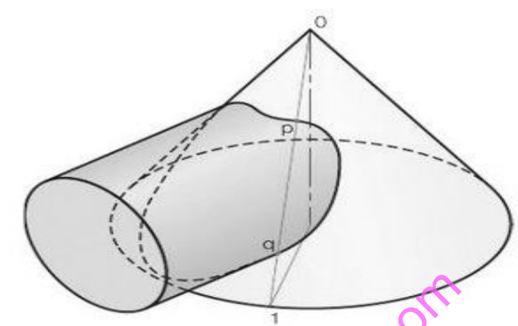
1. Davies, B. L., Robotham, A. J., & Yarwood, A. (1991). Computer-aided drawing and design. London: Chapman & Hall.

3.3.4.3 Self-Assessment

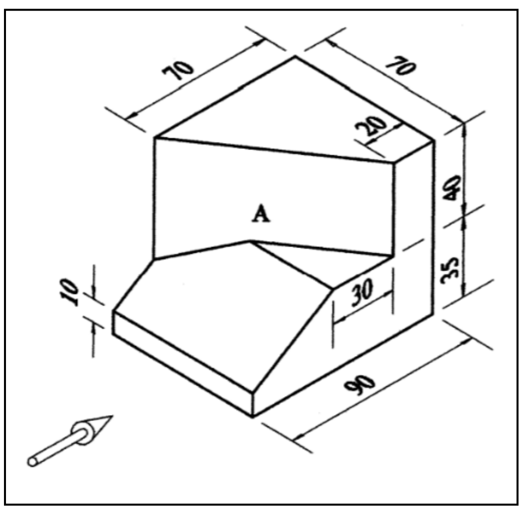
Written Assessment

1. A cylinder is placed on H.P on its base and section plane is parallel to V.P cutting the solid the section gives _______________
    a) parabola
    b) circle
    c) rectangle
    d) ellipse
2. A cylinder is placed on H.P on its base and section plane is parallel to H.P cutting the solid the section gives _______________
    a) Parabola
    b) Circle
    c) Rectangle
    d) ellipse
3. A cylinder is placed on H.P on its base and section plane is inclined to V.P and perpendicular to H.P cutting the solid the section gives _______________
    a) Parabola
    b) Circle
    c) Rectangle
    d) ellipse
4. If a plane is inclined with both the reference plane then the plane come under _____________
    a) auxiliary plane
    b) oblique plane
    c) perpendicular plane
    d) cross planes

5. If a plane is inclined to both the reference planes then the traces would meet at _________ line except the plane perpendicular to picture plane.
    a) XY reference
    b) Vertical reference
    c) Above the XY reference plane
    d) Below the XY reference plane
6. Draw a radial element (0, 1) in one of the orthographic views. Find the points on the line of interpenetration (i.e., p & q) and project them to the other views. Repeat with more radial elements until you have enough points to draw the lines of interpenetration.



7. An isometric view of a shaped solid is shown the figure below.
    a) Draw an elevation of the solid looking in the direction of the arrow.
    b) Project a plan from the elevation.
    c) Project a new elevation from the plan of the solid which will show the true shape of the surface



Oral Assessment

What is solid geometry

Practical Assessment

Given pyramid is cut by plane, ⊥ to the frontal plane and inclined at 70o to the top plane. The cutting plane cuts the axis of the pyramid at 15mm from the apex. Draw the projections of the remaining part of the pyramid and the true shape of the cut section.

3.3.4.4 Tools, Equipment, Supplies and Materials

- Drawing room
- Computer lab
- Drawing equipment and materials
- Computers
- CAD package
- Overhead projector

3.3.4.5 References

Aouad, G., Wu, S., Lee, A., & Onyenobi, T. (2013). Computer aided design guide for architecture, engineering and construction. Routledge.

Bergen, S. D., Bolton, S. M., & Fridley, J. L. (2001). Design principles for ecological engineering. Ecological Engineering, 18(2), 201-210.

Liu, S. X., Hu, S. M., Chen, Y. J., & Sun, J. G. (2001). Reconstruction of curved solids from engineering drawings. Computer-Aided Design, 33(14), 1059-1072.

3.3.5 Learning Outcome No 4: Produce Pictorial and Orthographic Drawings of Components

3.3.5.1 Learning Activities

Learning Outcome No 4: Produce Pictorial and Orthographic Drawings of Components	
Learning Activities	**Special Instructions**
4.1 Identify and interpret the meaning of symbols and abbreviations 4.2 Interpret and produce first and third angle orthographic drawings 4.3 Dimension orthographic elevations	

3.3.5.2 Information Sheet No3/LO4: Produce Pictorial and Orthographic Drawings of Components

Introduction

This outcome covers meaning of pictorial and orthographic drawings, sectioning, symbols and abbreviations, drawing of isometric, oblique, axonometric, auxiliary and perspective views, drawing of first and third angle projections, sectioning of components, and free hand sketching of tools, equipment, components, geometric forms and diagrams.

Definition of key terms

Axonometric (Pictorial) Projections- These are drawings in which the object is drawn in three dimensions (3-D) i.e. three sides of the object

Content/Procedures/Methods/Illustrations

4.1 Solid geometry principles

All views presented in a solid geometry are assumed to be from the same object, and only the particular object but from different points of view and that all views are at the same scale. All the visible edge is depicted by a line and assumptions are made that those edge progress away from the viewer to form faces that are flat but at right angles. The true angle between a line and a plane is seen in a view showing the line as a true length and the plane as an edge. All horizontal sections of an upright or inverted right cone are circles. A sphere appears as a circle in every view.

A sphere and cone in contact will have a common tangent plane. When two spheres touch one another: the point of contact lies on the line joining the two centers, the distance between their centers is equal to the sum of the radii, and the point of contact can be located in any view, by dividing the line in the ratio of the radii. The vertical trace of a plane is the line in which the plane meets the vertical lane. The horizontal trace of a plane is the line in which the plane meets the horizontal plane.

Axonometric (Pictorial) Projections

These are drawings in which the object is drawn in three dimensions (3-D), i.e. three sides of the object appear in one drawing. Normally only one drawing is prepared/used.

- They are used extensively in artistic drawing.
- A three-dimensional view (i.e. shows length, width and height of the object simultaneously).
- Provides only a general impression of the shape of the object by allowing the observer to see three of its sides as well as its three overall dimensions.
- An exact and complete description of its shape, particularly as applied to its slots on the underside is lacking.

Two standards are currently used for axonometric projections: diametric projection and isometric
Projection.

Diametric Projection

In diametric projection, all dimensions along two axes are drawn to TRUE SIZE. The dimensions along the third axis are HALVED. This projection is preferred when one view of the object is to be emphasized than the other two views (i.e. when that one view is of more interest than the other views).

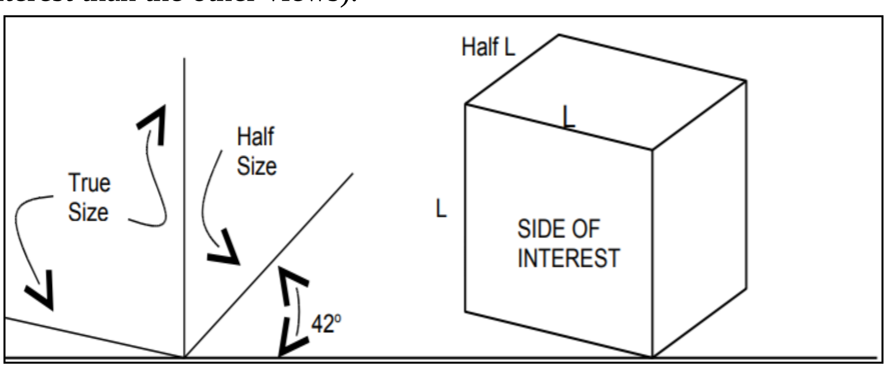


Figure 47: Diametric Projection

Isometric Projection

In isometric projection, all dimensions along all the three axes are drawn to TRUE SIZE. Isometric projection is preferred when the three views of the object are of equal importance for accurate presentation of the object.

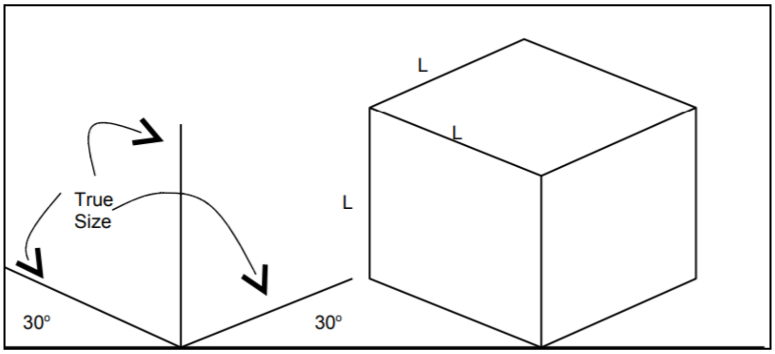


Figure 48: Isometric Projection

4.3 Orthographic Projections

To present an object in a unique way, generally more views (and sometimes sections) are required. In orthographic projection, the views are seen in directions that make right angles (i.e. 90^0) with each other. The number of views needed should be sufficient to represent the object completely and conveniently, but it should be kept to the minimum. For most purposes, three views are usually sufficient.

- Engineering (Technical) drawings usually utilize orthographic views (OV) rather than pictorial views.
- Orthographic (OV) help to record the shapes of objects exactly and completely.
- OV is a two-dimensional (2-D) drawing. It shows only one side of an object and two of its overall dimensions.
- A minimum of two OV is required to show the three dimensions of any object and therefore to describe its shape completely Some features of the object that do not directly appear on viewing the object from any specific direction (known as hidden details) are shown on the drawing as dotted lines.

Naming of Views

In orthographic projection, three views are normally drawn. The three chosen views may be any of the six hypothetical faces of the object. These views are named as shown below.

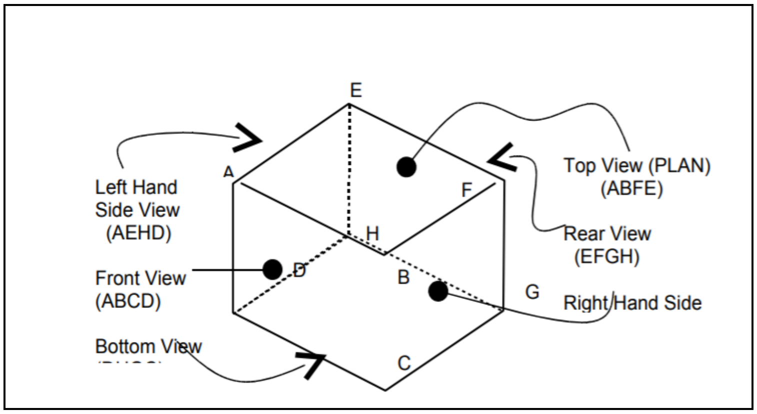


Figure 49: Naming of views

The Front View (ABCD) – abbreviated as FV, is that view of utmost importance in representing the object (normally the most complicated of all the views) as seen when the object is placed directly in front of the viewer. This view generally serves to represent the object (e.g. a work piece) in the most common position in which it is used. It is normally the first view to be drawn – other views following thereafter. The Rear View – RV (EFGH) is directly opposite the FV at the back of the object. The Right-Hand Side View – RHSV (BFGC) and the Left-Hand Side View – LHSV (AEHD) appear on the right and left sides of the object, respectively. The Top (ABFE) and Bottom (DCGH) Views are at the top and bottom sides of the FV. As you must have noted, these six views are at right angles to one another.

4.4 Standard Orthographic Projections

Two standards are commonly in use in orthographic projection of drawings; the First Angle Projection and the Third Angle Projection (American projection). It should be noted that corresponding views are identical in both methods of projection except for their relative positions on the drawing paper.

The First Angle Projection
Symbol:

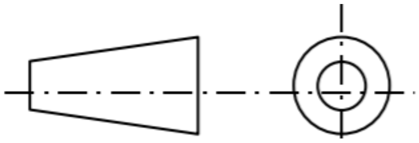


Figure 50: First Angle projection

In here, the front view (A) is the basis (reference) and the other views are drawn as 'shadows' of that view. That is, the left-hand side view for instance is drawn on the right side of the front view. Similarly, the top view (plan) is drawn at the bottom of the front view, etc.

The Third Angle Projection
Symbol

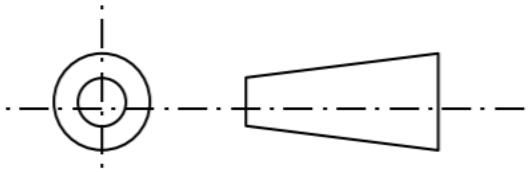
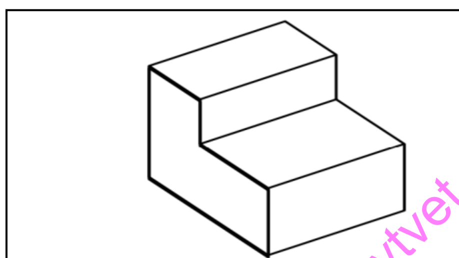
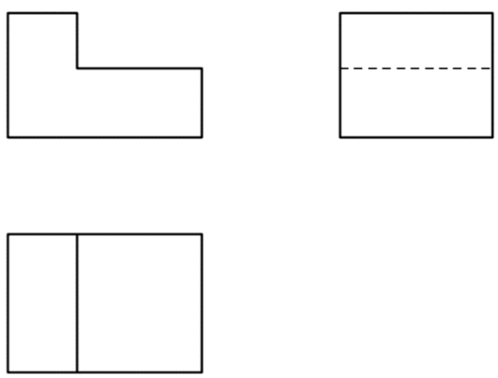


Figure 51: The Third Angle Projection

In here, the front view is the basis (just as before) but the other views are drawn as 'reflections' of that view. The left-hand side view is drawn on the left-hand side of the front view. Similarly, the top view (plan) is drawn at the top of the front view.
Example: The Front View (FV), Left Hand Side View (LHSV) and Top View (PLAN) of the given object

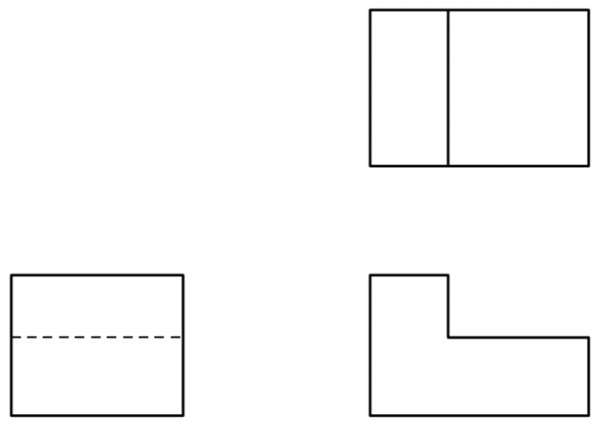


SOLUTION I
First Angle Projection



SOLUTION II

Third Angle Projection



Assembly Drawings

As the name indicates, assembly drawings are nothing more but a collection of detail drawings (each of which forms part of that assembly) put together in a logical way. The drawing serves someone who is to assemble the individual parts so as to get a single unit in its working condition**.**

Notes

- Only the external extreme dimensions of the assembly are indicated.
- Each component is identified by its part reference number. This number is used in the parts list.
- (Where details of that part are indicated e.g. the drawing number for its detail drawing).
- Sectional views are in most cases preferred as they show in a detailed form how the parts interact in an assembly.
- Only one view is normally drawn, unless where the unit is so complex such that the interaction of all parts cannot be clearly presented in one view.

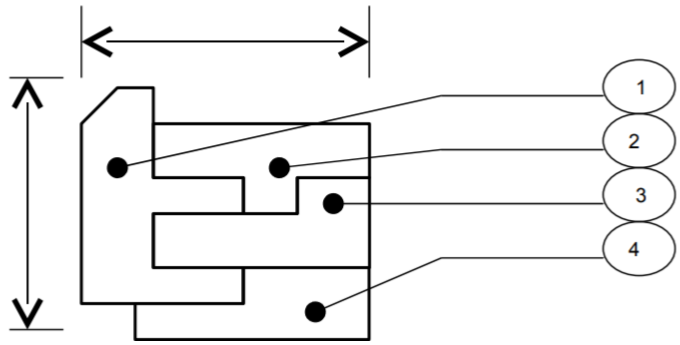


Figure 52: Assembly drawing

If the unit has one or more moving parts, the extreme positions of the moving part are indicated in dotted lines (and the dimensions). This allows for consideration on space limitation during installation

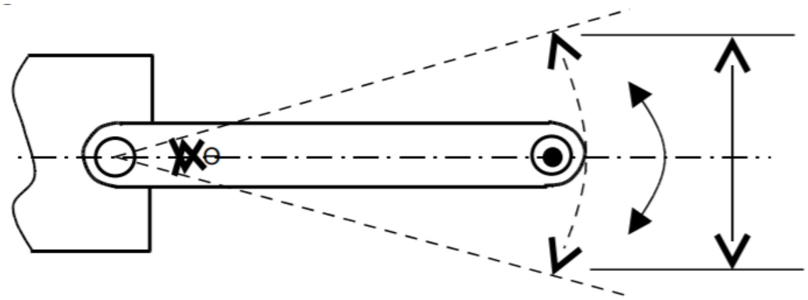
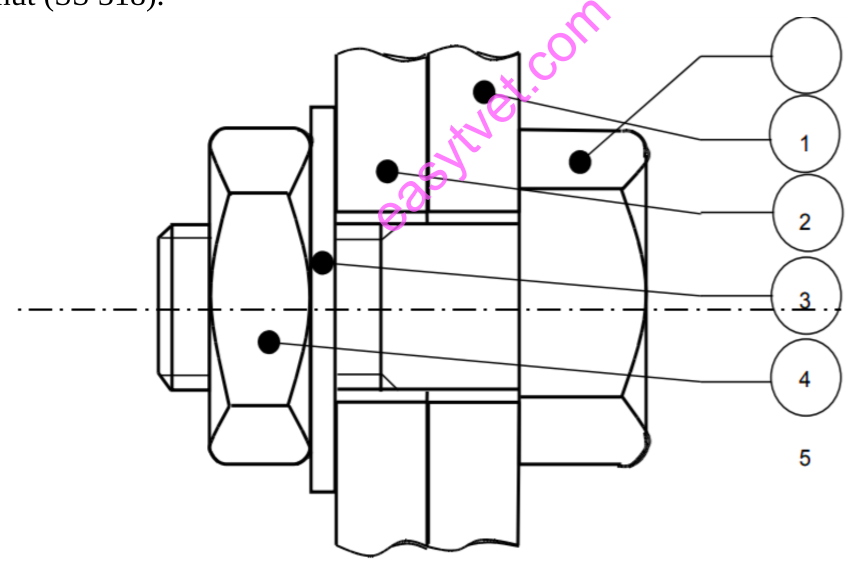


Figure 53: Assembly drawing without detail Specifications

Detail specifications of the individual parts are never shown on an assembly drawing (as they already appear on the respective detail drawing of the respective part)

Exercise to summarize

1. Draw an assembly of two stainless steel plates (SS 306) held together by a bolt and a nut (SS 318).



REF. NUMBER	NAME OF PART	NO. REQ'D	MATERIAL	STANDARD/ DIMENSION	DRW. NUMBER
5	Nut	1	SS 318	M10	005
4	Washer	1	SS 318	M10	004
3	Plate # 2	1	SS 306	–	003
2	Plate # 1	1	SS 306	–	002
1	Bolt	1	SS 318	M10	001

Figure 54: Stainless steel plates

NOTE: Materials SS 306 and SS 318 are different

2. Draw the orthographic projections of the following points.
    a) Point P is 30 mm above HP and 40 mm in front of VP
    b) Point Q is 25 mm above HP and 35 mm behind VP
    c) Point R is 32 mm below HP and 45 mm behind VP
    d) Point Sis 35 mm below HP and 42 mm in front of VP
    e) Point T is in HP and 30 mm. is behind VP
    f) Point U is in VP and 40 mm below HP
    g) Point V is in VP and 35 mm above HP
    h) Point W is in HP and 48 mm in front of VP

Projection of Lines

The shortest distance between two points is called a straight line. The projectors of a straight line are drawn therefore by joining the projections of its end points. The possible projections of straight lines with respect to V.P and H.P in the first quadrant are as follows:

i. Perpendicular to one plane and parallel to the other.
ii. Parallel to both the planes.
iii. Parallel to one plane and inclined to the other.
iv. Inclined to both the planes.

Conclusion

This outcome covered orthographic views, pictorial drawing, oblique drawings, sectioning, axonometric, auxiliary first, and third angle projections, and free hand sketching.

Further Reading

1. Geometric and Engineering drawing Third Edition K Morling.
2. Engineering Drawing with CAD Applications by O. OSTROWSKY

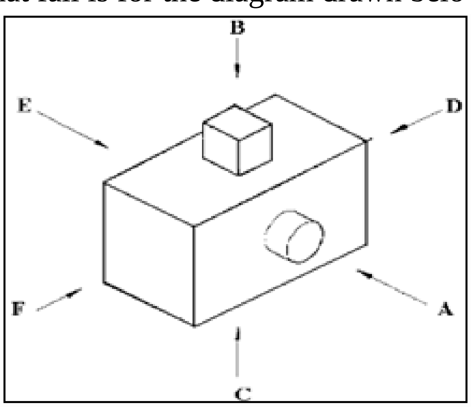
3.3.5.3 Self-Assessment

Written Assessment

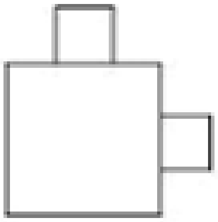
1. Orthographic projection is drawn using two methods which is ___________
    a) Second angle and third angle method
    b) First angle and third angle method

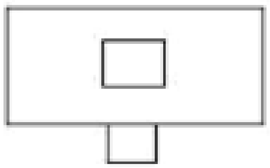
c) First angle and fourth angle method
d) Second angle and fourth angle method

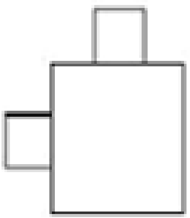
2. The method in which the object is placed in the first quadrant is known as ____ method.
   a) Third angle
   b) Second angle
   c) First angle
   d) Fourth angle
3. In first angle method the top view is drawn _______ of the front view.
   a) Above
   b) Right Side
   c) Left side
   d) Bottom
4. The method in which the object is placed in the third quadrant is known as __________ method.
   a) Third angle
   b) Second angle
   c) First angle
   d) Fourth angle
5. In third angle method the top view is drawn _______ of the front view.
   a) Above
   b) Right Side
   c) Left Side
   d) Bottom
6. Question that fall is for the diagram drawn below:

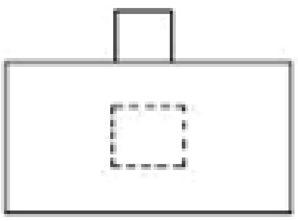


7. Taking 'A' as the FRONT VIEW. Which view will letter 'D' represent?

a) 

b) 

c) 

d) 

Oral assessment

What is the difference between orthographic projection and isometric drawing?

Practical Assessment

Draw the orthographic of vehicle engine

3.3.5.4 Tools, Equipment, Supplies and Materials

- Drawing room
- Computer lab
- Drawing equipment and materials
- Computers
- CAD package
- Overhead projector

3.3.5.5 References

Morling, K. (2010). Geometric and engineering drawing. Routledge.

Shrock, C. R. (2004). Exercise workbook for beginning AutoCAD 2005. Industrial Press Inc.

Yamaguchi, F. (2012). Curves and surfaces in computer aided geometric design. Springer Science & Business Media.

3.3.6 Learning Outcome No 5: Apply CAD Packages in Drawings

3.3.6.1 Learning Activities

Learning Outcome No 6: Apply CAD Packages in Drawings	
Learning Activities	**Special Instructions**
5.1 Select CAD packages 5.2 Apply CAD packages in production of electrical drawings	• Provide all the information of the object to be drawn i.e.

3.3.6.2 Information Sheet No3/LO6: Apply CAD Packages in Drawings

Introduction

This outcome covers use of CAD applications to draw pictorial and orthographic drawings and sectioning, symbols and abbreviations, 2D and 3D drafting technique and apply CAD packages in production of electrical drawings.

Definition of key terms

CAD (Computer Aided Design): It is the use of computer software to design and document a product's design process.

Engineering drawing: The use of graphical symbols such as points, lines, curves, planes and shapes.

Content/Procedures/Methods/Illustrations

CAD (Computer Aided Design) is the use of computer software to design and document a product's design process. To many engineering problems, a solution requires a combination of organization, analysis, problem solving principles and a graphical representation of the problem. Objects in engineering are represented by a technical drawing/drafting that represents designs and specifications of the physical object and data relationships. Since a technical drawing is precise and communicates all information of the object clearly by use of Computer Aided Design. CAD is used to design, develop and optimize products. CAD is used in the design of tools and equipment required in the manufacturing process as well as in the construction domain.

How CAD software system works

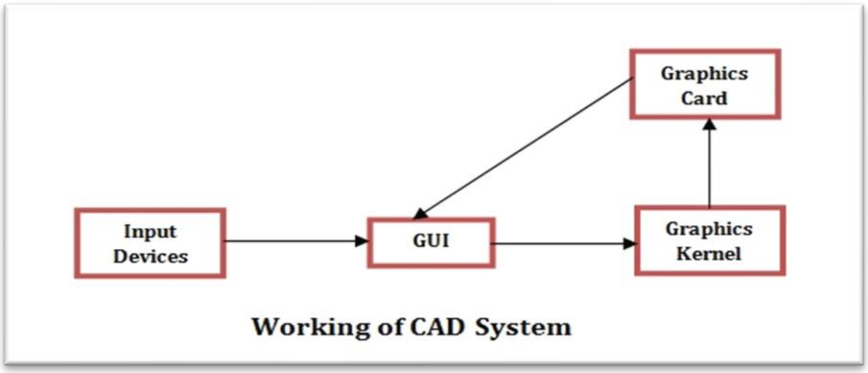


Figure 55: Working of a CAD system

CAD software enables

- Efficiency in the quality of design
- Increase in the Engineer's productivity
- Improve record keeping through better documentation and communication

Types of CAD Software

- 2D CAD
- 3D CAD
- 3D Wireframe and Surface Modelling
- Solid Modelling

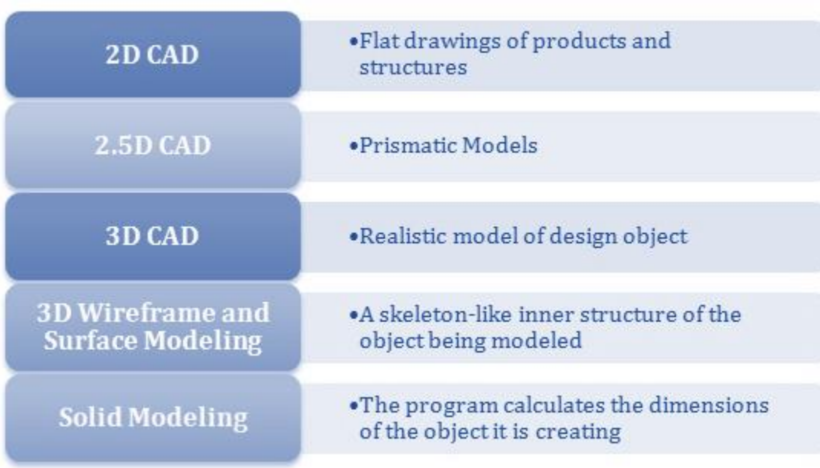


Figure 56: Types of CAD software

2-Dimensional CAD (2D CAD)

2D CAD is the pioneer of CAD software, developed in the early 70s. It relies on basic geometric shapes like lines, rectangles, circles, etc. to produce flat drawings. Autodesk is one of the pioneering companies that has played a significant role in developing CAD software.

3-Dimensional CAD (3D CAD)

It is a step up from the 2D CAD software. It allows creation of 3D images that are realistic. These images are called 3D models as they can be viewed and rotated in any direction – X, Y or Z.

Classification of CAD software in terms of their operating parameters

a) **Single-file-mode systems**: This type of CAD software that allows only a single user to work on a single file at a time.
b) **Referenced file-mode systems**: This type of software, users work on their own files with the files of other users attached as a background. This enables users to leverage other users' work as background data.
c) **Collabourative-mode systems**: These CAD systems take the referenced-mode system to the next level. They allow a team of users to collabouratively work with each other's data and see the changes other users make to the data as they go. The giants in this field e.g. AutoCAD is used in different modes of an operation.
d) **Wire-frame models**: They create skeleton like models with lines and arcs. Since they appear to be made of wires, and everything in the background is visible, they are called wire-frame models.
e) **Surface models**: These models are created by joining 3D surfaces. The surface models are quite realistic.
f) **Solid models**: They are the most useful CAD models. They also have additional properties like weight, volume and density, just like actual physical objects. These models are commonly used as prototypes to study engineering designs.
g) **Nano CAD:** It is a professional grade CAD tool that is used by thousands of engineers and designers around the world. Nano CAD plus comes with some additional features. Both of the versions are available at a low-cost annual subscription including timely updates and priority online support.

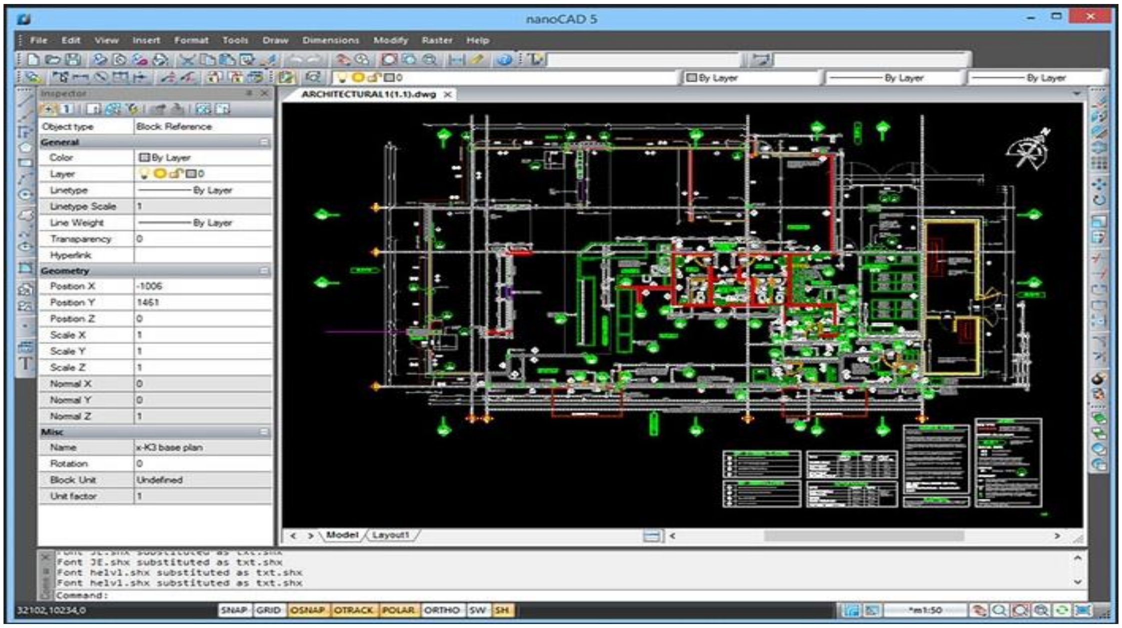


Figure 57: Nano CAD
Source: www.actcad.com

Features

- Nano CAD and Nano CAD versions are designed For Microsoft Windows (Vista 7, 8, and 10).
- Nano CAD software provides great user experience as it is a multipurpose free drafting software.
- The classic-style CAD user interface offers a command set and UI elements that are familiar and comfortable to users of many other compatible applications of CAD.
- Nano CAD software natively uses the industry-standard DWG (*.dwg) file format.
- It has a powerful Excel-style table editor having an extensive set of capabilities.
- ActiveX Automation and LISP to automate everyday routine tasks.
- C++/C# API and several other types of API to build CAD applications.

User interface and various tool bars and commands

CAD has a very versatile user interface that allows you to control the program in several different ways. At the top of the window is a row of menus. Clicking on the Home, Insert, or Annotate causes another selection of menus to appear. This new selection of commands is frequently called a Ribbon or a Dashboard. You can operate the program by clicking on the icons in these menus.

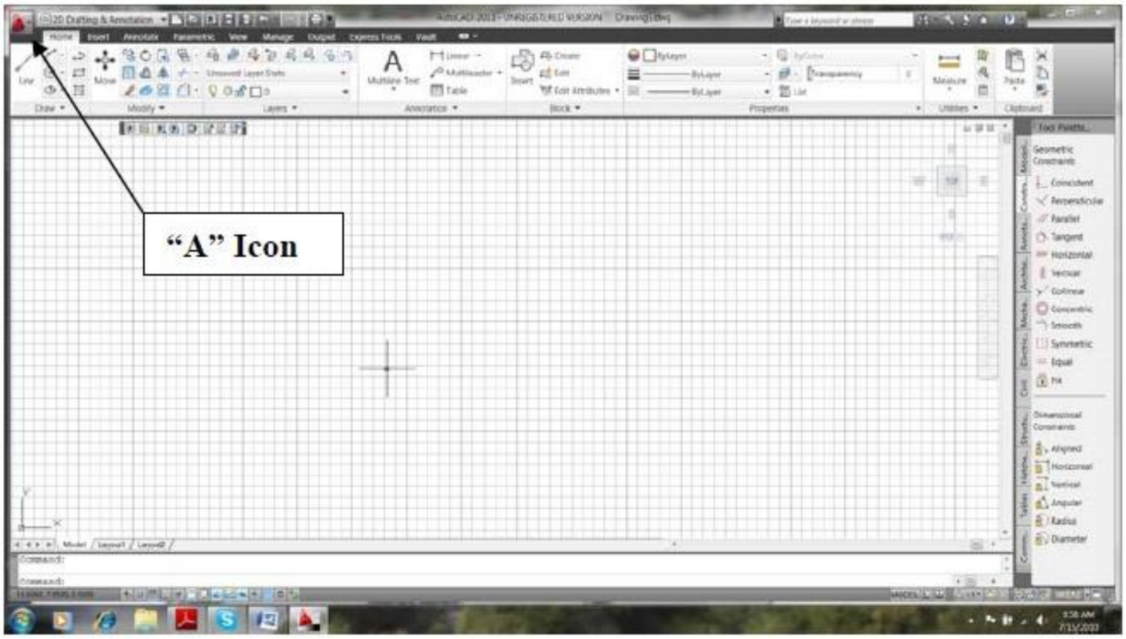


Figure 58: 2D user interface
Source: www.actcad.com

Application of CAD in engineering (2D and 3D)
Set the CAD parameters as per the drawing's requirements.

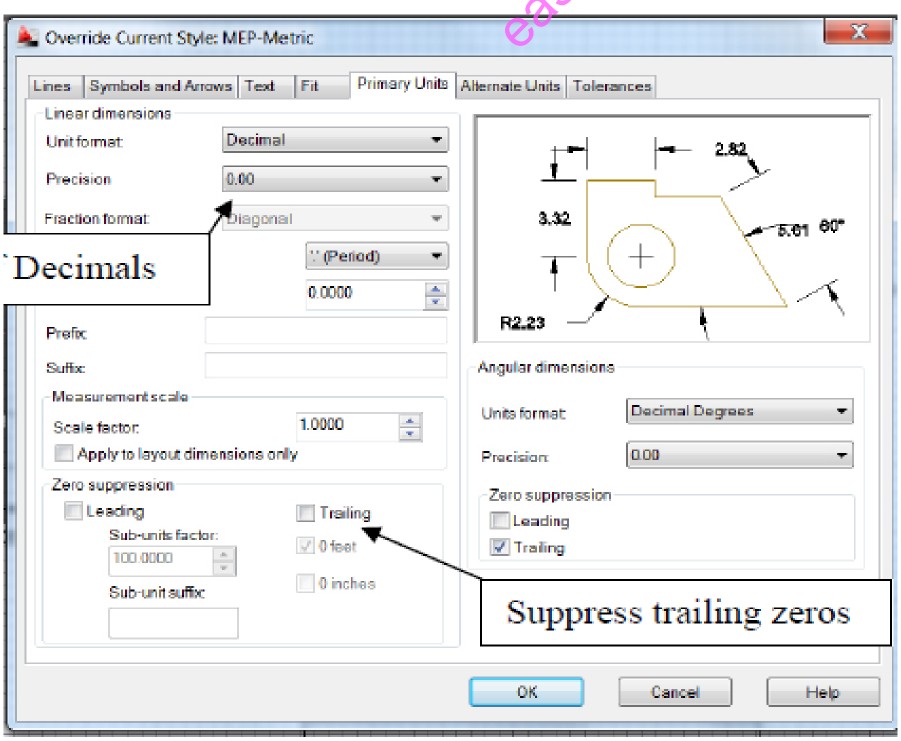


Figure 59: Setting CAD parameters
Source: www.actcad.com

Apply different commands to produce engineering drawings.

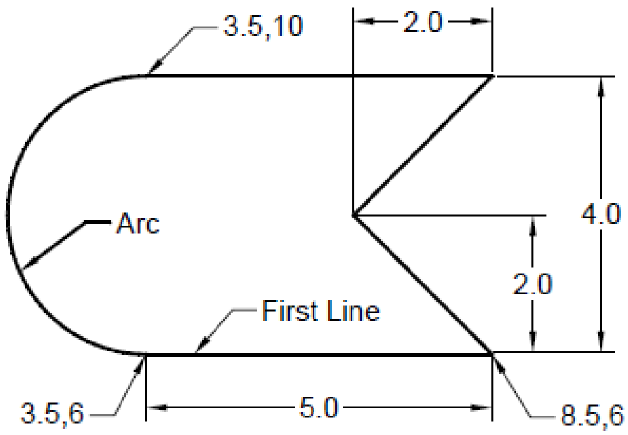


Figure 60: 2D CAD illustration
Source: www.archdaily.com

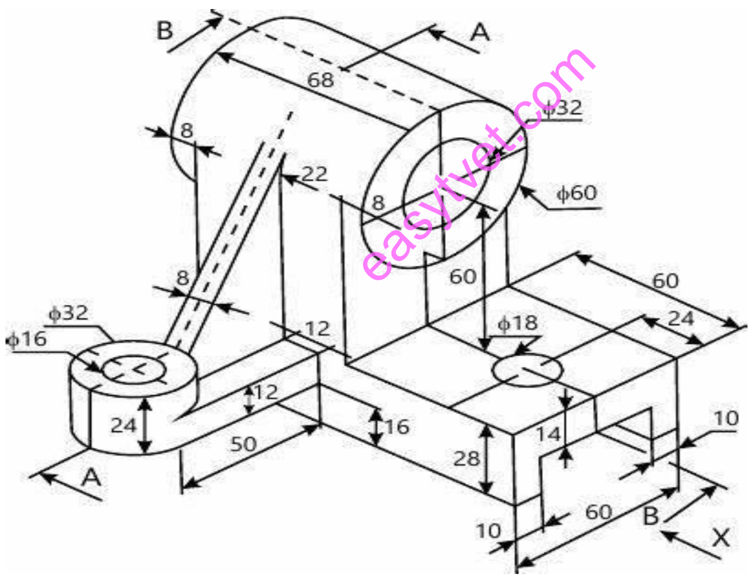


Figure 61: 3D CAD illustration
Source: www.archdaily.com

Electrical drawings

Electrical drawings are technical documents that depict and notate designs for electrical systems. Workers use these documents to install systems on-site. Every type of component and connection has its own specialized symbol and every detail matter in electrical drawings.

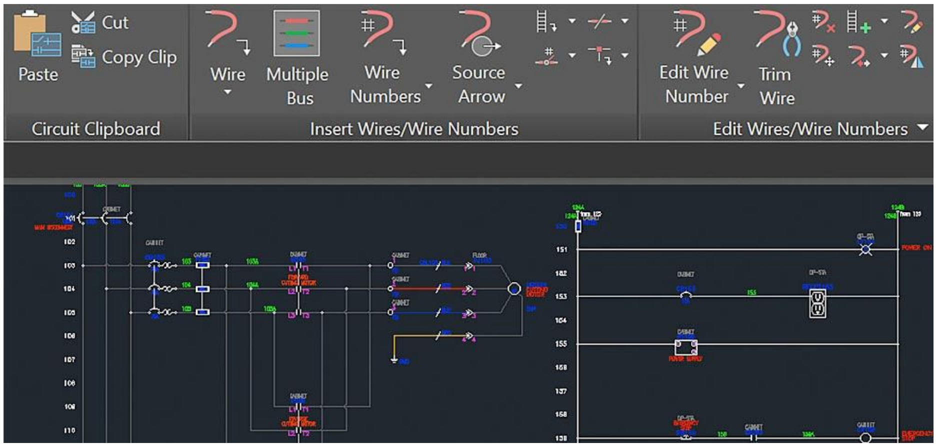


Figure 62: Electrical drawing
Source: www.electrical-engineering-portal.com

CAD enables these engineers to create electrical and electronic diagrams, control circuit diagrams, schematics and documentation. CAD certainly improves the productivity of electrical engineers as they are able to build default circuits and reuse them later. CAD comes with libraries of parts and symbols which allow electrical engineers to automate design tasks and generate bills of materials (BOM) reports. It's possible to create electrical schematic designs based on wire material type, temperature and maximum voltage drop.

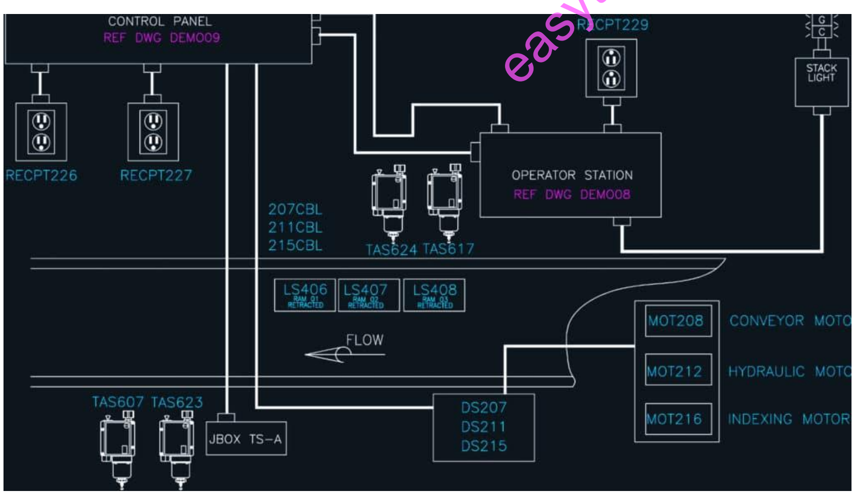


Figure 63: Electrical engineer design
Source: www.electrical-engineering-portal.com

How to read electrical drawings

Symbols used to notate components in an electrical drawing

Lights

Use AutoCAD tools to diagram lighting sources

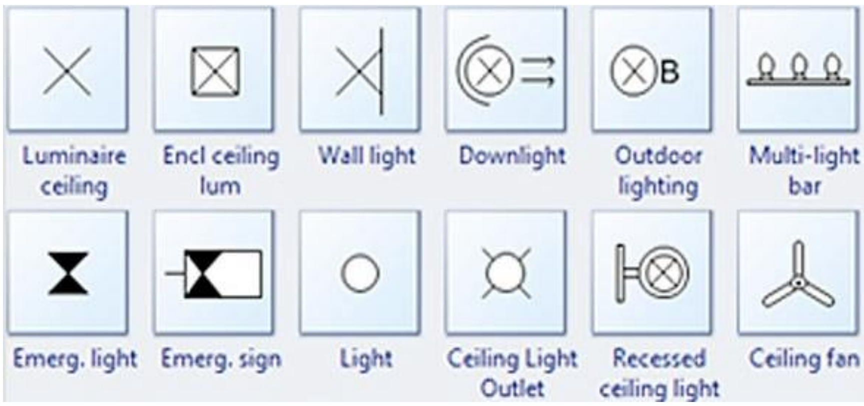


Figure 64: Lights symbol

Source: www.electrical-engineering-portal.com

Switches

From single-pole to multiple-pole, AutoCAD can help you diagram electrical circuits.

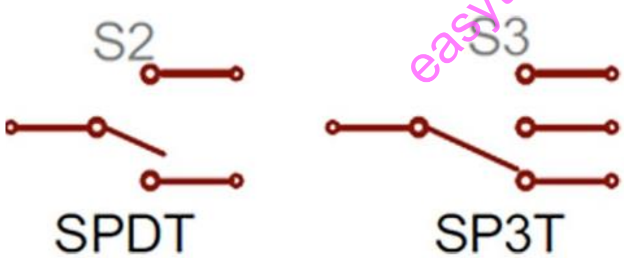


Figure 65: Switch symbol

Source: www.electronicshub.org

Fuses

Fuses limit the flow of current to prevent damage to other components. With AutoCAD, fuses are easier to design and diagram.

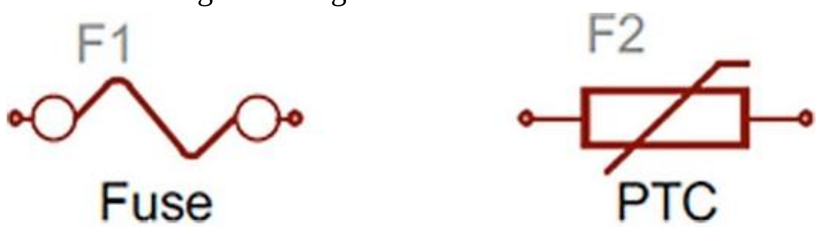


Figure 66: Fuse symbol

Ground

Electrical circuits must connect to the ground to maintain safety. the correct ways to diagram electrical grounds with AutoCAD

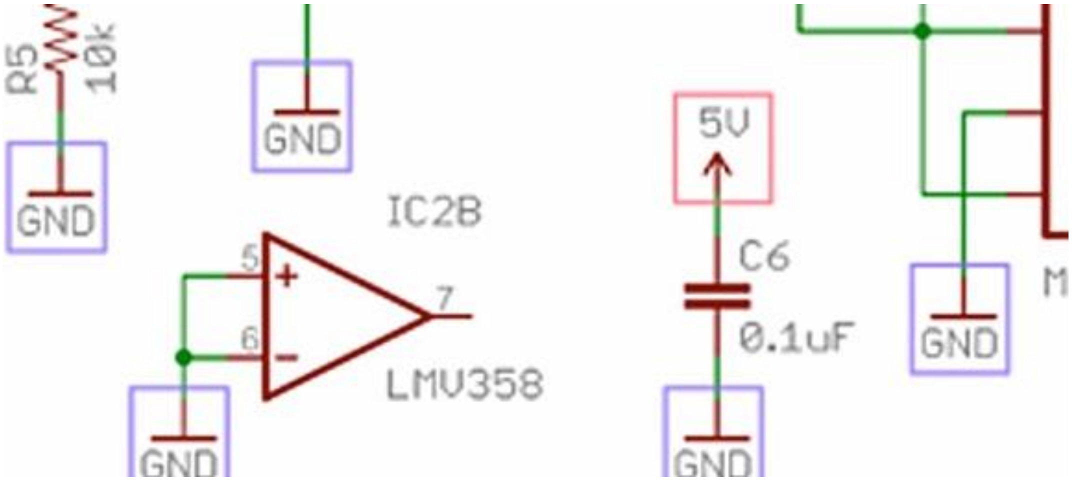


Figure 67: Ground symbol
Source: www.electronicshub.org

WIRES

Wires connect components, and AutoCAD gives you the design power to specify what you need.

Figure 68: Wires symbol
Source: www.electronicshub.org

Resistors

AutoCAD gives you the design tools to diagram resistors, which reduce current flow, adjust signal levels, divide voltages, and more.

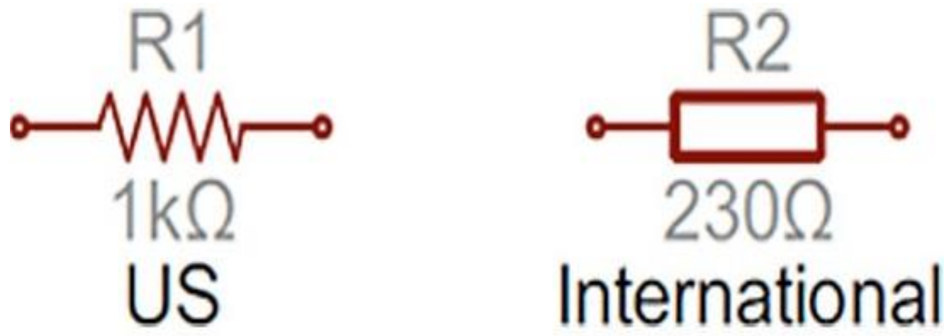


Figure 69: Resistor symbols
Source: www.electronicshub.org

Capacitors

Capacitors store potential energy; they're polarized or non-polarized. The AutoCAD Electrical toolset enables you to diagram capacitors correctly.

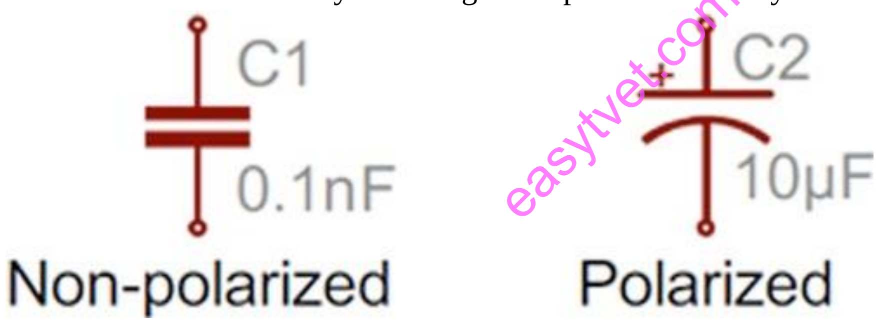


Figure 70: Capacitor
Source: www.electronicshub.org

Power sources

AutoCAD makes the planning and design from DC to AC currents and batteries process easy.

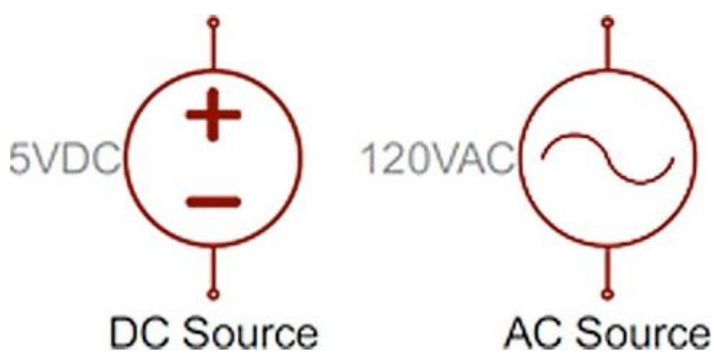


Figure 71: Power sources symbols
Source: www.electronicshub.org

Mechanical Engineering

Mechanical engineers are concerned with the improvement and modification of mechanical components and systems**.** They research, design, develop and test mechanical devices. They also research designs and make recommendations based on industry standards and regulations. CAD comes in handy as engineers can design components and assemblies to fit their strict technical specifications. Some CAD programs can also automatically generate a bill of materials (BOM) for a particular design, based on a library of components. Mechanical engineers also make use of simulation to test everything from stress to measuring vibrations in order get the perfect output without having to create and modify real-world prototypes.

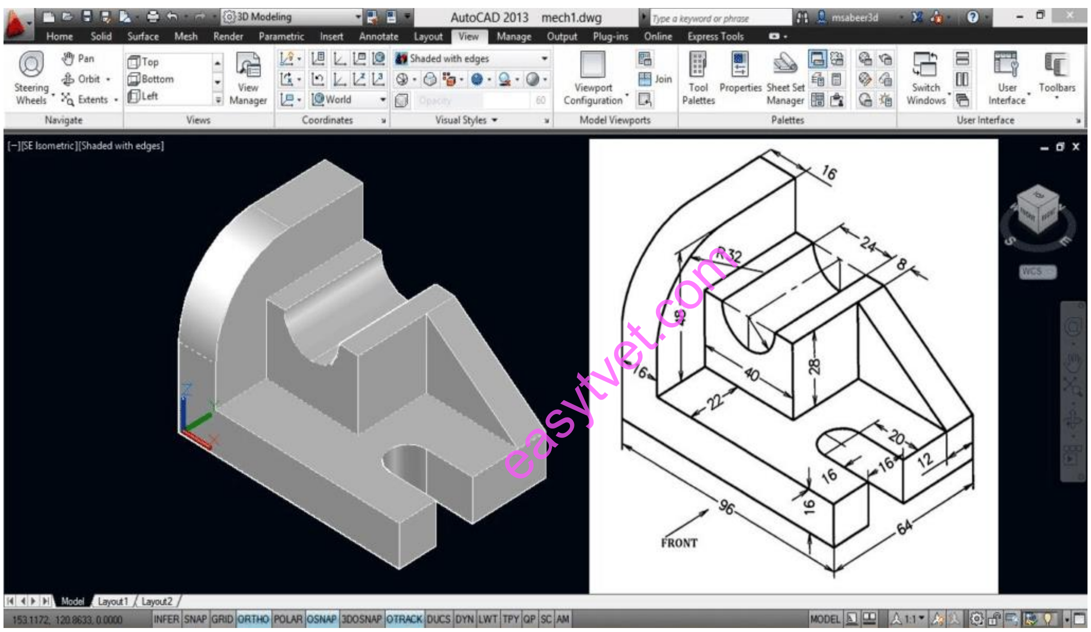


Figure 72: CAD mechanical design
Source: www.cadpro.com

Advantages of CAD

- Designs can be altered without erasing and redrawing.
- It offers "zoom" features analogous to a camera lens, whereby a designer can magnify certain elements of a model to facilitate inspection.
- Computer models are three dimensional and can be rotated on any axis, much as one could rotate an actual three-dimensional model in one's hand, enabling the designer to gain a fuller sense of the object.
- Lend themselves to modelling cutaway drawings, in which the internal shape of a part is revealed, and to illustrating the spatial relationships among a system of parts.

Disadvantages of CAD

- Have no means of comprehending real-world concepts, such as the nature of the object being designed or the function that object will serve.
- Function by their capacity to codify geometrical concepts thus the design process using CAD involves transferring a designer's idea into a formal geometrical model.

Benefits of CAD to the Engineering Industry

- More precision and control
- Faster design execution
- Cost efficiency
- Better documentation and collabouration

Conclusion

The learning outcome covered types of CAD and 2D and 3D drafting technique.

Further Reading

1. https://www.scan2cad.com/cad/how-engineers-use-cad/

3.3.6.3 Self-Assessment

Written Assessment

1. The computer-aided design (CAD) hardware doesn't include ___________
    a) Graphic display terminals
    b) Computer
    c) Computer programs
    d) Keyboard
2. How many types of CAD are there?
    a) 6
    b) 4
    c) 2
    d) 5
3. Modem CAD systems are based on ____________
    a) ICG
    b) GCI
    c) GIF
    d) IFG

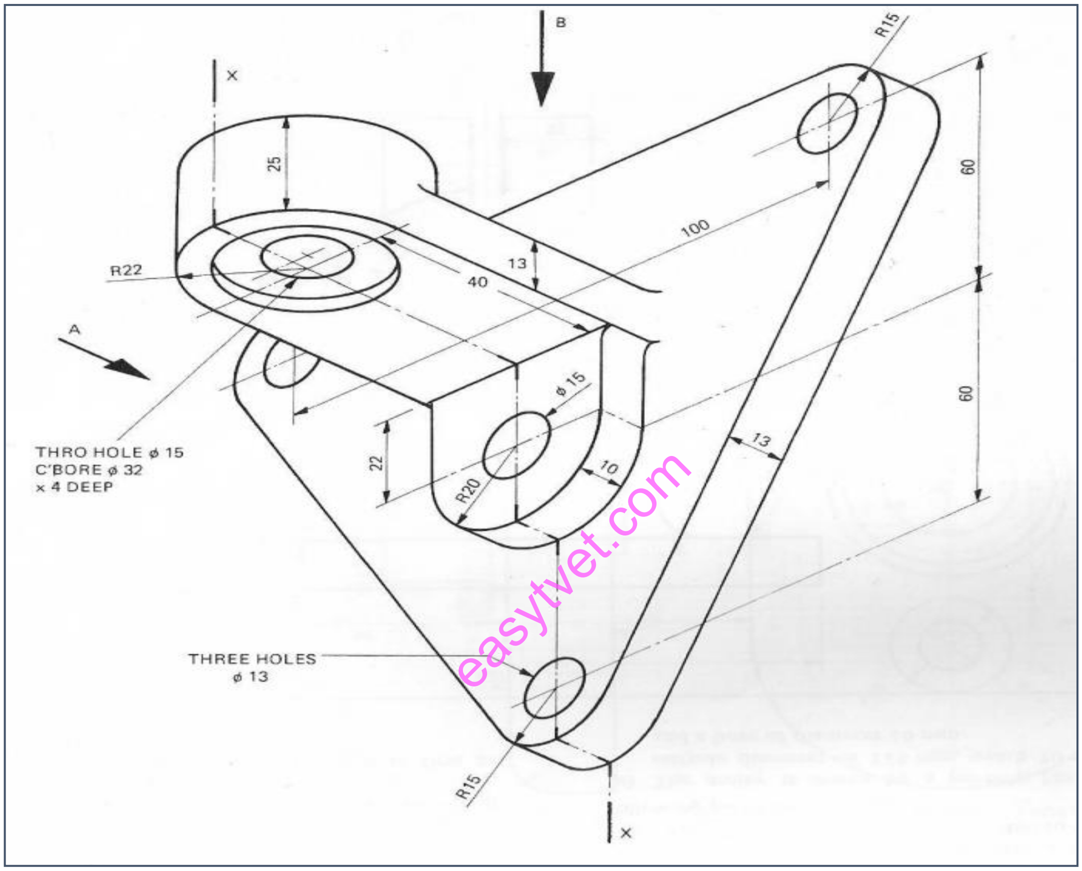
4. The computer communicates with the user via ___________
    a) CPU
    b) CRT
    c) Graphics
    d) Display button
5. The process of designing consists of __________ identifiable steps.
    a) 8
    b) 5
    c) 4
    d) 6
6. The functionality areas of CAD application can be grouped into __________ categories.
    a) 2
    b) 3
    c) 4
    d) 5
7. The colour on CRT screen is obtained by the combination of ____________
    a) Red, yellow, blue
    b) Red, green, blue
    c) Green, black, yellow
    d) Red, black, yellow
8. The input devices in CAD can be divided into _____________
    a) 2
    b) 5
    c) 3
    d) 4
9. An orthographic projection map is a map projection of __________
    a) Sphere
    b) Earth
    c) Cartography
    d) Top view

Oral Assessment

1. What are the benefits of CAD?
2. What are the uses of CAD in mechanical engineering?

Practical Assessment

1. Use CAD application to draw the following views of the figure below in first angle projection.
    a) Front elevation looking from the direction arrow A
    b) End elevation looking from the direction arrow B



3.3.6.4 Tools, Equipment, Supplies and Materials

- Drawing room
- Computer lab
- Drawing equipment and materials
- Computers
- CAD package
- Overhead projector

3.3.6.5 References

Hubka, V. (2015). Principles of engineering design. Elsevier.
Morling, K. (2012). Geometric and Engineering Drawing. Routledge, amazon

CHAPTER 4: STRUCTURAL DESIGN AND ANALYSIS

4.1 Introduction

This Unit describes the competencies required to Perform Structural Design and Analysis. It involves analysing structural designs, designing structural elements, preparing structural drawings interpreting structural drawings and applying structural drawings

4.2 Performance Standard

Analyse structural elements, design structural elements, prepare structural drawings, interpret structural drawings and apply structural drawings according to building codes, structure, drawing and support requirements, and structural design requirements.

4.3 Learning Outcomes

4.3.1 List of Learning Outcomes

a) Analyse structural elements
b) Design structural elements
c) Prepare structural drawings
d) Interpret structural drawings
e) Apply and use structural drawings

4.3.2 Learning Outcome No 1: Analyze Structural Elements

4.3.2.1 Learning Activities

Learning Outcome No 1: Analyse Structural Elements	
Learning Activities	**Special Instructions**
1.1 Determine methods used in analyses of structural members 1.2 Work loadings 1.3 Sketch structural members 1.4 Determine maximum moments in each section 1.5 Draw shear force and bending moments diagram	• Demonstration by trainer • Practical work by trainee • Demonstration videos • Projects • Group discussions

4.3.2.2 Information Sheet No4/L01: Analyse Structural Elements

Introduction to learning outcome

This learning outcome covers Analyses of structural elements, Preparation of sketches, Determination of maximum moments and Structural designs.

Definition

Building codes: These are laid down standards for any building structure.

Bending moments: These are structural reactions when a structure is subjected to moment or applied load.

Shear force: This is the reaction imposed by a structure when loads are imposed.

Content/Procedures/Methods/Illustrations

1.1 Determine Methods used in analyses of structural members according to building codes

Several methods are used in the analysis of structural members. A structural system is made up of different members and each member is analysed differently. The methods of analysis used in beams include:

a. Energy methods

   Two methods are commonly used i.e.

   - Methods of virtual work
   - Castigliano's theorem

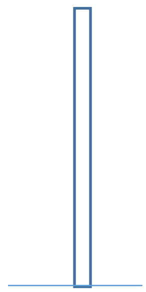
b. Displacement methods of analysis
   - Slope deflection methods
   - Moment distribution methods
c. Approximate methods of analysis.
   - This method is used in the analysis of statically indeterminate structures.
d. Double integration method
   - In this method, sign convention and boundary conditions are well defined. It is mostly used in determining deflections.
e. Elastic beam theory
   - The method relates to slope, displacement as well as the internal moments of a beam. Its development is fully dependent on this.
f. Moment area methods
   - This method is mainly used when checking for deflection. It involves determining slope and deflection of an elastic curve.
g. Conjugate- beam method
   - This method relies mainly on statics for determining deflection in beams.
h. Stiffness method of analysis

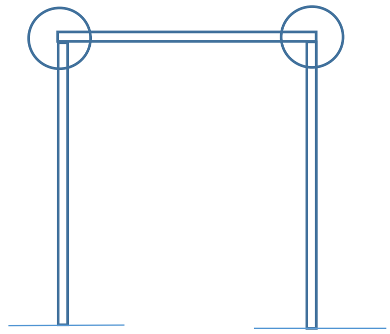
1.2 Work loadings on according to the structure

These are loadings that are subjected to a structure. Different structures are subjected to different loadings depending on the location, height as well as purpose of use.

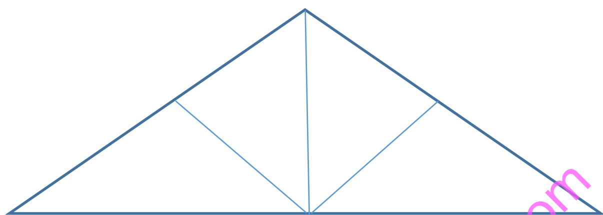
a. Dead loads
   - These are loads that are permanent in a structure. They include the self-weight of the structure, finishes, masonry etc.
   - During analysis, these loads are taken into considerations to ascertain the safety of the structure.
b. Live loads
   - These are loads that are temporary. They include people, furniture, etc.
   - There are other types of live loads such as impact loads (loads imposed by moving cars), highway bridge loads (caused by traffic), wind loads and snow loads.

1.3 Sketch structural members as per the drawings and support requirements





i. Column ii. Frame iii. Beam



iv. Truss

Figure 73: Sketch structural members

1.4 Determine maximum moments in each section in accordance with appropriate methods

Maximum moments in different sections of a structural member is determined using mathematical equations.

It is also necessary to note that maximum moment occurs at zero- shear force.

The line of influence method of determining maximum moment is often used for statically determinate structures.

The method assumes that summation of shear force area under the influence line is the moment at any given section in the structure.

That is, Mmax= Summation of area under shear

- ✓ For statically indeterminate structures, the force method is used in which,

$Mmax = \frac{PL}{8}$ ----- fixed support beams

$Mmax = \frac{PL}{8}$ ------ Simply supported beams

1.5 Draw shear force and bending moments diagram according to structural design requirements

Drawing shear force and bending diagrams is very essential since it creates an image of how a structure will fail.

Before doing so, one is required to follow certain procedures as discussed below:

Shear force diagram

a. Determine Shear, V at distance x. Distance x is always the distance from one load application to another.

b. Plot a graph of V against x

Bending moment diagram

a. Determine moment, M by find the area under shear in the SFD.

b. Plot a graph of moment M, against distance x.

The diagram attached below is an example of how to draw a bending moment diagram (BMD) as well as the shear force diagram (SFD)

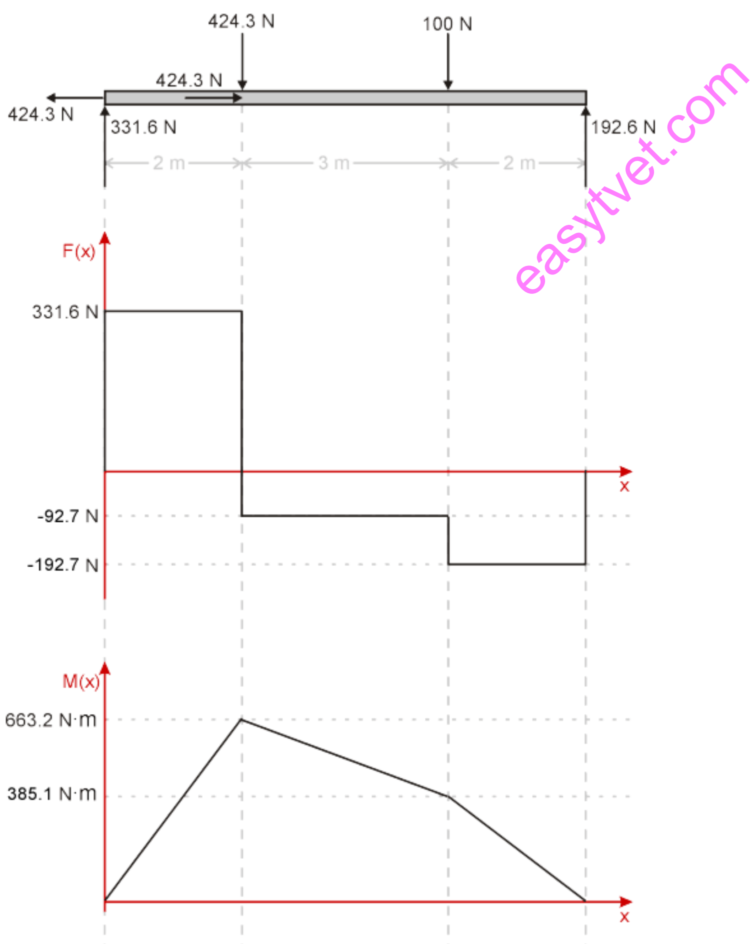


Figure 74: bending moment

Source: Structural mechanics, 2008

Conclusion

This learning outcome covered Analyses of structural elements, Preparation of sketches, Determination of maximum moments and Structural designs.

Further Reading

4.3.2.3 Self-Assessment

Written Assessment

1 Which one of the following is a type of load?
   a) Furniture load
   b) Rail truck load
   c) Live load
   d) Steel load

2 Which of the following is a method is used to analyze statically indeterminate structure?
   a) Influence line analysis method
   b) Superposition
   c) Energy methods
   d) Finite element method.

3 The following methods are used in the analysis of trussed which one is not?
   a) Method of joints
   b) Method of sections
   c) Virial work methods
   d) Influence line methods

4 Which of the following is not a displacement method of analysis?
   a) Castigliano’s theory
   b) Slope deflection equations
   c) Moment distribution method

5 Which of the following is not a structural member?
   a) Beams
   b) Walls
   c) Columns
   d) Frames

6 Define what is a structure

7 Explain the importance of structural analysis
8 Differentiate between Structural design and structural analysis
9 What is the difference between influence line and shear force and bending moment diagram?
10 Differentiate
    1. Column
    2. Beam
    3. Frame
    4. Truss
11 Discuss Displacement methods in details
12 For each of the methods outlined, discuss their shortcomings.

Oral Assessment

1. What is analysis?
2. Why do we need to analyze structures?

Project Assessment

1. Analyze a one-story building.

4.3.2.4 Tools, Equipment, Supplies and Materials

- Computers
- Office equipment
- Calculators
- Scale rule
- Computer software
- Design codes (British Standards)
- Stationery
- Standard design manuals
- Dust coat
- First aid kit

4.3.2.5 References

Bhavikatti, S. (2010). Structural analysis. New Delhi: Vikas Publishing House.
Hibbeler, R. (2012). Structural analysis. Upper Saddle River: Prentice Hall.
Kaveh, A. (2004). Structural mechanics. Baldock, England: Research Studies Press.
Stanford, J. (2012). Structural Analysis Made Easy.

4.3.3 Learning Outcome No 2: Design structural elements

4.3.3.1 Learning Activities

Learning Outcome No 2: Design structural elements	
Learning Activities	**Special Instructions**
2.1 Gather Design recourses 2.2 Identify types of structural elements 2.3 Identify different methods of designs 2.4 Identify different types of standard design codes 2.5 Determine maximum moments used in design 2.6 Identify and gather design tools and equipment 2.7 Design structural elements	• Demonstration by trainer • Practical work by trainee • Demonstration videos • Projects • Group discussions

4.3.3.2 Information Sheet No4/L02 Design structural elements

Introduction to learning outcome

This learning outcome covers Structural designs, Methods of designs, Design codes, Design tools and equipment, Structural elements designs and Schedules for different elements.

Definition of key terms

Structural elements: Structural elements have to do with the part of the building that is concerned with preserving the physical integrity (ensuring the structure satisfies the ultimate limit state and the serviceability limit state requirements) and continues to exist in the world as a physical object.

Structural designs: This refers to the process of undertaking a structural analysis and selecting materials, member types, configuration and size to safely carry and transfer the intended loads both in a serviceability and ultimate limit state.

Content/Procedures/Methods/Illustrations

2.1 Gather *Design recourses* according to standard design requirements

In design, it is said that there is no one way of solving a design problem. Focusing on just one solution instead of considering other alternatives is almost certain that you are overlooking other attractive solutions. Generating design options is a phase in project planning known as conceptual design and it includes producing ideas and taking into account the advantage and limitations of implementing those ideas.

This is done to manage costs, minimize the likelihood of errors, evaluate success and assess risks of undertaking the intended project. Some of the design recourses undertaken in project include:

i) Changing the materials.
ii) Changing the member types.
iii) Changing the member configuration and arrangement.
iv) Changing the member sizes.

2.2 Identify types of structural elements as per building codes

Structural elements have to do with the part of the building that is concerned with preserving the physical integrity (ensuring the structure satisfies the ultimate limit state and the serviceability limit state requirements) and continues to exist in the world as a physical object. The following are some of the structural elements:

i) **Foundations:** The foundation is part of an engineered system that transmits to the underlying soil or rock the loads supported by the foundation itself and its self-weight in such a way that the soil is not overstressed or excessive settlement occurs.
ii) **Columns:** These are vertical members that majorly resist axial compressive loads.
iii) **Beams:** These are horizontal members that primarily carry vertical loads and resist failure in bending.
iv) **Walls:** A wall is a structure that demarcates the different spaces in a building as well as the external boundary. Some walls are load bearing and carry the structural loads of the building.
v) **Ties:** This is a slender structural element that carries the loads in tension.
vi) **Struts:** This a structural member that carries the loads in compression only.
vii) **Trusses:** This a structure that is composed of a series of struts and is used to carry loads in compression.
viii) **Frames:** This type of structure is composed of beams and columns that are either pin or fixed connected.
ix) **Slabs:** This are horizontal structures built to provide a flat surface in buildings.

2.3 Identify different methods of designs as per the design manuals

The following are the design methods according to BS 5950:

i) Simple design method: The connections between members are assumed not to develop moments adversely affecting either the members or structure as a whole. So, the structure is assumed to be pinly-jointed for analysis.
ii) Semi-rigid design method: Are capable of transmitting some moments. Here the joints are capable of transmitting partial moment.

iii) Rigid design method: Connections are assumed to be capable of transmitting 100% moment required by analysis assuming full continuity.

iv) Experimental verification: The code states that where design of a structure or elements by calculation in accordance with any of the above methods is not practical, the strength will be confirmed by loading tests.

2.4 Identify different types of standard design codes according to construction materials

The following are some of the design codes currently in use in Kenya:

i) Design of reinforced concrete structures- BS 8110

ii) Design of steel framed buildings- BS 5950

iii) Design of timber structures- BS 5628

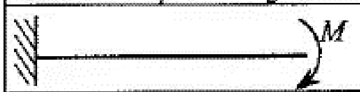
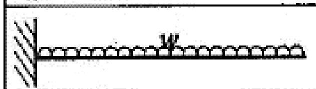
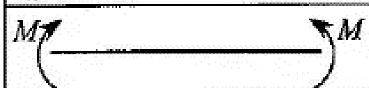
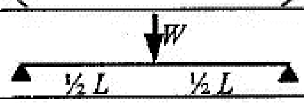
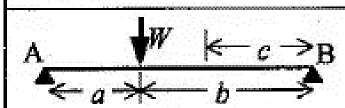
iv) Design code on the occupancy load requirements of a building- BS 6399 Part 1.

2.5 Determine maximum moments used in design according to standard specification manuals

The maximum bending moment occurs in beam where the shear force is zero. Below is a table showing how to calculate bending moment for various types of beams:

Table 4: How to calculate bending moment for various types of beams

BEAM BENDING

L = overall length W = point load, M = moment w = load per unit length	End Slope	Max Deflection	Max bending moment
	$\frac{ML}{EI}$	$\frac{ML^2}{2EI}$	M
	$\frac{WL^2}{2EI}$	$\frac{WL^3}{3EI}$	WL
	$\frac{wL^3}{6EI}$	$\frac{wL^4}{8EI}$	$\frac{wL^2}{2}$
	$\frac{ML}{2EI}$	$\frac{ML^2}{8EI}$	M
	$\frac{WL^2}{16EI}$	$\frac{WL^3}{48EI}$	$\frac{WL}{4}$
	$\frac{wL^3}{24EI}$	$\frac{5wL^4}{384EI}$	$\frac{wL^2}{8}$
 $a \leq b, \quad c = \sqrt{\frac{1}{3}b(L+a)}$	$\theta_B = \frac{Wac^2}{2LEI}$ $\theta_A = \frac{L+b}{L+a}\theta_B$	$\frac{Wac^3}{3LEI}$ (at position c)	$\frac{Wab}{L}$ (under load)

Source: www.learneasy.info

2.6 Identify and gather design tools and equipment according to standard design manuals

Check the tools, equipment, supplies and materials section.

2.7 Design structural elements as per the design codes

The following is the procedure followed in the design of a beam according to BS 5950:

i) Determine the loading condition of the beam.
ii) Calculate the design load of the beam.
iii) Perform structural analysis to determine the design moment and the design shear.
iv) Perform a strength classification and section classification.
v) Choose a section based on its moment capacity equation.
vi) Perform a moment capacity check.
vii) Perform a shear capacity check.
viii) Evaluate whether it's a low or high shear load.
ix) Perform a deflection limits check.
x) Perform a web bearing check.

Conclusion

This learning outcome covered structural designs, methods of designs, design codes, design tools and equipment, structural elements designs and schedules for different elements.

Further Reading

1. British standards Institute. (2002). Design of reinforced concrete structures-BS 8810. BSI.
2. British standards Institute. (2002). Design of steel structures-BS 5950. BSI.
3. British standards Institute. (2002). Design of timber structures-BS 5628. BSI.

4.3.2.3 Self-Assessment

Written Assessment

1. Which of the following is not a type of foundation?
    a) Mat
    b) Isolated footing
    c) Retaining wall
    d) Combined footing
2. Which of the following is not a check done during the design of reinforced concrete beam?
    a) Shear capacity check.
    b) Moment capacity check.
    c) Web buckling check.
    d) Deflection check
3. Which of the following is not a phase during design of structures?
    a) Technical design
    b) Developed design
    c) Conceptual design
    d) Handover
4. Which of the following is not a structural element?
    a) Ties
    b) None
    c) Trusses
    d) Joists
5. Design a reinforced concrete beam of your choosing according to the design code BS 8110.

6. Describe the various type of foundations and when should be used.
7. Describe the design principles that should guide an engineer during the design process.
8. Describe the main design theories.
9. Write an essay describing the how an engineer with poor communication skills can lead to poor quality construction.

Project Assessment

1. Using a BIM software application of your choice obtain architectural drawings from the internet and develop a corresponding structural model.

Oral Assessment

1. Describe how you as a student pursuing a diploma of civil engineering can develop shop drawings for fabrication of steel members when requested by the professional engineer.
2. What skills have you gained as a result of performing the project assessment described above.

4.3.2.4 Tools, Equipment, Supplies and Materials

- Computers
- Office equipment
- Calculators
- Computer software
- Design codes (British standards)
- Stationery
- Standard design manuals

4.3.3.5 References

Abdy Kermani (2008) Structural timber design. Blackwell science, London.

N. Subramanian (2010). Steel structures design and practice. Oxford university press, New Delhi.

W.H Mosley, R. Hulse, J.H Bungey (2012). Reinforced Concrete Design. Red Globe Press, New York.

4.3.4 Learning Outcome No 3: Prepare Structural Drawings

4.3.4.1 Learning Activities

Learning Outcome No 3: Prepare structural drawings	
Learning Activities	**Special Instructions**
3.1 Identify and gather drawing resources 3.2 Determine methods of drawing for structural members 3.3 Prepare standard working structural drawings for various elements 3.4 Prepare materials schedules	• Demonstration by trainer • Practical work by trainee • Demonstration videos • Projects • Group discussions

4.3.4.2 Information Sheet No4/ L03 Prepare structural drawings

Introduction to learning outcome

This learning outcome covers Drawing tools and equipment, Methods of drawing, Standard structural drawings and Preparation of material schedules.

Definition of key terms

Drawing resources: This refers to the various resources required in order to produce the complete set of structural drawings.

Structural members: Structural members have to do with the part of the building that is concerned with preserving the physical integrity.

Content/Procedures/Methods/Illustrations

3.1 Identify and gather drawing resources according to structural elements designed

- Computers
- Office equipment
- Calculators
- Computer software
- Design codes (British standards)
- Stationery
- Standard design manuals

3.2 Determine methods of drawing for structural members as per the designs

Structural drawings confine themselves to the load-carrying members of a structure.

The following outlines the methods for drawing structural members:

i) Structural plan. These drawings show the floor, foundation and roof plan of a building and provide information like location and size of different elements present in the plans.

ii) Elevations. These shows the exterior walls of a building or structure and the structural properties of elements present in the walls and cannot be seen in plan drawings.

iii) Sections. These are referenced in the plan drawings and provide more information about elements that may not be seen in plan drawings.

iv) Detail drawings. These provides particular information on how to connect or construct the structural elements.

3.3 Prepare standard working structural drawings for various elements as per designs

Structural drawings have to be produced as the design process evolves since the drawings are required in construction of the structure. Production of structural drawings takes place as follows:

i) The schematic architectural drawings are obtained from the architect. (Conceptual design phase)

ii) The engineer determines the loadings applied to the structure based on the drawings and performs design to size the members according to the forces applied to the building. (Developed design phase)

iii) As the design process evolves the engineer produces more detailed drawings, bar bending schedules, notes, specifications, details and at the end of this stage we have construction ready documents. (Technical design phase)

iv) The drawings are included in a tender pack to be tendered together with drawings from other disciplines during the bidding and tendering process.

3.4 Prepare materials schedules as per design codes

A material schedule is a detailed list of construction materials required to complete construction of the intended project.

i) Decide what is required. This requires that you thoroughly interrogate the drawings and specifications to determine the required materials.

ii) Decide whether to prefabricate the materials or construct on-site. This involves deciding whether to purchase materials for construction on-site or purchase prefabricated components.

Conclusion

This learning outcome covered drawing tools and equipment, methods of drawing, standard structural drawings and preparation of material schedules.

Further Reading

1. N.Krishna Raju (1992) Structural design and drawing: Reinforced concrete and steel. Universities Press.
2. Leonard Koel. (1999) Construction print reading. Delmar Cengage Learning.

4.3.4.4 Self-Assessment

Written Assessment

1. Which of the following is not a method of drawing structural members?
   a) Specifications
   b) Structural plans
   c) Elevations
   d) Details
2. Which of the following is not among the drawing resources required to produce structural plans?
   a) Computers
   b) Computer software
   c) Standard design manuals
   d) Office equipment
3. Which of the following is not a phase during design of structures?
   a) Technical design
   b) Developed design
   c) Conceptual design
   d) Handover
4. State the various computer software required in the production of structural drawings.
5. Explain the procedure of developing shop drawings.
6. Describe what is detailing of structural drawings.
7. Write an essay describing Building Information Modelling (BIM) and its impact on the production of structural drawings.

Project Assessment

Obtain a set of structural drawings for a project from the internet and interpret them to draw up a material schedule.

Oral Assessment

1. Explain the skills required to competently interpret structural drawings.
2. Explain the steps followed in interpreting structural drawings.

4.3.4.4 Tools, Equipment, Supplies and Materials

- Computers
- Office equipment
- Calculators
- Computer software
- Design codes (British standards)
- Stationery
- Standard design manuals

4.3.4.5 References

R.K Dhawan (2012). A textbook of engineering drawing. S.Chand 3rd rev.
Leonard Koel. (2000) Construction print reading. Delmar Cengage Learning.

4.3.5 Learning Outcome No 4: Interpret structural drawings

4.3.5.1 Learning Activities

Learning Outcome No 3: Interpret structural drawings	
Learning Activities	**Special Instructions**
4.1 Identify project 4.2 Identify and obtain structural drawings 4.3 Obtain and prepare steel schedules and materials schedules	• Demonstration by trainer • Practical work by trainee • Demonstration videos • Projects • Group discussions

4.3.5.2 Information Sheet No4/ L04 Interpret structural drawings

Introduction to learning outcome

This learning outcome covers Identification of project, Structural drawings, Steel and material schedules preparation and Standard construction procedures

Definition of key terms

Steel schedules: This is a list that explains the location, mark, type, size, length and number of each steel bar in a reinforcement drawing of a structure.

Structural drawings: These are plans illustrating in detail how a structure or building should be constructed. Engineers come up with structural drawings from performing checks using the loads that the structure is to carry, co-currently with standard codes.

Content/Procedures/Methods/Illustrations

4.1 Identify project according to the contract document

Project Identification is one of the major stages of a project cycle

Steps taken in identifying a project:

- Preliminary stakeholder analysis
- Analyzing the problem
- Setting of Objectives
- Analyzing alternatives
- Analyzing accountability
- Logical framework thinking
- Analyzing assumptions and associated risks
- Definition of Progress indicator

4.2 Identify and obtain structural drawings as per design manuals

Structural drawings

These are plans illustrating in detail how a structure or building should be constructed. Engineers come up with structural drawings from performing checks using the loads that the structure is to carry, co-currently with standard codes.

Structural drawings should basically include the following information;

- Setting out dimensions
- Notes describing the specifications
- Sections, plans and elevations
- Compass direction – North point

Reinforcement Drawing

These are drawings describing the location, number, size, type of reinforcement and illustrate the direction in which the reinforcement is to be laid.

Standard Details

This is a description of certain standard details that keep recurring in several structural drawings and are kept for use whenever necessary.

Standard details include;

- Notes
- Expansion joints details
- Concrete box culverts
- Pile caps and column bases

Record Drawings

This is a drawing that has been revised to cater for unforeseen challenges. A revision letter is normally included in the revised drawing to indicate that it is a revision.

4.3 Obtain and prepare steel schedules and materials schedules according to construction procedures

Factors to be considered when preparing a Steel Schedule

- Location of reinforcement
- Mark of reinforcement
- Type of reinforcement
- Size of reinforcement – diameter of steel
- Length of reinforcement

Factors to be considered when preparing a Materials Schedule

- Type of material
- Amount of material

Conclusion

This learning outcome covered identification of project, structural drawings, steel and material schedules preparation and standard construction procedures.

Further Reading

Read further on the Project cycle

4.3.5.3 Self-Assessment

Written Assessment

1. Structural drawings should basically include the following information. Which one is not among them?
    a) Setting out dimensions
    b) Notes describing the specifications
    c) Sections, plans and elevations
    d) Amount of material
2. While developing a steel schedule, the site engineer left out one crucial detail necessary. Which one of the following is it?
    a) Color of reinforcement
    b) Location of reinforcement
    c) Dimensions of structure
    d) Height of the structure
3. Define the term Structural drawings
4. State three types of construction drawings
5. Discuss in detail the steps taken in project identification

Oral Assessment

Why is it necessary to master the art of interpreting structural drawings?

Practical Assessment

Get construction drawings of a given structure and point out the different structural element present and come up with a steel schedule for the reinforcement

4.3.5.4 Tools, Equipment, Supplies and Materials

- Computers
- Office equipment
- Calculators
- Scale rule
- Computer software
- Design codes (British standards)
- Stationery
- Standard design manuals
- Dust coat
- First aid kit

4.3.2.5 References

McCormac. (2007). Structural Steel Design. Prentice Hall, 4th edition. ISBN:013221816X
Segui (2006). Steel Design. Cengage-Engineering, 4th edition. ISBN: 0495244716

4.3.6 Learning Outcome No 5: Apply and use Structural Drawings

4.3.6.1 Learning Activities

Learning Outcome No 5: Apply and use Structural Drawings	
Learning Activities	**Special Instructions**
5.1 Identify and obtain construction resources 5.2 Gather statutory documents 5.3 Determine setting out activities 5.4 Establish foundation 5.5 Prepare structural members 5.6 Develop and adhere to working drawing, steel schedules and materials schedules	• Demonstration by trainer • Practical work by trainee • Demonstration videos • Projects • Group discussions

4.3.6.2 Information Sheet No5/ L05 Apply and use structural drawings

Introduction to learning outcome

This learning outcome covers Interpretation of drawings, Statutory requirements, Foundation engineering, Preparation of structural elements and Development of working drawing, steel schedules and materials schedules

Definition of key terms

Statutory documents: This refers to documents with instructions or requirements which are applicable by virtue of law enacted by the government.

Steel schedules: This is a list that explains the location, mark, type, size, length and number of each steel bar in a Reinforcement Drawing of a Structure.

Content/Procedures/Methods/Illustrations

5.1 Identify and obtain construction resources as per the tender documents

Construction resources – this is basically the materials and personnel necessary for the construction process from start to finish.

Construction resources include;

a) **Time –** Time as a resource in construction is very sensitive since most construction projects are working under a certain time frame requested by the client. The fact that some construction works such as concrete works which require *curing time* makes the resource of time quite valuable.

b) **Materials –** Construction materials are a great resource since they sum up the ingredients necessary to have a finished structural work. These include but are not limited to building blocks, cement, sand, water, ballast etc.
c) **Labour –** this includes human personnel, from the manual worker to the construction experts such as engineers.
d) **Plant and Machinery –** These are necessary in order to have some finished products such as concrete which requires a *concrete mixer*.
e) **Health and safety equipment** – This is whereby we have guard rails at the edge of high-rise buildings under construction, the use of bright coloured tape surrounding shafts, presence of fire extinguishers on site and health and safety training for all personnel.
f) **Technology** – technology such as a crane which is necessary for lifting heavy construction materials such as steel, scaffolding, shuttering, buckets of concrete etc.
g) **Works Requirement –** This comprises of the working drawings and specifications required for the construction project.
h) **Construction site** – This is the very place where the proposed structure is to be constructed.

5.2 Gather statutory documents as per the project requirements

Statutory documents

This refers to documents with instructions or requirements which are applicable by virtue of law enacted by the government. Almost every proposed development project has statutory obligations that do not arise out of the contract, but are imposed by law. These obligations are applicable to the design, construction and operation of buildings and will depend on the specific nature of the proposed development.

Statutory documents are required for the following areas when drafting construction contracts:

Labour

- The Employment Act 2007
- The Labour Institutions Act
- The Labour Relations Act

Tax

- The Income Tax Act

All workers in any construction project must be subject to the payment of income tax

Health and Safety

- Occupational Safety and Health Act 2007 (OSHA)
- Work Injury Benefit Act, 2007

Environment and Pollution

- Environmental Management and Coordination Act

Noise

- Legal Notice No.61 (NEMA)

Traffic

- The Road Traffic Act

Building

- Building Regulations

Planning

- The Urban Planning Act

Public Procurement

- The Social Value Act

Products and Services

- The Supply of Goods and Services Act

5.3 Determine setting out activities according to the approved drawings and standard construction processes

Setting Out – the act of establishing the location points of site boundaries, columns, foundations, center-lines of walls and any other necessary structural part.

Types of Setting Out

- **3-4-5 method**
  Used especially in setting out right angles from certain points on the base line.
- **Rope method**
  The rope method is used in setting out a perpendicular line in reference to the base line, beginning from a point which is not on the base line.
- **Single and Double Prismatic Square**
  This is used in setting out both right angles and perpendicular lines.

The methods of setting out listed above are used in conjunction with the total station, prisms, etc.

Steps undertaken in Setting out a building

- Clearing the site
- Obtain the working drawing of the proposed building
- Ensure that the materials for construction are ready
- A parallel line is then established
- The 3-4-5 setting out method is then used for setting out
- Profiles are then established
- The points of excavation on the profiled are nailed
- The points of the column on the profile are then nailed.

5.4 Establish foundation as per the working drawings and standard construction procedures

Factors to be considered when establishing the foundation

- Excavation depth and volume
- Soil bearing capacity
- Base area of foundation
- Proximity to property lines

5.5 Prepare structural members in accordance with the working drawings

Structural Members

These are simple structural elements that when viewed or put together, make up the structural body in a drawing

Structural members include;

- **Columns** – these are vertical elements that carry loads from slabs and beams.
- **Beams** – these are horizontal elements that carry loads from slabs and sometimes walls
- **Slab** – these is a horizontal element that covers a described portion in the x-plane and carries both fixed and static loads depending on the use of the structure
- **Stairs** – are structural elements that are in the z-plane. They can be diagonal or vertical in the y-plane and are horizontal in the x-plane.
- **Walls** – These are vertical elements constructed using masonry and can carry loads.
- **Foundations** – this is a substructure element that transfers the loads of the superstructure to ground

5.6 Develop and adhere to working drawing, steel schedules and materials schedules according to standard construction processes

Factors to be considered in developing Working Drawing

- Internal forces – Moment and Shear (ULS – Ultimate limit state)
- Safety Checks on deflection, cracking, corrosion and fire resistance
- Loads – dead loads and imposed loads
- Partial Safety factors – On dead loads a partial safety of 40% ($1.4G_k$) and a partial safety factor of 60% on imposed loads ($1.6Q_k$)
- Moment distribution

Factors to be considered when developing a Steel Schedule

- Location of reinforcement
- Mark of reinforcement
- Type of reinforcement
- Size of reinforcement – diameter of steel
- Length of reinforcement

Factors to be considered when developing a Materials Schedule

- Type of material
- Amount of material

Conclusion

This learning outcome covered interpretation of drawings, statutory requirements, foundation engineering, preparation of structural elements and development of working drawing, steel schedules and materials schedules.

Further Reading

Read further on statutory documents necessary for construction works in Kenya.

4.3.6.3 Self-Assessment

Written Assessment

1. Sophia is a student undertaking a diploma course in civil engineering. While arranging a bookshelf at her home, she came across structural drawings to their proposed new home in Ruai. Which of the following was not a structural member in the drawings?
   a) Columns
   b) Beams
   c) Slab
   d) Steel reinforcement
2. Victor a recently graduate civil engineer was asked to come up with a steel schedule back at work. Which of the following is not a factor he should consider while developing the steel schedule?
   a) Location of reinforcement
   b) Size of reinforcement
   c) Color of reinforcement
   d) Length of reinforcement
3. In an interview for a civil engineering job, an interviewee was asked to state the steps undertaken when setting out a building. Which of the following should have been his first step?
   a) Establishing the profile
   b) Using the 3-4-5 method to set out
   c) Clearing the site
   d) Establishing a parallel line
4. State construction resources necessary for the construction process
5. State 5 factors to be considered when developing a working drawing
6. Using examples, define statutory documents
7. Discuss the significance of partial safety factors on loads and materials

Performance Based Evidence

Oral Assessment

What are the factors considered when selecting concrete cover?

Practical Assessment

Given a 4 by 5 two-way spanning solid slab, with the aid of a structural drawing, develop a steel schedule for the slab.

4.3.6.4 Tools, Equipment, Supplies and Materials

- Computers
- Office equipment
- Calculators
- Scale rule
- Computer software
- Design codes (British standards)
- Stationery
- Standard design manuals
- Dust coat
- First aid kit

4.3.6.5 References

McCormac. (2007). Structural Steel Design. Prentice Hall, 4th edition. ISBN:013221816X

Segui (2006). Steel Design. Cengage-Engineering, 4th edition. ISBN: 0495244716

CHAPTER 5: CONSTRUCTION MATERIAL SCIENCE

5.1 Introduction

This unit describes the competence in applying building materials science. It involves identifying essential construction materials, selecting quality construction materials, testing construction materials and demonstrating knowledge in use of construction materials.

5.2 Performance Standard

Identify essential construction materials, identify properties of construction materials, manufacture construction materials, and select quality construction materials, use construction materials, test construction materials and handle construction materials safely based on construction requirements and project scope.

5.3 Learning Outcomes

5.3.1 List of Learning Outcomes

a) Identify essential construction materials
b) Identify the properties of construction materials
c) Manufacture construction materials
d) Select quality construction materials
e) Use construction materials appropriately
f) Test construction materials
g) Handle construction materials safely

5.3.2 Learning Outcome No 1: Identifying Essential Construction Materials

5.3.2.1 Learning Activities

Learning Outcome No 1: Identifying Essential Construction Materials	
Learning Activities	**Special Instructions**
1.1. Obtain and interpret Bills of Quantities and working drawings 1.2. Identify essential construction materials (stones, bricks, clay and clay products, lime, cement, timber and timber products, metals and alloys, paints and varnishes and roofing materials)	Visit construction sites. Conduct practical lessons.

5.3.2.2 Information Sheet No5/LO1: Identifying Essential Construction Materials

Introduction

This learning outcome covers engineering drawings interpretation, bills of quantities and construction materials.

Definition of key terms

Bill of Quantities: This is a document typically prepared by the quantity surveyor that provides a project's specified measured quantities of the items of work in accordance with the drawings and specifications in the tender documentation. Also referred to as BOQs or BQ.

Drawings: These are visual representations of structures or objects which provide dimensional and graphical information that can be used by a contractor in construction works or suppliers to fabricate components of the work.

Specifications: They describe the specific materials and level of workmanship required i.e. by compliance with manufacturers' requirements.

Construction material: This refers to any material used for construction purposes.

Content/Procedures/Methods/Illustrations

1.1. Bills of Quantities and working drawings are obtained and interpreted

Bills of Quantities list all the materials required to complete the design for a construction project of any structure. The BQs assist tenderers in the calculation of the construction cost of their tender. The quantities may be measured in number, length, area, volume, weight or time.

How to prepare Bills of Quantity (BQs)

Preparing a Bill of Quantity requires that the design is complete and a specification has been prepared.

A standard method of measurement (SMM) is a reference document used to determine the localized technique of construction measurement procedure needed to produce a valid and good Bill of Quantity which is then incorporated into the contract document for the project. Preparing a BQ based on SMM will help a contractor price the tender in a realistic way. A standard method of measurement is reflective of actual works.

Set up a spreadsheet for the BQ (bill of quantity)

This includes columns to fill the item number, the rate for the item and total cost for the item.

Table 5: Bill of Quantity

Item No	Description	Unit	Quantity	Rate	Total Cost

The columns on the rate and total cost will be filled in by the contractor or binding on the project. Technically you won't have any values in those columns while drafting your BQ

List all the materials needed to complete the project

From the architect's plan, write a list of the building materials required and the amounts needed for each. The architect can also specify the type of materials recommended for the project. For example, when building a residential house, one might need bricks, concrete, flooring materials etc. It is important to identify the unit of measurement for each of the materials. Once you have determined the materials needed, fill your spreadsheet i.e,

Table 6: Materials needed to complete a project

Item no	Description	Unit	Quantity	Rate	Total cost
A	**Excavations** Clear the site of all shrubs and undergrowth	S.M.	249	50	
B	Excavate vegetable soil average 150mm deep	S.M.	249	100	

Categorize the project into specific sections.

Since different parts of the project will be handled by different subcontractors, it is good to split the list into sections. This makes it easier for the contractors or subcontractors to know exactly what their cost will be for the project.

Make an initial cost estimate based on the architect's design

The standard method of measurement provides the prices of materials and labour required. Summing up all these cost estimates gives a rough idea of the project cost even before it starts. Materials suppliers, on the other hand, give different costs during the bidding. Comparing bids from contractors ensure that one gets the best bid for their project.

Table 7: Initial cost estimate

Item No	Description
A	Element No 1
	Substructures
B	Excavations
A	Element No 2
	Superstructure
B	Reinforced concrete

Example: Proposed residential house

Table 8: Bill of Quantities

Item	Description	Unit	Quantity	Rate	Total cost
	Element No 3 **Internal Finishes** **FLOORS** Cement and sand (1: 4) screeding smooth trowelled				
A	32mm thick sand cement screed prepared to floor	SM	120	300	36,000.00
B	32mm thick screed prepared to receive ceramic tiles	SM	120		66,000.00
	TOTAL FOR ELEMENT NO 8 **(CARRIED TO SUMMARY)**				

Advantages of Bills of Quantities

- Assist tenderers in the calculation of construction costs for their tenders
- Provides a schedule of rates assisting with the valuation of variations s
- Helps in valuing interim payments or the labourers
- For tenderers, it helps to create a low-risk and low-cost tendering environment

Working Drawings

These are construction drawings provided by the architect, to the contractor to facilitate construction of works, or given to suppliers to fabricate components of the works.

Working drawings describe plans, sections, and elevation.

Types of Construction Drawings

- **Architectural drawings:** These demonstrate where the building will be located and where all the building parts will be placed provided by the architect to the contractor on site
- **Structural drawings:** They are drawings Prepared by the structural engineer showing information about the structure, like the strength of different structural elements, size and placement of reinforcement
- **Electrical drawings**: These are prepared by the electrical engineer showing details and location of electrical wiring, fixtures, sub-station etc
- **Plumbing and Sanitary drawings**: Prepared by the services engineer, they show location of sanitary, piping for water supply systems, fixtures and process to connect every fixture.

Essential construction materials

Building /construction materials refer to any substance either natural or manmade which is used for construction purposes to create structures and buildings.

Some of the most building materials include;

a) **Stone**

It is the most commonly used material in Kenya.

There are two types of stones;

- Manually cut stones

b) **Fired bricks**

Commonly used for constructing walls and also arches, as a substitute to stone. How bricks are made-clay is compressed to form blocks. It is then left to dry in the air. After drying, they are burnt or fired in a kiln to permanently harden them.

c) **Metal**

Steel is the most popular metal used in the structural framework of buildings. It is preferred in construction because it is strong, flexible and long-lasting. Other metals used are aluminium and copper because of their rust and corrosion resistance. Copper is used for electric wires, piping for water supply etc. Aluminium is used as roofing sheets, gutters, decorations etc.

d) **Sand**

Used together with cement to make mortar, or masonry work and plaster.

e) **Cement**

Cement is mixed with sand and gravel aggregates to form concrete, used in building floors, roads, bridges etc.

- It is the most essential building material.
- It is used in masonry work as an adhesive to hold bricks, blocks and stones in place.
- It is also used in plastering

f) **Wood**

Wood is used mostly in flooring, panelling and finishes. It is also popularly used in the construction of roofs (trusses), doors etc

g) **Roofing tiles**

Most commonly known as clay tiles**,** they are durable and good in harvesting rainwater. The tiles are thin flat slabs of fired clay, concrete, cement or metal laid in rows to form a cover. Other types of construction materials include; glass, bamboo, EPs panels, glazed ceramic tiles etc.

The choice of building materials to be used in construction is determined by the following factors;

- Availability
- Cost
- Durability

Conclusion

The learning outcome covered engineering drawings interpretation, bills of quantities and construction materials.

Further Reading

1. Read more on building materials in modern industry from building material (2002) by SK Nugget.

5.3.2.3 Self-Assessment

Written Assessment

1. What is the purpose of a working drawing?
    a) To convert a design into construction information and communicate to different players in construction.
    b) Present to the client for presentation works
2. Which material among the following is preferred as a load-bearing?
    a) Fired bricks
    b) Glass
    c) Manually cut stones
3. Cement is mixed with gravel and sand aggregates to form?
    a) Concrete
    b) Tiles
    c) Blocks
4. What is the role of an architect in relation to identification of materials?
    a) Provide a Bill of Quantities
    b) Generate construction drawings which will be used by the contractor

5. Which of the following is not a virtual building material?
    a) Images
    b) Text
    c) Wood
6. Is finishing drawing also a type of working drawing?
    a) Yes
    b) No
7. Which of the following is not a roofing material
    a) Clay tiles
    b) Aluminium sheets
    c) Cement
8. Describe the difference between presentation drawings and working drawings?
9. Justify the roles of a quantity surveyor in relation to Material identification.
10. Using relevant examples, construct five types of working drawings
11. Steel is a preferred metal in construction. Justify.
12. Mention and explain 5 popular building materials in modern industry

Oral Assessment

1. Summarize the properties of building stone as a Building material.
2. Mr Waweru wants to construct a two bed room house. As an architecture, you have been contracted to oversee the project and advice. Prepare a list of the materials he is likely to use and justify the reasons.

Practical Assessment

Generate a complete Bill of Quantities from the information provided by the lecturer
Use the standard method of measurement (SMM) as a reference document

5.3.2.4 Tools, Equipment, Supplies and Materials

- Computer
- Labouratory testing equipment
- Labouratory apparatus
- Hand tools
- Machine tools

5.3.2.5 References

S.K. Duggal (2000). Building Material, New York: New International Publishers

The federation of civil engineering contractors (2015) Civil Engineering Standard Method of Measurement: ICE Virtual Library

The constructor (2009), Building Technology Guide. Nairobi: New International Publishers

5.3.3 Learning Outcome No 2: Identifying Properties of Construction Materials

5.3.3.1 Learning Activities

Learning Outcome No 2: Identifying Properties of Construction Materials	
Learning Activities	**Special Instructions**
2.1. Identify physical properties (porosity, surface texture, strength, density, thermal conductivity and wear and tear) of construction materials 2.2. Identify chemical properties (corrosion resistance and chemical resistance) of construction materials 2.3. Identify mechanical properties (toughness, hardness, fatigue, strain and stress and creep and stress rupture) of construction materials	• Demonstration • Practical assessment • Direct instruction

5.3.3.2 Information Sheet No5/LO2: Identifying Properties of Construction Materials

Introduction

This learning outcome covers physical properties of construction materials, chemical properties of construction materials, mechanical properties of construction materials engineering drawings interpretation, bills of quantities and construction materials.

Definition of key terms

Code of practice: It is a document containing guidelines on how professionals in a specific industry are supposed to conduct themselves in different situations when they appear as consultants.

Chemical properties: It is any material’s character that showcases itself during or after its interaction with the environment or other materials.

Mechanical properties: These are physical properties that construction materials exhibit when forces (tension, compression and shear forces) are applied in different ways. Some of these include tensile strength, elongation, fatigue limit and hardness.

Physical properties: These refer to physical attributes of materials that can be measured or observed without changing the composition of materials. They include porosity/permeability, surface, density, thermal conductivity and wear and tear.

Building code: This refers to a document created/drafted by a government to control or act as a standard for which all activities and specifications within the industry have to be met.

Content/Procedures/Methods/Illustrations

2.1 Physical properties of construction materials

Porosity

It is the measure of void spaces within the composition of a material and forms the basis of telling how permeable material is (permeable-ease with which fluids percolate through the voids of a material). It majorly affects materials such a masonry blocks and bricks among others. It can be determined by checking the weight change of a material after it has been submerged in water for a specific period of time by a structural engineer or experienced masons. It affects the choice of the place where the material will be used whether indoors or as an external material.

Surface texture

- It refers to the overall appearance of a material in its natural form and varies from smooth to rough.
- It is necessary as it influences additional activities that are required for it to perform its intended purpose and appearance.
- It is mostly decided by the client and architect based on the desired appearance.
- Its value is internationally determined but also subject to local trading laws and desired profit margins by manufacturers.

Strength

- It refers to the ability of a material to bear an applied force without failure or deformation.
- The desired strength of building material is determined by a structural engineer before construction during the design stage when calculating the loading.
- It majorly affects loads bearing materials like columns and beams (concrete and steel reinforcement) among others.
- It's the measure that determines structural soundness.
- It's determined by calculating comprehensive strength.

An important strength calculation in buildings is that of steel and it's done through the formula

$$Compressive\ strength = Force \div Area.$$

$$CS = F \div A$$

Density

It refers to the mass per unit volume of a material. Knowledge of density is important as it provides necessary information for the distribution of loads for structural purposes.
It's calculated by the formula.

$$Density = \ Mass\ \div Volume$$

It's mostly relevant to the structural engineer.

2.2 Chemical properties of construction materials

Corrosion resistance

Corrosion refers to a process through which metallic materials change into more stable compound namely oxides, sulfides and hydroxides in a natural gradual destruction process due to exposure to elements. Corrosion-resistance refers to how well a material can withstand damage from exposure to elements such as moisture and wind. It's determined by carrying out experiments in controlled environments by manufacturers. It majorly affects reinforcement window and door frames and roofing materials.

Chemical resistance

It refers to the strength of a material to withstand changes from interaction with other chemicals or solvents. It majorly affects the choice of paints and construction adhesives. It's measured and rated by manufactures with consideration made to the ISO standards. It is necessary as it aims products that have zero to minimal effect on the people using the spaces the materials are used. This is rather important when choosing materials for internal finishes as use of toxic substances cannot be allowed in (reader's digest, 2020) (reader's digest, 2020)living spaces. This is rather important when choosing materials for internal finishes as toxic substances cannot be allowed in living spaces.

2.3 Mechanical properties of construction materials

Toughness:

It refers to a material strength to understand adverse conditions or rough handling.
It is necessary as fragile materials are handled with care while tough ones can even be left exposed to the elements. The degree of toughness also affects the location and mode of storage as well as when they would be ordered, purchased and delivered on-site. Manufactures normally outline their materials degree of toughness and how to install and handle them. It's necessary as it enables professionals to avoid loses due to poor handling and installation.

Hardness

It refers to the comparative resistance of a mineral to scratching or the ability of a material to resist deformation, indentation or penetration by means such an abrasion, drilling, impact and wear measure in Mohs hardness scale. It's important as it affects the workability of materials.

Fatigue

It refers to the weakening of material in a progressive and localized manner caused by repeating application of load. In structures, damage occurs when the materials experienced stress range is considerably higher than material rating. It is calculated by manufactures who then produce products with different ranges. On-site cracking of members shows that there is fatigue.

Strain, stress, creep and stress rupture

These are forces that affect materials.

- **Strain:** Occurs as a result of tensional forces along the long axis.
- **Stress**: It refers to force per unit area that a material experiences which can be tensile or compressive majorly external forces.
- **Creep**: Refers to the tendency of a solid material to slowly change in position or deform when exposed to long term forces.
- **Stress rapture:** Its sudden and complete failure of a material under stress.

The impact of forces on materials is carried out by manufacturers and structural engineers refer to their standards in designing. As the spectrum of ranges is rather varied it is necessary to conform to standards.

Conclusion

This learning outcome covered physical properties of construction materials, chemical properties of construction materials, mechanical properties of construction materials engineering drawings interpretation, bills of quantities and construction materials.

Further Reading

From the internet read more on:

1. Properties of manufactured products/ engineered materials
2. Special materials such as rubber.
3. ISO standards

5.3.3.3 Self-Assessment

Written Assessment

1. Which of the followings, not a construction material property?
    a) Surface texture
    b) Density
    c) Corrosion
    d) Hardness
2. Which of the following properties is necessary when choosing a waterproof material?
    a) Density
    b) Surface texture
    c) Fatigue
    d) Hardness
3. Which of the below is not a physical construction material property.
    a) Thermal conductivity
    b) Wear and tear
    c) Strength
    d) Corrosion resistance
4. When a material undergoes permanent deformation, we say it has undergone? I.e. (over a long period of time gradually)
    a) Stress
    b) Creep
    c) Strain
    d) Stretch
5. Who is in charge of calculating the strength of building materials?
    a) Construction manager
    b) Structural engineer
    c) Client
    d) Architect
6. Why is calculating of forces necessary?
    a) To avoid fatigue
    b) To cut on cost
    c) To enhance the construction rate
    d) To produce quality.
7. What does porosity affect?
    a) Permeability
    b) Toughness
    c) Fatigue
    d) Hardness

8. Analyse permeability in reference to selection of Building materials.
9. Name two factors that affect the strength of building materials.
10. Summarise chemical properties that affect strength of materials during construction.
11. The mechanical properties of materials affect the strength of the material. As an architect, justify.
12. Evaluate ways in which the toughness of a material affects its handling and storage?

Oral assessment

1. John has been advised to buy bricks to build a 5-storey building. Compose a report outlining the advantages and physical properties of Brick.
2. State two mechanical properties of materials.

Practical Assessment

With reference to this learning outcome, carry out a project within a period of a weeks. Collect 5 samples of building materials and produce a properties document for presentation.

5.3.3.4 Tools, Equipment, Supplies and Materials

- Calculators.
- A computer for research/ smartphones

5.3.3.5 References

Adam, S., Ogier, J. M., Cariou, C., Mullot, R., Labiche, J., & Gardes, J. (2000). Symbol and character recognition: Application to engineering drawings. International Journal on Document Analysis and Recognition, 3(2), 89-101.

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Pacheco-Torgal, F., Jalali, S., & Fucci, A. (Eds.). (2012). Toxicity of building materials. Elsevier.

5.3.4 Learning Outcome No 3: Manufacturing Construction materials
5.3.4.1 Learning Activities

Learning Outcome No 3: Manufacturing construction materials	
Learning Activities	**Special Instructions**
3.1. Identify raw materials 3.2. Manufacture construction materials	• Demonstration • Use of charts • Field trips

5.3.2.2 Information Sheet No5/LO3: Manufacturing construction materials

Introduction

This learning outcome covers identifying raw materials based on construction materials to be produced and manufacturing construction materials as per manufacturing procedures.

Definition of key terms

Raw materials: Raw materials are substances or materials used in the initial manufacturing and production of materials.

Concrete: It is a material comprising a mixture of aggregate and cement or asphalt.

Content/Procedures/Methods/Illustrations

3.1. Raw materials are identified based on construction materials to be produced

There are three main types of construction materials in Kenya:

- **Cement:** Primary raw materials are limestone (supplies the lime in bulk) and clay, marl or shale (supplies the silica, alumina and ferric oxide in bulk). Other supplementary materials such as fly ash / pulverised fuel ash (PFA), sand or ironstone to achieve the desired bulk.
- **Brick:** The raw material is clay.
- **Concrete**: The raw materials are fine and coarse aggregate, water and cement.

3.2 Construction materials are manufactured as per manufacturing procedures

Cement: Cement manufacturing is a complex procedure that begins with mining and grinding raw materials which include clay and limestone, to a fine powder known as raw meal, which is then heated to a sintering temperature as high as 1450^0c in a cement kiln. In this process, the chemical bonds of the raw materials are broken down and recombined into new compounds which are known as clinker, which are rounded nodules between 1mm and 2.5mm across. Clinker is ground to a fine powder in a cement mill and mixed with gypsum to create cement. The powdered cement is then mixed in water and aggregates to form the concrete that is used in construction.

Clinker quality depends on raw materials composition, which has to be closely monitored to ensure cement quality.

Concrete

The main concrete manufacturing process is as follows

- Batching
- Mixing
- Transporting
- Placing
- Compacting
- Curing

Batching: This is a major stage in the manufacturing of concrete. There is a measuring of materials (raw materials) such as aggregates, cement and water necessary for the preparation of different grades.

There are two processes:

- The volume batching is by mixing volume of the materials.
- The weight batching is by mixing materials with its volume. it has a ratio according to standard codes such as M10, M20, M25, and M30 for concrete

Mixing: This is done to produce high quality and uniform concrete. Separate paste mix shows the mixing of water and cement into a paste then combines with aggregates. This increase the compressive strength of concrete. This mix of paste in shear-type mixer is at high speed with 0.30 to 0.45 water-cement ratio. Aggregates are blended with premix paste. The remaining batch final and water mix complete in a rotating concrete mixing equipment.

Transporting - After mixing, it should be transported on the site with great care. The concrete transporting by trucks reach the construction site early and are more efficient.

Placing: In a good manner without segregation to reach maximum efficiency. The height depends on the separation of cement paste and aggregates; the higher the height the more probability of separation. Segregation of concrete causes honeycomb.
Compacting: Is the process which expels air trapped from freshly placed concrete and packs the particles together to increase the density of the concrete.

Curing: This is done to provide the best hardness and strength to concrete which helps the concrete to gain strength. It prevents cracking at the surface and avoids freezing and overheating of concrete.

Flow chart for manufacturing concrete

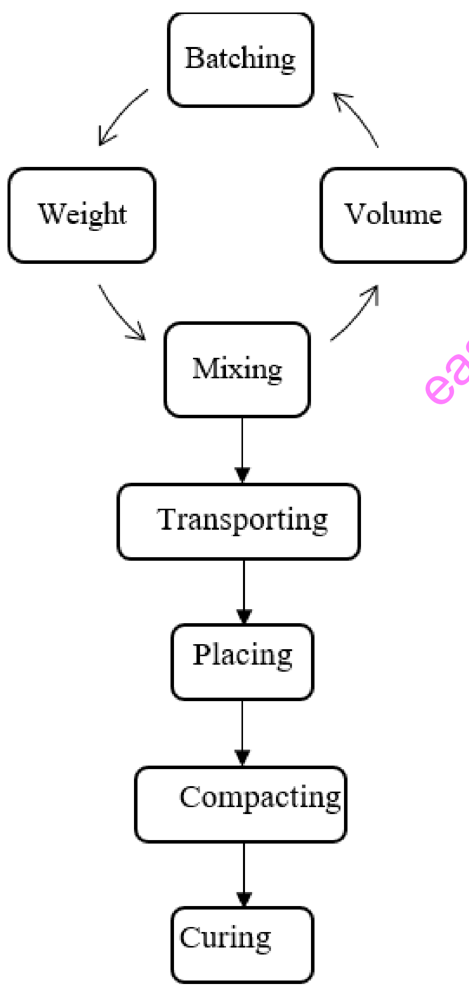

Figure 75: Flow chart for manufacturing concrete

Brick

There are four main different operations are involved.

- Preparation of clay
- Moulding
- Drying
- Burning

a) Preparation of clay

It is done in six steps:

i. **Unfailing of clay-** Pure clay is needed, the top layer of soil contains impurities, therefore, 200mm depth of clay is thrown away

ii. **Digging**- Clay is dug out from the ground and spread on the plain ground

iii. **Cleaning**- is the removal of stones and vegetable matter, then it is washed and cleaned.

iv. **Weathering-** The clean clay is exposed to the atmosphere for softening. The period maybe 3-4 weeks.

v. **Blending**- Addition of any ingredient to the clay by making the clay loose and spreading the ingredients over it.

vi. **Tempering**- Addition of water to clay and mixing or pressing. The pressing is done by cattle or men according to the scale of the project.

b) Moulding of clay

The prepared clay is moulded into a brick shape. It can be done in two ways (according to the scale of the project)

- Hand moulding for small scale
- Machine moulding for large scale

c) Drying of raw bricks

It is done otherwise they may be cracked while burning. The process is done naturally. Therefore, it is to remove moisture from the bricks.

d) Burning of brick

The dried bricks are burned either in kilns (for large scale) or clamps (for small scale) up to a certain temperature. The required temperature required for burning is about 1100^0c. this stage, the bricks gain hardness and strength as require.

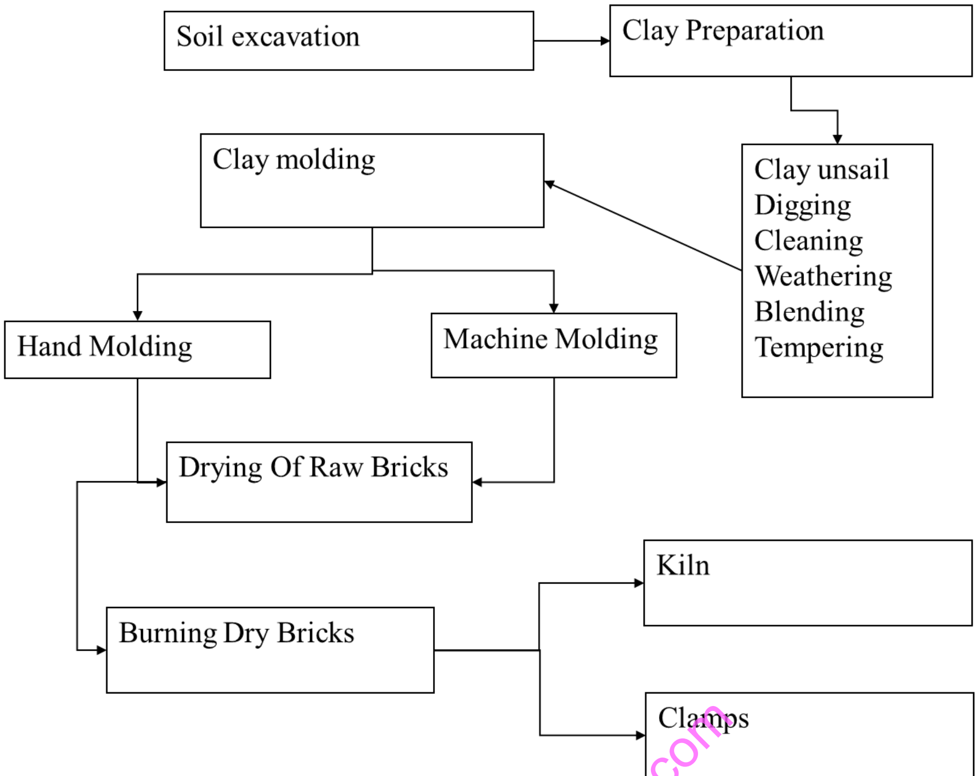

Figure 76: Flowchart for manufacturing brick

Conclusion

The learning outcome covered identifying raw materials based on construction materials to be produced and manufacturing construction materials as per manufacturing procedures.

Further Reading

1. Building Materials by S.S Bhavikatti
2. Building Materials by S.K Duggal
3. Fundamentals of Building Construction by Edward Allen

5.3.4.3 Self-Assessment

Written Assessment

1. Which process stage is not in the manufacturing of concrete?
   a) Compacting
   b) Burning
   c) Batching
   d) Curing

2. How many degrees are needed in burning during the manufacturing of bricks?
    a) $1100^{0}c$
    b) $1500^{0}c$
    c) $650^{0}c$
    d) $900^{0}c$
3. Which is the supplementary material information of cement?
    a) Water
    b) Clay
    c) Limestone
    d) Fly ash
4. Which batching ratio is not according to standard code?
    a) M10
    b) M25
    c) M40
    d) M30
5. What is the purpose of compacting in concrete manufacturing?
    a) To remove impurities for the concrete
    b) To strength the concrete
    c) To make the concrete durable
    d) To remove entrapped air from the concrete
6. Which one is not a stage in preparation of clay?
    a) Digging
    b) Moulding
    c) Weathering
    d) Blending
7. What determines the type of moulding will be done?
    a) The scale of the project
    b) The number of raw materials
    c) Time of the year
    d) The workmanship of the workers
8. Demonstrate batching of different types of materials.
9. Briefly discuss the main stages in concrete manufacturing.

Oral Assessment

1. Demonstrate the process of manufacturing of bricks?
2. Identify the raw materials used in cement, concrete and brick respectively?
3. Outline the procedure for preparing concrete

Practical Assessment

In groups of five with the aid of teacher bake ten bricks in the school workshop.

5.3.4.4 Tools, Equipment, Supplies and Materials

- Computer
- Labouratory testing equipment
- Labouratory apparatus
- Hand tools
- Machine tools

5.3.4.5 References

Cachim, P. B. (2009). Mechanical properties of brick aggregate concrete. Construction and Building Materials, 23(3), 1292-1297.

Rajgor, M., & Pitroda, J. (2013). Stone Sludge: Economical solution for the manufacturing of bricks. International journal of innovative technology and exploring engineering, 2(5), 16-20.

Roberts, L. R., & Taylor, P. C. (2007). Understanding cement-SCM-admixture interaction issues. Concrete International, 29(1), 33-41.

5.3.5 Learning Outcome No 4: Selecting Quality Construction Materials

5.3.5.1 Learning Activities

Learning Outcome No 4: Selecting Quality Construction Materials	
Learning Activities	**Special Instructions**
4.1. Evaluate and analyse cost implications of construction materials 4.2. Select quality construction materials	• Written tests • Oral • Practical tests/Project

5.3.5.2 Information Sheet No4/LO4: Selecting Quality Construction Materials

Introduction

This learning outcome covers evaluating and analysing cost implications of construction materials and selecting quality construction materials based on their costs and project requirements.

Definition of key terms

Cost implications: This refers to the technique used to derive the duration, cost and energy required to manufacture and maintain construction materials.

Quality of construction material: This is the stability, durability and cost-efficiency of construction material.

Content/Procedures/Methods/Illustrations

4.1. Cost implications of construction materials are evaluated and analysed

The cost implication of construction materials involves analysis of time, money and energy required to efficiently produce and maintain building materials. Currently, the construction industry is one of the fastest-growing sectors of any economy, be it in developed countries or developing ones. The urge to deliver the best product output in terms of a well-designed building project, which is able to satisfy the client's needs and ultimate users cannot be emphasized (Safiki. A, Solikim. M, Nursahid. M, 2015). This can also be expressed by the value of money i.e. having to incur costs that cannot be dealt with. It is essential to calculate the most likely cost of a project to check if the project will be able to start and finally be successful. As an architect, you have to balance the need to maintain adequate internal control of a project while still constraining the construction budget. This is done to satisfy the needs of the client according to his/her budget. To do this, an effective control system is vital to making sure that long- term investment goals are achievable.

There are two types of cost implications that affect construction materials i.e. direct and indirect cost implications.

a) Direct cost implications

This focuses on how building strategies can affect the annual budget of a project. For instance, hiring additional casual labourers to a site to increase the rate of construction/manufacturing building materials might be too expensive for small firms/construction companies. Therefore, the number of casual labourers are decreased to increase the rate of affordability. This also improves, the quality of production improves due to efficiency in quality check.

b) Indirect cost implications

Efficiency in operations and productivity can be affected by the indirect cost of a project. For instance, managing manual cash in a site through verification of transactions e.g. purchase of steel, cement or stone; payment authorization from the lead consultant/contractor; and account reconciliation procedures between the parties. All these might lower efficiency resulting in wastage of time in production resulting in fewer products.

A change to the work or design as per the contract will incur additional charges that will, in turn, increase the cost of construction. This can occur through time lag between completion of designs and the time the project is to start depending on client's finance. As a result, friction between the client and contractor can result to cost overrun. If this is not solved, then the project might end up being abandoned. To control the variations in a project, the architect ensures that the variations are valid. I.e. they exist in writing, signed by the lead consultant, and finally submitted to registered offices for approval purposes.

4.2. Quality construction materials are selected based on their costs and project requirements

Materials will determine the aesthetics of your design or building. By ensuring high-quality materials, the level of workmanship is assumed to be of high quality. The factors that promote material and process selection include; the number of elements to be constructed, the size of elements, weight of the component and the precision required to satisfy the needs of the client. In terms of material, evaluation of material selection focuses on the ability of the material to be manufactured and processed into a finished structure. For instance, how easily can steel be cut on-site as compared to the manufacturing company?
Also, the sustainability of the products i.e. whether or not the materials manufactured can be reused for a different purpose as compared to what it is designed for. The quality of materials is determined by defect-free, the surface finish, dimensional accuracy and tolerance from external factors. From this, one can establish economic considerations which include, the cost to be considered, the quantity according to the volume of commodity and the rate of production of the commodity.

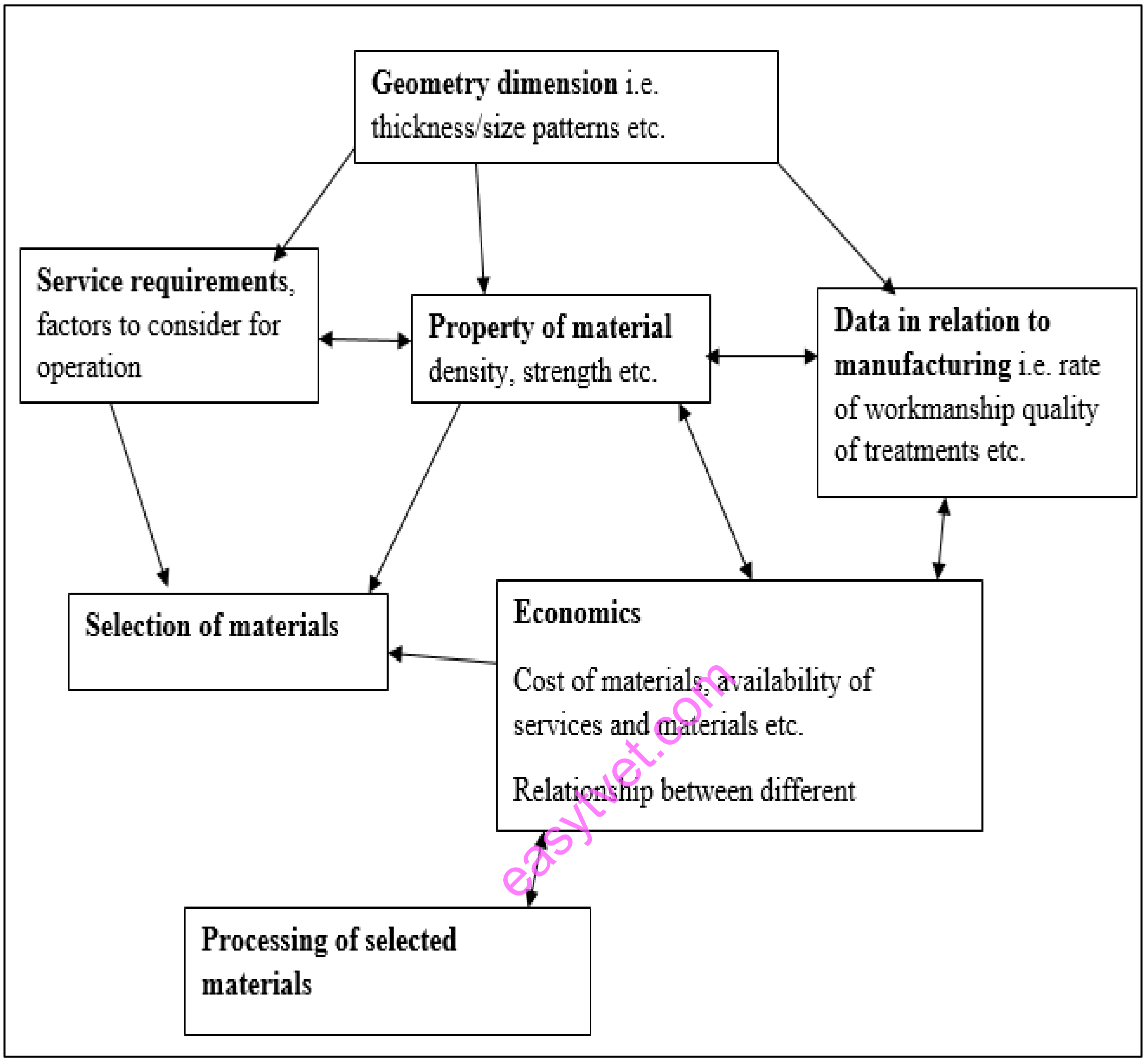

Figure 77: Quality construction materials selection

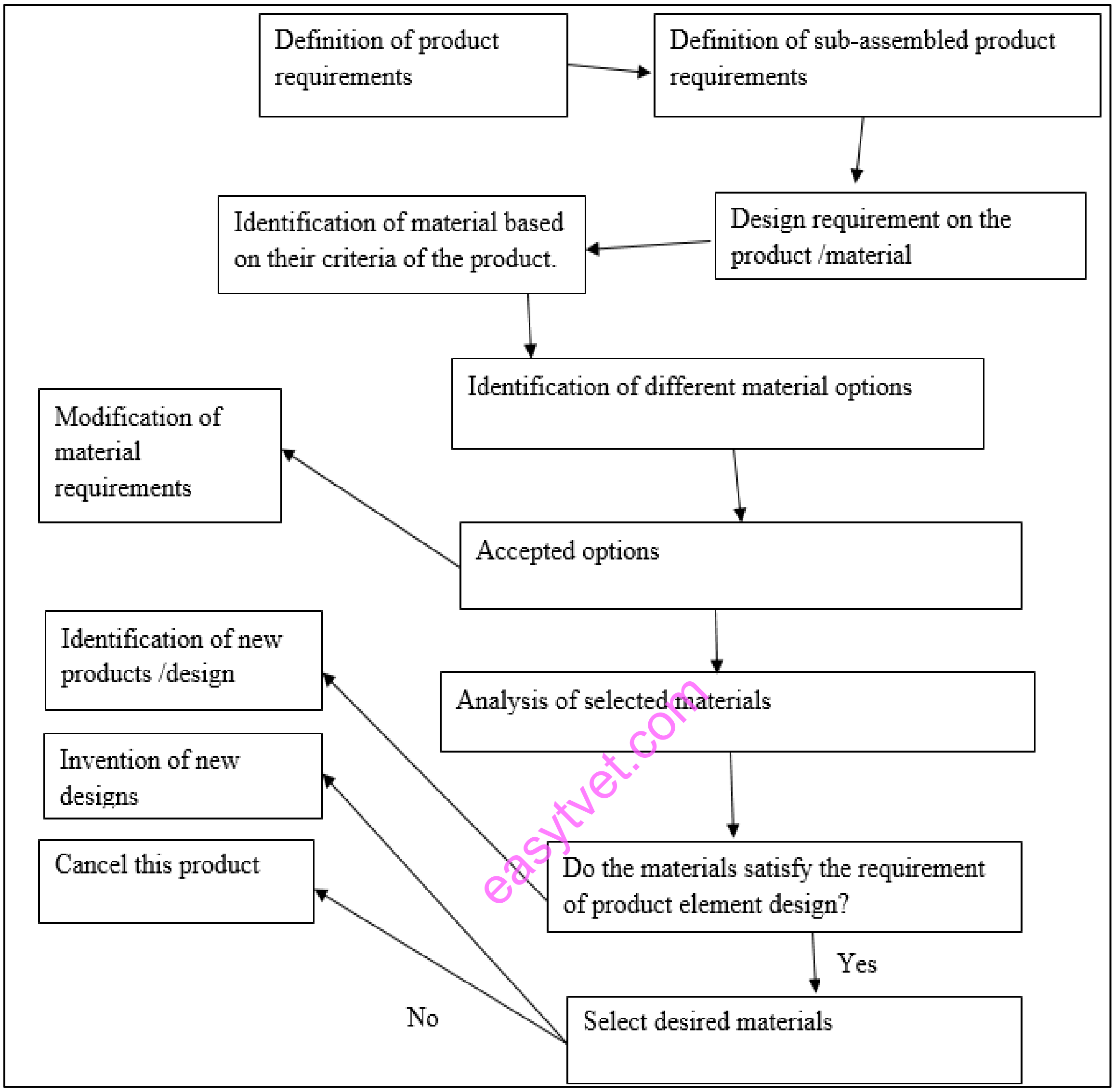

Figure 78**:** Process of material selection

Conclusion

The learning outcome covered evaluating and analyzing cost implications of construction materials and selecting quality construction materials based on their costs and project requirements.

Further Reading

1. Read further on cost implications and its effect on the built environment.
2. Read further on the selection of materials in relation to quality, availability and cost.

5.3.5.3 Self-Assessment

Written Assessment

1. Who of the following is in charge of ensuring variations are in the contract?
    a) Contractor
    b) Architect
    c) Clients
    d) Structural engineer
2. Why should cost implications be derived?
    a) To produce sustainable materials
    b) To derive solutions to construction
    c) To supply goods efficiency
    d) To efficiently connect pre-fabricated materials.
3. Which of the below is not a factor that promotes material and process selection?
    a) Size of materials
    b) Process of materials
    c) Weight of materials
    d) Number of materials
4. Identify the type of cost implication from the following?
    a) Cost implication variable
    b) Material cost implication
    c) Direct cost implication
    d) Serviceability cost implication
5. How can a building strategy affect the annual budget?
    a) Following the contract variable
    b) Addition of construction material
    c) Reduction of time for a project
    d) Employing additional casual labourers
6. Which activity is material selection in design associated with?
    a) Technical design
    b) Manufacturing
    c) The efficiency of the product
    d) Processing.
7. What factor describes the quality of the product?
    a) Availability
    b) Location of production
    c) Freedom from defects
    d) Ease of use

8. Justify the quality of construction materials used in building wood houses.
9. Evaluate freedom from defects?
10. Summarize the process of determining the quality of workmanship?
11. Briefly describe the process planning?
12. Justify material experience?

Oral Assessment

1. Propose the strategy will you use to ensure efficient cost analysis.
2. Evaluate material selection in reference to Construction.

Case study

Dunhill towers, Nairobi constructed a skyscraper using masonry concrete and steel. With references, produce a cost-benefit analysis and cost implications of the project.

5.3.5.4 Tools, Equipment, Supplies and Materials

- Computer
- Labouratory testing equipment
- Labouratory apparatus
- Hand tools
- Machine tools

5.3.5.5 References

Lotey .J. (2020). Cost Implications Of Internal Control. Retrieved From Https: // Small Business. Chron.Com/Cost-Implications-Internal-Control 81335.Html

Ruegg, R., & Marshall, H. (2013). Building Economics: Theory and Practice. Springer Science & Business Media.

Science Direct (2020). Material Selection Process. Retrieval from Htpp//Ww.Sciencedirect.Com/Topics Engineering/ Material Selection Process

5.3.6 Learning Outcome No 5: Using Construction Materials Appropriately

5.3.6.1 Learning Activities

Learning Outcome No 5: Using Construction Materials Appropriately	
Learning Activities	**Special Instructions**
5.1. Assemble construction materials, tools and equipment 5.2. Use Construction materials depending on the construction process	• Demonstration • Oral assessment • Written assessment

5.3.6.2 Information Sheet No4/LO5: Using Construction Materials Appropriately

Introduction

In this learning, outcome covers assembling construction materials, tools and equipment based on the construction method and using construction materials based on the construction process.

Definition of key terms

Construction tools: This is any manufactured product component or equipment that is used in the construction process

Construction equipment: This is a variety of heavy-duty vehicles, tools and machinery which are capable of withstanding the harsh conditions experienced throughout the construction site.

Construction methods: These are the procedures and techniques that are used during the building process.

Building: It is the relatively permanent enclosed construction over a plot of land, having roof, windows doors often have a different use such as living, entertainment, manufacturing or residential.

Content/Procedures/Methods/Illustrations

5.1. Construction materials, tools and equipment are assembled based on construction methods

In order to come up with a structurally strong building and completion of a construction project, appropriate use of materials is one of the key elements. Use of materials majorly determined by the use of the building which includes the following:

- Residential building
- Education
- Assembly
- Storage
- Infrastructure
- Institutional
- Commercial

Construction materials

This is any manufactured product compound or equipment that is useful in the construction process. The most common materials used are:

- Stone
- Brick
- Lime
- Cement
- Concrete

a) Stone

Use of stone

- **Structure-** stones are used for foundation walls, columns, lintels, arches, roofs, floors, damp proof.
- **Aesthetic**- stones are adapted to give the massive appearance to the structure wall of bricks and facing is done in stones of desired shades.
- **Paving stones-** these are used to cover the floor of buildings of various types such as residential commercial, industrial etc.
- **Basic material**- are disintegrated and converted to form a basic material for cement concrete forum of roads

b) Bricks

Bricks are obtained by moulding clay in rectangular blocks of uniform size and then by drying and burning them.

Properties of bricks as a construction material:

- Durability
- Colour
- Texture
- Size variation
- Compressive strength
- Absorption

Classification of Bricks

First-class brick (A-type)

Thoroughly burnt bricks are deep, red, or copper colour. The surface of these bricks is smooth and rectangular with sharp and straight edges and square corners.

It is used for painting, exposed face work in a masonry structure, flooring and reinforcement brickwork. The water absorption is about 12%- 15%.

Second class (B-Type)

They are supposed to have some of the requirements in 1^{st} class though they have some cracks and distortions and have more absorption power of about 16%- 20%

They are used in important hidden masonry works and centring of reinforced brick structures.

Third class bricks (C-Type)

These are under burnt bricks. They are soft and light-coloured producing a dull sound when struck against each other. Their absorption power is about 25% of dry weight. They are used in building temporary structures.

Fourth class bricks (D-Type)

Fourth class bricks are over burnt and badly distorted in shape, size and are brittle in nature. Used in filling foundation and floors.

a) Concrete

The cement and water form a paste that hardens and bonds the aggregated together.

It composes of

- water
- Aggregate
- Chemical mixture
- Cement

Properties of concrete

- Concrete has a higher compressive strength.
- It is a corrosion-resistant material and atmospheric agent has no effect on it.
- It is more economical than steel.
- It forms hard surface cable for resisting abrasion.
- Concrete walls and floors slow the passage of heat moving through and reduce temperature swing.
- Being naturally five resistant concrete forms a highly effective barrier to five spread.

Reinforced cement concrete

Strong in compression as the aggregate efficiently carries the compression load. Weak in tension as the cement holding aggregate in place can crack allowing the structure to fail. Reinforced concrete solves these problems by adding either metal reinforcing bars, steel fibres, glass fibre, or plastic fibre to carry tensile loads.

Use

RCC is used as a structural member wherever bending of the member is required: Like in footing, columns, beams, lintels, and stairs.

d) Cement

The crystalline compound of calcium silicate and other calcium compounds having hydraulic properties.

Use.

- Main use in the fabrication of concrete and mortars.
- Building (floors, beams, columns, roofing, piles, brick, mortars, panels, plaster)
- Transport (roads, pathways, crossing bridges viaduct tunnels)
- Water (pipes, drains, canals, dams, banks, pools)
- Civil (piers, docks, retaining walls, silos, warehousing, poles, pylons, fencing)
- Agriculture (building, processing, house irrigation)

e) Limestone

Limestone is a sedimentary rock composed largely of the minerals calcite and aragonite which are different crystal forms of calcium carbonate (CaCO3).

Uses.

- It is the raw material for the manufacture of quicklime
- (Calcium oxide), slacked lime (calcium hydroxide) cement and mortar.
- It is crushed for use as aggregate- the solid base for many roads.

Construction Equipment

This is a variety of heavy-duty vehicles, tools and machinery which are capable of withstanding the harsh conditions experienced throughout the construction site.

Criteria to select construction equipment

The type, size and other particulars of equipment. Whether the equipment is to be purchased, rented or to be procured hire-cum-purchase arrangement.

Advantages

- Increase the rate of output through work progress with the best effective and efficient methods.
- Reduce overall construction cost especially for large contracts.
- Carry out activities which cannot be done manually or to do them more economically and much faster.
- Eliminate the heavy manual work by human thus reducing fatigue and eliminates various other hazards and health issues.
- Maintain the planned rate of production where there is a shortage of skilled or unskilled labour.

Disadvantages

- If the machine breaks down, it can cause delay of construction work.
- Electric tools can cause a short circuit which may result to fire.
- Only skilled labour can operate the equipment.
- Special assistance is required to operate them as it may harm people on the site.
- Contractors in small projects create an issue over buying or rating of equipment and may charge high charges.

Types of Equipment

- Electric hand tools
- Vibrators
- Pumps
- Compactors
- Rollers
- Concrete mixers
- Hand pumps for ready-mix- concrete
- Transport equipment

Electric Hand Tools

A power tool is an instrument that is actuated by an additional power source and mechanism other than the solely manual labour uses with hand tools.

They include:

- Saws
- Drills
- Polishers
- Plate compactors
- Concrete vibrators
- Electric drivers
- Ceramic file cutter
- Jackhammer

5.1. Assembling construction materials, tools and equipment based on the construction method.

Procedure

i. Site clearing

This is the removal of vegetation and topsoil from the site.
For this, you assemble equipment such as
Bulldozers, excavators and graders for a large project but for small projects normal digging with jembes are recommended.

ii. Foundation

This is the structure in a building that transmits building load to the ground and holds the building firmly into the soil.
For this, it requires the use of the following materials:

- Steel (for reinforcement)
- Cement(adhesive)
- Concrete (structural strength)
- Scaffolding (to hold the concrete in place)

Assembled equipment include:

- Concrete mixers
- Vibrator

iii. Superstructure

This includes partitions, beams and columns.
For this process the following materials are assembled:

- Stone (masonry) used as a partition.
- Cement (Adhesive) to bind stone together.
- Concrete (for the making of columns and beams)
- Steel (Reinforcement in the concrete)

The beams and columns are laid out with the use of moulds. They are left to cure as water is poured. Masonry stone is laid out to create partitions according to the drawings.

iv. Roofing.

This is the top covering of the structure. The following materials are assembled:

- Iron sheets or roofing tiles which are the topmost covering of a house.
- Wood- laid out as a skeleton to hold the iron sheets in place.
- Nails- to hold the wood to the iron sheets.

5.2. Construction materials are used based on the construction process

Construction process

a) Foundation

The building site is graded and excavated and the boundaries of the foundation are laid out before the basic plumbing is installed the foundation is poured. The clearing of the site is done with equipment such as excavator and Levelized by graders. The foundation to be poured is majorly concrete on top of the stones used for pack filling of the foundation trenches.

b) Framing

The interior and exterior walls are installed. The wall is made of masonry stone from the quarry or machine cut stone, they are joined together using cement. In other places such as the exterior wall back is used for aesthetic purposes.

c) Plumbing, mechanical and electrical configuration

A host of installation occurs during this phase as the water and wastewater piping is installed along with the electrical wiring, ducting HVAC system and water heater.

d) Insulation and drywall installation

The walls are insulated and then the drywall is installed over the walls. At this stage, you'll be able to see your vision start taking form.

e) Exterior and interior

The final touches are made to the construction project. All remaining electrical mechanical HVAC and plumbing system are installed and the ceiling, doors, window sills, cabinets, tiles, countertops, mirrors, light and other fixtures are finalized. If a driveway is involved. It's at this stage that it is completed along with the sidewalk modification and landscaping can begin for your garden and footpath.

Conclusion

The learning outcome covered assembling construction materials, tools and equipment based on construction methods and, using construction materials based on the construction process.

5.3.6.3 Self-Assessment

Written Assessment

1. What do you understand by the word construction material?
    a) An instrument used in construction.
    b) The powder used as an adhesive in building
    c) Any manufactured product component or equipment that is used in the construction process.
2. Which of the following is construction equipment?
    a) Spade
    b) Excavator
    c) Spoon
3. The tool used to drive a nail in a piece of wood is called?
    a) Hummer
    b) Cement
    c) Sand
4. Which material is most appropriate for the making of foundation?
    a) Concrete
    b) Reinforced concrete
    c) Sand
5. Justify the advantages of reinforced concrete over ballast.
6. Analyse the properties of bricks that make it an appropriate construction material.
7. As an architect, evaluate the advantages of State one advantage of construction equipment.
8. State one disadvantage of construction equipment.
9. Explain the construction process.

Oral Assessment

1. Define construction material
2. Outline construction materials are seen in any construction site you have visited

Practical Assessment

With the help of trained personnel use the following materials to come up with a foundation slab of measurements 1m×1m×0.5m

a) Cement
b) Ballast
c) Sand
d) Water
e) Steel reinforcement

5.3.6.4 Tools, Equipment, Supplies and Materials

- Computer
- Hand tools
- Machine tools
- Chats with the picture and names of construction equipment.
- Drawing books.
- Rulers and T- square

5.3.6.5 References

Francis D.K. Ching (2008) Building construction illustrated (New Jersey) John Wiley and Sons, Inc.

Frederick. S. Merrit (2000) Building Design and Construction Handbook (California) McGraw Hill

Roy Chudley (2014) Building Construction Handbook (London) Routledge

5.3.7 Learning Outcome No 6: Testing Construction Materials

5.3.7.1 Learning Activities

Learning Outcome No 6: Testing Construction Materials	
Learning Activities	**Special Instructions**
6.1. Sample construction materials randomly 6.2. Identify **test parameters** 6.3. Test construction materials	• Trainer to conduct field trips • Conduct lab tests • Trainer to conduct field trips • Trainer to carry out demonstration

5.3.7.2 Information Sheet No5/LO6: Testing Construction Materials

Introduction

This learning outcome covers randomly sampling construction materials as per SOPs, identifying test parameters (compression, weathering, durability, water absorption, impurity test and tensile tests) as per the construction requirements and engineer's instructions and testing construction materials as per SOPs.

Definition of key terms

Impurity test: They are aimed at the identification and management of the presence of foreign substances in a material.

Weathering: Refers to decaying and decomposition of materials caused by physical or chemical agents

Test parameters: Refers to the various aspects of a material that can be subjected to tests

Content/Procedures/Methods/Illustrations

6.1. Construction materials are sampled randomly as per SOPs

Construction materials basically refer to manufactured and naturally occurring substance that may be used in the building of houses, bridges etc. The standard operating procedures (SOP's) govern matters such as quality of the construction materials and their compliance to regulations as per the zones where construction will take place. Sampling is generally conducted so as to allow for tests to be carried out on the construction materials.

Construction materials are samples based on quality availed for construction, extraction of material e.g. by manufacturing a natural occurrence and also by the construction process that would be required for certain construction material. Ideally, the most reliable method to ascertain the sample of the materials to be tested include the whole scope of a construction process by incorporating a stratified random sampling procedure into the sampling process to ensure a successful implementation of this divide the samples into a recommended number of equal groups in accordance with the standard. In the event that the groups are of an unequal size weighing the samples to ensure a reliable sampling process is necessary. For example, sampling for wood or timber construction materials may be conducted by selecting model trees in a test area and sticks specimen. The selection may be based on their girth. The specimen selected shall be clear and straight, free from decomposition and protection from moisture and weather is necessary.

6.2. Test parameters (compression, weathering, durability, water absorption, impurity test and tensile tests) are identified as per the construction requirements and engineer's instructions.

Test parameters refer to the characteristics or qualities of a material to be used in construction that can and should be subjected to tests since the various qualities would affect the quality of a construction project if they go unchecked. The parameters may include the strength of a material, climatic compliance of a material i.e. how the material is affected by different climates for example rains or too much heat, maintenance demand, water absorption capabilities of a material, impurity content etc. The need for identification of these parameters is to ensure productivity and efficiency of building materials. Identification of these parameters helps to keep within the originally approved budgets since identified parameters are addressed during testing and budgeted, improve the quality of building and infrastructure. The most desirable parameters to be considered for a choice of a building material include:

- **Ease of installation**

The ease or complications of installing a material may, in the long run, affect the budget thus consideration should be put on how easy it is to install the material.

- **Durability**

The construction materials should be weather compliant so as to reduce the cost incurred in replacing a material that has been damaged by adverse weather conditions. Tests should be conducted on the material to gain knowledge on the effects the weather will have on it.

- **Health safety**

The effects a certain building material will have on health need to be identified through tests. Different materials may have effects such as the release of pollutants by asbestos materials and fire management.

Tests on fire hazards such as ignitability, the spread of flame and fire resistance need to be carried out to ensure that the occupants can live safely from such hazards. Harmful effects can be contained by limiting the use of substances that contain harmful solvents, provision of good ventilation and following manufacturer's recommendations (Daily monitor, 2007).

- **Test for compression**

This is where variables such as strain and deformation are measured in a material by determining its response to compressive load. This helps to determine the materials elastic limit, yield strength etc. therefore determining the suitability of the materials for a purpose.

- **Test for weathering**

This is a test to determine how the material is affected by different weather elements and the rate to which elements can be exposed e.g. for roofing materials and which need to be protected from weather elements.

- **Test for water absorption**

This test determines the coarse and fine aggregates water holding capacity. The purpose of this test is to measure the strength and quality of the material.

- **Impurity test**

This is a test to enable realization and control of foreign substances in a material that would compromise the materials structural integrity.

- **Tensile tests**

This test is usually done by measuring the force required to elongate the test material to its breaking point. This helps professionals determine how materials will behave in their intended applications.

6.3. Construction materials are tested as per the SOPs

Testing of construction materials basically refers to the procedures intended to establish the quality and the reliability of structural materials that would be used to build projects from foundations to roof. The tests to be carried may be physical, chemical, verification of quantity and checking for damage.

Construction materials are tested for the purpose of:

- **Complying with regulatory requirements**

The government of every particular state or regulatory bodies have a set standard to be met by manufacturers of every material. This helps to restrict the manufacturing of substandard or hazardous materials.

- **Material and treatment selection**

Testing of the materials enables one to understand and determine whether certain material or treatment is suitable for a specified application

Product design and improvement

Testing quantifies the strength, hardness, elasticity etc. of a structure. Testing, therefore, helps to determine the most appropriate design that will hold up at a particular site. Materials tested may include soils and aggregates which are tested during excavation activities, asphalt, concrete, masonry etc. are tested to ensure that the specified conditions meet the acceptable criteria specified.

Destructive tests on construction materials are used to understand a specimen's failure to learn how it behaves under different loads. Destructive tests destroy the specimen such that even if it passes the test it is no longer fit for service while non-destructive tests, the specimen can be used for service (TWT, 2017)

For example, the concrete slump test is as follows:

a) Put the mould for the slump test in a frustum
b) Put the base on a smooth surface and concrete-filled in three layers
c) When the mould is filled, the top surface is struck off
d) Carefully lift the cone vertically let the unsupported concrete slump.

Precaution for slump test: Inside of the mould and its base should be moistened.

Conclusion

The learning outcome has covered randomly sampling construction materials as per SOPs, identifying test parameters (compression, weathering, durability, water absorption, impurity test and tensile tests) as per the construction requirements and engineer's instructions and testing construction materials as per SOPs.

Further Reading

1. Read on other tests for concrete and soil
2. Read on ideal locations to carry out construction materials testing.

5.3.7.3 Self-Assessment

Written Assessment

1. The resistance of the soil with depth is measured by a tool called?
    a) Seismometer
    b) Ammeter
    c) Potentiometer
    d) Penetrometer
2. What is the average depth of a test pit?
    a) 10 M
    b) 2 M
    c) 1.5 M
    d) 15 M
3. Shocks that travel within the soil are measured by an instrument called?
    a) Microphone
    b) Geophone
    c) Receiver
    d) Sensors
4. Which of the following has more fire-resisting characteristics?
    a) Granite
    b) Compact sandstone
    c) Marble
    d) Limestone
5. Due to the effects of dry rot, the timber?
    a) Cracks
    b) Shrinks
    c) Reduces to powder
    d) None of these

6. For testing the compressive and tensile strength of cement, the cement mortar is made up by mixing and standard sand in properties of:
    a) 1: 2
    b) 1: 3
    c) 1: 4
    d) 1: 6
7. Clay and silt content in good brick earth must be at least?
    a) 50%
    b) 40%
    c) 30%
    d) 25%
8. Evaluate the uses of a retarder in concrete?
9. Iron ore has different levels of purity, Summaries.
10. Justify the use of Stretcher bonds in masonry.
11. Summarise the different types of rocks.
12. Distinguish the different effects of excess alumna on bricks.

Oral Assessment

1. Which material is used in binding mortar?
2. What is the content of carbon in wrought iron?

Practical Assessment

Carry out stratified random sampling to be used to sample timber

5.3.7.4 Tools, Equipment, Supplies and Materials

- Computer
- Labouratory testing equipment
- Labouratory apparatus
- Hand tools
- Machine tools

5.3.7.5 References

Foster (2007). Mechanical testing of metals and alloys. New York. Oxford university press
Heinemann (2006). Building construction handbook. Oxford Routledge publishers
Williams (2007). Increase in greenhouse emissions from projects. Washington. The sightline institute

5.3.8 Learning Outcome No 7: Handling Construction Materials Safely

5.3.8.1 Learning Activities

Learning Outcome No 7: Handling Construction Materials Safely	
Learning Activities	**Special Instructions**
7.1. Identify construction materials 7.2. Identify Safety requirements 7.3. Safely handle construction materials	• Written tests • Oral • Practical tests/Project

4.3.8.2 Information Sheet No5/LO1: Handling Construction Materials Safely

Introduction to learning outcome

This learning outcome covers identifying construction materials to be handled, identifying safety requirements based on the construction materials and safely handling construction materials based on the safety requirements. Construction materials are materials used for construction purposes. Material handling is the movement, protection and storage of these materials. Therefore, handling and storing of construction materials involves diverse operations such as hoisting tons of steel with a crane, driving a truck loaded with concrete blocks carrying bags of materials manually; and stacking palletized bricks or other materials such as barrels and lumber.

Definition of key terms

Safety requirements: These requirements that are defined for purposes of risk reduction e.g. all-new powered industrial trucks except vehicles intended primarily for earth moving or the over the road hauling must meet the design and construction requirements for powered industrial trucks established in the American National Standard for Powered Industrial trucks, Part2, ANSI B56.1-1969

Safety measures: These are activities and precautions taken to improve safety on-site mainly to reduce the number of accidents associated with workplace equipment; employees in the proper use and limitations of the equipment they operate e.g. Proper use of cranes on site.

Material handling: This is the movement, protection and storage of construction materials on-site in a safe manner. For example, never lift a load over an obstacle and perform lifts in areas with adequate footing, space and lighting.

Content/Procedures/Methods/Illustrations

7.1. Construction materials

Construction materials refer to any materials used for construction purpose. They are materials used for house building. These include wood, cement, aggregates, metals, bricks, concrete, and clay. The choice of these materials is based on their cost-effectiveness for building projects.

Types of building materials used in construction

Wood

It is a product of trees, and sometimes other fibrous plants used for construction purpose when cutting or pressed into lumber and timber such as fiberboards and plants. It is a generic building material and is used in building about any type of structure in most climates. Wood can be very flexible under loads, keeping strength while bending and is incredibly strong when compressed vertically. Wood is also basically used and preferred in interior design because it is timeless in nature and does not increase in value.

Historically, wood for building large structures was used in its unprocessed form as logs. The trees were just cut to the needed length, sometimes stripped of bark and then notched or lashed into place. Currently with the invention of mechanizing saws came the mass production of dimensional lumber. This made buildings quicker to put up and more uniform, thus the modern western styles home was made.

Advantages of Dimensional Lumber (Glulam)

i. Size- one can get the very huge size of wood depending on how you glue the wood strips.
ii. Architectural freedom- the wood can span long distances past 6m and 8m e.g. In open spaces such as Amphitheaters.
iii. Quality of wood is good since the control processes of drying and bonding of the wood strips are done in the factory.
iv. There is the efficient use of lumber grades-there is minimum wastage of wood since wood is placed where it is needed most.
v. It is environmentally friendly.

Brick and Block

A brick is a block made of kiln-fired materials usually clay or shale but it also may be of lower quality mud etc.

Clay bricks are formed in moulding (the soft mud mothered) or in commercial manufacture more frequently by extruding clay through a die and then wire-cutting them to the proper size the stiff mud process). Bricks were widely used as a construction material in 1700, 1800 and 1900s. This was probably due to the fact that it was much more flame retardant than wood in the ever-crowding countries and fairly cheap to produce. Another type of block replaced clay bricks in the late 20th century. It was the Cinderblocks made mostly from concrete. An important low-cost material in developing countries is the sand rete block which is weaker but cheaper than the fired clay bricks.

Concrete

Concrete is a composite building material made from the combination of aggregate (composite) and a binder such as cement. The most common form of concrete is Portland cement concrete which consists of mineral aggregate (generally gravel and sand) Portland cement and water. After mixing the cement hydrates and eventually hardens into a stone-like material. When used in the generic sense, this is the material referred to by the term concrete. For a concrete construction of any size, as concrete has a rather tensile strength, it is generally strengthened using steel rods or bars known as robes. This strengthened concrete is then referred to as reinforced concrete. In order to minimize any bubbles that would weaken the structure, a vibrator is used to eliminate any air that has been entrained when the liquid concrete mix is poured around the ironwork. Concrete has been the predominant material in this modern age due to its longevity, formability and ease of transport.

Metal

It is used as a structural framework for larger buildings such as skyscrapers or as an external surface covering. There are many types of metals used for building. Steel, for instance, is a metal alloy whose major component is iron and is the usual choice for metal structural construction. It is strong and flexible and if refined well and well treated last a long time. Corrosion is metals, prime enemy, when it comes to longevity. The lower density and better corrosion resistance of aluminium alloys and tin are sometimes overcome by their greater cost. Brass was more common in the past but it is usually restricted to specific uses or specialty items today. Other metals used include titanium, chrome, and gold, silver. Titanium can be used for structural purposes but is much more expensive than steel.

Glass

Clear windows have been used since the invention of glass to cover small openings in a building. They provided human with the ability to both let light into the rooms while at the same time keeping demand weather outside. Glass is generally made from mixtures of sand and silicates and is very brittle. Modern glass "curtain walls" can be used to cover the entire façade of a building.

Glass can also be used to span over a wide roof structure in a space frame.

Ceramics

They are such things such as tiles, fixtures etc. They are mostly used as fixtures or coverings in buildings. Ceramic floors, walls, countertops even ceilings. Many countries use ceramic roofing tiles to cover many buildings. Ceramics used to be just specialized form of clay pottery firing in kilns but it has evolved into more technical areas.

- **Plastics**

Plastics vary immensely in heat tolerance, hardness and resiliency. Combined with this adaptability, the general uniformity of composition and lightness of plastic ensures their use in almost all industrial applications today.

- **Brush**

Are built entirely from plant parts and are generally found in the tropics. These are mostly built with branches, twigs and leaves and bark similar to a beaver's top.

7.2. Safety requirements are identified based on the construction materials

Safety requirements are requirements that are purposefully set for risk reduction on a construction site. They include:

i. Scaffold must be sound, rigid and sufficient- to carry its own weight plus four times the maximum intended load without settling or displacement. It must be erected on solid footing.
ii. Employees should consider using aerial lifts or elevated platforms in a case where there are unstable working surfaces so as to provide safer elevated working surfaces.
iii. Provide or erect guardrail systems with tool boards and warning lines or install control line systems to protect workers near the edges of floors and roofs so as to prevent cases of fall.
iv. Ladders and stairways are other sources of injuries and fatalities among construction workers. Make sure there is the use of the correct ladder for the task and make sure the ladders are long enough to safely reach the work area.

v. Slips, trips and falls on stairways are a major source of injuries and fatalities among construction workers. Ensure stairways treads cover the entire step and landing. Ensure also that the stairways having four or more risers or rising more than 30 inches must have at least one hand drain.
vi. Sloping- maximum allowable slopes for excavations less than 20 feet (6.09M) based on the soil type and angle to the horizontal.
vii. Failure to recognize the hazards associated with chemicals can cause chemical burns, respiratory problems and fires and even explosions. Ensure that you maintain an MSDS (Material Safety Data Sheet) for each chemical in the facility.
viii. Serious head injuries as a result from blows to the head- ensure that the workers wear hard hats where there is potential for objects falling from above, bumps to their heads from fixed objects, or accidental head contact with electrical hazards.
ix. Trench collapsing injuries to the employees- ensure no employee enters an unprotected trench.
x. Existing energized (not) electrical circuits should be prohibited to avoid accidents.

7.3. Construction materials are handled safely based on the safety requirements

i. Do not place the construction materials within 6 feet of any hoistway or inside floor openings or within 10 feet of an exterior wall that does not extend above the top of the material sheet.
ii. Stack bagged materials by stepping back the layers and cross keying the bags at least every ten bags high.
iii. Do not stack brick more than 7 feet in height. When stacks of bricks reach 4 feet height, start tapering it back 2 inches for every foot of height above the 4-foot level.
iv. Masonry blocks typically stack easier than brick but when stacking masonry blocks higher than 6 feet, taper the stack back one-half blocks per tier above the 6-foot level.
v. For lumber stacked by machine, the piles cannot exceed 20 feet in height. Lumber that is going to be handled manually can’t be stacked more than 16 feet high. For lumber storage;
    - Remove all used nails before stacking
    - Stack lumber on level and solidly supported sills
    - Stack lumber so it is stable and self- supporting
    - Do not store excess materials on the scaffolds’ or runways. Keep only the amount needed for immediate operations.

Figure 79: Dimensional Lumber (GLUELAM) being dried up in a kiln drier.

Conclusion

The learning outcome has covered identifying construction materials to be handled, identifying safety requirements based on the construction materials and safely handling construction materials based on the safety requirements.

5.3.8.3 Self-Assessment

Written Assessment

1. Material handling consists of movement of material from
   a) One machine to another.
   b) One shop to another shop
   c) Stores to shop
   d) All of the above
2. Principle of "unit load" states that
   a) Materials should be moved in lots
   b) One unit should be moved at a time.
   c) Both a and b
   d) None of the above.
3. The economy in material handling can be achieved by
   a) Employing gravity food movements
   b) Minimizing the distance of travel
   c) By carrying material to destination without using manual labour
   d) All of the above.
4. The forklift truck is used for
   a) Lifting and lowering
   b) Vertical transportation
   c) Both A and B
   d) None of the above

5. Cranes are used for
   a) Lifting and lowering
   b) Vertical transportation
   c) Both a and b
   d) None of the above
6. Wheelbarrows are used for
   a) Lifting and lowering
   b) Vertical transportation
   c) Both A and B
   d) None of the above.
7. Which one of the following is not a construction material?
   a) Concrete
   b) Ceramics
   c) Wood.
   d) Bill of quantities
8. Mention three types of building materials in construction
9. What is the difference between safety requirements and material handling and storage?
10. Classify different safety measure to be observed while handling lumber as a building material.
11. Analyse safety requirements.
12. Develop a check list on the properties to consider while identifying materials.

Practical Assessment

Visit a potential construction site. Observe how the construction materials are being handled safely on site. Mix cement and sand aggregates using the concrete mixer in a clean and safe manner; using appropriate ratios of 1: 2

4.3.8.4 Tools, Equipment, Supplies and Materials

- Drawing books
- Reference books
- Set Squares
- T-squares

4.3.8.5 References

Code of Federal regulation. (2002) Concrete and Masonry construction.US OSHA
Code of Federal regulation. (2004) Control of Hazardous Energy. US. OSHA
Job Hazard Analysis. (2002) Personal Protective Equipment. The US.OSHA

CHAPTER 6: WORKSHOP TECHNOLOGY PRACTICES

6.1 Introduction

This unit describes the competence in applying workshop technology practices. It entails performing masonry, plumbing and carpentry tasks. It also involves performing electrical and mechanical operations.

6.2 Performance Standard

Perform masonry tasks**,** plumbing tasks**,** carpentry tasks, electrical operations and mechanical operations as per Manufacturer's specifications and as per SOPs.

6.3 Learning Outcomes

6.3.1 List of Learning Outcomes

a) Perform masonry tasks
b) Perform plumbing tasks
c) Perform carpentry tasks
d) Perform electrical operations
e) Perform mechanical operations

6.3.2 Learning Outcome No 1: Perform Masonry Tasks

6.3.2.1 Learning Activities

Learning Outcome No 1: Perform Masonry Tasks	
Learning Activities	**Special Instructions**
1.1 Identify the safety requirements in the workshop environment. 1.2 Use masonry hand tools appropriately to perform tasks in masonry workshop 1.3 Use masonry machine tools appropriately to perform tasks in masonry workshop 1.4 Maintain Masonry tools used in construction work	• Video instruction • Research • Group discussion • Drawings • Direct Instructions

6.3.2.2 Information Sheet No6/LO1: Perform Masonry Tasks

Introduction

This learning outcome covers safety requirements in the learning environment, appropriate use and performance of masonry hand tools, appropriate use of masonry machine tools and maintenance of masonry tools as per manufacturer's specifications.

Definition of key terms

Course: Refers to a horizontal continuous layer of masonry units

Wythe: Refers to the vertical section of masonry, one unit in thickness.

Mortar: Refers to the mixture of cement, aggregate and water used as a binding for material such as blocks and bricks.

Content/Procedures/Methods/Illustrations

1.1 Safety Requirements in the Workshop Environment are identified

- Always check tools against defects before using
- Use the correct and appropriate tools, instruments or equipment as per the task required.
- Always wear personal protective equipment (PPE) e.g. gloves, goggles, hard hat, safety boots and others all the time.
- Follow instructions provided by the authority of the person in charge

- Report any malfunction of tools, equipment or instrument of any incident to the person in charge.
- Provide materials that show no-go zone such as fencing, these no-go zones may include possible collapse zones.
- Provide designs and materials for temporary supports
- Building walls and cross walls at the same time to ensure they support each other
- Avoid stacking material against masonry walls
- Wait for masonry walls to attain the correct strength before backfilling.
- Establishing stop heights to allow the masonry walls to achieve or gain strength.
- Provide temporary supports for walls considering its characteristics
- Designing walls to provide additional stability during the construction phase i.e. adding sequential core filling with reinforcing.

1.2 Masonry Hand Tools are Used Appropriately to Perform Tasks in Masonry Workshop

A hand tool is a device or equipment that does not require electric power and instead relies on human hand energy supply to operate and used to perform a particular intended purpose. The commonly used hand tools include:

- **Floats**

Used for levelling, filling voids and smoothening surfaces before trowelling. Mainly made of aluminium, wood, stainless steel or magnesium. There are two types of floats depending on the scale of use.

  - Bull float – used in large areas of concrete
  - Hand float – used in small areas of concrete

- **Trowel**

Trowel comes in different sizes and shapes and is made using stainless steel for the purpose of durability and quality. Handles are commonly made of wood or plastic. Larger towels are used for spreading mortar and also random cutting of soft bricks. Smaller trowels are used for repairing damaged mortar joint. Learning how to hold and load a trowel is a skill to develop over time.

- **Mason's Hammer**

This tool has two ends, square and flat end for hammering nails and the other sharp-chisel like the end for breaking blocks and bricks. To break blocks and bricks, light blows are subjected along and around the required point of split and then a sharp blow using a hammered end will give the required cut. The cut is then cleaned off of burrs, surplus material and straightening edges and surfaces to greater accuracy using the chisel-like side.

- **Blocking Chisel**

A blocking chisel is made of steel and comes in a variety of shapes and sizes/ they are heavier and wider. They are required when more or several blocks or bricks are needed to be split. They are operated by holding the narrow end while striking continuously using a mashing hammer, sledgehammer or mullet against the bricks to give a clean cut.

Levels

Levels are used to ensure, keep and check horizontal surfaces and planes at 180 degrees and vertical planes and surfaces at 90 degrees. To achieve the level surface or the right-angle plane, the bubble inside the tube should line up between two lines at the centre of the tube.

Mason's Line

Mason line is a nylon or Dacron string stretches close to the masonry wall from one end or corner to the other. It is required to make laying blocks or bricks easier and in a straight line i.e. without bulges and hollows.

Steel Square

This tool is used for checking and verifying a 90-degree angle at the corners of a rectangular or a square wall while it is being built.

Plumb Bob

This tool is used for laying blocks/bricks and checking a 90-degree angle on walls while during construction. It consists of a string tied to a weight called bob and straight wood board with uniform edges and a hole for the string at the centre. On a vertical wall, the plumb bob must be in the groove line.

Masonry Hammer

Used to strike chisel while splitting a brick/block

Mixing tools

These are tools required for mixing mortar. They include:

The Shovel; used for scooping and measuring aggregate

Hoe; mixing the mortar sand, cement and water, with two holes for ease of use.

1.3 Masonry machine tools are used appropriately to perform tasks in masonry workshop

Concrete mixer

This is a mechanical device that consists of a rotating drum powered by a mortar that mixes cement, aggregate and water to form concrete at a slightly higher rate.

Masonry saws

This is a powered tool used to cut concrete block/bricks, tiles etc. into precise shapes and sizes.

Process of Using a Mixer

i. Measure the required amount of material needed for the structure
ii. Connect the mixer to a power source and start the machine
iii. Pour the ingredients into the cement mixer starting with a measured amount of water followed with cement and ballast if needed.
iv. Allow the machine to rotate until the ingredients are mixed evenly and ready for use
v. Tilt the mixer and pour the mixture into a carrier (wheelbarrow)
vi. Repeat as needed

Stone Cutting machine

A tile cutter is used in the splitting of tiles to fit uneven flooring. The following are operational principle;

i. Select the appropriate tile cutter, 2.5 cm longer than the dimensions of the tile
ii. An experienced professional should conduct the process to avoid wastage and loss of valuable material
iii. Make a mark where you need to cut. Trace a line using a pencil and a ruler to mark this point. The cuts will correspond with the dimensions of the floor or space.
iv. Double-check the dimensions to make sure that it's the required size
v. Side the lever of the cutter towards you until the cutter stops
vi. Place a tile with the glazed side facing up. Centre the tile beneath the block rails and push it forward until it fits snugly against the end stop.

1.4 Masonry tools used in construction works are maintained as per manufacturer's specifications

Maintenance of Masonry Tools

i. Use the appropriate and right tool for the tasks to prevent tool and user damage.
ii. Keep all tools in good condition and perform regular checks against defects. Only qualified professionals should install or repair equipment to avoid mechanical failure.
iii. Clean tools after use and store the dry tools in a dry place.
iv. Ensure that each tool is free from damage before use to avoid further damage.
v. Avoid altering tools in ways that reduce the performance and effectiveness of the tool.

vi. Comply with manufacture's manual guide and instructions most pieces of equipment come with guidelines on procedures of using and maintaining them to ensure machine effectiveness.
vii. Store all tools in dry places to avoid rust and mechanical damage caused by dampness.

Conclusion

This learning outcome has covered safety requirements in the learning environment, appropriate use and performance of masonry hand tools, appropriate use of masonry machine tools and maintenance of masonry tools as per manufacturer's specifications.

Further Reading

1. Study more on other masonry hand and machine tools and their appropriate use.

5.3.2.3 Self-Assessment

Written Assessment

1. How is mortar cleaned from tools?
    a) Waiting for the mortar to dry up and then can be easily removed
    b) Cleaning immediately using water
    c) Cleaning immediately using linseed oil and kerosene
    d) Soaking in water and leaving it
2. What is the best way of preventing tools from rusting?
    a) Oiling the tools
    b) Clean the tools and immediately store in air-conditioned room
    c) Keep the tools clean and dry before storage
    d) Store wet tools in airtight boxes
3. Which of the following tools is used for checking vertical walls?
    a) Level
    b) Plumb bob
    c) Masons line
    d) Steel square

4. Most moving parts of masonry machine tools are maintained by?
    a) A cleaning agent provided by the manufacturer
    b) Clean water
    c) Oiling
    d) None of the above
5. The following are safety requirements in the workshop environment except one. Which one is not?
    a) Provide signs and perimeters to no go zones
    b) Wear personal protective equipment (PPE) while performing tasks
    c) Follow instructions from the supervisor
    d) Construct masonry walls beyond stop heights to finish construction time
6. Identify one way of maintaining masonry tools?
    a) Storing tools in a dry place
    b) Cleaning tools before storage
    c) Oiling moving parts of tools
    d) All of the above
7. Why are tools such as hammers frequently checked against signs of cracking, chipping or defects?
    a) To maintain their cost value
    b) To ensure that they are in good condition
    c) To ensure that the tools are well-classified
    d) To ensure that the tools are not missing

8. Propose some of the tools to be used while constructing a brick wall.
9. Examine the components of mortar?
10. Give four personal protective equipment required during masonry instruction
11. Create a list of safety precautions to observe while handling masonry tools.
12. Distinguish hand tools and power tools

Oral Assessment

1. Classify different masonry tools.
2. Summarise the maintenance of the above tools

Practical Assessment

Construct one-meter high wall 3-meter long brick wall under the supervision of the instructor

6.3.2.4 Tools, Equipment, Supplies and Materials

- Spade
- Shovel
- Vibrator
- Pneumatic hammer
- Bench shears
- Anvil
- Pipe wrench
- Pliers
- Bending machine
- Portable power drill
- Saws
- Hammer
- Marking gauges
- Hand drill
- Portable drill machine
- Screwdriver
- Pliers
- Leather gloves
- Hand vices
- Pliers
- Submersible
- Reciprocating pump
- Hand pumps

Materials and supplies

- Lumber
- PPR pipes
- PVC pipes
- GI pipes
- Pipe fittings
- Cement
- Sand
- Lime
- Sheet metal
- Steel plates
- Electrical materials
- Electrical appliances
- Plumbing appliances

- Fuel
- Grease
- Oil
- Filters

Personal protective equipment (PPEs)

- Helmets
- Gloves
- Safety goggles
- Safety boots
- Overalls
- Dust masks
- Gas masks
- Dust coats

6.3.2.5 References

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6.3.3 Learning Outcome No 2: Perform Plumbing Tasks

6.3.3.1 Learning Activities

Learning Outcome No 2: Perform Plumbing Tasks	
Learning Activities	**Special Instructions**
2.1 Safety requirements in the workshop environment are identified 2.2 Plumbing hand tools are used appropriately to perform tasks in plumbing workshop 2.3 Plumbing machine tools are used appropriately to perform tasks in plumbing workshop 2.4 Plumbing tools used in construction works are maintained	• Practical projects • Demonstration • Oral assessment • Direct instruction

6.3.3.2 Information Sheet No6/LO2: Perform Plumbing Tasks

Introduction

This learning outcome covers plumbing workshop safety requirements, plumbing hand tools, and plumbing machine tools, maintenance of Plumbing tools and use of Plumbing tools.

Definition of key terms

Workshop: It is a fully equipped space containing tools and equipment specific to a particular task. E.g. a plumbing workshop containing plumbing machinery and equipment.

Plumbing hand tools: These any plumbing tools that function using mechanical means only without the use of external power.

Plumbing machine tools: These are plumbing tools that use electric power to run their mortars. They cannot function by mechanical means only.

Content/Procedures/Methods/Illustration

2.1 Safety requirements in the workshop environment are identified

The safety requirements are important to keep both the students and instructor safe and should be observed at all times in workshops.

They include:

- Listening carefully to the instructor and following instructions
- No running in the workshop
- Know where the emergency stop buttons are positioned
- Know where the emergency exits are located.
- Always wear an apron to hold loose clothing
- Put all stools away when attempting practical work
- Do not bring bags to the workshop
- Not use machines that one has not been shown how to use properly.
- Keep hands away from moving machinery
- Use tools carefully
- Report any damaged equipment

The safety procedures are identified by observing the type of machinery in the workshop and by reading instruction manuals of specific machines.

2.2 Plumbing hand tools are used appropriately to perform tasks in plumbing workshop

Plumbing hand tools include pipe fitters, telescopic tube cuter, adjustable spanner, adjustable pipe wrench, slip joint pliers, locking pliers, pipe bender, plunger etc.

Table 9: Plumbing tools

Tool	Use
Pipe cuter	• It is used to cut through most piping with ease. They are quicker and produce a designer cut than hacksaws. • They can be used in tight spaces
Telescopic tube cutter	• It can cut pipes made of copper clearly and neatly • It cuts pipes and tubing with a thickness of 6-35 mm
Adjustable spanner	• Used to turn nuts and any type of fastening • They are easily adjusted to fit multiple bolt sizes
Adjustable pipe wrench	• It is one of the most basic and essential tools • It is used to grip onto objects like bolts and surfaces and can be used to remove stuck objects
Slip joint pliers	• They are also known as water pump pliers • They are used for gripping and holding tops

How to use an adjustable pipe wrench

i. Select the proper pipe wrench and attach it to the pipe correctly. Adjust the wrench to fit the appropriate size of the bolt.

ii. One should always make sure to leave some space (about 1.3 cm) between the shank of the hook jaw on the pipe wrench and the pipe itself. This is because the gripping action is better with the gap introduced.

iii. When the grip is secure make sure the pipe sits in the "V" of the hook and is in contact with either side of the "V" to avoid slipping

iv. Proceed to turn the wrench in the desired direction over and over again until the bold is either tightened or loosened depending on the need.

2.3 Plumbing machine tools are used appropriately to perform tasks in plumbing workshop

Plumbing machine tools include a sink auger, drill and laser tape measure.

Table 10: Plumbing machine tools

Machine tool	use
Sink auger 	• To break up and clear clogs in sinks and tub drain
Drill	• This is a machine used to drill holes pipes and other materials
Laser tape measure	• It is used to measure distances such as lengths widths and heights accurately

How to use a sink auger to unclog a drain?

The auger has a corkscrew end attached to a flexible cable that is coiled within a drum canister. It also has a thumbscrew in the collar for locking the cable when the clog is reached.

- First, remove the stopper from the drain.
- Loosen the setscrew at the collar to pull out the cable and then insert it into the drain opening.
- Proceed to push the cable into the opening and when you feel the clog pull out an extra 30 cm and tighten the set screw.
- Press the button to turn the cable or turn the crank in a manual auger.
- Once the cable is pulled back clean the cable and remove the P-trap.
- Clean and maintain the auger.

2.4 Plumbing tools used in construction works are maintained as per manufacturer's specifications

Plumbing tools are prone to contamination of bacteria due to exposure to sewers and other contaminated matter.

How to clean and disinfect

Larger tools and equipment are cleaned using a spray disinfectant between regular clearings.

- Wear appropriate personal protective equipment
- Removes debris
- Wipe or spray all the surfaces with the recommended disinfectant
- Wait for recommended contact time
- Discard all wipes
- As recommended in the instructions follow up with regular cleaning and oiling

Plumbing tools should be maintained by the users or professional maintenance crew for complex machinery.

Conclusion

This learning outcome covered plumbing workshop safety requirements, plumbing hand tools, and plumbing machine tools, maintenance of Plumbing tools and use of Plumbing tools.

Further Reading

1. More tools and equipment used for plumbing
2. Methods of using professional equipment

6.3.3.3 Self-Assessment

Written Assessment

1. Which one of the following cannot be used to tighten a bolt?
    a) Pipe cutter
    b) Shovel
    c) Adjustable pipe wrench
    d) Masking tape
2. Which tool is the best among the following to be used to make clean fine cutting copper tubes
    a) Telescope tube cutter
    b) Slip joint pliers
    c) Sink auger
    d) Drill
3. Which one of the following is a plumbing machine tool?
    a) Hand saw
    b) Auger
    c) Telescope tube cutter
    d) Adjustable spanner
4. Propose some of the safety requirement in a workshop
5. Distinguish between plumbing hand tools and plumbing machine tools.
6. Describe the use of a drill in plumbing.
7. Demonstrate the use of ae an adjustable pipe wrench.
8. On a given drawing material, illustrate the use of a sink auger.

Oral Assessment

1. Outline the safety measures to be observed while carrying out a plumbing exercise.
2. Compare and contrast the uses of a pipe cutter and a handsaw when cutting a 10 mm pipe?

Project Assessment

Make a well-detailed drawing and analysis of a cold-water system in a simple maisonette. The house is assumed to have 5 bedrooms, 2 of which are unsuited and one extra share bathroom. The ground floor has 1 unsuited room and one toilet and the first floor has 1 unsuited room, 3 extra rooms, one bathroom and one toilet.
Use clear illustrations to support your answer.

6.3.3.4 Tools, Equipment, Supplies and Materials

- Spade
- Shovel
- Vibrator
- Pneumatic hammer
- Bench shears
- Anvil
- Pipe wrench
- Pliers
- Bending machine
- Portable power drill
- Saws
- Hammer
- Marking gauges
- Hand drill
- Portable drill machine
- Screwdriver
- Pliers
- Leather gloves
- Hand vices
- Pliers
- Submersible
- Reciprocating pump
- Hand pumps

Materials and supplies

- PPR pipes
- PVC pipes
- GI pipes
- Pipe fittings
- Cement
- Plumbing appliances
- Fuel
- Grease
- Oil
- Filters

Personal protective equipment (PPEs)

- Helmets
- Gloves
- Safety goggles
- Safety boots
- Overalls
- Dust masks
- Gas masks
- Dust coats

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6.3.4 Learning Outcome No 3: Perform Carpentry Tasks

6.3.4.1 Learning Activities

Learning Outcome No 1: Perform Carpentry Tasks	
Learning Activities	**Special Instructions**
3.1 Identify safety requirements in the workshop environment 3.2 Use carpentry hand tools appropriately to perform tasks in carpentry workshop 3.3 Use carpentry machine tools appropriately to perform tasks in carpentry workshop 3.4 Maintain carpentry tools used in construction works	• Demonstration • Group work • Practical assessment

6.3.4.2 Information Sheet No6/LO3: Perform Carpentry Tasks

Introduction

This learning outcome covers identification of safety requirements in the workshop environment, appropriate use of carpentry machine tools in the carpentry workshop, appropriate use of carpentry machine tools to perform tasks in the carpentry workshop and maintenance of carpentry tools used in construction work as per the manufacturer's specifications.

Definition of key terms

Welding: This refers to the act of joining together metal or plastic parts by exposing the surface to heat and pressure.

Carpentry: This is the act of shaping, cutting, joining and sculpting of wood or timber

Content/Procedures/Methods/Illustrations

3.1 Safety requirements in the workshop environment are identified

Safety requirements in a workshop

All persons using workshops should apply good housekeeping practices which are;

- Removal of rings and lose jewellery before operating machinery.
- Always keep a tidy workplace which makes it easier to spot and avoid hazards.
- Always wear appropriate footwear and clothing such as gloves, overalls and safety glasses.
- Only use the workshop for its intended purpose.
- Do not operate electrical machinery using wet hands.

- Long hair should be tied up and nails kept neat and short
- The workshop should be well lit.
- The workshop should have adequate sanitary and hygienic washing facilities.
- The workshop should be equipped with adequate fire-fighting equipment.

3.2 Carpentry hand tools are used appropriately to perform tasks in carpentry workshop

Carpentry hand tools

All carpentry hand tools should be used and stored appropriately to perform tasks in a carpentry workshop. Some of the carpentry hand tools used in the making of a quality end product are listed below:

- Claw hammer
- Tape measure
- Utility knife and blades
- Moisture meter
- Chisel
- Level
- Screwdriver
- Nail set
- Sliding level
- Layout square
- Pliers
- Anvil

a) **The claw hammer:** This is a tool primarily used for driving nails or pulling them out from an object
b) **Tape measure:** This is a tool primarily used to measure the distance from one point to another. It consists of metal, ribbon, plastic or fibreglass with linear measurements markings.
c) **Utility knife and blades:** This is a tool used for general cutting consisting of a blade usually 4-7 inches.
d) **Moisture meter:** This is a digital instrument used to detect the level or amount of moisture content in materials.
e) **Chisel:** This refers to a tool shaped cutting edge of a blade on its end used for carving, sculpting or cutting materials such as wood.
f) **Level:** This is a tool consisting of a small glass tube containing alcohol or a similar liquid and an air bubble used to indicate the horizontal plane of a material or a surface.

How to use a level?

Place the level on a flat surface and mark at the end of the level. Make another mark along the side of the level under the flacon in the Centre. Take the reading of the position of the bubble.

3.3 Carpentry machine tools are used appropriately to perform tasks in carpentry workshop

Carpentry machine tools

Carpentry machines are usually powered by electric motors intended ro process wood. Some of these machines are listed below;

Table 11: List of Tools

Drill press	Wood lathe
Bench grinder	Panel saw
Mortiser	Pin router
Band saw	Nail gun
Combination machine	Chain saw
Drum sander	Electric drill
Jointer	Thicknesses

- **Drill press**

Figure 80: Drill press
Source: Https: //gistgear.com

Also known as pedestal drill, pillar drill or bench drill is a machine mounted on a stand or bolted on the floor used for producing holes in hard materials.

How to use a drill press?

Open the chuck, side in a bit snuck the chuck by hand around the bit's shaft, then tighten the chuck's three jaws with the key. Make sure to remove the chuck. When drilling large holes, drill a smaller pilot hole first. Set the table to the desired height for the operation you have to perform. Secure the workpiece to be drilled. Make sure the drill is operational and introduce it to the bit of the workpiece. Once you have finished drilling, release pressure on the level and it would return to its original position.

- **Bench grinder**

This is a benchtop or worktop type of machine used to drive abrasive wheels for grinding materials.

- **Mortiser**

Figure 81: Mortiser
Source: Https: //www.gdmlindex.co.uk

This is a machine used to cut square or rectangular holes in a piece of timber. Some types of mortises include; square chisel, horizontal or slot mortise and chain mortiser.

- **band saw**

Figure 82: Band saw
Source: Https: //www.toolnut.com

This is a machine consisting of a long, sharp blade with a continuous band of toothed metal stretched between two wheels used in cutting materials.

- **Combination machine**

This is a machine that combines the functionality of two or more separate machines into a single unit used for woodworking and customized craftsmanship.

- **Drum sander**

This is a powerful machine with replaceable abrasive sheets which sand wooden surfaces to a shiny smooth finish.

- **Jointer**

This is a machine used to merge two edges or surfaces in order to produce a wider board by producing flat edges on boards.

3.4 Carpentry tools used in construction works are maintained as per manufacturer's specifications

Maintenance of carpentry tools

After performing woodworking activities and processes, the tools and equipment should be properly cleaned and stored to prevent damage to the tools and promote their life cycle through;

i. Proper storage of tools through hanging them on pegboards, putting them in boxes or drawers or chests
ii. Clean, inspect and care for tools through wiping using a rag so as to be sure they are free of residual debris.
iii. Inspect tools for wear and damage in order to prevent additional costs for the purchase of new equipment.

iv. Lubricate moving machine parts so as to prevent rusting, wear and tear.
v. Keep batteries, plugs and wipes in shape so as to prevent them from intertwining causing breakages and acid leakage from batteries.

Conclusion

This learning outcome covered identification of safety requirements in the workshop environment, appropriate use of carpentry machine tools in the carpentry workshop, appropriate use of carpentry machine tools to perform tasks in the carpentry workshop and maintenance of carpentry tools used in construction work as per the manufacturer's specifications.

Further Reading

From the internet, research more on the safety requirements in a workshop, examples and use of carpentry hand tools and machinery.

6.3.4.3 Self-Assessment

Written Assessment

1. Which one of the following mortises is false?
    a) Signature chisel mortiser
    b) Circular chisel mortiser
    c) Horizontal mortiser
    d) Chain mortiser
2. Which one of the following is not an example of a carpentry hand tool?
    a) Claw hammer
    b) Mallet
    c) Tape measure
    d) Level
3. Which one of the following is a machine used to cut square or rectangular holes in a piece of timber?
    a) Square chisel
    b) Horizontal mortise
    c) Slot mortiser
    d) Chain mortise

4. Among the following; which one is not a carpentry machine use in a workshop?
    a) Jointer
    b) Drum sander
    c) All of the above
    d) None of the above
5. In a level, a specific liquid is usually placed in the air bubble to identify the liquid among the following choices
    a) Alcohol
    b) Spirit
    c) Water
    d) Oil
6. Which of the following is not an example of a carpentry hand tool?
    a) Claw hammer
    b) Level
    c) Mortise
    d) Combined machine
7. Which of the following materials is not used when marking the linear measurements in a tape measure?
    a) Ribbon
    b) Metal
    c) Wood
    d) Plastic
8. Outline the uses and function of a mortise.
9. Compare and contrast the types of mortise.
10. Develop a plan to carry out machinery maintenance in a simple workshop.
11. Investigate the function of a combination machine
12. Develop a safety guide for a workshop.

Oral Assessment

1. Propose hand tools to use when building a wooden bench
2. Classify the different machine tools.

Practical Assessment

Among the methods and procedures of maintenance of hand tools, carry out one of the methods of tool maintenance and take sufficient photographs showing how you carried out the task in a systematic order.

6.3.4.4 Tools, Equipment, Supplies and Materials

- Spade
- Shovel
- Vibrator
- Pneumatic hammer
- Bench shears
- Anvil
- Pipe wrench
- Pliers
- Bending machine
- Portable power drill
- Saws
- Hammer
- Marking gauges
- Hand drill
- Portable drill machine
- Screwdriver
- Pliers
- Leather gloves
- Hand vices
- Pliers
- Submersible
- Reciprocating pump
- Hand pumps

Personal protective equipment (PPEs)

- Helmets
- Safety goggles
- Safety boots
- Overalls
- Dust masks
- Gas masks
- Dust coats

6.3.4.5 References

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6.3.5 Learning Outcome No 4: Perform Electrical Operations

6.3.5.1 Learning Activities

Learning Outcome No 4: Perform electrical operations	
Learning Activities	**Special Instructions**
4.1 Safety requirements in the workshop environment are identified 4.2 Conventional tools used in the electrical workshop are identified 4.3 Power supply sources are identified 4.4 Basic electrical circuits are installed and maintained	• Demonstration • Practical assessment • Oral assessments

6.3.5.2 Information Sheet No6/LO4: Perform Electrical Operations

Introduction

This learning outcome covers identification of safety requirements in the workshop environment, identification of conventional tools as per SOPs, identification of power supply sources as per SOPs, installation and maintenance of basic electrical circuits as per IEE regulations.

Definition of key terms

IEE wiring regulations.

Are based on the British standards (7671) which set the standards for all domestic and industrial installations and wiring.

Side cutter

This is a tool used to cut the wire and the leads of components in electrical devices as well as in stripping the insulation from wires.

Content/Procedures/Methods/Illustrations

4.1 Safety requirements in the workshop environment are identified as per SOPs

When working in an electrical workshop, safety and caution must be observed to avoid injury or in extreme cases death. Safety requirements can be identified and given form verbal instructions from the supervisor, written instructions from the manuals obtained from some equipment in the workshops, general and careful observations of students and common knowledge.

The basic safety requirements for an electrical workshop include;

a) Avoid working with both hands since it increases the likelihood of current passing through the chest cavity.
b) Assume all electrical devices to be live to avoid ignorant accidents or incidents.
c) Disconnect devices from the power source before doing any repair works.
d) Do not use tools with conducting handles when working with electrical devices to avoid cases of electrocution.
e) Wear nonconductive protective clothes to handle plugged in equipment and devices.
f) In case of spillage, do not move live equipment or devices away from the source but instead shut off power at the main switch or circuit breaker.
g) Ensure all conductors and contacts are properly enclosed to avoid injuries and accidents.
h) Do not handle equipment with wet hands, feet or body when standing on a wet floor to avoid electrocution.
i) Highly flammable fluids should not be stored near electrical equipment to avoid any accidents arising.
j) Avoid equipment with damaged insulation or broken plugs.
k) Drain capacitors before removing them from a circuit to avoid electric shock.
l) Wear goggles and avoid fumes when soldering circuit boards.
m) Do not overload electric outlets.
n) Use non-metallic drawing equipment like pencils and rulers as well as non-metallic watchbands and jewellery to avoid electrical shock.

4.2 Conventional tools used in the electrical workshop are identified as per SOPs

Electrical tools are essential for carrying out electrical operations effectively. These tools have been proven over the years to meet the demands of the current generation but there remain tools that every electrical personnel require. They can be further be classified into hand tools and machine tools.

a) Hand tools

These are tools that are operated without the use of external power sources and can be operated by hand and are usually portable.

Examples of hand tools

- **Multimeter**

It is a flexible instrument as it is able to measure voltage, current resistance and capacitance among others. They can either be analogue or digital depending on preference.

Figure 83: Multimeter
Source: Https: //www.uline.com

How to use a digital multimeter
A multimeter has 3 main parts: Display, selection knob and ports.

On measuring voltage,

i. Plug the black test lead into the terminal labelled "COM" for voltage to measure both AC and DC voltage.
ii. Move the dial to V- for AC voltage (voltage in a socket) or V- for DC voltage (power sources directly i.e. batteries)
iii. Turn the dial to a higher voltage than the one expected or if unsure set it in a generally high region before lowering it to get a better reading.
iv. Connect the black probe to the batteries ground/'-and the red probe to power or '+' to measure the DC voltage.
v. Put probes in corresponding wall socket slots to measure AC voltage but avoid probes from contacting each other. Additional caution is required when dealing with AC current as it can be dangerous. Thus, a noncontact tester is preferred than a digital multimeter.
vi. Observe the multimeter to acquire the reading needed to show whether the voltage is appropriate.

NOTE: If you encounter a negative reading on the multimeter, it simply means the red and black probes are switched.

Wire stripper

It is a handheld tool used to strip or cut off wire insulation and is designed with various sized cutting teeth to accommodate different sizes of wires. It also includes cutting jaws for trimming wire ends. There are some types that combine the use of crimping wires and stripping the vinyl insulation from wires.

Figure 84: Wire Stripper
Source: Https://saudi.souq.com

Fish tape

This is a tool used to pull wires through electrical and PVC conduits by creating a new route for wiring.

This is done by pulling the tape out of the wheel by pressing a button or pulling a lever then feeding the tape into the conduit until it emerges from the other end where the wires are attached to the fish tape in order to pull them through the conduit.

Figure 85: Fish tape
Source: Https: //www.homedepot.com

Pliers

There are various types of pliers required for electrical operations with the main ones including side cutting pliers specially designed for trimming wires and cutting small wires. Longnose pliers are used for cutting and holding of fine wires in tight spaces. Other types of pliers include slip joint pliers, retainer ring pliers and snap ring pliers.

Screwdrivers

They are essential to most crafts and technical disciplines including electrical operations. They are used to loosen or tighten screws with slotted heads.

The different types of screwdrivers include electronic screwdrivers, multi-tip screwdrivers, precision screwdriver sets and many more.

b) Machine tools.

i. electric drill.

It is a motor-driven power drill with a replaceable drill bit used to make holes in wood, metal, plastic. It is especially useful with larger products.

Figure 86: Electric drill

Source: Https: //haiwangtool.en.made-in-china.com

ii. Power saw

Power saw varies with the type and scope of the work being done with examples of saws used for electrical work including hole saws, cut off saws and portable band saws. They are especially useful to ensure clean cuts at optimum speed and high performance.

Figure 87 power saw; source copia.co.ke

4.3 Power supply sources are identified as per SOPs

A power supply source is an electrical device used to provide electrical supply to electrical and electronic equipment.

There are two main types of power supply;

a. AC power supply

An AC power source such as AC mains used to supply power to homes acquires voltage from the mains supply and uses a step up or step down the voltage.

AC power supply is further classified into:

- Single-phase systems.
- Three phased systems

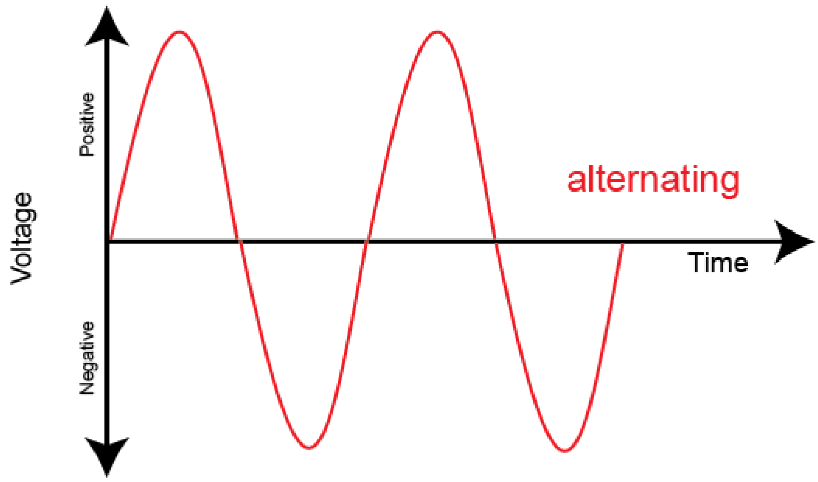

Figure 88: AC Graph

c. DC power supply

These are power sources that produce DC currents as the output basic DC is built with 4 circuits each with a core function.

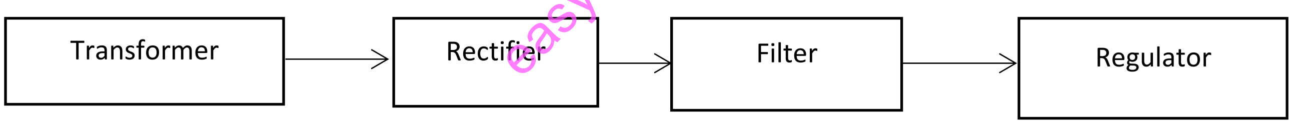

Figure 89: Transformer.

Step-up/step down voltage.

Rectifier

Provides a pulsating DC signal.

Filter

Change/convert DC signal to non-pulsating DC signal.

Regulator

- Smooth DC signal.
- Provides constant voltage at the output.

There are other types of the power supply based on AC and DC current including linear power supply, switched power supply, uninterrupted power supply, regulated power supply, programmable power supply, computer power supply and linear power supply.

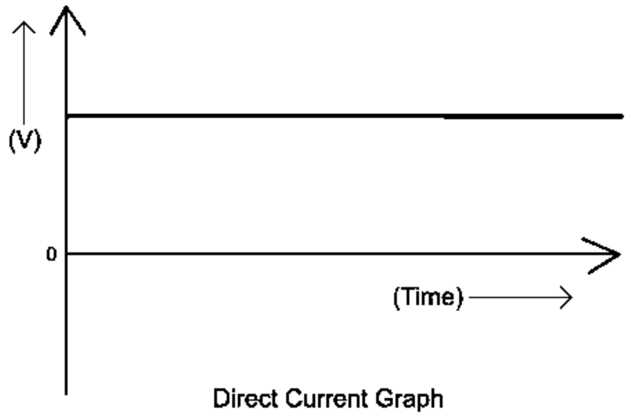

Figure 90: DC Graph

4.4 Basic electrical circuits are installed and maintained as per IEE regulations

An electrical circuit is a continuous path or loop that allows electrical current to flow from the power source through the wiring to the electrical device and back to the power source.

Electrical circuits essentially convert electrical energy to another source of energy at the load (electrical device) such as a bulb.

There are generally two types of circuits; AC and DC-based on the power supply but there are other types such as series circuit, short circuit, open circuit and closed circuit based on the construction of the circuit.

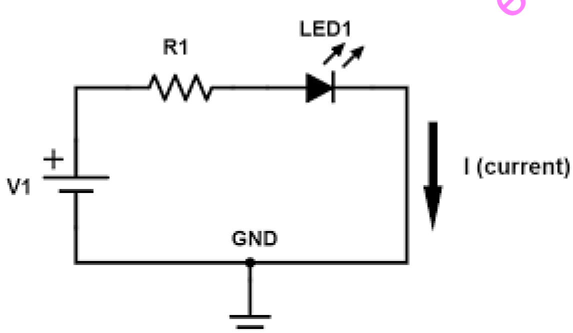

Figure 91: Basic electric circuit

Installation of basic circuits

Installation procedure described as per IEE regulations of a switched socket which in this case is a 15A switched socket outlet for 50Hz, 240V AC power supply.

Material requirement.

- PVC box for 15A switched socket outlet.
- 1 switched outlet.
- 1 MCB 16A from an already installed Distribution Board (DB).

Preparation

i. Install socket outlet box at the required position.
ii. Lay 13mm PVC conduit from the Distribution Board to the receptacle position.
iii. Colour code wires correctly.

Procedure

i. Ensure power is isolated (shut down).
ii. Connect the phase (live wire) to the outgoing side of a 16A MCB from Distribution Board.
iii. Connect the neutral wire to the neutral link provided in the DB and draw 15A receptacle and connect to the terminal marked N.
iv. Connect the earth wire to the earth link provided in the DB.
v. It is advisable to number the phase and neutral wires at the DB for easy identification.

Maintenance of electrical circuits

Lubricate rollers and bearing surfaces in the operating mechanism to avoid drying out which slows down the operating speed of the circuit breaker.

Conclusion

This learning outcome covered identification of safety requirements in the workshop environment, identification of conventional tools as per SOPs, identification of power supply sources as per SOPs, installation and maintenance of basic electrical circuits as per IEE regulations.

Further Reading

1. Specifications required for power supply.
2. Features of AC and DC power supplies.
3. IEE wiring regulations.
4. Single-phase systems.
5. Three-phase systems.

6.3.5.3 Self-Assessment

Written Assessment

1. Which measuring tool is used to measure more than one function?
   a) Voltmeter.
   b) Multimeter.
   c) Fish tape.
   d) Tape measure.
2. What is the function of a filter in a DC power supply?
   a) Convert DC signal to AC signal.
   b) Convert AC signal to DC signal.
   c) Convert DC signal to non-pulsating DC signal.
   d) Convert AC signal to non-pulsating DC signal.
3. Which tool is used to strip or cut off the insulation from wires?
   a) Pliers.
   b) Wire stripper.
   c) Screwdriver.
   d) Electric drill.
4. Which one is not an example of a hand tool?
   a) Screws.
   b) Power saw
   c) Fish tape.
   d) Pliers.
5. How many circuits are found within a basic DC supply?
   a) 2.
   b) 6.
   c) 1
   d) 4
6. Which one is not a type of electrical circuit?
   a) Series circuit.
   b) AC circuit.
   c) Parallel circuit.
   d) Conduct circuit.
7. What does SOPs stand for?
   a) Standard operating procedure.
   b) Standard occupational procedure.
   c) Short operating procedure.
   d) Specific operating procedure.

8. Sketch a simple electric circuit using a cell and two bulbs
9. Outline safety requirements for an electric workshop.
10. Develop a safety requirement plan for a busy workshop.
11. Compare and contrast direct current and alternating current
12. Why is it important to avoid using both hands in the workshop? Explain

Oral Assessment

1. Demonstrate the use of a multimeter.
2. Given electrical drawings, derive the materials required to perform the electrical tasks.

Practical Assessment

Design an electric layout plan for a simple 2-bedroom bungalow and thereafter create a simple electric circuit for wiring a fluorescent lamp using 1 36W 4ft fluorescent lamp, 1 starter and base, 2 fluorescent lamp holders, 1 MCB of 6A from an already installed Distribution Board, 1, 2.5 microfarad correction capacitor.

6.3.5.4 Tools, Equipment, Supplies and Materials

- Pliers
- Portable power drill
- Saws
- Hand drill
- Screwdrivers
- Close-cut saw
- Portable drill machine
- Long nose
- Side cutter
- Draw in wire
- Electrical knife
- Electrical hammer

Materials and supplies

- Electrical materials
- Electrical appliances

Personal protective equipment (PPEs)

- Helmets
- Gloves
- Safety goggles
- Safety boots

- Overalls
- Dust masks
- Dust coats

6.3.5.5 References

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6.3.6 Learning Outcome No 5: Perform Mechanical Operations

6.3.6.1 Learning Activities

Learning Outcome No 5: Perform mechanical operations	
Learning Activities	**Special Instructions**
5.1 Identify Safety requirements in the workshop environment 5.2 Use Mechanical hand tools appropriately to perform tasks in the mechanical workshop 5.3 Identify diesel and petrol engine components 5.4 Operate diesel and petrol engines 5.5 Perform simple engine maintenance 5.6 Identify water pumps based on the working principle 5.7 Perform basic maintenance on water pumps	• Practical tests • Direct instruction • Oral assessment

6.3.6.2 Information Sheet No6/LO5: Perform Mechanical Operations

Introduction

This learning outcome covers identification of safety requirements in the workshop environment, appropriate use of mechanical hand tools to perform tasks in the mechanical workshop, identification of diesel and petrol engine components, operation of diesel and petrol engines, maintenance of the simple engine, identification of water pumps and performance of basic maintenance on water pumps.

Definition of key terms

Tinsnips: Also known as shears they are designed to cut and trim sheet metals and other tough materials.

Centrifugal: This is moving or directed away from the axis or centre. A centrifuge is an equipment that applies a centrifugal force that puts an object in rotation around a fixed centre.

Reciprocating pump: This is a class of positive displacement pumps where a volume of liquid is collected in an enclosed space and discharged using pressure.

Content/Procedures/Methods/Illustrations

5.1 Safety requirements in the workshop environment are identified as per sops

Before using any machine or equipment in the workshop all persons should read the following carefully and understand the safety requirements which include;

- Always listen carefully and follow the teacher's instructions
- No running in the workshop, it could cause an accident
- Locate the position of all the emergency exits and stop buttons in the workshop.
- Always wear overall, dust coat or apron to protect your clothes and the safety of the eyeglasses to protect your eyes.
- Wear heavy-duty boots when coming to the workshop.
- Always wear reflective jackets and helmet when operating machinery.
- Put all stools away when working on practical.
- Do not operate a machine without supervision unless you have been shown how to operate it safely.
- Report any damages to tools, machines or equipment immediately

Safety procedures in a workshop can be identified through;

i. Completely reading the instruction manuals for machinery and equipment.
ii. Observing the type of machinery and equipment in the workshop
iii. Careful listening to the instructions given by the teacher or instructor

5.2 Mechanical hand tools are used appropriately to perform tasks in mechanical workshop

Mechanical hand tools are tools which are driven by hand and not powered by electricity or a motor. These tools are categorized by;

a) **Wrenches**- it is used to loosen or tighten, bolts, screws, nuts, mechanical caps and casing. They are classified into
    - **Key**: They look like old fashioned keys without teeth and are specialized i.e. bottle openers, window cranks and Allen wrenches
    - **Socket**: It can either be a handle that is attached to a cylindrical socket or a single piece
    - **Spanners**: It has pins or hooks and is used to turn spanner handle i.e. adjustable wrenches

b) **Pliers**: It is used to firmly hold objects, bend and compress materials. The different types of pliers include;
    - Hose clamp pliers; it compresses hose and spring clamps.
    - Snap ring pliers; used for gears on mountain bikes and similar vehicles
    - Battery pliers; maintain bolts on car batteries and jumper cables.

c) **Snips;** used for cutting and trimming sheet metal and other tough materials. They are categorized as:
    - Tinnier snips: Straight pattern
    - Compound action snips: Cut down aluminium in the construction of aircrafts
    - Configuration snips: Snips that are different in configuration.

d) **Screwdrivers:** Used for removing or installing screws. It is classified by its tip i.e.
    - Slotted drivers; it has a single slot on the head of the screw and is driven by a flat-bladed screwdriver.
    - Cruciform drivers; the head of the fastener has cross shape i.e. reason screwdriver

Procedure on how to use a wrench

i. Identify the item to be tightened or loosened is it a bolt, nut, screw, mechanical cap or casing
ii. Turn the screw mechanism to open the adjustable wrench to fit the size of the screw
iii. Slip the open jaw over the screw then turn the screw mechanism to clamp tightly
iv. Turn the wrench clockwise or anticlockwise to tighten or loosen respectively
v. Loosen the screw mechanism on the adjustable wrench to remove it

5.3 Diesel and petrol engine components are identified based on their functions and engine system

A diesel engine is any internal combustion engine which air is compressed to a sufficiently high temperature in the cylinder to ignite diesel fuel through mechanical compression.

Components of a diesel engine

- Cylinder block: Solid casting including cylinder and water jackets
- Cylinder holes: Found in the cylinder block and contain the piston
- Pistons: Movable plugs open at one end which transfer explosion force to the connecting rod.
- Connecting rod; a link between the piston and crankshaft
- Crankshaft; changes the reciprocating motion of the piston to the rotary motion in the power train.
- Crankshaft gear drivers- idle gear/camshaft
- Camshaft; have cam lobes which operate the values
- Timing gear; drives the camshaft
- Cam lobes; eccentrics on the camshaft which operate values
- Timing rods; rod links that transfer motion from the lifter to the rocket arm
- Rocket arm; transfer motion from pushrod to a valve
- Valve lifter; rides on the camshaft so that the cam lobe raises it to operate the valve.

- Cooling passageways; hollow spaces in the block through which coolant circulates.
- Wrist pin; floating connecting piece for piston and connecting rod.
- Oil pump; minimizes friction by providing pressure to circulate oil to rotate engine parts
- Oil pan; a reservoir for engine or oil
- Intake valve; allows air to enter the cylinder.
- Exhaust valve; allows exhaust gases to be expelled from the engine
- Flywheel; attached to the end of the camshaft and provides inertia to carry the crankshaft from one firing impulse to the other
- Pushrods; links that transfer motion from the lifter to the rocker arm.
- Valves; open and close the cylinder to allow air to enter or gases to leave.

These parts or components of an engine can be identified through instructions by a teacher or instructor through illustrations from a model of an engine. The petrol engine is an internal combustion engine with sparks, ignition or spark plugs and the air end fuel are mixed after compression to ignite the air-fuel mixture. It comprises of

- Spark plugs; supply the plugs that ignite the air-fuel mixtures
- Valves; intake and exhaust valves open and close to let in air and fuel and expel exhaust respectively
- Piston; a cylindrical piece of metal that moves up and down inside the cylinder
- Piston rings; provides a sliding ring between the outer edge of the piston and the inner edge of the cylinder to prevent air-fuel mixtures and exhaust from leaking into the sump and prevent oil from the sump from leaking into the combustion area
- Connection rod; connects the piston from the crankshaft
- Crankshaft; turns pistons up and down in a circular motion
- Sumps; contains oil/ reservoir (oil pan)

5.4 Diesel and petrol engines are operated based on the manufacturer's manual

Operating a diesel engine

i. When the piston begins to move down, the inlet valve opens and the air is sucked in
ii. Then the inlet valve closes at the bottom of the stroke and the piston rises to compress air
iii. At the top of the stroke fuel is squirted in which then ignites and forces the piston down
iv. When the piston is travelling upwards the exhaust valve opens and the burnt gas/ exhaust is expelled.

5.5 Simple engine maintenance is performed as per manufacturer's specifications

- Perform regular oil changes to prevent the accumulation of black sludge
- Regular checking of the engine coolant and the cooling system to prevent the engine from overheating
- Regular changing of oil filters to ensure that the air entering the engine is clean free from debris.

Simple engine maintenance could be done through checking the engine oil, coolant and air filters in an existing engine and determining if they are up to standard or functioning.

5.6 Water pumps are identified based on the working principle

A water pump is a machine that moves water from one point to another through mechanical action. They are categorized as;

- Direct lift
- Displacements
- Gravity pumps

Types of water pumps

- **Gravity pumps:** Water is lifted by gravity and gravitational force.

- **Impulse pumps:** It uses the pressure created by gas where the gas trapped in the liquid is released and accumulated in the pump which creates pressure which creates pressure which pushes the liquid upwards.

- **Centrifugal pumps**: It uses centrifugal force to pump water and is mostly operated by an electric motor. Water pumps can be identified by reading the instruction manual to understand how it functions in order to determine the type.

5.7 Basic maintenance is performed on water pumps as per sops

- Double-check to ensure that speed of water pumps corresponds with the output of horsepower
- Examine for any damages, leakages, or wear and tear
- Check and clean seals and oiling bearings

Performing basic maintenance could be done through checking of the:

- Functioning
- Output
- Sound

Conclusion

This learning outcome covered identification of safety requirements in the workshop environment, appropriate use of mechanical hand tools to perform tasks in the mechanical workshop, identification of diesel and petrol engine components, operation of diesel and petrol engines, maintenance of simple engines, identification of water pumps and performance of basic maintenance on water pumps as per sops.

Further Reading

From the internet, read more on:

1. Parts of pliers
2. Parts of screwdriver
3. Operating a petrol engine
4. Borewell compressor
5. Shallow good pumps
6. Pressure booster pumps

6.3.6.3 Self-Assessment

Written Assessment

1. In a diesel engine, the fuel is injected by
    a) Igniter
    b) Heat resulting from compression
    c) Spark
    d) Injected fuel
2. A diesel engine has
    a) One valve
    b) Two valves
    c) Three valves
    d) Four valves
3. All are safety wears expect
    a) Overall
    b) Training boots
    c) Helmet
    d) Reflector jackets

4. All the following are mechanical hand tools except
   a) Allen wrench
   b) Battery pliers
   c) Tinsnips
   d) Power saw
5. The moving part of a centrifugal pump is called a
   a) Impeller
   b) Volute
   c) Diffuser
   d) Suction nozzle
6. In a centrifugal pump, the liquid enters the pump
   a) At the centre
   b) At the bottom
   c) At the top
   d) From sides
7. To carry out engine maintenance you do the following except
   a) Regular oil changes
   b) Changing of oil filters check and mend seals
   c) Checking engine coolant
8. Analyse five parts of a diesel engine
9. Evaluate on cooling passageways
10. Compare and contrast between the diesel engine and petrol engine.
11. Evaluate two basic maintenance of a water pump
12. Develop a safety plan to be carried out in a workshop in case of emergency

Oral Assessment

1. Simulate how a diesel engine work?
2. Analyse a cooling passage?

Case Study Assessment

Mr Karanja who is an architect was going for a site visit discovered that his car was expelling black smoke from its exhaust. As a mechanical operations consultant explain to Mr. Karanja what he should do to avoid polluting the environment

6.3.6.4 Tools, Equipment, Supplies and Materials

- Centrifugal
- Submersible
- Reciprocating pump
- Hand pumps
- Hand grinder

Materials and supplies

- Fuel
- Grease
- Oil
- Filters

Personal protective equipment (PPEs)

- Helmets
- Gloves
- Safety goggles
- Safety boots
- Overalls

6.3.6.5 References

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James Rishel (2001) Water pumps and Pumping Systems. New York; M.C. Grow Hill Education

Klaus Mollenhaver, Helmut Tschoke (2010). Handbook of Diesel Engines. New York; Springer Science and Business Media

CHAPTER 7: MEASUREMENT OF WORKS AND COST ESTIMATION

7.1 Introduction
This unit describes competencies required to perform measurement of works and cost estimation. It involves preparing tender documents, taking off quantities, working up dimensions and abstracting measured quantities

7 .2 Performance Standard
Prepare tender documents, take off quantities, work up dimensions and abstract measured quantities as per the client's requirements, SOPs, specifications and drawings, nature of the project, conditions of the contract, and nature of the contract.

7.3.1 Summary of Learning Outcomes
a) Prepare tender documents
b) Take off quantities
c) Work up dimensions
d) Abstract measured quantities

7.3.2 Learning Outcome No 1: Prepare Tender Documents

7.3.2.1 Learning Activities

Learning Outcome No 1: Prepare Tender Documents	
Learning Activities	**Special Instructions**
1.1 ***Working drawings*** **(**Architectural, Structural, Electrical, Mechanical, Civil) are prepared 1.2 Identify ***Specifications*** (Material, Workmanship) are prepared 1.3 Bill of quantities is prepared 1.4 Schedule of rates are prepared 1.5 Condition of contract is prepared 1.6 Form of agreement is prepared 1.7 Form of tender is prepared	• Direct instruction • Project • Case studies • Field trips

7.3.2.2 Information Sheet No7/LO1: Prepare Tender Documents

Introduction to learning outcome

This learning outcome covers prepare tender documents, working drawing, specification and bill of quantities.

Definition of key terms

Bill of quantities: These are documents that contains all measured quantities required for the completion of the project.

Tender documents: This is a document containing specifications, BoQ, schedules as well as working drawings that are to be used during the project.

Content/Procedures/Methods/Illustrations

1.1 *Working drawings* (Architectural, Structural, Electrical, Mechanical, Civil) are prepared as per client requirements

Working drawings are a guide to how the final outcome should resemble. These drawings should be followed closely and interpreted in the right way to ensure that the project being undertaken meets the desires of the client.

Such drawings include:

a. Architectural drawings

Architectural drawings form the back bone for all construction works. This is because, it defines the site plan as well as the placing of objects and the required type of material needed for the construction works.

b. Structural drawings

Structural drawings define the specific sizes of the structural members. These structural members could be beams, columns, and load bearing walls as well as trusses.

The structural drawings are fully dependent on the architectural drawings.

c. Electrical drawings

These drawings normally show the position of electric switches as well as positions for electronics installations.

d. Mechanical drawings

e. Civil drawings

These includes drawings for highway/ transport projects. They define the materials to be used as well as the thickness of the transport system.

Apart from the transport system drawings, civil drawings also define the positions of water and waste water pipes.

1.2 Identify *Specifications* (Material, Workmanship) are prepared as per SOPs

Specifications are such as designs, drawings, blueprints etc.

- They describe the work, material as well as the kind of work that need to be done by the contractor.
- The type of material and its required quality should never be compromised for any project.
- It is very important to ensure that as a contractor you have clearly understood the specifications of your work and hire someone to interpret to you if need be.
- Also, the contractor is expected to involve only experts in the given field to work with otherwise, he/she, might compromise the quality of the work done.

1.3 Bill of quantities is prepared based on specifications and working drawings

Bill of Quantities, (BOQ) is a document that contains all measured quantities required for the completion of the project. The BoQ is prepared in such a way that it meets specifications and drawings provided.

Below is a sample BoQ.

Table 12: A sample BoQ.

	Item	Quantity	Unit price	Total price
1	Cement	25bags	1000/=	25000/=
2	Ballast	20 lorries	800/=	16000/=
3	Sand	15 lorries	1500/=	22500/=
4	Steel, T16	250kg	100/=	25000/=
5	Steel, T12	400kg	200/=	80000/=
6	Masonry	20 lorries	300/=	6000/=

Note: The data above is only used for the purpose of demonstrating how a BoQ looks like. The values are not correct.

1.4 Schedule of rates are prepared as per SOPs

These are provided by the contractor pertaining the rates of plants hire, man power costs as well as rates of work completion. The schedule of rates is commonly developed by the contractor who submits it to the client. This is important as it gives a clear indication on what is expected on site and the client can easily supervise the kind of work done.
Due to the variation in contracts types, schedule of rates differs as well.

1.5 Condition of contract is prepared based on nature of the project

Contract is a legal agreement between two or more parties. For example, an agreement between the client and the contracting company. Every contract is unique in its own way depending on the nature of the project. The key elements in any contract are;

- Payment considerations
- Exists an offer and an acceptance
- Both parties have an intention to create a legal relationship

The different types of contracts are:

a. Lump sum contract
  - This type of contract is also known as fixed contract.
  - In this type of contract, the contractor agrees to do a specified amount of work at a fixed amount of money.

b. Admeasurement contracts
  - It is also known as measure and value contract.
  - For this contract, the client provides the Bill of Quantities and the contractor quotes against each of the listed items in the BoQ.
  - The sum of the item costs forms the total project cost.
  - Other types of contracts under admeasurement contracts include; -
    - ♦ Cost plus contracts
    - ♦ Unit price contracts

c. Turnkey contract

- In this type of contract, the contractor is given the work and has to delivered the project in a completion. The client doesn't take part in any decisions in this type of contract.
- Instead, he/she can hire a developer who makes such decision for them.

d. Design and build

- As the name states, the contractor agrees to do both design and construction works.
- This method has become common these days as many engineers are turning into contractors and do the entire design and construction works.

1.6 Form of agreement is prepared as per the conditions of the contract

These are standardized forms in which the agreement of the client and the contracting company is put.

Standard forms (forms of agreement) differ based on;

- Type of the project
- Main contract or sub-contract
- Public or private works
- Local or international

Some of the standard forms include:

- Joint Building council Kenya (JBC)
- The FIDIC
- Public Procurement Oversight Authority (PPOA)
- The Orange book

1.7 Form of tender is prepared based on the nature of the contract

Also known as the tender document. As discussed above there are different contracts. Different contracts contain different tender forms.

However, certain elements in the tender forms are common and they include: -

- Work Drawings
- Specifications
- Bill of quantities
- General conditions
- Construction schedule

Tender forms are normally issued before the contract can be awarded to a contractor. Once the form is filled with the relevant information, it is submitted back to the client who gives consideration to one contractor who meets the threshold of his specifications putting budget into considerations.

Conclusion

This unit covers competencies required to perform measurement of works and cost estimation. It involves preparing tender documents, taking off quantities, working up dimensions and abstracting measured quantities

Further Reading

7.3.2.3 Self-Assessment

Written Assessment

1. The following are types of contracts which one is not?
   a) Turn key
   b) Lumpsum contract
   c) Design and build contract
   d) Public contracts
2. Which of the following is not included in the BoQ?
   a) Quantity
   b) Unit price
   c) Specifications
   d) Item
3. Working drawings are necessary for any engineering works. Which of the following is not a working drawing?
   a) Civil drawings
   b) Mechanical drawings
   c) Civil works
   d) Electrical drawing
4. Which of the following is not a standard contract form?
   a) JBC
   b) PPOA
   c) BoQ
   d) FIDIC

5. Nature of the contract document depends on the following except?
    a) Public/private works
    b) Local/international works
    c) Type of the project
    d) Time of the year
6. Tender forms have the following except?
    a) Specifications
    b) Construction schedule
    c) FIDIC
    d) BoQ
7. What is not included in a contract document?
    a) Payment considerations
    b) Exists an offer and an acceptance
    c) Both parties have an intention to create a legal relationship
    d) Specifications
8. Define turnkey contracts
9. What is Bill of quantities
10. Why is it important to tender?
11. What are civil drawings?
12. Define civil drawings
13. Compare and contrast Turnkey contracts and design and build contracts
14. Describe the different types of working drawings

Oral Assessment

1. In your own understanding define tendering
2. Who is eligible for tendering?

Oral Assessment

1. Why do you think it's important to tender?
2. How is the tendering system in Kenya today?

Practical Assessment

Obtain a Tender document and try to interpret it.

7.3.2.4 Tools, Equipment, Supplies and Materials

- Computers
- Office equipment
- Calculators
- Scale rule

7.3.2.5 References

Ashworth, A. Contractual procedures in the construction industry.

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Brook, M. (2004). Estimating and tendering for construction work. Amsterdam: Elsevier Butterworth-Heinemann.

7.3.3 Learning Outcome No 2: Take Off Building Quantities

7.3.3.1 Learning Activities

Learning Outcome No 2: Take Off Building Quantities	
Learning Activities	**Special Instructions**
2.1 Prepare dimension sheet/paper 2.2 Prepare List of quantities to be measured 2.3 Book Dimensions 2.4 Describe booked items	• Demonstrate using charts • Practical assessment • Group work

7.3.3.2 Information Sheet No.7/LO2: Take Off Building Quantities

Introduction

This learning outcome covers Acquiring and interpreting Building plans as per workplace procedures, Preparing Dimension sheet/paper based on the standard format, Preparing List of quantities to be measured based on SMM, calculating Quantities based on the unit of measure Book Dimensions based on the principles of measurement and Describing Booked items based on the standard method of measurement for building and associated civil works (SMM) and civil engineering standard method of measurements (CESMM).

Definition of key terms

Dimension sheet/paper- a piece of paper divided into a series of columns concerning multiplication factors, dimensions, squaring and work descriptions used in taking off

Building plans: A set of drawings prepared by the design consultant as a means of communicating construction information in form of floor plans, elevations, cross sections, site plans.

Civil engineering standard method of measurements (CESMM): This is an interpretation format used by civil engineers to prepare bills of quantities for civil work.

Content/Procedures/Methods/Illustrations

1.1 Dimension sheet/paper is prepared based on the standard format

A dimension sheet is an important part of taking off as it is a tool that assists in the identification, measurement and pricing of elements for construction works.

A dimension paper is made up of a series of columns each concerned with informational specific aspect. The most commonly used method of ruling of dimension paper conforms to the requirements of B.S 3327: 1961-Stationery for Quantity Surveying

Procedure for preparation of dimension sheet

i. Split the sheet of paper into two identically ruled parts each consisting of four columns.

1	2	3	4	1	2	3	4

Column 1 is known as the "timesing column" in which multiplying figures are entered when there is more than one of the particular item being measured.

Column 2 is known as the "dimension column" in which the actual scaled dimensions are provided in the drawing are entered.

Column 3 is known as the "Squaring Column" in which the length, area or volume obtained by multiplying together the figures in column 1 and 2 is recorded, ready for transfer to the abstract or bill.

Column 4 is known as the "description column" in which a written description of each item is entered.

ii. For each work item input the material information provided in the appropriate column.

iii. Compute the qualities and generate the accompanying costs.

1.2 List of quantities to be measured is prepared based on SMM

The items used in the taking off procedure may be determined through the following procedure:

i. Analyzing the scope of work to be done based on the drawings given.
ii. Break down the work into construction tasks.
iii. Systematically arrange the tasks into a check list with work activities following a chronological order.
iv. Generate the material requirements list with regard to the specific tasks being covered.
v. Consider items with no given material but require a cost.

1.3 Quantities are calculated based on the unit of measure

Computation phase of the taking off process is usually done using the information contained in the first three columns that is the time sing dimension and the squaring column.

Procedure for computational of building process

i. In the time sing column, indicate the number of times an item with the measurement appears; to avoid replicating calculations.
ii. In the dimension column, indicate the measurement value provided in the drawings.
iii. In the squaring column, multiply the measurement value provided with the factor indicated in the time sing column. The value obtained should be correct to 2 d.p.
iv. Repeat these steps for all recurring items within a specific task.
v. Add the values obtained together in the squaring column and double underline the total value of measurement.

Check list (work items)

- Site clearance
- Excavate vegetable soil
- Excavate for foundation
- Concrete blinding
- Concrete footing
- Foundation walling
- Backfilling
- Hardcore fill
- Blinding to hardcore above
- DPM
- BRC mesh

- Concrete in floor bed
- Apply plaster to walls
- Paint walls

Item 1 Site Clearance

A	B	C	D
2/	11.10	O.40	
2/	0.20	1.00	
	0.50		
	11.10		
	0.40		
	1.00	12.50	
2/	6.00		
2	O.20	0.40	
	0.50		
	6.00		
	0.40		
	1.00		
		1.00	
	12.50		
	7.40		
		7.40	
		92.50	

Clear the site of all bushes and burn/dispose the arising.

1.4 Dimensions are booked based on the principles of measurement

The dimensions are entered into the dimension sheet following the principles below:

- They are set down in order of horizontal length, horizontal width and finally vertical depth.
- The units of measurements used include

LM- Linear meter i.e. 2M
SM- square meter i.e. 2M*2M
CM- cubic Meter i.e. 2M*2M*2M

KG- Kilogram
Enumerated Items i.e. Nr 3
The dimensions are then put in the dimension column as illustrated in the table below.

1.5 Booked items are described based on the standard method of measurement for building and associated civil works (SMM) and civil engineering standard method of measurements (CESMM)

The items that are entered into the dimension sheet are usually described in the description column. The description used is dependent on the format used; whether SMM or CESMM for CESMM refer to the example below
CESMM   Page 15, Class F: In Situ Concrete:
Item descriptions for components classed as other concrete forms shall include:

- The principal dimensions of the concrete component.
- The type or mark number of a concrete component whose principal dimensions are given on the drawings.
- A statement identifying or locating a concrete component whore principal dimensions are given on the drawings.

Conclusion

This learning outcome has covered Acquiring and interpreting Building plans as per workplace procedures, Preparing Dimension sheet/paper based on the standard format, Preparing List of quantities to be measured based on SMM, calculating Quantities based on the unit of measure Book Dimensions based on the principles of measurement and Describing Booked items based on the standard method of measurement for building and associated civil works (SMM) and civil engineering standard method of measurements (CESMM)

Further Reading

1. Read on the method of description of booked items from SMM 7^{th} edition
2. Read further on the principles of taking off from Building Quantities Explained by I.H. Sehley
3. Principles of Measurement from the principles of measurement for works of construction by the RICS group.

7.3.3.3 Self-Assessment

Written Assessment

1. The measurements used in taking off should be rounded off to?
    a) d.p
    b) d.p
    c) d.p
    d) 1 d.p
2. Linear measurement are recorded in the
    a) Dimension column
    b) Squaring column
    c) Description Column
    d) Timensing Column
3. Which of the following is not a unit of measurement?
    a) LM
    b) CM
    c) MM
    d) KG
4. Which column of the dimension sheet is not used during computation of quantities?
    a) Dimension
    b) Squaring
    c) Description
    d) Timensing.
5. Who among the Following consultants is not involved in the preparation of bills of quantities?
    a) Architect
    b) Engineer
    c) Quantity Surveyor
    d) Construction Manager
6. Which of the following is not considered when preparing a measurement list during a pre-contact stage?
    a) Scope of work
    b) Chronology of tasks
    c) Nonmaterial costs
    d) Contractors estimate

7. How many classes of work are contained in the CESMM?

a) 26
b) 30
c) 15
d) 20

8. What is meant by the term dimension sheet?
9. Enumerate the uses of SMM
10. Compare and contrast SMM and the CESMM?
11. Describe how plans are acquired and interpreted.
12. The dimension sheet is based on which industry standard(s)?

Oral Assessment

1. Analyse the principle of measurements
2. Develop a presentation on the preparation of dimension sheet.

Practical Assessment

You have been provided with the building documents for A 4-bedroom bungalow. Using this information;

a) Derive the building quantities.
b) Prepare a bill of Quantities (BOQ)

7.3.3.4 Tools, Equipment, Supplies and Materials

- Dimension sheets
- Abstract sheets
- Billing sheets
- Measuring tools
- Calculators
- CESSM/SMM

7.3.3.5 References

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7.3.4 Learning Outcome No 3: Work Up Dimensions

7.3.4.1 Learning Activities

Learning Outcome No 3: Work Up Dimensions	
Learning Activities	**Special Instruction**
3.1 Carry out Timesing of dimensions 3.2 Determine Quantities	• Conduct group discussions • Practical assessments • Project demonstrations

7.3.4.2 Information Sheet No7/LO3 Work Up Dimensions

Introduction

This learning outcome covers Carrying out Timesing of dimensions as per SOPs and Determining Quantities as per SOPs.

Definition of key terms

SOPs: (Standard Operating Procedures). These are the documented processes that a company has in place to ensure services or products are delivered consistently overtime

Timesing: This is the multiplication of measurements taken from taking off of the drawings in the dimension column during the preparation of Bill of Quantities.

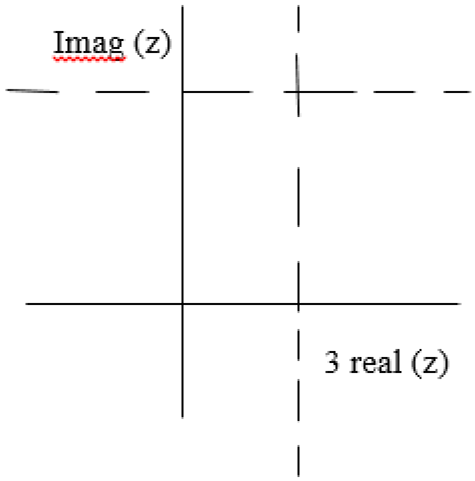
Content/Procedures/Methods/Illustrations

3.1 Complex numbers are represented using Argand diagrams

Argand diagram

A diagram on which complex numbers are represented geometrically using Cartesian axes. The horizontal coordinate representing the real part of the number and the vertical coordinate the complex part.

The vertical axis represents imaginary numbers. The axes cross ta zero, again just like in a Cartesian graph, eg a complex number like $z = 3 + 4i$ would have the co-ordinates $(3, 4)$ on an Argand diagram.



The horizontal axis is labeled Real (Z) and the vertical axis is labeled Imag (Z) where the word imaginary has been shortened to Imag.

The Argand diagram is used in the calculation of dimensions during the casting up and setting out during the construction.

3.2 Operations involving complex numbers are performed

A complex number is a number that can be put in the form $a + bi$ $a + b$ where a and b are real numbers and i is called the imaginary unit, where $iz = -1$ $i2 = -1$. Complex numbers have applications in many scientific areas, including signal processing, control theory, electromagnetism, fluid dynamics, quantum mechanics, and cartography and vibration analysis. Complex operations involve addition, subtraction, multiplication, etc, defined on ordered pairs of scalars according to conventions of complex algebra eg in the preparation of the abstraction sheet and the transfer of booked quantities within the sheet and the multiplication of the items to get the amount.

Example

Complex numbers in the running through dimensions in the Bill of Quantities in the taking off of quantities.

	2	3.00		EXCAVATIONS
		2.00		FOUNDATIONS
			6.00	
	3	3.00		DEDUCT
	3	3.00		FILING
			9.00	

Complex numbers evident in the symbols used in the construction of the Bill of Quantities. Some of the operations of complex numbers are as follows:

1. Simplify $\frac{3}{2i}$

$$\frac{3}{2i} = \frac{3}{2i} \cdot \frac{i}{i} = \frac{3i}{2i^2} = \frac{3i}{-2} = \frac{-3i}{2} = \frac{-3i}{2}$$

Whereby, $i^2 = -1$

2. Simplify $\frac{3}{2+i}$

Differentiation of squares in Complex Numbers

$$\begin{aligned}(a+bi)(a-bi) &= a^2 - abi + abi - (bi^2)\\ &= a^2 - b^2(i^2)\\ &= a^2 - b^2(-1)\\ &= a^2 + b^2\end{aligned}$$

The meanings of the symbols used in the running through dimensions is as follows:

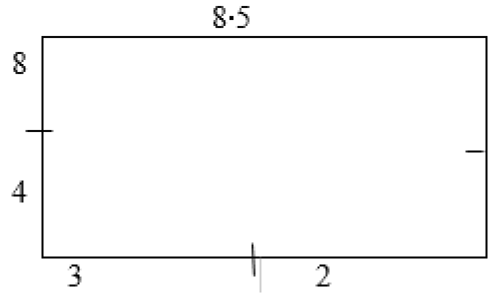
$$a^2 \rightarrow \textit{Square of } a$$

$$(-) \rightarrow \textit{Subtraction}$$

$$\frac{3}{2+a^2} \rightarrow \textit{Division of the number}$$

$$3i \cdot a^2\ (\cdot) \rightarrow \textit{Multiplication of the numbers}$$

The symbols come in handy in the running through dimensions eg on site as follows.



$Eg\ In\ the\ calculation\ of\ the\ areas\ of\ a\ site\ 12 * 8 = 96cm^2$

3.3 Calculations involving complex numbers are performed using De Moivre's theorem

De Moiré's Theorem

De Moiré's theorem gives a formula for computing powers of complex numbers. The theorem is applied during the multiplication of complex numbers by squaring the complex numbers.

The theorem states that:

$(cos\,\theta + i\,sin\,\theta)n = cos(n\,\theta) + i\,sin(n\theta)\ \forall n \in R\ \ where\ I\ is\ the\ root\ of\ -1.$

The examples

Given any complex number $cos\,\theta$+i$sin\,\theta$ and any integer n,

$(cos\,\theta + i\,sin\,\theta)^n$=$cos\,n\theta$+i$sin\,n\theta$

Whereby:

(1) $[cos\,\theta - i\ \ sin\,\theta]^n$ = $cosn\,\theta -$ i $sinn\,\theta$

(2) $[cos\,\theta + i\ \ sin\,\theta]^{-n}$=$cosn\,\theta - i\ \ sin\,\theta$

(3) $(cos\,\theta - i\ \ sin\,\theta)^{-n}$ =$cos\,\theta + i\ \ sin\,\theta$

(4) $sin\,\theta + i\ \ cos\,\theta =$ i($cos\,\theta - i\ \ sin\,\theta$)

Example One

If z= $(cos\,\theta + i\ \ sin\,\theta)$, show that $Z^n + {}^1/_{Z^n} = 2\ \ cos\,n\theta$ and

$$Z^n - [{}^1/_{Z^n}] = Zi\ \ sin\,\theta$$

By de Moivre's solution;

$$Z^n = (cos\,\theta + i\ \ sin\,\theta)^n = cos\,n\theta + i\ \ sin\,n\theta$$
$$Z^n = (cos\,\theta + i\ \ sin\,\theta)^n = cos\,n\theta + i\ \ sin\,n\theta$$
$$\frac{1}{Z^n} = Z^{-n} = cos\,n\theta - i\ \ sin\,\theta$$

Therefore, $Z^n + \frac{1}{Z^n} = (cos\, n\theta + i\ \ sin\, n\theta) + (cosn\,\theta - i\, sin\, n\theta)$

$$Z^n + \frac{1}{Z^n} = 2\, cos\, n\theta$$

Similarly, $Z^n - \frac{1}{Z^n} = (cosn\,\theta + i\, sin\, n\theta) - (cosn\,\theta - i\, sinn\,\theta)$

The $cos\,\theta$ and $tan\,\theta$ are among the symbols used in casting up and running through e.g in calculations of the angles of a site during design.

Conclusion

This learning outcome has covered Carrying out Timesing of dimensions as per SOPs and Determining Quantities as per SOPs.

Further Reading

Research further on the applications of De Moivre's theorem and applications of complex numbers in construction industry.

7.3.4.3 Self-Assessment

Written Assessment

1. What is timesing?
   a) Division of measurements during taking off on site.
   b) Multiplication of measurements during taking off.
   c) Measurements of site dimensions.
   d) Using a tape measure to determine dimensions of site.
2. What is the threshold requirement of the column numbers in an abstracting sheet
   a) Four
   b) Six
   c) Three
   d) Five
3. Which of the following best states the De Moivre's theorem mathematically?
   a) $(cos\,\theta + i\ \ sin\,\theta)n = \ cos(n\theta) + i\ \ sin(n\theta)\forall n \in R$
   b) $cos\,\theta = tan\,\theta * i\, sin\,\theta$
   c) $cos\,\theta + sin\,\theta i + tan\,\theta i$
   d) None of the above

4. What is the meaning of this symbol as used in work up dimensions? a^2
    a) Division of the number
    b) Multiplication of the number
    c) Square of the number
    d) Subtraction of the number
5. Which of the following is not part of running through dimension
    a) Dimension of the measured variables
    b) Symbol of the measurement
    c) The extended line
    d) Arrowheads
6. On an abstracting sheet, the stroke symbol below an entry of the first column represents?
    a) Divide
    b) Multiply
    c) Add
    d) Subtract
7. Which of the following procedures is often indicated on the third column of abstracting sheet
    a) Dimensioning
    b) Multiplication
    c) Squaring
    d) Description
8. What is meant by timesing?
9. Outline the De Moivre's theory and state its application
10. Explain the meanings of three symbols used in work up dimensions
11. Describe the applications of complex numbers in dimensioning.
12. Elabourate on the procedures performed during timesing

Oral Assessment

1. Simplify $\frac{3}{2+i}$
2. If z= $(cos\, \theta + i\ \ sin\, \theta)$, show that $Z^n + {}^1/_{Z^n} = 2\ \ cos\, n\theta$ and

$$Z^n - [{}^1/_{Z^n}] = Zi\ \ sin\, \theta$$

Practical Assessment

1. Use De Moivre's formula to find $z7$ where z=1+i.
2. Perform the indicated operation and write your answer in standard form.
    a) $(4 - 5i)(12 + 11i)$
    b) $(-3 - i) - (6 - 7i)$
    c) $(1 + 4i) - (-16 + 9i)$

7.3.2.4 Tools, Equipment, Supplies and Materials

- Dimension sheets
- Abstract sheets
- Billing sheets
- Measuring tools
- Computers
- Office equipment
- Calculators
- Computer software
- CESSM/SMM
- Stationer
- Dust coat
- First aid kit

7.3.2.5 References

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7.3.4 Learning Outcome No 4: Abstract Take Off Data

7.3.4.1 Learning Activities

Learning Outcome No. 4: Abstract Take Off Data	
Learning Activities	**Special Instructions**
4.1 Prepare Abstracting sheet 4.2 Transfer Description of booked items to the abstracting sheet 4.3 Transfer Quantities **(**Cubic, Square, Linear, Numbers (enumeration)) to the abstracting sheet 4.4 Calculate Net quantities 4.5 Carry out Running through dimensions	• Classroom instructions • Group work activities • Practical work

7.3.4.2 Information Sheet No. 7/LO. 4 Abstract Take Off Data

Introduction

This learning outcome covers: Preparing abstracting sheet based on the standard format**,** transferring description of booked items to the abstracting sheet as per sops**,** transferring **quantities (**cubic, square, linear, numbers (enumeration)) to the abstracting sheet, calculating net quantities as per sops and carrying out running through dimensions as per SOPs.

Definition of key terms

Abstracting sheet – this is the tabulated summary of an in-depth building or any construction analysis mainly done by the quantity surveyor for all the construction work.

Taking off – this refers to the detailed measurement of materials and labour to the required specifications that are needed to ensure the successful completion of construction projects. This entails the breakdown of the project into specific units that are easier to measure.

Booked quantities – these are quantities shown on a sale order which are not restricted by any means and are not associated with any particular orders.

Content/Procedures/Methods/Illustrations

4.1 Abstracting sheet is prepared based on the standard format

Abstract sheet

No.	Item Description	Quantity	Rate	Per	Amount

Figure 92: Sample Abstract sheet

An abstract sheet is normally prepared by a quantity surveyor and is mainly divided into several sections depending on the complexity and size of the construction project. Within those sections, there are specific requirements that need to be fulfilled in order to achieve the accurate measurements for all quantities. On the abstracting sheet, there is usually the name of the project e.g. KENCOM Towers. This project name is usually stated at every stage and each stage is normally arranged in a chronological order as per the activities that will be carried on the ground. In each section, there is a list of activities that will be carried out and, on each activity, there is a list of building materials to be used.

Dimensions must be provided for each of the materials used and areas where necessary in case one is accounting for materials such as poured concrete. An abstract sheet is normally prepared during the design stage of a project after all the architectural designs are prepared and before construction commences. It is normally done to measure the accurate dimensions of the building materials to be used for proper costing.

4.2 Description of booked items are transferred to the abstracting sheet as per SOPs

The items to be transferred to an abstracting sheet are obtained from the working drawings and specifications of the building materials by the architect. Once the quantity surveyor has analysed the architect's specifications, he/she writes them down in the abstracting sheet in the required thickness e.g. Structural timber rafters of 100mm by 50 mm. (Insert picture, specifications sample 1 and 2).

After writing down the required material thickness the quantity surveyor calculates the required size of the building materials in accordance with the standards units of measurements (Si units) whether in dimensions. (Length and Width) or in other areas.

These calculations are derived from the architectural plans and elevations provided by the architect. During this stage, the booked items are normally transferred to a rough abstracting sheet where all the calculations are done before transferring them to a clean sheet.

4.3 Quantities are transferred to the abstracting sheet

When transferring the quantities to an abstracting sheet, the following procedure must be followed.

Note: The abstraction sheet contains four columns

Table 13. Abstraction sheet columns

A	B	C	D
This is the multiplication column	This is the dimension column. All quantities in this column are added as per the specific section.	This is the squaring column. All quantities in this column are added as per the specific section.	This is the description column

i. At the beginning of the abstract sheet, all sections are stated in a chronological order as per the activities to be carried out during the construction process.
ii. Dimensions of each quantity are then recorded in the second column of the abstract sheet.
iii. Write down the number of quantities of quantities required to be multiplied on the first column in order to determine the total dimensions required for the specific quantity. If there is only one quantity required, there is no need to fill the first column. When indicating the number of multiplied, always use the stoke symbol below the number e.g. 6/ to indicate that the quantity needs to be multiplied by six.
iv. After multiplying, fill in the new dimensions on the third column where all quantities of the same nature are added up.
v. Provide a brief description of the specific quantity stating its thickness for instance in wood, ratios in case of concrete or any other detail of a material that is specific to it.

4.4 Net quantities are calculated as per SOPs

Description of calculations on the fourth column

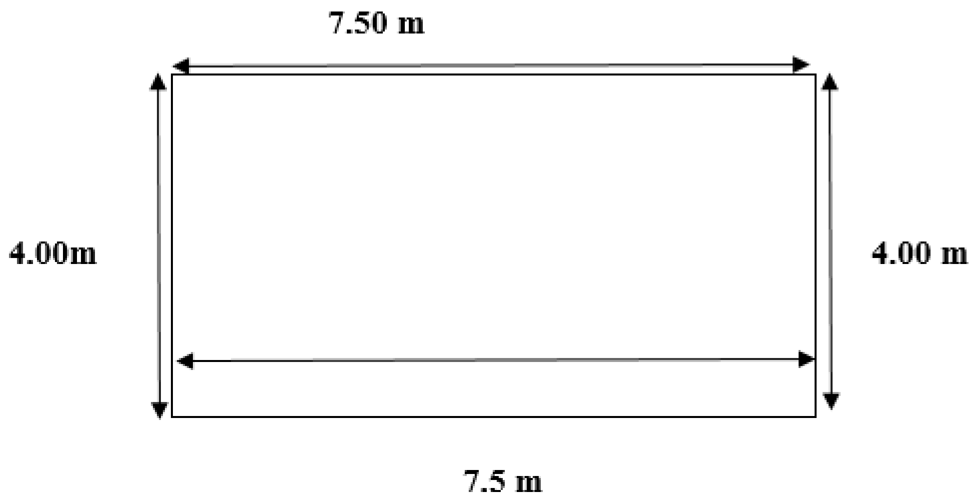
A	B	C	D
	5/	5/	This represents an item that has been repeated 5 times
4/	1/	4/	This means the same item can be expressed as 4 multiplied by 1
	5.00	5.00	This means that the length of the item is 5 meters. NB: The difference between 5.00 and the 5 at the first row is the decimal point. Once a decimal point is introduced. The item ceases to be in quantity and becomes a measurement.
	8.00 4.00	12.00	This means that the lengths of 8 meters and 4 meters are added together to get 12 meters
	8.00 4.00	32.00	This means that the area if the item is 32 square meters and it has sides measuring 8 meters and 4 meters.
	3.00 2.00 7.00 6.00	6.00 42.00 48.00	This section shows two areas that add up to 48 square meters. Whereas in the second column, lack of a line below a measurement means multiplication with the underlying measurement, in the third column, lack of a line means addition.
	5.40 3.60 50.00	 972.00	This means that the item has been measured as a volume of 972 cubic metres consisting of a length of 5.4 metres, width of 3.6 metres and a depth/height of 50 metres
	5.00 3.00 7.00	 15.00	The lines separating the dimensions indicate three separate linear measurements that ass up to 15 meters unlike the three measurements in the above row which indicate a volume.

4.5 Running through dimensions is carried out as per SOPs

A running dimension is that which is taken from one end of the structure to another end but has multiple points in between that increases consistently. Running dimensions are usually used to mark out boundaries and other linear measurements of items which constitute a perimeter whether on regular or irregular polygons when setting out. The dimension itself has one extension line, one arrow head and a numerical value of the item being dimensions.

Below is an example.

Running Dimension



When carrying out running through dimensions, one must first identify the number of complete sides and partitions that a proposed project has. Using a tape measure, measure the lengths of each sides and partitions of the proposed construction project. Draw and extended line along the side of the partition with arrowheads at both ends. Write the dimensions of the sides or partitions on top of the extended line. Repeat the above procedure to all the other sides and partitions hence making up their running through dimensions.

Conclusion

This learning outcome has covered: Preparing abstracting sheet based on the standard format**,** transferring description of booked items to the abstracting sheet as per sops**,** transferring **quantities (**cubic, square, linear, numbers (enumeration)) to the abstracting sheet, calculating net quantities as per sops and carrying out running through dimensions as per SOPs.

Further Reading

1. Find and research more on the various standards and formats of abstracting sheets.

7.3.4.3 Self-Assessment

Written Assessment

1. Which one of the following procedures is normally indicate on the fourth column of an abstracting sheet?
    a) Dimensioning
    b) Squaring
    c) Description
    d) Multiplication
2. On an abstracting sheet, the stroke symbol below on entry on the first column represents?
    a) Divide
    b) Add
    c) Multiply
    d) Subtract
3. Which one of the following is not part of a running through dimension?
    a) Arrowheads
    b) Dimension unit of measurement
    c) An extended line
    d) Symbol of measurement

4. Which one of the following clearly shows the difference between 5 and 5.00 on an abstracting sheet?
    a) One is a measurement unit while the other shows the quantity of an item.
    b) Both are the same
    c) One has a decimal point and the other does not
    d) None of the above
5. When is an abstracting sheet prepared?
    a) During construction of a project
    b) Before architectural drawings are prepared
    c) During project commissioning
    d) After preparation of architectural drawings but before construction
6. During transferring of booked quantities on an abstracting sheet, which of the following is not included?
    a) Number of booked quantities
    b) Description of booked quantities
    c) Price of the booked quantities
    d) Dimensions of the booked quantities

7. What is the minimum number of columns that a standard format abstracting sheet have?
    a) Four
    b) Six
    c) Three
    d) Five
8. Enumerate procedures represented by each column on an abstracting sheet.
9. Elabourate the use of underlined quantity on an abstracting sheet.
10. Using a sketch illustration, draw and state the various parts of a running through dimension.
11. Outline the basic standard units of measurement used in abstracting sheets.
12. Compare and contrast between booked items and net quantities in relevance to abstracting take off data.

Oral Assessment

1. Outline the steps taken when ferrying quantities to an abstracting sheet.
2. Analyse the relevance of preparing an abstracting sheet in quantity surveying.

Practical Assessment

In groups of five members, prepare an abstracting sheet for an architectural drawing that one of your members has done.

7.3.2.4 Tools, Equipment, Supplies and Materials

- Dimension sheets
- Abstract sheets
- Billing sheets
- Measuring tools
- Computers
- Office equipment
- Calculators
- Computer software
- CESSM/SMM
- Stationer
- Dust coat
- First aid kit

7.3.2.5 References

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CHAPTER 8: WATER AND WASTEWATER TECHNOLOGY

8.1 Introduction of the Unit of Learning

This unit describes the competence required to apply water & wastewater technology practices. It involves applying basic water supply principles, principles of wastewater collection & treatment and basic irrigation & drainage principles.

8.2 Performance Standard

Apply basic water supply principles, principles of wastewater collection and treatment, and basic irrigation and drainage principles based on particular use, demand, water source, water characteristics and quality, design, international standards, water system, and code of practice.

8.3 Learning Outcomes

8.3.1 List of Learning Outcomes

a) Apply basic water supply principles
b) Apply principles of wastewater collection and treatment
c) Apply basic irrigation and drainage principles

8.3.2 Learning Outcome No 1: Apply Basic Water Supply Principles

8.3.2.1 Learning Activities

Learning Outcome No 1: Apply Basic Water Supply Principles	
Learning Activities	**Special Instructions**
1.1 Calculate water demand 1.2 Identify sources of water 1.3 Identify water abstraction methods 1.4 Identify water treatment processes 1.5 Identify water pipes and appurtenances 1.6 Identify water supply symbols 1.7 Identify water distribution systems 1.8 Identify water storage structures 1.9 Observe work safety	• Direct instruction • Field trips • Discussions • Demonstration by trainer • Practice by the trainee • On-job training

8.3.2.2 Information Sheet No8/lo1: Apply Basic Water Supply Principles

Introduction to learning outcome

This learning outcome covers water demand, sources of water, water abstraction methods, water treatment processes, water pipes and appurtenances, water supply symbols, water distribution and water storage structures.

Definition of key terms

Appurtenances- Is a sub class of something belonging to a broader class.

Water abstraction- It's obtaining water from its source to serve different purposes as chosen by human beings like irrigation.

Water Appurtenances- distinct devices needed to regulate water movement during supply

Content/Procedures/Methods/Illustrations

1.1 Calculate water demand based on particular use

Water demand also referred to as water use is the mean daily use per person (per capita). Water demand include;

- Industrial:130-140 l/d
- Domestic: 48-52 l/d
- Institution and comercial: 18-24 l/d
- Public and civil use: 8-10 l/d
- Agriculture
- Recreation

Calculation of demand per capita

q=total yearly use of the city in litres/ (365*design population)

Design population will vary according to particular use for example industrial use design population will be given by the industrial area or the capacity of blending beverage.

1.2 Identify *Sources of water* based on demand and particular *use.*

There are three major providers (sources) of water.

i. Surface water include lakes, rivers, oceans etc.
ii. Ground water include aquifers etc.
iii. Rainwater

For a long time, the surface water sources were used to satisfy water needs but due to increased water demand and industrialisation man come up with other ways to obtain more water to cater for the rising demand since ground water was also not readily available for use.

1.3 Identify Water abstraction methods based on the water source

Water abstraction methods are ways through which water is taken away from its source either permanently or temporarily mostly for agricultural purposes like irrigation or water curing for drinking and they include;

- **Surface water abstraction-** which is acquiring water from a river by laying a perforated drain pipe below the river bed to collect water.
- **Ground water abstraction** – involves acquiring water from a ground provider e.g. aquifer.

1.4 Identify Water treatment processes based on water characteristics and water quality.

Water treatment processes methods

Water treatment is the improvement of the physical, chemical and microbiological properties of water (water quality) to make it acceptable for a particular use in the end or for environmentally safe discharge back to the hydrological cycle.

Water characteristics include; polarity, cohesion, adhesion and high specific heat and also have to reach the acceptable standards. Waste water has these characteristics distorted and thus has to be restored for example it has a very unpleasant smell, increased temperature due to bio-chemical activities, high turbidity due to suspended material among others. Water treatment process include;

Waste, surface and storm water treatment process

- **Collection**- is water from different places is brought together via a system of pipes which normally contains household water.
- **Screening and staining**-this is the removal of objects like plastic and metal that can cause damage and cogging of downstream equipment
- **Chemical addition**-chemicals like sodium chloride and potassium chloride are added and aid in the organic contaminant removal by exchange of ions.
- **Coagulation and flocculation-** removal of suspended solid from water.
- **Sedimentation and clarification**-is the removal of the suspended matter by adding compounds and stirring. These suspended materials vary in property and the added compounds cause them to collide and grow hence they seize to be suspended and thus easily removed.
- **Filtration**- is the separation of the solid from the liquid using a filter
- **Disinfection**- is the killing of germs and can be done using UV chlorine among others
- **Storage**- keeping the water before it is released to the public as different tests are being run on it to confirm treatment
- **Distribution**- supply of water to users after treatment

Other treatment methods include reverse osmosis where excess ions are removed depending on the end use of the water. There is also ocean water treatment that removes the excess salts among others like bottled water treatment, containerised water treatment etc.

1.5 Identify Water pipes and appurtenances based on the design

Water pipes –are hollow tubes designed to transport treated water to the final user

They include:

Figure 93: water pipes
Source; Lee Wallender, the Spruce

1. PEX Pipe

PEX, or cross-linked polyethylene, pipe is one of the newest and most popular pipes to hit the plumbing market. PEX is used only to supply water. PEX is a pipe that is rigid enough to withstand the pressures of water supply but flexible enough to weave throughout walls, ceilings, basements, and crawlspaces. PEX has truly delivered water-supply plumbing into the hands of do-it-yourself and professional plumbers.

Pros

- Color-coded red for hot water and blue for cold water
- Highly flexible, with 90-degree curves possible
- Attaches with push-fit plumbing fittings, among other types
- Inexpensive
- Able to join with copper pipe
- Cuts easily

Cons

- Long-term capabilities untested
- May leak with push-fit plumbing fittings
- Cannot be recycled

1. PVC Pipe

PVC, or polyvinyl chloride, pipe is a drain or vent line type of plumbing pipe. PVC initially gained popularity because it was lighter and easier to work with than traditional galvanized steel pipe. PVC pipe is moderately easy to install and requires little more than a hacksaw and a meter box to cut. PVC glues together with solvents.

Pros

- Diameters clearly marked on the white surface of the pipe
- Inexpensive and can be used for long runs such as for irrigation
- Easier to work with than steel or copper

Cons

- The pipe cannot be unjointed and must be cut
- Glued pipes can be prone to leaking
- Degrades in sunlight

2. Rigid Copper Pipe

Rigid copper is often used for water supply lines within the home. Rigid copper is easily cut with a hacksaw or with a special copper tube cutter. The connection is a different matter, as it requires a practiced hand to solder copper pipe together. Rigid copper pipe is great for water supply because it does not come with any health risks.

Pros

- Though it is called rigid, this pipe can be slightly bent
- Handles heat well
- Stands up against intense pressures
- Easy to recycle and waste copper pipe even has monetary value

Cons

- Difficult for do-it-yourselves to work with due to soldered connections
- Expensive
- Develops pinhole leaks
- Inside of pipe may eventually corrode and impede water flow

3. ABS Pipe

ABS (acrylonitrile butadiene styrene) pipe is mainly used as a vent and drain line. ABS pipe looks very much like PVC pipe, except that it is black and slightly softer.

Pros

- Stronger than PVC pipes
- Good for underground exterior use
- Works well in cold temperatures

Cons

- Often not permitted by building code
- Warps and deforms at certain temperatures

4. Flexible Copper Pipe

Flexible copper pipe or tubing is used for final runs to water heaters, refrigerators, and some sinks. Flexible copper is used only for short runs and can be cut with ease with a hacksaw. It can be bent to fit around corners.

Pros

- High heat Fits in tight, unusually shaped areas
- tolerance

Cons

- Expensive
- Thin and prone to breaking

5. Galvanized Steel Pipe and Cast Iron

Two additional types of pipe are sometimes found in older homes and are infrequently installed, especially by do-it-yourself steel and cast-iron pipe. Galvanized steel pipe was used for decades for drainage, water supply, gas supply, and any number of other purposes. While galvanized steel pipe is still around (particularly for gas supply) it is far less used and is never used for water supply in new construction or remodel projects. Each end of the pipe is threaded, and individual pipes are screwed into each other with connecting joints. Cast iron pipe was often used for sewer and other drainage purposes. Cast iron pipe is still found in many homes. Cast iron pipe is viable until the point that it rusts completely through. Cast iron is very heavy and difficult to cut. Retrofits tend to replace cast iron pipe with rigid plastic pipes such as ABS.

Pros

- Galvanized steel pipe has the advantage of being extremely strong.

Cons

- Galvanized steel pipe eventually corrodes and blocks water flow.
- Some galvanized steel pipe may pass lead into the water supply.

Others include;

- Metallic (GI, Steel, ductile iron, cast iron)
- Plastic (PVC, uPVC, CPVC, PE, PPR, PEX)
- Cement (RC pipes)

Appurtenances – these are devices needed to control the flow water, cub leakages and carry out other functions in water supply systems.
Reasons for using appurtenances include;

- For efficient and less hectic water supply
- To regulate opposite direction flow of water the pipe
- To reduce wastage and leakages in pipes
- To control the flow of water
- To ensure water is used for the intended function

Properties of these appurtenances includes:

- Strength- should be very strong
- Durability-highly durable
- Cost- should be economical
- Resistance- should have high resistance to corrosion
- Flexibility- should be easy to remove and maintained and repair

The appurtenances include;
1. **Valves**- devices that regulate the flow and pressure within a system
Types of valves ;(gate valve, sluice valves, ball valves, globe valves, butterfly valves, check valves, PRV, pressure relive valves, float valves, air valves, washouts)

Functions of valves;

a) Release or allow in air
b) Regulate water flow
c) Regulate the pressure build up
d) Regulate direction of flow
e) Stop or start flow

2. **Meters-** device used to determine the amount of water being discharged through a pipe
Types of meters; (displacement meters, velocity meters, ultra-sonic, electromagnetic.)

a) Properties of a good meter;
b) Should have low resistance to water flow
c) Should be less reactive
d) Should have high accuracy to avoid error
e) Should be cost effective

3. **Fittings** (couplings, adapters)
4. **Tanks and bib cocks** (taps which are used to stop or allow outflow of water from a system)

1.6 Identify Water supply symbols based on international standards

Water supply symbols- water supply is the providing of water by public service, commercial organisation or individuals while the symbols are diagrammatic expressions of the different parts in the supply system and they are shown below.

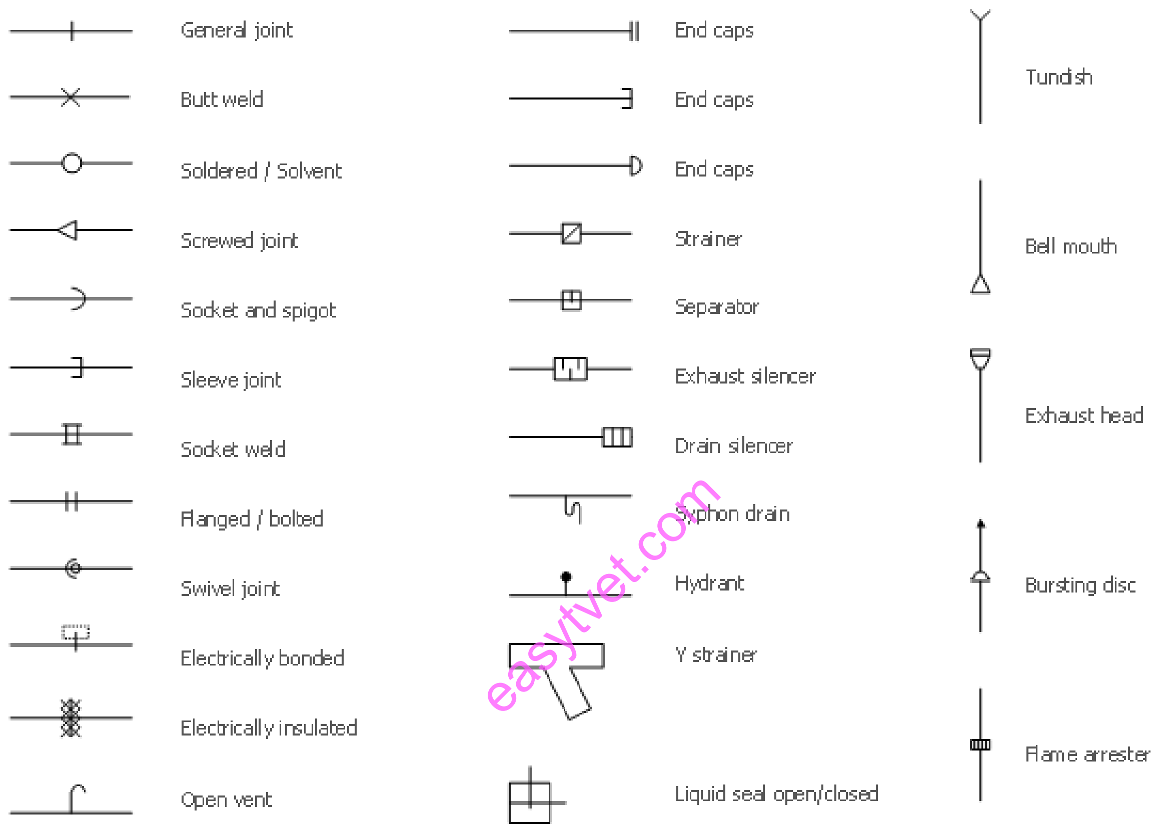

Figure 94: Water supply symbols

Source; Design Elements-Pipes (part 1) Plumbing and piping plans

1.7 Identify Water distribution systems based on design

Water distribution systems-ensures water supply using technically synced hydrological and hydraulic components. The main function of a distribution system is to ensure satisfactory quality and quantity of water.

Characteristics of a good distribution system

- Water quality should be maintained
- Pressure should be maintained at all intended places
- Pipes should be laid 1m apart
- It should be a watertight system to minimize losses

Below are the types of water distribution systems

- **Grid iron system**- in this system the main line lies at the centre and the branches
- **Radial system**- in this system the area is divided into subareas with a central water storage at a higher elevation than the distribution pipe and is located radially from the edge of the distribution sub area
- **Dead end or tree system** - the main pipe lines at the centre of the area then sub branches branch from both sides in a manner demarcating the area and have further sub branches.
- **Circular or ring system**- the main line forms a circle around the distribution area and the branches cross the main and each other too

1.8 Identify Water storage structures based on water system

Water storage structures- these are manmade features that serve a purpose of storing water

- **Weirs and Dams**- a dam is barrier across a river and form a reservoir upstream while a weir is a small-scale dam and raises water level upstream
- **Tanks** (elevate, surface and sub-surface)- large container for water storage
- **Water pans& ponds**

1.9 Observe Work safety based on code of practice

Work safety refers to general precaution are important in every scope of life. Safe to prevent injuries, loss of life and property damage. Work safety rules while operating tools and machinery includes:

- Operate a machine when you are well conversant with it and you have the necessary authority.
- Clean and arrange tools after use
- Take heed to any operating instruction
- Put on PPE’s and other protective gadgets
- No operation of unauthorised machinery
- Follow operating instructions
- Be aware of fire hazards

Conclusion

This learning outcome covered water demand, sources of water, water abstraction methods, water treatment processes, water pipes and appurtenances, water supply symbols, water distribution and water storage structures.

Further Reading

Read further on advantages and disadvantages of each water distribution system. https://sswm.info/sswm-university-course/module-2-centralised-and-decentralised-systems-water-and-sanitation-1/network-design-and-dimensioning

10.3.2.3 Self-Assessment

Written Assessment

1 Explain and differentiate the following water sources.
   a) Ground water
   b) Runoff water
   c) Surface water
   d) Rainwater

2 Select which of the following is not an appurtenance and explain their function.
   a) Gate
   b) Sluice
   c) Butterfly
   d) Tap

3 Which one is not a characteristic of water?
   a) Adhesion
   b) Polarity
   c) Flowrate
   d) Specific heat

4 Summarize 5 functions of valves in the water distribution system

5 Classify 3 types of pipes used in the water supply system

6 Distinguish and name any 7 water supply symbols

7 Explain 6 characteristics of a good water distribution system

8 A dam is a structure built across a river while a weir is a small-scale dam. Distinguish the two and summarize what each structure entails.

Oral Assessment

1. Evaluate the importance of adhering to work safety practices as per the code of standards?
2. Explain the importance of water treatment in the water supply chain

Case Study Assessment

You have been given an area around Lake Victoria to come up with a water distribution method. After a field survey select a distinguished system and explain its relevance.

Performance Based Evidence

Oral Assessment

Distinguish between flocculation and coagulation?

Explain the chemical treatment of water. What happens and which chemicals are used.

Practical Assessment

Class visit to Nairobi water and evaluate which distribution system is commonly used in Nairobi and prepare a report on the field visit.

8.3.2.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Relevant reference materials
- Stationery
- Relevant practical materials
- Labouratories (chemical, biological & soils)
- Internet
- Projector

10.3.2.5 References

Clark, R. M., Sivaganesan, M., Selvakumar, A., & Sethi, V. (2002). Cost models for water supply distribution systems. Journal of Water Resources Planning and Management, 128(5), 312-321.

Matilainen, A., Lindqvist, N., Korhonen, S., & Tuhkanen, T. (2002). Removal of NOM in the different stages of the water treatment process. Environment international, 28(6), 457-465.

8.3.3 Learning Outcome No 2: Apply Principles of Wastewater Collection and Treatment

8.3.3.1 Learning Activities

Learning Outcome No 2: Apply Principles of Wastewater Collection and Treatment	
Learning Activities	**Special Instructions**
2 .1 Identify Need for wastewater collection and disposal 2 .2 Identify ***Sources of waste water*** 2 .3 Illustrate ***Sewer system layout*** 2 .4 Identify ***Sewerage systems*** 2 .5 Illustrate ***Sewer appurtenances*** 2 .6 Characterize ***Wastewater*** 2 .7 Identify ***Wastewater treatment processes*** 2 .8 Describe ***Principles of Wastewater treatment*** 2 .9 Identify ***Wastewater symbols*** 2 .10 Identify ***Wastewater colour coding*** for pipes and exhauster trucks 2 .11 Observe Work safety	• Direct instruction • Field trips • Discussions • Demonstration by trainer • Practice by the trainee • On-job training

8.3.3.2 Information Sheet NO8/L02: Apply Principles of Wastewater Collection and Treatment

Introduction to learning outcome

This learning outcome covers Sources of waste water, Types of sewers, Sewerage systems, Characteristics of wastewater, Sewer appurtenances, Wastewater Treatment processes and disposal, Wastewater symbols and Wastewater colour coding for pipes and exhauster trucks.

Definition of key terms

Sewer- is an underground tunnel for carrying sewage

Sewer appurtenances are devices along a sewerage system placed at reasonable intervals to aid in the proper function of the system

Wastewater refers to contaminated water and not fit for human use

Content/Procedures/Methods/Illustrations

2 .1 Identify Need for wastewater collection and disposal based on water quality standards

Waste water is water that has been contaminated and therefore cannot be released in to the environment without the removal of the contaminants themselves because of the factors listed below;

i. To avoid ground water pollution- when the waste water is left uncollected and disposed on land it seeps underground leading to ground water contamination which supposed to be a source of water for future generations thus unsustainability

ii. To avoid killing marine life which may further lead to extinction of some species as this waste water if not treated finds its way to the seas and oceans and due to its distorted composition, it cannot support marine

iii. May lead to an imbalance in the ecosystem since every part of the ecosystem depends on water and if this water is

2 .2 Identify Sources of waste water based on water quality standards

Sources of waste water-main supply of waste water. Waste water characteristics vary depending on its source

- **Industrial**- waste produced by industrial processes
- **Domestic waste**- is waste generated from the house water that include grey water and black water
- **Storm waste**-waste generated from runoff water
- **Agricultural waste-** waste generated mostly from the farm that include fertilizers

2 .3 Illustrate Sewer system layout based on sewerage design manual

Sewer system layout is a plan of system of conduits that carry waste from the point of generation to where it is treated.

There are two types of sewer system layouts; domestic and industrial and storm system lay out

Requirements for system layout;

- The outlet for the system must be specified
- The area of coverage by the tributary should be estimated
- The site for the main sewer and tank should be identified
- Identify suitable location for a pump
- The system should adheres to the topography of the area and the main sewer should be at a lower topography
- The mains should be designed to take in future loads as well
- Minimum distance of 3m between waste water pipes and clean water pipe should be observed as per the code
- Manhole should be positioned at the layout junction
- During construction the area is first excavated after all considerations have been put in place then the pipes are laid.

2 .4 Identify *Sewerage systems* based on the design

Sewerage systems is a combination of tunnels from the generation source to treatment them release of waste water. There are 3 types

- Domestic and industrial system-normally involve treatment before release into the environment
- Storm system- involves a temporary storage before its channelled and disposed back to stream or river
- Combined system where storm is mixed with domestic and industrial waste and treated the same way

2 .5 Illustrate *Sewer appurtenances* based on sewer code

Sewer appurtenances are devices along a sewerage system placed at reasonable intervals to aid in the proper function of the system and they include

- **Manholes** (Shallow, Deep, Drop), -is an opening to a confinement underground and is used to access the sewer system
- **Inlet**- pathway from the manhole top
- **Catch basins**- infrastructure engineered to drain of excess water from surfaces or pavements
- **Clean out** –used to remove unwanted material
- **Flushing tank**- this is the collection point
- **Flushing units,**
- **Lamp holes**

2 .6 Characterize Wastewater based on effluent discharge regulations (NEMA).

Wastewater is water which has lost its water determining characteristics through human use contamination

There are physical characteristics;

- Odour-bad smell due to contamination
- High temperature due to increased reaction
- High turbidity due to dissolved substances

2.7 Identify Wastewater treatment processes based on wastewater characteristics

Wastewater treatment processes- deals with the process that take place during waste water treatment

i. Collection- is water from different places are brought together via a system of pipes which normally containing household water majorly.
ii. Screening and staining-this is the removal of objects like plastic and metal that can cause damage and cogging of downstream equipment
iii. Chemical addition-chemicals like sodium chloride and potassium chloride are added and aid in the organic contaminant removal by exchange of ions.
iv. Coagulation and flocculation
v. Sedimentation and clarification-is the removal of the suspended mater by adding compounds and stirring. These suspended materials vary in property and the added compounds cause them to collide and grow hence they seize to be suspended and thus easily removed.
vi. Filtration- is the separation of the solid from the liquid using a filter Sludge digestion,
vii. Sludge drying
viii. Waste stabilization ponds (Anaerobic, Facultative, and Maturation)
ix. Disinfection- is the killing of germs and can be done using UV chlorine among others
x. Storage- keeping the water before it is released to the public as different tests are being run on it to confirm treatment
xi. Distribution- supply of water to users after treatment

2.8 Describe Principles of Wastewater treatment based on treatment unit.

Principles of Wastewater treatment- deals with the process that take place during waste water treatment

- Collection- is water from different places are brought together via a system of pipes which normally containing household water majorly.
- Screening and staining-this is the removal of objects like plastic and metal that can cause damage and cogging of downstream equipment

- Chemical addition-chemicals like sodium chloride and potassium chloride are added and aid in the organic contaminant removal by exchange of ions.
- Coagulation and flocculation
- Sedimentation and clarification-is the removal of the suspended mater by adding compounds and stirring. These suspended materials vary in property and the added compounds cause them to collide and grow hence they seize to be suspended and thus easily removed.
- Filtration- is the separation of the solid from the liquid using a filter Sludge digestion,
- Sludge drying
- Waste stabilization ponds (Anaerobic, Facultative, and Maturation)
- Disinfection- is the killing of germs and can be done using UV chlorine among others
- Storage- keeping the water before it is released to the public as different tests are being run on it to confirm treatment
- Distribution- supply of water to users after treatment

2.9 Identify Wastewater symbols based on international standards
Wastewater symbols

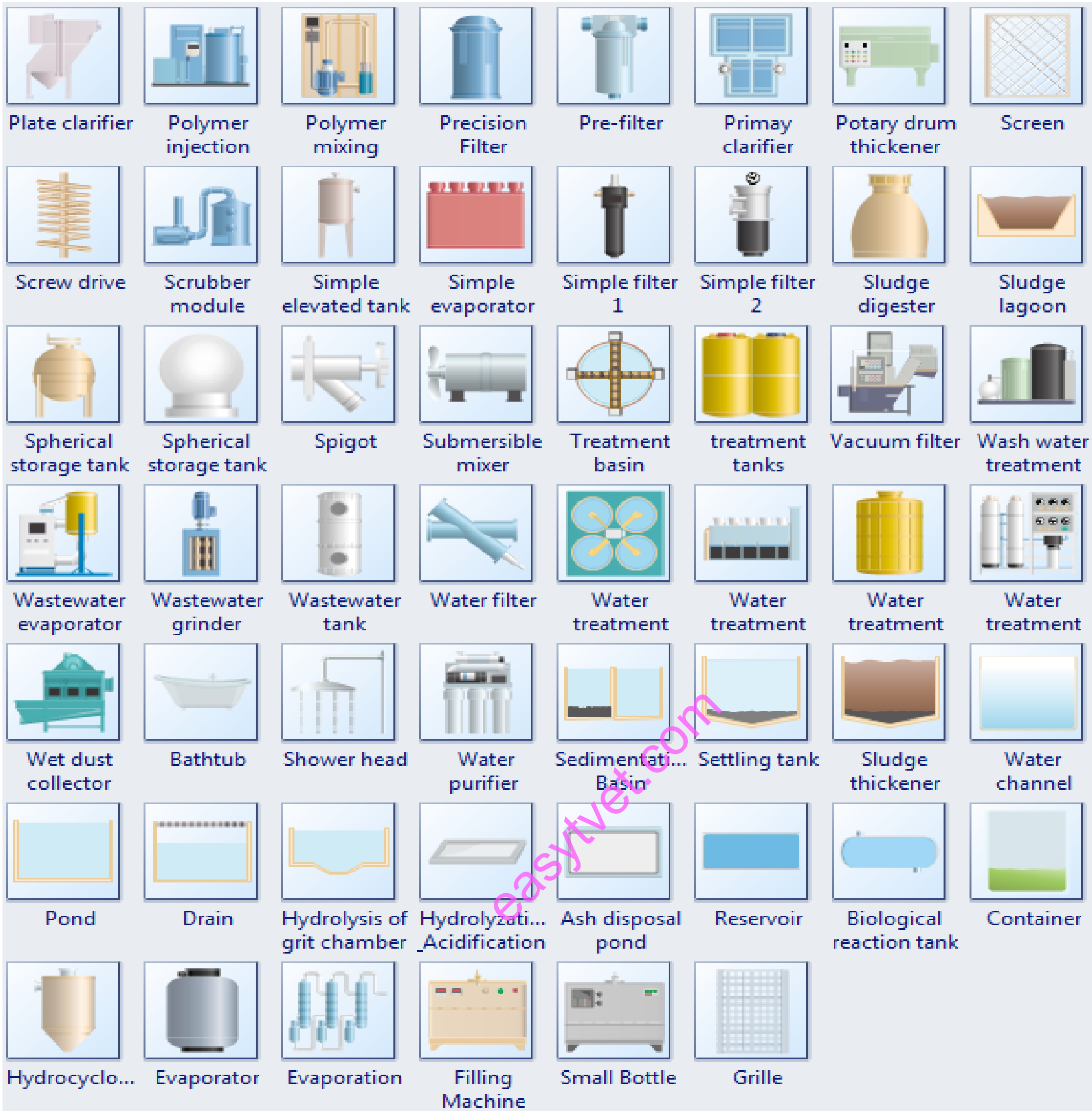

Figure 95: International Standards Wastewater Symbols

Source; https://www.edrawsoft.com

2.10 Identify Wastewater colour coding for pipes and exhauster trucks based on international standards.

Wastewater colour coding-help in content identification

Table 14 **:** Wastewater colour coding

Waste line	Pipe content	colour
	Backwash waste	Light brown
	Sludge	Dark brown
	Sanitary sewage	Dark grey

2.11Observe Work safety based on code of practice Operate a machine when you are well conversant with it and you have the necessary authority.

- Clean and arrange tools after use
- Take heed to any operating instruction
- Put on PPE's and other protective gadgets
- No operation of unauthorised machinery
- Follow operating instructions
- Be aware of fire hazards

Conclusion

This learning outcome covered sources of waste water, types of sewers, sewerage systems, characteristics of wastewater, sewer appurtenances, wastewater treatment processes and disposal, wastewater symbols and wastewater colour coding for pipes and exhauster trucks

Further Reading

Read further on sewer systems layouts

Read further on the chemical and biological characteristics of waste water

8.3.3.3 Self-Assessment

Knowledge Based Evidence

Written Assessment

1. The following are sewer appurtenances select which one is not.
   a) Hide out
   b) Manhole
   c) Clean out
   d) Catch basin
2. Distinguish and explain waste water systems except one
   a) Sanitary system
   b) Storm system
   c) Ground system
   d) Industrial system
3. Summarize the requirements for a sewer system layout
4. Explain the reasons for waste water treatment
5. Explain clearly what happens in each of the water treatment ponds

Essay questions

Describe the waste water treatment process

Oral Assessment

1. Explain the factors to be considered when laying out a sewer system
2. Explain what happens in the chemical treatment of waste water

Case Study Assessment

The sewer system in your area is not meeting the demands of the government. You have been assigned the duty to realize and solve the problem. Predict the possible reasons for failure and how to deal with each one.

Practical Assessment

You class is to carry out a field visit to a nearby water treatment plant and asses the immediate sewer system. Prepare and compile a report of the two visits

8.3.3.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Relevant reference materials
- Stationery
- Relevant practical materials
- Labouratories (chemical, biological & soils)
- Internet
- Projector

8.3.3.5 References

Hsu, M. H., Chen, S. H., & Chang, T. J. (2000). Inundation simulation for urban drainage basin with storm sewer system. Journal of Hydrology, 234(1-2), 21-37.

Wirahadikusumah, R., Abraham, D. M., Iseley, T., & Prasanth, R. K. (1998). Assessment technologies for sewer system rehabilitation. Automation in Construction, 7(4), 259-270.

8.3.4 Learning Outcome No 3: Apply Basic Irrigation and Drainage Principles

8.3.4.1 Learning Activities

Learning Outcome No 3: Apply Basic Irrigation and Drainage Principles	
Learning Activities	**Special Instructions**
3.1 Determine the Crop water requirement 3.2 Prepare Land 3.3 Identify Irrigation farm layout 3.4 Identify ***Quality of irrigation water*** 3.5 Identify ***Irrigation methods*** 3.6 Identify ***Methods of drainage*** 3.7 Observe Work safety	• Direct instruction • Group work • Demonstration by trainer • Practice by the trainee • Field trips • On-job-training

8.3.4.2 Information Sheet No8/LO3 Apply Basic Irrigation and Drainage Principles

Introduction to learning outcome

This learning outcome covers Soil, plant-water relationship, Land preparation, Sources of water for irrigation, Irrigation farm layout, Quality of irrigation water, Irrigation methods and Methods of drainage.

Definition of key terms

Drainage: Drainage is the removal of excess surface or subsurface water by the use of artificial mechanisms.

Farm layout: It is the location of fields concerning the function for which the land area

Land preparation: It is the process of harrowing land

Content/Procedures/Methods/Illustrations

3.1 Determine the Crop water requirement based on agronomic requirements

All the water that gets to the root zone is not utilized by the crop but escapes to the atmosphere in the form of water vapour through a process of transpiration. Soil surfaces experience water loss through evaporation. The water demand for a crop will thus consist of transpiration plus evaporation, also called evapo-transpiration expressed in mm/day.

3.2 Prepare Land based on the crop, type of irrigation method, size of the land, topography and available technology

Considering furrow irrigation, it is important to ensure sufficient wetting of the root zone, while maintaining minimum percolation losses at the top of the field and minimum runoff at the end of the field. The stream size must be of the right size to reach the end of the furrow in approximately one-quarter of the contact time.

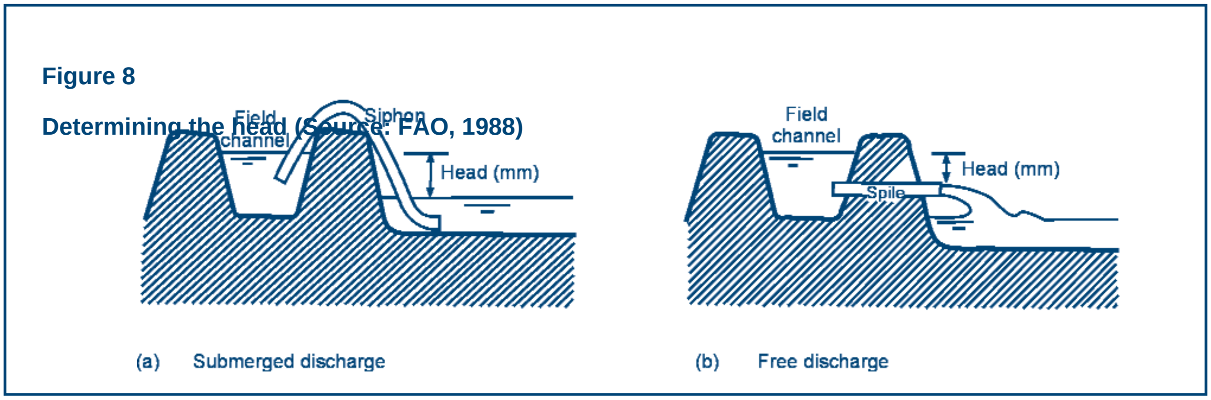

Figure 96: Irrigation method
Source: Irrigation Manual Vol II, (2002)

3.3 Identify Irrigation farm layout based on design principles

Factors to consider when determining scheme layout include topography, farm size and degree of mechanization, and the possible length of furrows.

Surface irrigation layout

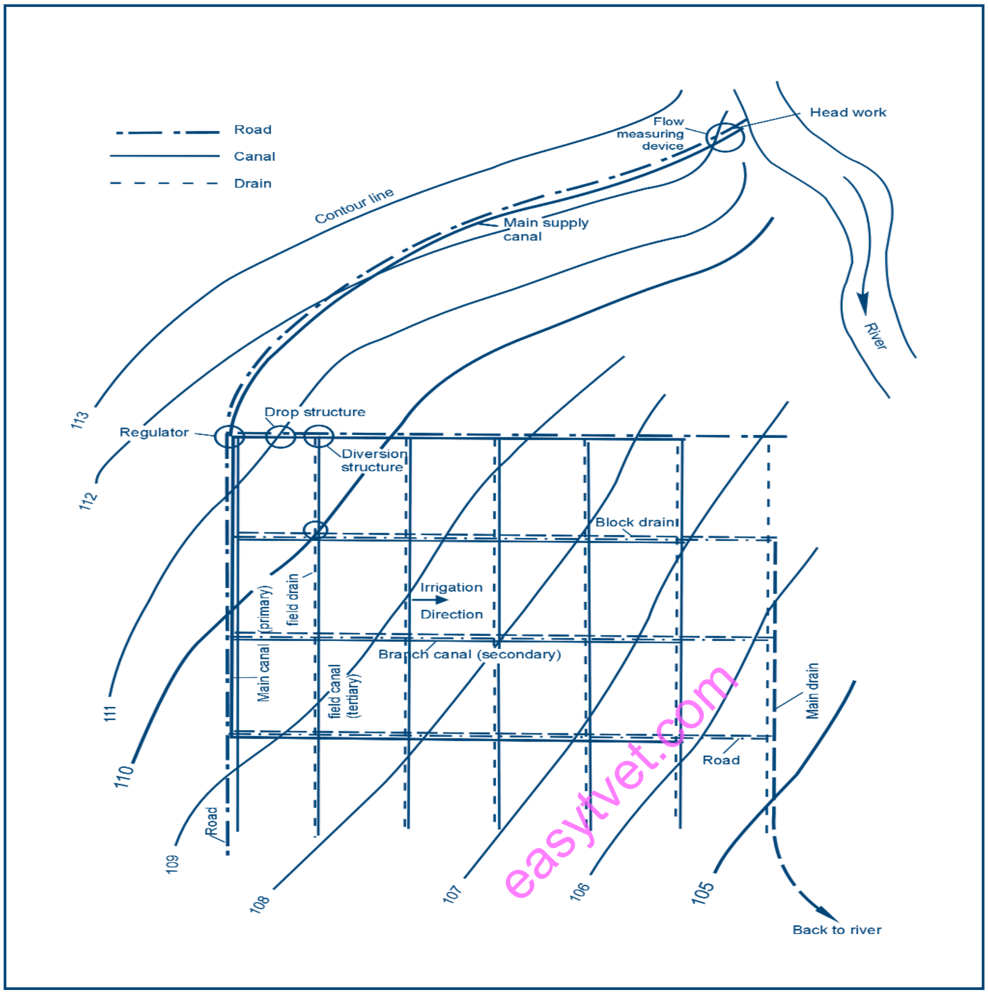

Figure 97: Surface irrigation layout
Source Irrigation Manual Vol II, (2002)

3.4 Identify Quality of irrigation water based on the standards (Physical, Chemical, biological)

The quality of water for irrigation is determined as the composition of soluble salts in the water. The water quality is key in terms of sustainability in using the water for various purposes. The criteria for irrigation water quality concerning purpose is as follows;

Irrigation Water quality standards

Table 15: Irrigation Water quality standards

Parameters	Unit Measure	Adequate for Irrigation	Warning	Extreme Restrictions
pH		6.00 ÷ 8.00	5.00–5.99 8.01–9.00	<5.00 >9.00
EC	dS m^{-1}	<0.70	0.70–6.50	>6.50
SAR		<3.00	3.00–9.00	>9.00
E. coli	mean number per 100 mL	<1000		>1000
Intestinal nematodes	arithmetic mean n. of eggs per litre	<1		>1
TSS	mg L^{-1}	<200	200–400	>400
HCO_3	mg L^{-1}	<150	150–300	>300
Fe	mg L^{-1}	<0.50	0.50–1.50	>1.50
Mn	mg L^{-1}	<0.10	0.10–1.50	>1.50
H_2S	mg L^{-1}	<0.50	0.50–2.00	>2.00

Source Irrigation Manual Vol IV, (2002)

3.5 Identify Irrigation methods based on the type of crop, type of soil, resources available, quantity, and quality of water.

Irrigation methods are the various ways by which water is applied on land and the method to be used is chosen based on economy **topographical** factors, **crop type**, and s**ource of water.**

1. Surface irrigation

The water application is either a controlled or uncontrolled manner. Water is distributed to the field by the use of small channels, which inundate the area to be irrigated up to the desired depth. The controlled method employs the use of corrugations, furrows, or ridges with water being guided from the head ditch.

2. Subsurface irrigation

Irrigation water is applied to the root zone utilizing buried pipes forming an underground network. The network comprises of mains, sub-mains, and laterals. The perforations allow the water to drip out at very slow rates allowing the soil around the root zone to absorb water continuously.

3. Overhead irrigation

This method employs sprinkler systems to distribute water in form of spray rain droplets The system consists of a network of interconnected mains sub mains, and lateral. The laterals are fitted with a series of nozzles through which water emanates as a fountain

3.6 Identify *Methods of drainage* based on crop water requirement, type of soil, quantity, and quality of water, (surface, and sub-surface).

Drainage is the removal of excess surface or subsurface water by the use of artificial mechanisms. A drainage system is the composition of the appurtenances used to remove water from the soil. Agricultural drainage criteria specify the highest levels allowable for the water table in or on the soil so that benefits are not hampered by waterlogging.

Methods of Drainage

They can be classified into two:

- Surface drainage system: Used when water logging is experienced on the soil surface
- Subsurface drainage system: Used when water logging extends in the soil

Checked drainage systems are allowed to function temporarily especially during crop seasons that are critical in crop development. Regular drainage systems also called relief drainage are supposed to be operational regularly as possible. Interceptor drainage employed to intercept surface water by installing catch canals

3.7 Observe Work safety based on the code of practice

- Work safety revolves around training of farmers on occupational safety and health to ensure that they can reduce mitigate and avoid certain risk on the firm and avoid unsafe work practices.
- Adequate allocation of resources to the enforcing bodies
- Risk assessment: to improve on safety and health in an irrigation scheme, the first thing is to assess the capacity to reduce, mitigate and avoid risks
- Provision of personal protective equipment

Conclusion

This learning outcome covered soil, plant-water relationship, land preparation, sources of water for irrigation, irrigation farm layout and quality of irrigation water, irrigation methods and methods of drainage

Further Reading

Read on pipeline design for an irrigation system

8.3.4.3 Self-Assessment

Written Assessment

1. Select what is used to measure the hydraulic conductivity?
    a) Manning's constant
    b) Runoff coefficient
    c) Ernest's formula
    d) Reynolds number
2. In a farm layout surface system the following are commonly used in irrigation, which one is the odd one out?
    a) Furrows
    b) Basins
    c) Nozzles
    d) Siphon
3. Examine which one is not a factor to consider in irrigation system design?
    a) Topography
    b) Surface tension
    c) Soil texture
    d) Water source
4. Select which one is not a specification for sprinkler system?
    a) Laterals
    b) Main
    c) Piston
    d) Gate valves
5. Explain why pumps are used in sprinkler irrigation by selecting on of the following.
    a) To raise the pump head
    b) To avoid cavitation
    c) To worm the irrigation water
    d) To raise alarm in case of an invasion
6. Differentiate types of the localized irrigation
7. Distinguish the components of a localized irrigation system

Essay question

Explain how to determine optimal furrow length in a furrow irrigation system

Oral Assessment

Summarize water quality parameters significant in irrigation water

Practical Assessment

Investigate the soil properties in your locality and evaluate the type of irrigation system suitable for application.

Project Assessment

Design a sprinkler irrigation system providing for the sizes for all components and then provide for the pipeline to convey water from intake works to the farm.

8.3.4.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Relevant reference materials
- Stationery
- Relevant practical materials
- Labouratories (chemical, biological & soils)
- Internet
- Projector

8.3.4.5 References

Mehla, M. K., Singh, Y. P., Ramesh, J. B., & Sharma, V. (2020). Farm Irrigations Systems Design Manual. *Publish Book Online*, *2*(1), 1-62.

Chapter 9: WATER RESOURCES, WATER SERVICES AND SANITATION MANAGEMENT PRINCIPLES

9.1 Introduction

This unit describes the competencies required to apply water resource management principles. It involves determination of hydrological processes, quantification of surface water, mapping of rock types and aquifers, establishment of suitable site for wells. It also involves conservation of environment and development of water harvesting structures. It also involves application of water and environmental law in water resource management and application of integrated water resources management (IWRM) principles.

9.2 Performance Standard

Determine hydrological processes, quantify surface water, map rocks and aquifers, establish well sites, conserve the environment, develop water harvesting structures, apply water and environmental law in water resource management, apply integrated water resources management principles based on WMO guidelines and OSH.

9.3 Learning Outcomes

9.3.1 List of Learning Outcomes

a) Determine hydrological processes
b) Quantify surface water
c) Map rocks and aquifers
d) Establish well sites
e) Conserve the environment
f) Develop water harvesting structures

9.3.2 Learning Outcome No 1: Determine Hydrological Processes
9.3.2.1 Learning Activities

Learning Outcome No 1: Determine Hydrological Processes	
Learning Activities	**Special Instructions**
1.1 Identify ***concepts of Hydrological cycle*** 1.2 Identify precipitation types and forms 1.3 Determine precipitation 1.4 Determine evaporation rate 1.5 Determine stream flow 1.6 Observe safety in hydrometry	• Project • Case studies • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

9.3.2.2 Information Sheet No9/LO1 Determine Hydrological Processes

Introduction to learning outcome

This learning outcome covers concepts of hydrology, hydrological cycle and hydrological processes, principles and application. The different areas of hydrology include drainage management, surface hydrology, hydrometeorology, hydro-informatics, isotope hydrology, eco-hydrology among others

Definition of key terms

Hydrology: - This is a branch of science that deals with the properties of the earth's water in relation to its movement, occurrence, and distribution near the earth's surface.

Hydrological cycle: It is the water recycling system which includes the sum of processes in which water moves around the earth. It's also called the water cycle. The elements of the cycle are evaporation, condensation, transportation, precipitation, groundwater, inflow and surface runoff.

Infiltration: It is the process of flow of water from the ground surface as it enters the subsurface layers.

Percolation: After water has entered the soil them it has to flow through it. The movement of water through the soil layers by forces of gravity, and capillarity.

Condensation: It is the transformation of a substance physical states of matter from gaseous phase into the liquid phase.

Content/procedures/methods/illustrations

1.1 Identify concepts of Hydrological cycle based on WMO guidelines Concepts of Hydrological cycle

Hydrological cycle is the water cycle that describes the movement of water from atmospheric surfaces to subsurface levels. The main benefit is the temperature regulation, soil formation, creates rainfall, mineral circulation and the presence geological features

Stages involved include:

1. **Evaporation:** The hydrological cycle starts with evaporation which occurs when water is changed from liquid to gaseous state factors that contribute to evaporation include, vapour pressure, solar radiation, atmospheric pressure and wind currents. Water absorbs energy from the turning into vapour. The transformation normally occurs larger scales in oceans, seas, lakes and storage reservoirs.
2. **Condensation:** Condensation is the process by which physical states of water vapour changes to liquid state at points which vapour in the air is at saturation point, in the form of particles in the form of clouds, fog, and dew. It’s an exothermic process that releases heat which was initially utilized in forming water vapour to the environment
3. **Precipitation:** When water particles fall from the atmosphere to the ground surface. Frictional drag forces and gravitational forces influence the particle decent till it hits the ground.
4. **Runoff:** The flow from the drainage basin that appears in surface streams. It consists of flaw that is unaffected by human or natural activities of diversion.
5. **Infiltration:** Infiltration involves water transfer as it seeps across the boundary layer of soil and is normally associated with soil profile, soil permeability and soil porosity.
6. **Percolation:** The movement of water that through the soil by virtue of capillary and gravitational forces is called percolation. Water contained in the aeration zone is called vadose water. In the saturation zone the water stored here becomes groundwater.

1.2 Identify precipitation types and forms based on WMO guidelines Precipitation types (Orographic, Convective, and Cyclonic)

The phase in which precipitation falls to the ground characterize the type of precipitation. The phase be either liquid or solid and sometimes transient which occurs in between the two. The forms of precipitation include, ice crystal, hail, snow, and graupel. Occurrences of precipitation commences when air saturated with water vapours, is no longer able to sustain the levels of water vapor in gaseous form. The process starts when dense moist air cools when an air mass rises through the atmosphere. The types of precipitation include:

1. Cyclonic

When a boundary of two air masses with different densities meet, the air which wormer and less dense rises above the colder air which is denser creating an effect of precipitation. Also called frontal precipitation which is as a result of frontal systems surrounding extra tropical cyclones. When worm air forces out an already existing cold air mass, it creates a worm front which is characterized with long periods of light rain. Cold fronts occur when denser cold air pushes worm air mass. The process occurs sharply causing intense precipitation with shorter durations.

2. Convection

When the earth's surface surrounded by an unstable moist atmosphere, is heated more than its surrounding, significant evaporation occurs. This type of precipitation is caused by convective clouds (cumulonimbus).

3. Orographic

Is also called relief rainfall which occurs when air masses are forced up the side of land formations as a result of adiabatic cooling normally referred to as an upslope effect. Relief features like mountains are subjected to consistent winds leading to a moist climate on the windward side which is the upwind side of a mountain than on the leeward side which is the downwind side. Rain shadow occurs when orographic lift removes moisture leaving drier air.

1.3 Determine precipitation based on the WMO guidelines Precipitation

Precipitation is determined in terms of the amount that reaches the ground over a certain duration and is expressed as the depth it would cover a given horizontal projection of the earth's surface.

The form of measurement adopted is by taking representative samples of the fall over the area to which measurement is required.

Rain gauge is used to measure rainfall by taking the catch of the instrument as the representation of precipitation within an area of perfect exposure.

The rain gauges can be classified as recording and non-recording. In a non-recording gauge precipitation is measured by a graduated cylinder and a graduated dip rod.
Error correction is necessary since they arise due measuring the catch or due to uncertainty effects arising instrument exposure. Daily gauges are read to the nearest 0.2 mm, weekly readings to nearest 1mm. recording gauges include the **weighing type**, **float type**, **tipping-bucket type**, **rainfall intensity recorder**. Snow consisting of ice crystals in flaky form is measured directly with graduated dip stick or scale

1.4 Determine evaporation rate based on WMO guidelines

The methods applicable in determination of evaporation include pan evaporation, evaporation models, and the water balance equation. The penman equation is applied in data analysis.

Penman Equation

$$Eo = \frac{700Tm/((100-A)+15(T-Td))}{(80-T)}\, mmday^{-1}$$

Where:
Tm = T +0.006h, h = Elevation (meters), T = Mean temperature, A = latitude (degrees)
Td = dew point value, (T-Td) = monthly means (obtained from tables)

1.5 Determine stream flow based on the WMO guidelines

Stream flow measurements can be either be **direct methods** or **by the use of hydraulic formulas**. Direct methods will be highlighted in this case since they present results of higher quality data.

Main methods

a) **Volumetric Method:** Discharge is calculated based on the time that has elapsed and volume of water run into graduated reservoir. This method is suitable for low discharge conditions. Water runways or flood gates can be used in case of specific measurements.

b) **Velocity Area Method:** This method is conducted by measuring the fluid flow speed at different points of a section and then the surface area of the wetted section.

c) **Hydraulic Methods:** This is determined by employing a correlation of forces which include Viscosity, Inertia, and weight of fluid

d) **Physical methods:** Physical properties of the fluid like concentration of dissolved elements and their variations during water flow are taken in to consideration

1.6 Observe safety in hydrometry based on OSH

Hydrological measurements are usually made over a wide range of conditions, some of which are hazardous. Appropriate training is necessary in order to create awareness of the hazards and the ways to avoid or minimize them. The use of Personal Protective Equipment should be encouraged at all times

Some of the hazards are shown in the following table and how they occur.

Table 16: Hazard consideration

Hazard	**Considerations**
Safety at recording station	Access (steps, ladders, footpaths) Platforms (slippery surfaces, handrails) Wells (falling)
Safety on bridges	Traffic hazard Suspended equipment
Safety while wading	Wadding techniques Safety lines and taglines Lifejackets Mishap technique
While working on boats	Lifejackets Use of tag lines Use of dinghies

Conclusion

This learning outcome covered Concepts of hydrology, Hydrological cycle and Hydrological processes, principles and application

Further Reading

1. Meteorological data collection instruments
2. Applications of hydrology in engineering

9.3.2.3 Self-Assessment

Written assessment

1. In determining evaporation, the penman equation is used. Distinguish which of the following is not a variable in the equation?
    a) Net radiation
    b) Heat capacity
    c) Atmospheric pressure
    d) Density
2. In the water cycle the mass balance equation is used to quantify precipitation, select one variable that is not applicable in computing precipitation
    a) Evaporation
    b) Outflow
    c) Evapotranspiration
    d) Inflow
3. Hydrological services should aid in achieving sustainable development goals. Select which one is not provided under the services rendered?
    a) IWRM
    b) WRA
    c) Water quality assessment
    d) Land conflict resolution
4. While collecting hydrometric data, select which of the following will be a safety precaution to observe
    a) Measure the length and width of land below
    b) Use of tag line while reading a rain gauge
    c) Use of life jacket while processing hydrometric data
    d) Peer education on risk factors
5. Distinguish which one is not a variable in the rational formula?
    a) Discharge (Q)
    b) Area (A)
    c) Rainfall intensity
    d) Gravitational force

Practical Assessment

Measure and predict the amount of evaporation around your local area.

Oral Assessment

Explain the cyclone formation process

Practical Assessment

Assemble a non-recording rain gauge network and use it to obtain daily precipitation for one month. Use the data to determine average annual precipitation

9.3.2.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Evaporation pan (Class A)
- Rain gauge
- Current meter
- Wading suit
- Tape measure
- Staff gauge
- Hand lens
- Clinometer
- GPS receiver
- Maps
- Steel file
- Steel knife
- Rock samples
- Minerals
- PPE

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9.3.3Learning Outcome No 2: Quantify Surface Water

9.3.3.1 Learning Activities

Learning Outcome No 2: Quantify Surface Water	
Learning Activities	**Special Instructions**
2.1 Identify sites for installation of ***hydrological instruments*** 2.2 Identify and installed hydrological Instruments 2.3 Collect hydrological data 2.4 Analyze and quantify hydrological data	● Project ● Case studies ● Field trips ● Discussions ● Demonstration by trainer ● Practice by the trainee

9.3.3.2 Information Sheet No9/LO2 Quantify Surface Water

Introduction to learning outcome

This learning outcome covers WMO guidelines on identifying site for irrigation of hydrological instruments as well as the identification and installation of some. It also covers collection and analysis of parameters to be measured.

Definition of key terms

Precipitation: This Consists of all forms of moisture that reach the earth from the atmosphere.

Stream flow: A stream can be defined as a flow channel into which the surface runoff from a specified basin drain

Hydrometry: It is the process of monitoring the occurrence of water, its properties and distribution on, beneath the earth's surface and also in the atmosphere.

Content/procedures/methods/illustrations

2.1 Identify sites for installation of *hydrological instruments* based on WMO guidelines

Hydrological instruments

- Rain gauges

A rain gauge is a meteorological instrument used for measuring rainfall. There are two main categories of rain gauges

a. Recording rain gauge
b. Non-recording rain gauge which includes: Tipping bucket rain gauge, Float type rain gauge, Weighing type rain gauge, Automatic-radio-reporting rain gauge

Below are the criteria for selecting a suitable site;

i. A rain gauge should be placed near the stream gauge if the observations will represent the entire general area
ii. It can be placed at a distance from the stream gauge depending on the topography of the location.
iii. It should be placed in a location such that the basin precipitation can be determined easily for each stream-gauging station
iv. Open place, away from obstruction at least four times the height of the tallest obstructing object.
v. Level ground to ensure gage mouth is horizontally exposed
vi. Site should be shielded from direct strong winds

- **Evaporation pans**

Evaporation pans are used to determine the rate of evaporation for a given catchment area. The site for placing an evaporation pan is selected according to the climatic region, size and shape of the lake/water body.

- **Current meters**

Current meters are devices used to record the velocity of water in a stream. The current meter stations should always be placed in stretches that are straight and uniform to ensure consistency in recording data. The stream channel should have smooth beds and banks and have minimal flow disturbances.

2 .2 Identify and install hydrological Instruments based on WMO guidelines

Hydrologic instruments include water level gauge, thermometer, soil penetrometer, water level gauge, thermistor, radiometer, pressure transducer, conductivity probe, encoder etc.

2 .3 Collect *hydrological data* based on parameters to be measured

Hydrological data

- **Rainfall data** is measured as the vertical depth of water (or water equivalent in case of solid forms) that would accumulate on a flat level surface if all the precipitation remained where it had fallen.

- **Evaporation data** -This is collected using Direct methods evaporation pan, atmometers or Indirect methods e.g. water budget, energy budget, aerodynamics or mass transfer, other empirical equations. Evaporation is measured in mm.

- **Evaporation Pan**: Measurement of evaporation is done by US Weather Bureau Class A pan (USWB class A pan) which may be installed as land pan, sunken or floating pan. Details of USWB class A pan installed as land pan is as sketched below.

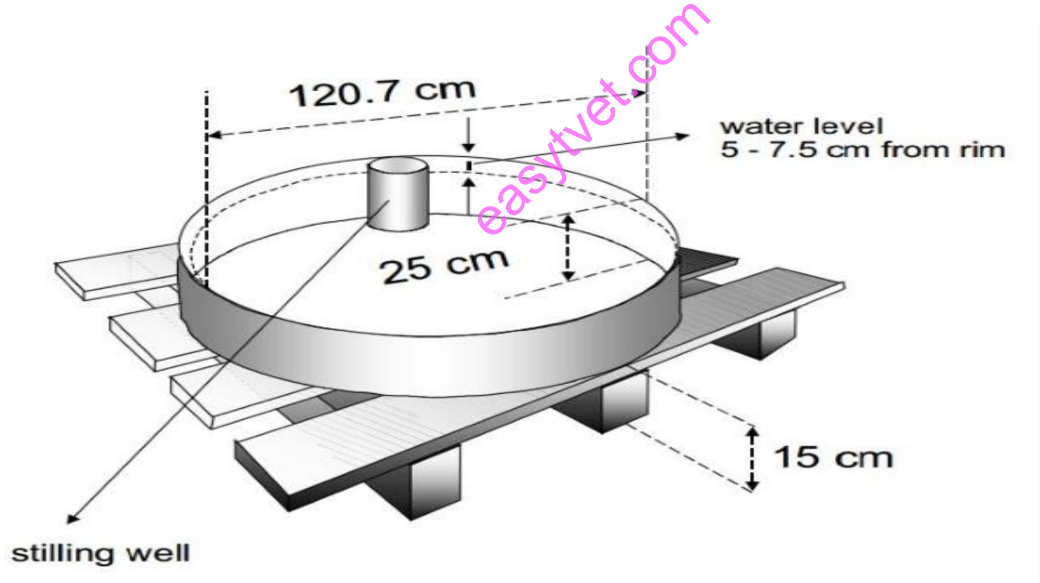

Figure 98: Evaporation Pan

Source:https://www.researchgate.net/figure/26-US-Weather-Bureau-Class-A-Evaporation-Pan_fig24_321299610

- **Stream flow data** - Streamflow is measured as discharge measurement (m^3/s) can be measured using the following methods:

i. Direct determination of stream discharge:

    (1) Area-Velocity method
    (2) Dilution techniques
    (3) Electromagnetic method and
    (4) Ultrasonic method (Mohit Mayoor, 2018).

ii. Indirect methods:

(1) Artificial controls e.g. weirs, flumes, slope-area formula as Manning's and Chezy's
(2) Ffloat gauging
(3) Indirect stage –rating

2 .4 Analyse and quantify hydrological data based on the collected parameters

Rainfall collected in the rain gauge is measured in mm and recorded

Evaporation- the amount of evaporated water is measured in millimetres. Evaporation is determined from the records of water level changes in the pan, corrected for the amount of water added to it by rainfall and artificially. When water level variation is measured by means of adding water to or removing water from the pan up to the constant water mark on its wall, the evaporation value is determined by using the following equation:

$E=P\pm\Delta H$ where E= evaporation in mm, P= rainfall depth in mm and ΔH= the depth of water added (+) or the amount removed (-) from the pan, the value of ΔH is computed using a standard cup equivalent to 0.5mm of rainfall.

ΔH = No. of cups added or removed x 0.5 mm. Note that if P=0, then $E = \pm\Delta H$ or E=0 when there is no change of level.

Streamflow is measured in m3/s

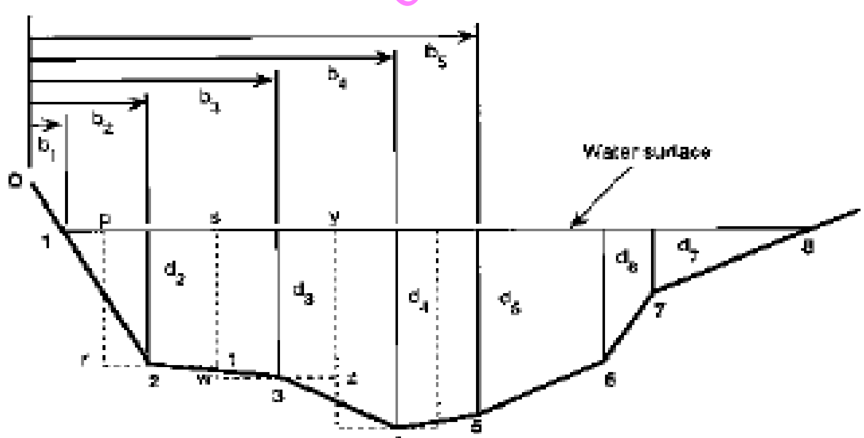

Figure 99: Streamflow
Source: Bartram,Et Al, 1996

Procedure: The horizontal distance b1 and b2 is measured from the reference point. The vertical distance d2 is measured.

Mathematical techniques like mid-section method or mean section method are used to derive area and mean velocity and the process is repeated on the other sections.

Conclusion

This learning outcome has covered Precipitation measurement- types of rain gauges, Evaporation measurement from US class A pan, Stream flow measurement- selection of a regular gauging station site, River gauging, Computation of stream discharge (mean section method, mid-section method; Stage discharge relationship and Personal safety in hydrometry.

Further Reading

Read more on mid-section and mean section methods of determining stream flow

9.3.3.3 Self-Assessment

Written assessment

1. Select which units are used in rainfall measurement.
    a) m
    b) cm
    c) mm
    d) km
2. Explain how evaporation is measured.
3. Select which is not a hydrological instrument?
    a) Rain gauge
    b) Current meter
    c) Multimeter
    d) Thermometer
4. Distinguish which of the following statement is false?
    a) A rain gauge site should be open without obstruction
    b) Accessibility of a rain gauge is not mandatory
6. Current meters should be placed in bends and corners of a stream, justify

7. Evaluate the following terms
    a) Precipitation
    b) Evaporation
    c) Streamflow
    d) Hydrology
8. Categorize the types of rain gauges

Oral Assessment

1. Explain the meaning of hygrometry in quantifying surface area

Practical Assessment

Visit your nearest meteorological station and identify the available hydrological instruments. Prepare a report on instruments available and explain their functions.

9.3.3.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Evaporation pan (Class A)
- Rain gauge
- Current meter
- Tape measure
- Staff gauge
- Hand lens
- Clinometer
- GPS receiver
- Maps
- Steel file
- Steel knife
- Rock samples
- Minerals

9.3.3.5 References

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9.3.4 Learning Outcome No 3: Map Rocks and Aquifers

9.3.4.1 Learning Activities

Learning Outcome No 3: Map Rocks and Aquifers	
Learning Activities	**Special Instructions**
3 .1Identify ***Tools and equipment*** for mapping 3 .2Identify ***Rock types*** 3 .3Identify ***Aquifer types*** 3 .4Map rock types and aquifers 3 .5Map aquifers	• Project • Case studies • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

9.3.4.2 Information Sheet No9/LO3 Map Rocks and Aquifers

Introduction to learning outcome

This learning outcome covers Geologic time scale (Eons, Eras, Periods, Series), Earth origin theories, Internal structure of the earth (crust, mantle, core), Earth processes (weathering, volcanism, isostasy, magmatism), Rock types and their characteristics: (sedimentary, metamorphic, igneous,), Rock structures, Minerology: Physical properties of minerals, rock forming minerals, mineral groups and Aquifer types and characteristics : confined, non-confined, leaky, perched.

Definition of key terms

Rock this is a naturally occurring material which contains minerals

Minerology this is the study of the physical and chemical properties of a mineral

Aquifer a rock under the earth's surface which can hold or transfer groundwater.

Content/procedures/methods/illustrations

3 .1 Identify Tools and equipment for mapping based on physical properties and user preference

- Rock Hammer.
- Hand Lens.
- Handheld GPS.

- Mineral Hardness Kit.
- Acid Bottle

3 .2 Identify *Rock types* based on their origin

An eon is defined as the geologic time scale that relates the stratigraphy of the earth to time. An era subdivides Eons to smaller periods the table below shows the time frame of eons and eras

Table 17: Time frame of eons and eras

Eon	**Era**	**Time**
Phanerozoic	Cenozoic Mesozoic Paleozoic	66m years ago to date 252m to 66m years ago 541 to 252 years ago
Proterozoic	Neoproterozoic Mesoproterozoic Paleoproterozoic	1000 to 541 years ago 1600 to 1000m years ago 2500 to 1600m years ago
Archean	Neoarchean Mesoarchean Paleoarchean Eoarchean	2800 to 2500m years ago 3200 to 2800m years ago 3600 to 3200m years ago 4000 to 3600 m years ago
Hadean		formation of the earth to 4000m years ago

The earth is divided into four main parts

- The outer crust which consists of the continental plate i.e. Main land and ocean surface
- The mantle (liquid form)
- The liquid outer core containing iron and nickel
- The solid inner core containing iron and nickel in liquid state

Rock types

- **Igneous rocks** are formed when magma from a volcano is rapidly cooled
- **Metamorphic**: this is either igneous, metamorphic or sedimentary rock that changes its nature due to exposure to high temperature or pressure
- **Sedimentary**-These rocks are formed by the piling up of dead animals and plants and which cement over a long period of time

3 .3 Identify Aquifer types based International Association of Hydro-geologists (IAH) guidelines

Aquifer types

- Confined -they are water bodies that accumulate in rock layers
- Unconfined- water bodies located near land surface and aren't enclosed with a layer of clay
- Perched- these are unconfined aquifers that occur when groundwater water body is separated from main groundwater. The amount of water is minimal.

3 .4 Map rock types and aquifers based on their formation

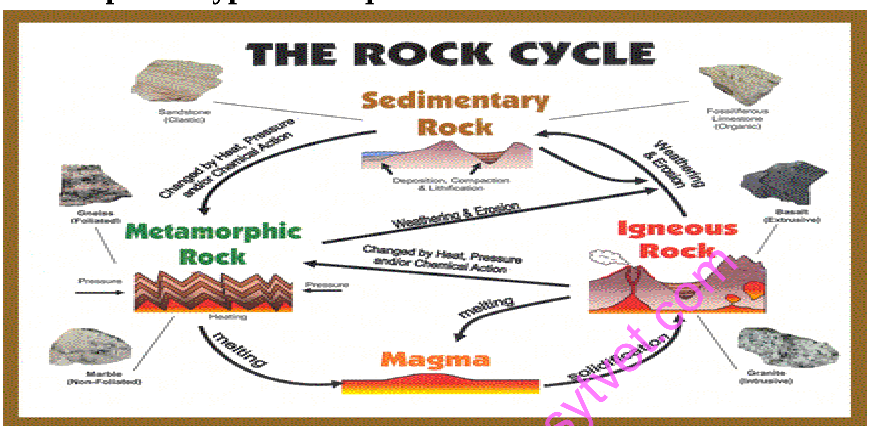

Figure 100: Map rock types and aquifers

Source: http://riovistad4.blogspot.com/2014/01/the-rock-cycle.html?m=1

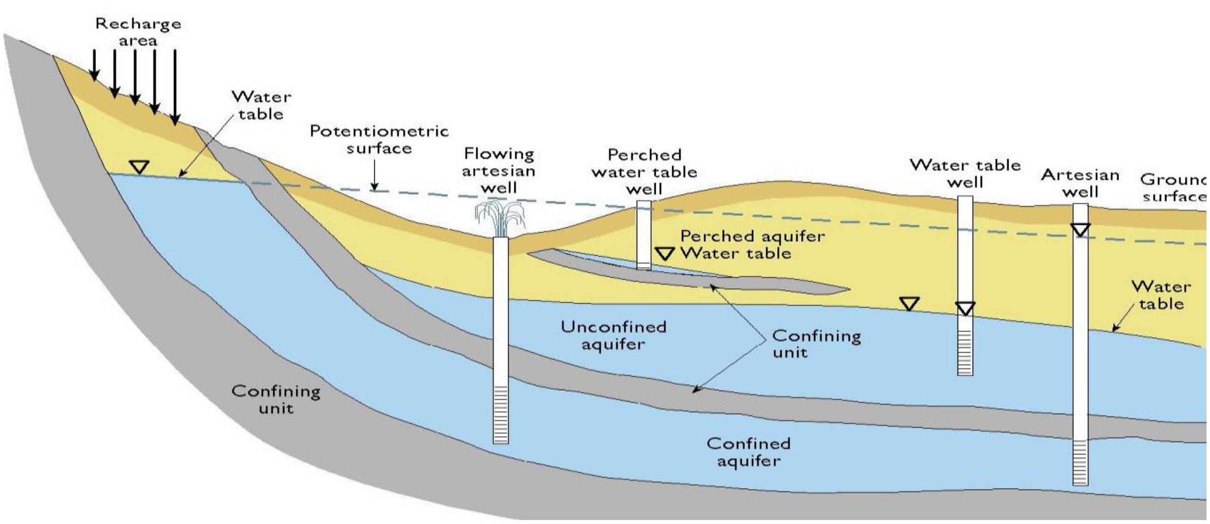

Figure 101: Map rock types

Source: The G360 Institute for Groundwater Research, 2017

3 .5 Map aquifers based on rock units

Aquifers are able to store groundwater due to the nature of the surrounding rocks' texture. The source of the groundwater is mainly from surface runoff and infiltration which is then the primary supplier of seas and streams. Rocks with fine and compact texture are less porous (excellent aquifer) hence have a higher water retaining capability while those with high porosity (poor aquifers) supply wells and springs. Poor aquifers contain granites and schist while excellent aquifers contain fractured volcanic rocks.

Conclusion

This learning outcome has covered Geologic time scale (Eons, Eras, Periods, Series), Earth origin theories, Internal structure of the earth (crust, mantle, core), Earth processes (weathering, volcanism, isostasy, magmatism), Rock types and their characteristics: (sedimentary, metamorphic, igneous,), Rock structures, Minerology: Physical properties of minerals, rock forming minerals, mineral groups and Aquifer types and characteristics .

Further Reading

Read more on a Leakey aquifer

9.3.4.3 Self-Assessment

Written assessment

1. Select the state of the outer core of the earth?
    a) Liquid
    b) Solid
    c) Gas
2. Distinguish and elabourate the tools and equipment used in mapping.
3. Summarize the process in which igneous rocks are formed
4. Select which rock are contained in poor aquifers and justify why they are
    a) Schist
    b) Sedimentary rocks
    c) Granite
    d) Volcanic rocks

5. Compare the categories of eons and their respective eons.
    a) Phanerozoic
    b) Hadean
    c) Archean
    d) Neoarchean
6. Briefly discuss what is contained in the inner core of the earth
    a) steel
    b) magnesium
    c) nickel
    d) iron
7. Justify the duration of the Hadean Eon and specify the exact timing.
    a) formation of the earth to 4000m years ago
    b) 2800 to 2500m years ago
    c) 3200 to 2800m years ago
    d) 3600 to 3200m years ago
8. Explain the following terms
    a) Rock
    b) Mineral
    c) Aquifer
9. Categorize the types of aquifers and explain each category
10. Distinguish and explain the three types of rock.
11. Explain how are sedimentary rocks formed?
12. State 5 hydrological tools

Oral Assessment

What water body feeds streams and seas?

Practical Assessment

Identify 3 different types of rock in your neighbourhood

9.3.4.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Evaporation pan (Class A)
- Rain gauge
- Current meter
- Wading suit
- Tape measure
- Staff gauge
- Hand lens

- Clinometer
- GPS receiver
- Maps
- Steel file
- Steel knife
- Rock samples
- Minerals
- PPE

9.3.4.5 References

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9.3.5 Learning Outcome No 4: Establish Well Sites

9.3.5.1 Learning Activities

Learning Outcome No 4: Establish Well Sites	
Learning Activities	**Special Instructions**
4 .1Identify Suitable sites for wells 4 .2Identify ***Suitable methods for well site establishment*** 4 .3Establish Suitable well sites 4 .4Prepare well site establishment report	• Project • Case studies • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

9.3.5.2 Information Sheet No9/LO4: Establish Well Sites

Introduction to learning outcome

This learning outcome covers identification of suitable sites for wells, methods of well site establishment, establishment of suitable well sites based on groundwater potential and well site establishment report writing.

Definition of key terms

Groundwater potential: Groundwater potential is the unrealized water found underground in the cracks and areas of soil, sand and rock according to www.groundwater.org.

Well siting: Well siting is the location of possible well sites to provide ample water to satisfy current and future water needs, according to geoservicesltd.com.

Content/procedures/methods/illustrations

4 .1 Identify Suitable sites for wells-based groundwater potential

Suitable sites: are those sites which have characteristics that meet the minimum requirements for the design, construction and operation of a sediment processing/ transfer facility in accordance with the standards established by the project (EPA, 2004)

Methods

Digital elevation mode (DEM) with a higher distance resolution is used to derive slope and drainage density map using the ArcGIS tool. The development of drainage density involves filling sinks, flow direction, flow accumulation and stream network (Tolche, 2020).

- Machine drilling
- Manual drilling
- Concrete lined dug well

4 .2 Identify Suitable methods for well site establishment based on user preference

Suitable methods for well site establishment

- Metallic rod pegs
- Hard wood pegs
- Concrete pegs
- Protected dug holes

4 .3 Establish Suitable well sites based on groundwater potential

Groundwater potential is the unrealized water found underground in the cracks and areas of soil, sand and rock according to www.groundwater.org

Factors to be considered include;

- Land formations in the area
- Distance of location from the latrine
- Ground water motion direction
- Distance between the water table and the base of the pit latrine

Table 18: Minimum Safe Separation Distance in Deep Water Table

Sediment Type	Depth to Water Table	Min. Safe Separation Distance
Clay, silt,or fine sand	5 meters or more	15 meters or more
Medium sand	5 meters or more	15 meters or more
Coarse sand or gravel	10 meters or more	15 meters or more
Fractured rock	10 meters or more	15 meters or more

Table 19: Minimum Safe Separation Distance in Shallow Water Table

Sediment Type	Depth to Water Table	Min. Safe Separation Distance
Clay, silt,or fine sand	0 meters (latrine at or near water table)	15 meters
Medium sand	0 meters (latrine at or near water table)	50 meters
Coarse sand or gravel	0 meters (latrine at or near water table)	500 meters
Fractured rock	0 meters (latrine at or near water table)	500meters

Source; http://www.clean-water-for-laymen.com/well-site.html

4 .4 Prepare well site establishment report based on Water Resource Management rules (WRM) 2007*

In writing a well establishment report the following must be taken into account;

- The main reason for the construction
- Method of construction
- The cost of construction
- The specific location of the well
- The area description; topology, geology, drainage etc.
- Ground water occurrence; discharge and recharge.
- Water quality
- Policy, legal and regulatory frame work

Conclusion

This learning outcome has prepared the student to be able to classify wells: dug, driven, drilled, identify a suitable well site, establish a suitable well site, know the factors affecting well siting, state the methods of well site establishment and Well site establishment report writing.

Further Reading

Read more on ground water potentials

9.3.5.3 Self-Assessment

Written assessment

1. Then following are classification of wells. Which one is not?
    a) Dug
    b) Borehole
    c) Drilled
    d) Dam
2. Analyze the steps one can use to identify sustainable well site
3. The following processes falls under hydrological cycle. Which one does not?
    a) Evaporation
    b) Infiltration
    c) Irrigation
    d) Surface run-off
4. Which of the following statement is false?
    a) 97% of the earth's water occurs in oceans.
    b) 2% occurs in the polar ice caps and frozen glaciers
    c) Only 3% is available as fresh water.
5. Explain the term groundwater
6. State the suitable methods for well site establishment
7. Explain the factors affecting well siting
8. Analyze the importance of establishing a well site

Oral Assessment

1. Explain the need of establishing a well site
2. Summarize the methods of well site establishment

Case Study Assessment

The reduction in the water table is known in groundwater terms as a drawdown. Why do you think drawdown occurs?

Practical Assessment

1. Plan the steps undertaken in identifying a suitable well site
2. Given the rain gauge observations during a storm. Construct the mass curve of precipitation.
3. Estimate rainfall using the Thiessen polygon method

9.3.5.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Evaporation pan (Class A)
- Rain gauge
- Current meter
- Wading suit
- Tape measure
- Staff gauge
- Hand lens
- Clinometer
- GPS receiver
- Maps
- Steel file
- Steel knife
- Rock samples
- Minerals
- PPE

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9.3.6 Learning Outcome No 5: Conserve the Environment

9.3.6.1 Learning Activities

Learning Outcome No 5: Conserve the Environment	
Learning Activities	**Special Instructions**
5 .1 Identify Factors affecting water and soil conservation 5 .2 Identify water and soil conservation measures 5 .3 Identify types of land degradation 5 .4 Identify causes of land degradation 5 .5 Identify effects of land degradation 5 .6 Identify control measures	• Project • Case studies • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

9.3.6.2 Information Sheet No9/LO5: Conserve the Environment

Introduction to learning outcome

This learning outcome covers Water conservation, Soil conservation, Water and soil conservation measures, Types of land degradation, Causes of land degradation, Effects of land degradation and Control measures of land degradation.

Definition of key terms

Soil conservation: Soil conservation is the preservation of soil from erosion and other forms of degradation in order to maintain soil fertility and productivity

Land degradation: Land degradation is a decline or loss of the productive potential of the biophysical environment

Water conservation: Water conservation is the method of using water effectively to reduce excessive water usage.

Content/procedures/methods/illustrations

5.1 Identify Factors affecting water and soil conservation based on natural and artificial activities.

Water conservation: is the method of using water effectively to reduce excessive water usage.

Soil conservation: Soil conservation is the preservation of soil from erosion and other forms of degradation in order to maintain soil fertility and productivity.

Factors affecting water conservation

- Climate change
- Deforestation
- Pollution
- Sedimentation
- Landscape changes
- Urban growth (Sprl, 2004)

Factors affecting soil conservation

- Practices on land use in agriculture: use of some fertilizers affects microorganisms in the soil to produce nutrients naturally.
- Mining: some methods of mining cause soil loss.
- Construction and development: some soils at construction sites washes or blow away because its protective plant cover has been removed according to www.classzone .com.

5 .2 Identify water and soil conservation measures based on the identified factors

Water conservation measures consist of measures aimed at reducing the quantity of drainage effluent and measures aimed at reducing the mass pollution of the constituents into the receiving water (Christen and Skehan, 2000).

Soil conservation measures reduces soil erosion and provides solutions on farms

Soil conservation measures

Practices on land use in agriculture: conserved through crop rotation, contour ploughing, wind breaks, conservation tillage and terracing.

Mining: by use of best methods of mining.

Construction and development: proper measures should be put in place during site clearance and all construction activities.

Water conservation measures

Sedimentation: there should be proper land use practices

Landscape changes: conserved through minimum use of conversion of natural landscape to farming and human activities.

Urban growth: proper measures should be put into place when cities grow to preserve water.

Deforestation: it is conserved through minimum clearing of forests and planting of more trees.

Figure 102: Fanya juu terraces

Source: **Fanya juu terraces** in a semi-arid area which have developed over time into benches: note well established grass strips along the bunds (Kenya). (c) Hanspeter Liniger, WOCA

5 .3 Identify types of land degradation based on environment

Land degradation: is a temporary or irreversible decrease in the productive ability of land (UNEP, 1992b).

Types of land degradation

Water erosion: includes all aspects of soil erosion by water, including soil erosion. Human-induced intensification of landslides triggered by forest clearing, road construction.

Wind erosion: refers to the loss of soil by wind, which occurs mainly in dry regions.

Soil fertility decline: is used in the short term to refer to what is more precisely described as deterioration of soil physical, chemical and biological properties.

Waterlogging: is a decrease in land productivity due to an increase in precipitation below the soil surface.

Salinization: is used in its broad sense to refer to all forms of soil deterioration caused by the increase of salts in the soil.

Lowering the water table: occurs as a consequence of excessive groundwater pumping bellow the water table.

5 .4 Identify causes of land degradation based on degradation types identified

Deforestation- cutting of forest will affect soil adversely since forest are helpful in binding up of soil particles with the help of roots if vegetation.

Excess use of fertilizers and pesticides - excess use of fertilizers causes an imbalance in the quality of certain nutrients in the soil which affects vegetation.

Overgrazing- over exploitation of pasture by livestock makes grass and other vegetation's unable to survive and grow. This lack of vegetation cover leads to soil erosion.

Desertification- this is the destruction of the biological potential of land due to mismanagement of forest, overgrazing, mining and quarries can lead to desert like condition.

Soil erosion- this is the loss of top fertile soil along with nutrient through run off water, strong wind may also blow the loose and coarse soil particle across long distance.

5 .5 Identify effects of land degradation based on degradation types identified

Water erosion: Once the soil enters the water supply, the concentration of phosphorous and nitrogen in the water increases, resulting in decreased water oxygen levels and reduced water quality.

Wind erosion: Wind erosion reduces the soil's ability to retain nutrients and water, rendering the atmosphere drier.

Soil fertility decline: Decrease in soil fertility causes a lack of the necessary soil nutrients for crops.

Waterlogging: Waterlogging prevents aeration and gas exchange and thus causes the soil to shut down in many habitats.

Salinization: Salinization causes plant dehydration leading to a decrease in yield

Lowering water table: Lowering the water table causes wells to be unable to access groundwater

5 .6 Identify control measures based on the identified factors

Water erosion degradation is managed by mulching which is covering the soil surface with a crop residue or growing plant cover.

Wind erosion degradation is controlled by the reduction of cultivated fallow, the maintenance of the vegetable cavity, the reduction of the tillage and the prevention of overgrazing,

Soil fertility decline is regulated by the retention of crop residues on site, the use of a reduced tillage method and the application of soil modifications or fertilizers.

Salinization is controlled by the monitoring of the groundwater levels and the quantity of salts and water in the land and encouraging preventative measures to stop the salts moving towards the surface.

Waterlogging is controlled by removal of excess water and minimizing compaction according to www.ccmacknowledgebase.vic.gov.au. The lowering of water table is managed by controlling sub-irrigation and drainage.

Conclusion

This learning outcome has covered Water conservation, Soil conservation, Types of land degradation, Causes of land degradation, Effects of land degradation and Control measures of land degradation.

Further Reading

Read more on land degradation and its control measures

9.3.6.3 Self-Assessment

Written assessment

1. Which is of the following is not a type of land degradation?
    a) Wind erosion
    b) Waterlogging
    c) Groundwater
    d) Salinization
2. Evaluate the importance of environmental conservation
3. The following are factors affecting water conservation. Which one is not?
    a) Sedimentation
    b) Mining
    c) Deforestation
    d) Overgrazing
4. Which of the following is a factor affecting soil conservation?
    a) Water logging
    b) Mining
    c) Sedimentation
    d) Salinization
5. Explain factors affecting water conservation
6. Evaluate the effects of land degradation
7. Distinguish the types of land degradation
8. Discuss the control measures based on land degradation

Oral Assessment

1. Explain land degradation
2. Summarize the causes of land degradation

Case Study Assessment

Investigate the causes and effects of land degradation in your area

Practical Assessment

Conduct a site visit to a mining location and come up with a strategy on how to conserve the soil.

9.3.6.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Evaporation pan (Class A)

- Rain gauge
- Current meter
- Wading suit
- Tape measure
- Staff gauge
- Hand lens
- Clinometer
- GPS receiver
- Maps
- Steel file
- Steel knife
- Rock samples
- Minerals
- PPE

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9.3.7 Learning Outcome No 6: Develop Water Harvesting Structures Situations

9.3.7.1 Learning Activities

Learning Outcome No 6: Develop water harvesting structures	
Learning Activities	**Special Instructions**
6 .1 Identify water harvesting techniques 6 .2 Identify suitable sites for water harvesting reservoirs 6 .3 Design simple water harvesting structures 6 .4 Operate and maintain simple water harvesting structures	• Project • Case studies • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

9.3.7.2 Information Sheet No9/LO6 Adapt First Aid Procedures for Remote

Introduction to learning outcome

This learning outcome covers Water harvesting techniques Types of water harvesting reservoirs), Site selection for water harvesting structures factors considered: Hydraulic properties of rock units (porosity, Permeability, compressibility), Topography and Proximity, Design of simple water harvesting structures and Operation and maintenance of water harvesting structures.

Definition of key terms

Water pans: this is depression on the ground that collect and stores surface runoff from uncultivated grounds, road.

Water dams: Are structures constructed along a water course to store water on its upstream besides controlling its flow.

Porosity: it is a measure of the void space in a material and can be further explained as fraction of the volume of voids over the total volume.

Permeability; It is the measure of the rate of flow of a fluid through a porous medium.

Content/procedures/methods/illustrations

6 .1 Identify water harvesting techniques based on site conditions

Water harvesting techniques are ways in which water is collected either on the surface or below the ground lever to store water during wet season to be used during dry period.

They include:

1. Roof catchments: a technique used for collecting rainwater with suitable roof cover conditions over buildings.
2. Rock catchment: they collect rain water from rock outcrops to concentrate the runoff water into a storage structure.
3. Surface water catchment; water is collected on land and channeled to a single point.

6 .2 Identify suitable sites for *water harvesting reservoirs* based on geological structures

Water harvesting reservoirs: Dams (Earth, sand, concrete), Water pans, Ponds, Man-made lakes

Suitable sites of the water harvesting reservoirs should be where:

a. Hydraulic properties involving the layers beneath should have low permeability and less porous earth material.
b. Topography involves mapping and detecting shallow depths to ensure a depth equal to the proposed height of reservoir.
c. Proximity entails the site being at a location where it is close to infrastructure for accessibility purposes.

6 .3 Design simple water harvesting structures based on the need

Designing a water dam will involve the following process

i. Description of the need and the location of dam
ii. A hydrological assessment of the dam in relation to catchment features and climatic conditions
iii. An assessment of environmental and social impacts of the dam
iv. Description and analysis of reservoir, embankment, spillway, draw-off system, scour and ancillary structures details
v. Preparation of the design drawings
vi. Description of catchment protection works
vii. Estimation of construction cost
viii. Preparation of construction works and schedule
ix. Preparation of operation rules and schedule of inspection and maintenance

6.4 Operate and maintain simple water harvesting structures based on standard operating procedures

Operation and maintenance are done by:

- Refilling erosion rills on the embankment slopes with compacted material
- Keeping and noting records of spillway flows
- Removing silt from reservoir area
- Frequent operation of valves during inspections to ensure they are working
- Regular inspections of the structure
- Addressing safety concerns by maintenance of fencing the structure and repainting of warning sign

Conclusion

This learning outcome has covered Water harvesting techniques Types of water harvesting reservoirs), Site selection for water harvesting structures factors considered: Hydraulic properties of rock units (porosity, Permeability, compressibility), Topography and Proximity, Design of simple water harvesting structures and Operation and maintenance of water harvesting structures.

Further Reading

Learners should do further reading on Environmental Impact Assessment of water harvesting reservoirs and be able to do computations on design of reservoir structures

9.3.7.3 Self-Assessment

Written Assessment

1. Distinguish the different water harvesting techniques used to collect and store water
2. Which one of the following is not a water harvesting technique based on site conditions?
    a) Roof catchments
    b) Micro-catchment
    c) Rock catchments
    d) Surface water catchment

3. The following are hydraulic properties of rock units except one which one?
    a) Compression strength
    b) Permeability
    c) Porosity
    d) Compressibility
4. Classify the various subsurface water harvesting used in Kenya.
5. Categorize the types of water harvesting reservoir?
    a) Dams
    b) Water pans
    c) Ponds
    d) Plant pits
6. Explain the term porosity
7. Differentiate between porosity and permeability
8. Summarize the ways of maintaining water harvesting structures
9. Evaluate the reliability of rain water harvesting as a technique for water harvesting.
10. Over the years Masinga dam has been serving its purpose as a water harvesting reservoir. Discuss its purposes and uses in Kenya.

9.3.7.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Evaporation pan (Class A)
- Rain gauge
- Current meter
- Wading suit
- Tape measure
- Staff gauge
- Hand lens
- Clinometer
- GPS receiver
- Maps
- Steel file
- Steel knife
- Rock samples
- Minerals
- PPE

9.3.7.5 References

Ministry of water and irrigation. (2015) practice manual for small dams, pans and other water conservation structures in kenya. Nairobi: state department of water and irrigation

Saeid eslamian. (2020). Handbook of water harvesting and conservation. John wiley & sons

CHAPTER 10: MATERIAL TESTING

10.1 Introduction of the Unit of Learning

This unit specifies the competencies required to Conduct Material Testing. It involves preparing for material testing, sampling construction materials, and performing tests on alignment soils, concrete, structural steel, bitumen materials and timber. It also includes documenting test results.

10.2 Performance Standard

Prepare for material testing, sample road construction materials, undertake tests on the alignment soils, perform concrete tests, carry out structural steel tests, perform bitumen tests, and perform timber tests as per the contract documents, project requirements, material testing manual, expertise and qualifications, standard tests and procedures, test procedures and requirements, and SOPs.

10.3 Learning Outcomes

10.3.1 List of Learning Outcomes

a) Prepare for material testing
b) Sample road construction materials
c) Undertake tests on the alignment soils
d) Perform concrete tests
e) Carry out structural steel tests
f) Perform bitumen tests
g) Perform timber tests

10.3.2 Learning Outcome No 1: Prepare for Material Testing

10.3.2.1 Learning Activities

Learning Outcome No 1: Prepare for Material Testing	
Learning Activities	**Special Instructions**
1.1 Conduct preliminary site investigations 1.2 Provide and maintain material laboratory 1.3 Obtain material testing manuals and contract documents 1.4 Acquire ***Material testing equipment*** 1.5 Identify material laboratory personnel 1.6 Develop sampling procedures 1.7 Determine types of material tests 1.8 Operate and maintain testing equipment	• Direct instruction • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

10.3.2.2 Information Sheet No10/1: Prepare for material testing

Introduction to learning outcome

This learning outcome covers site investigations, construction material laboratory, material testing, construction material and development of sampling procedures.

Definition of key terms

Construction material – in civil engineering, construction materials are any materials used for construction purposes. These may include; sand, rocks, cement etc.

Material testing- this is the act of determining the properties of raw materials using standard techniques. These properties include physical, mechanical and chemical properties.

Testing tools – in civil engineering, testing tools are items or objects used in determining the properties of raw materials.

Content/Procedures/Methods/Illustrations

1.1 Conduct preliminary site investigations as per contract document

Site Investigation

This is an inspection of the proposed site for construction to obtain information about its subsurface conditions thus determining the suitability of the proposed site. The steps for conducting a site investigation include:

- Conduct a ***site pre-visit*** to the proposed site of the construction.
  This is the first stage of site investigation and involves a field visit to the proposed site to obtain information on the topographical and geological features of the site. The pre-visit reveals information on the behaviour and type of adjacent structures noticeable slags, cracks and sticking doors and windows.
- Perform ***a preliminary site investigation*** to the area.
  This is the second stage of site investigation and is also known as general site investigation. Its main objective is to obtain an approximate assessment of the suitability of the site. Experimental borings and shallow tests are dug to collect soil samples and perform simple tests such as unconfined compressive test and moisture content.
- Conduct a ***detailed site investigation***
  This is the third stage of site investigation and is preferred for complex projects such as the construction of dams, bridges and high-rise buildings. It involves a detail assessment of the proposed site by performing more complex detailed field tests such as plate load test, in-situ vane shear test.
- Prepare a ***detailed soil investigation report***
  This is the fourth stage of site investigation whereby a detailed report of the site investigation findings is recorded and documented.

1.2 Provide and maintain material laboratory according to contract document

Materials laboratory- This is a laboratory specifically dedicated for assessing the physical and mechanical properties of construction materials. Maintaining a materials laboratory involves maintain the laboratory equipment present in the laboratory.

Five ways of maintaining a materials laboratory

- Repairing laboratory equipment
- Refurbishing laboratory equipment at regular intervals thus increasing their efficiency and functionality.
- Regular calibration services of the materials laboratory equipment.
- Performing in-house maintenance of equipment or at times outsourcing maintenance services.
- Regular cleaning of laboratory equipment.

1.3 Obtain material testing manuals and contract documents based on project requirements

Approved Material Testing manuals used in Kenya include the following;

- BS 1377-2-1990: For soil classification tests.
- BS1377-4-1990: For soil compaction tests.
- Road Design Manual Part III: For pavement material tests
- Road Design Manual Part III Section 17: For concrete works tests.

(BS – British Standard Codes)

1.4 Acquire Material testing equipment according to contact document and material testing manual

Material testing equipment- these are tools and objects used in determining the physical and mechanical properties of construction materials.

Material Testing Equipment and their uses

- **Penetrometer** – used in testing the plasticity of soils
- **Weighing Machine** – used in measuring the weight of material samples.
- **Oven** – used in drying material samples thus determining the moisture content of sample materials.
- **Measuring cylinder** – used in measuring liquid material samples.
- **Crushing machine** – used in determining the compressive strength of concrete sample.
- **Moisture bags** – used for preserving the moisture content in soil samples obtained from the field or from borrow pits.
- **Standard sieves** – used in the sieve analysis test, to determine the particle size of material samples.

Given the material tests to be conducted as per the contract, one should ensure that the necessary material testing equipment is available.

1.5 Identify material laboratory personnel according expertise and qualifications.

A **material's laboratory personnel** performs field or laboratory tests of construction and geological materials according to prescribed test procedures.

Identification of Material Laboratory Personnel is as follows;

Table 20: Identification of Material Laboratory Personnel

Material Labouratory Personnel	**Expertise**	**Qualifications**
Foreman	Is an intermediary between workers and management to organize, assign and directly supervise the work of a manual labourer?	Maintains cooperative work relationships with project engineers, contractors, vendors and employees
Specialist/ Lead Technician	Assigns work, sets schedules, determine methods, provides training and instruction, evaluates and approves completed tasks.	Effective scheduling and operation of the labouratory
Lead Technologist	Is more independent as compared to the trainees and uses standard techniques and methods to perform more complex material testing, including bituminous and concrete design mixes.	Accuracy in test measuring, documentation and verification
Sub-trainee	Assists in both field and labouratory material testing. Performs a number of standard tests on concrete, aggregates and soils.	Increased consistency and proficiency in performed tests.
Trainee	Works under close supervision and review of those ahead of him/her.	Application of test procedures to a number of construction materials and documenting test results.

1.6 Develop sampling procedures according to standard tests procedures
Considerations to me made while developing sampling procedures;

- Care should be used in the selection of a representative rather than an extreme sample.
- The sampling procedures should focus on specifying how many samples should be tested from each lot. A great error may occur if very few samples are chosen resulting in the contactor having to carter for the extra payments due to erroneous calculations. On the other hand, if too many samples are considered, this many end up consuming time and money without necessarily improving accuracy.
- Procedure for developing sampling procedures should be according the standard tests procedures.

1.7 Determine types of material tests according to test procedures and requirements
Types of Material Tests include but are not limited to;

- **Soil classification tests**: Liquid Limit test, shrinkage test, plasticity index test, sieve analysis, determination of moisture content etc.
- **Soil compaction tests**: Proctor test, CBR test, Sand replacement method(MDD, Maximum dry density test)
- **Bituminous material tests**: Marshall test.
- **Concrete works tests**: Slump test, Concrete strength test.
- **Aggregate tests**: ACV (Aggregate crushing value), FI (flakiness Index), Sodium Soundness Test (SSS).

1.8 Operate and maintain testing equipment as per the SOPs
Maintenance of testing equipment is one of the most important aspects of quality assurance as it contributes to the accuracy or labouratory reports.

A maintenance program for testing equipment should include the following concepts;

- Recording all breakdowns of testing equipment.
- Regular calibration of equipment to ensure accurate records of results.
- Registration of all equipment indicating their serial numbers, identification numbers and specific location in the labouratory.
- Mechanism for validating testing equipment
- Ensuring all new equipment are checked before installation thus ensuring safety of equipment.
- Performing periodic performance checks as recommended by the manufacturer.

Daily duties of maintaining material testing equipment are:

- Ensuring the testing equipment is cleaned after every use.
- Oiling the Shrinkage limit, CBR and Proctor molds before use.

- Ensuring the materials testing labouratory's surfaces are cleaned after every use.
- Cleaning the sieves with a hard brush to remove stuck material particles on the sieves.
- Regular calibration of equipment to ensure accurate records of results and availability of equipment for the required testing (Jennings et.al 2017)

Conclusion

This learning outcome covered site investigations, construction material labouratory, material testing, construction material and development of sampling procedures.

Further Reading

Read further in Site Investigation from the book Engineering Geology by F.G Bell 2nd ed. Go through the Road Design Manual Part III to see detailed procedures on material testing.

10.3.2.3 Self-Assessment

Written Assessment

1. A civil engineer has won his first tender for constructing additional classes in a high school. Which of the following will he not do in the preliminary site visit?
    a) Explore the ground conditions at the surface of the proposed construction site
    b) Explore the ground conditions below the surface of the proposed construction site
    c) Come up with detailed design drawings of the proposed classrooms
    d) Dig test pits
2. In a certain road project, the new trainee was asked to record test results from certain soil classification tests. Which of the following was not one of them?
    a) Sieve Analysis
    b) CBR (California Bearing Ratio)
    c) Shrinkage test
    d) Plasticity Index

3. The County Government of Kakamega was performing a maintenance check on its material testing labouratories. Which of the following material equipment was calibrated?
    a) Measuring cylinder
    b) Moisture bags
    c) CBR Crushing machine
    d) Mechanical Standard sieves
4. Evaluate the steps taken when conducting a preliminary site investigation.
5. Explain three types of aggregate tests outlining their testing tools and equipment.
6. Summarize five ways of maintaining material testing equipment
7. Using a sketch explain the slump test method of testing concrete works.
8. Discuss the Marshall test method of testing for bituminous mixes

Oral Assessment

Explain the main objective of conducting a preliminary site investigation

Oral Assessment

During the early stages of a pavement construction project, the level of compaction of the earth-works was tested using the sand-replacement method. Why was the soil obtained from the test pit, not carried back to the labouratory in an open container?

Practical Assessment

With guidance from your materials labouratory technician, obtain a soil sample from a suitable borrow pit and perform soil classification and compaction tests to determine the following;

i. Moisture content
ii. Liquid limit, Plastic limit, Plasticity index- cone penetrometer method
iii. Linear shrinkage
iv. CBR value

10.3.2.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data

- Drawing sheets
- Internet
- Relevant videos

10.3.2.5 References

Jennings et.al. (2017). Capacity Building and Knowledge Management Study of MTRD Kenya. Nairobi: Government Printers

10.3.3 Learning Outcome No 2: Sample Road Construction Materials

10.3.3.1 Learning Activities

Learning Outcome No 2: Sample Road Construction Materials	
Learning Activities	**Special Instructions**
2.1 Identify sources of **road construction materials** 2.2 Obtain sample procedures and manuals 2.3 Identify sampling tools and equipment and assembled 2.4 Carry out sampling 2.5 Store samples awaiting analysis 2.6 Operate and maintain testing equipment maintained	• Direct instruction • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

10.3.3.2 Information Sheet NO10/L02: Sample Road Construction Materials

Introduction to learning outcome

This learning outcome covers sources of road construction materials, sampling procedures, sampling tools and equipment, material sample analysis and storage of samples.

Definition of key terms

Sources of road construction materials – These are the places of origin of the materials that are used in road construction. The materials are either naturally occurring or man-made and the selection of sources of road construction materials mainly depend on the purpose of the road, the availability of that particular material, the location where the construction will take place and the climatic conditions of that region.

Sampling procedures and standard manuals - sampling procedures is term used to refer to how the selection of a representative portion of a material to be used in road construction is done and the standard manuals are small conveniently handled books with instructions on the standard procedures for carrying out tests on construction materials.

Sampling tools and equipment - These are devices or technical apparatus that are used to collect a representative sample of a material in order to test, monitor and analyse it.

Material sample analysis - This is a detailed study of a sample of a material used in road construction so as to understand it better.

Storage of samples- This is the proper keeping of collected sample materials in the lab from the time they are acquired till disposal.

Content/Procedures/Methods/Illustrations

2.1 Sources of road construction materials (Borrow pits, Quarries, River beds, Timber yard, Manufacturers) based on contract document

Sources of Construction Materials include:

Borrow pits- refers to an area where construction material have been dug for use at a different location.

Quarries- refers to a large deep pit from which stone and other constructions materials such as quarry dust, ballast etc. have been extracted.

River beds- refers to the ground at the bottom of the river from which sand and gravel as construction materials are obtain.

Timber yard- this is a specific location whereby products used in construction or for projects of home improvements, specifically wood-related products, are processed or stored.

Manufactures- aggregates required in road construction can also be made in factories as a result from the modification of materials, which may involve both physical and chemical changes. These types of materials are sometimes called synthetic or artificial aggregates.

2.2 Obtain sample procedures and manuals as per standard sampling procedures.

These sample procedures and manuals tend to derive sampling plans that may enable one to carry out the standard tests required for road construction materials.

Manuals and procedures used for sampling road construction materials include:

- ASTM-D1452
- ASTM: C 183-86 (a)
- SABS 471
- SABS 620
- SABS 626
- SABS 831
- SABS 824
- SABS Method 861

2.3 Identify sampling tools and equipment and assembled according to standard procedures

Sampling by Auger

Tools and equipment

- Hand augers with diameter of about 50 to 300 mm
- A riffler with openings of 25mm and pans.
- Shovels.
- Power augers of about 600 mm diameter.
- A prospecting pick.
- Tape measure to determine the sampling depth in millimeters.
- Suitable canvas or plastic sampling bags.
- Suitable canvas sheets of about 2 x 2m.
- Containers of about 500 mm diameter.
- Picks.

Natural rock mass sampling

Tools and equipment

For acquiring samples obtained from test pits that have been blasted with explosives

- A spade
- Containers suitable for rock samples e. g canvas bags (strong) prospecting pick.
- A pick
- A sledge-hammer with about 5 kg mass.
- Canvas sheets of about 2 x 2 m.
- A crowbar.

Tools used for obtaining core samples with the aid of a core drill

- Suitable enough containers to pack the cores such that they can be firmly packed to prevent sliding or mixing up in the process of transportation and handling.
- A suitable enough tape measure.

Sampling of stock piles

Tools and equipment

- Basin with a diameter of about 500mm diameter
- Shovels.
- Suitable canvas sheets.
- Picks.
- Suitable container or sample bags
- A mechanical loader-digger (if present).
- 25mm openings riffler and six matching pans.

Sampling of samples obtained from sampling pit in natural soil, gravel and sand

Tools and equipment

- A pick
- 19 mm sieve with 450mm diameter.
- A prospecting pick.
- Appropriate sampling containers.
- Tape measure.
- A spade
- Strong canvas or plastic bags as containers.
- Canvas sheets of about 2 x 2m
- A riffler with oenongs of about 25mm wide, with six matching pans.
- A basin of about 500mm diameter.

Sampling of cement and lime

Tools and apparatus

- Clean and appropriate containers such as tins that have tightly-fitting lids and have the capacity to hold be hold 5 kg of cement or lime.
- Suitable apparatus for taking samples e. g a grooved sampling device that can take samples from large containers, and a tube type sampling device that can take samples from small containers like bags

2.4 Carry out sampling as per standard sampling procedure

Procedure for sampling by auger

Drilling should be done by drilling the auger into the ground to the required depth, then withdrawing it, and the soil should then be removed so as to carry out sampling and examination.

The auger should then be reinserted in the hole then the process repeated where the various types of soil horizon occurs once enough material has been obtained for testing, e. g when adequate material has been removed by drilling, a labouratory sample is acquired by quartering and riffling.

In the situation of harder rock, in an instance where the power auger may end up causing pulverization, it is more advisable to:

- Drill a hole with diameter of about 600 mm, to the full required depth.
- Drill a second hole about 0.5 to `1.0 m away from the first hole, on the quantity of material required for the particular sample, to the depth of the first horizon that needs to be sampled.
- All the material between the two holes up to this depth should be removed and placed it on a hard, clean soil surface or on a canvas sheet.

- The second hole to the depth of the second horizon which is to be sampled is then drilled and all the material between the two holes removed and placed on a separate canvas sheet. The process is then to be repeated to the full depth of the first hole.

Still, samples may be obtained from a single hole by cutting down a groove in the material starting from the side that has the hole.

Procedure for Natural rock mass sampling

For Test pits that have been blasted with explosives which have then been manually opened;

Inspection should be carried out of the sides of the test pit to their full depth and results recorded with any observable changes in the rock and also the depths recorded between which such changes occur. Properties which should be considered are color, texture, rock type, hardness etc.

A crowbar should be used or the loosen pieces of each type of rock from each wall of the test pit should be picked and placed in a separate container. In a situation where the pieces are too large for the containers, they may be broken up by use of a sledgehammer. Some of the loose material taken from the test pit can be selected outside of the pit if there are no large types of rocks then each type can then be placed in a separate/different container. Loose earth or gravel layers of any kind appearing on top of the rock mass or which occurring in seams between the layers of rock must be sampled separately if by any chance it is to be used for some or other purpose later on.

The containers with samples must all be clearly marked so as to enable easy identification of the samples once they arrive in the labouratory.

Procedure for sampling of stock piles

Doing Sampling while the stockpile is being formed by the off-loading of material

i. Randomly selecting one or two positions on the consolidated surface of each layer of that stockpile while the pile is being formed.
ii. Vertical test hole should be made as deep as possible through the layer with the pick and shovel.
iii. A canvas sheet should then be placed in the bottom of the hole and a groove cut in the side of the hole from top to bottom that can let this material fall onto the canvas sheet.
iv. Gathering of enough quantity of material by cutting successive grooves, and frequently raising the canvas sheet from the hole then tipping its contents onto a different canvas sheet on the surface.
v. Mixing of the material on the canvas sheet and dividing it using the riffler and a method known as quartering method into the required size such that each sample bag has a representative sample of the material taken from the test hole.

Sampling from an already completed stockpile

- At least twelve sampling positions should be selected in a random manner. About half the positions may be on the stockpile if by chance, its surface is fairly large

Procedure for sampling of samples obtained from sampling pit in natural soil, gravel and sand

i. Begin by Inspecting the sides of the test pit to their full upper edge of the test pit then sample every distinguishable sand, gravel or soil layer by holding to the lower level of the layer a spade or canvas sheet against the side of the pit then cutting with a spade or pick a sheer groove to the full depth of the layer.
ii. The material is then obtained in this way in enough bags. The sheet of canvas may also be spread out on the floor of that test pit with at least twice the amount of material required for the final sample must be loosened from the layers.
iii. The material from each layer must be combined on either a clean, hard, even surface or on a canvas sheet as soon as all the layers have been sampled and properly mixed with the use of a spade.
iv. It is required to fill one small sample bag which can carry about 10kg, and two or three other larger bags with each of them holding about 30 to 40 kg.
v. When several test pits are made in a deposit and the materials have a slight difference, it is only necessary to fill large bags of each material type at each second or third test pit. At this point, the sampler must be guided by his /her discretion and experience. The sample containers must all be clearly labeled so that the samples can be easily identified in the labouratory with the identifying reference agreeing with that given in the covering report or form.

2.5 Store samples awaiting analysis based on test requirements
Particulars to consider when storing construction materials sample;

a) As the analysis is being done, the samples need to be stored in a position such that they will not be interfered with at any point.
b) Full particulars of each of those samples being stored must be given with full details including:
    - The sample size,
    - The size of containers used to put the samples,
    - The method of collection sample marked number,
    - The locations and
    - Depths at which the samples were taken.

Conclusion

This learning outcome covered sources of road construction materials, sampling procedures, sampling tools and equipment, material sample analysis and storage of samples

Further Reading

Read more on:

1. The determination of sample size and density based on the various road design manuals.
2. Building materials; third edition by S.K Duggal

10.3.3.3 Self-Assessment

Written Assessment

1. When carrying out sampling, what is the diameter of the 19mm sieve
    a) 40mm
    b) 450mm
    c) 950mm
    d) 5mm
2. Summarize the procedure for carrying out sampling by auger requires drilling.
3. Compare sampling procedures during the formation of a stockpile as opposed to sampling from an already completed stock pile.
4. Distinguish between test pit and quarries.
5. Which of the following is not a source of road construction materials?
    a) Quarries
    b) Trees
    c) Test Pits
    d) Manufacturers
6. Explain the use of a tape measure in sampling of construction materials.
7. Evaluate the testing tools and equipment used in natural rock mass testing
    a) Crowbar
    b) Pick
    c) Spade
    d) Stone
8. Differentiate between sampling manuals and sampling procedures.

9. Measure the scopes of the following sampling methods?
   i. Sampling by auger
   ii. Natural rock mass sampling
   iii. Sampling of stock piles
10. Summarize the ways of operating and maintaining testing equipment as per the SOPs
11. Explain precautions should be taken when collecting samples obtained from a sampling pit in natural soil, gravel and sand
12. Explain the selection of aggregators as road construction materials.
13. Classify the methods used for sampling stockpile.

Oral Assessment

1. Summarize the procedure for sampling by auger
2. Explain the importance of following the standard test procedures

Project Assessment

Conduct a practical assessment to find out the possible reasons as to why a section of John Momanyi Road in Nakuru County sunk to the ground in May 2020. You can use relevant data presentation techniques if necessary

10.3.3.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

10.3.3.5 References

David Doran, Bob Cather (2013) Construction Materials Reference Book, Edition2 revised: Routledge

Nicholas J. Garber, Lester A. Hoel (2014) Traffic and Highway Engineering, SI Edition

S. K Duggal (2008). Building Materials. Allahabad: New Age International Publishers.

10.3.4 Learning Outcome No 3: Undertake Tests on the Alignment Soils

10.3.4.1 Learning Activities

Learning Outcome No 3: Undertake Tests on the Alignment Soils	
Learning Activities	**Special Instructions**
3.1 Identify ***Soil tests*** 3.2 Obtained standard manuals and procedures 3.3 Identify and gather soil testing tools and apparatus 3.4 Obtain alignment soil samples according to test requirement *3.5* Conduct ***Soil tests*** 3.6 Record and analyse results 3.7 Prepare and present report 3.8 Operate and maintain testing equipment	• Direct instruction • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

10.3.4.2 Information Sheet No10/LO3 Undertake Tests on the Alignment Soils

Introduction to learning outcome

This learning outcome covers soil tests, standard manuals, gathering of tools and equipment, alignment of soil samples, conduct soil samples, recording and analysing results, prepare and present report and operate and maintain testing equipment.

Definition of key terms

Shear test- This is a labouratory or field test that is used to measure the shear the strength properties of rock or soil materials.

Triaxial- This is a test used to measure the mechanical properties of deformed solids such as soil and rocks.

Plastic limit- This refers to the water moisture content at which 3.2mm diameter strand of clay soil stops behaving like a plastic material and begins to crumble.

Content/Procedures/Methods/Illustrations

3.1 Identify *Soil tests* according to contract document

CBR- this is a penetration soil test used to evaluate the subgrade strength of road and pavements.

Atterberg Limit- This is the water level at which the state of soil changes from one form to the other. In this test, there is measuring of the critical water content of fine-grained soils. They are the Plastic Limits (PL), Shrinkage Limits (SL) and Liquid Limits (LL).

Liquid Limit (LL) - This is an atterberg test that determines the water content at which clayey soil tends to change it's from plastic to liquid form. It measures the moisture content at which the soil sample will flow until it closes the one-half inch groove within it after dropping the standard LL equipment 25 times.

Plastic Limit - This refers to the water moisture content at which 3.2mm diameter strand of clay soil stops behaving like a plastic material and begins to crumble.

Proctor/compaction - This is a way of determining the optimum moisture content at which a particular soil type will become the densest enabling it to achieve maximum dry density when experimented on in the labouratory.

Field density- This is a common test which is used to find the field density of a particular pavement or soil sample. The test works on the principle that sand with a known density is used to replace soil excavated materials hence we can calculate the volume of the sand that is required to fill the hole.

Particle size distribution Analysis – this is a test that determines and reports information on the size and range of particles representative of a given material.

3.2 Obtain standard manuals and procedures in accordance with test requirement

The standard manuals and procedures used to carry out these soil tests are;

- **ASTM D 422 -** Test Method for Particle-Size Analysis of Soils
- **ASTM Standard**: D653 Standard Definitions of Terms and Symbols Related to Soil and Rock Mechanics**.**
- **NYSDOT** Geotechnical Engineering Bureau method of determining the moisture content of soils etc.
- **BS 1377 – 2 – 1990:** for soil classification tests
- **BS 1377 – 4 – 1990:** for soil compaction tests

3.3 Identify and gather soil testing tools and apparatus based on test requirements

Soil testing instruments include;

- C.B.R. Test tools are C.B.R molds, soaking basin, C.B.R testing machine, hammer.
- Atterberg limit test tools are penetro meter, casagrade. Brass dish and shrinkage troughs

- Proctor test tools are proctor molds, hammer of mass 2.5 kg large mixing pan, weighing balance and detachable base plate.
- Field density testing tools are sand cone density plate, sand cone density apparatus test, and calcium carbonate chamber and moisture bag.
- Particle size distributions testing tools are testing sieves from 5 inches to 20 inches, sieve shakers and hard hand brush

3.4 Obtain alignment soil samples according to test requirement

The soil test sample testing is carried out in the alignments as outlined below:

- Standard test method for the unconsolidated - undrained strength testing of soils. This is a procedure that outlines the method which is used by the NYSDOT, geotechnical
- Engineering bureau in the unconsolidated - undrained strength testing of Soils. Its applicable documents are ASTM standard: D653 standard definitions of terms and symbols relating to soil and rock mechanics.
- Standard test for the consolidated - undrained Strength of soils. This procedure tends to outline the method used by the NYSDOT, geotechnical.
- Engineering bureau for determining the consolidated - undrained strength parameters of soils with applicable documents as ASTM standards: D653 standard definitions of terms and symbols relating to soil and rock mechanics.
- Standard test for the consolidated - undrained Strength with pore pressure of soils. This is a procedure outlines the method used by the NYSDOT geotechnical
- Engineering bureau for determining the effective consolidated - undrained strength parameters of soils with applicable documents as ASTM standards: D653 standard definitions of terms and symbols relating to soil and rock mechanics. Standard tests for the labouratory determination of moisture content of soils.
- Is a procedure that outlines the NYSDOT geotechnical engineering bureau method of determining the moisture content of soil?
- Standard tests for the one - dimensional consolidation testing of soils. In this section, the procedures described are those used by the soil mechanics labouratory. To determine the one-dimensional consolidation properties of the soils tested with applicable documents as ASTM standards: D653 standard definitions of terms and symbols relating to soil and rock mechanics. D2435 standard method for one-dimensional consolidation of soils.

3.5 Conduct Soil tests as per standard procedures

The specific soil tests are then supposed to be conducted as per the standard test procedures while following the steps provided to the later so as to ensure that the results acquired are as accurate as possible

Approved standard manuals for soil tests include;

- BS 1377-2-1990: For soil classification tests.
- BS1377-4-1990: For soil compaction tests.
- Road Design Manual Part III: For pavement material tests

3.6 Record and analyse results according to standard procedures

Recording results is basically the act of putting down obtained results from the practical.
Analysis of results is comparing the obtained results to the expected appropriate results by putting the results into a meaningful and well understood form that one can easily interpret.
Recording and analyzing of data is done to ensure that correct conclusions are made concerning the tested sample.
The obtained data calculation and/or analysis is presented in the following ways;

- charts,
- graphs,
- Tables etc.

3.7 Prepare and present report based on contract document requirement

After carrying out of the tests while following the required procedures then collecting and analysing the acquired data, the student will be required to prepare a detailed report on the relevant steps that were followed. This report follows the following structure;

i. Title of the given test – this is basically the heading for the given test.
ii. Introductions –this comprises of short theoretical explanation of the test undertaken.
iii. Objective of the test – this basically explains the purpose for taking the given test.
iv. A list of tools and equipment used for the test.
v. Procedure followed during the test – the procedure should be in reported speech since by the time the student is writing the report, he/she has already done the test.
vi. Results obtained- this is a record of values obtained from taking the results.
vii. Analysis of obtained results – this can be done by the help of mathematical calculations, tables, graphs etc.
viii. Conclusion – this is an explanation for the analysis.

Conclusion

This learning outcome covered soil tests, standard manuals, gathering of tools and equipment, alignment of soil samples, conduct soil samples, recording and analyzing results, prepare and present report and operate and maintain testing equipment.

Further Reading

Read more on: Soil tests, for both soil classification tests and soil compaction tests.

10.3.4.3 Self-Assessment

Written Assessment

1. Distinguish the following Atterberg limit test.
    a) Plastic limit
    b) Shrinkage limit
    c) Condensation limit
    d) Liquid limit
2. Outline the steps undertaken in testing for shrinking limits.
3. Compare and contrast the CBR test and proctor test.
4. The water level at which the state of soil changes from one form to the other is known as?
    a) Field density
    b) Atterberg limit
    c) Plasticity Index
    d) Proctor
5. Categories soil testing apparatus according to the following test.
    a) Field density
    b) CBR test
    c) Proctor test
    d) Atterberg test
6. Classify soil testing methods according to soil classification tests and soil compaction test
7. Summarize the content of a detailed soil report.
8. Explain the triaxial test.
9. Compare the different types of Atterberg limits?
10. Contrast soil testing equipment used for soil classification test and soil compaction test.

11. Classify the difference standard manuals used in soil test.
12. Distinguish between plastic limit and liquid limit?
13. Clearly outline the contents of a detailed labouratory report on soil tests.
14. Summarize the various ways of analyzing and presenting data acquired from soil tests?

Oral Assessment

1. Explain the procedure of carrying out particle size distribution.
2. Evluate the benefits of preparing a final labouratory report.

Case Study Assessment

Perform an assessment on the effect of that drastic rise in environmental temperature has on soils used in construction.

10.3.4.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

10.3.4.5 References

American Society for Testing and Materials. (2002). The Unified Soil Classification System. Annual Book of ASTM Standards, Vol. 4.08, West Conshohocken, PA.

Jamal, Haseeb. (Retrieved 23rd Sept.2019) "CBR Test". AboutCivil.Org.

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Soil Mechanics Test procedures. (Aug 2015). Geotechnical Testing procedures revision#6.

10.3.5 Learning Outcome No 4: Perform Concrete Tests

10.3.5.1 Learning Activities

Learning Outcome No 4: Perform Concrete Tests	
Learning Activities	**Special Instructions**
4.1 Identify **concrete tests** 4.2 Obtain standard manuals and procedures 4.3 Concrete testing tools and apparatus are identified and gathered 4.4 Obtain samples 4.5 Prepare samples 4.6 Cast cubes 4.7 Cure cubes 4.8 Test, obtain and record cubes, and results 4.9 Carry out and report analysis of test result	• Direct instruction • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

10.3.5.2 Information Sheet No10/LO4 Perform Concrete Tests

Introduction to learning outcome

This learning outcome covers concrete tests, concrete testing tools, preparation of samples, cast cubes, cure cubes and testing and recording of test results and report analysis

Definition of key terms

Casting cubes: This is a process of placing concrete in cube molds and socking them in water for 7 to 28 days to allow them to gain strength before performing compression test.

Curing cubes: This is a process of socking concrete cubes in water for about 7 to 28 days before testing for compression using the compression testing machine at day 7,14 and 28 consecutively.

Compressive strength: It is the ability of a material to resist breaking when subjected to compression forces.

Slump test: It is the measure of consistence of fresh concrete.

Content/Procedures/Methods/Illustrations

4.1. Identify concrete tests (Compressive strength, Slump, Cleanliness, Particle size distribution) according to contract document

As discussed in other outcomes, concrete is a mixture of cement, fine aggregates, coarse aggregates and water. Different tests need to be performed on these elements before they can be used to make concrete. This ensures that the produced concrete is of high quality. These tests include:

- **Compression test**

Compression test is performed to determine the compressive strength of concrete, which is defined as load per unit area.

- **Slump test**

Slump test is used to measure the wetness of concrete. It is mainly done to confirm workability of concrete. A slump can be true slump, collapse and shear slump as shown below.

Figure 103: Slump test
Source: www.concrete.org.uk

- **Cleanliness**

Aggregates which make part of concrete can affect the properties of concrete if they have any organic matter such as clay. It is therefore important to test the cleanliness of aggregate to ensure it is safe for use.

- **Particle size distribution**

This is also referred to us gradation. It is a test that determines and report information on the size a range of aggregates representative of a larger sample of aggregates.

4.2 Obtain standard manuals and procedures in accordance with test requirement

Standard manuals and procedures are meant to guide the student on how to perform a specific test and attain desired results without a lot of struggles.

These Standard manuals include;

- Road Design Manual Part III Section 17: For concrete works tests.
- BS1881: Part 102:1983 – Slump test
- BS1881: Part 108:1983 - Making of Concrete Test Cubes
- BS1881: Part 116:1983 - Concrete Cube Strength

4.3 Identify and gather concrete testing tools and apparatus based on test requirements

Tools and apparatus are often used to conduct the test. They are parts that make up for the success of any practical.

Testing tools and apparatus for ***Slump concrete test*** include;

- A 300mm rule graduated on 5mm intervals
- spatula
- Slump mold of galvanized iron or steel
- tamping rod
- Sampling tray

Testing tools and apparatus for ***concrete cubes test*** include;

- Spatula
- Sampling tray
- Tamping rod or vibrating table
- Cube or spherical mold of galvanized iron or steel.
- Plasterer’s steel float.

Testing tools and apparatus for ***concrete cube strength test*** include;

- Compression testing machine
- A weighing balance

4.4 Obtain samples as per test requirement and contract document

A **sample** is a presentation of a whole.

For different tests, samples are tested and the results represent a whole of the same make.

For example;

- Compression test and Slump test

Samples of cement and aggregates are used

- Cleanliness and particle size distribution

Samples of aggregates are used

4.5 Prepare samples according to standard test procedures

Methods for taking samples in concrete tests include;

i. When performing the slump test, the concrete sample should be taken from the labouratory mix 2 minutes after mixing and the slump determined instantly.
ii. In the event that the concrete is delivered to the site by a mixing truck, the concrete slump test sample should be collected from the initial discharge.
iii. In obtaining samples for the concrete cube test, a sample should be collected directly from the construction site and thoroughly mixed before it is placed in the mold
iv. Two test cube specimens should be prepared from each sample of fresh concrete.

4.6 Cast cubes as per standard test procedures

Standard test procedures vary. Below is a common procedure for casting cubes.

Procedure for cube casting;

- Take the concrete mortar and place it in a 150*150*150mm mould in 3 layers, ensuring that you compact using a tamping rod after every layer using 35 Nos of strokes
- Leave the cube for 24 hours and then remove it from the metal mould
- Do the above to make 2 more moulds and for each mould, test for compressive strength after 7 days and 28 days of soaking in water.

Once this procedure is completed, an analysis of the collected data is done.

4.7 Cure cubes as per standard test procedures

Curing is done when determining the compressive strength of concrete. It occurs when the cube is left in water for a number of days.

Curing of cubes can be attained in the following different ways;

- Ponding
- Sprinkling
- Wet coverings
- Membrane curing compounds
- Formwork

Depending on the test and specifications of the procedure manual, one of the above curing methods is adopted.

4.8 Test, obtain and record cubes, and results according to standard procedures

For every labouratory test, you will be needed to do the test in at least 3 samples. Once you get your sample and you have obtained the required cubes, you will need to record and label the samples such as Sample A, B… This will help you not to confuse your analysis. Remember that 1 or 2 sample tests are not adequate and could both be faulty at the same time, hence the need for a third test. Below is an example of a recording chart for most lab works.

Table 21: Recording Chart

SAMPLE	RESULTS
A1	3.2
A2	3.1

4.9 Carry out and report analysis of test result according to standard procedure and contract document

- Once the practical is concluded, you will be required to do your analysis. Analysis can be either graphical, calculations etc.
- A well-done analysis results to an accurate conclusion.
- For example, assuming the results gained above are true values, then, the average of the results is taken as the actual result. That is, (3.2+3.1)/2 hence 3.15 is the actual result for the sample

Conclusion

This learning outcome covered concrete tests, concrete testing tools, preparation of samples, cast cubes, cure cubes and testing and recording of test results and report analysis

Further Reading

Read further on concrete tests in the mentioned standard manuals.

10.3.5.3 Self-Assessment

Written Assessment

1. Concrete is made up of each of the following except?
   a) Cement
   b) Aggregates
   c) Lime
   d) Water
2. Which of the following is not an organic material?
   a) Clay
   b) Silt
   c) Aggregate
   d) Manure
3. Which of the following is true?

   Table 22: Concrete Curing Duration

CONCRETE CURING DURATION	STRENGTH
Day 1	99%
Day 14	50%
Day 28	14%

4. Which of the following is the odd one out?
   a) Gap graded
   b) Open graded
   c) Wide graded
   d) Uniformly graded
5. The following are ways of analyzing data. Which one is not?
   a) Graphically
   b) Mathematically
   c) Using calculations
   d) Observation
6. There are different types of concrete tests. Which one is not?
   a) Aggregate Crushing test
   b) Compression test
   c) Slump test
   d) Cleanliness test
7. Classify concrete and explain its preparation process.
8. Explain the curing process.
9. Summarize the slump test.
10. Differentiate casting and curing

11. Differentiate the different types of slump test

Essay questions

1. Explain the compression test.
2. Evaluate the preparation of concrete cubes.

Oral Assessment

1. Estimate the performance of concrete test
2. Distinguish the factors considered when conducting concrete test.

Oral Assessment

1. Classify the reasons why test are necessary.
2. Who is responsible for conducting tests in Kenya for actual projects?

Practical Assessment

What was your take on the results you got from the laboratory practical's?

10.3.5.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

10.3.5.5 References

Duggal, S. (2008). Building materials. New Delhi: New Age International.
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10.3.6 Learning Outcome No 5: Carry out Structural Steel Tests

10.3.6.1 Learning Activities

Learning Outcome No 5: Carry out Structural Steel Tests	
Learning Activities	**Special Instructions**
5.1 Obtain structural steel sample 5.2 Identify, obtain and calibrate tensile testing 5.3 Conduct test according to standard test procedures 5.4 Record and analyze results 5.5 Prepare and present report 5.6 Operate and maintain testing equipment	• Direct instruction • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

10.3.6.2 Information Sheet No10/LO5 Carry out Structural Steel Tests

Introduction to learning outcome

This learning outcome covers structural designs, calibration tensile testing, recording and analysing results, preparation and presenting of report and operation and maintenance of testing equipment.

Definition of key terms

Tensile strength: It is the ability of a material to resist tension stresses/forces.

Structural designs: This is an investigation of structures rigidity and strength and subsequently giving provisions to the material standard to be used.

Calibrate tensile testing: This is the verification of the accuracy of the tensile testing machine to ensure that measurements are within the outlined tolerance and if not, they are adjusted.

Content/Procedures/Methods/Illustrations

5.1 Obtain structural steel sample based on structural designs

Procedure for Sampling Structural Steel

i. Ideally, requests for sampling structural steel normally come from the Design division. Therefore, the first step is to obtain copies of the plan of site, plan of the structure and structural steel details.
ii. Determine the location of the structure (I.e. Bridge) and its site limitations.
iii. Prepare proposed sample locations having in mind possible challenges that may arise with these locations such as water below the structure, heavy traffic, railway tracks etc.
iv. Obtain the structural steel samples from the proposed location or from locations advised by the Ministry of Transport. Ensure a sufficient number of samples are obtained to provide a good average for testing.
v. Samples are commonly taken from compression areas since steel has a good tensile strength compared to its compression ability.

Steel members include but are not limited to:

- H - sections
- I - sections
- T - sections

5.2 Identify, obtain and calibrate tensile testing as per test requirement and manufacturers manual

The following are reasons why Calibration is done for testing equipment;

- Statutory as provided for in relevant legislation
- Driven by event such as; damage of the equipment, new equipment, rental equipment.
- Driven by time events such as; heavily used equipment, un-used equipment for an extensive period of time, prescribed calibration schedules.

Factors to be considered when performing calibration for testing equipment;

- The person performing the calibration should be conversant with the calibration procedure for that particular piece of equipment.
- Equipment owner’s manual should be reviewed with the respect to the procedure.
- The company policy should be reviewed and understood if available.
- All proper forms should be in hand and kept where easily available.

When to calibrate;

- In case of equipment damage.
- When equipment is subjected to shock.
- Equipment has been repaired.
- New equipment.
- Expiry of the stated time limit

5.3 Conduct test according to standard test procedures

Tests conducted for structural steel are as follows;

Charpy Impact Test – This is used to determine fracture toughness for structural steel. Steel samples are tested by immersing them in an oil bath at temperature above 40^0F for 24 hours. The steel samples are then placed into the Charpy machine to test for their fracture toughness.

Tensile Test – This is used to determine yield, ultimate load strengths, percentage elongation and percentage reduction of area.

The procedure for conducting the tensile test is as follows:

i. Prepare the steel sample and record it initial dimension.
ii. The tensile test machine is prepared.
iii. The prepared sample is gripped in an apparatus (tensile machine) and subjected to tensional force
iv. Record the time until the sample fractures.
v. The increase in length for the material is converted to strain while the pulling force (load) is converted to stress.
vi. The process is repeated for other samples with results being recorded.

Chemical Analysis: This is used to determine the presence of chemical elements and their percentages in steel. Chemical elements that are generally tested for include;

- Carbon
- Silicon
- Sulphur
- Phosphorous
- Manganese

The test results are then compared to the recommended ASTM standards.

5.4 Record and analyze results as per standard procedures

Recording results is basically the act of putting down obtained results from the practical while **analysis** is comparing the obtained results to the expected appropriate results by putting the results into a meaningful and well understood form that one can easily interpret. Recording and analyzing of data is done to ensure that correct conclusions are made concerning the tested sample. During testing activity, the one conducting the test is required to ensure that they have put down in writing all observations. It is necessary to note that different procedures require different recording and analysis techniques depending on the type of apparatus used. The analysis could be in terms of tables, charts, graphs or equations.

Below is an example of recorded data from the tensile test;-

Table 23: Data recording table

	Sample A	**Sample B**	**Sample C**
Maximum load	20kN	18kN	21kN
Initial length	30mm	30mm	30mm
Final length	42mm	41mm	43mm
Initial diameter	5mm	5mm	5mm
Final diaeter	3.8mm	3.6mm	4mm
Testing duration	100seconds	94seconds	102seconds

Analysis of tensile tests is normally done by the use of a graph as shown below:

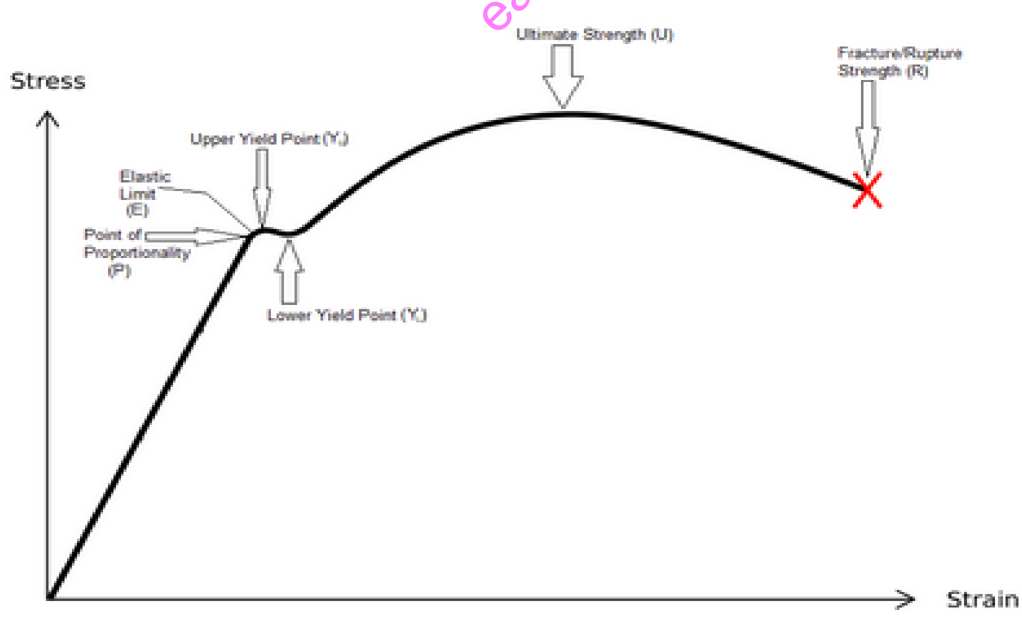

Figure 104: Analysis of tensile tests
Source: Strength of materials, 2010

5.5 Prepare and present report according to the contract document

At the end of the test, you will be required to prepare a report normally called a labouratory report. The format for preparing a report is as outlined below;

- **Introduction:** The introduction contains a brief description of the test that have already been done.
- **Literature review:** This section is meant to explain a small background regarding the tests being done.
- **Methodology:** Methodology is a section where one explains the procedures used. Note that in this case, procedures are in past tense.
- **Data collection and analysis:** This section contains data collection sheets as well as graphs and equations used into the analysis.
- **Conclusion and recommendations:** After completion of analysis, you will be required to draw a conclusion of the obtained data.
- **References:** This is a list of books that one referred to.

Conclusion

This learning outcome covered structural designs, calibration tensile testing, recording and analyzing results, preparation and presenting of report and operation and maintenance of testing equipment

Further Reading

Read further on structural steel tests from the recommended standard manuals

10.3.6.3 Self-Assessment

Written Assessment

1. Tensile testing is used to measure the following except?
   a) Yield strength
   b) Elongation
   c) Compressive strength
   d) Elastic modulus

2. Which metal is commonly used for construction?
    a) Aluminum
    b) Steel
    c) Iron
    d) Copper
3. A report should contain each of the following except?
    a) Body
    b) Introduction
    c) Conclusion
    d) Data collection and analysis
4. Poor maintenance could lead an equipment into?
    a) Crushing
    b) Underperforming and failure
    c) Cracking
    d) Over-performing
5. Where do we get procedures for practical's?
    a) Internet
    b) Labouratory technician
    c) Text books
    d) Our lecturer
6. Steel is strong in?
    a) Compression
    b) Tension
7. Classify structural design?
8. Distinguish tensile strengths.
9. Describe in your own words the following
    a) Elastic modulus
    b) Elongation
    c) Tensile strength
10. Design literature review of the report.
11. Analyze the maintenance procedures of the equipment.
12. Prepare a tensile test.
13. Summarize what is structural steel.

Oral Assessment

1. What is a structure?
2. Categorize the instances in which steel is not used in constructions.

Oral Assessment

1. Which companies are responsible for manufacturing steel?
2. Are there instances when steel is not used in construction? Elabourate.

Practical Assessment

What was your take home after conducting the tensile test practical? What are your recommendations and what should be improved?

10.3.6.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

10.3.6.5 References

Rajput, R. (2000). Engineering materials. New Delhi: S. Chand & Company.
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10.3.7 Learning Outcome No 6: Perform Bitumen Tests

10.3.7.1 Learning Activities

Learning Outcome No 6: Perform Bitumen Tests	
Learning Activities	**Special Instructions**
6.1 Identify **Bitumen tests** 6.2 Obtain standard manuals and procedures 6.3 Identify and gather testing tools and apparatus 6.4 Obtain samples 6.5 Prepare samples 6.6 Conduct test 6.7 Record and analyze test results 6.8 Prepare and present report 6.9 Operate and maintain testing equipment	• Direct instruction • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

10.3.7.2 Information Sheet No10/LO6 Perform Bitumen Tests

Introduction to learning outcome

This learning outcome covers bitumen tests, gathering of testing tools and equipment, obtaining of samples, conducting of test, recording and analyzing test results, preparation and presenting report and operation and maintenance testing of equipment.

Definition of key terms

Bitumen: It used as the surface layer during road construction.

Bitumen tests: These are the various tests used to determine the quality of bitumen.

Samples: These are small pieces taken from bitumen that are used for analysis.

Content/Procedures/Methods/Illustrations

6.1 Identify Bitumen tests according to contract document

The bitumen tests are used to test the various properties of bitumen and whether it is suitable for use during road construction. The following are the tests:

Penetration test: It calculates the hardness or softness of bitumen. It is done by determining the distance in which the penetration needle pierces through the bitumen sample at standard conditions.

Cleanliness: This is the removal of bitumen. It can be done using solvents that are able to dissolve it.

Viscosity test: This test measures the resistance to flow of bitumen. It helps in identifying the consistency of bitumen in different grades of bitumen and how they should be mixed to bring out the best.

Ductility test: Ductility is the ability of a material to straighten. In this case, this property is tested in bitumen. It is necessary to make sure that bitumen does not crack upon force being applied by traffic load.

Flash test: Hot bitumen emits hydrocarbon compounds that are flammable. This test determines the lowest temperatures at which this vapour catches fire temporary then puts itself out.

Fire test: This determines the lowest temperatures in which the hot bitumen catches fire and burns. It helps in coming up with suitable precautionary measures to avoid danger during heating of bitumen.

Float test: This test is used to determine steadiness of bitumen that other tests are unable to.

Loss on heating test: This test is carried out after bitumen has cooled off. A sample is weighed first then heated for some time. The sample specimen is weighed again and the loss is expressed as a percentage.

Specific gravity: The specific gravity of bitumen is the ratio of its weight to the weight of equal volume of water at 27^{o} C. The specific gravity is measured using either pycnometer. The specific gravity of bitumen ranges from 0.97 to 1.02.

Softening point test: This tests the temperatures in which bitumen attains softening.

Spread rate test: This determines the rate at which bitumen spreads.

Importance of Bitumen Tests

- To determine the consistency of bitumen.
- To check its appropriate usage under different climatic conditions and various constructions
- To determine its elongation properties.

- To determine its ability to withstand extreme temperatures that is, very low and very high temperatures.
- To determine the mixing ratio of different bitumen grades.
- To determine its resistance to flow hence determine where to use it.

6.2 Obtain standard manuals and procedures in accordance with test requirement

The manual includes:

- Road design manual Part III: Materials and Pavement Design for new roads. It clearly states how the procedures should be followed for the testing of any material.

6.3 Identify and gather testing tools and apparatus based on test requirements

The testing apparatus for bitumen include:

- **Asphalt Ignition Oven** – for heating the bitumen
- **Cleveland Flash and Fire Point Apparatus** – conducts Flash and Fire test on bitumen
- **Ductility Testing Machine-** for conducting Ductility test
- **Float Test Apparatus** – for conducting Float test
- **Penetrometer** – for conducting Penetration test
- **Ring and Ball Apparatus** – for conducting softening point test on bitumen.
- **Viscometer** – for conducting viscosity test

6.4 Obtain samples as per test requirement and contract document

Process of obtaining the samples

i. Determine the location in which the samples are going to be collected.
ii. There are various places as to where bitumen can be found;
iii. Asphalt Mix plant where bitumen is processed.
iv. An ongoing road construction site.
v. Determine the sample size.
vi. Prepare the equipment you are going to use for collecting the sample such as scoop, shovel, sampling containers, dish containers etc
vii. Collect the samples and take them for testing. The process of collecting includes the following:
    - A shovel is used to collect the sample from the site and placed in sampling containers.
    - A scoop is used to collect a portion from the sampling containers until the right size is acquired.
    - The sample is placed in a dish container and then taken for testing preparations.

6.5 Prepare samples in accordance with test procedures

Process of preparing bitumen samples

(i) The sample is then heated in an oven until it is fluid-like.
(ii) It is then poured into a container.
(iii) The sample is then stirred to remove the air that is trapped within it.
(iv) The sample is allowed to cool under room temperature
(v) The sample is now ready to be conducted for other tests.

NB: Some tests may require water bath

6.6 Conduct test according to standard procedures and contract document

Process of conducting test

i. Obtain the right machinery for testing.
ii. Obtain the right conditions before commencement of any test eg. the temperature, air pressure, humidity etc. In case the conditions cannot be met, modify or use alternative ones.
iii. The machines should be examined for damage and should be dried and clean. A suitable bitumen solvent is used for cleaning the equipment.
iv. Connect the parts that need to be attached.
v. The sample is then placed for testing.
vi. Results are obtained and recorded.

6.7 Record and analyse test results according to standard procedures

The results should contain the following:

- The form and grade of bitumen tested
- The properties tested
- The testing procedures used according to the standard manual
- The results of the tests
- The SI units of the values.
- The range in which the values should lie that is, the minimum and maximum values

6.8 Prepare and present report as per contract document

The report should have:

- Name of the Labouratory that conducted the test
- The date, time, form, grade and quantity tested.
- The testing procedures used
- Test results
- Approval
- Signatory

Conclusion

This learning outcome covered bitumen tests, gathering of testing tools and equipment, obtaining of samples, conducting of test, recording and analyzing test results, preparation and presenting report and operation and maintenance testing of equipment.

Further Reading

Read through the various bitumen tests in detail.

10.3.7.3 Self-Assessment

Written Assessment

1. The prerequisite of any bitumen test is heating it until its fluid-like. Which of the following does not require heating?
    a) Bitumen emulsion
    b) refined bitumen
    c) Cut back
    d) Paving grade
2. Which grade of Bitumen is the softest?
    a) 30/40
    b) 60/70
    c) 80/100
    d) None
3. What should be the minimum distance between samples in a penetration test?
    a) 30mm
    b) 50mm
    c) 10mm
    d) 200mm
4. What is the significance of the following tests?
    a) Ductility
    b) Float test
    c) Flash and fire
5. Evaluate the standard conditions of bitumen before carrying out the tests?
6. Evaluate the properties of bitumen.
7. Classify the safety precautions that should be undertaken when collecting the samples?

Oral Assessment

1. Summarize the factors affecting each test?
2. Categorize bitumen.

Case study Assessment

Evaluate how bitumen is laid during road construction.

Oral Assessment

1. Select the precautionary measures when carrying out the bitumen test.
2. Distinguish the penetration grades in warmer and colder regions.

Practical Assessment

Prepare the penetration test for bitumen

10.3.7.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

10.3.7.5 References

Road design manual Part III – Materials and Pavement Design for new roads. (2001). Pdf. Retrieved from http://kenha.co.ke

10.3.8 Learning Outcome No 7: Perform Timber Tests

10.3.8.1 Learning Activities

Learning Outcome No 7: Perform Timber Tests	
Learning Activities	**Special Instructions**
7.1 Identify timber tests 7.2 Obtain standard manuals and procedures 7.3 Identify and gather testing tools and apparatus 7.4 Obtain samples 7.5 Prepare samples 7.6 Conduct test 7.7 Record and analyze test results 7.8 Prepare and present report 7.9 Operate and maintain testing equipment	• Direct instruction • Field trips • Discussions • Demonstration by trainer • Practice by the trainee

10.3.8.2 Information Sheet No10/LO7 Perform Timber Tests

Introduction to learning outcome

This learning outcome covers timber tests, gathering of testing tools and equipment, obtaining of samples, conducting of test, recording and analysing test results, obtaining of samples, conducting tests, preparation and presenting report and operation and maintenance testing of equipment.

Definition of key terms

Timber samples: These are small pieces of timber picked from the whole and are used for testing.

Samples: Small pieces of an object that is to be tested that are used to represent the whole.

Contract document: This is a document that contains details of an agreement between two or more parties.

Content/Procedures/Methods/Illustrations

7.1 Identify timber tests according to contract document

Timber that is free from defects should undergo these tests. The tests are used to determine its properties. These properties are elastic, strength and vibration properties. The tests include:

- **Compression test:** This test involves applying forces towards each other at the sides of a material. This may lead to the material crushing and so a universal test machine is used to determine the compression strength. It is basically, how long a material can take before it gets crushed.

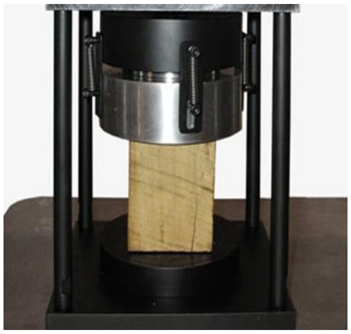

Figure 105: Compression test
Source from www.intron.us

- **Tension test:** Forces heading in opposite direction are applied at the sides of the material. The material will be pulled until it fractures.
- **Shear test:** forces are applied in a material such that part of the material slides in the opposite direction to the other.

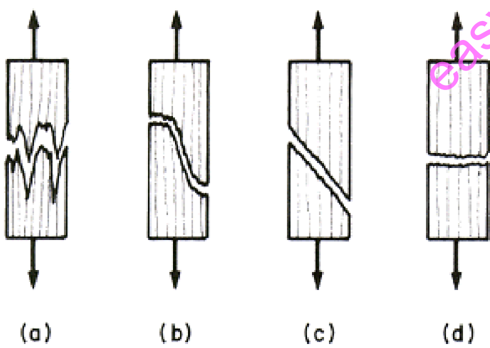

Figure 106: Examples of shear on timber
Source from classes.mst.edu

7.2 Obtain standard manuals and procedures in accordance with test requirement

The manuals used are:

- BS 5268-2:2002
- BS EN 380 which provide the testing requirements.

7.3 Identify and gather testing tools and apparatus based on test requirements

They include:

- Universal Test Machine – it carries out the various tests in timber
- Machete or power saw – for cutting the timber

- Measuring tape – for taking the measurements
- Marker – for putting marks on the samples

7.4 Obtain samples as per test requirement and contract document

Process for obtaining the samples

i. Where to obtain the samples
   - Safety precautions should be considered
   - The accessibility should be considered
   - Getting permit if necessary

ii. When to obtain the samples
   - Climatic conditions of the location
   - The season

iii. What type of specimen do you require- the maturity and species are considered?

iv. Method of sampling – mostly through cutting

v. Tools to be used

7.5 Prepare samples in accordance with test procedures

Process of sample preparation

i. The samples should be obtained from their members. They should have the following characteristics; they should be small, clear, straight-gained and free from defects.

ii. They should then be cut into the dimensions stated in the standards e.g. compression test samples should be 2” by 2” and 8” in length along the grain.

iii. Markings should be made to differentiate the e.g. sample no.1 from member 4.

iv. The specimen should then be conditioned to standardize its moisture content and then kept for testing.

NB: The samples should be cut carefully to ensure that the grain surfaces are parallel to each other.

7.6 Conduct test according to standard procedures and contract document

The procedure for conducting timber tests

i. A universal test machine is used and the standard test method is applied.

ii. The various tests are applied that is, compression, tension and shear tests and they are applied both perpendicularly and parallel to the sample grain.

iii. Results are taken and recorded.

The purpose of conducting the tests

- It is to determine the behaviour of timber when subjected to stain, stress and shear.
- To determine certain parameters such as elastic limit, ultimate compressive strength, elastic modulus, yield strength, ultimate tensile strength, elastic limit, yield strength etc.
- To determine the various kind of failure that may occur in timber.
- To determine the suitability of timber.

7.7 Record and analyse test results according to standard procedures

Procedure for recording and analysing test results

i. Calculations are carried out according to test procedures
ii. The test results should be recorded in a table form. The table should contain the following:
    - The source of the sample
    - The sample number
    - The type of test carried out
    - The testing procedures used
    - The results
    - The SI units of the values
    - The specifications if available
iii. Appropriate graphs are drawn
iv. Conclusions are stated

7.8 Prepare and present report as per contract document

The report should contain the following:

- Name of the Labouratory that conducted the test
- The subject
- The sample number
- Date and time of the test
- The testing procedures used
- Test results
- Approval
- Signatory

Conclusion

This learning outcome covered bitumen tests, gathering of testing tools and equipment, obtaining of samples, conducting of test, recording and analysing test results, preparation and presenting report and operation and maintenance testing of equipment.

Further Reading

Read on more tests that are carried out in timber
Describe the various properties of timber
Read more on the defects of timber and how they affect its quality.

10.3.8.3 Self-Assessment

Written Assessment

1. In timber, shearing action occurs;
    a) Across the grain
    b) Parallel to the grain
    c) Along the grain
    d) All of the above
2. What is the ratio of stress to strain in shear?
    a) Modulus of elasticity
    b) Young's modulus
    c) Modulus of rigidity
    d) Rolling shear
3. Which method is used to carry out shear test?
    a) Non-destructive testing
    b) Creep test
    c) Tensile test
    d) Torsion test
4. Using relevant diagrams describe a timber specimen.
5. Compare the force applied on timber grain.
6. Evaluate which are engineered timber and give examples.
7. Explain the compression test of timber.
8. Classify the errors eliminated during individual test results?
9. Categorize the method used in measuring the strength of timber.

Oral Assessment

1. Distinguish the crack formed in timber
2. Explain the results obtained from a compression test of timber.

Case Study Assessment

Compare the trees near your area and determine the strongest using observational skills.

Oral Assessment

1. Evaluate the significance of carrying out each of the timber tests.
2. Summarize the various failures visible in the trees and timber structures around your area.

Practical Assessment

Prepare the strength, compression and shear tests of both natural timber and engineered timber and compare the results.

10.3.8.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

10.3.8.5 References

EAS. (2002). Timber – Sampling Methods and General Requirements for Physical and Mechanical Tests

Khokhar., A. (2009). Determination of Shear Strength of Timber Joists by Torsional Testing.

Standards Policy and Strategy Committee. (2002). British Standard 5286. (5th ed., pp. 151-154).

CHAPTER 11: HIGHWAY SURVEY

11.1 Introduction of the Unit of Learning

This unit specifies the competencies required to Perform Highway Survey**.** It involves undertaking preliminary site survey, performing levelling activities, conducting tacheometry works and drafting road cross-sections. It also includes carrying out setting out activities, performing traversing works and performing traffic engineering survey.

11.2 Performance Standard

Undertake preliminary site survey, carry out setting out activities, conduct tacheometry works, perform levelling activities, draft road cross-sections, perform traversing works, and perform traffic engineering survey in accordance with contract document, standard road construction procedures and SOPs.

11.3 Learning Outcomes

11.3.1 List of Learning Outcomes

a) Undertake preliminary site survey
b) Carry out setting out activities
c) Conduct tacheometry works
d) Perform levelling activities
e) Draft road cross-sections
f) Perform traversing works
g) Perform traffic engineering survey

11.3.2 Learning Outcome No 1: Undertake Preliminary Site Survey

11.3.2.1 Learning Activities

Learning Outcome No 1: Undertake Preliminary Site Survey	
Learning Activities	**Special Instructions**
1.1 Prepare preliminary site survey plan 1.2 Identify and mobilize ***survey resources*** 1.3 Obtain and interpret survey drawings 1.4 Assess and record findings of ***site conditions*** 1.5 Establish and document original ground level (OGL) is 1.6 Establish reference points 1.7 Prepare preliminary survey report	• Written tests • Observation • Case study • Oral questions • Third party report

11.3.2.2 Information Sheet No11/LO1: Undertake Preliminary Site Survey

Introduction to learning outcome

This learning covers preparing of contract documents, interpreting of the documents, assessing of site conditions as well as following laid procedures in the standard road construction procedure.

Definition of key terms

Site survey; It is the process of interpreting construction plans and marking location of planned new projects, such as roads or buildings. Site survey is necessary before any construction starts, it helps in determining the precise location, access, best orientation for the site & the location of the obstacles. Site survey provides insights to the project manager, it also saves a lot of trouble and potential dangers that are identified before the project starts.

Contract document; those documents which include a contract. For example; Construction contract documents define the agreement basis including the roles, obligations of both parties and a detailed description of the work or service, such as drawings, specifications, procedures, any other conditions, etc.

Reference points; these are objects or places used in determining if something is in motion. They may include buildings, trees or signs.

Content/Procedures/Methods/Illustrations

1.1 Prepare preliminary site survey plan in accordance with contract document

Preliminary site assessments are undertaken to determine the most appropriate land-use. With current growth in population with limited land, development properties maximize the available land. In preliminary site survey it involves collection of adequate data for map preparation to be used for planning and design.

There are three types of preliminary survey; ***control surveys***, ***aerial surveys***, ***topographical surveys***. The preliminary survey results form the basis for the project's design, detailed plans and cost estimates. The following are guides when preparing preliminary survey;

- Calibration reports for devices and the calibration worksheets
- Field notes
- Preliminary survey scope form
- Field notes
- Presurvey conference meeting.
- Special use permits
- Traffic control plans indicating possible access routes
- GPS specification of the proposed site
- GPS planning and network reports to indicating possible future connections.
- Final land survey control diagrams
- Copies of utility maps

1.2 Identify and mobilize *survey resources* (Human resources, tools, equipment, stationery, legal documents, power back-ups and location maps) as per the contract document

Contract document contains the responsibilities of personnel and their duties that they are obligated to perform by the contract.

Human resources; each project requires both skilled and unskilled labour to make sure that the work specified is done as dictated. For example, **Land surveyor**;

Tools & Equipment; these are various device that are used in surveying e.g. theodolites, dumpy lever, rods etc.

Legal documents; these are documents that are tied to the proposed site. They include Purchase certificate, Permit survey form**.** Such documents should be ensured that are in order to avoid lengthy court cases which may delay construction.

Power backups; Source of electricity near the site should be surveyed. If electricity is not reliable consider providing for backups

Location maps; Locations maps should be produced based on site visits and observations at the site. These maps should be able to capture a lot on useful information to be used in planning and design stage**.**

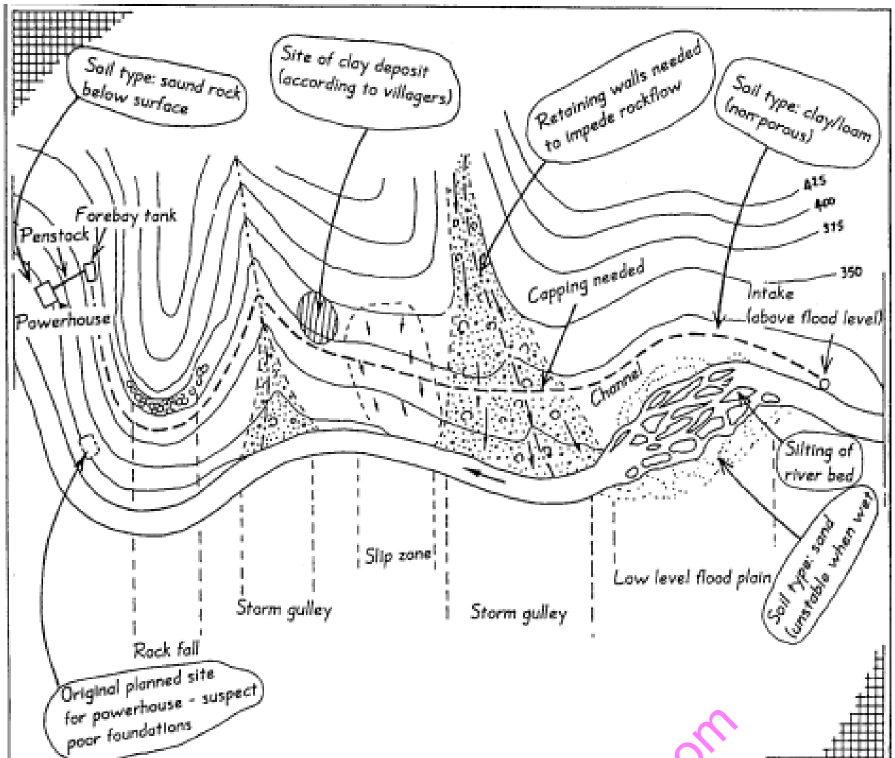

Figure 107: A geological sketch based on site observations
Source; Surveying Manual

1.3 Obtain and interpret survey drawings as per the contract document Assess and record findings of site conditions according to standard road construction procedures

a) **Topography;** Aerial photographs are used to study the topography of the proposed site. With advance technology the mosaic prints of digitized images from where, the GPS coordinates of the points can be mapped.

b) **Soil Types Profiles;** Soil type and profile have a great influence on the project. The soil type and profiling of the soil of the proposed site is recommended to have better understanding of the geotechnical properties of the underlying soil.

c) **Vegetation;** in reconnaissance stage the vegetation covering the site should be noted in order to procure the right machinery and for the purpose of cost estimation costs**.**

d) **Settlement;** this can be captured in the local map; this is necessary for design purposes of the proposed project. This is necessary for evaluation of possible future expansion or estimation of unoccupied land. Settlement properties should be well laid out.

e) **Utility services;** these include water connection to the mains, supply of power, existing underground communication cables. Utility services should be well indicated in consultancy with the municipal council existing within the project limits

f) **Water Table level;** wetland surveys should be done to determine the water level where the projects will be situated. It should be controlled and oversee by the relevant body in Kenya its NEMA.

1.4 Establish and document original ground level (OGL) is as per standard road construction procedures

Original ground level is level achieved after applying machinery to make the ground after clearing and grubbing. Natural level ground is the ground elevation in its original form, to achieve the original ground level which is suitable for construction of roads, railway & highway, areas and volume of the sections of the road need to be evaluated. The following sub-topics should be covered in class to have idea on original ground level.

- Mass haul curves
- Mid ordinate rule
- Average ordinate rule
- Simpsons rule
- Areas and volumes.
- Transversing
- Tacheometry

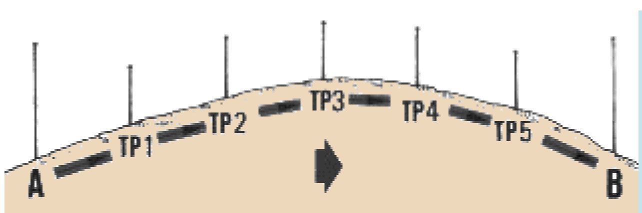

Figure 108: Tacheometry
Source; Google

From point A of a known elevation, survey through five turning points, TP1 ... TP5, and discover point B elevation. To check on the levelling error, survey by traversing BA through four other turning points, TP6 ... TP9; Then measure the A rise. If the established starting point A elevation is 153 m, and the measured amount of A at the end of the survey is 153.2 m, the closing error is 153.2 m-153 m = 0.2 m.

1.5 Establish reference points based on standard road construction procedures

A **control point** is a point at the ground or some permanent structure known for its horizontal and vertical position. If these control points are used to determine other points, then they act as **reference point** to the new points.

The following procedure is used in establishing horizontal control;

i. Key points are identified and marked that would act as the control (reference) for the subsequent surveying. These could be points located at the boundary of the mapped area, maximum or minimum elevation points, significant characteristics, etc. There should be at least 3 points clear from each point.
ii. Establish the baseline, a distance precisely determined between 2 control points, which should occupy fairly level ground. Measure the baseline distance with a 50 m tape to closest 10 mm. If the distance is greater than mark 50 m with survey pins to the tape lengths. Measure the length of the average in both directions. When the 2 measurements vary by more than 50 mm repeat both measurements, using the mean of the two distances otherwise. Measure the vertical angle between controls points to that the length of the surface to a horizontal distance.
iii. The tripod is placed above a control point.
iv. Mount the transit onto the tripod (theodolite). Slide the transit laterally until it is placed as seen through the optical plunge, directly above the control point. Turn the 3 leveling screws device which centers the bubbles in the 2 orthogonal spirit levels.
v. Release the screw at the top of plate. Rotate the telescope around the vertical axis until the Vernier scale mark 0 is aligned with the outer horizontal scale proper magnetic declination. You can make small changes by tightening the set screw and using the tangent screw.
vi. Document horizontal angle visible from the instrument station to each of the control points. View of a rod or pole ranging on a stadium. The focusing screw is mounted outside the normal and does not contain the vertical circle. The centering ring for the crosshairs is on the eye piece.
vii. Document horizontal angle visible from the instrument station to each of the control points. View on a stadium rod or pole frame.
viii. By 1800, rotate the telescope around its vertical axis. Adjacent to the telescope is the telescope set screw. The tangent screw with the focusing screw for fine adjustment of the telescope 's inclination is located on normal.
ix. Push the transit and repeat instructions 3-8 until horizontal angles between all the control points are formed.

1.6 Prepare preliminary survey report according to SOPs

The following are what is included in a preliminary survey report;

1. **Introduction:** This provides general description of the preliminary surveying process
   - It contains the surveying activities to be carried out, projects schedule & safety in the site.
2. **The preliminary survey processes:** The following are under this stage.
   - Survey meeting held by engineer to determine schedule and assign responsibilities.
   - Land ownership permission to survey; Map studying, avail of permit documents to survey.
3. **Preliminary and supplemental survey data:** A preliminary survey consists of field data collected used to construct mapping files for the project. Collecting, editing and submission of data is done here.
4. **Carrying out of the appropriate type of preliminary survey:** Control, Aerial geological, wetlands, land survey etc. to be carried and report documented.
5. **Distribution of survey and mapping files:** Production of previewing of the finalized documents.

Conclusion

This learning covered preparing of contract documents, interpreting of the documents, assessing of site conditions as well as following laid procedures in the standard road construction procedure.

Further Reading

Read further on how to establish the Original Ground Level in pavement construction.

11.3.2.3 Self-Assessment

Knowledge Based Evidence

Written Assessment

1. Theodolite should be provided with calculation__________ to measure the magnetic bearing of a line
   a) Extra telescope
   b) Compass
   c) Spirit level
   d) Through compass
2. If both ends are inter-visible, to run a straight line between two lines. We define intermediate points via
   a) Line of sight
   b) Balancing
   c) Use of a random line
   d) Backsight
3. Evaluate theodolite can be used for horizontal angle setting.
4. Summarize the reasons as to why the instrument should be levelled.
5. Define setting out with respect to theodolite.
6. The following offsets were taken from a chain line to hedge:

Distance	0	20	40	60	80	120	160	220
Offset	9.4	13.6	11.2	9.6	8.4	7.5	6.3	4.5

Compute the area included in the chain area, hedge and the offset by

I. Mid-ordinate
II. Average ordinate
III. Simpsons rule
IV. Trapezoidal area

7. Evaluate the following:
   a) Theodolite
   b) Vertical axis
   c) Bubble axis
   d) Collimation axis
   e) Horizontal axis
8. Distinguish the adjustments of a common theodolite type.
9. Explain the adjustment of a transit by collimatica.

Essay questions

1. Explain how a transit theodolite is checked and calibrated to allow for accurate reading of vertical angles, if appropriate.
2. Enumerate the constant adjustments of a theodolite transit.

Oral Assessment

1. Briefly differentiate between traversing and tacheometry.
2. Classify the following terms ‘face left, ‘face right’, ‘swing right’, swing left’ operation of theodolite.

Project Assessment

Conduct a theodolite procedure

11.3.2.4 Tools, Equipment, Supplies and Materials

- Surveying tools and equipment
- Computers
- CAD & GIS Software
- Construction manuals and guidelines
- Projectors
- Flip charts
- Calculators
- Stationery
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos
- Printers
- Workstation
- Standard of specifications

11.3.2.5 References

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11.3.3 Learning Outcome No 2: Perform Levelling Activities

11.3.3.1 Learning Activities

Learning Outcome No 2: Perform Levelling Activities	
Learning Activities	**Special Instructions**
2..1 Identify and select ***levelling tools and equipment*** 2..2 Calibrate levelling tools and equipment 2..3 Set road levels 2..4 Carry out monitoring and control of road levels	• Written tests • Observation • Oral questions • Third party report

11.3.3.2 Information Sheet No11/LO2 Perform Levelling Activities

Introduction to learning outcome

The leaner should cover levelling tools and equipment, calibrate levelling tools, set, monitor and control of road levels per the standard construction requirements.

Definition of key terms

Levelling tools; Levelling tools are what aid us in determination of height in respect to one known height. Some of the tools include; dumpy level, levelling staff, tilting levels, tape measure, pegs & ranging rods.

Road levels; Road is said to be in level if it remains within the surface without the loss or gain through displacement. Road level is arrived after taking chainage and balance the cut and fills.

Equipment; it is a tangible property that is used for a particular purpose. Examples of equipment includes; machine, tools

Content/Procedures/Methods/Illustrations

2.1 Identify and select *levelling tools and equipment* (Dumpy level, tilting levels and automatic levels, levelling staff, tilting levels, Automatic levels, Tape measure, Pegs, ranging rods) according to contract document

Dumpy Level; is an optical instrument used to set horizontal or transfer measure in surveying & building. According to surveying manual, dumpy level operates under two conditions of adjustments;

i. **Bubble tube**

To **test**; the instrument is set up such that the bubble is directly over two levelling screws, the bubble is entered carefully. The instrument is rotated at an angle of 90 degree for the bubble to be placed over the remaining pair of screws. To reverse, the instrument is rotated at 180 degrees. To **adjust**-distance moved by the bubble is twice the error present. The bubble is brought back halfway to correct the error by turning the adjusting nuts at one end of the bubble tube. Two level screws are used to renter the bubble.

ii. **Horizontal cross hair;** Reticule is adjusted to the manner of the automatic levels.

Figure 109: Dumpy Level
Source: www.theconstructor.org

- **Tilting Level;** Tilting level consists of a telescope that enabled horizontal rotation and rotation in its vertical plane approximately 4 degrees. Tilting screw is used to center the bubble.

Figure 111: Tilting level
Source: www.theconstructor.org

- **Automatic Levels;** It similar to the dumpy level, it has a telescope fixed at its support. For approximate levelling the circular spirit level is attached at the of the telescope. Compensator is fixed inside the automatic level for accurate levelling. They are fast, accurate and easy to use.

Figure 112: Automatic Level
Source: www.theconstructor.org

- **Tape Measure**; It is a tool used for measuring distance. It is used in levelling to find the distance of chosen points.

- **Pegs**; they are used to mark boundaries and show points and position in a site. Usually made of wood.

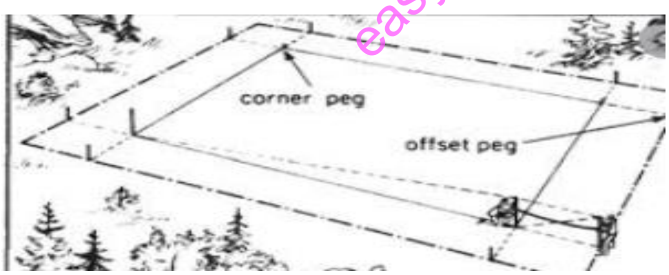

Figure 113 : Pegs used in a site for layout
Source: www.theconstructor.org

- **Ranging Rods**; these are tools used to mark the position of the survey stations and the viewing of those stations as well as the range of straight lines. They are used where the survey lines are long for proper boundary lines.

2.2 Calibrate levelling tools and equipment according to manufacturer's manual
To Calibrate is the process of relating readings of an instrument with those of standards to check the instrument's accuracy. Overtime levelling tools or any tool needs to be adjusted to try and bring it to its specification for it to give reliable data.

Calibration of tools & equipment

- If a piece of equipment has been subjected to an instance that would require the initiation of a new calibration, such a calibration shall be carried out;
- The recording of results used.
- To inform the project manager of any defective equipment and ensure that the equipment is labeled as "OUT of CALIBRATION" and is removed from service until it is restored/serviced.
- Consultation with the project manager or the employer on how to proceed in case of any doubt.
- Tools & any equipment should be calibrated as per the Instrument Manual.

Reasons why an equipment should be calibrated;

- Statutory as provided for in the Surveys Act or other relevant legislation
- Driven by event such as; damage of the equipment, new equipment, rental equipment.
- Driven by time events such as; heavily used equipment, un-used equipment for an extensive period of time, prescribed calibration schedules.

When calibrating the following should be taken note of;

- The person performing the calibration should be conversant with the calibration procedure for that particular piece of equipment.
- Equipment owner's manual should be reviewed with the respect to the procedure.
- The company policy should be reviewed and understood if available.
- All proper forms should be in hand and kept where easily available.

When to calibrate;

- In case of equipment damage.
- When equipment is subjected to shock.
- Equipment has been repaired.
- New equipment.
- Expiry of the stated time limit

2.3 Set road levels according to the design data

Road level is set through profile levelling, which is determination of elevation of points measured along a fixed line such as centreline line of rails, sewer line or roads.

Field procedure for levelling

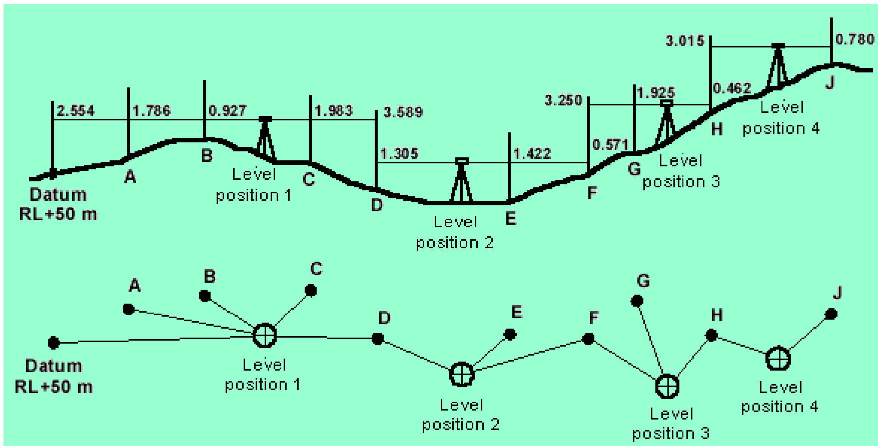

Figure 114: Sketch to guide in levelling
Source: www.geomag.nrcan.gc.ca

i. Levelling instrument is set at position 1.
ii. The staff is held at (RL+50M) and reading taken, this is taken as the Back Sight since is the first reading after the intermediate sight.
iii. Move the staff to A to take reading, this would be Intermediate Sight.
iv. Move the staff to B, take the reading, this point is taken as Intermediate Sight.
v. Move the staff to C to take the reading for another Intermediate Sight.
vi. Move staff to D take the reading, this is taken as Foresight, the level.
vii. The distance between two station should measure and data recorded in field book.
viii. Level is set at level 2 and leave the staff at D on the change plate. Turn out the staff so that it faces the level & take the reading, and this should be your back sight.
ix. Move staff to the point E and take the reading, this point is an intermediate sight.
x. Move the staff to point F and take the reading, this is your foresight since after taking the reading the levelled is moved.
xi. Move the level to level position 3, leave the staff at F on the change plate.
xii. Repeat the stated process from **i** to **k** until the last point at J.

NOTE: All the staff reading should be recorded in a field book; -Students are required to know how to feed the field book with, staff data.

- To eliminate errors resulting from line of sight also known as collimation back sight and should be equal in distance.

- Work usually commences from a known Bench Mark and close the level transverse. This facilates for level run to be checked.

  Booking Levels

  There are two methods of taking booking levels.

  I. Rise and fall method

  II. Height of collimation method.

I. Rise and fall Method

- In the appropriate columns on different lines, backsight, intermediate sight and foresight readings are entered. However, as shown in the fig below, if you adjust the level instrument, the back sights and foresights are put on the same side**.**
- The first lowered level is the datum height, baseline, or R.L.
- If an intermediate sight or foresight is lower than the read of the immediately preceding staff then the difference of the two readings is in the column of rise.
- If an intermediate sight or foresight is greater than the readings of the staff immediately preceding then the difference between two readings is in the fall column.
- The previous reduced level (RL) is increased in case there is a rise and a drop are subtracted from the previous RL.

NOTE; Arithmetic checks are run to check for any error, it only proves that the rise and fall is correctly in appropriate columns of rise & fall.

Checks

∑BS-∑FS

∑Rise-∑Fall

Last RL – first R

Table 24: A Worked Out Tabled Using the Rise and Fall Method

Back-sight	Inter-mediate	Fore-sight	Rise	Fall	Reduced level	Distance	Remarks
2.554					50.00	0	**Datum** RL+50 m
	1.783		0.771		50.771	14.990	**A**
	0.926		0.857		51.628	29.105	**B**
	1.963			1.037	50591	48.490	**C**
1.305		3.587		1.624	48.967	63.540	**D** / change point **1**
	1.432			0.127	48.840	87.665	**E**
3.250		0.573	0.859		49.699	102.050	**F** / change point **2**
	1.925		1.325		51.024	113.285	**G**
3.015		0.496	1.429		52.453	128.345	**H** / change point **3**
		0.780	2.235		54.688	150.460	**J**
10.124		**5.436**	**7.476**	**2.788**	**54.688**		Sum of B-sight & F-sight, Sum of Rise & Fall
-5.436			-2.788		-50.000		Take smaller from greater
4.688			**4.688**		**4.688**		Difference should be equal

Source: www.quora.com

II. Height of collimation

- Booking is similar to that of rise and fall method for back sight, fore-sight and intermediate sight. In place of rise and fall column is replaced with height of collimation.
- The first reading of back sight (datum, benchmark or RL staff) is added to the first RL which gives collimation height.
- The next reading of staff is entered in the corresponding column but on a new line. The station's RL is calculated by subtracting staff reading from the collimation height.
- Only when the level is moved to a new position will the collimation height change. The new collimation height is found by adding the back sight to the change point on the RL.
- It should be noted that the accuracy of intermediate RLs is not tested and errors cannot be detected.

  NB; Students should prefer to use rise and level method because it’s easier to note errors, a check of all columns is run.

Table 25: A worked-out table using the height of collimation

Back-sight	Inter-mediate	Fore-sight	Height of collimation	Reduced level	Distance	Remarks
2.554			52.554	50.00	0	**Datum** RL+50 m
	1.783			50.771	14.990	**A**
	0.926			51.628	29.105	**B**
	1.963			50591	48.490	**C**
1.305		3.587	50.272	48.967	63.540	**D** / change point **1**
	1.432			48.840	87.665	**E**
3.250		0.573	52.949	49.699	102.050	**F** / change point **2**
	1.925			51.024	113.285	**G**
3.015		0.496	55.468	52.453	128.345	**H** / change point **3**
		0.780		54.688	150.460	**J**
10.124		**5.436**		**54.688**		Sum of B-sight & F-sight, Difference between RL's
-5.436				-50.000		Take smaller from greater
4.688				**4.688**		Difference should be equal

2.4 Carry out monitoring and control of road levels as per the standard construction requirements

- Plans, processes, tools and organization carried out by professional design are required to track the quality of the contract document and ensure compliance with the standard construction specifications applicable.
- Monitoring and quality control includes observation, inspection, tests, documentation that checks the quality process such as road level.Monitoring and control of road levels is necessary to ensure the project meets the requirements of the contract.
- Monitoring is described as data gathering prior to and during implementation of the project. Upon analysis, these data identify progress or constraints as soon as possible, allowing project managers to modify project activities as needed. It also provides the basis for evaluating commitments. It is the duty of the contractor to ensure the desired quality is achieved. By ensure that construction materials are supplied according to contract requirements the overseeing body should ensure the supplied materials and process of construction is within the required standards. This is achieved by regular visit by the third party.

Actions to ensure monitoring and control of road levels

- Ensure adherence to the established standards and description of methods.
- A maintenance standard with defined levels for monitored parameters e.g. cut & fill levels.

- A common system of coordinates which supports connection and Database synchronization.
- Methods of control of the received data.

Checking and maintenance

In road levels precise rods are used in matched pairs. Test the rods regularly to verify that vary in index stays constant. The index is checked using comparison High and low measurements done on the same rod Item. If index has changed, it is either the tape guides are fouled or the rod is broken. If a tape gets damaged badly, replace the rod. Tape replacements are not available. The guides are carefully disassembled and washed if the tape guides are fouled.

Conclusion

The leaner covered levelling tools and equipment, calibrate levelling tools, set, monitor and control of road levels per the standard construction requirements.

Further Reading

Read further on how to monitor and control road levels

11.3.3.3 Self-Assessment

Written Assessment

1. A staff intercepts.
    a) Maximum if the staff is kept to the line of sight truly normal
    b) Is minimum if the staff holds the line of sight truly normal
    c) Decreases when staff are tilted away from normal
    d) Increases if the staff is tilted towards normal
2. Pick the correct statement from the following:
    a) The tangent screw allows for small movement in smooth and positive control conditions
    b) The levelling screws are used to tilt the instrument, so that its angle of inclination is vertical
    c) The levelling head or tribrach needs to stand on a tripod
    d) All of the above

3. Closed contours of falling values to their center represent.
    a) Depression
    b) A Hill
    c) Bed of a river
    d) Saddle or a pass
4. When conducing survey works, what name is given to an imaginary line that joins the points of equal elevation on the earth's surface?
    a) Contour line
    b) Surface contour
    c) Level line
    d) None of the above
5. Explain the sensitivity of bubble tube in levelling and state its effect on accuracy of levelling.
6. Explain levelling and distinguish the tools used.
7. Evaluate the term calibration as used in levelling and it importance.
8. Writes short notes on dumpy level as used in levelling.
9. Complete the levelling table given below. If a gradient of 1 vertical in every 7 horizontal starts at 1 m above the peg 0, what is the height of gradient above or its peg below peg 7. (I.C.E London)

Table 26: levelling table

Station	Dist.	Back-sight	Inter-sight	Fore-sight	Rise	Fall	R.L.
B.M		3.10					193.62
0	0		2.56				
1	20		1.07				
2	40	1.92		3.96			
3	60	1.20		0.67			
4	80		4.24				
5	100	0.22		1.87			
6	120		3.03				
7	140			1.41			

Essay questions

1. Sketch the modern tilting level and name its main part. Describe step by step how it is used and its advantage over the dumpy level.
2. Draw a neat sketch of dumpy level and name its parts.

Oral Assessment

1 Briefly discuss rise and fall method for booking levels. Why would you prefer this method compared to Height of collimation?

2 Elabourate the importance of arithmetic checks booking levels?

Practical Assessment

PRACTICAL 1; LEVEL REDUCED BY RISE AND FALL METHOD

Equipment: Dumpy level, Leveling staff

Procedure: The field procedure and staff reading booking is done in the same way as explained in the instrument method height (each reading is entered on a different line in the corresponding column, except at a change point, where an FS and BS hold the same line).

Tabulation Format;

Table 27: Tabulation

STATIO N	READINGS			RISE	FALL	REDUCE D LEVEL	REMARK S
	B.S	I.S	F.S				

Calculations:

1. The elevation difference between any two successive points (say, A and B) may be calculated as;

Difference in elevation between A and B = first reading in A-second reading in B

2. **NOTE:** For every 2 sequential readings by staff:
    - A rise is represented if the second reading is of a smaller value than the first reading. (rep.by a positive sign).
    - A fall is represented if the second reading is f a greater value than the first reading. (rep. by a negative sign).
3. If the elevation of the first is known the second elevation can be calculated as;

    Height of B=Height of A + (rise) or Height of B= Height of A- (fall)

4. The following arithmetic checks are performed on the booking levels;
   A. Number of BS readings=No of FS readings
   B. $\sum BS-\sum FS=\sum Rise-\sum Fall$=RL of last point-RL of first point.

Project Assessment
Carry out a closed levelling of your school flower bed

11.3.3.4 Tools, Equipment, Supplies and Materials

- Surveying tools and equipment
- Computers
- CAD & GIS Software
- Construction manuals and guidelines
- Projectors
- Flip charts
- Calculators
- Stationery
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos
- Printers
- Workstation
- Standard of specifications

11.3.3.5 References

Roy, S. (2005). Fundamentals of Surveying. New Delhi.
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11.3.4 Learning Outcome No 3: Conduct Tacheometry Works

11.3.4.1 Learning Activities

Learning Outcome No 3: Conduct Tacheometry Works	
Learning Activities	**Special Instructions**
3.1 Identify and select ***tacheometry tools and equipment*** 3.2 Carry out calibration of tools and equipment 3.3 Determine horizontal distances 3.4 Determine vertical distances 3.5 Collected tacheometry data is 3.6 Document data collected	• Written tests • Observation • Oral questioning • Third party report

11.3.4.2 Information Sheet No11/LO3: Conduct Tacheometry Works

Introduction to learning outcome

The student is expected to cover tacheometry tools, horizontal and vertical distances as well as data collection by the end of the topic.

Definition of key terms

Tacheometry:

Tacheometry is a surveying branch in which the horizontal and vertical distances are obtained by optical means in contrast to the ordinary chain and tape processes. This is do ne with the aid of two special types of instruments: a theodolite and stadia rod.

Horizontal distance

On a horizontal plane the distance between two points is the horizontal distance.

Vertical distance

The elevation of a point above a reference level surface (datum) is its vertical distance.

Content/Procedures/Methods/Illustrations

3.1 Identify and select *tacheometry tools and equipment* (Theodolite, levelling staff, Total station and accessories, cutting tools, driving tools) according to contract document

This involves the process of establishing the different types of tacheometry tools available. In identification of these tools, a clear description of the tools is required.

Theodolite: A theodolite is a precision measurement device in horizontal and vertical planes for calculating angles. A modern theodolite is a movable telescope that is positioned between the horizontal axis and the vertical axis. The angle of each of these axes can be determined with great accuracy when the telescope is pointed towards a target object.

Levelling staff: A levelling staff is a wooden or aluminium rectangular rod with graduations. The staff has metal shoes at the bottom to withstand wear and tear.

Total station: The instrument is a mixture of electronic theodolite and electromagnetic distance measurement (EDM). It also consists of a micro-processor with a memory unit that deals with records, readings and the simple measurement calculation. It is designed to measure horizontal and vertical angles, including measurement of object sloping distance to instrument.

Cutting tools: These tools are important for site clearing, which is normally the first operation to be performed once alignment is established. Examples of these tools are grass slashers and crosscut saws. The kind of cutting tools required depend on the nature of the site. A site containing grass will require a slasher, while a site requiring tree felling will require a crosscut saw.

Driving tools: The most common driving tool used in tacheometry is a hammer. The hammer consists of a metal head and a wooden handle. It is used to drive in pins and probes into the ground.

3.2 Carry out calibration of tools and equipment according to manufacturer's manual

This is the process of comparing a known measurement (the standard) and the measurement using your instrument. Calibration defines the accuracy and quality of measurements recorded using a piece of equipment. Overtime there is a tendency for results and accuracy to 'drift' when using particular equipment. To be confident in the results being measured, there is an ongoing need to maintain the calibration of equipment throughout its lifetime for reliable, accurate and repeatable measurements.

Reference Standards

- Whenever possible, reference standards traceable to SI units (International System of Units) shall be used. In situations where SI units cannot be used, certified reference material provided by a competent supplier shall be used if available.
- Reference standards shall be calibrated by an accredited organization or vendor that can provide proof of traceability. These typically would include, but not be limited to, ISO certified companies.

- Reference standards shall only be handled by employees authorized by the Quality Assurance manager/supervisor and shall be stored to prevent contamination and/or deterioration.
- Reference standards shall be calibrated before and after any adjustment. All reference standards, certified reference materials, or reference materials used for calibration shall be uniquely identified. A certificate of traceability, if applicable, shall be retained to ensure traceability.

3.3 Determine horizontal distances based on datum coordinates

Determination of horizontal distance is done using the stadia method. While finding the horizontal distance between an instrument station and a point and the elevation of a point with respect to the instrument station, the line of sight is horizontal.

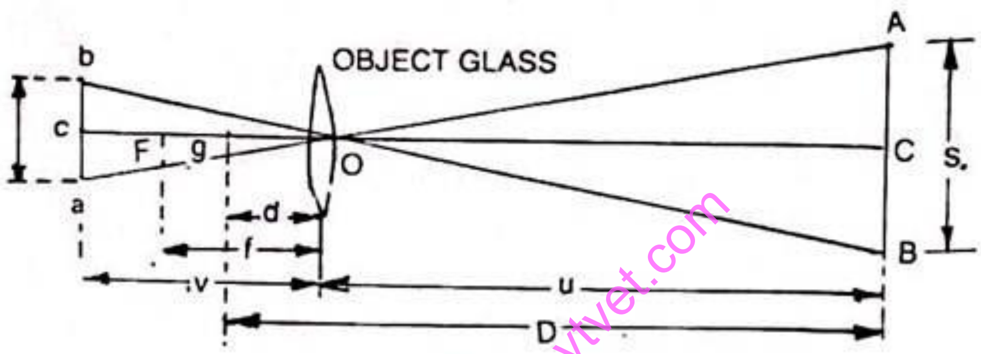

Figure 115: object glass
Source: www.slideshare.com

When the line of sight is horizontal and the staff is held vertical, in this case the horizontal distance from the axis of the instrument to the staff station is:

$D = \frac{f}{i} S + (f + d)$

Staff intercept, S is found by subtracting the reading of the upper and lower stadia reading. The constant K = f/i is called the stadia interval factor and the constant (f + d) =C is known as the additive constant of the tacheometer. These constant values are supplied by the manufacturer.

3.4 Determine vertical distances based on datum coordinates

This is the process of determining the elevation of a point with respect to a particular datum.

Procedure to determine vertical distance

i. Choose a benchmark, with a known elevation. This is the backsight.
ii. Choose the point that you require the elevation. It should be no more than 100 meters away from the instrument. This is the foresight.
iii. Set up the level in a position that is equidistant from the backsight and foresight. Ensure that from this position, a staff held on either point is visible.
iv. Sight at the backsight, and take a reading. Ensure that the readings obtained are correct.
v. Add the backsight reading to the backsight elevation. This gives you the Height of Instrument HI.
vi. Sight to the foresight, and carefully take a reading.
vii. Subtract the foresight reading from the H.I. This gives you the elevation of the foresight.

3.5 Collected tacheometry data is based on standard procedures

Data collection in tacheometry refers to the process of obtaining information regarding to vertical and horizontal distances and levels.

Data collection requirements

- The surveyor should include raw values and only use initial entries. They should include data that is the basis for calculations. These data include coordinates for inversed distances and bearings for calculated angles and azimuths or bearings.
- The surveyor should write true, comprehensive explanations of all record points, in particular points of origin and closing points and, lastly, cite references for all record points used.

3.6 Document data collected based on standard road construction procedures

Documentation of tacheometric data is the process of organisation of data collected in the field.

Procedure for documentation of data

i. All details are booked in either level books or levelling sheets
ii. These level books or loose-leaf levelling sheets must be numbered and indexed in a ledger in order to be listed in the history and inspection forms of the station.
iii. The surveyor must enter details of the location, job, date, observer, chainman, booker, weather, wind, instrument and any other related item.
iv. The surveyor must ensure neatness of records which will be used as referrals.
v. These documents should also be stored in fireproof space.

Conclusion

This learning outcome covered on how to conduct tacheometry works such as data collection, determination of vertical and horizontal distances and calibration of tools.

Further Reading

Refer to Schofield, W. (1984). Engineering surveying. London: Butterworths. for further reading on tacheometry.

11.3.4.3 Self-Assessment

Written Assessment

1. Stadia method can also be known as __________
    a) Fixed hair method
    b) Sub tense method
    c) Tangential method
    d) Movable hair method

2. The value of multiplying constant is generally taken as _________
    a) 60
    b) 80
    c) 90
    d) 100
3. Summarize tacheometric methods used in engineering survey.
4. Distance and elevation formulae for fixed hair method assuming line of sight as horizontal and considering an external focusing type telescope is D = Ks + C. where K is _______
    a) f/i
    b) i/f
    c) f + c
    d) f – c
5. Which among the following represents stadia interval factor?
    a) f + d
    b) f – d
    c) f / i
    d) i/ f
6. Define the stadia interval factor

7. Differentiate between a backsight and a foresight?
8. Differentiate between a theodolite and a total station
9. Elabourate the tacheometry?
10. Discuss how to determine horizontal distance between two points

Oral Assessment

1. Categorize the importance of tacheometry?

Practical Assessment

Using the knowledge gathered in class. Conduct an exercise to measure horizontal and vertical distances between two points.

Oral Assessment

1. What was observed as the difference in measuring horizontal and vertical distances in tacheometry?

11.3.4.4 Tools, Equipment, Supplies and Materials

- Surveying tools and equipment
- Construction manuals and guidelines
- Projectors
- Flip charts
- Calculators
- Stationery
- Charts with presentations of data
- Drawing sheets
- Relevant videos
- Printers
- Workstation
- Standard of specifications

11.3.4.5 References

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11.3.5 Learning Outcome No 4: Draft Road Cross-Sections
11.3.5.1 Learning Activities

Learning Outcome No 4: Draft Road Cross-Sections	
Learning Activities	**Special Instructions**
4.1 Compute and record road levels 4.2 Produce reduced levels 4.3 Draft ***road cross-sections*** (Cut and fill) 4.4 Interprets road cross-sections 4.5 Establish road designs	• Written tests • Observation • Oral questions • Third party report

11.3.5.2 Information Sheet No11/LO4: Draft Road Cross-Sections

Introduction to learning outcome

At the end of this topic, the leaner is expected to have a clear understanding on road-levels as well as road cross-sections.

Definition of key terms

Drafting

Drafting, otherwise known as scientific drawing, is the development of accurate representations of artifacts, structures, or houses for academic, architectural or engineering uses.

Cross-sections

This is a depiction of the element under construction, from the structure's side. A cross section's simplest explanation is to assume that the part of the structure was cut across its centre. That would allow the viewer to see all the different components that make up the entire item being drawn.

Content/Procedures/Methods/Illustrations

4.1 Compute and record road levels based on SOPs

Computation and recording of road levels is an essential process that involves the use of levelling methods. There are two methods of booking levels taken in the field: Height of Collimation Method or Rise and fall Method.

Procedure for computation of road levels using Rise and fall method

Table 28: Procedure for computation of road levels using Rise and fall method

Backsight	Intermediate sight	Foresight	Rise	Fall	Remarks
2.554					Datum RL + 50m
	1.783		0.771		A
	0.926		0.857		B
	1.963			1.037	C
1.305		3.587		1.624	D/change point 1

i. Backsight, intermediate sight and foresight readings are entered in the appropriate columns on different lines. However, as shown in the table above backsights and foresights are placed on the same line in the case of a change point.
ii. The first reduced level is the height of the datum, benchmark or reduced level.
iii. If an intermediate sight or foresight is smaller than the immediately preceding staff reading, then the difference between the two readings is placed in the rise column.
iv. If an intermediate sight or foresight is larger than the immediately preceding staff reading, then the difference between the two readings is placed in the fall column.

Procedure for computation of road levels using Height of Collimation method

Table 29: Procedure for computation of road levels using Height of Collimation method

Backsight	Intermediate sight	Foresight	Height of collimation	Reduced level	Remarks
2.554			52.554	50.000	Datum RL + 50m
	1.783			50.771	A
	0.926			51.628	B
	1.963			50.591	C
1.305		3.587	50.272	48.967	D/change point 1

i. Booking is the same as the rise and fall method for back, intermediate and foresights. There is no rise or fall columns, but instead a height of collimation column.
ii. The first backsight reading (staff on datum, benchmark or reduced level) is added to the first R.L giving the height of collimation.
iii. The next staff reading is entered in the appropriate column but on a new line.

iv. The height of collimation changes only when the level is moved to a new position. The new height of collimation is found by adding the backsight to the RL at the change point.

4.2 Produce reduced levels based on computed road levels

Computation of reduced levels using Rise and fall method

Table 30: Computation of reduced levels using Rise and fall method

Backsight	Intermediate sight	Foresight	Rise	Fall	Reduced level	Remarks
2.554					50.000	Datum RL + 50m
	1.783		0.771		50.771	A
	0.926		0.857		51.628	B
	1.963			1.037	50.591	C
1.305		3.587		1.624	48.967	D/change point 1

For computation of R.L using the rise and fall method, A rise is added to the preceding RL and fall is subtracted from the preceding RL

Computation of reduced levels using Height of Collimation method

Table 31: Computation of reduced levels using Height of Collimation method

Backsight	Intermediate sight	Foresight	Height of collimation	Reduced level	Remarks
2.554			52.554	50.000	Datum RL + 50m
	1.783			50.771	A
	0.926			51.628	B
	1.963			50.591	C
1.305		3.587	50.272	48.967	D/change point 1

For computation of R.L using the Height of collimation method, the new RL is obtained by subtracting staff readings from the height of collimation.

4.3 Draft road cross-sections (Cut and fill) based on road levels

Drafting of road sections involves the use of design software that utilize survey data on road levels to come up with cross sections of the road. Such software includes CAD software such as civil 3D. These cross-sections allow for calculation of the areas of cut and fill once the sections have been plotted.

Plotting of cross-section

Cross sections are run at right angles to the longitudinal profile and on either side of it for the purpose of lateral outline of the ground surface. They provide the data for estimating quantities for earthworks and other purposes. The cross sections are numbered consecutively from the commencement of the centreline and are set out at right angles to the main line of the section which the chain and tape, the cross staff or the optical square and distances are measured left and right from the centre peg cross section may be taken at each chain. The length of cross-section depends upon the nature of work

4.4 Interpret road cross-sections as per standard procedures

Interpretation of road cross sections involves explaining what the cross sections are trying to convey.

Ways of interpreting road cross sections

Cross-sections display a right-angled vertical section of the ground or structure to the centreline of the roadway. There may be hundreds of cross-sections depending on the length and topographical complexity of the route. Each cross-section is linked to a station. Material can either be excavated or filled depending on the position of the proposed road and the natural ground line. These levels of the proposed route and ground levels are determined by cross- sections. Cross-sections show the slope gradients proposed for cutting and filling and provide the designer with a means to determine slope steepness.

4.5 Establish road designs based on interpreted road cross-sections and profiles

Most road designs are based on the particular cross-sections provided. Cross-section selection is key to finding a cost-effective approach to meet traffic needs.

Ways to establish road designs

The cross section displays the location and number of lanes and sidewalks for vehicles and bicycles, along with their cross slope or banking. The cross-sections also show drainage features, surface layout and other elements beyond the geometric style group. Depending on the kind of cross-section, the road design may require additional material to fill in so as to attain the desirable levels of the proposed route, the cross sections also affect road designs in terms of cost. Generally, a road should be designed in such a way that it is economical and guarantees proper performance, depending on the type of cross section and profile present.

Conclusion

This learning outcome covered on road cross-sections, reduced levels as well as road designs.

Further Reading

Refer to Ritter, L., Paquette, R., & Wright, P. (1987). Highway engineering. Chichester: Wiley for further reading on highway construction

11.3.5.3 Self-Assessment

Written Assessment

1. What is the creation of accurate representations of objects, buildings or houses for technical, architectural or engineering purposes?
    a) Drafting
    b) Drawing
    c) Sketching
    d) Plotting
2. Compare and contrast between the following methods of computing and recording road level
    a) Height of Collimation
    b) Rise and fall
3. Elabourate with a sketch how cross-sections help define cut and fills on a slope
4. Elabourate the use of a cross-section in design of economical and high performance road.
5. Categorize the step taken when reducing level.
6. Elabourate the steps taken when conducting a draft.
7. Using a sketch explain the term cross-section
8. Classify the methodes used in computing road level.
9. Explain the effects of cross-section on road design.
10. Discuss how road cross sections affect cut and fill.

Oral Assessment

Explain the importance of drafting of road sections.

Practical Assessment

Using the knowledge gathered in class. Ask the students to measure levels and compute road levels using either method.

Oral Assessment

Did the two methods of computation yield the same results?

11.3.5.4 Tools, Equipment, Supplies and Materials

- Surveying tools and equipment
- Computers
- CAD & GIS Software
- Construction manuals and guidelines
- Projectors
- Flip charts
- Calculators
- Stationery
- Internet
- Printers
- Workstation
- Standard of specifications

11.3.5.5 References

Kutz, M. (2013). Handbook of transportation engineering. New York: McGraw-Hill.
Ritter, L., Paquette, R., & Wright, P. (2005). Highway engineering. Chichester: Wiley.

11.3.6 Learning Outcome No 5: Carry out Setting out Activities

11.3.6.1 Learning Activities

Learning Outcome No 5: Carry out Setting out Activities	
Learning Activities	**Special Instructions**
5.1 Identify and select s***etting out tools and equipment*** 5.2 Carry out calibrations of equipment 5.3 Determine proposed alignment 5.4 Horizontal alignment is set out 5.5 Vertical alignment is set out 5.6 Book and compute Alignment data is	• Written tests • Observation • Oral questioning • Third party report

11.3.6.2 Information Sheet No11/LO5: Carry out Setting out Activities

Introduction to learning outcome

This learning outcome deals with setting out tools as well as equipment's. It includes making calibrations on alignment tools and being able to book and compute alignment data.

Definition of key terms

Alignments: This refers to the placing of survey points along a line. There are two types of alignments, vertical alignment and horizontal alignment

Setting out: This is the creation of a mark and a line to show levels and specific location of the elements for the construction work, so that the work can continue with respect to them.

Content/Procedures/Methods/Illustrations

5.1 Identify and select s*etting out tools and equipment* (Strings, Tape measures, ranging rods, Pegs, cutting tools, driving tools, Angle measuring tools, Plumb bob, marking tools and equipment) according to contract documents

Setting out tools and equipment are the tools used to create marks and measuring boundaries in order to describe a particular location or given alignment of a highway. The tools and equipment must be correctly identified and they must also be in good working condition for the correct setting out to be carried out.

Factors to be considered when identifying and selecting setting out tools and equipment

- **Quality;** Choose tools and equipment that are made of high-quality materials so they have the ability to withstand the deterioration caused by exposure to harsh environments and the punishment of environmental elements. In addition, you will save maintenance and repair costs. Please test the quality and Strength of the equipment before you purchase it.
- **Availability of spare parts**
- **Knowledge of using the equipment;** Ensure that only skilled and qualified technicians are responsible for using these tools and equipment to improve the efficiency and to keep the workplace healthy and avoid injuries.
- **Its availability in the vicinity to the work site**
- **Cost and reliability**

Considerations to be made when using the tools and equipment

- Check the condition of all tools before work begins
- Never use defective equipment when setting out, report any of those that you notice.
- Read the manufacturer's instructions on any devices, appliances and products you are using that you are not familiar with.
- Use tools for their intended use only.

How to identify and select setting out tools and equipment

- **Strings:** These are tools commonly made of a hard-thin linen that are used to indicate the alignment and levels during road surveys
- **Tape measures:** Different types of tape measures exist in the market. The most commonly used tape measure for setting out has a length of 30m and the tapes are usually made of steel or linen. The numbers on the tape must be legible.
- **Ranging rods:** These are sticks or steel rods which are commonly 2.5m-3.0m long with approximately 25mm. Are made of different types of materials such as steel, wood or plastic and are commonly provided with a pointed metal head.
- **Pegs:** These are used to mark levels and alignment of the road and are commonly made of wood. Examples are survey pegs, reference pegs and multi-purpose pegs. Reference pegs should have a length of 400mm and a cross section of 50mm round. Reference pegs are commonly used to show road chainages
- **Cutting tools:** These are tools such as hacksaws which are used to cut material that are used for setting out purposes
- **Driving tools:** These are tools that are used to drive other tools into the ground such as driving pegs into the ground.

- **Angle measuring tools:** These tools are used for different purposes such as setting out a right angle to a centerline and estimating or controlling the steepness of gradients. Are commonly manufactured from 3 wooden laths or steel.
- **Plumb bob:** This is a weight or bob lead that has a pointed end attached to the end of a string and is used to indicate the plumb or what is vertical with reference to the element being studied.
- **Marking tools and equipment:** These are tools such as chalk, paint, road marking crayons and survey nails that are used to indicate the boundaries of the given alignment

5.2 Carry out calibrations of equipment according to manufacturer's manual

Calibration is the process of checking or adjusting equipment and tools by comparing with standard specifications.

Reasons for Carrying out Calibration of equipment

- When an instrument is new
- When observations begin to appear questionable
- If the equipment usage/operating time has elapsed.
- When an instrument has had a shock or vibration that may have put it out of calibration

Calibration is taken as the process of modifying the final output on an equipment in order to agree with a value of the Standard specification. This is an important step when setting out of a highway since the number of errors are minimized. Different equipment have different procedures for calibration. It should be ensured that the calibration activity is done as per the equipment or instruments' manual and as per the contract terms.

5.3 Determine proposed alignment is in accordance with preliminary survey report

This process determines where the road will be placed. A preliminary survey serves the following purposes:

- To survey the various different alignments proposed after the recognition and gather all the necessary basic information on topography, soil data and drainage
- Comparing the various ideas in light of the successful alignment criteria.
- To estimate the quantity of earthworks and other building elements, and to assess the expense of alternative proposals

How to determine proposed alignments

The alignment of the highways is influenced by terrain. The landscape or topography of a region is usually categorized as flat, rolling, or mountainous. In level terrain, the selection of an alignment is affected by factors such as right-of - way costs, land use, rivers that may require costly bridging, existing roads, railroads and underlying conditions. A number of factors must be considered in rolling terrain, including: grade and curvature, cut depths and fill heights, drainage structures and number of bridges. Grades in mountainous country are the biggest challenge. Many approximate maps are usually drawn, showing various alignments. Selecting an alignment is a trial and error process, because the proposed alignments are tested for compliance with the requirements for horizontal and vertical power. The final alignment selection is based on a cost assessment and the environmental and social impacts.

5.4 Horizontal alignment is set out based on OGL

A horizontal alignment deals with the configuration of the lateral shift of the Highway on a horizontal line (original ground level). It consists of a horizontal arc and two transition curves that create a curve that joins two straights. Under certain circumstances, the transition curve may have zero length.

A horizontal alignment should be built to the highest standard in line with the topography and carefully chosen to ensure good drainage and reduce earthworks.

How to set out horizontal alignment based on OGL

Step 1: setting out of straight lines

Set out the centerline of the road on flat ground as a series of straight lines. For this, ranging rods and pegs are used. The distance between the pegs of the centerline should not exceed 20000mm.

Step 2: Setting out of curves

It is the process of defining on the ground the centerline of the curve by pegs at intervals of 10m to 30m. The points of tangent and intersection are first be set in the field, in their correct location.

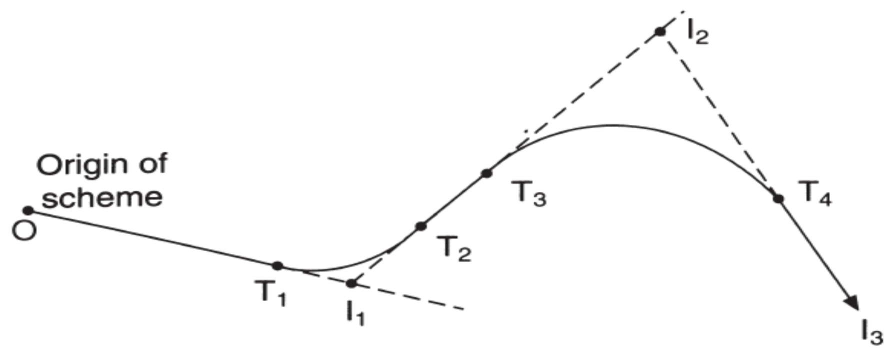


Fig. 10.3 *Through chainage*

Figure 116: Defining on the ground the centerline

The straights OI1, I1I2, I2I3 etc. are built in the plan. Appropriate curves will then be constructed using railway curves to link the straight lines. The tangent points of these curves will then be set, making sure that the tangent lengths are equal, i.e. T1I1 = T2I1, T3I2 = T4I2; The origin coordinates, point O, and all the intersection points will now only be carefully scaled from the plan. Using these coordinates, the straight bearings are measured, and even the coordinates of the tangent points are determined using the tangent lengths on these bearings. The difference of the straight bearings provides the deflection angles (almost) of the curves which, in combination with the tangent length, allows the radius of the curve to be calculated by means of chaining and all set-out data. The tangent and intersection points are now calculated from existing survey stations, and the curves distributed between them using the following methods:

- Using coordinates
- Using theodolite and tape
- Setting out using EDM

5.5 Vertical alignment is set out based on OGL

The vertical alignment shows the level of the road and are used to link vertical plane intersection gradients. It consists of a set of straight-line gradients connected by curves, typically parabolic in form. Therefore, such vertical parabolic curves must be given at all gradient shifts. The curvature will be determined by the speed of the design, which is sufficient to provide adequate driver comfort with reasonable stop sight distances. They are normally set out after the horizontal alignment has been set out.

How to set out Vertical alignment based on OGL

Vertical alignment of a road in rugged terrain takes a lot of practice. Following the terrains contours can lead to less earthworks. The largest allowable gradients will not be reached.

- Survey pegs are set out to indicate future levels of the road
- The supervisor of the road then places the pegs at least 0.5m away from the area to be excavated.
- Multi-purpose pegs are placed to direct the workers at the position where the earthworks will begin. Then, these pegs are linked to strings.
- Whenever "cuts" or "fills" are needed, the pegs must be marked to show how much will have to be produced or filled. When measurement rates are inscribed on the peg, always measure from the top of the peg.
- Set out outside the area to be excavated to avoid the loss of the pegs during construction.

5.6 Book and compute Alignment data as per the standard construction procedures

This is the process of recording alignment data for storage and for the computation of alignment data. Once observations are made from the setting out of alignments, the data is booked. Booking data takes various forms, and the format will be shared by your lecturer and it can also be found from different references. Procedure for booking alignment data and computation:

- Carry out the survey as per the standard operating procedures.
- Book the data as shown by your lecturer
- Carry out computations from the booked data.

Conclusion

This learning outcome covered: alignment, calibration of equipment as well as setting out of tools and equipment's**.**

Further Reading

Watch a video on how setting out is done. You can google it or watch from You Tube

11.3.6.3 Self-Assessment

Written Assessment

1. Select the best answer for the definition of an alignment from the following choices.
    a) Setting out using EDM
    b) Use tools for their intended use only.
    c) placing of survey points along a line
    d) The centerline of a road
2. All the following are setting out tools and equipment except?
    a) Strings
    b) Tape measures
    c) Phone
    d) ranging rods
3. The following are all factors considered when selecting setting out tools except?
    a) Quality
    b) Availability of spare parts
    c) Knowledge of using the equipment
    d) Tools for their intended use only
4. The procedure of setting out horizontal curves is? Select the best answer from the following choices
    a) Setting out of straight lines, setting out of curves
    b) Setting out of curves, setting out of straight lines
    c) Setting out of straight lines, placing of survey points along a line
    d) Setting out of curves, setting out of straight lines
5. Differentiate between horizontal alignment and vertical alignment
6. Level pegs are needed when a road passes through a flat terrain. True or false?
7. Summarize reasons for carrying out calibration of tools and equipment
8. Explain the purpose of carrying out setting out?
9. Elabourate the steps taken in carrying out the calibration of an equipment

Case Study Assessment

Visit a road construction site and note down the setting out activities.

Practical Assessment

With the help of your lecturer, carry out a survey of a flexible pavement in your school and determine its horizontal and vertical alignment.

Oral Assessment

Explain to your teacher or friend the procedure you used for carrying out vertical and horizontal alignment.

11.3.6.4 Tools, Equipment, Supplies and Materials

- Surveying tools and equipment
- Computers
- CAD & GIS Software
- Construction manuals and guidelines
- Projectors
- Flip charts
- Calculators
- Stationery
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos
- Printers
- Workstation
- Standard of specifications

11.3.6.5 References

J. Uren, W.F.Price (2010), *Surveying for engineers*, Fifth Edition Publishes by Palgrave Macmillan

Us. Department of Transportation (2015). *Standard highway signs* 2004 edition. Create space Publishers

11.3.7 Learning Outcome No 6: Perform Traversing Works

11.3.7.1 Learning Activities

Learning Outcome No 6: Perform Traversing Works	
Learning Activities	**Special Instructions**
6.1 Identify and select t***raversing tools and equipment*** 6.2 Calibrate tools and equipment 6.3 Determine horizontal and vertical angles 6.4 Bearings and datum coordinates respectively. 6.5 Determine bearings 6.6 Measure distances 6.7 Plot traverses	• Written tests • Observation • Oral questions • Third party report

11.3.7.2 Information Sheet No11/LO6: Perform Traversing Works

Introduction to learning outcome

This learning outcome deals mainly with traversing activities such as traversing tools and calibration of the tools. It also elabourates on standard procedures for bearings and distances.

Definition of key terms

Theodolite: This is a surveying instrument used in measuring horizontal and vertical angles.

Traversing: This is a method in surveying, used in the establishment of control networks.

Data collection: In field survey, data collection is the process of measuring angles in various planes and recording the results obtained, in reference to some datum.

Content/Procedures/Methods/Illustrations

6.1 Identify and select t*raversing tools and equipment* (Traverse kits, Compass, GPS Survey equipment) according to contract documents

Traversing tools and Equipment

Traverse kits

This is a package containing tripods, tribrach, carrier, prisms along with protective container to carry the total station.

Figure 117: Traverse kits
Source: www.civiljungle.com

Compass

This is a navigation tool used in field survey to determining the bearing of traversing including the angles between waypoints and direction.

Figure 118: Compass
Source: www.civiljungle.com

GPS Survey equipment

These are tools and machines used to determine the position of objects on the surface on the earth by using signals from satellites.

Figure 119: GPS Survey equipment
Source: www.civiljungle.com

6.2 Calibrate tools and equipment according to manufacturer's manual

Calibration: This is the act of eliminating or reducing bias in an instrument's readings by adjusting the precision and accuracy of the measuring equipment using a standard equipment with the assigned correctness.

Methods used in the calibration of traverse equipment and tools.

Table 32: Methods used in the calibration of traverse equipment and tools

EQUIPMENT	TESTED AGAINST	CONDITIONS	COMMENTS
Prisms	Baseline test	Done on unknown baseline	
Prism poles	Test for vertical with a total station	The bubble should be tested in the office bracket	Adjust bubble as required
Steel tape	Approved tape	Tapes to be at similar temperatures	Tension handles are used
Level rods	Tested steel tape		
Tribrach	Test and adjust in office bracket	Ensure that all screws are tight	
Thermometer	A correct thermometer	Permit enough time for the thermometers to acclimatize	
Total stations	Check horizontal angles and adjust as per the user's manual		Always double critical angles

Rod bubbles	Known vertical		Testing item should be vertical
Levels	Two peg test and adjust	Test as required	Set up a baseline on larger projects

Reasons for equipment calibration

- Statutory as provided for in the Surveys Act or other relevant legislation
- Driven by event such as; damage of the equipment, new equipment, rental equipment.
- Driven by time events such as; heavily used equipment, un-used equipment for an extensive period of time, prescribed calibration schedules.

When calibrating the following should be taken note of

- The person performing the calibration should be conversant with the calibration procedure for that particular piece of equipment.
- Equipment owner's manual should be reviewed with the respect to the procedure.
- The company policy should be reviewed and understood if available.
- All proper forms should be in hand and kept where easily available.

When to calibrate

- In the event of equipment damage.
- When equipment is subjected to shock.
- After equipment has been repaired.
- When dealing with new equipment.
- Expiry of the stated time limit of equipment useful life

6.3 Determine horizontal and vertical angles based on datum bearings and datum coordinates respectively

Horizontal angle: A horizontal angle is formed when two lines intersect in the horizontal plane.

Vertical angle: A vertical line is formed when two lines intersect in the vertical plane.

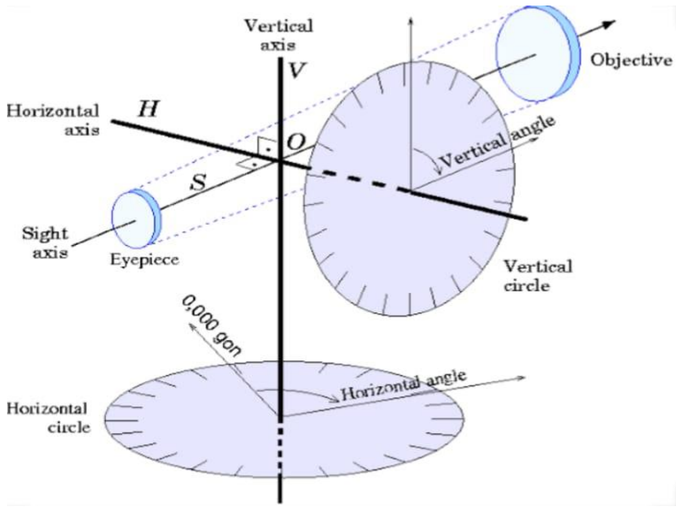


Figure 120: Vertical angle
Source: www.civiljungle.com

Determining Horizontal angles

In determining the horizontal angles, measurement between three survey points A, B and C is considered as follows;

i. The instrument is set up, centered and leveled on survey point B. Parallax is then removed.
ii. Begin on, 'face left', this carefully bisects the target set at survey point A and the horizontal scale reading of 25^o is noted.
iii. The instrument rotated to survey point C which is bisected. The horizontal scale reading is noted as 145°.
iv. The horizontal angle is the difference of the two directions. Forward Station (C) minus Back Station (A), $(FS - BS) = (145^\circ - 25^\circ) = 120^\circ$.
v. Change face and then observe survey point C on 'face right'. The reading is then noted as 325°.
vi. Swing to point A, and the reading of 205° is noted.
vii. The readings or directions are subtracted in the same order as in, $C - A$. Therefore, $(325^\circ - 205^\circ) = 120^\circ$

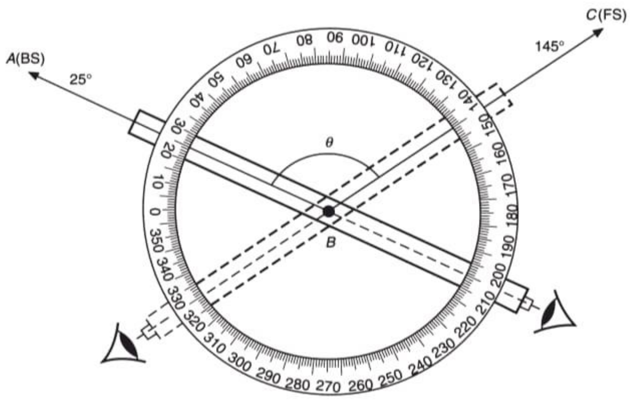


Figure 121: Readings or directions
Source: Text book, Engineering Survey by W. Schofildmark.

Determining Vertical Angles

In the case of determining vertical angles, the protractor moves relative to a fixed horizontal index.

i. Figure (a) below, shows the telescope horizontal and reading 90◦, changing face would result in a reading of 270◦ being realized.
ii. In Figure (b) below, the vertical circle index remains horizontal whilst the protractor rotates along with the telescope, as the top of the spire is observed.
iii. The vertical circle reading of 65◦ is the zenith angle, equivalent to a vertical angle of (90◦ − 65◦) = +25◦ = α.
iv. This illustrates the basic concept of vertical angle measurement.

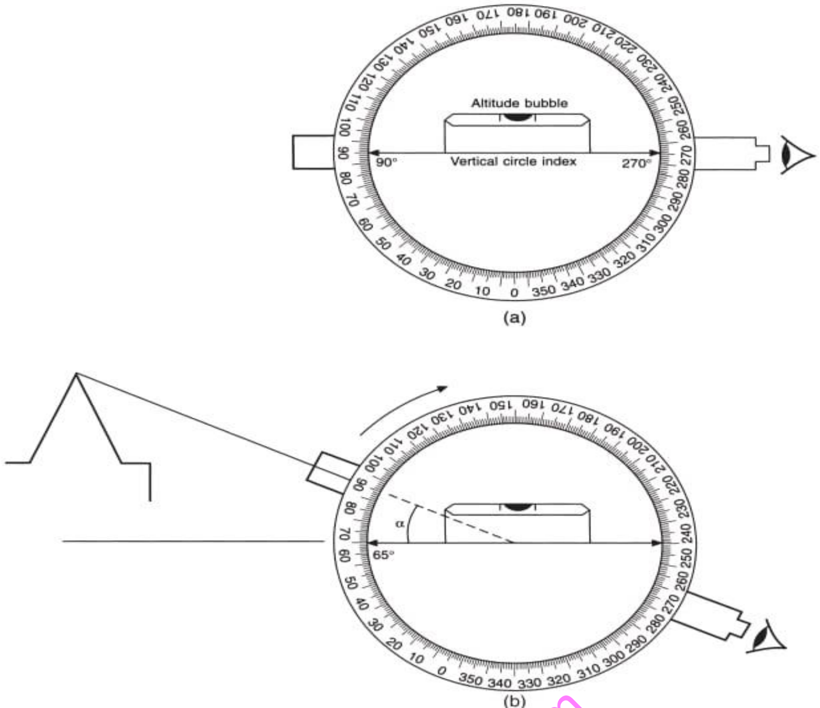


Figure 122: Vertical angle measurement
Source: Text book, Engineering Survey by W. Schofildmark.

6.4 Determine bearings according to standard procedures

Bearing of a line is the direction of the line.
Bearings are of two types; quadrantal and whole-circle bearing.

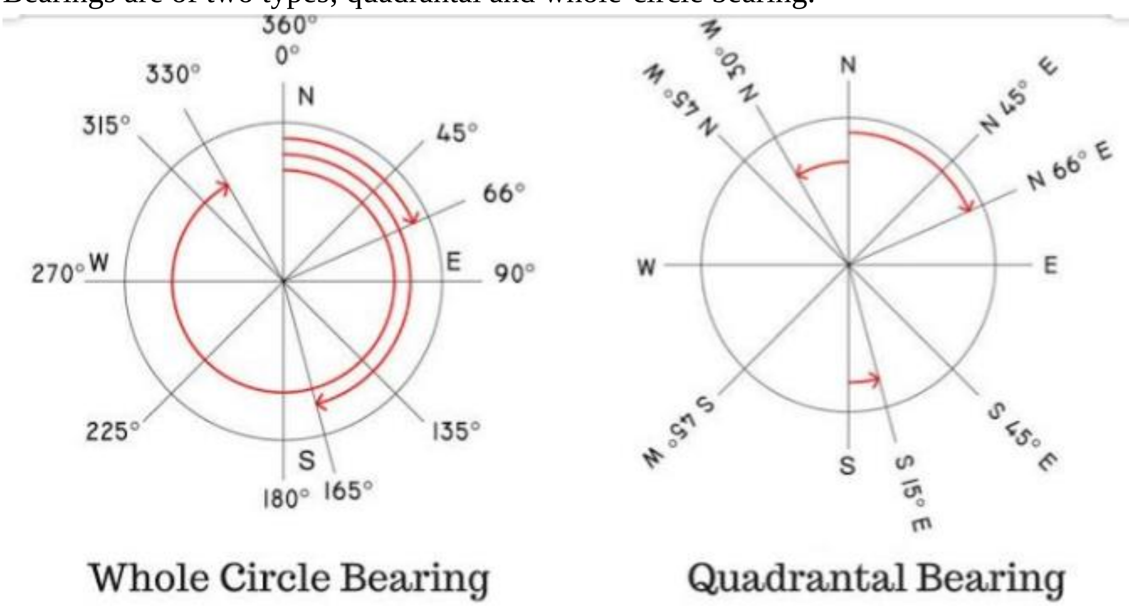


Figure 123: Quadrantal and whole-circle bearing.
Source: https://www.google.com/civilsnapshot.whole-circle-bearing-quadrantal-bearing

Quadrantal Bearing

This is whereby bearings are measured either from the north or from the south towards the east or west. For every quadrant the values range from 0 to 90 degrees.

Whole-circle bearing

This is whereby bearings are measured in a clockwise direction from north and range from 0^0 to 360^0.

6.5 Measure distances according to standard procedures

In performing traverse works, the main objective of determining distance is to establish the horizontal distance between two points. The methods involved in determining distance include; tape and plumb bob, tape and calculation

The method used to determine horizontal distance depends on the following factors;

- Accuracy needed
- Available equipment
- Type of terrain

Procedure for measuring horizontal distance using tape is whereby the horizontal distance is directly measured.

6.6 Plot traverses according to bearings and distance

Traversing is a method in surveying, for the establishment of control networks.

Advantages of Traverse Networks

- Very little pre-sit visit is required compared with that needed for an interconnected network of points.
- Observations only involve three stations at a time therefore planning the task is simple.
- Traversing permits the control to follow the route of a highway, pipeline or tunnel, with the minimum number of stations.

Types of Traverses

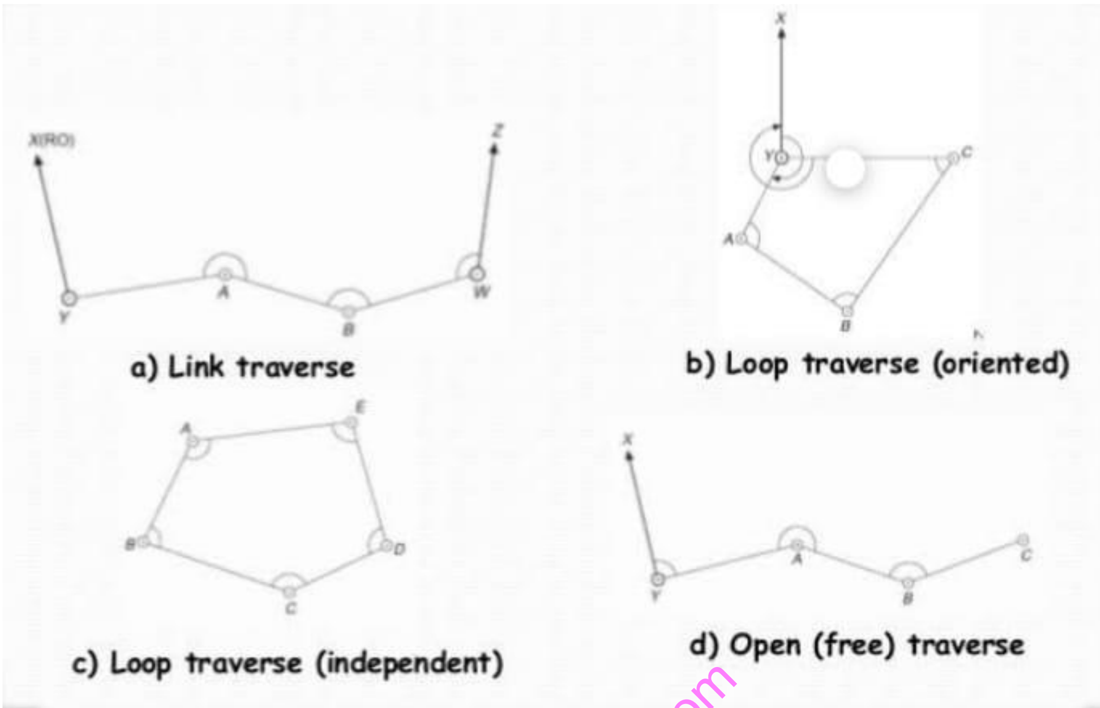


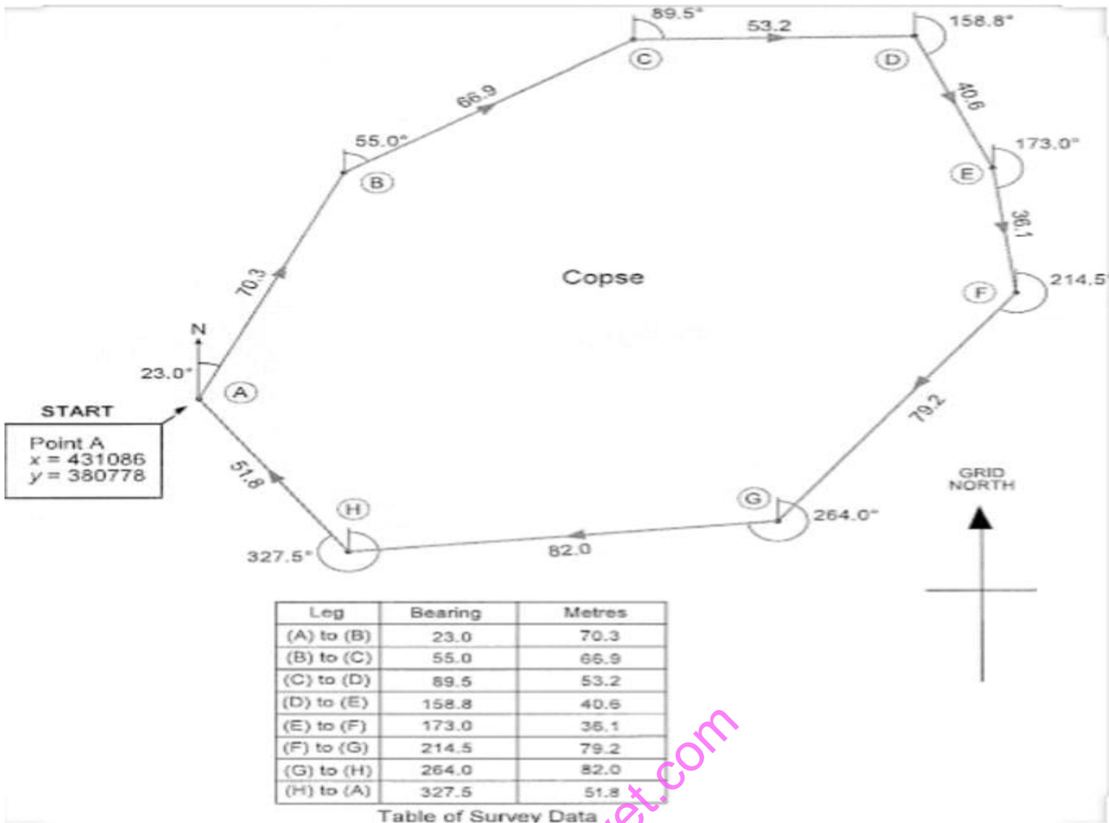
Figure 124: Types of Traverses
Source: www.engineersdaily.com

Methods used in plotting a traverse

- By using bearings through Each Station
- By quadrants or reduced bearing
- By using a central bearing or Paper Protractor
- By using Rectangular Co-Ordinates:
- Using Chords

Traverse plotted using Bearing method follows the following procedure;

- Having the position of the starting point at a given point A, draw a line representing the true north.
- With a protractor, plot the bearing of line AB (θ1), and ensure it is according to the scale.
- Then at point B, draw a line parallel to the previous line representing the meridian and plot the bearing of BC (θ2) then measure its length with the scale.
- Repeat the whole process until all the lines are drawn.
- If the type of traverse is a closed one, the last line should end at the starting point. If it does not, discrepancy is said to be the closing error.



Leg	Bearing	Metres
(A) to (B)	23.0	70.3
(B) to (C)	55.0	66.9
(C) to (D)	89.5	53.2
(D) to (E)	158.8	40.6
(E) to (F)	173.0	36.1
(F) to (G)	214.5	79.2
(G) to (H)	264.0	82.0
(H) to (A)	327.5	51.8

Table of Survey Data

Figure 125: Closed traverse
Source: www.engineersdaily.com

Conclusion

This learning outcome covered performance of traversing works. Which included traversing tools and equipment’s as well as bearings and distance measurements.

Further Reading

Read further on how to plot traverses using the Bodwitch method.

11.3.7.3 Self-Assessment

Written Assessment

1. The school's labouratory technician was asked to purchase a traverse kit. Which of the following was not in the package?
    a) Tripods
    b) Tribrach
    c) Prisms
    d) Stopwatch
2. A student was asked to construct a closed traverse in the School's hockey pitch. Which of the following was not a factor he should have considered when determining the method to use in determining the horizontal distance?
    a) Accuracy required
    b) Available equipment
    c) Topography of the field
    d) Day of the week
3. During a revision session with her classmates, Nancy was not sure about the types of bearing using in field survey. Which of the following should she have chosen as a type of bearing?
    a) Straight bearing
    b) Vertical bearing
    c) Whole circle bearing
    d) Diagonal bearing
4. Elabourate the term bearing
5. Distinguish between horizontal and vertical angles
6. Classify the different types of traversing
7. Using sketches, discuss the difference between whole circle bearing and quadrantal/reduced bearing.

Practical Assessment

Conduct a calibration check on the traversing tools and equipment present in your school's engineering labouratory

11.3.7.4 Tools, Equipment, Supplies and Materials

- Surveying tools and equipment
- Computers
- CAD & GIS Software
- Construction manuals and guidelines
- Projectors

- Flip charts
- Calculators
- Stationery
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos
- Printers
- Workstation
- Standard of specifications

11.3.7.5 References

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W. Schofield (2007) Engineering Survey. Burlington, UK. Elsevier Ltd.

11.3.8 Learning Outcome No 7: Perform Traffic Engineering Survey
11.3.8.1 Learning Activities

Learning Outcome No 6: Perform Traffic Engineering Survey	
Learning Activities	**Special Instructions**
7.1 Identify pavement location 7.2 Prepare traffic survey for 7.3 Carry out traffic counts 7.4 Estimate traffic and road characteristics	• Written tests • Observation • Oral questions • Third party report

11.3.8.2 Information Sheet No11/LO7: Perform Traffic Engineering Survey

Introduction to learning outcome

This learning outcome tends to deal mainly with pavement survey. This entails pavement location as well as traffic and road characteristics that entail the analysis of traffic behaviour in order to come up with designs that will ensure economical, smooth and safe operations in the traffic sector. In order to come up with such a traffic sector, there is need to have vast and adequate knowledge on the nature of traffic flow by knowing the traffic stream parameters and the kind of mutual relationship that they have. This learning outcome will therefore equip the learner with the basic concept of performing a traffic engineering survey.

Definition of key terms

Traffic: This is a term that is mainly used in Civil Engineering to refer all the vehicles moving on a section of road or all the pedestrians or transportation vessels moving along a particular route at a given time.

Pavement: This is a structure with layers of processed materials that are superimposed on top of the natural soil sub grade with the aim of transmitting stresses brought about by wheel loads onto the sub grade to reduce them sufficiently.

Survey: This is a term used to refer to the analyzation/examination or inspection of the behaviour in a particular area while taking down records in order to ascertain a condition or come up with a plan, map or description of the area characteristics.

Content/Procedures/Methods/Illustrations

7.1 Identify pavement location

Before the construction of a pavement, there is usually need to first identify the most suitable route or section.

Steps undertaken in identifying a suitable location for pavement construction

i. There should to be a thorough examination of the existing records for that location.
ii. Subsurface explorations are conducted in order to establish the various engineering properties of the rock and soil that is present in that area.
iii. The relevant properties like durability, strength susceptibility to moisture and even durability is then determined either by empirical estimates as per the soil types, field tests or even by carrying out measurements in the labouratory.
iv. When carrying out the tests, the sample is first tested in its weakest expected state which is normally the materials most probable moisture content.
v. Its possible performance when subjected to various traffic conditions is then identified.
vi. After the tests have been completed, the soils found to be unsuitable for laying the final pavement are identified and removed then replaced with the most suitable materials.
vii. Finally, the degree of compaction that ought to be attained is identified together with the drainage requirements then the location can now be considered as the most suitable for the pavement construction.

7.2 Prepare traffic survey for as per SOPs

The section of the outcome tends to outline the steps to be followed in carrying out the traffic survey to data collection and recording.

Types of data and data sources

Various data/variables will be required in order carry out a successful study with the nits of analysis and units of observation classified.

a) Units of analysis include;
   - Means of transport and modal split/division
   - Road network and traffic route
   - Pedestrian routes
   - Transportation facilities
   - Road design and condition
   - Road user behavior
   - Traffic volumes and capacity
   - Conflict points and accident point

b) Units of observation include;
   - Generators of traffic
   - Land use
   - Road user (pedestrians, Motorists, cyclists, motorcyclists,)

Population sampling
The population area should then be stratified with the required stratified random sampling in order to take into account data from the whole of the population subgroup using the road. The main sub-groups present will include private vehicle owners, public vehicle operator and even pedestrians. The samples will then be selected based on periods and areas of high traffic congestion and traffic conflict i.e. the points selected will have to be given ample time to fetch/collect qualitative data. From the first 2 strata, about 15 respondents can be requested to fill in a questionnaire with the questionnaires being availed to the motorist at the beginning of a jam density/congestion then collected at the other end of the jam density i.e. before vehicles left the jam. Interviews can be carried out for the pedestrians if necessary.

7.3 Carry out traffic counts
This is the section of the outcome that requires the student to do the actuals traffic count and data collection. When conducting the survey, data from primary and secondary sources will be required collection of data consisted of both qualitative and quantitative techniques. As discussed below;

i. Secondary data
This is the data sourced from literature review of the existing works by other scholars and researchers on vehicular and pedestrian traffic challenges as well as transportation planning. One could also use other source of secondary information like aerial photographs case studies, maps and other documents obtained from the library, government office or even media and the internet.

ii. Primary data
This will include data collected directly from the field through any of the following methods:

- Observation

It is a systematic selection, watching and recording of behaviour and characteristic of subject, object or phenomena that is related to the study. Variables are observable and can include pedestrians, motorist and other road users.

- Questionnaires

Written questionnaires that had been presented to respondents who were expected to answer the question in written form. The questions were both structured and open-ended questions with some having choices to choose from for precision purposes while others required full explanation.

- Interviews

Written interviews

Interview schedules can be drafted and prepared for the relevant stake holder in the traffic management sector which may include the Ministry of roads, ministry of transport, traffic personnel and the NCC (transportation section). The type of data to be collected from the mentioned sources include planning data on traffic patterns and management as well as the challenges and prospects of highway traffic

Oral interviews

This is part of the data collected through talking to respondent individually or as a group. It will mainly be used for complementing questionnaires especially where the sample characteristic did not understand the questionnaire. In such a case the questionnaire will have been converted into a discussion between the respondent and the interviewer with the most convenient language for both parties.

iii. Mapping and photography

For this section, existing maps can be used to map out the spatial traffic scenarios within the area under survey. Photographs can also be used to enhance the analysis of the existing traffic situation along the area under study.

7.4 Estimate traffic and road characteristics

This section of the outcomes deals with the data analysis, presentation and synthesis. The data which has been collected may be analysed using computer-based analysis and/or other various models by doing computer- based analysis with programs such as SPSS or other programs that help in solving theories and concepts such as the green shield model and green berg. The data synthesis can then be presented in the form of graphs, charts, tables, maps or diagrams that may help in interpret the data and aid in the estimation of the traffic and load characteristics.

Conclusion

By the completion of this section of the outcome, the student should be well equipped with the knowledge on performance of traffic engineering survey as this learning outcome covered traffic counts, traffic survey as well as determining pavement location. The outcome goes to elabourate on the steps required to effectively carry out the survey and even how to analyse and present the collected data.

Further Reading

Read on:

1. Highway traffic analysis and design by R. J salter.
2. Transportation Engineering by Alfredo Adkins
3. Watch videos on how to create traffic data reports

11.3.8.3 Self-Assessment

Written Assessment

1. All transport vessels moving along a particular route at a given time is referred to as?
    a) Transport
    b) Travel
    c) Traffic
    d) Survey
2. Which of the following is not a unit of analysis in traffic survey?
    a) Pedestrian routes
    b) Land use
    c) Transportation facilities
    d) Road design and condition
3. Differentiate between traffic and transportation?
4. Evaluate the of traffic data analysis
5. Differentiate between written and oral interviews
6. Classify methods of carrying out traffic data counts
7. Categorize the ways in which traffic and road characteristics can be estimated

Oral Assessment

1. Discuss units of observation under types of data and data sources
2. Outline the process of identifying pavement location

Case Study Assessment

Carry out a traffic survey on a section of a chosen road, collect the data, analyze it and present it in any relevant or suitable form.

Oral Assessment

What was the selected time intervals selected for carrying out the survey?

Practical Assessment

What tools or equipment are relevant when performing a traffic survey?

11.3.8.4 Tools, Equipment, Supplies and Materials

- Computers
- SPSS Software
- Traffic survey manuals and guidelines
- Projectors
- Calculators
- Stationery
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos
- Workstation

11.3.8.5 References

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Mannering, F.L.; Kilareski, W.P. and Washburn, S.S. (2005). Principles of Highway Engineering and Traffic Analysis, Third Edition.

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CHAPTER 12: BASIC PAVEMENT STRUCTURES

12.1 Introduction of the Unit of Learning

This unit specifies the competencies required to design basic pavement structures. It involves conducting site visit, designing highway drainage and hydraulic structures, designing road geometrics, designing pavement structure, designing pedestrian and cyclist path and designing for road furniture.

12.2 Performance Standard

Conduct site visit, design highway, drainage and hydraulic structures, road geometrics, pavement structure, pedestrian and cyclist paths, and road furniture based on contract documents and standard procedures.

12.3 Learning Outcomes

12.3.1 List of Learning Outcomes

a) Conduct site visit
b) Design highway, drainage and hydraulic structures
c) Design road geometrics
d) Design pavement structure
e) Design pedestrian and cyclist paths
f) Design road furniture

12.3.2 Learning Outcome No 1: Conduct Site Visit

12.3.2.1 Learning Activities

Learning Outcome No 1: Conduct Site Visit	
Learning Activities	**Special Instructions**
1.1 Determine pavement location 1.2 Undertake preparation for site visit 1.3 Collect ***On site data***	• Direct instruction • Case studies • Field trips/site visits

12.3.2.2 Information Sheet No 12/LO1: Conduct Site Visit

Introduction to learning outcome

This learning outcome covers preliminary site visit, data collection methods, tools and equipment for data collection, collection of onsite data and determining pavement location.

Definition of key terms

Datum points: Are landmarks and heights from which all other heights and levels are measured.

Road reserve: An area of land set aside for potential construction of roads, for which construction is not permitted.

Settlement: Downward motion of the ground due to traffic loading.

Content/Procedures/Methods/Illustrations

1.1 Determine pavement location based on contract documents.

This is the process of identifying the most feasible location of a pavement i.e. a surfacing of a road, footpath, airstrip etc. A pavement transmits loads such as traffic loads, to the underlying soil. Pavements can either be flexible or rigid. In the case of flexible pavements, the surface is usually applied in two layers-the base course and wearing the course, with the base course and the extension of the road base layer, but providing a regulatory course on which the final layer is applied. In the case of rigid pavements, the structural function of both roadsides and the surface layers are built into the concrete slab approaching their workstations where they will provide the stipend and budget as well as those having expertise in the area.

The location of the site is described in the various specifications.
The site of the works shall be the area within the various road reserves, spoil areas, access roads and deviations, contractor's installations, storage areas, camp sites,

Engineer's offices, labouratories and accommodation, shown on the drawings or established specifically for the contract with the approval of the engineer.

Selecting the location of a proposed pavement is an important initial step in the design process.

Factors Affecting Choice of a Pavement location

The choice of location is usually based on:

- Usage: The traffic loading in terms of usage of a pavement determines its location.
- Topography; terrain of a place affects the cost as well as the ease of construction of a pavement which in turn affects its location.
- Soil characteristics; Different soil types have different characteristics; some soil types may exhibit favorable characteristics while other types such as expansive soils like clay may be unfavorable in terms of providing a stable foundation.
- Environmental factors such as noise and air pollution; Environmental pollution such as noise and air are an important factor when deciding the location of a pavement. Pavements are located away from residential areas as per standards due to their contribution.
- Economic factors; the cost of constructing a pavement is a core factor in deciding locations of pavements. The most economical designs of pavements are normally selected depending on location selected.

The process of positioning the pavement involves four processes as per contract documents as follows

i. Conducting an Office Study of Current Information on the pavement; this allows for a study on the available data and specifications required for the positioning of a pavement.
ii. Conducting a Recognition survey: This is conducted by carrying out a pre-visit to the selected locations.
iii. Conducting a Preliminary location survey: The survey of the possible locations identified for the pavement will help in determining their feasibility.
iv. Conducting a Final survey of the location identified: From the preliminary survey conducted a feasibility report is prepared and the location selected is surveyed in order to gather more data on the pavement location.

1.2 Undertake preparation for site visit as per contract document

Site Visits are a component of the contract documents. These include visiting the site where you are hoping to deploy your services for the purpose of obtaining in-depth information on the pavement. The procedure to be followed deals with a number of items that should be considered when preparing for visits to the actual and virtual site as per contractual documents.

Steps Undertaken in preparation for site visits

Step 1: desk study

This involves obtaining and reviewing documents relating to the pavement.

Useful sources of information for desk duty

- Geographical maps, including historical maps, can provide information on topography, drainage and the site 's former uses
- Geological maps may show the possible conditions on the ground and, for example, whether there is a possibility of subsidence or shear.
- Aerial photography records and Google maps provide valuable information to help recognize or validate past use of the site, unknown structures, and topographical and river course adjustments.
- Records of utilities can help to identify hidden utilities such as: power cables, irrigation, telephone cables.
- Past inquiries, estate record sketches

Step 2

- List all matters to be dealt with during the site visit in advance.
- Obtain all necessary equipment such as safety kits and any required procedures agreed upon.
- Note in advance all relevant issues, such as weather conditions, plant and equipment locations, measurements, etc.
- Revisit the matters to be dealt with during the site visit

Step 3

This stage includes a physical visit to the site, making observations and taking photographs of the conditions of the site.

The site conditions include general topography, access to rigs, geological features, land use conditions and water flow.

Step 4

Prepare a report from the site visit from the observations noted. Recommended items for a site visit:

- Field book
- Maps
- Sturdy boots
- Tape measure
- Reflective vest and hard hat
- Digital camera
- Introduction letter from your department in order to avoid conflicts.

Importance of undertaking preparation for site visits

- Assessing the ground conditions for the pavement to be designed
- To give prior knowledge and experience to the designing team
- To get a better understanding of the project.

1.3 Collect *On site data* (Datum points, Settlement, Natural features, Soil type, Water catchment areas, Accessibility of utility services, Land marks, Road reserve) according to standard procedures

This is the process of gathering data in order to enhance the implementation of the different types of pavements. On site data collection is an important step when designing different types of pavements. The data collected is helpful in the design process as the Engineer is able to understand site conditions and therefore design pavements according to specifications and standard procedures such as AASHTO Standards.

Factors that affect on-site data collection

Some of the factors that may affect the quality of data are but not limited to:

- Availability of tools and equipment; the availability of the right tools as per the standard specifications is an important factor.
- Weather; Adverse weather conditions may deter the data collection activity
- Cost; Data collection must not be an expensive activity.
- Bias- certain demographic factors such as the type of person collecting data may affect its quality. It must always be ensured that the person collecting data is an ethical profession in this field.

The methods used for data collection include and are not limited to; conducting surveys, sampling, observations and experiments.

Steps considered for on-site data collection

i. Identify the data element to be collected and determine the necessary tools needed for data collection.
ii. Determine the data collection procedure for the specific element as per the standard procedures.
iii. Conduct a site visit with the necessary tools and equipment and do the on-site data collection as per the specification used.

Conclusion

This learning outcome covered preliminary site visit, data collection methods, tools and equipment for data collection, collection of onsite data and determining pavement location.

Further Reading

Read more on the standard specifications for pavement design used in Kenya

12.3.2.3 Self-Assessment

Written Assessment

1. From the following choices choose the data collection methods
   a) Surveys
   b) Interviews
   c) Experiments
   d) Questionnaires
2. The following is a list of data collection tools, identify the tool that's not appropriate
   a) Camera
   b) Book
   c) Computer
   d) Calculator

3. Choose a step which is not part of determining pavement location based on contract documents.
    a) List all matters to be dealt with during the site visit in advance.
    b) Obtain all necessary equipment such as safety kits and any required procedures agreed upon.
    c) Determine the data collection procedure for the specific element as per the standard procedures.
    d) Determine the data collection procedure for the specific element as per the standard procedures
4. Select the correct answer from the following
    a) Road reserve- An area of land set aside for potential construction of roads, for which construction is not permitted
    b) Road reserve-An area of land set aside for potential construction of roads, for which construction is permitted
    c) Road reserve- An area of land set aside for construction, for which potential construction of roads is not permitted
    d) Road reserve- an area that has been set aside for construction of drainage features
5. On site data may include but are not limited to all the following. Select the best answer?
    a) Datum points, Settlement, Natural features, Soil type
    b) Datum points, road reserve, Natural features, Soil type
    c) Accessibility of utility services, roads, waterways
    d) Land marks, Road reserve, datum points, vehicles
6. Define Datum point
7. State four data collection methods
8. What is a preliminary site visit?
9. State the six tools and equipment used for data collection
10. Discuss how to conduct a preparation for a site visit as per contract documents

Practical Assessment

Using the knowledge that you have gained, conduct a site visit to a location where a pavement is being constructed and do data collection with the help of your lecturer.

Oral Assessment

State how you conducted the site visit according to the standard specifications.

12.3.2.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras

- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

12.3.2.5 References

Garber, N. J., & Hoel, L. A. (2020). Traffic and highway engineering. Cengage.
Rogers, M. G., & Enright, B. (2016). Highway engineering. Chichester: Wiley-Blackwell.

12.3.3 Learning Outcome No 2: Design Highway, Drainage and Hydraulic Structures

12.3.3.1 Learning Activities

Learning Outcome No 2: Design Highway, Drainage and Hydraulic Structures	
Learning Activities	**Special Instructions**
2.1 Conduct a preliminary site visit 2.2 Estimate the surface run-off 2.3 Design highway drainage structures 2.4 Design bridges 2.5 Design drifts and causeways 2.6 Design retaining walls 2.7 Determine construction materials	• Case studies • Field trips/site visits • Discussions

12.3.3.2 Information Sheet No 12/Lo 2: Design Highway, Drainage and Hydraulic Structures

Introduction to learning outcome

This learning outcome covers hydrology and hydraulic engineering, establishment of longitudinal sections of a river, determination of water levels of a river and location of highway drainage sites.

Definition of key terms

Water catchment area: This is an area from which the natural environment receives water. In a catchment, rainfall and runoff water ends up flowing into the groundwater system or into a water body. In a catchment, human and natural systems such as animals, streams, fields, houses, plants, dams and humans can co-exist.

Surface run-off: Surface runoff is the flow of water that occurs above the ground. This flow happens when the soil is completely saturated and the rainfall intensity is greater than infiltration rate. Surface runoff frequently occurs in impermeable areas (such as roofs and paving) that do not allow water to soak into the soil.

Slope: Watershed slope is total elevation change divided by hydrologic length.

Content/Procedures/Methods/Illustrations

2.1 Conduct a preliminary site visit

Preliminary site investigation is the first step of a site investigation that includes gathering information on site-specific features that may need to be addressed during planning, design and construction, or problems that might require more thorough physical investigations.

Purpose of preliminary site investigation

- Offers an initial understanding of the features of a site or region.
- Provides early detection of site features and possible threats, so that they can be handled more effectively.
- Informs the details, scope and methodology of the investigations that follow.
- May help prevent excessive, expensive or intrusive inquiries.

A preliminary site investigation takes place in two steps: a desk study and a site visit.

Procedure for preliminary site investigation

Step 1: desk study

This step involves obtaining and reviewing documents relating to the site.

Useful sources of information for desk duty

- OS maps, including historical maps, can provide information on topography, drainage and the site 's former uses
- Geological maps may show the possible conditions on the ground and, for example, whether there is a possibility of subsidence or shear.
- Aerial photography records and Google maps provide valuable information to help recognize or validate past use of the site, unknown structures, and topographical and river course adjustments.
- Records of utilities can help to identify hidden utilities such as: power cables, irrigation, telephone cables.
- Past inquiries, estate record sketches

Step 2: Site visit

This stage includes a physical visit to the site, taking observations and pictures of the conditions of the site and the performance of other surrounding projects. The conditions of the site include general topography, access to the rigs, geological features, conditions of land use and water flow. Usually, preliminary site investigations will be supplemented by more thorough physical inspections to identify areas where more information is needed, or where unique questions are posed.

2.2 Estimate the surface run-off

Estimating and evaluating surface runoff is an important and relevant concern of hydrological and geographic research. Runoff is a significant factor in flood analysis, soil erosion and other hydrological hazards.

Methods of estimating surface runoff

- Rational Method
- Curve Number Method

Curve Number Method

This method is a commonly used, easy and efficient method to calculate the quantity of runoff in a given area. Annual runoff values can be determined from this method. The requirements for this approach are very small. The value of curve number depends on the land use, hydrological group of soils and hydrological condition of the region. The general equation to obtain volume of runoff using this method is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (1)$$

Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins
I_a = initial abstratctions

$$I_a = 0.2\ S \qquad (2)$$

$$Q = \frac{(P - 0.2\ S)^2}{(P + 0.8\ S)} \qquad (3)$$

$$S = \frac{1000}{CN} - 10 \qquad (4)$$

Figure 126: quantity of runoff
Retrieved from https://engineering.purdue.edu

Values of the runoff curve numbers for typical land cover characteristics and a category of hydrological soils can be obtained from the United States Department of Agriculture.

Rational method

This method is the most common and easiest way of calculating surface runoff in the basin. The general equation for this method is given by

Q=ciA

Q = discharge (cumecs)

c = runoff coefficient

i = rainfall intensity, mm/hour

A = drainage basin area, acre

The runoff coefficient c is dependent on the drainage basin slope and soil type. The Rainfall intensity i, is obtained from rainfall duration /intensity curves for the particular geographical region.

2.3 Design highway drainage structures as per the design manuals and procedures

The objective of road drainage design is to remove the energy produced by flowing water. As their velocity increases, the destructive capacity of moving water also increases. Water must therefore have a velocity that minimizes wear along the drains.

Procedure for design of drainage structures

The commonly used equation for open channel flow design is the manning equation. This was developed in 1889 by the Irish mathematician Robert Manning. The Manning equation is based on uniform flow in open channels and it depends on roughness, slope and flow area. The general manning's equations is:

$V = \frac{k}{n}(\sqrt[3]{A/P})^2\sqrt{S}$

V = velocity (ft/s, m/s)

k = 1.0 for SI units and 1.49 for English units

n = Manning coefficient of roughness

S = slope (ft/ft, m/m)

Pw = wetted perimeter (ft, m)

A = cross sectional area of flow (ft^2, m)

Manning's roughness coefficients for various surfaces are tabulated and are given as a range.

Factors that affect n-values

- Silting / scouring
- Obstruction
- Surface roughness
- Shape of channel
- Vegetation

2.4 Design bridges as per the design manuals and procedures

A bridge is a structure that carries either a road or railway over an obstacle such as a river.

Figure 127: Example of a bridge, Nyali Bridge
Source: https://constructionreviewonline.com

Types of bridges

- Arch bridge
- Slab bridge
- Truss bridge
- Beam bridge
- Cable stayed/suspended bridge

Procedure for bridge design

Step1: Evaluating the Purpose of the bridge

In the process of design, the first significant step is understanding the purpose of the structure. Otherwise the design will end up being unbeneficial. The design team need to understand the bridge's purpose to ensure a design that is feasible, functional, and economical.

Step 2: Load Determination

The next step of design is the determination of the possible loads expected to act on the bridge. These loads are dependent on the function and location of the bridge. In design, engineers consider three categories of loads: dead loads, environmental loads and live loads:

- Dead loads include the self-weight and all other fixed components of the bridge, such as guardrails, road signals or road surfaces.
- Live loads- these include vehicles
- Environmental loads –these result from environmental factors such as wind and earthquakes.

Step 3: Load Combinations

To achieve the task of load combination, engineers use many methods. UBC and ASCE are the two most popular methods. The building code BS 5400 used in Kenya defines five different combinations of loads. With this approach, design planning uses the load combination which produces the most critical impact or highest load. In Kenya, the most common load combination includes dead load, live loads and wind load and in some cases earthquake loads depending on the location.

Step 4: Determination of Member Sizes

This step is conducted after the load combinations have been determined by the engineer. Depending on the loads the size of the members is determined. These members include beams (girders) and columns (piers. These members are designed separately suing different design techniques.

2.5 Design drifts and causeways as per the *design manuals* (Ministry of Works road design manuals, AASHTO Standards) and procedures

Drifts are essential structures, and can be the lowest type of construction of watercourse crossing. Drifts effectively provide a firm surface on which vehicles can pass a waterway on condition that the water level is low enough. Drifts are typically the most suitable option from an economical and technological point of view when big, normally dry rivers have to be crossed.

Procedure for drift design

i. On rivers with spans equal to or greater than 50 m and on rivers with spans of less than 50 m, the drift approach roads should be extended by 10 m on either side of the riverbank. The approach road should be built above the amount of flooding experienced to avoid damage at the end of the road when the floods are high.
ii. The foundations should have a minimum width of 500 mm, and a construction depth of 250 mm.

iii. Walls should have thickness of 300 mm. Depending on the volume of traffic and the typical load, the top slab, should have a thickness of 150-200 mm.
iv. The drift should be packed with hard-core material and compacted on sandy riverbeds to a maximum depth of 1 m, and 0.6 m on rocky riverbeds.
v. The foundations, walls, and slab should be bound together rigidly to provide maximum resistance to floodwaters being swept away by the drift. Depending on the form and amount of the expected traffic the width of the pavement slab will vary between 3 and 5 m.
vi. The drift height over the current riverbed should be a maximum of 1 m to ensure sufficient depth for upstream sand and water accumulation.

2.6 Design retaining walls as per the design manuals and procedures

A retaining wall is a structure designed and constructed for the purpose of withstanding lateral ground pressure and supporting soil materials. The lateral pressure comes from liquid pressure and the filling of soil

Types of retaining walls

- Gravity retaining wall
- Anchored retaining wall
- Cantilevered retaining wall
- Sheet piling retaining wall

Procedure for design of Retaining Walls

Calculate all loads applied. These include soil stresses, axial, wind, and surcharge loads.

i. Design the stem. Usually, this is a trial and error procedure. Design starts at the bottom of the stem where there's maximum moment and shear.
ii. Calculate overturning moments. These are calculated around the footing toe. An overturning factor of safety of at least 1.5 is considered standard
iii. Based on the assumed footing distance, measured around the front edge of the footing, compute resisting moments.
iv. Check sliding. A safety factor of 1.5 or more for the sliding is conventional. To achieve an accepted safety factor for sliding, an adjustment of footing depth is required.
v. Calculate the eccentricity of total vertical load based on an appropriate factor of safety against overturning.
vi. Calculate the toe and heel soil pressure. If the eccentricity, e, is > B/6, calculate another value of B
vii. Design moments and shear for footing. Pick reinforcement.

2.7 Determine construction materials

In road construction, a broad range of materials are used. These materials include soils), aggregates, bituminous materials and cement. The use of certain construction materials is dependent on their cost and availability.

Types of construction materials

1. **Soils**

Soil is the major material for many civil engineering construction projects such as the subgrade or even pavement for lower class. Soils serves as an embankment material for roads built on higher levels such as overpasses. Moreover, soil serves as foundation materials in many highway projects. For effective use of soils, they need to be are classified into a given system according to certain principles. A soil classification system groups different types of soil based on specific characteristics such as texture and gradation. The common systems used for general engineering classification of soils are:

- AASHTO Soil Classification System
- Unified soil classification system (USCS)

2. **Aggregates**

Mineral aggregates are the most significant materials used in construction of roads. Aggregates such as gravel are obtained naturally from disintegration of rocks. Other types of aggregates are manufactured. An example of this type of aggregate is blast furnace slag. To a highway engineer, the knowledge of the sources and types of aggregates, their evaluation and properties is of utmost importance. In general, aggregates are a widely sued construction material. Desirable properties of soil aggregates used the construction of road are:

- Strength
- Hardness
- Toughness
- Shape
- Texture

3. **Bituminous materials**

Bituminous materials or asphalts are a commonly used construction material in Kenya. This is because the materials are of relatively low cost and have excellent binding and waterproofing properties. Bituminous materials contain bitumen, which is a cementitious substance that can occur naturally or be manufactured. Bitumen is composed primarily of high molecular weight hydrocarbons. Bitumen is manufactured from crude petroleum through distillation

Different forms of bitumen

- Asphalt / bitumen cutback – these are also known as liquid asphalt and is obtained by dissolving bitumen in a distillate
- Bitumen Emulsion- A mixture in which asphalt cement is separated into globules in water containing an emulsifying agent.
- Straight run bitumen- This is bitumen manufactured from short residue this bitumen has a high viscosity.

4. Cement concrete

Cement concrete is a flexible commodity that has revolutionized civil engineering. A well-designed cement concrete provides a solid, stable and resilient pavement after setting and hardening after curing. A cement concrete pavement is able to resist repeated impacts from wheel loads, withstand adverse environmental conditions and its construction cost is relatively low.

Desirable properties of Cement Concrete

Workability

This is a property of fresh concrete and is defined as ease of placement. The workability of concrete is assessed using the slump test. A workable cement concrete mix allows the pavement to be easily placed and compacted. Dry mixes with a slump of 0-25 are used in road making.

Conclusion

This learning outcome covered the design of highways, drainage and hydraulic structures.

Further Reading

For further understanding of pavement construction refer to Ritter, L., Paquette, R., & Wright, P. (1987). Highway engineering. Chichester: Wiley

12.3.3.3 Self-Assessment

Written Assessment

1. How many soil classification systems are used in Kenya?
    a) 1
    b) 2
    c) 3
    d) I don't know
2. Which is not a desirable property of aggregates
    a) Strength
    b) Toughness
    c) Workability
    d) Texture
3. Which load is not considered in design of bridges in Kenya?
    a) Dead load
    b) Wind load
    c) Snow load
    d) Live load
4. Rational formulae for estimation of surface runoff is Q= ciA. where C is _______
    a) Runoff coefficient
    b) Roughness coefficient
    c) Curve number
    d) I don't know
5. Which among the following represents hydraulic radius in the manning's formula?
    a) Rh
    b) S
    c) V
    d) kn
6. List the three types of bitumen
7. What is the difference between a drift and a causeway?
8. List two methods used to estimate surface runoff
9. What is workability of concrete?
10. Discuss on the design procedure for bridges

Oral Assessment

Why do we conduct preliminary site investigations?

Practical Assessment

Using the knowledge gathered in class. Conduct a labouratory exercise to classify soils different types of soil

Oral Assessment

What is soil classification systems did you use and why?

12.3.3.4 Tools, Equipment, Supplies and Materials

- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

12.3.3.5 References

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12.3.4 Learning Outcome No 3: Design Road Geometrics
12.3.4.1 Learning Activities

Learning Outcome No 3: Design Road Geometrics	
Learning Activities	**Special Instructions**
3.1 Acquire ***resources*** 3.2 Obtain OGL (Original Ground Levels 3.3 Design horizontal alignments 3.4 Design vertical alignments 3.5 Design ***road intersections*** 3.6 Produce drawings 3.7 Prepare and present report	• Direct instruction • Discussions • Demonstration by trainer • Practice by the trainee

12.3.4.2 Information Sheet No 12/Lo 3: Design Road Geometrics

Introduction to learning outcome

This learning outcome covers the determination of the OGL, horizontal and vertical alignments, road intersections and preparation of working drawings and reports.

Definition of key terms

GIS: Stands for Geographic Information System, which is a computer system that by design captures, stores, analyses and displays data related to positions located on the surface of the Earth.

Horizontal curve: A horizontal curve is made between two tangent lengths of a roadway in order to provide a smooth transition. This is usually at the point where the road changes direction to the left or to the right.

Vertical Curve: These are curves that are used to connect stretches of roads going up or down a hill/slope. They can either be at the top of the hill, called summit curves/over verticals or at the bottom of a hill called sag vertical/ under verticals.

Content/Procedures/Methods/Illustrations

3.1 Acquire *resources* (Geometric tools, straight edge, ruler, compass, protractor, computers, AutoCAD Software, Civil 3D, Arch CAD, GIS) in accordance with geometric design requirements.

Geometric design of a highway refers to the determination of the dimensions and layout of the features of the highway. It is concerned with positioning these elements according to existing standards. The existing standards take into account the following factors:

a. Design speed
b. The type of vehicle
c. The slope/ road grade
d. The stopping distance
e. The view obstructions

The features include horizontal alignments, vertical alignments and intersections.

After the design parameters have been determined, the subsequent design will require resources. Stationery such as rulers, compasses and geometric tools can be bought easily from a nearby bookshop. Software such as Auto CAD, Civil 3D, Arch CAD, GIS can be acquired from the internet by directly purchasing it from the software provider. Subsequently, the software should then be installed on a computer so that it can be used.

3.2 Obtain OGL (Original Ground Level) according to standard road construction procedures.

Original Ground Level refers to the vertical height of an area with relation to the mean sea level. This is established after the site for the road has been cleared and machinery used to compact the ground.

Using survey equipment, the site for the road is levelled and the information recorded on a field book.

3.3 Design horizontal alignments based on standard road construction procedures.

Horizontal alignments are done so as to provide safe, continuous operation of vehicles at the designed speed for considerable lengths of highway. Considerations taken into account for horizontal alignment are the following:

a. Design speed
b. Topography
c. Safety
d. Profile grade
e. Geological features
f. Drainage
g. Existing highway
h. Likelihood of future developments

i. Cost of construction
j. Environmental issues
k. Right of way

These considerations have to be balanced to produce an alignment appropriate to the highway in terms of its location and classification.

Types and Properties of Horizontal Alignments

a. **Simple curves:** A simple curve is an arc that joins two tangents.
b. **Spiral curves:** A spiral curve is used to provide a gradual curvature change from a road that is straight to one that's circular.
c. **Reverse curves:** It is made up when two consecutive circular curves join at a point of tangency with their centers on opposite sides of the main tangent.
d. **Compound curves**

This is made up of two or more consecutive circular curves that are in the same direction which have varying radii.

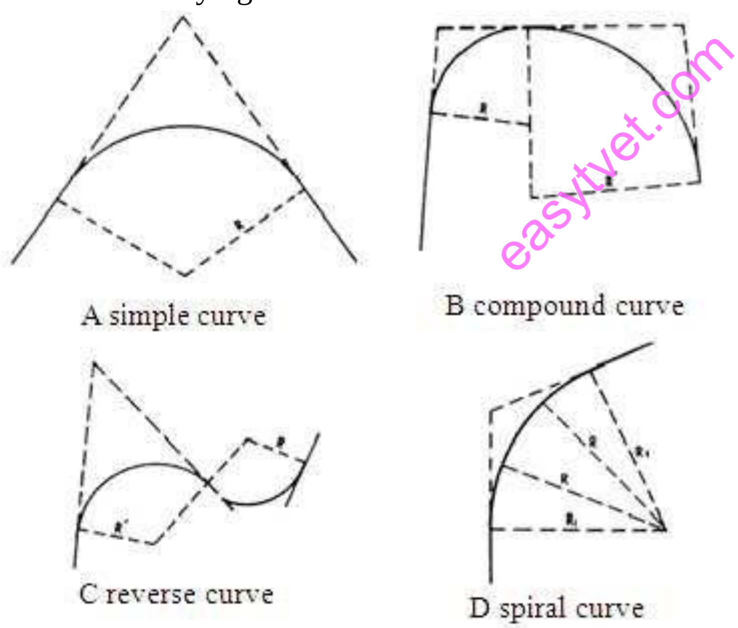

Figure 128: Types of Horizontal Curves
Source: Engineering Aid 1-Advanced Structural Engineering Guide Book, Chapter 11, Figure 11-3

The four main variables of simple curves include;

1. Radius,
2. Design speed,
3. Side friction factor and
4. Super elevation.

The parameters used in designing horizontal curves depend on the relationship between the curvature and design speed. This relationship co-relates also with super-elevation and side friction. Side friction factor is the lateral acceleration acting on a vehicle. It is calculated according to the following formula:

$$f = \frac{v^2}{127R} - 0.01e$$

Where,

f is the side friction factor

e is the rate of super elevation

v is the vehicle design velocity

R is the radius of the curve

Super elevation is having the highway tilted. It helps a vehicle overcome centripetal forces while going round a curve. It is usually set at 6%. In calculating the minimum radius, the following equation is used:

$$R_{min} = v^2/127(0.01e_{max} + f_{max})$$

Where,

v is the design velocity

e is the super elevation

f is the side friction factor

R is the radius of the curve

3.4 Design vertical alignments based on standard procedures

Vertical alignment curves should be able to provide:

a. Safety
b. Adequate sight distance
c. Comfortable driving
d. Good drainage
e. Pleasing appearance

Vertical curves are parabolic in nature. The minimum length to the crest is usually determined by the headlight stopping distance, where the lighting isn't sufficient. Where it is adequate, the passenger comfort factor is used to determine the length of the sag vertical. The minimum length of vertical curves should be 300 feet or according to design speed; it should be 3 times that value.

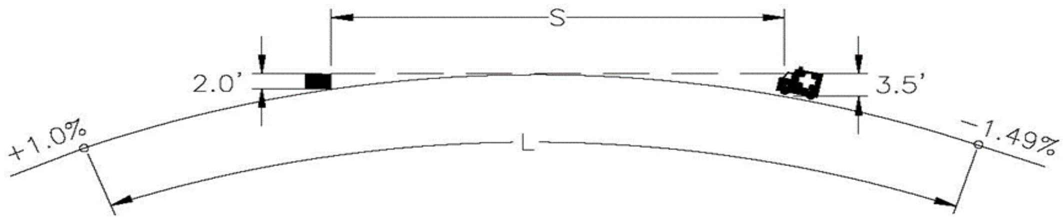

Figure 129: An Example of Crest Vertical Curve
Source: www.researchgate.net

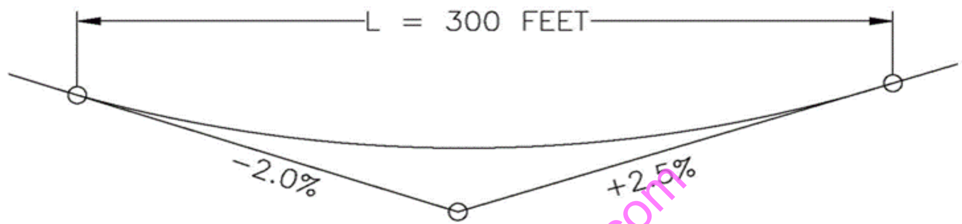

Figure 130: An Example of Sag Vertical Curve
Source: www.researchgate.net

Steps followed in determining the curve parameters.

1. **Deciding sight distance to be used:** When designing curves in a hilly place, the stopping sight distance is used. The intermediate sight distance is also useful while doing curve design.

2. **Determining the value of K:** After the design speed and road type are established, the value of K can be obtained from the following table:

MINIMUM VERTICAL CURVE 'K' VALUES.

Table 33: Minimum Vertical Curve 'K' Values

Design speed (km/hr)	Single lane roads (3.7m carriageway)	Two lane single carriageway roads (6.2 and 7.3m carriageway)			Dual carriageway roads (2 x 7.3)
	ISD	SSD	ISD	OSD	1SD
30	4	2	4	18	-
40	9	4	9	35	-
50	18	9	18	70	18
65	35	18	35	140	35
80		35	70	270	70
100		70	140	540	140

Source: adapted from Table 7.47, RMSS, Vol V11A

3. **Calculating A:** A is the change in grade in percentage form. It's necessary as it determines if the change in grade necessitates a vertical curve. The values can be obtained from the following table:

VERTICAL CURVE APPEARANCE CRITERIA.

Table 34: Vertical Curve Appearance Criteria.

Design speed (km/hr)	Max. Change in grade permitted without using a vertical curve (%)	Minimum length of vertical curve for good appearance. (m)
30	1.5	15
40	1.2	20
50	1.0	30
65	0.8	40
80	0.6	50
100	0.5	60

Source: adapted from Table 7.42&7.43, RMSS, Vol. V11A

4. **Calculating the length of the curve:** $L = K \times A$

5. **Carrying out cross checks:** Check L and compare it with the minimum length of the curve and adjust it if necessary. If the sight distance is longer than the vertical curve, use $L = 2S - 960/A$ to recalculate curve length where S is the sight distance.

6. **Checking for feasibility and doing any necessary amends:** Avoid using curves with a radius between ISD and SSD. This might tempt them to overtake.

3.5 Design road intersections (Y-junctions, T-junctions, underpass, overpass, roundabout, cross-junction, interchange) as per standard road construction procedures

An intersection is an area shared by two or more roads that enables drivers to change route directions. There are 3 categories of intersections;

- Grade separated intersections without ramps
- Grade separated intersections with ramps/ Interchanges
- At grade intersections

Intersections are of various forms including Y intersections, T intersections, scissor, cross, staggered etc. Intersections can also be circular, to produce a circular traffic pattern and reduce the crossing conflict points. These are called traffic circles. Roundabouts are a type of Traffic Circle but have the following definitive characteristics:

a. They yield control at each approach.
b. They allow speeds of below 30 miles /hour due to their geometric characteristics of the central island.
c. They separate conflicting traffic using raised islands or pavement markings.
d. Parking within the circulating highway is not allowed.

Generally, while doing design of an intersection, the four main elements that have to be taken into consideration are:

1. Human factors
2. Traffic considerations
3. Physical elements
4. Economic factors

3.6 Produce drawings as per design data

Based on the data gathered in designing of a highway from the design calculations drawings of the highway can be generated either on paper or by using software such as Auto CAD. The drawings will include cross sections, profile drawings and the plan drawing. The plan drawing will include alignments, the cross-section levels etc. When using software, one can easily be able to generate reports from the plan. It also facilitates generating a more presentable plan in 3D.

3.7 Prepare and present report as per contract document

Based on the requirements of the contract, the road design report should include the following sections:

1. The roadway design drawings
2. The specifications
   This includes the design and construction details and requirements.
3. The quality management plan
4. Construction quality management plan

Conclusion

This learning outcome covered the determination of the OGL, horizontal and vertical alignments, road intersections and preparation of working drawings and reports.

Further Reading

Read more on the geometric design of roads so as to be able to carry out the necessary calculations. Do some further reading and write notes on levelling.

12.3.4.3 Self-Assessment

Knowledge Based Evidence

Written Assessment

1. Which of the following is not a type of vertical alignment?
   a) Simple curve
   b) Complex curve
   c) Spiral curve
   d) Compound curve
2. Which one is not a category of intersections?
   a) At grade intersections
   b) Interchanges
   c) Bridge
   d) Intersections without ramps

3. Which one is not a main element while designing an intersection?
    a) Human factors
    b) Traffic considerations
    c) Specifications
    d) Economic factors
4. Define geometric design of highway.
5. What are factors affecting geometric design?
6. List five considerations taken while doing vertical alignment.
7. List three types of intersections.
8. Write an essay detailing the process of highway design and the steps taken until drawings are obtained.

Case Study Assessment

Based on roads in your vicinity, obtain the plans used and study them. Using the skills you have learnt point out any improvements that can be made especially on the curve design. Note down the improvements you came up with.

Oral Assessment

1. Mention four types of horizontal curves.
2. Mention some road intersection features.

12.3.4.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

12.3.4.5 References

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12.3.5 Learning Outcome No 4: Design Pavement Structure

12.3.5.1 Learning Activities

Learning Outcome No 4: Design Pavement Structure	
Learning Activities	**Special Instructions**
4.1 Acquire resources 4.2 Estimate traffic load 4.3 Determine ***road/pavement type*** 4.4 Design ***pavement structures*** 4.5 Produce pavement structural drawings 4.6 Develop materials schedules 4.7 Prepare and present a detailed report and specifications	• Case studies • Discussions • Project • Demonstration by trainer • Practice by the trainee

12.3.5.2 Information Sheet No 12/ Lo 4: Design Pavement Structure

Introduction to learning outcome

This learning outcome covers preparation of pavement structural drawings, development of material schedules and preparation and presentation of a detailed report and material specifications.

Definition of key terms

Subgrade: The in-situ materials or improved ground with imported materials that form the platform for a pavement structure.

Sub-base: In transportation engineering, a subbase is a load-distributing layer immediately below and usually of inferior materials to the road base.

Rigid Pavement: This is a pavement whose main structural layer is a concrete slab. They are termed rigid due to their high flexural strength or high modulus of elasticity.

Content/Procedures/Methods/Illustrations

4.1 Acquire resources in accordance with pavement structure requirements.

The design of pavement structures requires the determination of the thickness of layers and composition of materials. The resources and tools required in pavement design can be found through;

- Online USGS store for topographical maps
- Download Road Design Manuals online from the KeNHA web page.
- Visiting the library for literature on pavement structures
- Accessing design software from trusted online suppliers.

4.2 Estimate traffic load as per traffic survey information.

Traffic loading in transportation engineering is the cumulative load characterized by traffic volume, magnitudes, wheel repetition, and truck weight data. The procedure for determining traffic loading is:

- Determining the axle load
- Calculating the Equivalent Factor and the number of single axle loads (SAL)
- Calculating the total SAL as Cumulative standard axle (CSA)

4.3 Determine *road/pavement type* (rigid and flexible pavement) as per client/developer/financier requirements and nature of the ground.

Pavement types are categorized into two major types; rigid and flexible pavements.

The procedure for selection of a pavement structure involves:

- Assessing the initial cost of construction
- Evaluating life cycle costs in the pavement maintenance and subsequent rehabilitations
- Determining the traffic loading
- Identifying the topography and land use

4.4 Design *pavement structures* (sub-grade, sub-base, base, surface) based on traffic engineering analysis outputs and material testing results

The typical components of a pavement that functions to support and distribute traffic load are what makes a pavement system. The procedure for design is as follows:

- Collecting and analyzing traffic data into CSA
- Collecting and analyzing material testing results on subgrade for CBR, OMC and MDD.
- Determining the pavement thickness based on traffic and material testing results.

Figure 131: pavement thickness
Source: https://www.nbmcw.com/tech-articles/roads-and-pavements

4.5 Produce pavement structural drawings as per design outputs

Pavement structural drawings are documents that depict the detailed cross-section of a proposed road. The software that are commonly used are AutoCAD and Civil 3D.
The process of producing structural drawing should include:

- Drawing of cross-sections after every 100m or in areas of a sudden change in gradient.
- The area of fill and cut to be shown at all times

4.6 Develop materials schedules according to design results

Materials scheduling is the process of organizing and controlling the sequence of delivery of materials on site. Material scheduling requires considerable knowledge of technical specifications for each component in structural design. The procedure to develop material schedule is:

- Identifying and working out quantities of materials needed from the structural drawing
- Identifying where materials will be procured
- Identifying the unit cost of the materials
- Determining the lead times of the materials

4.7 Prepare and present a detailed report and specifications as per the contract document

A detailed project report and specifications is a planning and design output document that provides particulars for a specific project. The preparation and presentation of a detailed report and specifications, with regards to pavement design, will involve the following;

- Identifying the projects particulars such as the project description, the scope, existing conditions, and the field investigations.
- Collecting information on the final route location
- Collecting the specification for soils and materials
- Collecting and organizing design details of the pavement, culverts and other features
- Compiling and presenting all the projects details and parameters.

Conclusion

This learning outcome covered preparation of pavement structural drawings, development of material schedules and preparation and presentation of a detailed report and material specifications.

Further Reading:

1. Conduct further research on pavement structure from the Road Design Manual Part III -Materials and Pavement Design for New Roads. Chapter 9: The Standard Pavement Structure
2. Read more on preparation of detailed report from the article: Tips for Writing an Engineering Project Report https://www.projectengineer.net/tips-for-writing-an-engineering-project-report/

12.3.5.3 Self-Assessment

Written Assessment

1. Rigid Pavements are analyzed by
    a) Infinite layer theory
    b) Elastic plate theory
    c) Rigid plate theory
    d) Interlocking of aggregates
2. The most superior pavement layer is that which distributes loads as
    a) Uniformly varying load
    b) Uniformly distributed
    c) Point load
    d) Triangular load
3. Which among the following is not a contract document?
    a) Bill of Quantities
    b) Financial Statements
    c) Specifications
    d) Construction Scheduling

4. Load transfer in flexible pavements is by
    a) Consolidation of sub-grade
    b) Grain to grain contact
    c) Bending action of layers
    d) Shear deformation
5. Which of the following is not typical layer of flexible pavements
    a) Tack coat
    b) Road base
    c) Sub-base
    d) Sub-grade
6. Briefly describe the functions of each layer in flexible pavements.
7. What are the advantages of rigid pavements?
8. Briefly describe how material scheduling is conducted.
9. Briefly describe four factors controlling the design of pavements.
10. List and explain the various pavement design methods
11. Discuss the input data required to design a pavement

Oral Assessment

1. What is the importance of preparing Bill of Quantities and Specifications for pavement structures to contractors?
2. In which instances it would a rigid pavement be selected instead of a flexible pavement?

Project Assessment

You are first required to briefly highlight the procedure of CBR test. Thereafter, design a flexible pavement using MoPW Design Method using the following data; trial pits dug at intervals of 500mm produced CBR results ranging 10-20% for the subgrade and 25-40% for the subbase. The traffic data for the pavement is estimated to be 1500/day with predicted growth rate of 5% p.a. According to axle loading survey, Ef=2.25SA/CV. Design the pavement for design life of 15years.

12.3.5.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers

- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

12.3.5.5 References

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12.3.6 Learning Outcome No 5: Design Pedestrian and Cyclist Paths

12.3.6.1 Learning Activities

Learning Outcome No 5: Design Pedestrian and Cyclist Paths	
Learning Activities	**Special Instructions**
5.1 Identify and gather required resources 5.2 Estimate pedestrian and cyclist traffic 5.3 Determine a pedestrian and cyclist path location 5.4 Design pedestrian and cyclist paths 5.5 Produce drawings 5.6 Specifications	• Direct instruction • Case studies • Field trips/site visits • Discussions • Practice by the trainee

12.3.6.2 Information Sheet No 12/ Lo 5: Design Pedestrian and Cyclist Paths

Introduction to learning outcome

This learning outcome covers the determination, designing and locating of pedestrian and cyclist path.

Definition of key terms

Pedestrian crossing: This is a specially designated area on a road where pedestrians have the right way.

Information signs: These are traffic signs that function to guide motorists in navigation and offer information on important facilities along the way.

Warning signs: Traffic signs that caution road users of potential dangers along the road.

Content/Procedures/Methods/Illustrations

5.1 Identify and gather required resources as per design requirements

Resources required in the design of pedestrians and cyclists' paths are materials that will help in determining the thickness and dimensions of the paths. Resources for design include GIS tools, computer tools, and expertise, maps, and travel surveys.

The procedure of identifying and gathering resources include;

- Identifying information on demographical data, legislations for special needs groups, and land use
- Getting the areas plan and the available road reserve.
- Utilize the information to determine the dimensions of the paths

5.2 Estimate pedestrian and cyclist traffic in accordance with traffic survey information

Pedestrian and cyclist traffic are the aggregation of road users not using vehicular means of transport. According to Nordback, Sellinger, and Phillips (2017), the procedure to estimate this type of traffic involves;

- Evaluating land use and road network connectivity
- Enhancing models to conduct non-motorized trip generations in a smaller zone

5.3 Determine the pedestrian and cyclist path location according to road profile

Pedestrian and cyclist paths are routes that provide a safe passage from non-motorized road users. According to Segadilha and Sanchez (2014), selection of the location of a pedestrian and cyclist paths according to the road profile is subject to:

- Visibility
- Gradient and cross fall

5.4 Design pedestrian and cyclist paths as per design manuals and procedures

Pedestrian and cyclist paths should be designed to ensure minimal conflicts and with special consideration to people with impairments. The design of these paths demands;

- Providing paths dimensions and geometry that accommodate all users
- Surface materials to be selected on the basis of safety and convenience.
- Providing and designing street furniture's accordingly

5.5 Produce drawings according to design output

The design drawings for the pedestrian and cyclist path illustrates the cross-section layout of the paths. Design drawings are produced using software such as AutoCAD which will provide information on:

- Dimensions of the paths, including their thickness.
- Dimensions of the street furniture such as Kerb

5.6 Prepare and present the report and material specifications according to contract document

Reports according to contract documents give information on, but not limited to the project milestones, stages, labour, and equipment. The procedure to make a report will include;

- Collecting and organizing information on project activities, labour, and materials
- Structure the information into relevant segments
- Present the report with accurate charts and spreadsheets.

Conclusion

This learning outcome covered the determination, designing and locating of pedestrian and cyclist path.

Further Reading

Read more on providing footpaths and recommended dimensions

12.3.6.3 Self-Assessment

Written Assessment

1. Which among the following is NOT a zone of a footpath?
    a) Through route
    b) Frontage zone
    c) Carriage way
    d) Street furniture zone
2. All the following are traffic signs except
    a) Warning signs
    b) Explanatory signs
    c) Information signs
    d) Regulatory Signs
3. The following are design features of a pedestrian and a cyclist path except?
    a) Gradient
    b) Visibility
    c) Width
    d) Length

4. All the following are street furniture except
    a) Bollards
    b) Traffic signs
    c) Culverts
    d) Rubbish bins
5. A report provides information on
    a) Manpower
    b) Materials
    c) Project milestone
    d) All the above
6. What is the difference between a zebra crossing and a pedestrian crossing?
7. Given the information acquired, which measures will be most effective in reducing cyclist-motorist collision?
8. Give two instances where it is unsuitable for providing a pedestrian footpath along the way.
9. Highlight three surfacing materials used in pedestrian and cyclist paths.

Oral Assessment

1. Vehicles parking on pedestrian and cyclist path has been a common practice in the recent past. Which measure should be put in place to prevent cars from closing and obstructing side paths?
2. In your specific locality, which surfacing material is most common along pedestrian paths? Mention at least two advantages and disadvantages of the said materials.

Project Assessment

You are required to conduct a traffic survey for cyclists and pedestrians in your locality. Use the data collected to design a combined pedestrian and cyclist path. Your design output should be structural drawings, from AutoCAD or any other software, illustrating the cross-section, and width of the path. Please note to design for safety and aesthetics.

12.3.6.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data

- Drawing sheets
- Internet
- Relevant videos

12.3.6.5 References

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12.3.7 Learning Outcome No 6: Design Road Furniture

12.3.7.1 Learning Activities

Learning Outcome No 6: Design Road Furniture	
Learning Activities	**Special Instructions**
6.1 Gather required resources 6.2 Determine ***type of road furniture*** 6.3 Determine location of road furniture 6.4 Design road furniture 6.5 Produce drawings 6.6 Prepare and present the report and material specifications	• Direct instruction • Field trips/site visits • Discussions • Demonstration by trainer

12.3.7.2 Information Sheet No 12/ LO6: Design Road Furniture

Introduction to learning outcome

This learning outcome covers the determination and design of road furniture.

Definition of key terms

Guard rails: This is a boundary that is used to deter access to off-limits area, it allows light and visibility in a much greater way than a fence

Traffic lights: This is a signalling instrument found at road intersections, pedestrian crossings and wherever needed to control traffic flow

Street lights: This is a standard raised source of light at the boundary of a road or path

Content/Procedures/Methods/Illustrations

6.1 Gather required resources according to design needs

Design needs are those requirements that are required to be met to ensure the functionality and reliability of a structure. The resources that are required to be gathered include;

i. The Kenya National Highway regulations

ii. Experts in the road and Highway construction management sector

They can be gathered by approaching their workstations where they will provide the stipend and budget as well as those having expertise in the area

6.2 Determine *type of road furniture* (Road markings, information signs, warning signs, street lights, traffic lights, guard rails) based on road type and relevant manuals

Road Furniture are devices that provide road users with the necessary information on warnings, rules or directions in order to ensure safe use of the roads

- They serve many functions related to the usage of the streets in many ways whether directly or indirectly Their importance includes;
- Lead to a better usage of the streets as an urban space been used by people
- These setups the streets are not only passages of movement, but also living spaces that contains and improves people's lives and human activities
- With the lack of street furniture designs, these setups are considered as barriers and obstacles in the streets that may affect negatively, the functions being performed in the streets.

Road markings: This is any kind of physical representation of official information on a road surface end is usually placed with road marking machines

Information signs: This is a very readably printed or distinguishable placard to convey the purpose of an object or give the directive on the use of something

Warning signs: These are a type r regulatory signs that are used to show a potential hazard, obstacle or condition requiring caution

Street lights: These are standard raised source of light at the boundary of a road or path

Traffic lights: This is a signalling instrument found at road intersections, pedestrian crossings and wherever needed to control the flow of traffic

Guard rails: This is a boundary that is used to deter access to off-limits area, it allows light and visibility in a much greater way than a fence

6.3 Determine location of road furniture as per geometric road design

Road furniture are devices that provide road users with the necessary information on warnings, rules or directions in order to ensure safe use of the roads.

To determine the location of the road furniture the following steps must be undertaken:

a. Site visit
b. Collect the onsite data collected according to standard procedures
c. Identify the road intersections as designed as per standard road procedures
d. OGL (Original Ground Levels) are obtained according to standard road construction procedures
e. Horizontal alignments are designed based on standard road construction procedures
f. Vertical alignments are designed based on standard procedures
g. Sketch the data determined and a report is compiled of all the completed tasks

6.4 Design road furniture according to standard road construction procedures

Road Furniture are devices that provide road users with the necessary information on warnings, rules or directions in order to ensure safe use of the roads

The design of Road furniture includes

Route planning: Establish specific goals and prescriptions for road network development along with the more general location needs.

Design Criteria which includes the following among others;

- Resource management objectives; why is it needed
- Environmental and physical factors' topography and vegetation characteristics of the area
- Environmental and Social-political constraints e.g. high rainfall intensities and land ownership boundaries
- Traffic requirements; average daily traffic (ADT)
- Vehicle characteristics; distinguishing between "design vehicle" and "Critical vehicle"
- Road uses distinguishing from Administrative users, Agricultural users among others six Safety -Safety requirements such as stopping distance, sight distance or allowable deign speed
- Economics -Economic evaluations should be done

The design elements which include the Number of Lanes and Lane width, Road width and Turnouts, turn arounds, curve widening, Clearance, Speed and Sight distance, Horizontal and vertical alignment as well as travel time

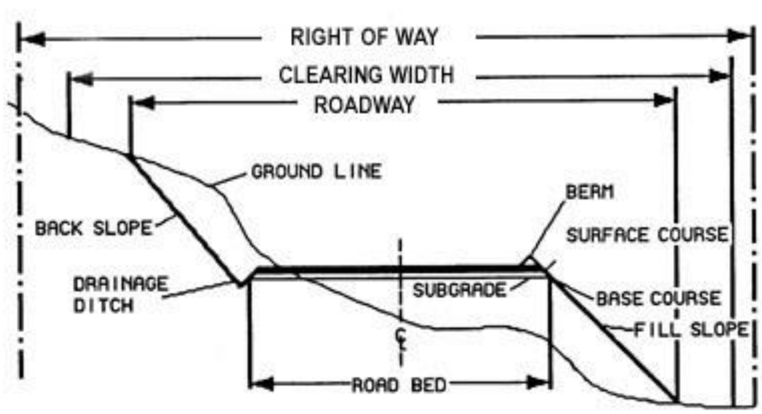


Figure 132: Design elements

Source: www.FAO.org

6.5 Produce drawings based on design requirements

The design and construction of Road furniture goes through a rigorous process which includes cooperation of many entities to deliver a quality road.

Basic Requirements for Producing Drawings

- Computer installed with Civil 3D software
- Survey data

Steps of Producing Drawings based on design requirements.

- OGL data of the road is taken with the help of the survey team using a Total Station
- The data is then loaded into a computer with the necessary processing power.
- The road is then designed as per the standard requirements in the Ministry of Roads and Transportation using different software, preferable Civil 3D
- A report is then generated from the design with all the cut and fill data as well as the elevations of the pavement.

Conclusion

This learning outcome covered the definition of various road furniture, the standards and design of road furniture.

Further Reading

Read on Standard Specification for Road works and standard specification
Project Management for Construction than develop a flow chart on the mandatory steps that must be conducted when designing a road furniture device.
Read manuals on the Safety Measures in developing countries and identify the specific to road users and Pedestrians
Read reports on Road and Highway constructions and determine the similarities in them

12.3.7.3 Self-Assessment

Written Assessment

1. Which of the following is not a road furniture?
    a) Standard lights
    b) Safety barriers
    c) Bridge
    d) Traffic lights
2. Which of the following is not an objective of Warning Signs?
    a) Convey the purpose of an object or give the directive on the use of something
    b) Indicate potential hazard
    c) Indicate obstacle or
    d) Indicate condition requiring caution
3. Which of the following is a factor to be considered as a standard in road furniture design?
    a) Original ground level
    b) Horizontal alignment
    c) Vertical alignment
    d) Economics

4. Which of the following is not a performance criterion when constructing a road furniture?
    a) Conduct site visit
    b) Design highway drainage structures
    c) Design road geometrics
    d) Quality system requirements
6. Which of the following is a requirement needed in a report prepared before construction of a road furniture?
    a) Referenced documents
    b) Social-political factors
    c) Road markings
    d) Agricultural users
7. Which of the following is not a skill required to be competent in road furniture construction?
    a) Drawings
    b) Innovation
    c) Leadership
    d) Marketing

8. Which of the following is the correct definition of a traffic light?
    a) These are standard raised source of light at the boundary of a road or path
    b) This is a signaling instrument found at road intersections, pedestrian crossings and wherever needed to control traffic flow
    c) This is a boundary that is used to deter access to off-limits area, it allows light and visibility in a much greater way than a fence
    d) These are a type regulatory signs that are used to show a potential hazard, obstacle or condition requiring caution
9. Briefly describe the various categories of Traffic Users (4 marks)
10. Explain five Environmental factors that influence the road furniture standards
11. What is geometric road design
12. Distinguish between "design vehicle" and "Critical vehicle", vehicle characteristics
13. Explain the resource management objectives that could lead to the construction of road furniture
14. List and explain the on-site data that should be collected during construction site visit
15. Explain the various pavement structures

Oral Assessment
1. What are the two types of Pavement types (2 marks)
2. Name 5 road furniture (5 marks)

Case Study Assessment
In the new constructed super highway there was a government directive to place Road furniture at every exit to assist the road users. According to the Standards of Road and Highway, identify 5 established exits identify the road furniture expected, specify the distances appropriate to place them and explain the social-political factors that influence the road furniture at a specific area

12.3.7.4 Tools, Equipment, Supplies and Materials
- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet

12.3.7.5 References

Barba J. Jackson (2010) Construction Management Jumpstart Sybex; 2 edition (June 3, 2010)

Journal of Modern Engineering Research (2014). The Importance of integrating Street furniture in visual image of the city

Kyle Perry (2018) Guaranteed Project Success New York

Paul Netscher (2017) Construction Management Tips and Insights, Panet Publications

CHAPTER 13: ROAD CONSTRUCTION WORKS

13.1 Introduction of the Unit of Learning

This unit specifies the competencies required to perform road construction works. It involves carrying out earthwork activities, constructing road/pavement structure layers and constructing parking, walkways and cyclist lanes, footbridges and bus bays. It also includes installing road furniture, construction of erosion prevention structures, constructing highway drainage and hydraulic structures and undertaking highway maintenance

13.2 Performance Standard

Carry out earthwork activities, construct road/pavement structure layers, parking, walk ways and cyclist lanes, foot bridges, bus bays, erosion prevention structures, highway drainage and hydraulic structures, install road furniture, and undertake highway maintenance as per contract documents, construction procedures, design output and SOPs.

13.3 Learning Outcomes

13.3.1 List of Learning Outcomes

a) Carry out earthwork activities
b) Construct road/pavement structure layers
c) Construct parking, walk ways and cyclist lanes, foot bridges, bus bays
d) Install road furniture
e) Construct erosion prevention structures
f) Construct highway drainage and hydraulic structures
g) Undertake highway maintenance

13.3.2 Learning Outcome No 1: Carry out Earthwork Activities

13.3.2.1 Learning Activities

Learning Outcome No 1: Carry out Earthwork Activities	
Learning Activities	**Special Instructions**
1.1 Obtain relevant legal documents 1.2 Identify and mobilize earthwork resources 1.3 Carry out Site clearance and demolition activities 1.4 Interpret drawings 1.5 Conduct Setting out for earthworks 1.6 Obtain Statutory requirements 1.7 Establish Road formation 1.8 Take and document ground levels 1.9 Determine Volumes of cut and fill materials 1.10 Carry out Haulage and disposal of waste material 1.11 Operate and maintain construction tools and equipment	• Direct instruction • Case studies • Field trips/site visits • Group discussions • Demonstration by trainer • Computer Aided Learning (CAL) • Practice by the trainee

13.3.2.2 Information Sheet No13/LO1 Carry out Earthwork Activities

Introduction to learning outcome

This learning outcome covers various learning activities such as interpreting drawings, determining volumes of cut and fill and operating and maintaining construction tools with the end goal of learning how to carry out earthwork activities which is part of road construction works.

Definition of key terms

Earthwork resources; earth filling or excavation of soil or rocks from one area to another by, hauling, dumping, crushing and compaction of soil

Site clearance and demolition activities; this involves removal of old infrastructure, removal of top soil, cut and fill.

Statutory requirements; verified documents used for the road construction.

Content/Procedures/Methods/Illustrations

1.1 Obtain Relevant legal documents as per the contract requirement

Legal document: it is an official document required by law that binds the client and the contractor

Types of legal document

- Scope of work: work is clearly defined including the materials to be used.
- Construction schedule: it helps the clients and contractors to know how and when the project will be completed.
- Conditions: involving general and specified conditions, general is rights for each party while specified is conditions for a given work and certain circumstances.
- Bill of quantities: this is the part of contraction project which includes labour, list of materials etc.
- Drawings: all contracts require drawings this include actual blueprints
  For project.

Steps of obtaining relevant Legal documents

- Obtaining surveying plan: this is to confirm if the land is the exact one and proof of the land ownership
- Obtain project report from (NEMA): this is to approve environmental impact of the project
- Obtain approval of the architectural plans: drawings are approved
- Obtain stamps on architectural and structural plans.

1.2 Identify and mobilize Earthwork resources as per the contract document

This is the process of determining the resources required and getting the necessary finance to acquire these resources.

Types of Earthwork resources

- Bulldozer: heavy tractor which assist in digging, pushing, excavating and levelling
- Hoe, mattock, pick axe, crowbar, spade: used for excavating materials
- Basket, stretcher, shovel, wheelbarrow: used for removing materials
- Rake, spreader, hoe: used for spreading
- Hand hammer: used for compaction
- Excavators: used to dig and load materials in a tractor
- Trenchers: used to dig trenches in the ground

Steps of Identifying and mobilizing the necessary resources

(i) Determine the particular earthwork activity to be carried out at the site. This is done so as to determine the type of earthwork resource required for the particular activity.

(ii) Acquire the necessary permits and financial resource to mobilize these resources.

(iii)Mobilize the earthwork resources from whichever location you identified as per the standard specifications of the contract documents.

1.3 Carry out site clearance and demolition activities based on contract document and construction procedure

Site clearance is the process or removing unnecessary vegetation and structures along the route planned for construction of the road. This is done so as to get a clear and workable site. It involves the removal and disposal of all bush, trees, roots, grass and top soil. This activity must be done before any construction of the roadway starts. Unless the Engineer agrees in writing otherwise, all materials including trees, grass, crops and structures, which fall within the road alignment must be removed.

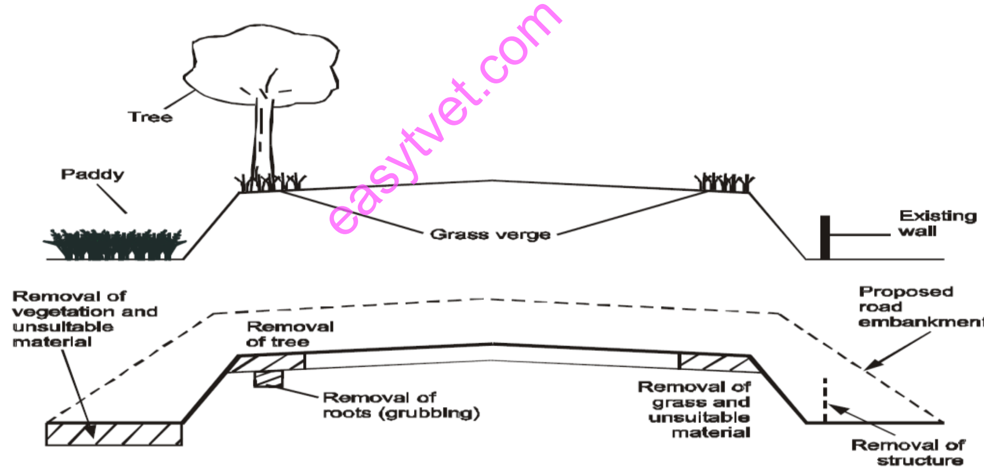


Figure 133: Clearing and Grubbing

Source: Construction practices and procedures manual May 2001

1.4 Interpret Drawings as per construction procedures

For easier interpretation and understanding of a drawing one should follow the following steps

- Commencing with the title block, which shows you the title of the drawing and what the drawing is all about
- Understand the basic symbols on the drawing
- Identify specific abbreviations and try to understand what they mean

Try to visualize the structure in your imagination

1.5 Conduct setting out for earthworks based on design output

Setting out process is used to establish the boundaries and marks for excavation of earthworks and is based on the design output. It enables construction to be carried out as it has been planned according to dimensions specified in layout drawings. Setting out can be done using various methods the most common being the profile board method.

Steps of Setting out Using the Profile Board Method

This method uses several profile boards and a string line level so as to provide control levels when constructing. A series of level boards are placed along where excavation will take place.

(i) The level boards have to be a meter above the excavation level.
(ii) Between 2 subsequent profile boards, a third profile board, called a traveler is used to control the depth of excavation. It has a fixed height and is put between the line of sight and the 2 profile boards. If it is below the line of sight, the excavation has been done too deep. If it is above the line of sight, more excavation is required.
(iii) Slots are established using the traveler where the right depth of excavation should be done. They are made at regular intervals of 4 to 5 meters along the line of sight.
(iv) Excavation is then done by joining the slots.

The traveler is then used to ensure that there are no too high or too low points.

A line level is used to control the level of the profile boards in the following ways:

a. Transferring the exact level of one profile board to another thus ensuring uniform level.
b. Measuring higher or lower from the horizontal level to set another profile board at a different level.
c. Measuring the slope between two fixed profile boards.

1.6 Obtain Statutory requirements based on contract document and standard construction procedures

Statutory requirements are the standard needs requires in carrying out road construction activities. These are required by the state.

Examples of Statutory requirements

- Bill of Quantities
- Drawings
- Contract Documents
- Practicing licenses

Reasons for obtaining statutory requirements

- These are legally binding documents which are necessary as per the contract terms

Steps of Obtaining Statutory requirements.

- Determine the activities to be conducted and the necessary statutory requirements for each specific activity.
- Acquire the statutory documents from the respective offices as per the Kenyan standard specifications on road construction

1.7 Establish Road formation based on standard construction procedures

A road formation is the surface of finished earthworks where the road pavement will be constructed. It includes the shape of the road, the basic drainage infrastructure but excludes storm water infrastructure.

Steps of establishing Road formation

Step 1: preparation of subgrade- This is the lowest layer of the pavement and is the first to be constructed.

Step 2: construction of sub-base- This a layer laid on the subgrade and is made up of mainly aggregates

Step 3: construction of base: This is the structural layer of the pavement and standards must be followed to the later during its construction

Step 4: Construction of Surfacing: This is made of mainly asphalt for flexible pavements

Step 4: preparation of wearing course- This layer is mainly made of aggregates that acts as a layer that induces friction to the tyres.

Step 5: construction of shoulders

Step 6: opening traffic

All construction standards and procedures must be followed as per the Design manuals and the contract terms.

1.8 Take and document Ground levels according to SOPs

SOP is a procedure that provides clear instructions to how teams operate for completion of certain processes. The ground level is the level of the ground as defined in a field survey authorized by a qualified surveyor. For road construction, ground levels are established by the process of levelling. Levelling is done using the following equipment:

- Dumpy level/ optical level
- Tilting level
- Automatic level
- Laser level
- Digital level
- Water level

The levels observed are booked in a levelling book. The steps followed when booking include:

(i) A new page should be used for a new job
(ii) Details are to be entered at the top of the page.
(iii) Observations that are booked should be legible and any mistakes should be crossed out. Avoid overwriting.
(iv) One line should be used for each position of the staff
(v) An entry should always be made in the remarks' column.
(vi) Work should be appropriately spread.

1.9 Determine Volumes of cut and fill materials in accordance with contract document

This is a procedure of achieving the standard level by removing some material in raised parts and adding standard material to sloppy parts. There are three major methods to compute volume of earthworks; cross-section method, spot height method and contours method. Volume from cross-section has four methods: mid-cross-section method, mean area method, end area method and prismoid formula.

Procedure of obtaining volume of cut and fill

- Calculate cross-section areas at given intervals along he projects
- Calculate area of cut and fill between areas of proposed formations
- Calculate aggregates algebraic volume for each section
- Longitudinal section along the proposed centerline is plotted proposed level included
- Axes of mass haul are drawn underneath the longitudinal profile
- Mass haul curve as the aggregates volume on the coordinates is plotted

1.10 Carry out Haulage and disposal of waste material as per the standard construction procedures

Haul is the total volume of material multiplied by the distance the material has been moved. Waste is the volume of the materials which is disposed due to unsuitability.

Disposal of waste materials

- Landfilling; the ground is covered with soil for use
- Incineration; burning at high temperatures
- Reuse; using materials which attain the standards required
- Compositing; waste is dumped in a pit

1.11 Operate and maintain Construction tools and equipment are as per the SOPs

Equipment's are classified into two types, hand tools and machineries. Hand tools are generally used in small depths of excavations.

Machinery tools

- Excavators; used to remove materials from ground
- Bulldozer: used to push
- Trenchers: used to dig trenches in the ground

Construction tools

- Hoe; used for soft soil
- Forked hoe; used for hard soil or stony
- Pick axe; used for hard stony soil
- Crow bar; stony soil
- Mattock;

Maintenance of tools

- Cutting tools are maintained sharpening
- Clean all the tools after use
- Store in dry and secure places
- Make sure all the tools are in there initial packaging
- Moving parts should be oiled

Conclusion

This learning outcome covered various learning activities such as, determining volumes of cut and with the end goal of learning how to carry out earthwork activities which is part of Road construction works.

Further Reading

Read more on:

Constructing the rise and fall and calculations involved.

Setting out of curves and their calculation.

From J. Uren, W.F.Price (2010), surveying for engineers, Fifth Edition Publishes by Palgrave Macmillan curves and mass haul diagram

13.3.2.3 Self-Assessment

Written Assessment

1. Which of the following is waste haulage waste disposal.
    a) Landfill
    b) Turning
    c) Setting out
    d) Haul
2. Which of the following refers to volume of material required to be excavated in a proposed area
    a) Mass haul
    b) Haul
    c) Overhaul
    d) Waste
3. Which of the following has the meaning of establishment of marks
    a) Excavation
    b) Setting out
    c) Benchmarks
    d) Waste
4. Which of the following require setting out
    a) Disposal of waste
    b) Types of excavation
    c) Tool maintenance
    d) Procedure of excavation
5. Which of the following is needed while carrying out excavation
    a) Spoons
    b) Seesaw
    c) Pickaxe
    d) Screw
6. Which of the following is a method of excavation
    a) Mass haul
    b) Bracing
    c) Levelling
    d) Overhaul

7. Which of the following tools is used for soft soil
    a) Hoe
    b) Crow bar
    c) Mattock
    d) Pick axe
8. Analyze the procedure for earthwork
9. Analyze importance of earthwork
10. Exam various type of earthwork
11. Give the procedure of setting out of curves
12. Draw a mass haul diagram and explain all the terms in it

Oral Assessment

1. Define terms used in excavation
2. Construct a mass haul diagram

Practical Assessment

Set out curves in the field and setting out

Project Assessment

Construct a mass haul diagram, and set out of curves after going to the field with the help of your lecturer.

13.3.2.4 Tools, Equipment, Supplies and Materials

- Computer
- Internet
- Workshop
- Construction materials
- Construction tools and equipment
- Construction designs and drawings
- Sample contract documents
- Computer software e.g. AutoCAD, ArchiCAD, Civil3D
- Stationery
- Road construction site
- Material testing labouratory
    - Molds
    - Tamping rods
    - CBR Machines
    - Crushing machines
- Schedule of work
- Standard manuals

- Road under construction
- Contract documents

13.3.2.5 References

Sixth edition Engineering Surveying W.Schofield and M.Break

J. Uren, W.F.Price (2010), surveying for engineers, Fifth Edition Publishes by Palgrave Macmillan

13.3.3 Learning Outcome No 2: Construct Road/Pavement Structure Layers

13.3.3.1 Learning Activities

Learning Outcome No 2: Construct Road/Pavement Structure Layers	
Learning Activities	**Special Instructions**
2.1 Acquire and mobilize required road construction resources 2.2 Interpret drawings 2.3 carry out levelling activities 2.4 Construct sub-grade pavement layer 2.5 Construct sub-base pavement layer is 2.6 Construct base layer 2.7 Document ground levels 2.8 Road surfacing is constructed 2.9 Carry out Quality control operations 2.10 Undertake maintenance of road/pavement structures	• Direct instruction • Case studies • Field trips/site visits • Group discussions • Demonstration by trainer • Computer Aided Learning (CAL)

13.3.3.2 Information Sheet No13/LO2 Construct Road/Pavement Structure Layers

Introduction to learning outcome

This learning outcome will cover various processes and activities that goes into the construction of road/pavement structure layers.

Definition of key terms

Road construction resources-these are elements such as materials, human resources, machinery and plant that are required in the process of road construction.

Levelling activities-these are actions undertaken in order to determine the height of one level relative to another.

Quality control operations-are activities undertaken to ascertain that products and facilities being generated meet the established standards.

Content/Procedures/Methods/Illustrations

2.1 Acquire and mobilize required road construction resources are as per contract document

In this process, all the relevant resources that are essential in the construction process are identified and sourced out. This involves the following steps

i. Identify the required resources (materials, plant and machinery) and their providers
ii. Make plans on how these resources will reach your site
iii. Make necessary arrangement for the proper storage of these resources

2.2 Interpret drawings as per construction procedures

For easier interpretation and understanding of a drawing one should follow the following steps

i. Commencing with the title block, which shows you the title of the drawing and what the drawing is all about
ii. Understand the basic symbols on the drawing
iii. Identify specific abbreviations and try to understand what they mean
iv. Try to visualize the structure in your imagination

2.3 carry out levelling activities as per standard construction procedures

Levelling activities include the following steps

i. Setting out-this process involves putting marks and lines that define a position and level where construction work is start with respect to them.
ii. Eliminating parallax error which results from the movement of the observer's eye at the eyepiece. Parallax will be eliminated when the eyepiece is adjusted until the cross hairs are in sharp focus.
iii. Making bookings

2.4 Construct sub-grade pavement layer according to contract document and standard road requirements

The process of constructing the sub-grade layer of the pavement begins at the sub-grade formation where the following activities are undertaken

i. The soil of choice in its loose condition is spread in a layer over the prepared surface using the appropriate equipment.
ii. Water is sprayed on the soil for it to achieve the optimum moisture content as determined in the labouratory.
iii. The soil is then compacted by a roller this aids in achieving the required density.
iv. This process is repeated till the required subgrade thickness is achieved.

2.5 Construct sub-base pavement layer is as per contract document and standard road requirements

The sub base layer is optional in some road construction work. It is mostly used in the strengthening of a weak subgrade or when it's economical (when the sub-base material is cheaper compared to base material). The procedure of construction of the sub base is the same as discussed previously in the sub grade construction.

2.6 Construct Base layer according to standard road construction procedures and contract document

This layer is composed of gravel and crushed rocks that is stabilized by either lime, cement or bitumen. It's a layer of very high stability and density. The main function of the base layer is to distribute the stresses created by the wheel load to the sub grade. In road construction the base course materials are spread on the prepared sub base. The thickness and cross section is maintained as per the design.

2.7 Document ground levels as per standard procedures

These are levels at the ground. During construction processes ground markings for boundaries and other elements can be made by following the procedure of setting out which involves

i. On the ground level a temporary bench mark is placed. This bench mark can either be a man hole cover or a post
ii. A baseline is then established where all the setting out activities start from.
iii. Horizontal controls –which are points of known coordinates with respect to a specific point are placed. Vertical points are also placed by timber post. These points are established through levelling.

2.8 Road surfacing is constructed as per the contract document and standard construction procedures

They are many road surfacing material available but the best material used is in road construction is concrete and asphalt. Concrete is usually used in areas where the road is expected to carry large volumes of vehicles thus a strong and durable road is needed, whereas asphalt is more resistant to weathering and it's also economical.

2.9 Carry out Quality control operations according to standard construction procedures

Quality control operations can be conducted on construction materials this is done by

i. Making sure all the materials that arrive to the site are at par with the set standards
ii. Ensure proper storage of materials so that they maintain their quality
iii. Materials that stay longer without usage should first be re-tested to ensure their quality is in check

2.10 Undertake maintenance of road/pavement structures as per maintenance procedures

The main purpose of road maintenance is to try keeping the roads in their best form. They are many types of maintenance that can be undertaken in order to preserve roads these include crack sealing, pothole repair, repair of paved edges, regular grading and reshaping of roads.

Conclusion

This learning outcome covered all the activities and processes that are involved during the construction of road/pavement structure layers

Further Reading

The learner can read and research further on types of pavements, the materials used in road construction and machineries used on the road construction.

13.3.3.3 Self-assessment

Written Assessment

1. What is not a levelling activity?
    a) Setting out
    b) Making bookings
    c) Preparing the subgrade
    d) Elimination of parallax errors
2. Which of the following is not among construction resources?
    a) Machinery
    b) Human resource
    c) Economics
    d) Materials
3. Which among the following is not a proper maintenance practice?
    a) overworking equipment
    b) following of safety rules
    c) wearing of protective garments
    d) regularly lubrication of machinery

4. In detail analyze levelling
5. In detail Examine quality control
6. In details investigate the necessary resources road construction
7. Examine in details all the activities that are carried out during levelling activities
8. Quality control involves activities that test materials to ascertain their viability discuss

Oral Assessment
1. Name the principle layers of a road/pavement
2. Give two road construction resources.

Case Study Assessment
Suppose you are invited by your community to help in a project of constructing an unpaved road. What steps will you follow in order to finish your task successfully?

Practical Assessment
Your lecturer asks you to carry out levelling around the department of civil engineering. How will you proceed to ensure your task is completed?

13.3.3.4 Tools, Equipment, Supplies and Materials

- Computer
- Internet
- Workshop
- Construction materials
- Construction tools and equipment
- Construction designs and drawings
- Sample contract documents
- Computer software e.g. AutoCAD, ArchiCAD, Civil3D
- Stationery
- Road construction site
- Material testing labouratory
    - Moulds
    - Tamping rods
    - CBR Machines
    - Crushing machines
- Schedule of work
- Standard manuals
- Road under construction
- Contract documents

13.3.3.5 References

M, G. Lay (2010). Handbook of road Technology 4th Edition. Taylor &Francis Publishers.

13.3.4 Learning Outcome No 3: Construct Parking Walk Ways and Cyclist Lanes, Foot Bridges, Bus Bays

13.3.4.1 Learning Activities

Learning Outcome No 3: Construct Parking Walk Ways and Cyclist Lanes, Foot Bridges, Bus Bays	
Learning Activities	**Special Instructions**
3.1 Acquire and mobilize required resources 3.2 Interpret Drawings 3.3 Construct parking 3.4 Construct Walk ways, cyclist lanes and bus bays 3.5 Construct foot bridges 3.6 Carry out Levelling activities 3.7 Document Ground levels 3.8 Carry out Quality control operations 3.9 Undertake maintenance of parking, walk ways and cyclist lanes, foot bridges, bus bays	• Direct instruction • Case studies • Field trips/site visits • Group discussions • Demonstration by trainer • Computer Aided Learning (CAL)

13.3.4.2 Information Sheet No13/LO3 Construct parking walk ways and cyclist lanes, foot bridges, bus bays

Introduction to learning outcome

This outcome covers all the activities that go into the construction of parking walk ways and cyclist lanes, foot bridges and bus bays. Some of the learning activities are; interpreting drawings, carrying out levelling activities and carrying out quality control operations as per standard construction procedures.

Definition of key terms

Quality Control- defines of a framework which specify all the procedures and works that should be undertaken so that the end product meets or surpasses the specified quality requirements as per the agreement.

Levelling-is the process undertaken to establish the height of one point in relation to another.

Content/Procedures/Methods/Illustrations

3.1 Acquire and mobilize required resources as per contract document

In this process, all the relevant resources that are essential in the construction process are identified and sourced out. This involves the following steps

(i) Identify the required resources (materials, plant and machinery) and their providers
(ii) Make plans on how these resources will reach your site
(iii) Make necessary arrangement for the proper storage of these resources

3.2 Interpret Drawings as per standard construction procedures

For easier interpretation and understanding of a drawing one should follow the following steps

(i) Commencing with the title block, which shows you the title of the drawing and what the drawing is all about
(ii) Understand the basic symbols on the drawing
(iii) Identify specific abbreviations and try to understand what they mean
(iv) Try to visualize the structure in your imagination

3.3 Construct parking according to contract document, design manuals and standard construction procedures

After all the design considerations for the parking lots are made, the following should be undertaken

(i) Preparation of the subgrade- the area where the subgrade is to be laid should be adequately prepared through clearing of bushes and vegetation cover on the surface. The subgrade material should be spread and properly compacted with the appropriate equipment
(ii) Paving of the parking lot- here paving blocks are laid and fitted properly to cover the entire area. Kiln dried sand is then poured to fill the spaces between the paving blocks

3.4 Construct Walk ways, cyclist lanes and bus bays according to contract document, design manuals and standard construction procedures

After all the design considerations for the walk ways, cyclist lanes, bus bays are made, the following should be undertaken

- Preparation of the sub base- the area where the sub base is to be laid should be adequately prepared through clearing of bushes and vegetation cover on the surface. The sub base material should be spread and properly compacted with the appropriate equipment
- Paving of the parking lot- here paving blocks are laid and fitted properly to cover the entire area. Kiln dried sand is then poured to fill the spaces between the paving blocks

3.5 Construct foot bridges according to contract document, design manuals and standard construction procedures

A foot bridge is a structure linking two points that are above the ground. This structure is to allow the passage of pedestrians only. After deciding on a suitable location and design of the footbridge to be constructed, the following can be undertaken:

- Making all the necessary clearance on the substructure works ie preparing the ground level where the abutments are to be erected etc.
- Making all the clearance on the superstructure work clearing of vegetation and bushes that may block the view/ the footbridge
  Below is a picture of a simple footbridge design.

3.6 Carry out Levelling activities as per standard construction procedures

Levelling activities include the following steps

i. Setting out-this process involves putting marks and lines that define a position and level where construction work is start with respect to them.
ii. Eliminating parallax error which results from the movement of the observer's eye at the eyepiece. Parallax will be eliminated when the eyepiece is adjusted until the cross hairs are in sharp focus.
iii. Making bookings

3.7 Document Ground levels as per standard procedures

These are levels at the ground. During construction processes ground markings for boundaries and other elements can be made by following the procedure of setting out which involves

i. On the ground level a temporary bench mark is placed. This bench mark can either be a man hole cover or a post
ii. A baseline is then established where all the setting out activities start from.
iii. Horizontal controls –which are points of known coordinates with respect to a specific point are placed. Vertical points are also placed by timber post. These points are established through levelling.

3.8 Carry out Quality control operations according standard construction procedures

Quality control operations can be conducted on construction materials and is done by

- Making sure all the materials that arrive to the site are at par with the set standards
- Ensure proper storage of materials so that they maintain their quality
- Materials that stay longer without usage should first be re-tested to ensure their quality is in check

3.9 Undertake maintenance of parking, walk ways and cyclist lanes, foot bridges, bus bays as per maintenance procedures

Regular maintenance of parking, walk ways, cyclist lanes, foot bridges, bus bays should be conducted to ensure proper working of these structure. These can be achieved through the following steps

- Clearing of bushes and vegetation cover that tend to cause an obstacle on and along the paths
- Cleaning of the side drain freeing it from any silt, rock debris and other obstacles that may interfere with the free flow of water
- Repair all the defective path surfaces i.e. through filling of pot holes

Conclusion

This learning outcome covered all the major activities and standard procedures that goes into the construction of parking, walk ways and cyclist lanes, foot bridges and bus bays.

Further Reading

The student should read extensively on different designs of foot bridges, the various materials used on the construction of parking lots, walk ways and foot bridges.

13.3.4.3 Self-Assessment

Written Assessment

1. Which of the following is not a levelling activity?
   a) making bookings
   b) elimination of parallax
   c) preparing of base layer
   d) Setting out

2. Which of the following is not a maintenance practice in caring of parking lots, cycle ways and bus bays?
   a) Clearing of bushes
   b) Preparation of subgrade
   c) Cleaning of side drains
   d) Repairing defective pathways

3. Which is not a method of operating and maintain construction equipment?
   a) Lubricate machine
   b) Following of safety rules
   c) Allow anyone without skills to operate complex equipment
   d) Wearing of protective gear
4. Explain the procedure of interpreting engineering drawings?
5. Summarize the procedure of levelling.

Oral Assessment

1. What is meant by quality control?
2. What is levelling?

Practical Assessment

You are invited in a community activity where they are to repair existing parking lots, walk ways and cyclist lanes in your area. As an expert in civil engineering, how are you going to guide them through this process?

13.3.4.4 Tools, Equipment, Supplies and Materials

- Computer
- Internet
- Workshop
- Construction materials
- Construction tools and equipment
- Construction designs and drawings
- Sample contract documents
- Computer software e.g. AutoCAD, ArchiCAD, Civil3D
- Stationery
- Road construction site
- Material testing labouratory
    - Moulds
    - Tamping rods
    - CBR Machines
    - Crushing machines
- Schedule of work
- Standard manuals
- Road under construction
- Contract documents

13.3.4.5 References

Ursula Baus, Mike Schlainch (2007). Footbridges: Construction, Design and History. Birkhauser Publishers.

Robert Delatte. (2008). Concrete Pavement Design, Construction and Performance. USA: Taylor and Francis Publishers.

13.3.5 Learning Outcome No 4: Install Road Furniture

13.3.5.1 Learning Activities

Learning Outcome No 4: Install Road Furniture	
Learning Activities	**Special Instructions**
4.1 Mobilize road furniture 4.2 Carry out interpretation of drawings 4.3 Determine location of road furniture on the road 4.4 Identify and acquire road furniture for installation 4.5 Install road furniture on the road 4.6 Undertake quality control procedures on road furniture installation 4.7 Carry out maintenance activities on road furniture 4.8 Review traffic signs 4.9 Undertake maintenance of road furniture	• Direct instruction • Case studies • Field trips/site visits • Group discussions • Demonstration by trainer • Computer Aided Learning (CAL)

13.3.5.2 Information Sheet No13/LO4 Install Road Furniture

Introduction to learning outcome

Installation of road furniture is a major activity during road construction that may ensure the safety of road users. The learning activities range from determining location of road furniture to understanding quality control procedures on road furniture.

Definition of key terms

Road furniture- these are objects that are fixed on the roads and road reserves that serves as a guide for traffic and pedestrians

Contract documents- are legal- binding documents that outlines the work, roles and responsibilities in a construction project as per the agreement between the parties involved.

Traffic signs-these are signs that are put up above or at roadsides to direct and give information to road users.

The following is an example of road furniture in Kenya

Figure 134: Traffic signs
Thika Road sign board. Photo Courtesy;

Content/Procedures/Methods/Illustrations

4.1 Mobilize road furniture according to contract document and designs

After identifying the type of road furniture to be set up at a particular area and the relevant authority has approved the installation, road furniture will be designed and manufactured in accordance to all the set standards. Once they are ready they will be transported to required location awaiting installation.

4.2 Carry out interpretation of drawings according to the contract document and relevant manuals

For easier interpretation and understanding of a drawing one should follow the following steps

i. Commencing with the title block, which shows you the title of the drawing and what the drawing is all about
ii. Understand the basic symbols on the drawing
iii. Identify specific abbreviations and try to understand what they mean
iv. Try to visualize the structure in your imagination

4.3 Determine location of road furniture on the road according to standard road procedures and legal requirements

They are many factors that determine where road furniture are placed along or on road sides. These include:

- Crash history of a site- with this analysis, the highway authority is able to place road furniture on these areas this helps guide road users of black spots
- Volume of traffic – the amount of vehicles on the road aid the planner on where to put road furniture.
- The number of school children that are crossing a particular road.
- The size of the community also helps in determining where road furniture are to be placed

4.4 Identify and acquire road furniture for installation as per contract document

The process of acquiring approval for the installation of road furniture take time, for instance it can go up to two years. The following is the process of acquiring approval for installation of road furniture.

- The applicant shall have to submit written documents on why they seek to have the road furniture
- Also the design concept and drawings shall also be submitted to the relevant authority.
- Wait for the relevant authority to decide if the applicant will be granted the approval.

4.5 Install road furniture on the road based on standard construction procedures

The installation process should be undertaken with keen and minimum disturbance to the road users. General safety should be practiced to avoid any accidents during the installation process. Before any installation process commences, a plan of the site must be reviewed. The following are the activities done during the installation process

- Barriers and sign board should be erected so signal vehicles and pedestrians of ongoing works.
- Excavation works of trenches where the signs are to be situated- the depth of these trenches will be as per the standards.
- Backfilling materials.
- Removal of surplus materials away from the site.
- Levelling of foundation ready to receive the road furniture for installation
- The installation of the equipment.

4.6 Undertake quality control procedures on road furniture installation as per relevant manuals

Before the installation process the quality of road furniture should be assessed to ensure standard work is put up. These include checking on this such as

- The road furniture should be visible at a legible distance for road users to easily spot them day and night.
- The road furniture should be the correct size, they should be big enough
- The road furniture should be durable to withstand harsh conditions i.e. (rain, dust and fog)

4.7 Carry out maintenance activities on road furniture based on standard maintenance procedures

Road furniture are regularly inspected so that it performs its function effectively. Maintenance of road furniture can be done through the following ways

- Cleaning – due to dirt build up, the visibility of road furniture is usually compromised the chemicals that may damage the road signs.
- Most of the times road furniture is stolen or vandalized. To prevent this, road furniture should always be fixed with special fasteners that make it difficult to remove these signs
- Clearing of vegetation cover- the growth of vegetation around road furniture reduces visibility. Clearing should be done regularly in areas where vegetation grows rapidly.
- Checking on the firmness of sign support – road furniture should always be in an upright position for easier visibility. Regular inspection should be done to make sure that these road furniture are in the correct standing position.

4.8 Review traffic signs according to standard requirements

This is the process of evaluating the effectiveness of traffic signs. Proper evaluation of traffic signs can be done by looking at a number of things/factors which indicate how effective the signs are. These factors are

- the development of an area
- the general layout of the area
- the number of vehicles using accessing that area
- the number of pedestrians using that road

The following picture shows the various traffic signs that are used in Kenya

4.9 Undertake maintenance of road furniture as per maintenance procedures

Road furniture regularly inspected so that it performs its function effectively. Maintenance of road furniture can be done through the following ways

- Cleaning – due to dirt build up, the visibility of road furniture is usually compromised therefore cleaning should be done. The cleaning agents should be free from any harsh chemicals that may damage the road signs.
- Most of the times road furniture is stolen or vandalized. To prevent this, road furniture should always be fixed with special fasteners that make it difficult to remove these signs
- Clearing of vegetation cover- the growth of vegetation around road furniture reduces visibility. Clearing should be done regularly in areas where vegetation grows rapidly.

Checking on the firmness of sign support – road furniture should always be in an upright position for easier visibility. Regular inspection should be done to make sure that these road furniture are in the correct standing position

Conclusion

This learning outcome covered all the processes go into the installation of road furniture from mobilization, acquiring, identifying and maintenance.

Further Reading

The student should read further on the types of road furniture and how to read them. This will aid to increase on their body of knowledge.

13.3.5.3 Self-Assessment

Written Assessment

1. Which of the following is not a maintenance practice of tools and equipment?
    a) Regular cleaning of tools
    b) Lubrication of tools
    c) Overworking of tools
    d) Proper storage of tools

2. Which of the following is not a maintenance activity on road furniture?
    a) Clearing of vegetation
    b) Not replacing stolen road furniture
    c) Anti-theft measures
    d) Regular cleaning of road furniture
3. Which is not a factor to consider when positioning road furniture?
    a) Crash history
    b) Size of the community
    c) Empty roads
4. Evaluate the procedure of acquiring road furniture.
5. Explain how you interpret drawings
6. Supposed you are asked to participate in a school project to install a crossing sign board near our school. What steps will you take to ensure the work is completed?

Oral Assessment

1. Summarize traffic signs
2. Explain road furniture

13.3.5.4 Tools, Equipment, Supplies and Materials

- Computer
- Internet
- Workshop
- Construction materials
- Construction tools and equipment
- Construction designs and drawings
- Sample contract documents
- Computer software e.g. AutoCAD, ArchiCAD, Civil3D
- Stationery
- Road construction site
- Material testing labouratory
    - Moulds
    - Tamping rods
    - CBR Machines
    - Crushing machines
- Schedule of work
- Standard manuals
- Road under construction
- Contract documents

13.3.5.5 References

Us. Department of Transportation (2015). Standard highway signs 2004 edition. Create space Publishers

National Transport and Safety Authority (2016). Highway Code for Road Users. Nairobi. Government Printers.

13.3.6 Learning Outcome No 5: Construct Erosion Prevention Structures

13.3.6.1 Learning Activities

Learning Outcome No 5: Construct Erosion Prevention Structures	
Learning Activities	**Special Instructions**
5.1 Mobilize construction resources 5.2 Determine erosion control structures for construction 5.3 Establish location of erosion prevention structures 5.4 Carry out interpretation of drawings 5.5 Carry out construction of erosion prevention structures 5.6 Undertake quality control procedures 5.7 Undertake maintenance of erosion prevention structures	• Direct instruction • Case studies • Field trips/site visits • Group discussions • Demonstration by trainer • Computer Aided Learning (CAL)

13.3.6.2 Information Sheet No13/LO5 Construct Erosion Prevention Structures

Introduction to learning outcome

This learning outcome deals with the construction of erosion prevention structures in road construction and involves various learning activities ranging from mobilizing construction resources to operating and maintaining construction tolls and equipment

Definition of key terms

Sediment Control Basins-These are basin structures that are constructed to control the flow within a drainage area

Diversion terraces-These are structures constructed in lieu with terraces across a slope to handle runoff

Grassed waterways-These are saucer-shaped channels constructed to move surface water across a farmland without causing erosion

Content/Procedures/Methods/Illustrations

5.1 Mobilize construction resources are as per contract document

Mobilizing consists of making sure one has resources and people agreed upon in the contract ready to begin work. The construction resources could include:

- Excavators
- Tractors,
- Ploughs,
- Man-power
- Bull dozers
- Graders,
- Back hoes

To mobilize the construction resources the following steps are to be considered;

i. Identify the key stakeholders in indicated in the documents
ii. Generate a work plan and share with all involved
iii. Continuously recognize effort and identify how to outsource the tasks if need be

The Mobilization of construction resources ensures efficient and effective delivery of product and service within the allocated time and within a pre-determined budget. Therefore, the mobilization occurs at the onset of the construction process

5.2 Determine erosion control structures for construction based on prevailing site conditions

Erosion control structures are devices that are used to reduce the erosive power of water hence protect soil. They are categories of Erosion construction structures such as;

- Control Basins-These are basin structures that are constructed to control the flow within a drainage area
- Diversion terraces-These are structures constructed in lieu with terraces across a slope to handle runoff
- Grassed waterways-These are saucer-shaped channels constructed to move surface water across a farmland without causing erosion

The erosion construction structures are determined by;

a. Making inquiries of the prevailing site
b. Determining the soil characteristics of the site
c. Observing the effects of uncontrolled flow of water to the site hence deducing the best way forward

The erosion control structures are based on prevailing site conditions to ensure the longevity and the efficiency of the structure. This activity is undertaken by the expert at the onset of the process, and as the process progress alterations may be adopted

5.3 Establish location of erosion prevention structures according to contract document

The location of prevention structures is a process that requires the skill of an expert such as a surveyor or engineer. When locating the appropriate site for such a structure the following must be considered;

- The topography of the location
- The type of the prevention structure to be constructed
- The supplementary uses of the water collected
- The drainage of the water collected

These is established by;

- Identifying the available resources
- Consulting the relevant authorities
- Approaching experts and research previously done on the location

The location is a critical piece of information so therefore it is established promptly by all the stakeholders involved, to ensure commencement of work and that all processes are abiding to the set regulations.

5.4 Carry out interpretation of drawings as per standard construction procedures

Interpretation entails using the skill of a trained personnel to explain and represent the drawings taken at the site. This is important as it helps to design the control structure appropriately avoiding wastage of time and resources. The drawings may be in form of Charts, Diagrams graphs and the drawings themselves which have used national and International standards and conventions to provide a universal visual language. There are various sources used for interpretation such as GIS, AUTOCAD and other design software's as this is done before the commencement of construction

A Standard scale of interpretation is already established by the parties concerned and experts are consulted to ensure it meets the standards agreed upon.

The following procedure is used when interpreting drawings;

i. Acquaint oneself with scale drawings -Always determine the scale first before examining in detail, if unsure consult the engineer who drew it for clarification
ii. Acknowledge the basic symbols used in engineering drawings-They may be rectangles, circles or triangles mainly indicating shapes, processes and dimensions. If unsure consult the engineer who drew it
iii. Look at circled numbers-Due to a very detailed drawing that may be produced and in a small scale the circled number often shows an area identified in greater detail on another page
iv. Identify specific abbreviations-Some common abbreviations may be ;DP-Depth and DIA-Diameter

5.5 Carry out construction of erosion prevention structures in accordance with standard construction methods

This entails involving all the personnel agreed upon to participate in the various activities such as;

i. Site clearance activities
ii. Cut and fills
iii. Standard road construction procedures e.g. excavation, cut material disposal and compaction
iv. Interpret drawings
v. Quality control procedures
vi. Levelling activities
vii. Establishment of structure

The process is a lengthy one and requires the continual advancement of the area, the construction of the structure will not only improve the quality of life in the region but improve the quality and quantity of products from the location

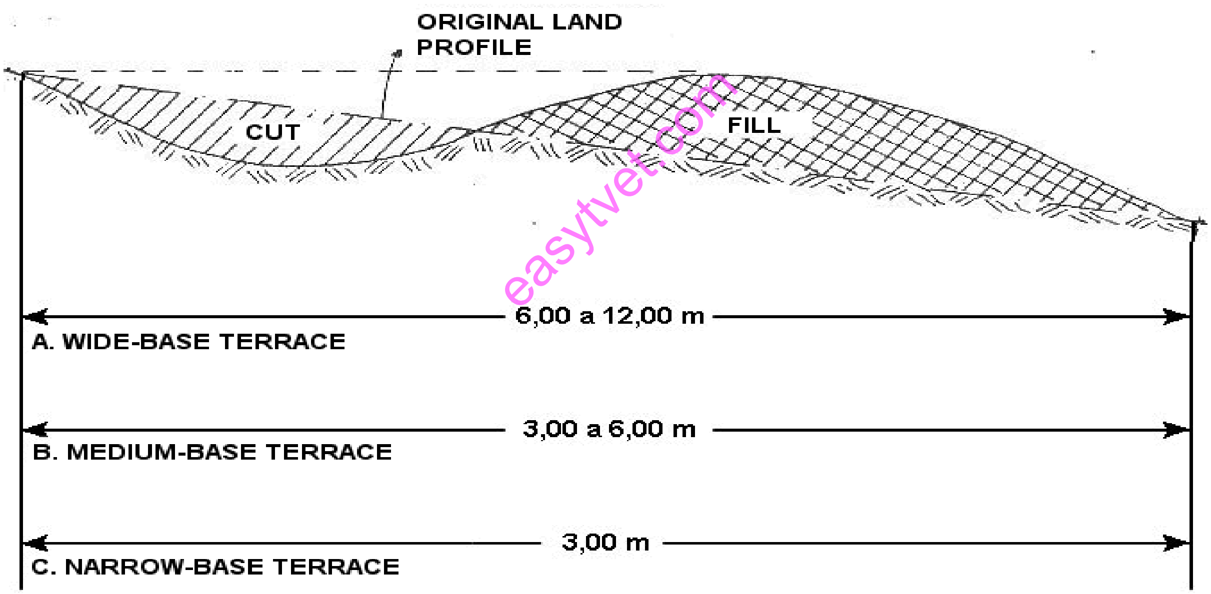


Figure 135: terrace showing different base sizes

A terrace showing different base sizes (FAO,2000)

5.6 Undertake quality control procedures according to standard procedures

Quality control procedures are a set of activities that are done at the area to ensure that the quality of the control structure meets the standard requirements of both the client and the specification. They are conducted by an expert in the field (surveyor, engineer) after the construction of the control structure with the guide of established standards such as those by AASHTO standards and FAO e.g.

i. Maximum dry density
ii. Cone penetration

iii. Plasticity index
iv. California Bearing Ratio (CBR)
v. Shear tests
vi. Marshall test

The tests are important to be undertaken early in the project so as to ensure that the characteristics and the conditions of the land are not overlooked that may cause adverse effects to the structure in future

5.7 Undertake maintenance of erosion prevention structures as per maintenance procedures

Maintenance of the erosion prevention structures ensures the preservation of the structure and its continued efficiency. The maintenance is done every season and requires the input of an expert, and the use of the earthwork machinery sparingly. They could include methods such as reinforcing the terrace and removing rocks inside the waterways firming up the soil through compaction.

An example of Maintenance Plan for sediment control structures;

- All Erosion and Sediment control practices will be checked for stability and operation after every run-off producing rainfall mandatorily every week. Repairs are carried out immediately to ensure practices are maintained as designed
- The sediment basin will be cleaned out when the level of sediment reaches 2.0ft below the riser. Gravel will be cleaned/replaced when the sediment pool no longer drains properly
- Sediment will be removed from the sediment trap and obstruct the gravel intake protection device when the storage capacity has been approximately 50%fillled., Gravel will be cleaned/replaced then
- Sediment will be removed from behind the sediment fence when it becomes about 0.5 ft deep at the fence. The fence will be repaired as necessary to maintain the barrier
- All seeded areas will be fertilized, reseeded as necessary and mulched according to specifications in vegetative plan to maintain vigorous, dense vegetative cover

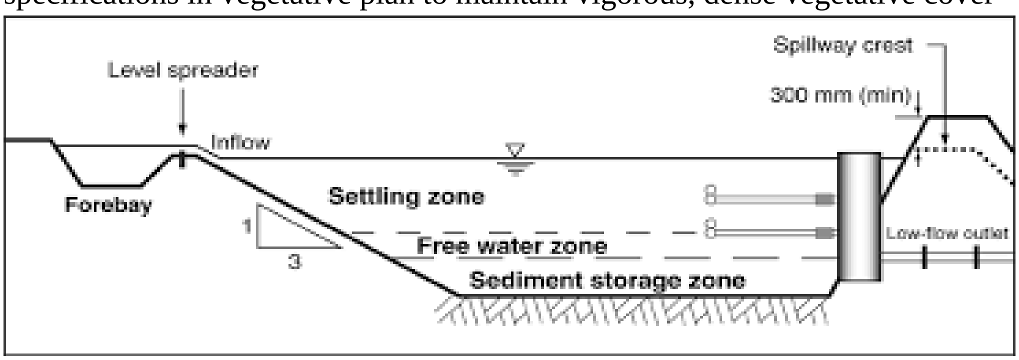


Figure 136: Sediment Basin Control Technique

Source**;** IECA Australia (June 2018) Sediment Basin Control Technique

Conclusion

This learning outcome covered the construction of erosion prevention structure and their maintenance procedures.

Further Reading

1. Read Erosion and Sediment Control Planning and Design Manual and identify the various erosions structures developed by governments
2. Read on technologies to combat soil erosion by World Overview of Conservation Approaches and Technologies
3. Sample Erosion and Sedimentation Control Plans

13.3.6.3 Self-Assessment

Written Assessment

1. Which of these is not an earthwork equipment?
    a) Grader
    b) Bull dozer
    c) Sub-soil
    d) Excavator
2. Which of the following is not an Erosion control Structure?
    a) Diversion terrace
    b) Green house
    c) Control Basins
    d) Grassed waterways
3. Which of the following is of most importance when determining the location of an erosion control structure?
    a) Topography
    b) width
    c) material
    d) procedure Manual

4. A grassed waterway
    a) These are saucer-shaped channels constructed to move surface water across a farmland without causing erosion
    b) The topography of the location
    c) The tools and equipment that are used in the construction of erosion control structures
    d) These are basin structures that are constructed to control the flow within a drainage area
5. Which of the following is not a Personal Protective Equipment (PPT) used during construction of an erosion control structure?
    a) Head gear
    b) Lab coat
    c) Gloves
    d) Reflective clothing
6. Which of the following is not an expert required in designing an Erosion control Structure?
    a) Engineer
    b) Agriculturalist
    c) Surveyor
    d) Telemarketer
7. Is a Terrace Constructed?
    a) Across a slope
    b) Below a valley
    c) Along the river
    d) Adjacent a basin
8. Evaluate 7 erosion construction structures and state their importance
9. Summarize the activities undertaken when conducting site clearing
10. Explain the different types of cut and fill materials used in construction
11. Evaluate the various procedures carried out in Quality control operations and state their importance?
12. Explain the statutory requirements and what are their importance?
13. What are control erosion structures and wat are their importance?
14. What is the personal protective equipment required and what are their relevance?

Oral Assessment

1. Distinguish 6 erosion control structures
2. Explain 3 quality control procedures adopted when constructing erosion control structures

Case Study Assessment

During the months of July and August 2019 the National government proposed the construction of a diversion terrace in Nyandarua. During the heavy downpour later the year the Terrace collapsed .State some of the procedures that would have been overlooked for such a scenario to occur

13.3.6.4 Tools, Equipment, Supplies and Materials

- Computer
- Internet
- Workshop
- Construction materials
- Construction tools and equipment
- Construction designs and drawings
- Sample contract documents
- Computer software e.g. AutoCAD, ArchiCAD, Civil3D
- Stationery
- Road construction site
- Material testing labouratory
    - Moulds
    - Tamping rods
    - CBR Machines
    - Crushing machines
- Schedule of work
- Standard manuals
- Road under construction

Contract documents

13.3.6.5 References

Pablo A Garcia (2015) Erosion control and Land restoration, Outskirts Press

R.P.CMorgan (2005) Soil Erosion and Conservation, 3rd Edition

Andre Bationo (2007) Advances in Integrated Soil Fertility Management in Sub-Saharan Africa

13.3.7 Learning Outcome No 6: Construct Highway Drainage and Hydraulic Structures

13.3.7.1 Learning Activities

Learning Outcome No 6: Construct Highway Drainage and Hydraulic Structures	
Learning Activities	**Special Instructions**
6.1 Plan for Highway drainage and hydraulic structures construction 6.2 Construct culverts 6.3 Construct side drains, meter drains and cut-off drains 6.4 Construct sub-surface drains and gullies 6.5 Construct bridges 6.6 Construct drifts and causeways 6.7 Construct retaining walls 6.8 Undertake maintenance of highway drainage and hydraulic structures	• Direct instruction • Case studies • Field trips/site visits • Group discussions • Demonstration by trainer • Computer Aided Learning (CAL) • Practical

13.3.7.2 Information Sheet No13/LO7 Construct Highway Drainage and Hydraulic Structures

Introduction to learning outcome

The construction of highway drainage and hydraulic structures is a learning outcome that is critical in the construction of roads/pavements. It involves various learning activities such as the construction of culverts, drains, bridges and retaining walls

Definition of key terms

Hydraulic structures: A hydraulic structure is a structure which remains partially or fully submerged in a body of water which alters, diverts or completely stops the flow of water naturally.eg dam, weir, flumes etc.

Retaining walls: A retaining wall is a structure which is designed and constructed to resists the lateral pressure of soil so as to prevent the material being retained from sliding away.

Bridges: A bridge is a structure carrying a road, path, railway across a river, road or other obstacles. It's constructed above the maximum flood level.

Content/Procedures/Methods/Illustrations

6.1 Plan for Highway drainage and hydraulic structures construction

An efficient drainage system allows disposal of water from the road in the shortest time possible. Some of the crucial features for such a system are:

- Road surface drainage which makes sure that water can flow from the road
- Side drains which are vital in collecting water from the road's surface
- Scour checks which slows down the flow of water and thus prevent the ditches from being eroded
- Culverts which are crucial in leading the water from the side drains.
- Bridges and drifts which ensures that the road cab go over roads and streams in all seasons.

To plan for a drainage system the following is required

- Observation of drainage patterns and requirements during rainy periods so that an accurate data about the amount of water can be determined.
- Establishing the exact cause and effect of the drainage failures.
- Determine a center line that avoids poorly drained areas, large runoffs and unnecessary stream crossings.
- Reducing the road gradients for roads with steep gradients so that the drainage of water from the road surface can be done in a controlled manner to avoid erosion

6.2 Construct culverts

Culverts can be built using a variety of material, include brick and stone masonry, corrugated steel, timber and concrete culverts are also constructed in a wide-range of shape and sizes. The most common types of culvert is fitted with one or several rows of circular pipes made of concrete. The most common is the pipe with a diameter of 60 cm.

The stages of construction of culverts

i. Estimation of the area of the culvert required.

The rule of thumb can be used to assume that the area of the culvert required is one-third of the area of waterway when the stream has reached its highest flood level, i.e. for every three-square meters of waterway one square meter of culvert should be placed.

ii. An apron should be made to protect the bed from erosion at the outlet side of the culvert

iii. Head/wing walls should be made at the inlet and outlet side of the culvert to protect the road embankment from the river water and serve also to support the embankment, so that the soil does not slide into the river when a vehicle passes;

iv. Proper compaction of the soil around, between and on top of the culverts. This compaction should be done in layers not exceeding 15 centimeters.

The gradient of culverts should normally be the same as the gradient of the stream bed and should not be greater than 5 per cent.
When a natural stream crosses the road at an angle, it is often better to construct a skew crossing or to realign the road, so that a 90° crossing can be constructed. If an existing channel bed is altered, usually a lot of erosion problems can be expected.

6.3 Construct side drains, meter drains and cut-off drains

Side drains, meter drains and cut-off drains are used to prevent the flow overshooting the drainage works or to direct flows into culvert inlets. They are also used as erosion checks. The type of side ditch selected must be checked to ensure that it will carry the expected flow without running as deep as to wet the road pavement nor so fast as to cause scour

6.4 Construct sub-surface drains and gullies

Subsurface drains: Includes any type of drain designed to collect groundwater whether this is rising from below or percolating from the surface

Gullies: include a small sump into which detritus may sink for subsequent removal, preventing it entry into the drainage system, where it may otherwise accumulate and cause blockages, and a 'trap' which prevents the entry of floating materials to the system. They can be positioned below the surface of the pavement, in which water will enter through a grating placed flush with the surface – known as channel inlet; or not one side of the pavement with an inlet mounted in the face of the kerb- (kerb inlet). Gratings and covers are in cast or ductile iron whilst the body of the gully is preformed, clayware/ plastic and is bedded in class 25/30 concrete

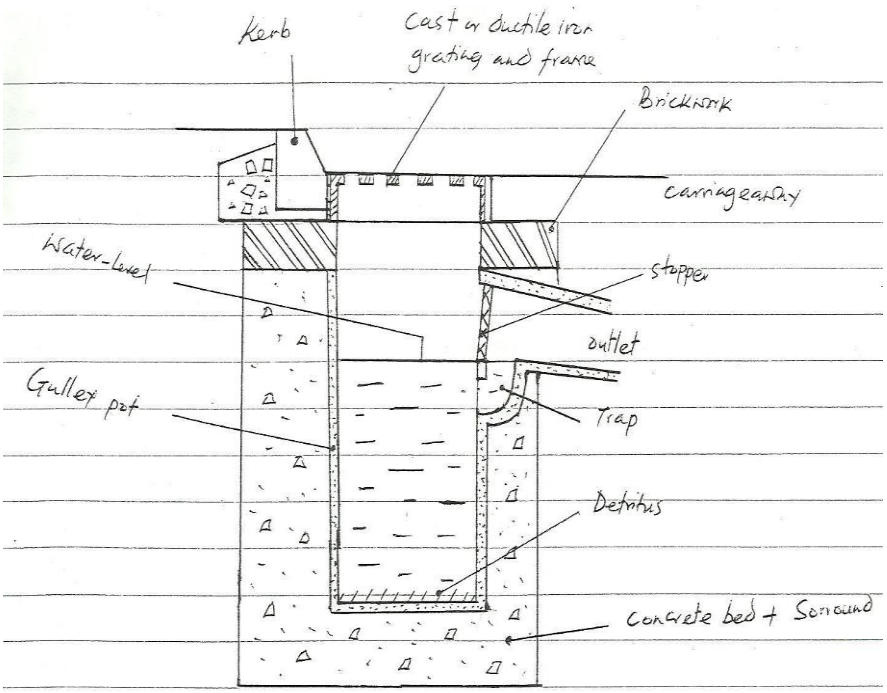


Figure 137: Sub-surface drains and gullies
Source: guide of trainer's manual.

6.5 Construct Bridges

The design procedure of constructing a bridge includes:

i. Site investigation: In this stage the highway engineer identifies a preferred location for the bridge and decides on the type, size and capacity of the structure
ii. Sketch of proposed bridge and brief technical descriptions of bridges
iii. Substructure design: this involves design of spread footings, driven piles, and drilled shaft foundations.
iv. Superstructure design: this stage deals with analysis and design of bridge decks and deck systems of concrete, metal, and wood or combinations thereof subjected to gravity loads.

6.6 Construct Drifts and causeways

Drifts: these are structures which are normally constructed to provide a firm place to cross wide, normally dry rivers which are periodically flooded. Construction of a drift depends on the design of the drift, however there are some general procedures as stipulated below.

i. Rechanneling of the water flow so as to obtain a dry working space.
ii. Setting out the center-line of the drift with survey pegs showing the future level of the drift surface.

iii. Setting out reference pegs at the down-stream and the up-stream sides of the drift. These pegs should be used to ensure the drift surface follows the gradient of the existing river.
iv. Place multi-purpose pegs showing where the foundation trenches will be excavated. These trenches should be wide enough to allow sufficient working space to the masons or carpenters.
v. Excavation of foundation trenches until you have reached a solid layer (rock, hard soil). In case of (high water-table) the water should be drained by means of buckets, pump, and meter drain whichever is convenient. In such conditions, a gabion foundation wall can be used or else fill the trench with rocks up to the water level and continue with masonry until you have reached the correct levels.
vi. After completing the foundation wall(s) excavate the area in between and place the hand-packed stone.
vii. Provide a concrete finish if specified in the design.

Causeways: this are structures which are designed and in such a way that the normal dry-weather flow of the river passes through culverts below the roadway. The construction procedure of causeways is similar to drifts for the first four steps and thereafter a bed level for the culverts is prepared using a minimum gravel layer of 15cm and preferably topped with a minimum concrete layer of 7.5cm. The culverts are then laid in positions and at a gradient of 3.5 per cent. Thereafter the headwalls are constructed up to road level and a smooth layer of concrete is provides a smooth surface for the traffic.

6.7 Construct Retaining walls

There are different procedures of constructing retaining walls depending on their type. Cantilever retaining wall is the most common type and it's constructed from reinforced concrete, precast concrete, or prestressed concrete. The Design criteria of retaining walls involves the subsequent stages: Determining the ranking active pressure and the resisting moments about the toe of footing. Checking the factor of safety and determining the size of key and finally the design of masonry and footing. During construction footings should be placed on firm undisturbed soil, or on adequately compacted fill material. Backfilling against retaining walls should not be permitted until the masonry has achieved sufficient strength or the wall has been adequately braced. During backfilling, heavy equipment should not approach closer to the top of the wall than a distance equal to the height of the wall. During construction, the soil and drainage layer, if provided, also needs to be protected from saturation and erosion. Weep holes should be provided to prevent the accumulation of water behind the face of the wall and to reduce the possible effects of frost action.

6.8 Undertake maintenance of highway drainage and hydraulic structures as per maintenance procedures

It is important to have a drainage plan indicating the location and layout of lateral and main drains, outfalls, surface water inlets and other drainage structures for purposes of maintenance. The maintenance plan involves:

- Looking for signs of sediment in drain discharge and in the receiving ditch Locate the area where the sediment is entering the drainage system and repair the drain or remove the sediment using one of the methods described earlier in this Factsheet.
- Removing any trash, debris or plant material that has accumulated around the inlet to make sure that it functions properly
- Cleaning lateral drains through the use of sewer-cleaning rods or
- Flushing using high pressure pumps where the deposit is only for a short stretch of pipe.

Conclusion

This learning outcome covered the construction of highway drainage and hydraulic structures.

Further Reading

Research on the various types of retaining walls, their design and construction

13.3.7.3 Self-Assessment

Written Assessment

1. State whether true or false a foundation of a culvert can be improved by
    a) Improving the existing subsoil.
    b) Placing gravel material.
    c) Constructing a floating floor.
    d) Pouring a concrete floor.
2. Which of the following is not part of a bridge superstructure
    a) Bridge deck
    b) Bridge guard rails
    c) Pipe handrails
    d) Piers

3. Which of the following is not part of a bridge substructure
    a) Abutments
    b) Retaining walls
    c) Culverts
    d) Bridge bearings
4. State whether true or false
    a) A bridge site must offer appropriate vertical and horizontal alignments.
    b) The soil of a bridge site must be of sufficient strength to ensure the stability of the structure.
    c) The bridge and its associated works should not harm adjoining land or buildings, or be susceptible to damage from/to the local environment.
    d) A bridge can only be built at a river crossing.
5. Which of the following is not a type of a retaining wall
    a) Masonry retaining wall
    b) Cantilever retaining wall
    c) Counterfort retaining wall
    d) Gabion wall
6. With the aid of a diagram differentiate between a causeway and adrift
7. Categorize the different types of culverts
8. Categorize the various types of hydraulic structures
9. Differentiate between a kerb inlet and a gully pot
10. Summarize the preliminary stage in the design of the bridge
11. Summarize the phases involved in the construction of a retaining wall.

Oral Assessment

When would a drift be a preferred option over a causeway?
What is the importance of hydraulic structures in the agriculture sector?

Case Study Assessment

Determine the efficiency of subsurface drains a case study along Thika superhighway.

Oral Assessment

Summarize how the drainage and hydraulic structures affect the design life of a pavement?

Practical Assessment

Visit an urban center in your local area and try to identify the various types of culverts, Drains retaining walls and any other hydraulic or drainage systems about this chapter.

13.3.7.4 Tools, Equipment, Supplies and Materials

- Computer
- Internet
- Workshop
- Construction materials
- Construction tools and equipment
- Construction designs and drawings
- Sample contract documents
- Computer software, e.g. AutoCAD, ArchiCAD, Civil3D
- Stationery
- Road construction site
- Material testing labouratory
    - Molds
    - Tamping rods
    - CBR Machines
    - Crushing machines
- Schedule of work
- Standard manuals
- Road under construction
- Contract documents

13.3.7.5 References

Design Manual for Roads and Bridges Part 6(a)-Bridges and Culvert
Guide to the Training of Supervisors - Trainees' Manual/Part 2 - For Labour-Based Road Construction and Maintenance (ILO, 1981, 254 p.)
Principles and Practices of Highway Engineering- Dr.L. R Kadyali and Dr.N.B. Lal

13.3.8 Learning Outcome No 7: Undertake Highway Maintenance

13.3.8.1 Learning Activities

Learning Outcome No 7: Undertake Highway Maintenance	
Learning Activities	**Special Instructions**
7.1 Assess pavement conditions 7.2 Prepare for maintenance activities 7.3 Carry out Emergency maintenance works 7.4 Perform routine maintenance activities 7.5 Carry out periodic maintenance works	• Direct instruction • Case studies • Field trips/site visits • Group discussions • Demonstration by trainer

13.3.8.2 Information Sheet No4/LO7 Undertake Highway Maintenance

Introduction to learning outcome

Undertaking highway maintenance is the last outcome in road construction and is a key element that should be mastered

Definition of key terms

- **Maintenance activities**

These are essential procedures undertaken to;

i. Preserve a highway to be in its initial constructed condition.
ii. Provide user safety and protection of nearby resources.
iii. Enable efficient and convenient transportation on the highway.

These activities can be done either as a routine to determine any minor damages to the pavement, slopes or drainage. They can also be carried out periodically, which involves more detailed investigation and works on various facilities and structures. They can also be carried out in case of emergencies to restore the pavement or nearby resources due to the occurrence of an accident or a natural disaster.

Content/Procedures/Methods/Illustrations

7.1 Assess pavement conditions

An accurate assessment of pavement condition is the first step to a successful maintenance procedure. This is mostly done by visual inspection to determine the surface distress; this is to assess the cracking of the surface. This is carried out for each segment of the highway and represented as Surface Rating and Dominant Distress. However, it is important to note that the performance or a highway is not just limited to surface cracking. Factors such as friction, structural soundness and user comfort are also very important in efficient and convenient use of a road. It is important to factor in the road user satisfaction in the decision making, design and maintenance of any road because it is the first thing any road user notices. The ability of a pavement to provide comfortable, safe and economical riding surface to the user can be measured in terms of present serviceability index (PSI). Many countries use pavement condition rating (PCR) to assess a road condition. The structural soundness of a road is measured in terms of response of the road to load application, volume of traffic is represented as Average Annual Daily Traffic (AADT) in this case.

Assessment Procedure

The assessment procedure entails majorly a detailed observation of the road. If the area to be assessed is large, it can be opted to use digital data collection such as a video footage of the road segment or digital images. Data pertaining to roughness can be collected using survey vehicles such as the fifth wheel and appropriate interpretation of the result done. Assessment should be carried out in inspection units. These are small portions of the road usually 15 to 60 meters. The inspection units provide the advantage of a detailed report of the current road conditions and the avoidance of overlooking of some segments.

Figure 138: Alligator cracking

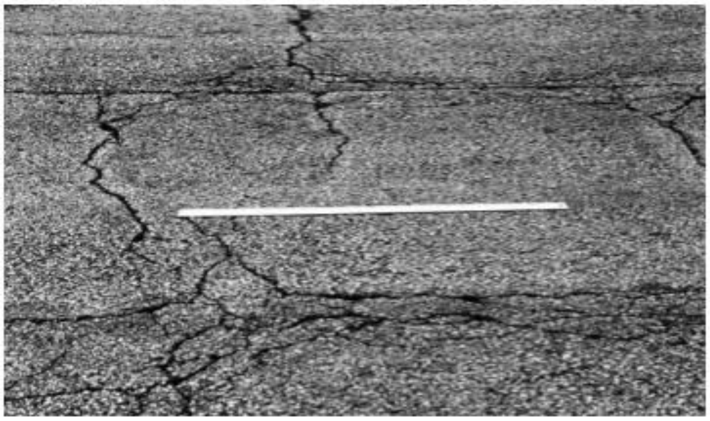


Figure 139: Block cracking

Figure 140: Bleeding

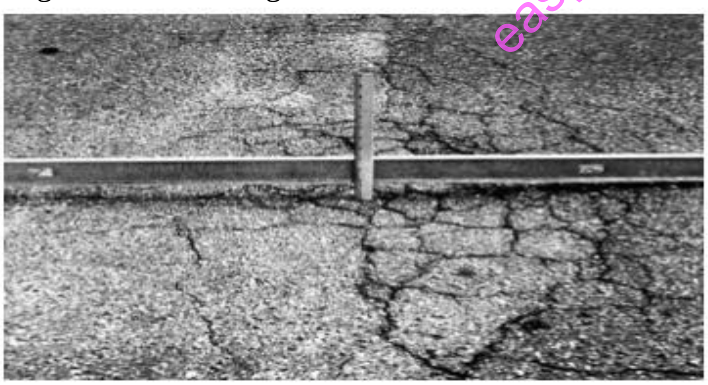


Figure 141: Depression

Figure 142: Edge cracking

Figure 143: longitudinal and transverse cracking

Figure 144: Patching

Figure 145: Rutting

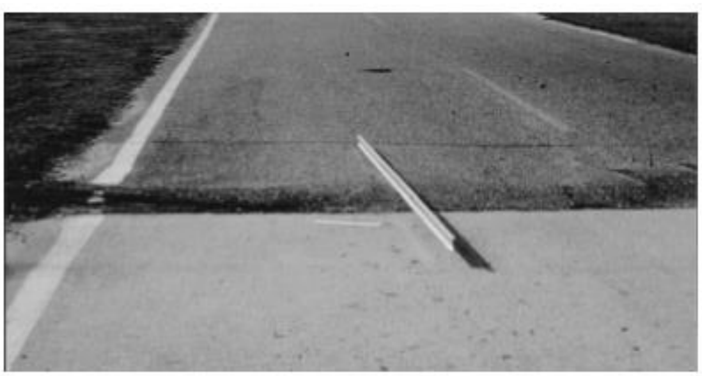


Figure 146: Shoving
Source: FHWA, 1998

7.2 Prepare for maintenance activities

Preparation for maintenance activities would involve the various activities as indicated in the flow chart below.

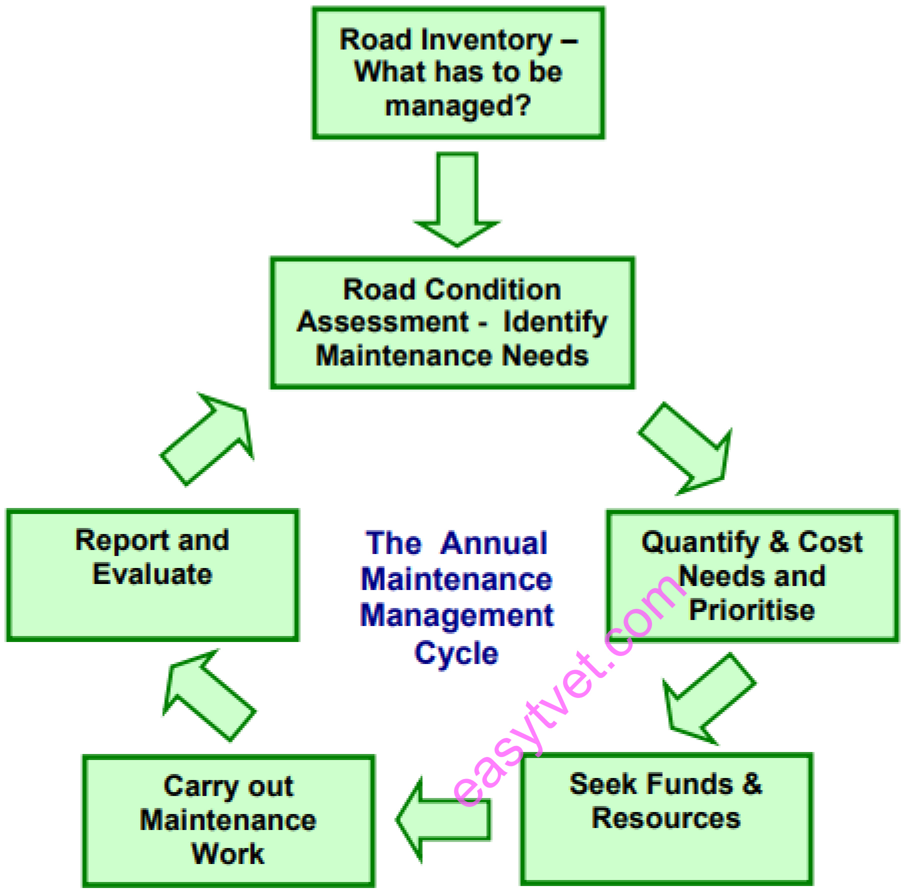


Figure 147: Road maintenance activities

Source: Rural Road Maintenance Handbook / Ministry of Transport, 2003

1. Budget estimate: this is done based on the budget or recent routine maintenance done on the road. This provide useful information in the discussion of the funds required and can also be used pending the final budgeting.
2. Road mapping: this is done by the application of GPS technology
3. Road inventory: this include all the information about the road and can always be found at road departments of each government. The inventory does not need regular updates but is essential to be updated when a major change has been done to the road design.
4. Inspection and assessment of the road: this can be done by an observer in a vehicle moving along the road. He notes and indicates which sections needs maintenance and also recommends the kind of maintenance required.
5. Preparation of the community maintenance agreement: this is the document that outlines the responsibilities of the community as well as the government or local

government in the routine maintenance of the road. The document should contain the names of signatories, responsibilities under agreement, amount of work, issuing and returning hand tools, timing and condition of payment, starting and expected finish date and how to deal with any disagreement.

6. Selection of the maintenance team: this team should comprise members above 18 years old, live in the locality, literate and with relevant experience.
7. Inspection of work; this is done to assess the quality of work. Once the work done is satisfactory, interim payments are made. The inspection process continues until the completion of work and would also involve the solution to emerging disputes.
8. Returning of tools: the team ensures that all the tools issued out are returned in the perfect shape and any damage beyond reasonable expectation from the kind of work deducted from the pay.
9. Awareness creation: the last step would be to sensitive the locality on the importance of proper road maintenance.

7.3 Carry out Emergency maintenance works

Emergency maintenance works are carried out to restore a road following damage due to accidents or natural disaster. Some of the activities would include;

- Minor repairs of bridges awaiting final restoration following the damage. This would include stiffening with steel, reinforced concrete or timber.
- Replacement or repair of failed or washed away culverts
- Removal of earth material or any debris on the road
- Creation of short-term diversions in the aftermath of an event pending repair of the road.

It is important to have a rapid response structure to deal with emergencies that could interfere with traffic flow or endanger users' lives. Reserve funds should be allocated yearly in order to deal with emergency situations. All emergency maintenance should focus on reinstating the road to its original sate or to temporarily enable the road serve awaiting further repair.

7.4 Perform routine maintenance activities

The process of routine maintenance would be carried out on various items as follows;

i. **Vegetation;** vegetation should be cut if they are affecting the vision of the road user or interfering with the drainage in the shoulder. Also, in the case where the shoulder is getting eroded, grass should be planted. Any cut vegetation should be disposed of safely in order not to affect the functionality of the road.
ii. **Drainage;** ensure that silt and debris are removed from the drain before the rainy seasons and after storms to avoid blocking of the drains. Construct new drainage or side turnout drains with adequate lining to avoid water ponds on the sides of the road. Repair eroded ditches and drains.

iii. **Earth works:** Trim and will the embankment with the same material to the appropriate slope. After which vegetation should be planted. Trees may also be planted in order to stabilize the slope. Constant watering should be done to ensure the growth of the vegetation. Fill erodes slopes by first cutting the gully into a workable shape then compacting the material. Drive piles at the bottom of eroded embankment to avoid slope failure. Remove any small landslide material on the road.
iv. **Shoulder;** the shoulders should be reshaped with the correct slopes to ensure that they drain water away from the road.
v. **Cleaning;** any debris or loose material should be removed and safely disposed away from the pavement in order to avoid being washed back. Keep bridges and decks clean always. Remove any kind of obstruction in the channels.
vi. **Dust control:** sprinkle water on dusty roads to avoid vision obstructions on the road that might lead to accidents.
vii. **Road sign;** regular cleaning of road signs and removal of any form of obstruction to the road sign is necessary.
viii. **Road surface;** in case of pothole, the surface should be cut in vertical sides and filled with the same material about 1cm above the nearby surfaces. In the case of a wet surface as in rural roads, the road section should be built up with material of appropriate moisture content. Periodic reshaping and cambering of the road is also appropriate.
ix. **Structures;** loose bolts, damaged rivets, rusted trusses and damaged welding joints for a bridge should be repaired. Other defects on culverts, retaining walls and causeways should be assessed and remedied as well.

7.5 Carry out periodic maintenance works

The process of periodic maintenance would be carried out on various items as follows;

Re-graveling; this involves relaying of the road foundation. This is done following a structural evaluation of the road segment. Graveling can also be done on the pavement to improve the safety of the road by providing more friction

Resealing/surface dressing; this is done to seal the distresses on the surface by applying the necessary sealant so as to protect the subgrade from damage and thus prolong the structural life of the road.

Maintenance of traffic signs and road markings. This is done to ensure the safety of all road users. Traffic signs are very important in providing information to the road user and together with appropriate road markings ensure efficient use of the road.

Conclusion

This learning outcome covered highway maintenance.

Further Reading

Read further on road assessment techniques as described in “Oversees Road Note 1. Road management for district engineers”.

13.3.8.3 Self-Assessment

Written Assessment

1. Which of the following is not an activity conducted in routine maintenance?
    a) Rehabilitation of embankments
    b) Marking of road
    c) Digging of ditches
    d) Erecting road signs
2. When should payments be made in a road maintenance project?
    a) At the signing of contract
    b) After return of tools
    c) After inspection of work
    d) After auditing the work
3. Which of the following is assessed in before road maintenance?
    a) Bleeding
    b) Creep
    c) Buckling
    d) Rutting
4. Which one of the following is not an activity in surface dressing?
    a) Pre-patching
    b) Cleaning any loose material
    c) Applying bituminous binder
    d) Applying chippings
5. Which one of the following is not a cause of alligator cracking on paved roads?
    a) Inadequate pavement thickness
    b) Low modulus base
    c) Brittle base or wearing course
    d) High traffic volume

6. Explain three benefits of road maintenance
7. Explain three reasons for carrying out road maintenance.
8. Outline the requirements of an individual to form a maintenance team.
9. Differentiate between routine maintenance, periodic maintenance and emergency maintenance
10. Summarise the preparation process of maintenance activities.
11. Summarise various activities in routine road maintenance.

Oral Assessment

1. Why do we need an inventory for a road in performing a road maintenance?
2. Which in your opinion would be the most expensive phase of road maintenance?

Case Study Assessment

https://openjicareport.jica.go.jp/pdf/11721644_09.pdf consider the following case study of a proposal for a road assessment.

Oral Assessment

1. Why did you choose your recommended maintenance methods?
2. How much do you think your proposal would cost?

Practical Assessment

Visit a local rod near you and perform an assessment on the road. Recommend various routine maintenance that should be carried out on the road.

13.3.8.4 Tools, Equipment, Supplies and Materials

- Computer
- Internet
- Workshop
- Construction materials
- Construction tools and equipment
- Construction designs and drawings
- Sample contract documents
- Computer software e.g. AutoCAD, ArchiCAD, Civil3D
- Stationery
- Road construction site
- Material testing labouratory
    - Moulds
    - Tamping rods
    - CBR Machines
    - Crushing machines

- Schedule of work
- Standard manuals
- Road under construction
- Contract documents

13.3.8.5 References

(ASTM, the American Society for Testing and Materials 2007).Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. ASTM D6433-07 http://www.astm.org/Standards/D6433.htm, last accessed on June 23, 2020.

Broten, P.E., and Sombre, D.E. (2001).The Airfield Pavement Condition Index (PCI) Evaluation Procedure: Advantages, Common Misapplications, and Potential Pitfalls. Proceedings of the 5th International Conference on Managing Pavements, August, Seattle Washington, United States.

CHAPTER 14: ENGINEERING STRUCTURES DESIGN

14.1 Introduction of the Unit of Learning

This unit specifies the competencies required to design engineering structures. This involves load estimation, designing structural elements, assessing of cost effectiveness of designs, analysing site test data and modifying structural designs.

14.2 Performance Standard

Calculate load estimates, design structural elements, assess cost effectiveness of the design, and modify structural designs client's needs, design standards and structural use, and code procedures.

14.3 Learning Outcomes

14.3.1 List of Learning Outcomes

a) Calculate load estimates
b) Design structural elements
c) Assess cost effectiveness of the design
d) Modify structural designs

14.3.2 Learning Outcome No 1: Calculate Load Estimates

14.3.2.1 Learning Activities

Learning Outcome No 1: Calculate Load Estimates	
Learning Activities	**Special Instructions**
1.1 Determine intended use of a structure 1.2 Create the layout of the structure from the architectural drawings 1.3 Determine the codes of practice/manuals required to obtain the required loading 1.4 Carry out load analysis/estimation	• Demonstration by trainer • Practical work by trainee • Demonstration videos • Projects • Group discussions

14.3.2.2 Information Sheet No14/LO1: Calculate Load Estimates

Introduction to learning outcome

This learning outcome deals with the determination of the intended use of a structure as per clients need, creation of layouts from architectural drawings, load analysis and estimation and gaining knowledge of codes of practice and manuals.

Definition of key terms

Codes of practice – refers to a set of rules in the form of a written document which explains and guides how people in a certain profession should behave or act in their professional practice.

Layout – refers to a drawing or a plan that shows how a structure will be build.

Intended use – refers to the purpose for which a structure is built for.

Content/Procedures/Methods/Illustrations

1.1 Determine intended use of a structure as per client needs

The intended use of a structure can be determined based on the purpose for which the larger part (space of the building) of the total floor area of the building is used. The intended use of a structure can be but not limited to the following

- Residential – used for peoples dwelling
- Commercial – used for business purposes
- Industrial – used for various purposes such as processing etc.
- Educational – used for learning purposes
- Agricultural – used for agricultural purposes such as storage facilities

In order to carry the intended use of a structure, BS6399-1:1996 gives various categories of occupancies and usage of structures. This categorizes helps know the types and magnitude of loads experienced by each occupancy. These include;

- Domestic and residential areas
- Office and work areas
- Shopping areas
- Areas that are susceptible to accumulation of goods
- Areas where people congregate
- Traffic and vehicle areas

1.2 Create the layout of the structure from the architectural drawings as per design standards and structural use

Creation of a building layout helps mark out positions of columns, walls, boundaries or any other structural element of a building. An understanding of the type of dimensions present in the drawing is necessary in order to create a layout. The layout gives other engineers the type of structural elements presents in the building. The general rules or procedures of preparing a structural layout are as follows;

a) Adhere to the architect's original plan – architectural drawings supersede structural layouts. Make your arrangement to coincide with the architect's work.
b) Choose a stable arrangement – the layout should represent the structural behavior of the structure. Ensue stability and equilibrium.
c) Build ability – the arrangement you select should be buildable. The consideration of the technical capacity of the contactors is necessary.
d) Balance between economic and structural aspects – consider a choice that is more economical for instance the use of more concrete or steel.
e) Produce the layout on a CAD software.

Once the layout is created, the setting out of the structure can be carried out to establish the building physically on the ground. An example of a layout from an architectural drawing is shown below.

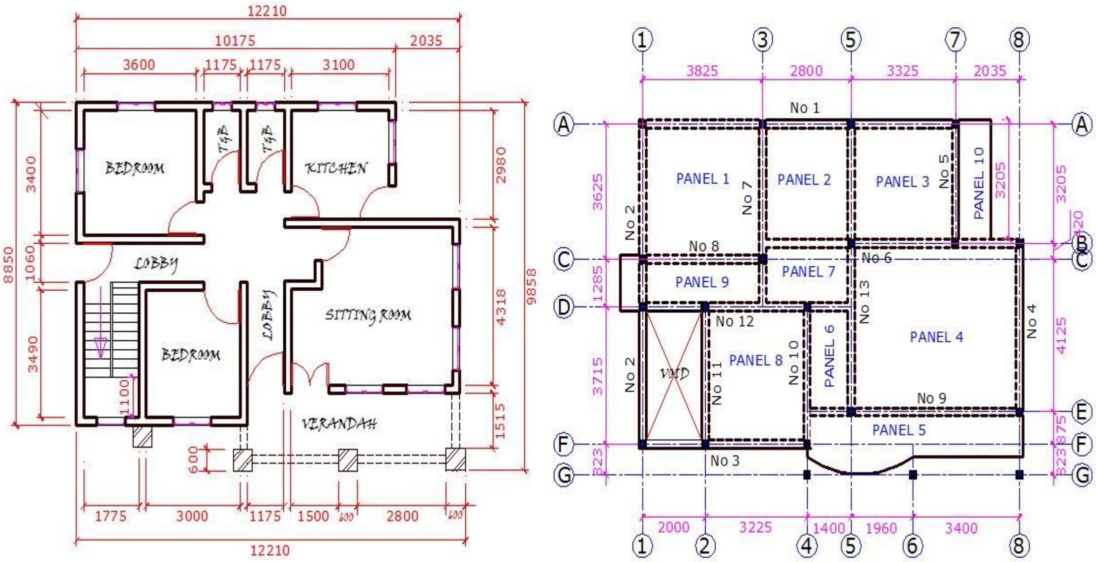


Figure 148: Floor plan and corresponding structural layout
Source: Structville.com

1.3 Determine the Codes of practice/manuals required to obtain the required loading are based on structural use.

A code of practice to be used can be determined on various aspects;

- Type of construction material – e.g. the code for steel is different from that of timber
- Type of structure – e.g. the code for buildings is different from the code of practice for roads
- Type of loads experienced – e.g. the code for wind loads is different from the code of practice for
- Region – the environmental factors also influence the choice of the code of practice. Additionally, various regions have different codes of practice.

Some of the commonly used codes of practice are;

- BS6399 –Part 1:1996 – for loads on various structures depending on the occupancy
- BS8110 – Part 1:1997 –for the design and construction of reinforced concrete structures
- BS5950 –Part 1:2000 – for the design of rolled and welded steel sections in building construction.
- Eurocodes- these are currently being developed to replace the BS codes.

1.4 Carry out load analysis/estimation as per code procedures

Load estimation is based on the structural elements such as beams, columns, slabs and other elements which are not necessarily structural such as partitions, furniture and finishes. Load estimation also starts with a knowledge of the various types of loads that the structure may experience. The following are categories of loads which can be experienced by a structure.

- Dead loads – these are the permanent elements in the structure. They include the roof, floor, walls,
- Imposed or live loads – these are the temporary elements or components in the structure. They include; furniture, people etc.
- Wind loads
- Earthquake loads
- Snow loads

Dead loads are obtained by multiplying the unit weight of the material used with the volume of the element. Imposed load values are read from BS6399-1:1996 and they depend on the type of occupancy or usage of the structure. Loads analysis can be carried out as follows;

a) Determine the type of structural elements present in the structure – these include beams, columns, slabs etc.
b) Calculate the dead loads (G_k)
c) Calculate the imposed loads (Q_k)
d) Multiply the loads with the safety factors to get the design loads
e) Determine the ultimate design load (W) from the combinations of dead and imposed loads. $W = 1.4G_k + 1.6Q_k$
f) Calculate shear, moment and deflection.

Example of Column load calculation

Unit weight of concrete = 24kN/m3

Volume of column = Length (l) x Width (w) x Height (h) x No. of columns

Weight of columns = unit weight x volume

Example of load calculation of a slab

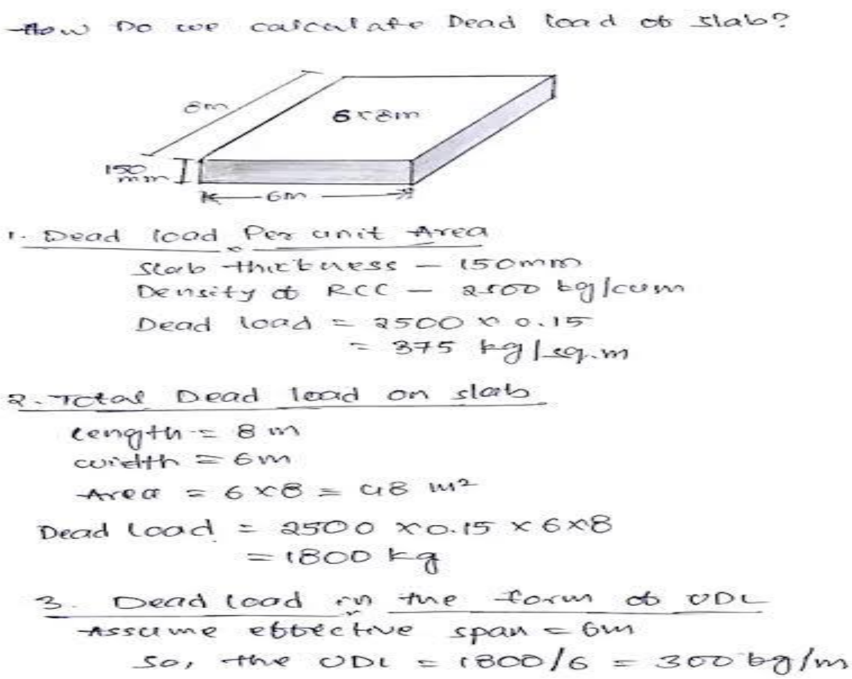


Figure 149: Example of load calculation of a slab
Source: Quora.com

Conclusion

This learning outcome covered codes of practice, creation of different layouts from architectural drawings and load analysis and calculations as per the codes of practice.

Further Reading

Read more on the following;

1. Design loads acting on structural elements
2. Types of structural loads - buildings and other structures(Wind loads, earthquake loads and snow loads)
3. Methods of structural load analysis

14.3.2.3 Self-Assessment

Written Assessment

1. The following are various types of structural layouts except one;
    a) Foundation layout
    b) Beam layout
    c) Floor plan
    d) Column layout
2. Dead load usually comprises of the following, which one?
    a) Temporarily attached loads
    b) Permanently attached loads
    c) Permanent and temporary attached loads
    d) Wind and snow loads
3. Structural loads are of various categories, select the odd one out.
    a) Dead load
    b) Rain load
    c) Live load
    d) Wind load
4. Explain the following different types of loads; dead loads, Imposed loads
5. Evaluate at least four structural elements in a building.
6. Apart from dead and imposed loads, define other types of loads which may be experienced in a building.
7. A code of practice guides the way work should be done. Why were codes of practice developed?
8. According to BS6399-1; 1996 building loads are determined with the type of usage for the building. List the various categories of occupancy listed.

Essay question

Describe the procedure of producing a building structural layout using illustrations.

Oral Assessment

Explain the various existing codes of practice and the applicability in load estimation
What would happen to the loads in a structure in the case the usage of the structure is changed from the original intended use.

Practical Assessment

Visit a nearby construction project site and identify the following structural elements, columns, beams, foundation, and slab. Sketch the layout on a piece of paper and carry out structural load analysis of the various elements.

14.3.2.4 Tools, Equipment, Supplies and Materials

Tools and equipment

- Computers
- Printers
- Measurement tools
- Survey instruments

Materials

- CAD software
- Stationery
- Workstations
- Civil Engineering labouratories
- Legal documents (Engineers Act)
- Civil Engineers Code of Practice

14.3.2.5 References

Allen, A. (2002). Reinforced Concrete Design to BS8110 simply explained. CRC Press.
Chudley, R., & Greeno, R. (2013). Building Construction handbook. Routledge
Hibbeler, R.C., & Kiang, T. (2015). Structural Analysis. Upper Saddle River: Pearson Prentice Hall

14.3.3 Learning Outcome No 2: Design Structural Elements

14.3.3.1 Learning Activities

Learning Outcome No 2: Design Structural Elements	
Learning Activities	**Special Instructions**
2.1 Select design methods 2.2 Determine design software 2.3 Design structural elements	• Demonstration by trainer • Practical work by trainee • Demonstration videos • Projects • Group discussions

14.3.3.2 Information Sheet No14/LO2: Design Structural Elements

Introduction to learning outcome

This learning outcome deals with design methods which are cost effective and design softwares such as AutoCAD Structural Design Software, Prokon, and Revit. The design of various structural elements is also dealt with in this outcome.

Definition of key terms

Design methods- procedures of designing which provide different kinds of activities that someone designing is able to apply during the process of design.

Design software- computer based operating information and programs that aid in the drawing or plan developed to demonstrate the working of a building.

Structural elements- load bearing components of a structure.

Content/Procedures/Methods/Illustrations

2.1 Select design methods based on cost effectiveness and client needs as per code standards

Cost effective design methods are those structural design procedures that require very low cost or no cost at all, while client needs are the specifications of the clients that must be met by the design method while code standards are set specifications preset by structural design organization for uniformity in the field. The coast effective design methods include;

a) Utilization of cost and value engineering

Most of the time projects are not given excess money but money just enough, therefore, all expenses have to fall below budget. Utilizing cost is the management of all these costs. Value engineering is the controlling of the expenses involved so that every one of them falls within the budget

b) Economy analysis for alternative designs

For many industries if not all take this into serious account. Things like operation, maintenance, replacements and investments are looked into prior to the building's design. With time the cost of these things change hence future projections are very important. Understand how the buildings future investments will be rated.

c) Considering priceless gains such as aesthetics, sustainability etc.

Not everything can be bought or charged at a price. Some building features such as formality are not an exception. The main reason of a life cycle assessment is to determine costs and benefits of design other options for better decision-making. Something like cost is easily measurable compared to gain since it has a price on it. Gains have no price attached to them. In some cases, priceless cases are able to come ahead of quantity available cost comparisons.

d) Full analysis and design software;

- Effective and fast design method.
- Each of the members is designed and modeled in one workflow
- Materials, members, forces and section properties can all be accessed automatically from the software model.
- Standards can be preset for reference.

2.2 Determine design software as per organizational standards.

Software as per organization standards are software that meet the specification of procedures or methods of structural design. The organization standards include;

- Accuracy
- Appearance
- Scalability
- Flexibility

The design software that meet these standards include;

1. **AutoCAD structural software-**

A product of Autodesk. Its major application is creation of different dimensional designs, drafting of layouts, modeling workflows etc. It enables you to; evaluate and digest the project performance, responds quickly to changes and maintains data and processes consistently. Some of its advantages include;

- Appearance - drawings are clear, simple to use when reduced (minimized) and predictable.
- Scalability- AutoCAD drawing sheet is enormous thus eliminating scaling error possibilities and also allows the drawing to be printed at any scale.
- Flexibility - work can be shared and distributed electronically

2. **Autodesk Revit structural software**

A product of Autodesk used for modelling and enables design of structures, buildings and components in 3D also allows access to building information from building model data base. Some of its advantages are that it allows modifications on different structures hence flexibility and scalable.

3. **Prokon**
    - Software that allows structural design of elements.
    - Easier and faster input and comprehensive integration.
    - Easier access to detailed analysis output.

4. **SAP2000-** Civil engineering software good for design and analysis of any type of structural system. Looks forward to bring together distinct modules in a company

5. **RISA**-Develops creative structural design and analysis tools to solve most of recent engineering problem.

Some of its advantages include;

- It is fast
- It is productive
- It is accurate
- Has a user-friendly interface that interacts with other products such as RISA foundation.
- It comes embedded with the most recent design codes for steel design, cold-formed steel, concrete design, aluminium, masonry and timber
- Provides needed tools in case of multi material structure

6. STAAD Pro- does structural analysis design and modelling, also provides a user-friendly interface easy to navigate.

- Easy to use interface

7. Naviswork

A product of Autodesk. This is a comprehensive project review solution. Navisworks is used by design, engineering and construction management professionals. Its use is to obtain detailed insight into the project and enhance productivity and quality.

Some of its advantages include;

- Allows the users to open, combine, review and share detailed design models in various file formats.
- Easy to Import all file formats and merge all the files to create a model

2.3 Design structural elements as per design standards

The procedure of design

i. Determination of loads acting on the structure

ii. Determination of loads acting on individual elements

iii. Determination of bending moments, shear forces and deflections

i. Beam sizing

ii. Column sizing

Structural elements are load bearing parts of a structure and include;

- Columns Slabs
- Wall beams
- Trusses cables
- Frames

In concrete, steel, timber and masonry.

Factors to understand during structural elements analysis

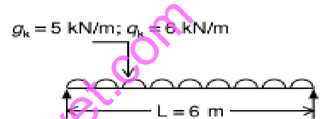
a) Free body diagrams – these are to understand the load path and checking your assessment. Free body diagrams are load and moment diagrams drawn which show the applied loads and moments at an equilibrium with corresponding reaction loads and moments and shear forces.
b) Buckling –this is majorly in columns
c) 3D rigid body analysis - Sometimes this method is used in determination of loads on joints, a classical hand calculation in structural analysis.

Example: design of a beam singly and doubly reinforced rectangular

A simply supported beam for an office building has a span of 6 m. Calculate the values of the design bending moments, M_{Ed}, assuming

(a) the beam supports uniformly distributed permanent and variable actions of 5 kNm^{-1} and 6 kNm^{-1} respectively
(b) in addition to the actions described in (a) the beam also supports an independent variable concentrated load of 20 kN at mid-span.

LOAD CASE A



Since the beam is subjected to only one variable action use equation 8.6 to determine E_d where

$$E_d = \sum_{j\geq 1} \gamma_{G,j} G_{k,j} \text{ "+" } \gamma_{Q,1} Q_{k,1}$$

$$\Rightarrow F_{E,d} = 1.35 \times (5 \times 6) + 1.5 \times (6 \times 6) = 94.5 \text{ kN}$$

Hence, $M_{E,d} = \dfrac{F_{E,d}L}{8} = \dfrac{94.5 \times 6}{8} = 70.9$ kNm

An alternative estimate of $M_{E,d}$ can be obtained using equations 8.8 and 8.9, respectively

$$E_d = \sum_{j\geq 1} \gamma_{G,j} G_{k,j} \text{ "+" } \gamma_{Q,1} \psi_{Q,1} Q_{k,1} \text{ "+" } \sum_{i>1} \gamma_{Q,i} \psi_{Q,i} Q_{k,i}$$

$$\Rightarrow F_{E,d} = 1.35 \times (5 \times 6) + 1.5 \times 0.7 \times (6 \times 6) + 0 = 78.3 \text{ kN}$$

$$E_d = \sum_{j\geq 1} \xi_j \gamma_{G,j} G_{k,j} \text{ "+" } \gamma_{Q,1} Q_{k,1} \text{ "+" } \sum_{i>1} \gamma_{Q,i} \psi_{Q,i} Q_{k,i}$$

$$\Rightarrow F_{E,d} = 0.925 \times 1.35 \times (5 \times 6) + 1.5 \times (6 \times 6) + 0 = 91.5 \text{ kN (critical)}$$

Hence $F_{E,d}$ is 91.5 kN and $M_{E,d} = \dfrac{F_{E,d}L}{8} = \dfrac{91.5 \times 6}{8} = 68.6$ kNm.

Figure 150: Design of a beam singly and doubly reinforced rectangular
Source: Design of structural Elements by Chanakya Arya

Conclusion

This learning outcome covered design methods, design softwares and structural elements.

14.3.3.2 Further Reading

Read on:

1. Design of Structural Elements
2. Stress analysis https://www.stressebook.com/classical-hand-calculations-in-structural-analysis/
3. Whole Building Design Guide https://www.wbdg.org/design-objectives/cost-effective

14.3.3.3 Self-Assessment

Written Assessment

1. Of the following which one is not a structural design element?
    a) Train
    b) Truss
    c) Arch
    d) Cables
2. From below which structural design software has the highest rating
    a) AutoCAD
    b) Prokon
    c) Revit
    d) Miniso
3. Select a design method which is not cost effective
    a) Free Software
    b) Spreadsheets
    c) Hand calculation
    d) Charged software
4. Define the term structural design
5. Explain scalability of a design software
6. Give two advantages of Prokon design software

Essay questions

AutoCAD adheres to organization standards, elabourate.

Oral Assessment

Why would you choose Revit if you are given a structural design project?

Case Study Assessment

Kenyatta University intends to expand the school of engineering building another workshop. The civil engineering in charge has selected you as his assistant and has given you a sketch of the building and told you to present it to the board during the launch of construction to all board members. Select the most appropriate software to use to present the design and give reasons why and also design the elements of construction for the steel frame.

Oral Assessment

Why would you need to analyse different design methods before choosing the one to use?

Practical Assessment

Using AutoCAD design a three-floor building with a 300 people carrying capacity

14.3.3.4 Tools, Equipment, Supplies and Materials

Tools and equipment

- Computers
- Printers
- Measurement tools
- Survey instruments

Materials

- CAD software
- Stationery
- Workstations
- Civil Engineering labouratories
- Legal documents (Engineers Act)
- Civil Engineers Code of Practice

14.3.3.5 References

Arya, C. (2009). Design of structural elements: concrete, steelwork, masonry and timber designs to British standards and Eurocodes. CRC Press.

Lurie, K. A., & Cherkaev, A. V. (2018). “Effective Characteristics of Composite Materials and the Optimal Design of Structural Elements. In Topics in the mathematical modelling of composite materials (pp. 175-271). Birkhäuser, Cham.

Mazars, J., Kotronis, P., Ragueneau, F., & Casaux, G. (2006). Using multifiber beams to account for shear and torsion: Applications to concrete structural elements. Computer Methods in Applied Mechanics and Engineering, 195(52), 7264-7281.

14.3.4 Learning Outcome No 3: Assess Cost Effectiveness of the Design

14.3.4.1 Learning Activities

Learning Outcome No 3: Assess Cost Effectiveness of the Design	
Learning Activities	**Special Instructions**
3.1Determine alternative cost saving design methods and materials 3.2 Review preliminary designs to determine elements that can be reduced or replaced	• Demonstration by trainer • Practical work by trainee • Demonstration videos • Projects • Group discussions

14.3.4.2 Information Sheet No14/LO3: Assess Cost Effectiveness of the Design

Introduction to learning outcome

This learning outcome deals with cost saving design methods and optimization of the design cost by either replacement or reduction of some elements.

Definition of key terms

Cost effective design: this is a plan that is affordable and efficient.

Content/Procedures/Methods/Illustrations

3.1 Determine alternative cost saving design methods and materials based on site conditions

Cost effective design methods are those structural design procedures that require very low cost or no cost at all likewise to the materials in this case we look at those based on site condition which are mostly harsh weather conditions like rainy or sunny. They include;

a) The process of design;

The advice you seek from consultancy firms play an important role in the reduced cost of your building. Websites provide affordable designs for buildings. It will enable you to obtain a proper design within what you can afford within limited time.

b) Application of technology;

The latest technologies like the use of renewable energy which are maximumly affordable and keep buildings cost effective. They don't make your building dismal but purpose is more important and you don't have to go bankrupt.

c) Location selection

Where you choose to build your building will determine the cost you incur in designing the building. A higher percentage of this is true among commercial buildings. For example, the right selection of a commercial property location influences the final outcome positively as this makes it easy to estimate the traffic load in order to correctly arrange the layout of the property. Therefore it is possible to start the process of designing a cost-effective building design before the actual blueprints have been initialized.

d) Orientation of the building

Orientation of building is in terms of the position of sunlight at various times of the day. Buildings are designed around the movement of the sun over an area. Most of the activities are planned in sections where the intensity of the sun is not high.The same way, sections that have limited interactions are designed to be in areas where the sun is intensified. This orientation helps create buffer zones between the sections thus keeping spaces with more activity cooler in a passive way.

e) Plan Layout

When properly done can really sell out. A proper layout helps obtain affordable building specifications. For example; if the west side of your structure will be subject to high sunlight throughout the day, it will be unthoughtful of you to put the kitchen on this side otherwise you will need engineered cooling methods, that will rather be expressive. Therefore, placing on the eastern part will be more logical

f) Wall Cladding

The physical appearance of a building is enhanced with the walls of the structure. How long the structure will last will be determined by the durability of the materials that make up the walls. In this manner a low temperature is maintained in the room by insulating walls. Proper wall cladding will enable a big difference in maintaining the running cost of your establishment to the minimum. For cost-effective building design, wall cladding play a very important method.

g) Roof Materials

Just like the wall, the roof details are very vital when it comes to creating a cost-effective building design. How long the structure will last will be determined by the durability of the materials that make up the roofing materials as well.

h) Interior design and interior furniture

Interior design can entail small details that can make the design quite expensive. Some simple interior design rules can help make a cost-effective building design.

i) Sourcing Materials

Understanding where to get the best, low cost materials will sky rocket you career in building and construction. Beware of high-end places that give poor quality materials at very high prices. Carry out research concerning all the places where you can get materials before decide on one final choice

j) MEP & HVAC

The selection of MEP (Mechanical, Electrical and Plumbing) and HVAC (Heating, Ventilation and Air Conditioning) is crucial in determination of the overall cost of the design process. However, high quality systems can make a building costs much lower as compared to low quality systems. The following should be considered in the selection of such systems.

- System should have an efficiency of more than 90%
- Ensure no energy is wasted by choosing the right size
- Adaptability of the system to future extensions, choose a system that is adaptable

3.2 Review preliminary designs to determine elements that can be reduced or replaced as per design standards

This is referred to as design optimization technique which simply means using available resources to obtain maximum benefit. Factors to be considered while doing optimization include;

- Model of structure
- Dimensionality of structure
- Choice of design variable.

Problems encountered also include;

- Sizing optimization-boundary and connectivity
- Shape optimization - area
- Topology optimization.

The main components of optimization include;

- Design parameters- specify the geometry and topology of the structure and also the physical parameter of the structural elements like area etc.
- Constraints which includes stress, buckling, deflection etc
- Object functions which merit the structure; if the fiction is something like weight of the structure then it is to be minimized, if its energy or thermal requirement then it is to be maximized if both then it will need balance. This equation is solved mathematically.

Conclusion

This learning outcome covered cost saving design methods.

Further Reading

Read on:

1. Cost saving design methods
2. Structure and design https://comelite-arch.com/blog/cost-effective-building-design-solutions/

14.3.4.3 Self-Assessment

Written Assessment

1. From below, choose the odd on out
    a) Topology optimization
    b) Constraints
    c) Design parameters
    d) Object function

2. The following are factors which influence design optimization except one, which one?
    a) Design variable choice
    b) Structure type
    c) Dimensionality of structure
    d) Shape
3. The following are design constraints except which one
    a) Deflection
    b) Weight
    c) Buckling
    d) Stress
4. Evaluate alternative cost saving design methods and materials based on site conditions.
5. Summarize the problems encountered during design optimization.
6. Summarize the factors that contribute to design optimization.

Essay questions

Design optimization is a complicated process. Elabourated.

Oral Assessment

Why do you think design optimization is important in structural design?

Case Study Assessment

A proposed structural design was found to be very expensive compared to the normal average design of such a building during engineers review meeting. If you are awarded with the duty to optimize the design. Outline the factors you will consider and the modules you will maximize or minimize during the process.

Oral Assessment

Of the fundamental modules of design optimization, explain what design parameters represent

Practical Assessment

Your class is to visit a nearby construction sites and recognize the cost saving design methods and materials based on site conditions present in the site.

14.3.4.4 Tools, Equipment, Supplies and Materials

Tools and equipment

- Computers
- Printers
- Measurement tools
- Survey instruments

Materials

- CAD software
- Stationery
- Workstations
- Civil Engineering labouratories
- Legal documents (Engineers Act)
- Civil Engineers Code of Practice

14.3.4.5 References

Thanedar, P. B., & Vanderplaats, G. N. (2005). Survey of discrete variable optimization for structural design. Journal of Structural Engineering, 121(2), 301-306.

Koski, J. (2000). Multicriterion optimization in structural design. TAMPERE UNIV OF TECHNOLOGY (FINLAND).

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14.3.5 Learning Outcome No 4: Modify Structural Designs

14.3.5.1 Learning Activities

Learning Outcome No 4: Modify Structural Designs	
Learning Activities	**Special Instructions**
4.1 Modify preliminary designs to suite site conditions 4.2 Retest preliminary hypotheses for practicality to site conditions 4.3 Establish new hypotheses to support new designs and reflect site conditions	• Demonstration by trainer • Practical work by trainee • Demonstration videos • Projects • Group discussions

14.3.5.2 Information Sheet No14/LO4: Modify Structural Designs

Introduction to learning outcome

This learning outcome deals with modification of preliminary designs to suite site conditions, retesting of hypotheses for practicability to site conditions with the establishments of new hypotheses to support new designs.

Definition of key terms

Preliminary design: Gerson Sunyé - University of Nantes Definition of Preliminary Design is the first step of software design. During this phase, a high-level design concept that meets the requirement specification is created. The concept is expressed as a set of components with clear interfaces. The preliminary design fills up the void between conception of the design and the detailed design.

Content/Procedures/Methods/Illustrations

4.1 Modify preliminary designs to suite site conditions as per code of practice standards.

The Preliminary design stage is the most low-cost and applicable stage to make design changes such as modifying design variables. These changes therefore should conform to the code of practice standards and suite the site conditions provided. Modification of these preliminary designs may be influenced by either internal or external factors of the project at hand.

Some of the internal factors influencing such changes include:

Factors from the client:

- Client's wish to modify or change the design.
- Additional work.
- Omission of work.
- Financial difficulties from the client.
- Errors due to incorrect information.

Factors from the design consultant:

- Insufficient information in the drawings.
- Alterations made as per the consultant's request.
- Presence of conflicts that may arise due to the contract.
- Illogical period of project completion.
- Significant variations in the structural and architectural plans.

Factors from the managing consultant:

- Miscommunications between members I the project.
- Lack of accurate resolutions.
- Lack rapid formulation and execution of resolutions.
- Improper checking of planning documentation.

Factors from the contractor:

- Illogical construction schedule from the contractor.
- Correction of construction and structural mistakes.
- Alterations made as per the contractor's request.
- Inadequate project management by the contractor.
- Quality improvement change by the contractor.

Some of the external factors influencing such changes include:

Factors due to the environment:

- Unexpected conditions in the ground.
- Lack of enough data about the geological composition of the site.
- Natural occurrences disasters.
- Unpredicted weather changes.

Economic and political factors:

- Lack of enough tools and materials.
- Changes in material pricing due to fluctuation.
- Changes in the original use of the project.
- A change in policy.

Factors due to third party:

- Alterations made as per the end user request.
- Grievance from the vicinity.
- Alterations made as per the regulation bodies request.
- Alterations made as per the new investor's request.

4.2 Retest preliminary hypotheses for practicality to site conditions as per design standards.

Retesting of the preliminary hypotheses is quite critical in the design process for many various reasons and therefore the hypothesis should be practical to the site conditions and as per the design standards.

Some of the importance of testing include:

- It enables one to determine whether the hypotheses being tested are true.
- It enables to determine whether the proposed solution will achieve the goals targeted.
- It enables the enhancement of the design process.
- To determine whether the hypothesis will guarantee an improvement for further progress.

During the process of retesting of hypotheses, some of the steps involved will include:

- Stating of the hypotheses including both null hypothesis and alternative hypothesis.
- Formulation of the analysis plan that will include both the test method and the significance levels.
- Analyzing of the sample data.
- Interpreting of the results to draw conclusion.

4.3 Establish new hypotheses to support new designs and reflect site conditions as per the required conditions.

In order to establish a new hypothesis one can follow the steps below:

- Coming up with a question that is specific and is within the constraints of the project.
- Conduct preliminary research that will lead to a conceptual framework.
- Formulate and refine the hypothesis according the relevant variables of the project and the predicted outcome.
- Phrase the hypothesis in three ways.
- Write a null hypothesis

Conclusion

This learning outcome covered the modification of preliminary designs to suite site conditions and the application of hypothesis to test the practicability of the site conditions.

Further Reading

Refer to Admin, How to Write a Hypnosis, https://www.scribbr.com/research-process/hypotheses/, last accessed 24th June 2020. For further reading on how to write a hypothesis.

14.3.5.3 Self-Assessment

Written Assessment

1. In which stage of a project is the modification of structural designs relevant.
    a) Project conception
    b) Construction stage
    c) Detailed design stage
    d) Preliminary design stage
2. Explain the preliminary design stage in the most low-cost and relevant stage in the modification of structural designs.
3. Modification of preliminary designs to suite site conditions should conform to?
    a) An educated guess
    b) Code of practice standards
    c) Profits of the project
    d) Personal interest only
4. Explain the term hypothesis?
5. Explain the term preliminary design?
6. Explain the different components found in a preliminary design.
7. Summarize on the importance of retesting of a preliminary hypothesis.
8. Summarize on the steps taken to test a hypothesis.

Oral Assessment

Outline the need to modify structural designs.

Practical Assessment

Given the project of the construction of a single storage room, with initial site conditions and preliminary design of your choice. Modify the preliminary design given that the site conditions change due to a 50% reduction in the available land for the construction of the project.

14.3.5.4 Tools, Equipment, Supplies and Materials

Tools and equipment

- Computers
- Printers
- Measurement tools
- Survey instruments

Materials

- CAD software
- Stationery
- Workstations
- Civil Engineering labouratories
- Legal documents (Engineers Act)
- Civil Engineers Code of Practice

14.3.5.5 References

Admin, How to Write a Hypnosis, https://www.scribbr.com/research-process/hypotheses/last accessed 24th June 2020.

Bang, Anne & Krogh, Peter & Ludvigsen, Martin & Markussen, Thomas. (2012). The Role of Hypothesis in Constructive Design Research.

Admin, How to Test Hypotheses, https://stattrek.com/hypothesis-test/how-to-test-hypothesis.aspx, last accessed 24th June 2020.

CHAPTER 15: BUILDING DRAWINGS

15.1 Introduction of the Unit of Learning

In this unit, the aspects of building design that involve preparation and interpratation of engineering drawings, including architectural drawings, structural and civil drawings,plumbing layouts, as well as electrical and mechanical, will be addressed based on principles of engineering design.

15.2 Performance Standard

Interpret architectural drawings, prepare structural and civil drawings, interpret electrical drawings, design plumbing layout, and interpret mechanical drawings according to the size of the proposed site, construction regulations, planning requirements and client specifications, architectural code of design, ***building code***, and local authority by laws, regulatory requirements.

15.3 Learning Outcomes

15.3.1 List of Learning Outcomes

a) Interpret architectural drawings
b) Prepare structural and civil drawings
c) Interpret electrical drawings
d) Design plumbing layout
e) Interpret mechanical drawings

15.3.2 Learning Outcome No 1: Interpret Architectural Drawings

15.3.2.1 Learning Activities

Learning Outcome No 1: Interpret Architectural Drawings	
Learning Activities	**Special Instructions**
1.1 Identify **Construction dimensions** 1.2 Interpret architectural drawings	• CAD Software integration • GPS mapping • Reference codes

15.3.2.2 Information Sheet No15/LO1 Interpret Architectural Drawings

Introduction to learning outcome

Before implementing a project, the architect has to prepare architectural impression of what is to be built. This impression must have dimensions in SI units of length. The design must also conform to the set international standards of practice like the BS code, Euro codes and other local standards.

Definition of key terms

Project plan – A project plan is a document that displays the objectives and relays the scope, in a time frame, of all the activities that will be undertaken in a given project.

Building code – A building code is a set of regulations that govern and designate the standards for the construction of buildings/structures.

Site investigation – A site investigation is a process of collecting relevant information from a given site, analyzing and processing the information for the purposes of highlighting the unknown potential problem that lies underneath the site.

Content/Procedures/Methods/Illustrations

1.1 Identify Construction dimensions according to the size of the proposed site, construction regulations, planning requirements and client specifications, (vertical dimensions, horizontal dimensions)

Construction dimensions are numerical values expressed in an appropriate unit of measure and are indicated on drawings along with lines, arrows, symbols, and notes to define the size and specification of an object. Vertical dimensions are all dimensions that have their alignment at a right angle to a horizontal plane such that their top is directly above their bottom. Horizontal dimensions are all dimensions that have their alignment at a right angle to a vertical plane such that they are parallel to the horizon.

There are two standardized forms of dimensioning named:

- Linear dimensioning which involves displaying of dimensions along the X-Y axis. This form of dimensioning is made up of a dimension line, which is in between, and perpendicular to extension lines.
- Ordinate dimensioning is a form of dimensioning that displays the length along the X-Y axis with the use of a leader line.
  Radial dimensions use leader lines to measure ellipses, circles and arcs.

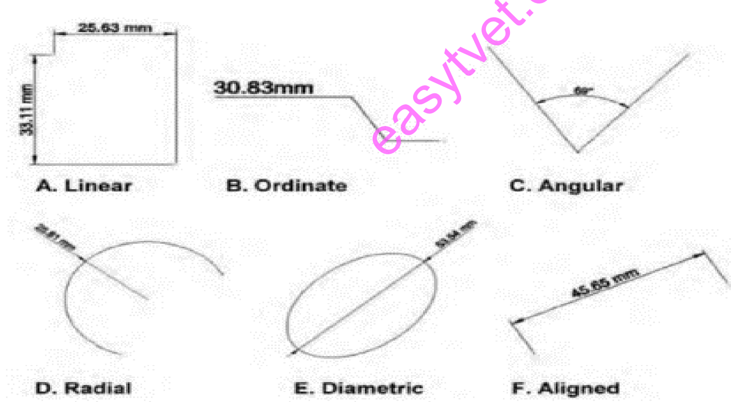

Figure 151: Different types of dimensions and diagram
Source: https://www.construction53.com/2011/08/understanding-dimensions/

1.2 Interpret architectural drawings in accordance with the architectural code of design, *building code*, local authority by laws, regulatory requirements and client specification, (BS 8110, Eurocodes, Kenya Building Codes, 1968 Civil engineering codes).

An architectural drawing is a specialized drawing that shows the views, sections and elevations of a structure/building. These drawings should conform to the mechanisms, design guidelines and standards put in place as a guideline in the production of architectural drawings.

Such mechanism exists as documents including the architectural code of design and the building code: BS 8110, Eurocodes, Kenya Building Codes, 1968 Civil engineering codes that provide regulations that govern and designate the standards for the drawing and construction of buildings/structures. Interpreting of Architectural plans requires one to be systematic and organized in order not to miss any piece of information provided. Here are some of the few guidelines one can adopt:

a) Start with the interpretation of the drawings from the upper left corner and hovering meticulously towards the right lower corner.
b) Read through the plan cover sheet since it contains a lot of information regarding the plans such as the projects information, architect, date, etc.
c) Forms of reference points such as structural references and a grid system may be used between sets of drawings and different professionals.
d) Review the plan index, which provides a list of all plan sheets.[1]
e) Begin with the site plan, which provides information on the plot boundary details and orientation.
f) You should be quite familiar with the symbol legend so that you may have a deeper interpretation on the plans through the symbols provided.
g) Before reading the actual architectural sheets always read the notes that communicate the design details via text to acquire a deeper interpretation.

Conclusion

This learning outcome has covered the basic aspects on how to interpret architectural drawings

Further Reading

Refer to Admin, (2011). *Understanding Dimensions,* http://www.construction53.com/2011/08/understanding-dimensions/, last accessed 23rd June 2020. For further reading on construction dimensions and architectural drawings.

15.3.2.3 Self-Assessment

Written Assessment

1. Which of these is the SI Unit of length ___________
   a) Centimetre
   b) Foot
   c) Inches
   d) Meter
2. Choose the term that best describes architectural drawings.
   a) Artistic
   b) Technical
3. State the different components found in an architectural drawing.
4. Differentiate between vertical and horizontal dimensions.
5. State the different codes one should observe when producing an architectural drawing.
6. Discuss the different types of building codes and their importance in the interpretation of architectural drawings.

Oral Assessment

Why are site investigations important?

Practical Assessment

Using the CAD software prepare the plan of a single room store with dimensions of your choice and clearly show the horizontal and vertical dimensions of the drawing.

Oral Assessment

What was observed as the difference in horizontal and vertical dimensions in the architectural drawing?

15.3.2.4 Tools, Equipment, Supplies and Materials

- Measuring and drawing tools
- Computers/internet
- Cad software
- Printers/plotting device

15.3.2.5 References

Admin, (2011).Understanding dimensions,http://www.construction53.com/2011/08/understanding-dimensions/last accessed 23th June 2020.

Akboy-Ilk, S. (2016). THE NATURE OF DRAWING IN THE CHANGING CULTURE OF ARCHITECTURAL DOCUMENTATION. Journal of Architectural and Planning Research, 33(1), 29-44. Retrieved June 23, 2020, from www.jstor.org/stable/44113126

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15.3.3 Learning Outcome No 2: Prepare Structural and Civil Drawings

15.3.3.1 Learning Activities

Learning Outcome No 2: Prepare Structural and Civil Drawings	
Learning Activities	**Special Instructions**
2.1 Design Structural elements 2.2 Draw detailed plans and sections of designed elements 2.3 Bar bending schedule is prepared 2.4 Structural drawings are produced	• Reiterative allocation of rebar • Designing to standard codes of practice

15.3.3.2 Information Sheet No15/LO2 Prepare Structural and Civil Drawings

Introduction to learning outcome

Loading analysis - Loading analysis is performed in accordance with standard of practice, to come up with the reinforcement bar criteria and later on a bar bending schedule is prepared.

Structural detailing - Structural detailing is done to allocate the design rebar on to the structural drawing in accordance with the code of practice

Definition of key terms

Bar bending schedule – A list of reinforcement bars presented in form of a table that contains the details of the bars such as the diameter of the bar, the length of each bar, straight portions, angles of bending, shape of bending and the number of each type of bar.

Detailed plan – A technical drawing representing the layout of a structure, usually to scale, using set symbols where necessary to represents certain parts and showing specifications of precise dimensions.

Structural – Having structure or involving the mechanics of construction.

Content/Procedures/Methods/Illustrations

2.1 Design Structural elements according to the codes of practice (Slabs, Beams, Columns, Foundation, Stairs)

Slab design procedure:

i. Determine the condition of exposure of slab and assign nominal cover as per code of practice.
ii. Calculate the Design load, F.
iii. Calculate the ultimate bending moment, M_u.
iv. Calculate the lever arm, z, and Area of tension reinforcement A_s
v. Calculate the shear stress and check that it does not exceed design shear concrete stress.
vi. Check deflection and cracking requirements.
vii. Determine the diameter and spacing of links (reinforcement).

Beam design procedure:

i. Select concrete strength class, longitudinal & shear reinforcement grade, minimum member size and thickness of concrete cover.
ii. Estimate loads (dead & imposed) and calculate ultimate loads.
iii. Calculate design moment, M and design shear force.
iv. Estimate effective depth and width of beam.
v. Calculate ultimate moment of resistance, M_u
vi. Determine whether singly-reinforced or doubly- reinforced and design shear reinforcement accordingly.
vii. Check deflection
viii. Produce reinforcement details (diameter and spacing of links).

Column design procedure

i. Determine effective height of column.
ii. Determine whether short or slender.
iii. Calculate axial loading and check for buckling & compression failure.
iv. Produce reinforcement details.

Stairs design procedure

i. Determine thickness of concrete cover.
ii. Calculate design load & ultimate bending moment.
iii. Produce reinforcement details.
iv. Check for shear, deflection & cracking.

Foundation design procedure

i. Determine the design axial load, N.
ii. Determine plan area and dimensions of base.
iii. Determine self-weight of the foundation.
iv. Determine total ultimate load, W and Earth pressure ρ_s = W/Plan Area of base.
v. Calculate maximum design moment, $M = \frac{\rho s\ L2}{2}$
vi. Calculate ultimate moment M_u and determine whether compression reinforcement is required ($M_u > M$).
vii. Determine lever arm, z, and area of reinforcement, A_s.
viii. Calculate: punching shear, face shear and transverse shear.
ix. Produce reinforcement details.

2.2 Draw detailed plans and sections of designed elements as per dimensions and relevant standards

Once the design of the structural element is complete, a detailed drawing of the layout of the element must be produced on paper either manually or with the aid of Computer Aided Design software. Examples of these detailed plans are as follows:

- ✓ **Slab.**

The example below shows reinforcement details of an interior solid slab spanning 5000 mm, having a width of 175 mm and 20 mm nominal cover.

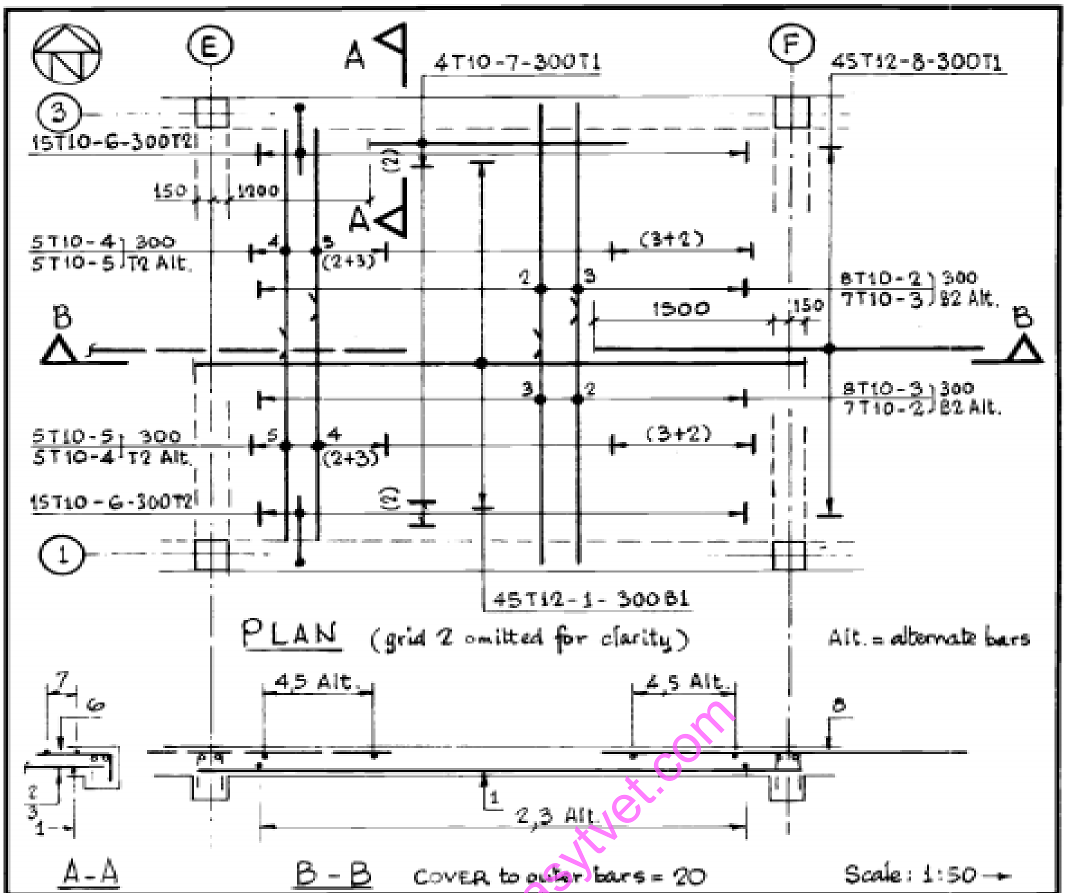


Figure 152: Designed elements as per dimensions and relevant standards

Source: Higgins, J.B. and Rogers, B.R., Designed and detailed (BS 8110: 1997), Crowthorne, British Cement Association, 1998.

- ✓ **Beam.**

The diagram below represents shows detailed plan of a two-way spanning flanged beam

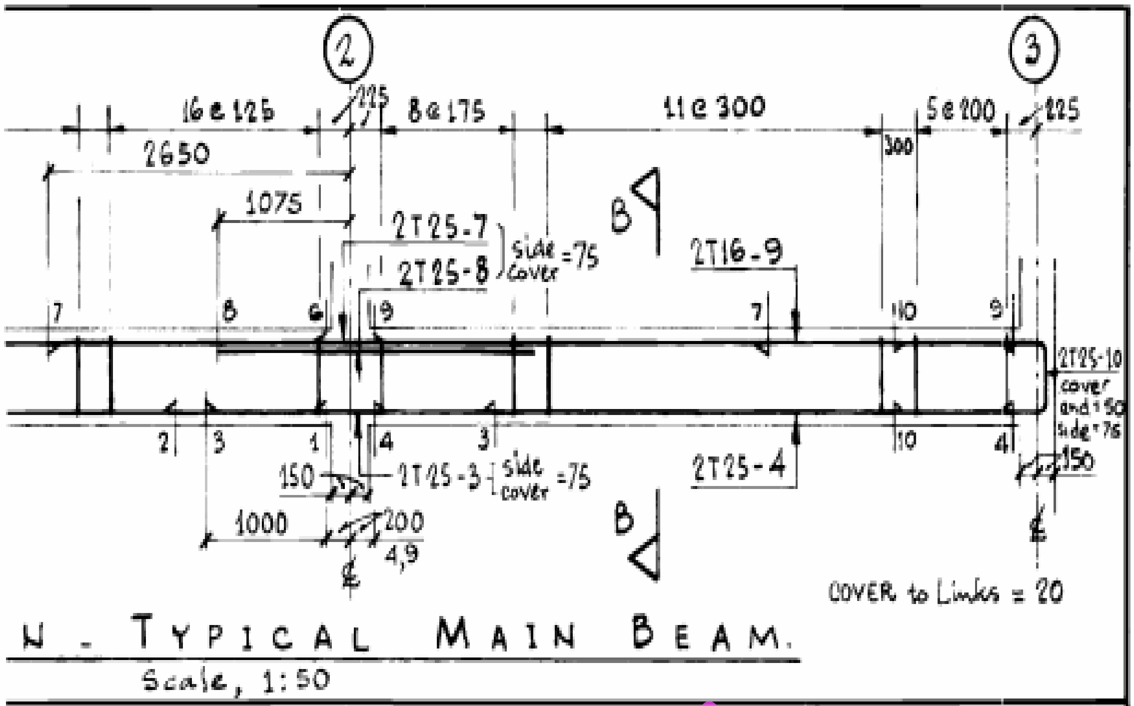


Figure 153: Detailed plan of a two-way spanning flanged beam

Source: Higgins, J.B. and Rogers, B.R., Designed and detailed (BS 8110: 1997), Crowthorne, British Cement Association, 1998.

- ✓ **Column.**

The schematic below shows sections in their relative positions adjacent to their vertical reinforcements. The tabular presentation adapts to element repetition.

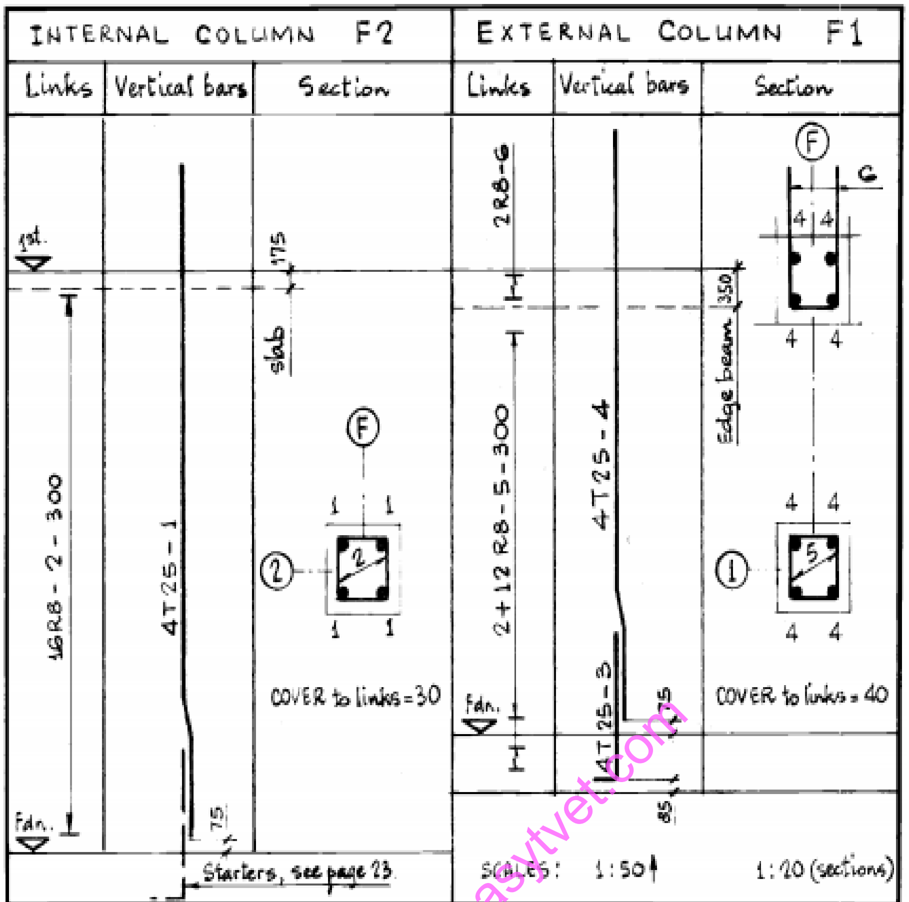


Figure 154: Relative positions adjacent to their vertical reinforcements

Source: Higgins, J.B. and Rogers, B.R., Designed and detailed (BS 8110: 1997), Crowthorne, British Cement Association, 1998.

- ✓ **Staircase.**

The following sketch shows the reinforcement details of an end-span continuous slab (staircase) with 20mm nominal cover.

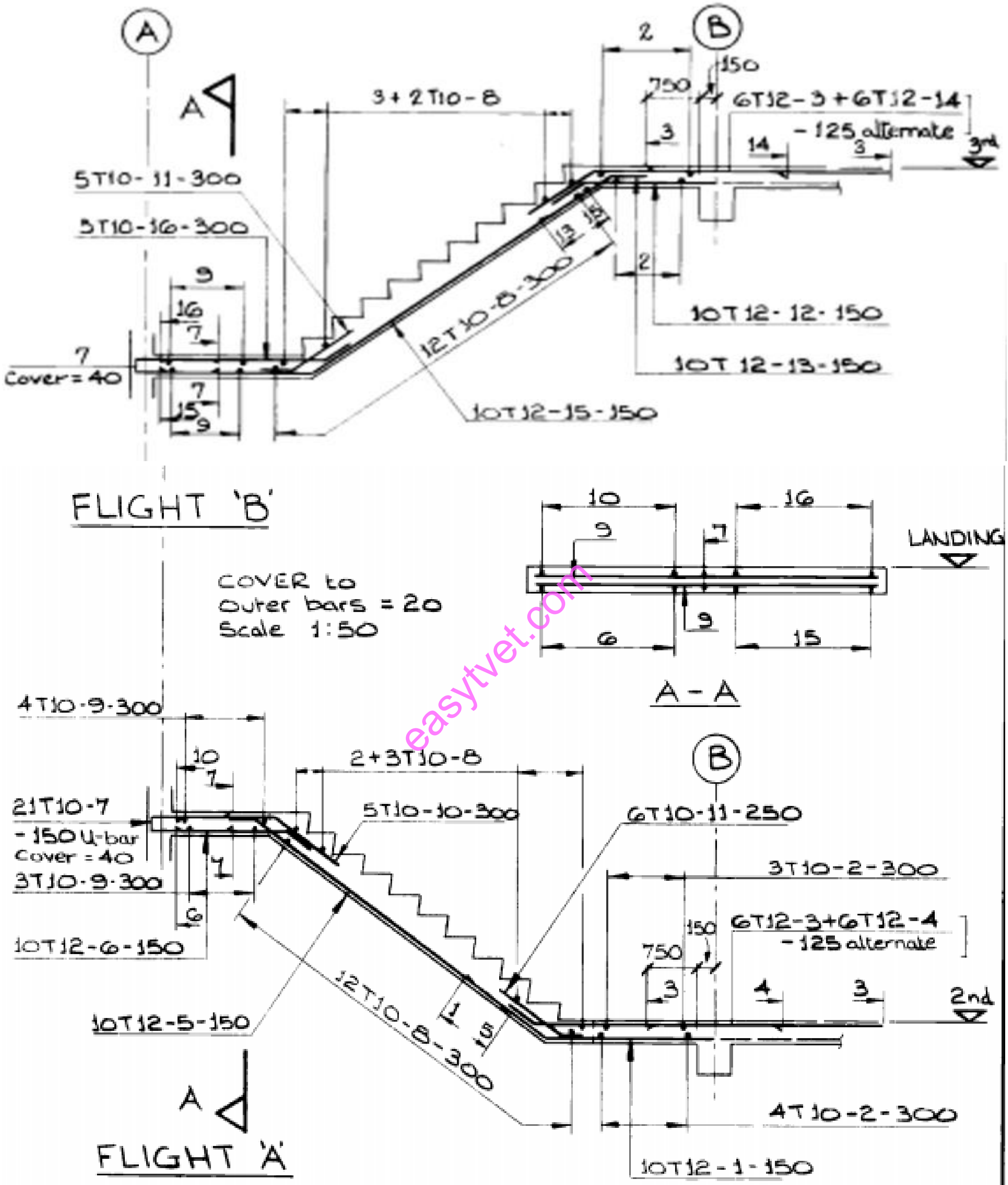


Figure 155: Reinforcement details of an end-span continuous slab (staircase) with 20mm nominal cover

Source: Higgins, J.B. and Rogers, B.R., Designed and detailed (BS 8110: 1997), Crowthorne, British Cement Association, 1998.

- ✓ **Foundation.**

The following is a 2750 × 600 reinforced pad footing.

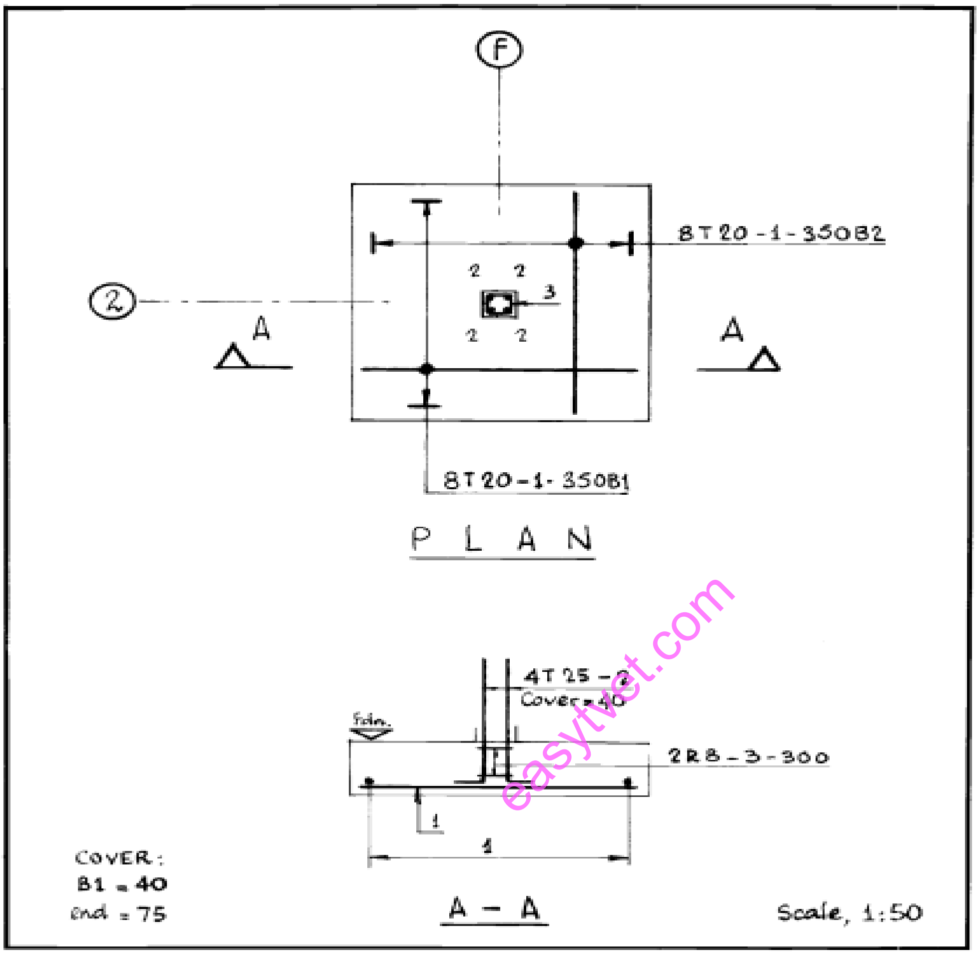


Figure 156: 2750 × 600 reinforced pad footing

Source: Higgins, J.B. and Rogers, B.R., Designed and detailed (BS 8110: 1997), Crowthorne, British Cement Association, 1998.

2.3 Prepare Bar bending schedule as per the code of practice

Bars should be grouped together for each structural element.

Bar Bending Schedule contains the following basic items: the member, description, bar No., spacing, bar shape, No. of bars, cut length, total length, No. of items and total weight as indicated in the example shown below:

Table 35: The member, description, bar No., spacing, bar shape, No. of bars, cut length, total length

Civil4M Solutions LLP

Forum Project

Address of the Project

Bar Bending Schedule

Name of the Project :	Sample Project	Location :	https://civil4m.com	Drawing No :	You can write the ref. drawing numbers at here
Prepaired by :	Dnyan	Level :	Learning at 100.00 meter		and here too
Checked by :	You	Structure :	Sample Structure Tower No 01	Date:	The date on which you prepared it

Sr No	Member	Shape of Bar	Bar Mark	Dia. of Bar	Diamensions of bar in meter										No of Members	Bars Per Member	Total No of Bars	Total Cutting length of bars in meter							
					a	b	c	d	e	f	45° 0.25	90° 0.5	180° 1	Cut Length				6	8	10	12	16	20	25	32
1	Column 1 (0.2 x 1 x 3m)																								
	Verticals		V1	25	3									3.000	4	10	40							120	
	Stirrups		St	8	0.1	0.16	0.92	0.16	0.92	0.1		5		2.340	4	30	120		280.8						
	Hooks		Hk	8	0.1	0.16	0.1					1	1	0.348	4	60	240		83.52						
2	Slab S1 (3 x 3 x 0.15)																								
	Bottom Long		BtL	12	0.1	2.95	0.1					2		3.138	2	20	40				125.52				
	Bottom Short		BTS	12	0.1	2.95	0.1					2		3.138	2	20	40				125.52				
	Top long		TL	10	0.1	2.95	0.1					2		3.140	2	20	40			125.6					
	Top Short		TS	10	0.1	2.95	0.1					2		3.140	2	20	40			125.6					
	Chairs		Ch	12	0.2	0.4	0.2					4		0.776	2	10	20				15.52				

Source: www.civil4m.com

2.4 Produce Structural drawings in accordance with building code, local authority by laws, regulatory requirements and client specification

The structural drawings can be produced manually or with the aid of computer softwares such as AutoCAD, Inventor, ArchiCAD, etc. Once produced, they must be approved by the county planning department before a building is erected. This ensures that the building is constructed in line with certain requirements such as public health, the environment, land rates etc. all the relevant departments must approve the drawings before onset of construction.

Conclusion

This learning outcome encompassed the details on how to prepare structural and civil drawings including: how designs should be done in line with codes of practice, how detailed plans should be drawn, preparation of bar bending schedules and approval of structural drawings by relevant departments.

Further Reading

Bond, A.J. et al., How to design concrete structures using Eurocode 2, The Concrete Centre, 2006

Read on bar bending schedule step by step preparation at www.civildigital.com or on www.quora.com.

15.3.3.3 Self-Assessment

Written Assessment

1 The following are structural elements except?

a) Slab.
b) Plan.
c) Column.

2. Structural elements can either be vertical or horizontal. Among the following, which is the vertical element?

a) Beam.
b) Slab.
c) Column.

3. Explain Cutting length, bending angle and bar shape in a bar bending schedule. Justify

4. Elabourate how structural drawings should be produced

5. Some of the codes of practice used in Kenya are listed below. Which one is false?

a) BS 8110 for reinforced concrete.
b) BS 5950 for steel work.
c) BS 5950 for unreinforced masonry.

6. For a building to be approved, the drawings must satisfy the requirements of the following departments EXCEPT?

a) Planning.
b) Agriculture.
c) Public health.

7. Differentiate beam and a slab in their structural element whereas a column and retaining walls are vertical elements

Essay questions

Summarize the procedure of designing a beam.

Summarize the differences between British Standards and Eurocodes as codes of practice used in the design of structural elements.

Oral Assessment

Explain the procedure of designing a slab.

Summarize some of the basic items that are provided in a bending schedule.

Practical Assessment

Prepare a one-page bar bending schedule for a two-storey building to be done in your local area.

15.3.3.4 Tools, Equipment, Supplies and Materials

- Measuring and drawing tools
- Computers/internet
- Printers/plotting device
- Cad tools

15.3.3.5 References

Allen, E. & Iano, J., (2013). Fundamentals of Building Construction: Materials and Methods, 6th edition. Hoboken, New Jersey: Wiley.

Arya, C., (2009). Design of structural elements: Concrete, Steelwork, Masonry and Timber Designs to British Standards and Eurocodes, third edition. New York: Taylor & Francis.

Geren, R., (2016). Applying the Building Code: Step-by- Step Guidance for Design and Building Professionals (Building Codes Illustrated), 1st edition. Hoboken, New Jersey: Wiley.

15.3.4 Learning Outcome No 3: Interpret Electrical Drawings

15.3.4.1 Learning Activities

Learning Outcome No 3: Interpret Electrical Drawings	
Learning Activities	**Special Instructions**
3.1 Sketch Electrical circuits drawings 3.2 Draw Electrical connection layout	• Network modeling software • Demonstration by trainer • Filed trip

15.3.4.2 Information Sheet No15/LO3 Interpret Electrical Drawings

Introduction to learning outcome

In this section, the architectural drawing is still used in conjunction with the electrical code to come up with the electrical circuit diagrams.

Definition of key terms

Circuit diagram- This is simply a graphical representation of an electrical circuit.

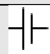
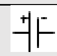
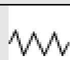
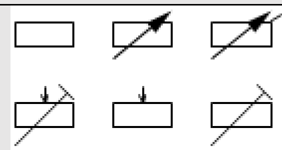
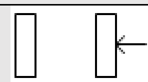
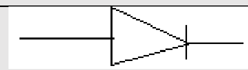
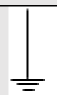
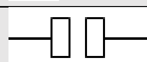
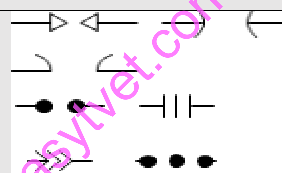
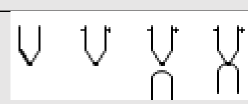
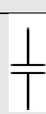
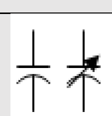
Layout- This is a diagram that makes use of electrical symbols and shapes to represent electrical devices and shows the entire wiring system of a structure such as housing unit.

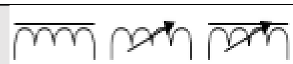
Content/Procedures/Methods/Illustrations

3.1. Sketch Electrical circuits drawings in accordance with the electrical code of practice and the architectural layout

- To be able to sketch electrical drawings, one must first get familiar with standard electrical symbols used in electrical engineering. This makes understanding of the circuitry easier.
- There are numerous electrical symbols in use today. These symbols may vary from one region to another.
- One electrical device may have several different representations.
- Some of the most commonly used electrical devices, their functionality and symbols are shown below.

Table 36: Electrical devices

Device	**symbol**	**Alternative symbol**	**Functionality**
Lamp			Produces light when electrical current flows through it.
Battery			Provide source of current.
Resistor			Reduces current flow.
Fuse			Stops flow of current when the intensity of current exceeds set value thus protecting electrical circuits.
Diode			Allows current flow in one direction
Ground/ Earth			Electrical shock protection and zero potential reference point.
Surge protector			Protects a circuit from a spike / surge in voltage.
Antenna			Marks a device, rod, or wire designed to capture radio and electromagnet waves into electrical signals and vice versa.
Circuit breaker			Protects an electrical circuit against damage caused by overload or short circuit.
Oscillator			Produces a repetitive electronic signal i.e. sine wave or square wave.
Thermocouple			Converts temperature difference at junction terminals to a voltage
Switch			Disconnects the current when open.
Capacitor			Stores electrical charge. Used with a resistor in timing circuits.

Inductor / coil			Stores energy in a magnetic field or flux.

- The example shown below illustrates a simple Surface installation of one lamp controlled by two, two- way switches.

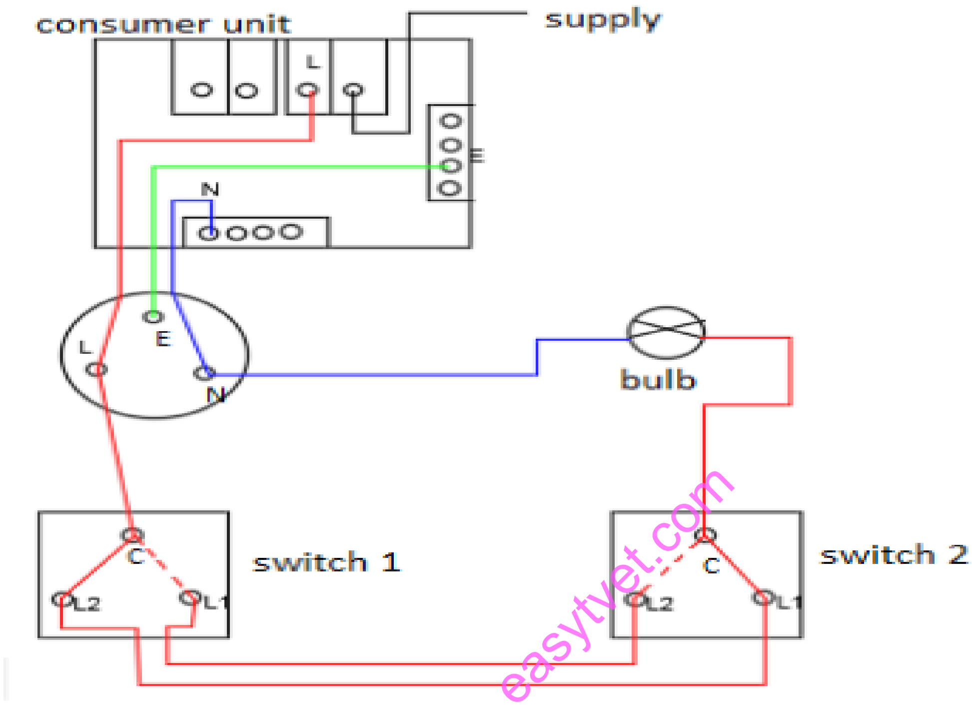


Figure 157: a simple Surface installation of one lamp controlled by two, two- way switches

3.2. Draw Electrical connection layout in accordance with the electrical code of practice

- After understanding all the symbols used in electrical circuitry, one may then draw a layout diagram easily.
- The diagram is provided with a legend/ key listing all the symbols used in drawing the layout to be able to assist one in interpreting the circuit.
- See the following example of a circuit diagram:

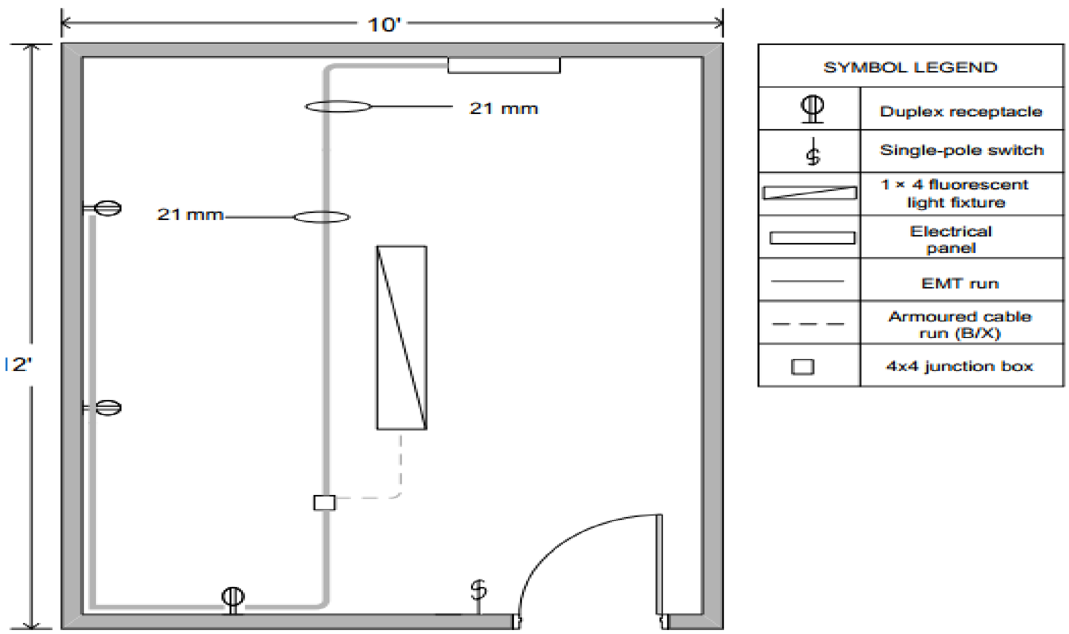


Figure 158: Circuit diagram

Source: https://mytrainingbc.ca.

- ✓ The following example illustrates a simple Surface installation of a ring socket. A ring socket outlet is an arrangement of sockets such that a ring of wires from a consumer unit go through all the sockets, each at a time, then back to the consumer unit. The ring is usually fed from a protective device located in the consumer unit, usually a fuse or a circuit breaker of rating about 32A. Wiring is done using a 2.5mm2 cable.

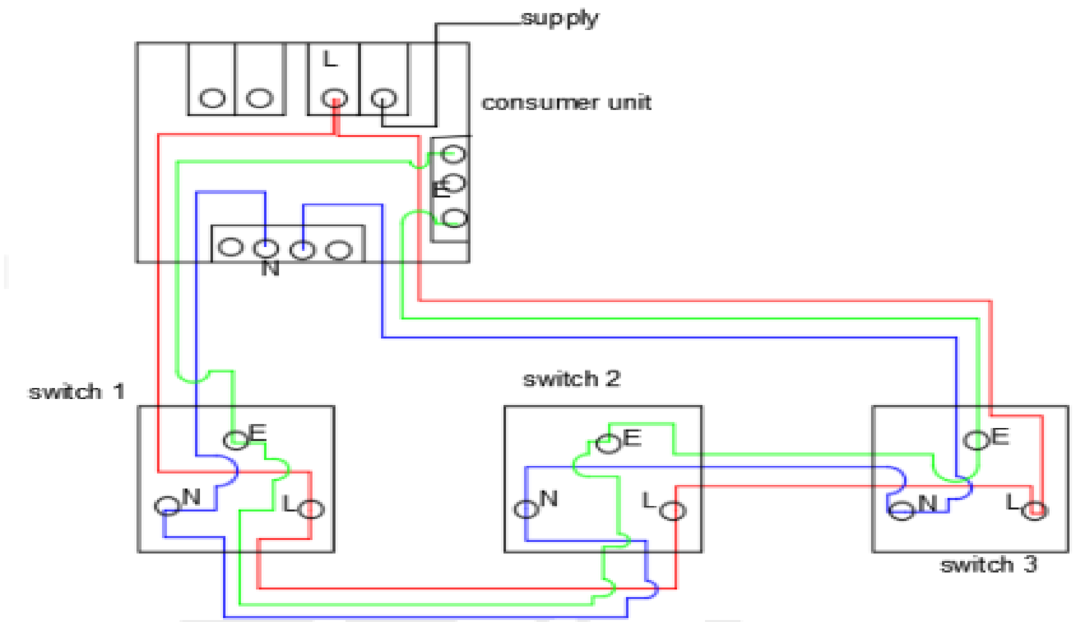


Figure 159: Simple Surface installation of a ring socket

Conclusion

This learning outcome reviews the basics on how to interpret electrical drawings which revolve around being able to identify every distinct electrical device and its interconnection with other devices in the circuit.

Further Reading

How to Read Electrical drawing – Edraw (https://www.edrawsoft.com).
Typical Electrical Drawing Symbols and Conventions – NRC (https://www.nrc.gov).
Alexander, C.K. & Sadiku, N.M., (2013). *Fundamentals of Electric Circuits, 5th edition*. New York, USA: MacGraw-Hill Companies Inc.

15.3.4.3 Self-Assessment

Written Assessment

1 Arrowheads placed on circuit line generally represent?
   a) Indicates the room in which the circuit is installed
   b) Indicates the circuit to be controlled by a wall switch
   c) Indicates the direction of current flow

2. Explain the electrical circuits diagrams bellow?
   a) Schematics and Pictorials
   b) Architectural diagrams

3. Electrical symbols are represented using?
   a) Pictorials
   b) Schematics
   c) Graphics

4. Identify the electrical device that is incorrectly matched with its functionality?
   a) Push button – momentarily allows current flow when button is pushed in, breaks current when released
   b) Antenna – Used for protection

5. The work of a Surge protector is to?
   a) Change AC voltage from high to low and vice versa
   b) Store electric charge and generate constant voltage
   c) Protect a circuit from a spike in voltage

6. Explain the work of a Diode is to?
7. The following symbol represents which electrical device?

   a) Fluorescent fixture.
   b) Flood Light.
8. Evaluate the various symbols used to indicate a fuse.
9. Color plays an important role in electrical code of practice, explain briefly?
10. Differentiate between an electrical circuit and a circuit diagram.
11. Differentiate between a lamp and a flood light by their symbols?

Essay questions

Draw and label at least fifty electrical symbols used in code of practice.
Draw a circuit diagram with two outlets that require separate circuits for a fridge and a dishwasher that go directly back to panel?

Oral Assessment

Differentiate between an electrical circuit and a circuit diagram.
Differentiate between a thermostat and rheostat?

Practical Assessment

Design a wiring diagram from a switch box running two lights. Include a Legend.

Project Assessment

Visit a nearby factory, study the electrical wiring diagram of the factory plant and see whether you understand it completely. Consult the Factory Engineer where necessary and try reproducing the same diagram in CAD, having understood it.

15.3.4.4 Tools, Equipment, Supplies and Materials

- Codes of practice
- Mechanical conventions,
- Workstation
- CAD & GIS Software

15.3.4.5 References

Alexander, C.K. & Sadiku, N.M., (2013). Fundamentals of Electric Circuits, 5th edition. New York, USA: MacGraw-Hill Companies Inc.

Robertson, C.R., (2008). Fundamentals of Electrical and Electronic Principles, 3rd edition. Oxford: Elsevier.

How to Read Electrical drawings; Retrieved from https://www.edrawsoft.com

Typical Electrical Drawing Symbols and Conventions Retrieved from (https://www.nrc.gov).

Standard electrical symbols for electrical schematic diagrams; Retrieved from https://www.edrawsoft.com/electrical-symbols.html

15.3.5 Learning Outcome No 4: Design Plumbing Layout

15.3.5.1 Learning Activities

Learning Outcome No 4: Design Plumbing Layout	
Learning Activities	**Special Instructions**
4.1 Identify building dimensions 4.2 Determine pipe sizes are 4.3 Determine pipe types and	• Sketch up software • Mathematical models • Practical exercise • Demonstration by trainer

15.3.5.2 Information Sheet No15/LO4 Design Plumbing Layout

Introduction to learning outcome

The plumbing layout will portray the orientation of the various pipe sections as they may appear superimposed on to the architectural drawing and structural drawings. The components are sized depending on the water demand of the building with respect to the consumptive use and future projections of population.

Definition of key terms

Building dimensions- is a numerical value defined in appropriate units and used to express the size, location, orientation, form or geometric properties of any part of a building.

Pipe– is a hollow tube with circular cross section for transportation of fluids (gases and liquids).

Content/Procedures/Methods/Illustrations

4.1 Identify Building dimensions as per the architectural drawings, structural and electrical drawings.

There are several standard forms of dimensions:

i. Linear dimensions;
   Measures the distance between points especially those in a line.
   These are used for measuring and displaying length along the horizontal or vertical axis.
   Are axial measurements either Y or X direction.

ii. Radial Dimensions
   Measures the radius of circular dimensions and displaying them with a leader line.
   This dimension is designated using an R followed by the value.

iii. Ordinate dimension- axial measurements are displayed as text using a leader..

Dimensions is composed of two parts; nominal value and a componential value which varies either higher or lower than the nominal value.

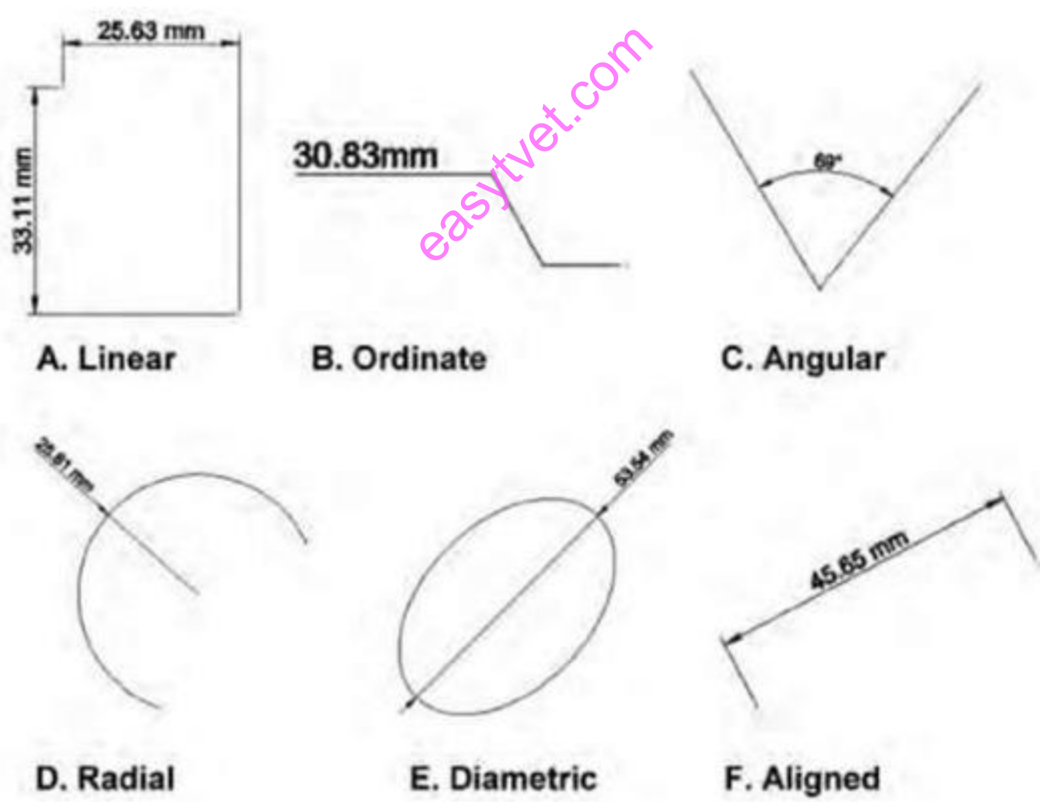


Figure 160: Ordinate dimension- axial measurements are displayed as text using a leader
Source: https://www.construction53.com/2011/08/understanding-dimensions/

4.2 Determine *Pipe* sizes are as per consumption (PVC, GI pipes, Mild steel, PPR)

Pipe sizing is used to determine the amount of fluid that can be supplied at a given rate. There are several ways of calculating pipe sizes for example determining friction head loss, sizing from velocity, determining pipe sizes arithmetically and many more.

Calculation of pipe size arithmetically

Information required include;

u = Flow velocity (m/s)
v_g = Specific volume (m³/kg)
$\dot{m}_s$ = Mass flowrate (kg/s
$\dot{V}$ = Volumetric flowrate (m³/s) = $\dot{m}_s \times v_g$

From this information, the cross sectional area (A) of the pipe can be calculated:

$$\text{Cross sectional area (A)} = \frac{\text{Volume flowrate } (\dot{V})}{\text{Flow velocity (u)}}$$

i.e.

$$\frac{\pi \times D^2}{4} = \frac{\dot{V}}{u}$$

Rearranging the formula to give the diameter of the pipe (D) in metres:

$$D^2 = \frac{4 \times \dot{V}}{\pi \times u}$$

Figure 161: Calculation of pipe size arithmetically
Source;spiraxsarco.com/learn-about-steam/steam-distribution/pipes-and-pipe-sizing.

Example

A process requires 5 000 kg/h of dry saturated steam at 7 bar g. For the flow velocity not to exceed 25 m/s, determine the pipe size.

Where:

Flow velocity (u) = 25 m/s
Specific volume at 7 bar g (v_g) = 0.24 m³/kg
Mass flowrate ($\dot{m}$) = 5 000 kg/h or 1.389 kg/s
Volumetric flowrate = $\dot{m} \times v_g$
Volumetric flowrate = 1.389 kg/s x 0.24 m³/kg
Volumetric flowrate = 0.333 m³/s

Therefore, using:

$$\text{Cross sectional area (A)} = \frac{\text{Volumetric flowrate } (\dot{V})}{\text{Flow velocity (u)}}$$

$$\frac{\pi \times \mathbf{D}^2}{4} = \frac{\dot{V}}{u}$$

$$\mathbf{D}^2 = \frac{4 \times \dot{V}}{\pi \times u}$$

$$\mathbf{D} = \sqrt{\frac{4 \times \dot{V}}{\pi \times u}}$$

$$\text{Pipe diameter } (\mathbf{D}) = \sqrt{\frac{4 \times 0.333}{\pi \times 25}}$$

Figure 162: Example of Calculation of pipe size arithmetically
Source; spiraxsarco.com/learn-about-steam/steam-distribution/pipes-and-pipe-sizing

Alternative pipe sizing methods

Procedure for sizing pipes.

i. A favorable diameter is assumed.
ii. An assumed size is always determined and proven to contain the expected flow.
iii. A flow rate is determined with considerations.
iv. Instead of maximum flow, it is designed for peak flows based on probability theory.
v. Use of charging units;
   - A charging unit is a number given to an appliance relating flow rate to the length of time while being used and probable usage.
vi. In case of continuity in flow
   - Automatic reservoirs must be considered as continuous flow instead of applying probability theory. For such appliances the full design flow rate for the outlet fitting must be used.
vii. Obtain the intended flow rate by adding (a) and (b).
   - The intended flow rate is the summation of the flow rate determined from charging units and the continuous flows.
viii. Effective pipe length determination
ix. Measured pipe length is determined;
x. Work out the pipe length for fittings that is equivalent;
   - Resistances to flow in fittings are conveyed in terms of length of pipe having similar resistance to flow as that of the fitting.
xi. Equivalent pipe length for draw for draw-offs is determined;
xii. By adding (d), (e) and (f), you obtain the effective pipe length.
   - Summation of the pipe length measured (d) and the equivalent pipe lengths for fittings (e) and draw-offs (f) gives effective pipe length.
xiii. Acceptable or permissible head loss is worked out:

xiv. (h) Available head is determined from the previous data and workings:
xv. Head loss per meter runs through pipes is determined;
xvi. (j) Determine the head loss through fittings;
xvii. (k) Followed by calculation of head loss through fittings on the pipe.
   - Permissible head loss= (m/m run)

xviii. Pipe diameter is then determined:
xix. Check whether the pipe size will give the intended flow rate in (C) without excess head loss.

- PVC

  They are different types depending on wall thickness: Low, Medium and high grade.

- PVC schedule

Is the thickness of the PVC pipe wall, mostly are 40 and 80. As the schedule gets larger the wall gets thicker from outside.

- Galvanised Iron pipes

  For corrosion protection, it is dipped into zinc and is used for water pipe lines.
  Used for distribution treated or raw water in rural or urban areas. These are cheaper, lightweight and easy to handle.

- Mild steel pipes

  These type of pipes are made of low carbon steel and due to this they do not harden and are usually easy to use. These type of pipes are strong in tension hence can withstand high pressure but not heavy loading as pumping main.
  Their major applications include supply of drinking water, fire fighting and HVAC systems.

- PPR

  This type of pipes refer to those made of Polypropylene Random Copolymer. They are usually made for hot and cold water supply and other heating applications. They have their uses varying from civil buildings such as hospitals, apartments, schools etc., commercial buildings such as hotels, restaurants, offices etc., to industrial buildings such as factories, air conditioning etc.
  The common outer diameter specifications of PPR water pipes are 20mm, 25mm,

Conclusion

Under this study the methods explored were centered on how to Design plumbing layout.

Further Reading

Explore additional ways of determining pipe sizes
Practice reading metric pipe schedule.

15.3.5.3 Self-Assessment

Written Assessment

1. Which is not a characteristic of plumbing application pipes.
    a) Pressure rating (Psi)
    b) NPS
    c) Length of pipe
    d) Manufacturers brand name
2. What is the most likely risk of injury when cutting large diameter pipes?
    a) You may damage your muscle due to continued use
    b) You may cut yourself
    c) Trapping of fingers
    d) A sharp metal may fly off and cause damage
3. State the safest mode of transportation of PPR pipes and Mild steel pipes based on their sizes and specifications.
4. Explain type of pipe is used below and above the ground?

Essay question

Students have been asked to determine pipe sizes of certain pipes provided. Use one method and describe the procedure.

Oral Assessment

1. Explain what scheduling entails
2. Explain how does poor pipe sizing affect building
3. Students have been asked to join plastic soil pipes in the space of a building using a strong hazardous solvent yet they've not been provided with Respiratory Protective equipment, what should you do

Project Assessment

Design a two-bedroom house so as to appreciate various building dimensions.

15.3.5.4 Tools, Equipment, Supplies and Materials

- Codes of practice
- mechanical conventions,
- workstation
- CAD & GIS Software

15.3.5.5 References

Jim J. Williams, Labouratory plumbing 101. Basharkhah Engineering, Inc

William p. Spence, (2000) Architectural working drawings. North Carolina: Wiley

15.3.6 Learning Outcome No 5: Interpret Mechanical Drawings

15.3.6.1 Learning Activities

Learning Outcome No 5: Interpret Mechanical Drawings	
Learning Activities	**Special Instructions**
5.1 Obtain Mechanical component dimensions 5.2 Identify ***Mechanical components*** 5.3 Interpret Mechanical drawings	• Open source modeling software • Numerical analysis

15.3.6.2 Information Sheet No15/LO7 Interpret Mechanical Drawings

Introduction to learning outcome

In this review the design of mechanical components starts with the identification and sizing of the components in accordance with the provided architectural and structural drawings, while making relevant referencing from the design codes of practice.

Definition of key terms

Mechanical drawing: Is a drawing of mechanical or architectural structures drawn to scale and with the use of precision instruments.

Specifications: Are information which describe the products, materials and work required by a construction contract.

Content/Procedures/Methods/Illustrations

5.1 Obtain Mechanical component dimensions as per structural and architectural drawings

Mechanical component refers to any single part of a machine (not programmable/ not digital) that is visible and when subjected to forces runs a machine.

Examples of mechanical components are;

- Bearing
- Shafts
- Bolts
- Nails
- Blades
- Cover
- Rods
- Gears

- Pulleys
- Chains

There exist conventions that that both a drafter and the interpreter of architectural and structural drawings.

The following therefore should be taken into consideration;

- Feet and inches both need to be shown for example 5 ft, 5 inch; even if the dimensions have no value, the 0 remains part of designation.
- The lines of dimensions are continuous with the number being placed at the center or placed slightly above the line or broken at the center and the number placed.
- Inches are used when the dimensions are too small.
- Dots, arrowheads or slashes are put at end of the dimension lines to show the extent of dimension.
- Irrespective of the scale used, dimension lines indicate actual building sizes.
- Dimension of doors is also shown in the floor plan symbol or represented by the door symbol.
- On plan views, dimension giving location are provided at the centerlines of both openings.
- To eliminate confusion with other dimension lines curves are used.

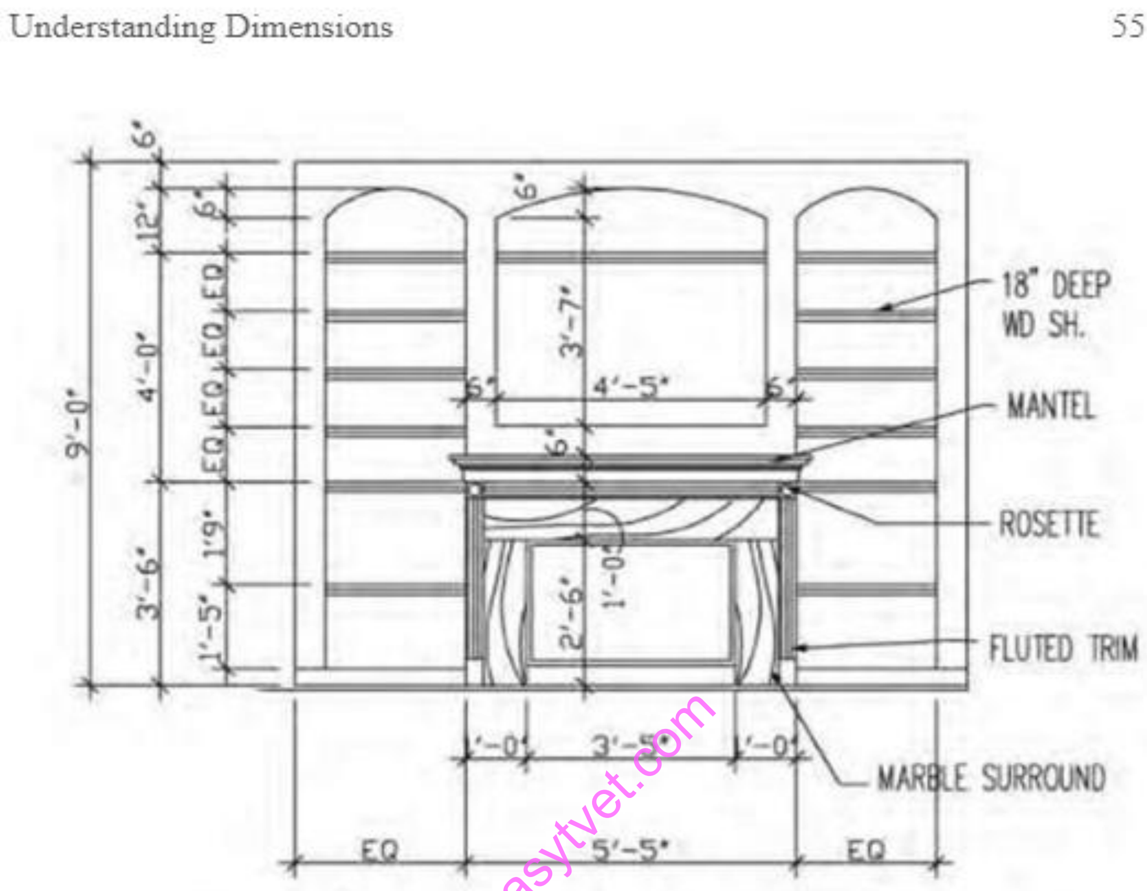


Figure 163: Dimensions
Source: https://www.construction53.com/2011/08/understanding-dimensions/

Mechanical components include various categories as follows:

i. Fasteners
The diameter is typically measured on the outside of the threads.
They include nuts and bolts, screws, pins and rivets.
Size; for most consists of three parts i.e. diameter, length and thread count.

ii. Nuts and washers.
Their sizes are the same the diameter of the fastener they are meant to work with.
Hence a 0.5inch washer fits 0.5inch bolt/ screw.

iii. Bolt
Is a form of a threaded fastener with external male thread. Strength and circumstance determine material selection for bolts.
Example of bolts include blind bolts, hex bolts, anchor bolts, carriage bolts and double end bolts.

iv. Joints -a section of a machine which is used to connect one or more mechanical parts to another. Integral joints include seams, shrink-fits and crimps.

5.2 Identify *Mechanical components* as per architectural and structural drawings (Union, Bends)

1. Union- Connects two pipes and allows for future disconnection for maintenance.

Used in pipe systems to link straight sections of pipe or tube and are flexible to accommodate different sizes or shapes and fluid flow regulation.

Consists of three parts: a nut, female and a male end.

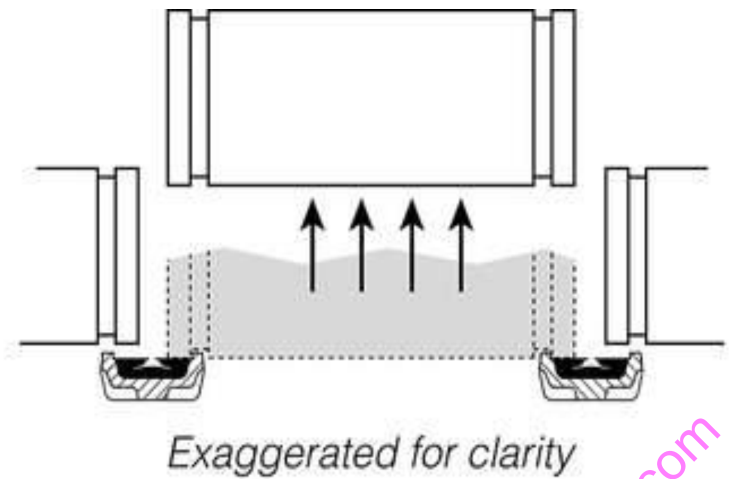


Figure 164: UNION

Source:https://media5.picsearch.com/is?Vd_nAZZ1cV1rnb7UevBg-VooU7uuVweHEizBErqw3E&height=194

2. Bends- is a device shaped with a bending to retain fluid. Traps are usually U, S, Q or J shaped. Bend is an offset or change in direction of in pipe networks.

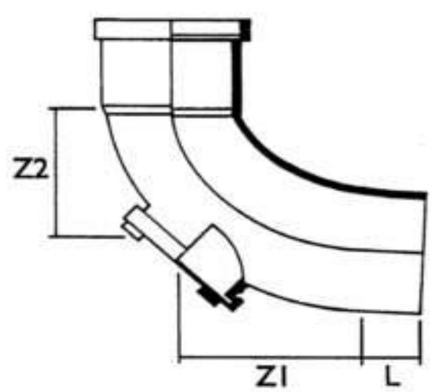


Figure 165: BENDS

Source:https://media1.picsearch.com/is?ByImvXIB5qUVwCWAmlgwmqWzPMz8hj72adZWCTmffcw&height=255

5.3 Interpret Mechanical drawings as per specifications

Interpretation of mechanical drawings depicts the major mechanical and electrical components in a building system or any kind of system, the links and the sensors placed for collection of data and monitoring of operation process. The components have an input and output which are sampled by the sensors and instruments so as to evaluate performance of the component to be evaluated and to determine adjustments needed. The components are represented symbolically and flow paths are usually depicted using distinctive line convention.

- For interpretation, conversion of mechanical drawings to CAD (Computer Aided Design) must be enabled and thus the following are required:
    i. Accuracy
       Converted information must be compatible to the input system.
    ii. Ability to recognize complex entities
    iii. Use of all properties.
- Reasoning on blocks
  The drawing is divided into various blocks whose relative position to one another has a technological meaning.
- Correction and conversion to CAD

Conclusion

The mechanical components to be constructed have been subjected to rigorous and ingenious process that starts with learning how to interpret mechanical drawings

Further Reading

How to obtain size of various mechanical components based on mechanical drawings.
Numerical analysis

15.3.6.3 Self-Assessment

Written Assessment

1. What is the first step in a mechanical drawing process
    a) Brainstorm solutions
    b) Prepare rough sketches
    c) Prepare a budget

2. Identify Critical issue drafters need to pay attention to
    a) Size of the sheet
    b) Designers intentions
    c) Scale of drawing
3. The size (diameter) of the hole in which the split pin is to be put is when D is the diameter of the hole.
    a) 0.1D
    b) 0.12D
    c) 0.4D
    d) 0.3D
4. Evaluate different types of mechanical components
5. Differentiate between mechanical drawing and fine art

Essay questions

Evaluate the process of interpretation of engineering drawing

Project Assessment

Perform a mechanical drawing of pip networks

15.3.6.4 Tools, Equipment, Supplies and Materials

- Codes of practice
- mechanical conventions,
- workstation
- CAD & GIS Software

15.3.6.5 References

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CHAPTER 16: BUILDING WORKS

16.1 Introduction of the Unit of Learning

This unit describes competencies required to carry out building works. It involves executing site preliminary works, building temporary works, substructure works, superstructure works, building finishes and external works.

16.2 Performance Standard

Execute site preliminary works, building temporary works, substructure works, superstructure works, building finishes, and external works as per standard construction procedures.

16.3 Learning Outcomes

16.3.1 List of Learning Outcomes

a) Execute site preliminary works
b) Execute building temporary works
c) Execute substructure works
d) Execute superstructure works
e) Execute building finishes
f) Execute building external works

16.3.2 Learning Outcome No 1: Execute Site Preliminary Works

16.3.2.1 Learning Activities

Learning Outcome No 1: Execute Site Preliminary Works	
Learning Activities	**Special Instructions**
1.1 Survey the building site 1.2 Determine site boundary 1.3 Hoard/screen building site 1.4 Demolish unwanted structures 1.5 Clear building site 1.6 Prepare site layout 1.7 Prepare site preliminary report 1.8 Identify site ***utilities*** 1.9 Construct storage facilities	• Be able to demonstrate how to prepare a site preliminary report • Conduct required practical works on site

16.3.2.2 Information Sheet No16/LO1: Execute Site Preliminary Works

Introduction to learning outcome

Building works need to follow a certain procedure of which site preliminary works forms the first step. This is crucial because if not undertaken then the success of building works is compromised.

Definition of key terms

Site utilities – These are services provided during construction that are essential for the normal functioning of the society. They include among others water, electricity and sewer system.

Surveying methods - These are techniques used to determine the relative position of objects on the earth surface for construction site investigation. These methods include plane surveying and geodetic surveying

Site installation - This is the erection of equipment and infrastructure such as power network equipment on site.

Content/Procedures/Methods/Illustrations

1.1 Survey the building site as per standard construction procedures

Surveying a building site is a process which comprises of assessing the suitability of the area of land for the building construction or other civil inferring works. The process involves taking note on key factors affecting the design of the building and security of the surrounding land. The main objective of the survey is to establish if the proposed building is feasible in technical terms and evaluate its economic benefits. In civil and construction works, surveying is done by making measurements relative to known or assumed datum for location, design and construction of civil engineering projects.

Other objectives include identifying different factors which cause difficulties in construction to aid in coming up with the best strategy and aid in coming up with a satisfying and economical building design.

Commonly used surveying instruments are;

- Theodolite
- Measuring tape
- Dumpy level
- Rod
- Electronic distance measurement
- Total station
- Automatic level

Procedure of surveying a building site

i. Carry out reconnaissance- involves examining the survey area to know the best possible ways of carrying out surveying, establish a system of horizontal controls and make a sketch showing the permanent features including the north line.
ii. Field measurements- the surveyor uses the surveying instruments to make linear and angular measurements.
iii. Field record- al the measurements are recorded systematically on a field book. the records maybe numerical value, written notes or even sketches.
iv. Office work- the surveyor carries out drafting, computing and designing using the values recorded.

1.2 Determine site boundary as per standard construction procedures

A site boundary is a temporally line, limit or a margin erected to define the perimeter of a construction site which is used to manage the public risk in a construction site.

The following factors are considered in site boundary identification and sizing;

- Population density of the area- in an area where the labour forces is scarce, there would be a need for more living facilities in the site. Also, in areas where the happening far from the industrial centers, there would be a need for more space for equipment maintenance and storage area.
- Project size - a project taking a lesser period would need less site space compared to a project taking a period of 10 years which would need a temporally structure of a permanent nature.
- Nature of the project - an industrial plant project would need more space for mechanical and electrical works compared to a highway project.
- Nature of the site – the land scape and existence of another site before

1.3 Hoard/screen building site as per standard construction procedures

This is an area marked by a boundary that is used to keep the members of the public from construction site hazards.

Some of the holding materials include the following;

- Wood
- Steel
- Aluminum
- Chain- link

Importance of holding and screening building site

- To separate the public and the work site
- To protect the public from hazards like falling objects
- To keep the building floors protected during site visits and before handing over the project

1.4 Demolish unwanted structures as per standard construction procedures

This is to bring down a structure to pave way for a future installation.

There are various methods of demolition of unwanted structures. They are as follows;

- Manual method
- Demolition by use of a machine from top to down
- Demolition by implosion
- Demolition of floor slabs
- Demolition by crane and a wrecking ball

Safety considerations during demolition of unwanted structures

a) Each employee should the equipped with the safety boots and helmets during demolition for their safety.
b) The building should be inspected before demolition to ensure that no single person is left in the building during demolition and also assign someone to guard the area from entrance by unauthorized persons.
c) Ensure the employees taking part in demolition are trained and experienced in the field.
d) After demolition is complete, clean up the debris which could the harmful to the safety and health of the public

1.5 Clear building site as per standard construction procedure

Clearing a building site includes removal of trees, unwanted infrastructure and of obstacles that may hinder construction of an infrastructure.

Tools and equipment used in clearing a building site are as follows;

- Tractors
- Bulldozers
- Backhoe
- Axe
- Wheelbarrow
- Rakes

Steps followed in clearing a building site

i. Clear the undergrowth vegetation for example; grass
ii. Cut down trees
iii. Remove tall stumps by use of machinery
iv. Remove the roots
v. Remove and relocate large stones
vi. Destroy the animal burrow by digging them out and fill them with clay
vii. Clear the vegetation near the surrounding of the building site

1.6 Prepare site layout as per standard construction procedures

Site layout is the detailing of the site by sizing and erecting temporary facilities for efficient flow of materials. A good site layout should increase the output and ensure safety and maximize the area used for temporary constructions.

Procedure of preparing a site layout plan

i. Gather information on site facilities to be required
ii. Get the measurements of the infrastructures to be constructed

iii. Determine how the different facilities in the site are inter- related
iv. Maximize the use of the site area

1.7 Prepare site preliminary report as per standard construction procedures

The following steps show the steps in preparing a site preliminary report;

i. Describe the project components which include the nature of the project.
ii. Verify the project components
iii. Prepare a site layout plan
iv. Conduct a feasibility study of the site
v. Identify the mode of payment of the project
vi. Determine the number of construction contracts needed
vii. Give a detailed opinion of the engineer

1.8 Identify *Site utilities* (Temporary washrooms, Source of water, Storage, Site office) as per standard construction procedures

Site utilities are- These are services provided during construction that are essential for the normal functioning of the society.

Temporary washrooms- number of toilets is better to be not less than the ratio of 25 people per toilet and reasonable allocation should consider the male to female ratio in construction area (Yang, 2017)

Source of water- water systems are highly regulated in building industry. All components of water used in construction must meet the requirement6s of building codes.

Storage- there should be adequate space, protection and control for materials and equipment that are to be kept in a construction site. Storage facilities will depend on the type of materials and equipment and their size.

Site office-office accommodation arrangements are a matter of choice for each individual contractor. Separate offices can be provided for site agents, clerk, administrative staff, site surveyor, secretary among others.

1.9 Construct storage facilities are as per standard construction procedures

Storage facilities in site provide adequate space for protection of materials, equipment and other valuable objects on site a good storage facility should be secure, affordable, and has enough space for storage.

The storage area can be calculated using the formula below;

Storage area A= $(\frac{Qmax}{Im})/Qn$

$Q_{max=}$ $q_{daily} \times t \times k$, $q_{daily} = \frac{Qtotal}{T}$

$Q_{max:}$ Maximum estimated quantity in storage space; I_m: Utilization index for materials;

$q_{n:}$ quantity of materials can be stored per m2;

T_{otal}: Total quantity of materials required for the project;

q_{daily}: estimated quantity required per day;

T: construction period (not total project duration);

t: Average stock (days);

k: Fluctuation factor

Conclusion

This learning outcome covered the competency of executing preliminary works that are required in building works.

Further Reading

Watch various videos on how various tools and equipment are used in site clearing.

16.3.2.3 Self-Assessment

Written Assessment

1. Three of the following instruments are used in surveying, which one is old one out?
    a) Dumpy level
    b) Rod
    c) Tractor
    d) Measuring
2. Explain the term utility giving examples
3. Select the old one out
    a) Tractor
    b) Backhoe
    c) Bulldoze
    d) Theodolite

4. There are various methods of demolition of unwanted structures. Which one of the following is among them?
   a) House demolition method
   b) Down to tot demolition method
   c) Explosive demolition method
   d) Manual demolition method
5. Among the following, which material is used for holding?
   a) Paper
   b) Wool
   c) Glass
   d) Wood
6. Define the term utilities
7. Explain the word surveying and give three instruments used in surveying
8. You have qualified to be the site engineer in a construction of a health care facility in your county. Give the main steps that you will use in preparing a site preliminary report.

Oral Assessment

Outline the various site clearing tools

Project Assessment

You are entitled to be in charge of a government project in your area, prepare a site layout plan for the project.

16.3.2.4 Tools, Equipment, Supplies and Materials

Tools and equipment

- measuring and drawing tools
- computers/internet
- printers/plotting device
- calculator

Materials and supplies

- Codes of practice
- mechanical conventions,
- site office
- standard manuals and guidelines

Personal protective equipment (PPEs)

- dust coat
- First aid kits

16.3.2.5 References

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16.3.3 Learning Outcome No 2: Execute Building Temporary Works

16.3.3.1 Learning Activities

Learning Outcome No 2: Execute Building Temporary Works	
Learning Activities	**Special Instructions**
2.1 Construct and dismantle trench timbering 2.2 Construct and dismantle building formwork/shuttering 2.3 Erect and dismantle building scaffold 2.4 Erect and dismantle building shores	• Undertake the project of building temporary works as required by the standard construction procedures

16.3.3.2 Information Sheet No16/LO2: Execute Building Temporary Works

Introduction to learning outcome

This section involves execution of frameworks that will guide the actual substructure works. It involves the general skeleton of what is expected after building works are completed.

Definition of key terms

Formwork – This is a temporary or a permanent structure in which fresh concrete is poured to construct structural elements which achieve its shape. Formwork can be classified into; engineered formwork, timber formwork and insulated formwork.

Scaffold – this is a temporary platform that is erected before commencement of construction or repair of a structure to ensure safety of workers, provide support on heights and also provide material during construction.

Content/Procedures/Methods/Illustrations

2.1 Construct and dismantle trench timbering according to standard construction procedures

A trench timbering is a process of providing boards and struts when the trench is large or the subsoil is loose to offer temporal support on the sides of the trench.

Timbering process

The timbering is made by placing vertical polling boards opposite each other against the walls of the trench and holding them in position by use of one or two rows of struts.

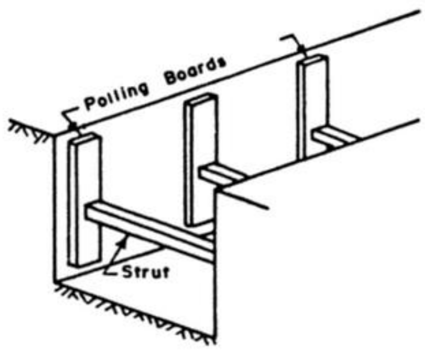

Figure 166: Timber vertical polling boards
Source: Building construction (punmia *et al*, 1987)

Dismantling process

Dismantling of a trench timbering is done under a supervision of a competent person to avoid the structure from collapsing. The trench timbering are dismantled step by step from below in a reverse order in which they were installed

Importance of trench timbering

a) To support the trench when;
   - The soil is loose
   - The trench is large
b) For the security of the workers

2.2 Construct and dismantle building formwork/shuttering according to standard construction procedures

A formwork is a process of creating temporary molds into which fresh concrete is poured and formed to make designated shapes. Formwork can be made of steel, wood or even fiber glass.

Steps in construction of formwork are as follow;

i. Using measuring tools such as a measuring tape measure and indicate borders of concrete slabs
ii. Guided by a string, frame the area
iii. Lay gravel at the base of the formwork
iv. Pour concrete inside the formwork

The formwork is dismantled only when the concrete has gained sufficient strength. Also, ensure stability of the remaining formwork during removal.

Steps followed in removing formwork are as follows;

i. Ensure that the concrete had dried before removing the formwork
ii. The forms are removed starting at the top of the sloping slabs
iii. Remove the stakes by use of a stake puller to avoid damaging the slab
iv. Use a little force to pull the forms away from the sides of the concrete

2.3 Erect and dismantle building scaffold according to standard construction procedures

Scaffold is a temporary platform that is erected before commencement of construction or repair of a structure to ensure safety of workers, provide support on heights and also provide material during construction

Recommended steps in making a scaffold

i. Ensure that the foundation to the scaffold is secure to avoid settling of the scaffold
ii. Assemble the scaffold frame and place the planks
iii. Make an access to the scaffold
iv. Attach guardrails to the scaffold
v. Ensure that the scaffold is safe to work with

Dismantling of a scaffold is trained by a competent person.

Importance of scaffolds in building construction

- Ensure safety of workers
- Easy access of different parts of the building like the ceiling
- Provide a working area for workers

2.4 Erect and dismantle building shores according to standard construction procedures.

Shores are made to offer support to an infrastructure which is at a risk of collapsing. Shores maybe made angled, horizontal of vertical. Shores carry vertical loads from the walls.

Types of building shores and how they are made

Raking shores-made by joining one or more timbers connecting the ground and the surface of the structure to be supported

Hydraulic shoring- a hydraulic piston is pumped outwards until it presses against the face of the structure to be supported

Flying shoring- in this technique, horizontal strut is placed between the wall plates and is supported by a system of needle and cleats.

Dead shoring- The dead shore consists of an arrangement of beams and posts which are required to support the weight of the superstructure and transfer same to the substructure

Shores should be dismantled by a trained person. The shores are removed when the concrete has gained enough strength to support itself

Importance of shoring in construction

Safety- ensure safety of the work site by holding the earthen wall up

Lower cost-reduce the possibility of collapsed excavations

Save time- if trench collapsed, more time would be spend in digging it out again, therefore avoiding the collapse saves more time

Conclusion

This learning outcome covered the building of temporary works that form the basis of the actual building works of erection and dismantling of support systems in construction.

Further Reading

Read more on process of execution of superstructure works in a building

16.3.3.3 Self-Assessment

Written Assessment

1. Among the following, which one is the old one out?
    a) Raking shores
    b) Flying shores
    c) Dead shores
    d) Live shores
2. Formwork can be classified into various classes. Which one of the following is not?
    a) Engineered formwork
    b) Timber formwork
    c) Insulated formwork.
    d) Concrete formwork

3. Which among the following is not a step in construction of formwork?
    a) Using measuring tools such as a measuring tape measure and indicate borders of concrete slabs
    b) Guided by a string, frame the area
    c) Lay gravel at the base of the formwork
    d) Pour water on the gravel
4. Evaluate how formworks are made.
5. What is the difference between scaffold and shores?
6. Evaluate three types of shores
7. Illustrate steps of constructing a formwork

Oral Assessment

Describe the importance of scaffolding

Project Assessment

Design a trench timbering to support the trench in your area.

16.3.3.4 Tools, Equipment, Supplies and Materials

Tools and equipment

- Measuring and drawing tools
- Computers/internet
- Printers/plotting device
- Calculator

Materials and supplies

- Codes of practice
- Mechanical conventions,
- 5site office
- Standard manuals and guidelines

Personal protective equipment (PPEs)

- Dust coat
- First aid kits

16.3.3.5 References

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16.3.4 Learning Outcome No 3: Execute Substructure Works

16.3.4.1 Learning Activities

Learning Outcome No 3: Execute Substructure Works	
Learning Activities	**Special Instructions**
3.1 Excavate building foundation 3.2 Set out the building 3.3 Lay the building foundation 3.4 Erect foundation walls 3.5 Construct solid ground floor	• Conduct setting out procedure and provide the necessary tools and equipment • Perform soil analysis

16.3.4.2 Information Sheet No16/LO3: Execute Substructure Works

Introduction to learning outcome

This involves the building of structures below the earth surface on site as guided by the standard construction procedures. These structures include the foundation or footings.

Definition of key terms

Foundation: This is an engineered system that transfers to and into the beneath soil or rock the loads supported by the foundation and its self-weight

Setting Out: this is a term referring to marks and line formation in order to define the position of the elements and their levels for the building works so that works may proceed with reference to them.

Content/Procedures/Methods/Illustrations

3.1 Excavate building foundation according to standard construction procedure

Excavation: refers to the process of removing soil, rock and other non-decomposing materials with tools, equipment or explosives. Excavation is used in building works to create foundations for structures. Excavation of building foundation involves several activities. These activities include:

Clearing the site before excavation, setting out of foundation layout before excavation and carrying out an actual excavation

- How Excavation for foundation is carried out

Excavation is carried out manually using the available tools like the spades, pick axes etc. in small building works. In the case of big constructions and deep excavations, mechanical earth moving machines like excavators and back hoes can be used.

3.2 Set out the building according to standard construction procedures

Setting out of a building is done in order to clearly define the outline of the excavation and the Centre line of the walls so that the construction can be carried out exactly according to the plan. Building setting out methods include

- Pegging method
- Blocks method

Setting out using pegging: this is done after obtaining the architectural building plan and the site has been cleared.

STEPS (according to the contractor website)

i. Initially, consider all the corners where the proposed columns or pillars will be situated and establish the corners relative to the dimension of the building floor plan and peg it.
ii. Hit nails at the middle – top of each peg and run a rope round all the pegs. Considering just one, measure the setback from back of the fence to the end of the building lines in that particular angle, then come to the front and measure the setback also as given in your drawing plan.
iii. Then use the back or the front as a reference depending on which setback is more important to you. Measure the setback from fence and establish these two points with pegs then put a rope to cross both pegs. Ensure they form a right angle or 90 degrees. To determine if your rope are at right angle, put a checker popularly called 'square' by bricklayers, this will tell you whether you need to shift the other rope that can be varied since one is already fixed to form a base mark.
iv. Next step is to ensure that your measurement correspond to the measurements on the drawing plan and then establish the other two points using the square.
v. Nail pegs at an interval of 3m round below the rope that marks your building line, then join the tie rods by nailing (flat thin wood) on top around the entire area.
vi. Institute the individual rooms measurements by nails (4 nails are required at each measurement) two will establish the two sides of the blocks one is going to excavate, the length of this is usually three times the width of the block that is being used.
vii. In accordance with the details in the plan, mark with line the width to be excavated with pegs at appropriate positions. The excavation width is marked using lime or by furrow with spade.

viii. The depth dug depends on the foundation type as recommended by your structural engineer.
ix. Cast the concrete bed/base
x. The next step is to determine where your blocks will follow by using the nails on your profile board. Set blocks 3-4 or more courses or partitions in reference to the topography of the site.
xi. All the trenches on the surface should be filled and then backfilled.
xii. Cast the solid floor slab for the ground or the oversite floor.

3.3 Lay the building foundation according to standard construction procedures

Steps for laying a foundation of a building

i. Select the type of foundation to build. The choice will depend on the type of superstructure it will support and the type of soil among many others.
ii. Set your footings 2 feet (0.61.) (60.96cm) crosswise. Add 2 feet on either side. This will ensure that the formwork is properly spaced and allows one to get the space they need for foundation laying.
iii. Arrange your 2inch wide by 10-inch-long (5.08cm wide by 25.4cm long) boards to make the footings formwork. Position and lay down the boards in the planned foundation shape and size.
iv. Straighten and level the form. The forms cannot be adjusted after the concrete is poured. Since the concrete is very weighty, make sure your formwork is strong and firmly in place.
v. Form the concrete by adding all the mixtures in proper ratio and mix thoroughly to come up with a uniform mixture.
vi. Pour the already made concrete in the form to make concrete foundation and then level using a trowel.
vii. Finish your concrete by letting it dry and carry out curing

Figure 167: Concrete by letting it dry and carry out curing
Source: Design building.com – foundation construction building site.

3.4 Erect foundation walls according to standard construction procedures

Several materials exist for making the walls for foundation. These materials can be rocks, concrete blocks, sand – cement, or stabilized earth materials. The choice of all the above-mentioned materials will depend on the availability of these material, the client's budget, and whether or not earthquakes or severe weather conditions will require reinforcement in the foundation.

How to erect foundation walls

i. Lay the blinding and cast the foundation
ii. Lay an impermeable material/layer on the predetermined positions
iii. Allow the combination to cure
iv. Cut the blocks and lay the subsequent course blocks
v. Add the reinforcements
vi. Finish the joints
vii. Lay the cap blocks

3.5 Construct solid ground floor according to standard construction procedures

The formation method of a solid concrete slab involves the construction of formwork, placing and reinforcement of the floor.

Construction steps

i. The first step is to combine and put up formwork.
ii. The second step is to put in order and place the reinforcements as directed by the structural engineer.
iii. The third step is to pour, compact and finish the concrete.
iv. The final step is curing and removal of formwork.

Conclusion

This learning outcome covered the execution of foundation building and construction of ground floor as per standard construction procedures.

Further Reading

Read on the types of foundations, the block method of setting out and the circumstances under which all the foundation types are used**.**

16.3.4.3 Self-Assessment

Written Assessment

1. Which one of the following is not a shallow foundation?
    a) Spread
    b) Strap
    c) Pile
    d) Combine
2. The following are not substructure element in building works, which one is?
    a) Foundation
    b) Roof
    c) Beams
    d) Columns
3. which one of the following is a not a deep foundation
    a) Pile
    b) pier
    c) strip
    d) caissons

4. The following activities are carried out during the construction of substructures. Which one is not
    a) Dewatering
    b) excavation
    c) setting out
    d) Finishing
5. In what circumstances are shallow foundations preferred?
    a) In case the client orders that a shallow foundation should be used
    b) When the construction cost is high and using a shallow foundation will cut the cost
    c) When the soil surface is hard and stable
    d) When the contractor is only perfect in construction of a shallow foundation
6. under what circumstances do we use deep foundations
    a) In case the structural engineer specifies so
    b) When the soil is stable and hard
    c) When the construction equipment is available
    d) When the contractor prefers deep foundation over shallow foundation
7. Why should the surface be excavated before the foundation is laid?
    a) To show that construction is yet to begin
    b) To remove top humus soil that are not favorable for laying of foundation
    c) To get soil used for construction
    d) To increase the number of construction days in order to increase the labour cost
8. Classify and evaluate the four types of foundations
9. Evaluate three equipment and tools used in excavation process
10. Distinguish the methods used to set out the building
11. Differentiate between the shallow and deep foundation
12. Explain the methods used to control termite in the site during the construction of substructure

Essay questions

1. Summarize the different activities that are carried out during excavation process
2. Discuss some of the tools that are used in the construction of substructure of a building.
3. Distinguish the circumstances under which dewatering is recommended and evaluate its importance.

Oral Assessment

1. Distinguish the role of an engineer in the construction of a substructure?
2. Explain the factors considered during the construction of a substructure?
3. Evaluate the importance of dewatering during the excavation process?
4. Why is it necessary to compact the ground after excavation?

5. What are the requirements to be met before walling begins?
6. What are the failure signs in the substructure?
7. Evaluate causes failure of the substructure?

Case Study Assessment

The county government of Siaya is planning to set up a training institute at ganja town. The site has been identified and from the soil study analysis, the site is underlain by expansive clay soul to a depth of 20 cm deep resting on a hard rock surface. Adjacent to the site is a water logged plot. As a fresh graduate from the institution, you have been selected by the county engineer to assist in the construction and supervision of the substructure of the administration building. You are tasked with the excavation works, setting out and laying of the foundation. How will you ensure that these works are successfully executed?

- During curing of a pad foundations of a two bedroomed house, you notice that the levels of the reinforcement bars are not equal, as a trainee technician, what action you should take. What could have caused this scenario?

Project Assessment

Your school has decided to construct a new female house. It is a two storey building. Both the architectural and structural drawings are available and the contractor is ready to start the construction work. As a student, you are tasked to visit the site and carry out some studies. Afterwards, you are tasked with coming up with a detailed report of the stepwise activities that were carried out at the site until the substructure of the building was complete.

16.3.4.4 Tools, Equipment, Supplies and Materials

Tools and equipment

- Measuring and drawing tools
- Computers/internet
- Printers/plotting device
- Calculator

Materials and supplies

- Codes of practice
- Mechanical conventions,
- Site office
- Standard manuals and guidelines

Personal protective equipment (PPEs)

- Dust coat
- First aid kits

16.3.4.5 References

Cao, J., Wang, W., Wang, J., & Wang, R. (2016). Excavation equipment recognition based on novel acoustic statistical features. IEEE transactions on cybernetics, 47(12), 4392-4404.

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16.3.5 Learning Outcome No 4: Execute Superstructure Works

16.3.5.1 Learning Activities

Learning Outcome No 4: Execute Superstructure Works	
Learning Activities	**Special Instructions**
4.1 Set out and construct superstructure columns 4.2 Set out and erect superstructure walling 4.3 Set out and construct superstructure beams, stairs and upper floors 4.4 Set out and erect building roof 4.5 Construct the fire place 4.6 **Fixtures** (electric sockets, light fixtures, plumbing installations, security and fire alarm systems) and **fittings** (furniture, hand driers, soap dispensers, towel hangers, cabinets) are installed	• Ensure the setting out procedure is based on the construction method used.

16.3.5.2 Information Sheet No16/LO4: Execute Superstructure Works

Introduction to learning outcome

This involves setting out, erecting and constructing the superstructure's columns, walls, beams, roof among other structures.

Definition of key terms

Fixtures: these are permanent equipment that are installed in a building to enhance client's satisfaction. They include the installation of sockets, water plumbing lines, alarm systems among many others

Fittings: are the temporary equipment that are brought in a building to enhance comfort. They include the furniture, electrical appliances, curtains etc.

Content/Procedures/Methods/Illustrations

4.1 Set out and construct superstructure columns based on the construction method

Column are compressional members that supports the loads from the beam or the slabs. In some cases they support moments as well. Columns are set out in accordance to the specification by the structural engineer. Before casting the columns, form work is first done. The forms will ensure that the lean concrete is held place. The already mixed concrete is then dispensed and compacted in order to avoid void formation as the concrete dries.

Steps for constructing a column.

i. Column layout work- the location is done essentially in the construction site by laying a rope as per the grid lines shown in the structural drawing plan
ii. Reinforcement of column work - when column marking is done, then the column location is done. However the reinforcement is done according to structural drawing
iii. Formwork for the column- it is used to grip the poured concrete in place
iv. Pouring of concrete- can be done manually or using machine or pump

4.2 Set out and erect superstructure walling based on the construction method

Several materials exist for the construction of walls. These materials are; glasses, masonry blocks, bricks and stones. The choice of these materials depend on the client's preference, the design specifications and the availability of materials. The walls are constructed in accordance to the specifications of both the structural engineer and the architecture. The mixtures must comply with the mix ratio design.

Steps for constructing masonry block wall

i. After the foundation has cured, lay the first course block
ii. Cut the blocks and lay the subsequent course blocks
iii. Add the reinforcements
iv. Finish the joints
v. Lay the cap blocks

Figure 168: Constructing masonry block wall
Source: The contractor website – reinforced concrete masonry wall

4.3 Set out and construct superstructure beams, stairs and upper floors based on the construction method

Beams are structural members that carry the axial compression loads as well as the moments and torsion. They carry weight from the slabs and transfer them to the columns. They are set out in places pre identified by the structural engineer. They are constructed according to the structural engineer's specifications. The reinforcements are first laid followed by form work then pouring of the already prepared concrete then vibration of the same. Stairs are meant to carry the lateral loads like wind and earthquake. Upper floors transits their dead loads and imposed loads (total loads) to the beams then to the columns and finally to the foundations.

Steps for setting out and constructing beams

i. Preparation and excavation of the ground for the beam in case the beam is located below the ground surface.
ii. Formwork installation for the beam
iii. Beam reinforcement as per the structural engineer specification
iv. Pouring of concrete into the formwork

Figure 169: Pouring of concrete into the formwork
Source: YouTube – tie beam fitted on foundation to construct a home

Steps for laying solid upper floors

a) Assemble and Erect Formwork- this will provide a base for laying the reinforcements
b) Prepare and Place Reinforcement- this should be done according to the specifications by a structural engineer
c) Pour, Compact and Finish Concrete- this will ensure that the thickness of the solid slab is uniform
d) Curing Concrete and Remove Formwork- curing increases the compressive strength of the concrete

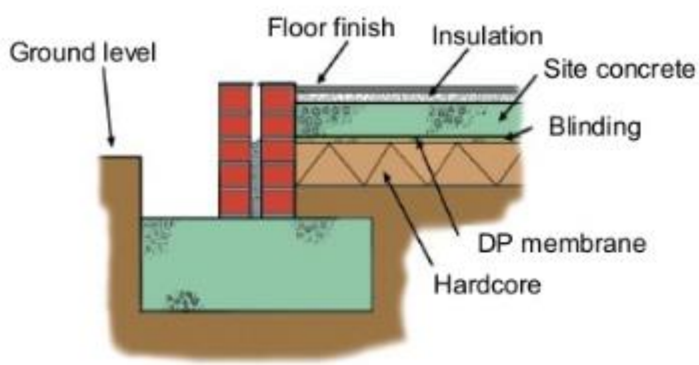

Figure 170: Curing Concrete
Source: slide share – section of solid ground floors

4.4 Set out and erect building roof according to standard construction procedures

Roof is the top most structure in a building. It can be made of tiles, iron sheets or concrete. The choice depends on the design, available materials and the client's preference. The roof is designed by the structural engineer and the dimensions given to the contractor. The type of the roof chosen depends on the design of the building

Steps for iron sheet roof construction

i. Preparation of trusses according to the drawing
ii. Preparation and joining of ties
iii. Joining of trusses to the ties and other members according to the drawing specifications
iv. Nailing of the iron sheets

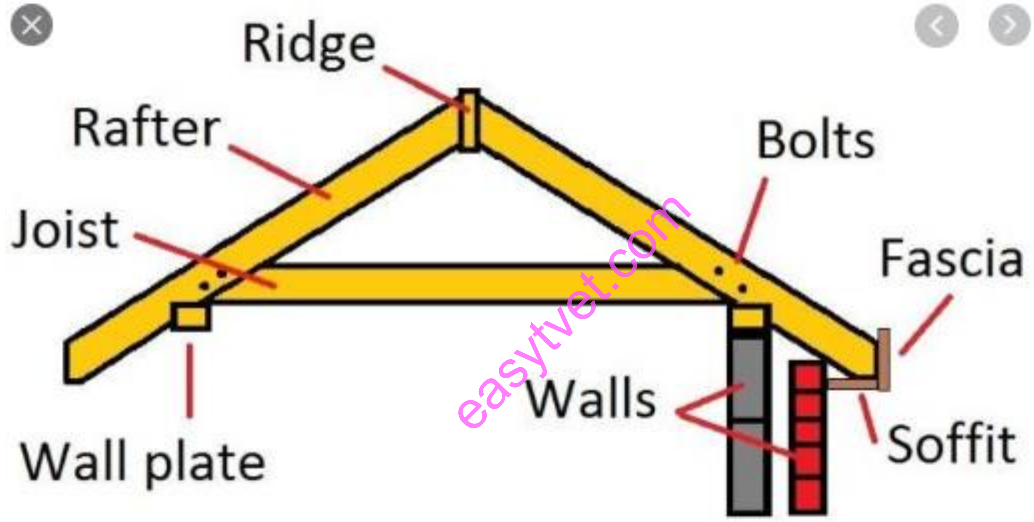

Figure 171: Erect building roof according to standard construction procedures
Source: Carpentry tips and tricks

4.5 Construct the fire place according to standard construction procedures

A fire place is specially designed and set aside for the purpose of heating the house and keeping it worm during cold seasons. It is constructed with high heat resistant concrete and it must be well ventilated.

Steps for constructing a concrete fire place

i. Assemble and erect formwork- this will provide a base for laying the reinforcements
ii. Prepare and place reinforcement- this should be done according to the specifications by a structural engineer
iii. Pour, compact and finish concrete- this will ensure that the thickness of the solid slab is uniform

iv. Curing concrete and remove formwork- curing increases the compressive strength of the concrete
v. Construct the walling and provide for ventilation.

4.6 Fixtures which are the permanently installed equipment in a building are installed according to standard construction procedures.

Process of installing electricity on an already built house

i. Assembling of the pipes and conduits
ii. Aligning the positions that the conduits will follow
iii. Mark the lines where the pipes will follow
iv. Dig the marked line positions
v. Insert the pipes and the wires as directed by the electrician
vi. Hide the pipes by plastering them.

Conclusion

This learning outcome covered the setting out and construction of the superstructure works and installation of required fixtures and fittings as per the standard construction procedures.

Further Reading

Read further on the types of staircases, the types of fittings and on the factors controlling the design and construction of the superstructure.

16.3.5.3 Self-Assessment

Written Assessment

1. The following are superstructures except one. Which one is it?
   a) Beams
   b) Columns
   c) walls
   d) Footings
2. The following are compression members except one. Which one is it?
   a) Masonry wall
   b) column
   c) Beam
   d) Ties

3. What is the main function of form work in the construction of superstructure?
    a) To add on the strength
    b) To ease curing process
    c) To hold the lean concrete
    d) To make the work look more structural
4. Which of the following materials listed below is not suitable for the construction of a wall?
    a) Concrete blocks
    b) masonry blocks
    c) bricks
    d) synthesized cotton
5. Which one of the listed materials is not suitable for roof construction?
    a) Corrugated iron sheets
    b) tiles
    c) concrete
    d) plastics
6. Differentiate between fixtures and fittings
7. Explain the circumstances under which the column carry loads from the slab
8. Explain the conditions should be met during the construction of a fire place
9. Discuss the advantages of curing
10. Classify all the superstructure elements
11. Explain the term super structure

Essay questions

Discuss all the structural members in the super structure outlining their functions

Discuss all the factors that determines the choice of each of the materials used in all the super structures.

Oral Assessment

Differentiate between a sub structure and a super structure

Distinguish all the structural elements in each case.

Case Study Assessment

The Nairobi city council has decided to renovate their offices to make them look more modernized. The contractor whom you are working under has been tasked with the same. As his most trusted employee, he sends you to access the condition of the superstructure and list down all the fixtures and fittings that should be included. As a loyal employer, give a detailed report on the same to your employer

Practical Assessment

In your school vicinity, identify all the super structure structural elements and give their functions.

Project Assessment

Come up with a model showing all the substructure and superstructure elements. Indicate the materials they are made of and show how the loads are transferred.

16.3.5.4 Tools, Equipment, Supplies and Materials

Tools and equipment

- Measuring and drawing tools
- Computers/internet
- Printers/plotting device
- Calculator

Materials and supplies

- Codes Of Practice
- Mechanical Conventions,
- Site Office
- Standard Manuals And Guidelines

Personal protective equipment (PPEs)

- Dust coat
- First aid kits

16.3.5.5 References

Malley, J. O. (2007). AISC Seismic Design Manual: Moment Frames. In New Horizons and Better Practices (pp. 1-3)

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16.3.6 Learning Outcome No.5: Execute Building Finishes

16.3.6.1 Learning Activities

Learning Outcome No 5: Execute building finishes	
Learning Activities	**Special Instructions**
5.1 Apply Floor ***finishes*** 5.2 Paint building surfaces 5.3 Apply building facings 5.4 Apply ***Wall finishes*** (5.5 Apply ***Ceiling finishes*** (5.6 Carry out pointing and jointing 5.7 Perform building rough casting	• Attach demonstration videos on how finishes are executed in building works.

16.3.6.2 Information Sheet No.16/LO5: Execute building finishes

Introduction to learning outcome

This unit focuses on building finishes that involves building surfaces and facings; floor, wall and ceiling finishes, as well as rough castings as per standard construction procedures.

Definition of key terms

Floor finishes-This is usually a permanent film applied to a floor in order to extend its life and act a protection. The covering also serves to provide an attractive appearance and friction preventing slipperiness.

Wall finishes-It's a film or a layer applied to the wall to enhance its look as it provides a decorative look either on the interior or exterior of a given structure.

Ceiling finishes- It's a layer to provide an embellishing skin to hide the components that have been used in building including structural members, wires, pipes, insulations and ductworks.

Content/Procedures/Methods/Illustrations

5.1 Apply Floor finishes (tiles, cement sand screed, terrazzo, wood parquets, and carpets) according to standard construction procedures.

Floor finishes are permanent films applied to a floor usually to extend its life and act as a protection. They also prevent slipperiness and appealing to the eye. Applying floor finishes in accordance to the standard construction procedure varies according to the type of floor finish. The following are the various standard procedures for applying the various floor finishes. Procedures;

i. Tiles

The type of tiles to be selected depends on the functional use and location. Substrate surface should be clean to ensure good bonding. Screed should be given ample time for curing by air according to the manufactures instructions. Provide level pegs before screeding then apply a slurry bond then the screed is laid immediately then levelled. Moisture content of the substrate is checked by the relative humidity method. The cement-sand render should also be allowed to air cure for at least 7 days.

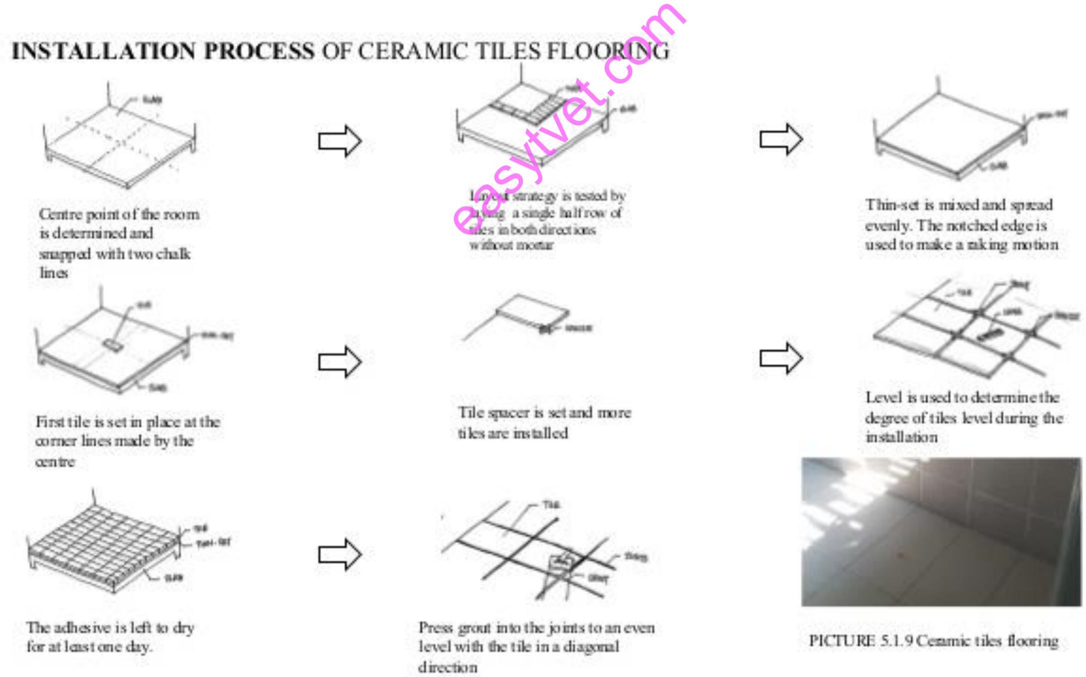

Figure 172: Installation process of ceramic tiles flooring

Source; https://image.slidesharecdn.com/buildingconstructioniireport-160714013425/95/building-construction-ii-report-47-638.jpg?cb=1468460102

ii. Cement Sand Screed

Check for the screed specification which should be according to the BS code of the practice requirements and ensure that the data sheets tally with the BS8000 and BS820. Inspect for the levels of base substrate for the attainment of the maximum or minimum screed thickness. Check for screed mix; required mixing proportion for normal cement and sand screed is 1:3 to 1:5. Check for batching and mixing requirements i.e. water and cement content and grading of the aggregate. Laying and compacting is followed by curing of screed, protection and testing.

i. Terrazzo

The materials should be thoroughly mixed for a uniform look (appearance). Uniform panels of not more than 2 sqm in neither area nor 2m long for the inner areas while for exposed areas it shouldn't be more than 1.25m long.2kg of cement slurry should be applied for every sqm before the under layer is laid over the cement concrete. Strips of specific thickness can be used as required. It's then laid when the under layer is hard, this is in order to stop the cement that might travel to the top surface. The figures below show the procedure for laying terrazzo over the ground and over a structural slab;

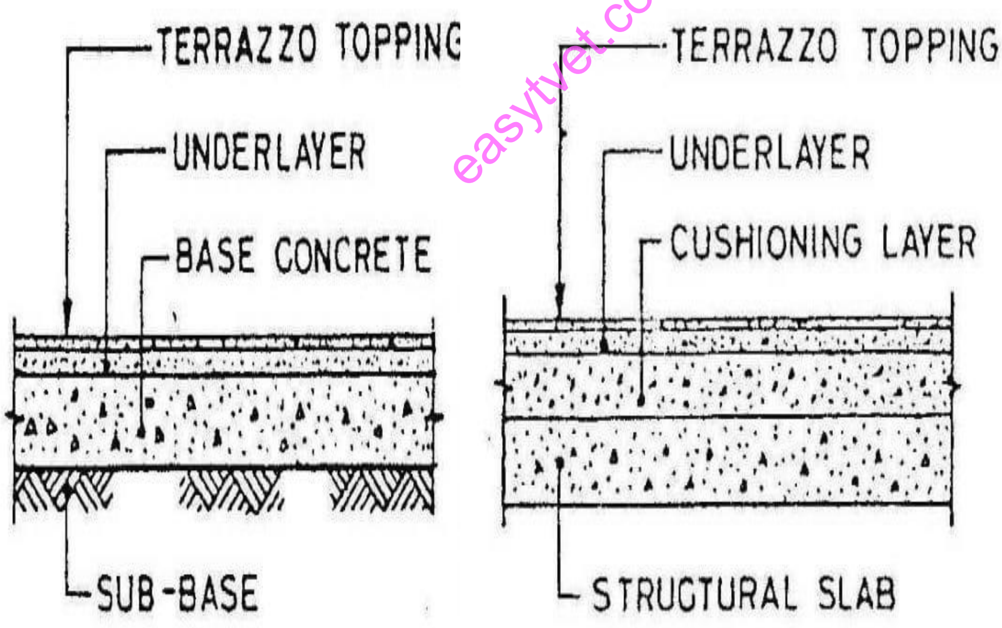

Figure 173: Installation process of terrazzo

Source;https://theconstructor.org/wp-content/uploads/2010/10/Terrazzo-flooring-laid-over-the-structural-slab-557x380.jpg

ii. Wood parquet

The first step is to carry out moisture content test of the underlying concrete slab. A film of 6-mil polyethylene is placed over the slab without mastic bonding. Then the plywood is then laid over the above film with the reinforcement of actuated nails made of concrete. Each panel takes about 9 nails of concrete. The arrangement of the panels is such that the end joints are staggered at 4 ft. The following illustrates the various patterns employed when installing wood parquet;

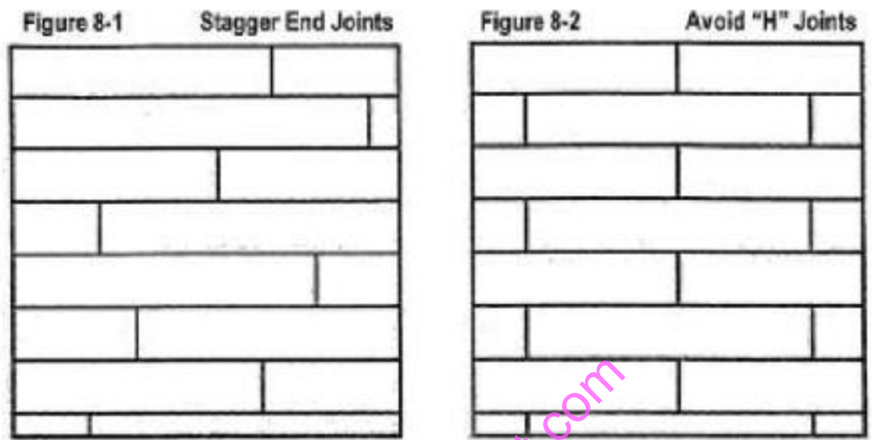

Figure 174: Wood parquet
Source; https://www.oldewoodltd.com/uploads/nwfa-figure8-1-xl-1-w800.gif

iii. Carpets

Broadloom Carpet entails various procedures as stated here; Carpet seaming that should be done according to the manufacturer's recommendations, trimming i.e. the seams, sealing the edges/seams, edge sealing. There's also the stretch-in installation that entails installing the carpet under tension using tack strips.

5.2 Paint building surfaces according to standard construction procedures.

Paint building of surfaces is done to bring colour, give a good texture and protect the surfaces. The painting of buildings should be in accordance with the British Standard codes that give for design considerations, selection of coating systems, special conditions and requirements, preparation and coating systems, surface preparations. Painting of plastered surfaces can be troublesome due to presence of moisture levels in the material of plaster. Painting entails 5 steps;

1. Primer application
2. Wall putty application
3. Second putty application
4. The selected paint is the applied according to the type of surface
5. Then a repeat application of the paint

5.3 Apply building facings according to standard construction procedures

Building facings entails building a wall in a manner to be called a facing of any of two wall faces. The bricks used are usually hard enough to safely carry loads. The procedure for obtaining a facing is usually by joining bricks together except that other substitute materials can be used e.g. tiles. It's a range of bricks hard-burned to be able to support normal loads and be able to withstand adverse climatic conditions.

5.4 Apply Wall finishes (wall mastering, wall lining, and clad building walls) according to standard construction procedures

These finishes are for protection and aesthetic and can either be interior or exterior finishes. The procedures for good wall finishes require; that they are straight and plumb, smooth surfaces and the combustible free. Finishes are selected according to the functional use and availability. The following are the steps for carrying out the various types of finishes;

i. Give time for brick to cure depending on type of construction material then allow the masonry brick to also cure
ii. Get the mortar ratio i.e. of cement and sand
iii. Next is to plaster the wall and give time to cure
iv. Surface preparation by rubbing by a wall plaster
v. Then the specific type of finish is applied

5.5 Apply Ceiling finishes (boards, T and G, gypsum board, acoustic ceilings) according to standard construction procedures

Ceiling finishes- It's a layer to provide an embellishing skin to hide the components that have been used in building including structural members, wires, pipes, insulations and ductworks. These are to be applied according to the manufacturer's instructions and detailing. The procedure for ceiling finishing involves the stated steps;

i. The ceiling is first chipped
ii. Its then washed by water which is then covered by cement grabbed
iii. The grabbing cement is covered by a mortar and the specific type of ceiling applied

5.6 Carry out pointing and jointing according to standard construction procedures

Jointing is defining the mortar joints finish between bricks in order to bring a about a neat joint. Flush joints are mostly used for brickworks for uniform bricks with surfaces that are smooth. Pointing is an operation that entails filing a joint with a material that has been uniquely selected for authenticity or protection against adverse weather conditions.

The process of jointing involves;

i. Cutting a cross joint
ii. Filling the cross joints first, and then the pointing mortar pressed firmly to compaction

The process of pointing is rarely done on brick layers and it involves first clearing of loose debris and then the place wetted before pointing.

5.7 Perform building rough casting according to standard construction procedures

Rough casting refers to applying a spatter dash finish to a building. Small pebbles and gravel or other materials are usually mixed into the concrete to create a rough finish. The finish is applied in a thickness equal to that of the board by pressing out. The following is the procedure for rough casting manually;

i. The wall is first cleaned and repaired if need be
ii. The wall is then dampened in preparation for the first mix
iii. Cement is chosen i.e. general cement or white cement
iv. Selection of gravel or stone to be used and sand then mixed
v. Water proofer and plasticiser is added to the mix then base coast applied
vi. Base coat is scratched then the second and final coat is applied.
vii. The sprayer is filled with the mixer then finally is clean up

Conclusion

This learning outcome covered the application of finishes such as floor, wall and ceiling finishes as per the construction procedures.

16.3.6.2 Further reading

Read more on:

1. Slide share on Wall finishes by Swapnika Reddy
2. Building Finishes, Fittings and Domestic Service by Chudley,R, R

16.3.6.3 Self-Assessment

Written Assessment

1. Which of the following is not a type of floor finish?
    - a) Tiles
    - b) Wood parquets
    - c) Terrazzo
    - d) Boards
2. Finishes fall in 2 categories except?
    - a) Self-finish and wet finish
    - b) Slippery finish and dry finish
3. The following are examples of wet finishes except?
    - a) Plaster
    - b) Paint
    - c) Wallpaper
    - d) Wood
4. The following are factors that affect the choice of floor finishes except?
    - a) Type of Base
    - b) Room usage
    - c) Cost
    - d) Colour
5. Floor finishes can be considered under the following 3 main heading. Which is not?
    - a) In situ
    - b) Applied
    - c) Timber
    - d) Gypsum
6. Explain the various methods of application of wood parquets?
7. Distinguish two types of floor finishes?
8. Differentiate between pointing and jointing?

Essay questions

Categorize various types of finishes

Describe the application of the terrazzo finish according to standard construction procedures.

Oral Assessment

What is a finish?

State the various types of finishes done on a building?

Case Study Assessment

A case study on the durability of terrazzo finishes over cement sand screed in buildings in Nairobi CBD

16.3.6.4 Tools, Equipment, Supplies and Materials

Tools and equipment

- Computers/internet
- Printers
- Calculator
- Measuring tools
- Trowels
- Rollers
- Jointer tool
- Polishers

Materials and supplies

- Codes of practice
- Site office
- Standard manuals
- Guidelines

PPE (Personal protective equipment);

- Overalls
- Reflectors
- Helmet
- First Aid Kits

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BS 5385-5 (2011) Wall and floor tilling. Design and installation of terrazzo, natural stone and agglomeration stone tile and slab flooring. Code of practice

16.3.7 Learning Outcome No. 6: Execute Building External Works

16.3.7.1 Learning Activities

Learning Outcome No 6: Execute Building External Works	
Learning Activities	**Special Instructions**
6.1 Lay external paving 6.2 Perform soft landscaping 6.3 Construct drainage system 6.4 Construct ***fences*** and gates	• Carry out group discussions on various external works • Carry out a project on external works

16.3.7.2 Information Sheet No16/LO6: Execute Building External Works

Introduction to learning outcome

This involves learning the external works from design interpretation, measurements to the actual building.

Definition of Key terms

Fence: It's a structure that serves as wall except that it doesn't have a solid foundation throughout its length. It encloses a given perimeter most of the cases outdoors and can either be a temporary or permanent structure.

Content/Procedures/Methods/Illustrations

6.1 Lay external paving based on the mode of construction

Laying of external paving basically entails laying pavements which is an outside floor that can be made of a variety of materials like concrete, asphalt, variety of stones and in some cases wood. Whether one is planning to install a brick, concrete or stone pavers, the following paver installation steps should help. The following are the steps that should be followed as briefly discussed;

a) **Planning and layout**

Decide whether your pavers will go and determine if there is enough space for them. Your plan can be drawn out and measured using graph paper.

b) Number of pavers required

The dimensions (length and width of the area) then calculate the area which is the square footage. Give an allowance of 5%

c) Excavation

Estimate the height the slabs should reach. After excavation temporary border is to be established.

d) Laying of the base material

This should be laid to a thickness that's tallies with the use planned for the pavers. The materials consists of crushed rocks of diverse sizes then compacted.

e) Jointing by sand

Basically involves sweeping sand over the pavers so as to fill the in between joints.

f) Sealing

The area after paving is first cleaned then sealed with a sand binding sealant preventing the sand from disappearing. Sealing also prevents stains and allows for easy cleaning.

g) The final step is maintenance that includes re-sealing, sweeping, regular cleaning.

The following figure demonstrates how to lay external pavers;

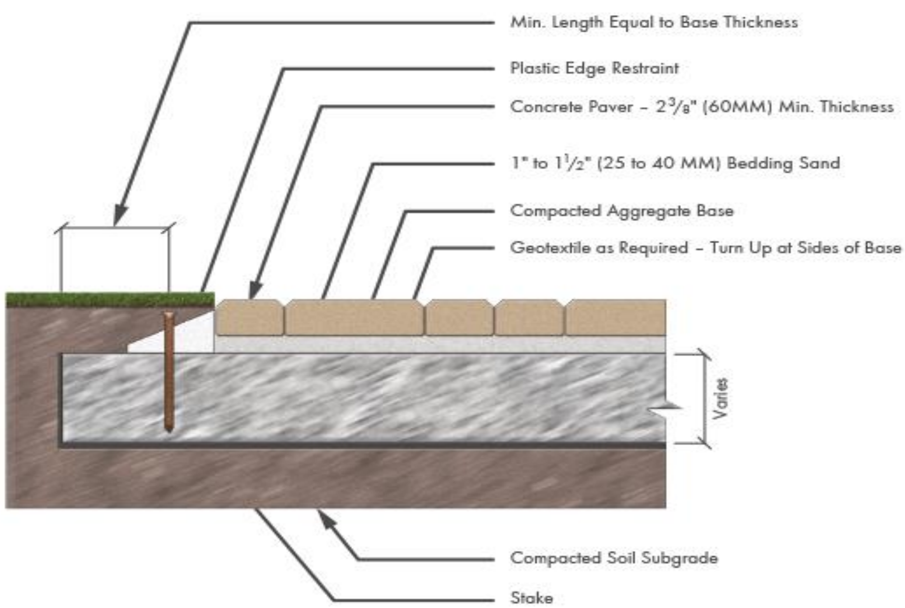

Figure 175: how to lay external pavers

Source; http://www.claytonco.com/assets/images/gsp/installation/installation-guide.gif

6.2 Perform soft landscaping based on the mode of construction

Soft landscaping involves operations on elements of landscape which are not construction related. Soft landscaping could involve working on trees, grasses, shrubs. Performing soft landscaping includes the following elements;

a) Top soiling preparation; Subsoil should be properly compacted and thoroughly broken down.
b) After soil preparation is cultivation to a depth of at least 100mm, weeding and cleaning of the area is also done at this stage.
c) Turf should be specifically provided by the contractor as proposed and should comply with the BS 3969
d) Planting whereby all the plants should comply with BS 3936 specifications
e) Mulching is done to provide a hedge around the planted grasses or trees
f) Protection of the grasses and trees at the hedges
g) Trimming of the grass at intervals as it grows and maintained at certain prescribed level.

6.3 Construct drainage system based on the mode of construction

A drainage system is the artificial or natural removal of water either from surface or sub surface of an area that has excess water. Construction of a drainage system based on the mode of construction involves the following steps;

i. Along the outside of the footing, a trench is dug that is at least 2 ft. wide. Depth can vary up to 6ft or as shallow as 2 ft.
ii. The pipe is the laid on the undisturbed soil i.e. with the grade sloping away from the house to allow for the water to flow away by gravity
iii. The pipe should then be covered by washed gravel (at least 12 inches)
iv. A filter is then laid over to prevent clogging of the pipe
v. The top soil is back- filled to its original grade height.

Below is a schematic of a drainage system;

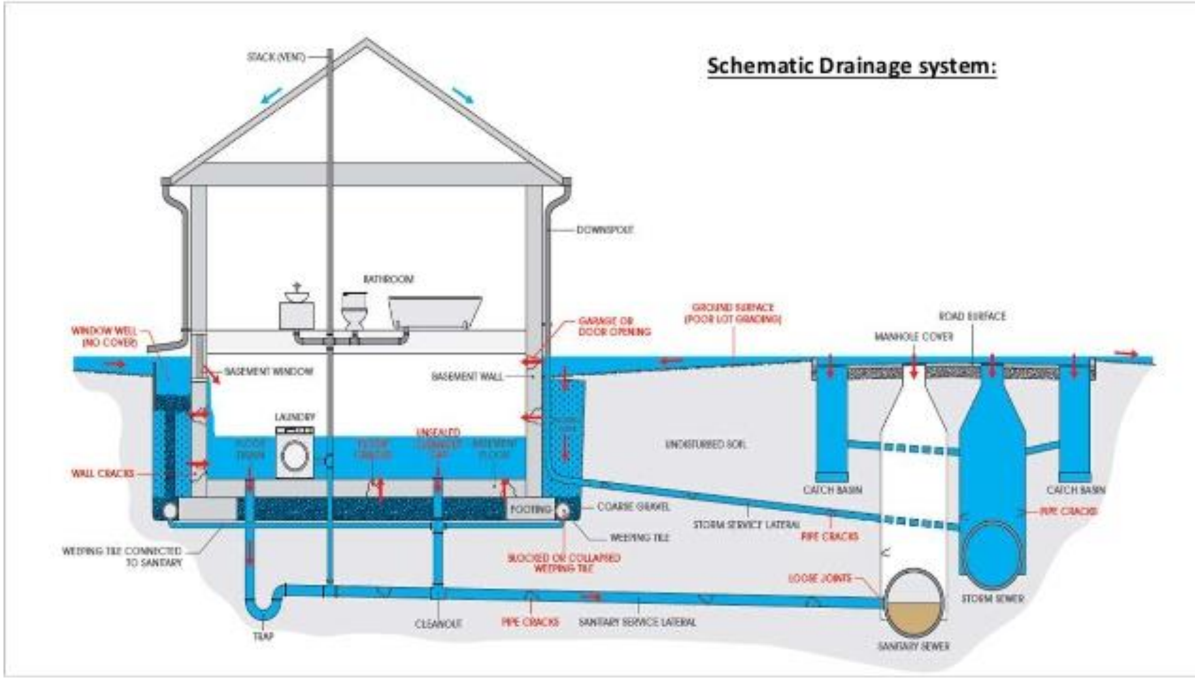

Figure 176: Schematic of a drainage system

Source; https://image.slidesharecdn.com/myppt-160811185915/95/drainage-system-for-a-building-9-638.jpg?cb=1471597169

6.4 Construct fences (masonry walls, live fence, reinforced concrete walling, wooden post and chain link/barbed wire, steel post and chain link, concrete post and chain link) and gates based on the mode of construction

A fence is a structure that serves as wall except that it doesn't have a solid foundation throughout its length. It encloses a given perimeter most of the cases outdoors and can either be a temporary or permanent structure.

Gate –is an entrance to a space that is fenced.

Construction of fences despite the various types of materials used must be homogeneous in terms of colour and design. Fences should be constructed in a manner to portray the completed side the fence to the lot adjoining or of any abutting. In residential areas the fence shouldn't exceed 3 ft. height unless for open mesh screening cases. The following are guidelines of constructing the above type of fences;

a) The Construction Specification 92 should be applied
b) The material specifications 591 that's compatible to Specification 92
c) The items to be included in contact specifications and drawings includes; the plan, fence dimensions, details of the speciality materials, assemblies and posts details, the details of the gates is also included and the type/kind of fencing and the protective coatings and finishes if need be.

The construction of gates shall include the following steps;

i. Erection at the place of manufacturing whereby it should first be assembled fully and inspected
ii. Erection of the metalwork complying with BS 449 part 5 and comply with the recommendations of BS 5531
iii. The gate is then tested after erection by the contractor to ensure it satisfies the clients' needs

Conclusion

This learning outcome covered external works such as paving, landscaping, drainage systems and fence and fence and gate construction.

Further Reading

Read more on;

1. Foundations, basement and external works by H W Harrison and P M Trot man
2. External works, Roads and Drainage by Phil Pitman

16.3.7.3 Self-Assessment

Written Assessment

1. The following are types of construction fences except one?
    a) Masonry wall
    b) Live fences
    c) Moving fences
    d) Chain link
2. Distinguish the various types of drainage systems.
3. Which of the following is not a step in the construction of a drainage system?
    a) The outside of the footing, a trench is dug that is at least 2 ft. wide. Depth can vary up to 6ft or as shallow as 2 ft.
    b) The pipe is the laid on the undisturbed soil i.e. with the grade sloping away from the house to allow for the water to flow away by gravity
    c) The pipe should then be covered by washed gravel (at least 12 inches)
    d) A concrete slab is laid over the pipe

4. Laying of external paving basically entails laying pavements which is an outside floor that can be made of a variety of the following materials except?

a) Concrete
b) Asphalt
c) Stones
d) Marble

5. The following are elements of soft landscaping except?

a) Top soiling preparation; Subsoil should be properly compacted and thoroughly broken down.
b) After soil preparation is cultivation to a depth of at least 100mm, weeding and cleaning of the area is also done at this stage.
c) Turf should be specifically provided by the contractor as proposed and should comply with the BS 3969
d) Planting whereby all the plants should comply with BS 5531 specifications

Short answer questions

Briefly explain the parts of a drainage system?
Differentiate between a wall and a fence?

Essay questions

Explain the steps of laying an external paving based on the mode of construction
Describe 5 elements of soft landscaping

Oral Assessment

How can one identify a soft landscape?
What is the difference between surface and subsurface drainage system?

Practical Assessment

Conduct a visit to KICC and document all elements of external building works employed in its design

Tools, equipment, supplies and Materials

- Survey tools
- Landscaping tools
- Design and rendering software
- Measuring and drawing tools
- Computers/internet
- Calculator

Personal protective equipment (PPEs)

- Overall
- Dustcoat
- Helmet
- Workshop Boots
- First Aid Kits

16.3.7.5 References

Xiu Hwei (2012).Water Drainage Engineering. China Architecture and Building Press
Yan Xushi, Liu Suiqing (2014).Water Supply and Drainage Engineering. China Architecture and Building Press

CIVIL CHAPTER 17: WATER RESOURCE QUALITY MANAGEMENT

17.1 Introduction of the Unit of Learning

This unit covers the competencies required to manage water resources quality. It involves monitoring, managing water resources quality, managing groundwater quality, managing wastewater quality and treating and disposing of wastewater.

17.2 Performance Standard

Monitor water resources' quality, surface water quality management, ground water quality management, and manage waste water quality based on the need, reconnaissance survey, SOPs, monitoring protocol, and best practice.

17.3 Learning Outcomes

17.3.1 List of Learning Outcomes

a) Monitor water resources quality
b) Surface Water quality management
c) Ground Water quality management
d) Manage wastewater quality

17.3.2 Learning Outcome No 1: Monitor Water Resources Quality

17.3.2.1 Learning Activities

Learning Outcome No 1: Monitor Water Resources Quality	
Learning Activities	**Special Instructions**
1.1 Carry out ***water quality reconnaissance survey*** 1.2 Identify ***environmental water sampling sites*** and ***water resource quality indicators*** 1.3 Identify ***matrices*** (Sediments) for water resource quality monitoring 1.4 Identify ***tools and equipment*** (GPS receiver, water quality testing instruments: UV-Vis) 1.5 Operate and maintain tools and equipment 1.6 Prepare water quality ***monitoring protocol*** 1.7 Implement water quality monitoring ***schedules*** 1.8 To prepare and submit water quality monitoring report	• Detailed labouratory water tests. • Use of customized computer software for data analysis • Field Trips • Demonstration by the trainer

17.3.2.2 Information Sheet No17/LO1: Monitor Water Resources Quality

Introduction to learning outcome

This section deals with the processes of ensuring a high degree of water quality. The quality that to be assessed is that of the receiving water on the surface including rivers, streams, or ocean, and that at the subsurface level that includes underground springs, and aquifers.

Definition of key terms

Environmental water sampling sites: - Refers to those specific locations at which surface water and subsurface water can be collected and preserved awaiting quality assurance.

Water resource quality indicators: - This is parameters that determine water quality

Matrices: - This are tables that indicate stages of water analysis relative to the parameters being investigated and their removal efficiencies

Content/Procedures/Methods/Illustrations

1.1 Carry out *water quality reconnaissance survey* (upstream, hot spots, effluent discharge points) based on the need.

The aim of this survey is to obtain water quality of the receiving water that includes surface water and subsurface water. Representative samples are obtained at points that represent conditions at the most unfavorable or at points of contamination.

Water quality monitoring process

1. **Physical monitoring**

Physical characteristics of the water are visually inspected or deductions made by sensory observation to ascertain its quality. This includes algae, sediment, suspended solids, odor, and stream bank. The channel geometry characteristics also can be instrumental in deciding which methods to employ.

2. **Chemical monitoring**

This is conducted as a microbial analysis measure to a rational health-based perspective to quality monitoring. The parameters include pH, chloride, phosphate, turbidity, and nitrates.

3. **Biological monitoring**

A sampling of micro-invertebrates (bugs) at points or sections of a stream. The microinvertebrates are grouped according to sensitivity levels to pollution

1.1 Identify *environmental water sampling sites* (boreholes, wells) and *water resource quality indicators* based on the reconnaissance survey

Environmental water sampling sites are the locations at which samples are picked. They are normally pointing of the source. The points selected should yield samples that represent the whole system. Automatic samplers collect samples on an hourly basis however manual sampling is also required especially at locations where automatic systems cannot be installed. Boreholes and wells are used to monitor contaminant flow in aquifer formations by introducing a tracer dye in the well upstream and then observe its path which represents the way dissolved pollutants move. The use of underground water quality modeling like Phreeq has enabled easier preparation of water quality matrices

Water resource quality indicators are the aspects of physical, chemical, and biological nature that depict the level of contamination or pollution. The table below shows the biological indicator commonly tested.

Table 37: The biological indicator commonly tested.

Physical	**Chemical**	**Biological**
Turbidity Electric conductivity Viscosity Temperature	Dissolved oxygen Pesticide content Salts, phosphates, nitrates, heavy metals pH	Bacteria Parasites Viruses Protozoa

1.2 Identify *matrices* for water resource quality monitoring based on the reconnaissance survey

Water quality monitoring matrices are correlations used to determine water quality status by testing water quality parameters using surrogate relations.

The correlation is between two or more parameters that have been tested, for example, the relationship between TSS might have a high or low correlation with BOD, NO3, COD, and turbidity. The chemicals which should never be discharged into the receiving water include: calcium carbonate, chloroform, Condensing water, Degreasing solvents, and color. WASREB has laid down the criteria for wastewater treatment, discharge, and reuse.

Water quality parameters correlation matrix

	Temp.	pH	EC	TDS	Cl	ALK.	TH	Ca	Mg	Na	K	F	NO_3	SO_4	PO_4	DO
Temp	1.00	-0.43^a	-0.90^a	0.89^a	-0.79^a	0.58^a	0.85^a	-0.60^a	0.86^a	0.93^a	0.93^a	0.53^a	0.52^a	0.88^a	0.67^a	-0.56^a
pH		1.00	-0.46^a	-0.46^a	-0.33^b	-0.34^b	-0.50^a	0.23^c	-0.48^a	-0.42^b	-0.42^b	-0.15^c	-0.06^c	0.27^c	-0.45^a	0.80^a
EC			1.00	1.00^a	0.91^a	0.78^a	0.97^a	-0.56^a	0.96^a	0.99^a	0.97^a	0.56^a	0.59^a	0.84^a	0.72^a	-0.63^a
TDS				1.00	0.91^a	0.78^a	0.97^a	-0.56^a	0.96^a	0.99^a	0.97^a	0.56^a	0.59^a	0.84^a	0.72^a	-0.63^a
Cl					1.00	0.80^a	0.85^a	-0.34^b	-0.82^a	0.91^a	0.85^a	0.55^a	0.65^a	0.83^a	0.64^a	-0.57^a
ALK.						1.00	0.75^a	-0.22^c	0.71^a	0.77^a	0.76^a	0.49^a	0.74^a	0.59^a	0.58^a	-0.57^a
TH							1.00	0.53^a	0.99^a	0.95^a	0.93^a	0.49^a	0.50^a	0.76^a	0.69^a	-0.61^a
Ca								1.00	-0.66^a	-0.57^a	-0.61^a	-0.20^c	-0.02^c	-0.53^a	-0.41^a	0.22^c
Mg									1.00	0.063^c	-0.07^c	-0.18^c	0.05^c	0.02^c	-0.07^c	-0.08^c
Na										1.00	0.98^a	0.59^a	0.61^a	0.86^a	0.71^a	-0.60^a
K											1.00	0.59^a	0.65^a	0.87^a	0.72^a	-0.60^a
F												1.00^a	0.46^a	0.54^a	0.46^a	-0.36^b
NO_3													1.00	0.56^a	0.49^a	-0.40^b
PO_4														1.00	0.55^a	-0.53^a
SO_4															1.00	-0.50^a
DO																1.00

$^a r > 0.46$ ($p < 0.001$); $^b r > 0.33$ ($p < 0.05$); $^c r < 0.22$ Not Significant; $df = 40$.

Figure 177: Water quality parameters correlation matrix

Source: Central Pollution Control Board (CPCB), Water quality status of Yamuna River, Parivesh Bhawan, Delhi, 1999–2000.

1.3 Identify *tools and equipment* (GPS receiver, water quality testing instruments: UV-Vis) based on the need.

The tools and equipments are the aids for monitoring. GPS tools can be used to monitor pollutant movement from the point of generation and the path it follows as it flows along the stream. The pollutant can be classified in arc map and identified in a particular color. Water quality instruments are used to test and indicate water quality parameters either real time or over a certain period. They include pH meters, BOD manometers, thermometers, and jar test equipment. The manometric method is used to test the sample for microbiological contaminants. Other instruments include multi-parameter water quality sonde, which is an automatic sampler that allows for discrete sampling of water quality parameters.

1.4 Operate and maintain tools and equipment based on standard operating procedures.

The equipment that requires operation and maintenance includes labouratory testing equipment, automatic samplers, analytical balance, glassware, fume hoods, ovens, and refrigerators. The Kenya Bureau of standards outlines the operational and maintenance standards required for such equipment. Automatic samplers are maintained and calibrated following the YSI user's manual.

1.5 Prepare water quality monitoring protocol (Surveillance, Pollution control) based on need

Monitoring aims to regulate and prohibit the discharge of effluent into the aquatic environment. The water quality guidelines as stipulated in the WHO guidelines on effluent monitoring, (2008), stipulates the conditions for discharge into surface water or injection or leaching into groundwater aquifers. The surveillance mechanisms include scheduled monitoring, unscheduled monitoring, self-monitoring, and demand monitoring.

Monitoring Protocol for pollution control

- Determination of water-course system standard conditions
- Detection of a decline in water quality
- Identify inflow streams that do not meet standards
- Identify the point and non-point sources for either surface or groundwater
- Determine the extent of contamination
- Estimate the pollution load transported to surface systems and groundwater
- Develop the water quality guidelines for specific use
- Develop sustainable quality assurance and quality control processes
- Develop a water pollution control protocol

1.6 Implement water quality monitoring *schedules* (Monthly, Quarterly, Annually) based on the monitoring protocol

Quarterly schedule on Water and Effluent Monitoring

Table 38: Quarterly schedule on Water and Effluent Monitoring

Issue	Status
Issue Status Water production to town [m3]	
Number of WSPs	
Number of separate networks	
Number of registered effluent dischargers	
Number of overflowing/broken sewers including a period of overflow	
Number of bacteriological tests within norm	
Summary of major deviations	

Guidelines on Water Quality and Effluent Monitoring, (2017)

Table 39: Annual Water and Effluent Monitoring schedule

Issue	Status
Water production to town [m3]	
Number of WSPs	
Number of separate networks	
Number of registered effluent dischargers	
Name (s) of labouratories where the analysis was carried out	
Number of tests conducted	
Other activities are undertaken to improve water and effluent quality	

Source: Guidelines on Water Quality and Effluent Monitoring, (2017)

1.7 Prepare and submit water quality monitoring report based on best practice

Table 40: System Description

Amount of effluent discharge (m3/yr)	
Number of separate networks	
Effluent discharge through network 1(m3/yr)	
Effluent discharge through network 2(m3/yr	

Guidelines on Water Quality and Effluent Monitoring

Table 41: Test reports

Network 1	**No of Tests per year**	**No of tests conduct**	**No of tests within KS**
BOD5			
COD			
pH			
Suspended solids			
Ammonia, NH4, Nitrate NO3, Nitrite NO			
Total Dissolved Solids			
E.Coli			

Network 2	**No of Tests per year**	**No of tests conduct**	**No of tests within KS**
BOD5			
COD			
pH			
Suspended solids			
Ammonia, NH4, Nitrate NO3, Nitrite NO			
Total Dissolved Solids			

Guidelines on Water Quality and Effluent Monitoring (2017)

Conclusion

This learning outcome covered the quality of water resources. Water is a very important natural resource in our daily lives

Further Reading

1. Changing trends in sampling methods
2. How to allocate monitoring wells in a potentially contaminated network
3. Wastewater treatment plant design

17.3.2.3 Self-Assessment

Written Assessment

1. After samples are collected from the source, how much time is allowed before the samples are tested.
    a) 12 hours – 1 day
    b) – 4 days
    c) – 24 hours
    d) 48 – 72 hours
2. When preparing water quality assessment parameters, which one is allowed to discharge freely into receiving water?
    a) Cyanide
    b) 30 mg/L BOD
    c) 5 mg/L Chromium V
    d) 100 mg/L COD
3. Identify the one which is not a criterion for water sampling frequency
    a) source of the water
    b) The volume produced and population
    c) Number of tests to be conducted
    d) Aquatic life population in the water
4. Evaluate the matrix concerning Nairobi River and compare with WHO or NEMA standards.
5. Summarize the roles of local authorities in control of pollution of water.
6. Distinguish the organizations responsible for water quality monitoring in Kenya.
7. Explain environmental management plan
8. Differentiate between point and non- point sources
9. Based on your knowledge of water resources explain the source of pollutants, their removal method, and mitigation measures to minimize their discharge into water bodies
10. Differentiate the stages of the non-conventional wastewater treatment process using well-labelled diagrams indicating the contaminants removed at each stage.

Practical Assessment

1. In a wastewater treatment plant evaluate the critical areas where sampling must be done
2. Determine BOD5 using samples obtained from your Kitchen water following the monitoring protocol

Oral Assessment

Prepare six slides on monitoring technologies adaptation in water sampling to be presented in class.

Project Assessment

By applying WHO and NEMA standards determine water quality parameters for a borehole in your vicinity and prepare a water quality correlation matrix.

17.3.2.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- water sampling kit (manual, automated)
- sampling equipment (sampling bottles, boats)
- Standard operating procedures
- Portable water quality test kits (with Thermometers, pH, EC, turbidity, DO meters,
- Microbial test kits for resent/absent etc.)
- GIS Software
- Digital cameras
- GPS
- Glass ware
- Marking devices

17.3.2.5 References

Cotruvo, J. A. (2017). 2017 WHO guidelines for drinking water quality: first addendum to the fourth edition. Journal-American Water Works Association, 109(7), 44-51.

James, C. A., Miller-Schulze, J. P., Ultican, S., Gipe, A. D., & Baker, J. E. (2016). Evaluating contaminants of emerging concern as tracers of wastewater from septic systems. Water Research, 101, 241-251.

Behmel, S., Damour, M., Ludwig, R., & Rodriguez, M. J. (2016). Water quality monitoring strategies—A review and future perspectives. Science of the Total Environment, 571, 1312-1329.

17.3.3 Learning Outcome No 2: Surface Water Quality Management

17.3.3.1 Learning Activities

Learning Outcome No 2: Surface Water Quality Management	
Learning Activities	**Special Instructions**
2.1 Identify surface ***water quality challenges and issues*** 2.2 Characterize surface water resources quality 2.3 Develop surface water quality management plan 2.4 Implement surface water quality management plan	• Surface water collection • Trainer demonstration • Detailed lab experiments • Use of standard equipment for testing

17.3.3.2 Information Sheet No17/LO2 Surface Water Quality Management

Introduction to learning outcome

Surface water forms a large percentage of water that is readily available for human consumption. Its quality should, therefore, be of great concern and the challenges and issues that arise be addressed.

Definition of key terms

Water quality challenges and issues – these are problems facing the efforts put in place by relevant stakeholders in ensuring there is the availability of clean water in accordance to the set standards.

Content/Procedures/Methods/Illustrations

2.1 Identify surface *water quality challenges and issues* based on management need

Challenges faced by stakeholders in the management of surface water quality are:

- Human Ambitions and Earth's Limits – humans have continued to modify the planet, and at some point, there is ignorance in conserving the surface water bodies which many at times are used as disposal points.
- Research needs and directions – even with the availability of improved technology over time, research on newer methods of conserving water quality is still slow as compared to the rate of pollution and contamination

- Urban and industrial water demands – water is an essential need for any livelihood, the high demand of such a commodity forces all lives(both human and wildlife) to tamper with the source risking and in most cases polluting them.

Surface water includes streams, rivers, lakes, dams, oceans, seas, and all visible water bodies on land. The main challenge facing the quality of water in these bodies is pollution which can be in different ways as shown in the table below:

Table 42: Quality of water

PROCESS TYPE	MAJOR PROCESS WITHIN WATER BODY	BRIEF EXPLANATION
Hydrological	Dilution	Occurs when water is saturated by a soluble pollutant
	Suspension and settling of particles	None soluble pollutants in surface water
Physical	diffusion	If one point of a surface water is polluted, it spreads onto the whole water body
Chemical	Photodegradation	A reaction where chemical compounds in water are broken down by photons
	Acid-base reaction	The reaction of alkaline compounds with acids in water
Biological	Decomposition of organic matter	The dead organic substance in water bodies when broken down release bacterial pollutants in the water body
	Bioaccumulation	An organism accumulates a substance from water or a suspended particle
	Biomagnification	Increase in concentration of a substance within a food chain

All of the above processes may as a result of human activities that discharge waste into the surface water bodies and also from natural causes.

2.1 Characterize surface water resources quality based on challenges and issues identified

Table 43: Surface Water Recourses

SURFACE WATER RECOURCES	CHALLENGES FACED
Lakes and reservoirs	Stratification. This is caused by a difference in solute concentration (discharged as waste from human activities) causing the water to split in two different layers due to differences in densities causing difference in quality of water in the two layers.
Rivers and streams	Nonsoluble sediments suspended in water. Can be from industrial, agricultural or municipal waste
Oceans and seas	Oil spills, dumping of plastic waste, and garbage patches are challenges facing the quality of water in the ocean and seas.
Dams and manmade water resources	Dumping of garbage.

2.2 Develop surface water quality management plan based on challenges and issues identified

Water quality management plan can be developed by the following steps

i. Examine current understanding
ii. Define community values and management goals
iii. Define relevant indicators
iv. Determine water quality guideline values
v. Define draft water quality objectives
vi. Assess if water quality objectives are met
vii. Consider additional indicators or refine water quality objectives
viii. Consider alternative management strategies
ix. Assess if water quality objectives are achievable
x. Implement agreed management strategy

Table 44: Example of a water quality management plan

TARGETED OBJECTIVES TO ADDRESSED RISKS	STRATEGIES	WATER MANAGEMENT SOLUTIONS AND MECHANISMS	MANAGEMENT PLAN.
Reduce the dumping of garbage to water bodies	Create an area for dumping garbage where they can be recycled	Dump all garbage at the dumping site	Garbage area plan
Stop discharge of domestic wastewater into water bodies	Develop a wastewater treatment site for domestic wastewater	Direct all domestic wastewater into the treatment site	Wastewater treatment plan

2.3 Implement surface water quality management plan based on challenges and issues identified

Based on the challenges and issues, the water quality management plan is implemented practically.

Conclusion

This learning outcome covered the creation of a quality management plan for surface water

Further Reading

Forms of surface water quality control for future changes in quality parameters

17.3.3.3 Self-Assessment

Written Assessment

1. Which of the following is not a surface water resource?
    a) Rivers
    b) Lakes
    c) Aquifers
    d) Dams

2. Choose a chemical process within a water body
    a) Dilution
    b) Decomposition
    c) Biomagnification
    d) Photodegradation
3. Evaluate the challenges facing the quality of surface water resources
4. Compare 4 surface water resources
5. Summarize the steps to follow when developing a water quality management plan
6. Explain how stratification occurs on water body.
7. Explain how the following affect water quality
    a) Human ambition and earth limits
    b) Urban and industrial water demands
    c) Research needs and directions

Oral Assessment
Explain biological processes that face water quality.

Case Study Assessment
In your residential area, how has the water quality situation been handled?

Performance-Based Evidence
Oral Assessment
Come up with a water quality management plan for your residential area

Practical Assessment
Visit a nearby water source and check the quality in terms of insoluble solutes and sediments.

Project Assessment
Visit a nearby water treatment plant and write a report on methods the use to improve water quality

17.3.3.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Water sampling kit (manual, automated)
- Sampling equipment (sampling bottles, boats)
- Standard operating procedures
- Portable water quality test kits (with Thermometers, ph, EC, turbidity, DO meters,

- Microbial test kits for resent/absent etc.)
- GIS Software
- Digital cameras
- GPS

17.3.3.5 References

Water Quality: An Introduction (2019) By Claude E. Boyd.

Hydrodynamics and Water Quality: Modeling Rivers, Lakes, and Estuaries (2017) By Zhen-Gang Ji.

Surface Water Quality: Have the Laws Been Successful? (2014) By Ruth Patrick, Faith Douglass, Drew M. Palavage, Paul M. Stewart.

17.3.4 Learning Outcome No 3: Ground Water Quality Management

17.3.4.1 Learning Activities

Learning Outcome No 3: Ground Water Quality Management	
Learning Activities	**Special Instructions**
3.1 Identify ***groundwater quality challenges and issues*** 3.2 Characterize groundwater resources quality 3.3 Develop a groundwater quality management plan 3.4 Implement a groundwater quality management plan	• Conduct borehole drilling tests • Conduct ionic balance charge analysis

17.3.4.2 Information Sheet No17/LO3 Ground Water Quality Management

Introduction to learning outcome

This learning outcome covers the identification of ground water, quality challenges and issues, characterization of ground water resources, development of groundwater quality management plan and implementation of groundwater quality management plan.

Definition of key terms

Groundwater quality challenges and issues - these are problems facing the efforts put in place by relevant stakeholders in ensuring groundwater is maintained as pure as possible.

Content/Procedures/Methods/Illustrations

3.1 Identify *groundwater quality challenges and issues* (Over-abstraction and groundwater pollution) based on management need.

Groundwater refers to the water below the earth surface, an example of around water are aquifers.

Ground water challenges and issues

1. Contamination – agricultural chemicals that leach into the soil may contaminate groundwater other contaminants are from industrial and municipal wastes
2. Poor quality of the water source- groundwater mainly comes from percolation of surface water or when streams and rivers reach a point where they get into the ground, if these streams and rivers are polluted the quality of groundwater will be affected
3. Poor site selection or protection of where the groundwater exists

3.2 Characterize groundwater resources quality based on challenges and issues identified

Quality of groundwater is based on features such as temperature, ph., color, and smell when these characteristics cause the challenges faced by the quality of groundwater.

Table 45: Quality of groundwater is based on features

CHARACTERISTICS	CHALLENGES
Temperature	This should be equal to mean air temperature above the surface, this can be altered by poor site selection.
Colour	Quality groundwater should be colourless, contamination by chemicals and leaching may alter this
Ph.	Should be neutral
Odour/smell	Quality groundwater should be odourless, this can be altered by contamination.

3.3 Develop a groundwater quality management plan based on challenges and issues identified.

This is similar to surface water quality management planning, the only change is strategies

Table 46: Example of a water quality management plan

TARGETED OBJECTIVES TO ADDRESSED RISKS	STRATEGIES	WATER MANAGEMENT SOLUTIONS AND MECHANISMS	MANAGEMENT PLAN.
Reduce the dumping of garbage to water bodies	Create an area for dumping garbage where they can be recycled	Dump all garbage at the dumping site	Garbage area plan
Stop discharge of domestic wastewater into water bodies	Develop a wastewater treatment site for domestic wastewater	Direct all domestic wastewater into the treatment site	Waste water treatment plan

3.4 Implement a groundwater quality management plan based on challenges and issues identified.

Based on the challenges and issues, the water quality management plan is implemented practically.

Conclusion

Groundwater quality is therefore vital as has been covered above. Our aquifers have to be protected against over-abstraction and pollution as they are a great source of groundwater.

Further Reading

How to conduct groundwater monitoring using PhreeQ software

17.3.4.3 Self-Assessment

Written Assessment

1. Categorize types of groundwater resources
2. Compare and contrast between physical and chemical characteristics of groundwater,
3. Which of the following is not a groundwater challenge?
    a) Contamination
    b) Poor site selection
    c) Dumping of garbage
    d) Poor water source
4. Evaluate how contamination of groundwater occur?
5. How does temperature affect the quality of groundwater
6. Briefly explain the term groundwater
7. Summarize how does following affect the quality of groundwater
    a) Temperature
    b) Ph7 multiple-choice questions
    c) Smell
    d) Color

Case Study Assessment

Research on how geological location affects the quality of groundwater

Practical Assessment

Using data from a known source of groundwater, check on the required standard of groundwater.

Oral Assessment

Explain 3 groundwater challenges and issues

Project Assessment

In groups discuss how standards of groundwater can be reached

17.3.4.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Water sampling kit (manual, automated)
- Sampling equipment (sampling bottles, boats)
- Standard operating procedures
- Portable water quality test kits (with Thermometers, ph, EC, turbidity, DO meters,
- Microbial test kits for resent/absent etc.)
- GIS Software
- Digital cameras
- GPS

17.3.4.5References

Septic Tank System Effects on Ground Water Quality (2017) ByCanter.

Artificial Recharge of Groundwater (2016) edited by Takashi Asano.

Groundwater around the World: A Geographic Synopsis (2013) By Jean Margat, Jac van der Gun.

17.3.5 Learning Outcome No 4: Manage Wastewater Quality

17.3.5.1 Learning Activities

Learning Outcome No 4: Manage wastewater quality	
Learning Activities	**Special Instructions**
4.1 Identify sources of wastewater 4.2 Assess wastewater quality 4.3 Prepare wastewater quality assessment report 4.4 Treat and dispose of wastewater 4.5 Interpret wastewater quality assessment report 4.6 Submit wastewater quality assessment report	• Proper wastewater collection • Proper wastewater treatment • Compliance with the wastewater quality treatment standards

17.3.5.2 Information Sheet No17/LO4 Manage Wastewater Quality

Introduction to learning outcome

This learning outcome covers the identification of sources of wastewater, assessing wastewater quality, preparation of wastewater quality assessment report, treating and disposing of waste water interpretation of waste water quality report and the submission of the waste water quality report.

Definition of key terms

Wastewater quality- These include indicators or labouratory tests done to wastewater to assess its suitability for disposal or future re-use. The indicators measure the physical, chemical, or even biological characteristics of wastewater.

Content/Procedures/Methods/Illustrations

4.1 Identify sources of wastewater based on characteristics

Table 47: Sources of wastewater based on characteristics

SOURCE	CHARACTERISTIC
Domestic/residential	Mainly greywater due to detergents for washing
Commercial	Used in garages, salons, etc.
Industrial	Chemical: Presence of heavy metals
Stormwater and runoff	Physical; Brown, High turbidity.

4.2 Assess wastewater quality based on selected parameters

The important characteristics measured in wastewater include:

- Biochemical Oxygen Demand (BOD) [100-300 mg/L as O2]
- Suspended solids (SS) [100 – 350 mg/L]
- Settleable solids [5-20 mL/L]
- Total Kjeldahl nitrogen (TKN) [20-80 mg/L]
- Total Phosphorus [5-20 mg/L as P]

A typical solids analysis of wastewater, of the total solids, 50% is dissolved, 50% suspended. Of the suspended solids, 50% will settle.

Industrial activity changes the composition of wastewater, often introducing toxic substances such as chromium and cadmium from plating operations

4.3 Prepare wastewater quality assessment report based on monitoring sites

Analysis of the influent and effluent of wastewater in a treatment plant in India produced the following data on wastewater quality;

Table 48: Wastewater quality assessment report based on monitoring sites

PARAMETER	INFLUENT	EFFLUENT
pH	7.75	7.8
TSS (mg/l)	251.5	81.5
COD (mg/l)	415.6	129.2
BOD (mg/l)	211.8	82.3
DO (mg/l)	6.6	4.4

The effluent concentrations of the above data exceeded the effluent standards indicating failure to meet quality standards set.

This could be due to operational problems in the biological treatment stage.

4.4 Treat and dispose of wastewater as per the environmental standards.

How is Wastewater Treated?

Wastewater treatment involves two major steps:

1. Gravity settling of solids (called primary treatment)
2. Microbial transformation of organics and ammonia to reduce BOD (called secondary treatment).

A typical treatment train in a wastewater treatment plant involves:

1. Bar racks to remove large debris
2. Primary treatment where Type II sedimentation for flocculated particles. The SOR ranges from 25-60 m/d, td ranges from 1.5 to 2.5 hours.
3. Secondary treatment involving the use of microorganisms to remove BOD of any solids that pass primary treatment. Oxygen is limited and must be supplied. The most common secondary treatment process is activated sludge.

4. Secondary sedimentation to remove microorganisms from secondary treatment.
5. Disinfection to kill pathogens using chlorine (typically HOCl)

Effluent standards are concentration pollutants expressed in terms of parts per million of wastewater discharged through outfall pipes

The following is a table showing wastewater parameter concentrations before and after treatment

Table 49: Wastewater parameter concentrations before and after treatment

PARAMETER	INFLUENT	EFFLUENT
pH	7.75	7.8
TSS (mg/l)	251.5	81.5
COD (mg/l)	415.6	129.2
BOD (mg/l)	211.8	82.3
DO (mg/l)	6.6	4.4

(Minimum) Goals of wastewater treatment plants include;

- Less than 30mg/l of BOD_5
- Less than 30mg/l of suspended solids
- Less than 200CFU/ 100ml of fecal coliforms

Anything greater than these values is disposed of.

4.5 Interpret the wastewater quality assessment report based on the monitoring plan

Table 50: Wastewater quality assessment report based on the monitoring plan

PARAMETER	INFLUENT	EFFLUENT
pH	7.75	7.8
TSS (mg/l)	251.5	81.5
COD (mg/l)	415.6	129.2
BOD (mg/l)	211.8	82.3
DO (mg/l)	6.6	4.4

From the above table one can deduce that;

The wastewater quality parameters reduce in volume after treatment. Thus, a well-functioning treatment plant meets the required standards on the parameter volumes during discharge i.e.

(Minimum) Goals of wastewater treatment plants include;

- Less than 30mg/l of BOD_5
- Less than 30mg/l of suspended solids
- Less than 200CFU/ 100ml of fecal coliforms

4.6 Submit the wastewater quality assessment report based on best practices

Best practices on wastewater quality assessment report include;

1. Sustainability -The treatment practices should meet the needs of today without compromising the future.
2. Finance and efficiency- Should be affordable to reduce billing charges levied on the users.
3. Reliability-The system should be dependable and robust in the execution of its duties
4. Security of service- Should have a proportional and secure design.

Conclusion

This learning outcome covered ways of proper management of wastewater before being discharged into water bodies

Further Reading

Read further on water quality modelling using remote sensing

17.3.5.3 Self-Assessment

Written Assessment

1. Which one is not a parameter of water quality?
   a) BOD
   b) COD
   c) Ph
   d) density
2. Which of the following is not a best practice on wastewater quality assessment.
   a) Sustainability
   b) Service quality
   c) Reliability
   d) Toxicology report
3. Which of the following is not part of a wastewater treatment plant.
   a) Bar racks
   b) Primary treatment chamber
   c) Secondary treatment chamber
   d) Tertiary chamber

4. Summarize waste water quality in terms of BOD and COD.
5. Categorize the sources of wastewater based on characteristics
6. Interpret wastewater quality assessment report based on monitoring plan

Essay Questions

1. Best practices in waste water quality is a concern. Discuss
2. Denmark is a pioneer in best water practices. Elabourate
3. Discuss the scenario of African economies in terms of wastewater quality and treatment.

Case Study Assessment

Basing on the Nairobi waste water treatment plant, discuss the shortcomings on waste water quality.

Oral assessments

Based on the experiment below, what are the observations?
What conclusions can be drawn?

Practical Assessment

Set up an experiment to measure the parameters in wastewater.

Project Assessment

Compare the effluents of the wastewater treatment plant nearby with the ideal environment standards and tabulate your findings.

Case Study Assessment

Basing on the Nairobi wastewater treatment plant, discuss the shortcomings of wastewater quality.

17.3.5.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Water sampling kit (manual, automated)
- Sampling equipment (sampling bottles, boats)
- Standard operating procedures
- Portable water quality test kits (with thermometers, ph, ec, turbidity, do meters,
- Microbial test kits for resent/absent etc.)
- Gis software
- Digital cameras
- Gps

17.3.5.5References

Gray, N. (2017). Water technology. CRC Press.

Rahmasary, A. N., Robert, S., Chang, I. S., Jing, W., Park, J., Bluemling, B., ... & van Leeuwen, K. (2019). Overcoming the challenges of water, waste and climate change in Asian cities. Environmental Management, 63(4), 520-5Katko, T. S., Kurki, V. O., Juuti, P. S., Rajala,

Salgot, M., & Folch, M. (2018). Wastewater treatment and water reuse. Current Opinion in Environmental Science & Health, 2, 64-74..

CHAPTER 18: DESIGN OF WASTEWATER COLLECTION AND TREATMENT INFRASTRUCTURE

18.1 Introduction of the Unit of Learning

This unit covers the competencies required to design wastewater collection and treatment infrastructure. It involves the collection of wastewater infrastructure design data, analysis of wastewater infrastructure design data, and calculation of wastewater infrastructure design parameters, drawing wastewater infrastructure units, and compiling wastewater infrastructure design reports. This standard applies to Water Industry.

18.2 Performance Standard

Apply hydraulic engineering principles, analyze structural elements, design structural elements, collect wastewater infrastructure design data, analyse wastewater infrastructure design data, calculate waste water infrastructure design parameters, draw wastewater infrastructure units, compile a wastewater infrastructure report based on standards and fluid properties.

18.3 Learning Outcomes

18.3.1 List of Learning Outcomes

a) Apply hydraulic engineering principles
b) Analyze structural elements
c) Design structural elements
d) Collect wastewater infrastructure design data
e) Analyze wastewater infrastructure design data
f) Calculate wastewater infrastructure design parameters
g) Draw wastewater infrastructure units
h) Compile a wastewater infrastructure design report

18.3.2 Learning Outcome No 1: Apply Hydraulic Engineering Principles

18.3.2.1 Learning Activities

Learning Outcome No 1: Apply Hydraulic Engineering Principles	
Learning Activities	**Special Instructions**
1.1 Identify ***properties of fluids*** 1.2 Identify ***tools and equipment*** for measurement of pressure, velocity, and discharge 1.3 Apply hydraulic principles	• Group discussions • Demonstration by trainer • Online videos • Powerpoint presentation • Exercises by trainee

18.3.2.2 Information Sheet No 18/LO1: Apply Hydraulic Engineering Principles

Introduction to learning outcome

This learning outcome covers fluid properties, fluid pressure measurement, discharge and velocity measurement, head losses in pipes, and simple channel sections.

Definition of key terms

Pascal's law- A pressure change at any point in a confined incompressible liquid is transmitted throughout the fluid such that the same change occurs everywhere.

Area of the flow-The region through which a fluid flows

Rate of flow-the the volume of fluid that flows per unit time.

Content/Procedures/Methods/Illustrations

1.1 Identify *properties of fluids* (Density, Surface Tension, Viscosity, Specific Weight, Specific Gravity, Compressibility, Capillarity, Specific Mass) based on standards

Table 51: Properties of fluids

Density	Mass per unit volume
Surface tension	The tendency a liquid surface to behave like a thin stretched elastic material.
Viscosity	Friction in fluids
Specific weight	Weight per unit volume of a material
Specific gravity	The ratio of density of a given substance to the density of a reference material
Compressibility	The measure of the relative-volume change of a fluid in reaction to pressure variation
Capillary	The capability of a liquid to flow in thin spaces without the aid of external forces

1.2 Identify tools and equipment for measurement of pressure, velocity, and discharge based on fluid properties

Table 52: Tools and equipment

Equipment/Tool	Use
Manometer	Measures gas pressure
Venturi meter	Increase the velocity of flow thus reducing the pressure to deduce flowrate
Orifice meter	Measures the flow rate of steam
Pitot tube	Measures fluid flow velocity
Weirs	Control the flow rate of a river
Notches	Regulate the flow of fluid
Mouthpiece	Tube opening for fluid discharge
Orifice	Hole opening for fluid discharge
Hydrostatic bench	Bench used for a wide range of fluid experiments
Open channel models	Simulation for fluid flow in open channels

Apply hydraulic principles based on the types of fluids

Hydraulic principles is an application of Pascal's law.

Types of fluids include;

1. Ideal fluid- Has no viscosity and is incompressible hence not affected by Pascals principles
2. Real fluid- has viscosity hence hydraulic principles applicable
3. Newtonian fluid-Refers to a real fluid that conforms to newton’s law of viscosity

4. Non-Newtonian fluid- A real fluid that does not obey the newtons law of viscosity
5. Ideal plastic fluid-shear stress is proportional to its shear strain

Conclusion

This learning outcome covered fluid properties, fluid pressure measurement, discharge and velocity measurement, head losses in pipes, and simple channel sections.

Further Reading

Read a book on introduction to fluid mechanics

18.3.2.3 Self-Assessment

Written Assessment

1. Select the odd one out in the fluid types listed.
    a) Ideal
    b) Real
    c) Newtonian
    d) Elastic
2. Which equipment measures gas pressures?
    a) Venturi meter
    b) Manometer
    c) Orifice
    d) Weir
3. The ratio of the mass of a fluid to its volume is called
    a) Capillary
    b) Specific mass
    c) Specific gravity
    d) Specific weight
4. Which one is not a variable considered in fluid mechanics.
    a) Pascal’s pressure law
    b) rate of flow
    c) Area of flow
    d) Couple coplanar forces
5. Derive Pascal’s law from first principles.
6. Summarize the types of fluids

7. Evaluate the functions of the following
    a) Weir
    b) notch
    c) mouthpiece
    d) orifice
    e) venture meter
    f) manometer
8. Distinguish between specific weight and specific gravity
9. Explain the properties of a real fluid
10. Highlight the applications of surface tension in real life
11. Differentiate between a notch and a weir
12. Discuss the benefits of understanding fluid mechanics to an engineer.
13. There exist no ideal fluids. Discuss

Oral Assessment
1. Based on the pressure law experiment.
2. What are the observations made from the experiment?
3. What conclusion can be made based on the above observations?

Practical Assessment
Set up an experiment to demonstrate Pascal's pressure law.

18.3.2.4 Tools, Equipment, Supplies and Materials
- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

18.3.2.5 References

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Abdulrahman, A. (2017). Numerical Solution of Manning's Equation in Rectangular Channels. International Journal of Civil and Environmental Engineering, 11(6), 740-743.

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18.3.3 Learning Outcome No 2: Analyse Structural Elements

18.3.3.1 Learning Activities

Learning Outcome No 2: Analyse Structural Elements	
Learning Activities	**Special Instructions**
2.1 Identify ***Properties of materials*** 2.2 Analyse ***Section properties*** 2.3 Analyse ***structural elements***	• Group discussions • Demonstration by trainer • Online videos • Powerpoint presentation • Exercises by trainee

18.3.3.2 Information Sheet No 18/LO2: Analyse structural elements

Introduction to learning outcome

This learning outcome covers the theory of simple bending, forces in frames, deflection in beams, section properties, properties of materials, and moments in beams.

Definition of key terms

Stress: This is defined as the intensity of the force acting on a member

Strain: This is a measure of the deformation of a material.

Mohr's theorem: Mohr's theorem is an engineering tool utilized to calculate maximum and minimum principal stresses and shear stresses.

Content/Procedures/Methods/Illustrations

2 .1Identify *Properties of materials* (Stress, Strain, Elasticity, Plasticity, Stiffness, Young's modulus) based on the job requirements.

The properties of materials are a key consideration for which the material is considered suitable for a specific need. The common physical and mechanical properties include some of the following:

i) Elasticity- This is defined as a material's ability to return to its original configuration when the twisting force is removed, which is the opposite of plasticity.

ii) Stress- Repeated stresses can lead to fatigue which can lead to fracture. Therefore higher repeated stresses will accelerate the time to failure.

iii) Strain- The ability of a material to deform and return to its original shape determines the point the material will no longer return to its original shape after being loaded.
iv) Plasticity- This determines the ability of a material to hold a new shape when subjected to a distortional force.
v) Stiffness- This refers to the ability of a material to resist deformation in response to a distortional force.
vi) Young's modulus- This is the relationship between the force applied and the resulting deformation. This is a key determination for applications where a high degree of stiffness is required under load.

2 .2Analyse *Section properties* (Centre of gravity, Centroids, 1st moment of area, 2nd, Section modulus, moment of area, Radius of gyration) based on the materials, loading, and sizes.

Section properties refer to the mathematical properties of structural shapes and they are applied to a great extent in structural analysis and design.

i) Centroids- This defined as the center of the moment of the area of a cross-section of material. Therefore, the centroid of a material is the geometric center of the material. Materials, therefore, have a different location of the centroids based on their shape.
ii) Center of gravity- This is the point from which the entire weight of an object is considered to act.

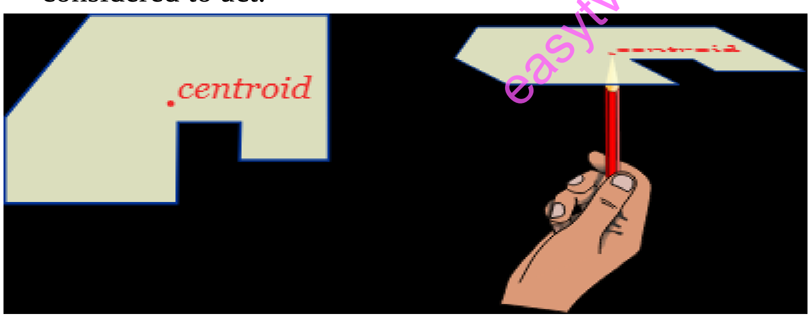


Figure 178: Center of gravity
Source: https://.mathsisfun.com].

iii) 1st moment of the area- This describes the distribution of an area about either its x or y-axes. It is determined as the summation of the product of each area and its distance from the axis.
iv) 2nd moment of the area- This is also known as moment of inertia and it measures the capability of a material to resist bending about a certain axis. As a result, structural elements with a higher moment of inertia have a higher capacity to resist bending.
v) Section modulus- It is defined as the proportion of the total moment countered by the section to the stress in the extreme fibre which is equal to yield stress.
vi) The radius of gyration- This the root mean square distance of the particles of a structural element about an axis of rotation.

2.3 Analyze *structural elements* (Stress, Strain, General slope and deflection formula, Double integration, McCauley's method, Mohr's theorems) based on material and loadings.

Structural analysis is the method(s) by which we find out the effects of loads on physical structures and internal forces. Structural analysis is a mandatory precursor to structural design. The science of structural analysis is so extensive that it would require several books to describe all the methods sufficiently.

i) Stress- This the internal resistance that the member to balance the effect of externally applied loads.
ii) Strain-This is the ratio between the changes in the length of the structural member to the original length as a result of an externally applied load.
iii) General slope and deflection formula- This formula expresses that the deflection can be computed by taking the double integral of the bending moment equation. It is used to compute deflection in beams.
iv) Macaulay's method- is referred to as the double integration method and to find expressions for the deflection of loaded beams. It is very efficient when applied to discrete loading.
v) Mohr's theorems- This a method to determine the rotation, slope, and deflection of beams and frames. It is also known as the moment area theorems. It is also used to calculate deflection in beams.

Conclusion

This learning outcome covered the theory of simple bending, forces in frames, deflection in beams, section properties, properties of materials, and moments in beams.

Further Reading

Read more on:

1. Structural analysis 8th edition by R.C Hibbeler.
2. Structural analysis by Gregory Mikaelson.(Youtube)

18.3.3.3 Self-Assessment

Written Assessment

1. Which of the following is not a property of a material considered during job requirements?
   a) Ductility
   b) Toughness
   c) Plasticity
   d) Centroid

2. Which of the following are all structural analysis methods?
   a) Double integration method
   b) Slope and deflection formula
   c) Mohr's theorems
   d) 1^{st} moment of area

3. Elabourate with examples why structural analysis is a mandatory precursor to structural design.

4. The following are all section properties except?
   a) Center of gravity
   b) Moment of inertia
   c) Section modulus
   d) Stress

5. Differentiate between structural determinate and indeterminate methods.
6. From first principles, derive the Mohr's circle state of stress.
7. Describe what is a continuous beam?
8. Describe what structural analysis software packages exist in the market and their features.
9. Most structures encountered in real life are indeterminate structures. From the foregoing, write an essay describing the various structural analysis methods that exist for indeterminate structures.

Project Assessment

Analyse an example of a continuous beam use Prokon software (obtained from either a textbook or the internet) and compare your manual solution with the solution obtained from the software.

Oral Assessment

1. How did your solution in the project assessment above compare with that of the software?
2. What indeterminate structural analysis methods work best for you?

18.3.3.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

18.3.3.5 References

John Case, Lord Chilver, and Carl Ross. (2003). Strength of materials and structures. John Wiley and Sons Inc. New York.

18.3.4 Learning Outcome No 3: Design Structural Elements

18.3.4.1 Learning Activities

Learning Outcome No 3: Design Structural Elements	
Learning Activities	**Special Instructions**
3.1 Identify structural elements 3.2 Design structural elements are designed 3.3 Produce structural drawings	• Group discussions • Demonstration by trainer • Online videos • PowerPoint presentation • Exercises by trainee

18.3.4.2 Information Sheet No 18/LO3: Design Structural Elements

Introduction to learning outcome

This learning outcome covers identifying structural elements, designing of structural elements and the production of structural drawing based on the design.

Definition of key terms

McCauley's method: Refers to the double integration method used to find expressions for the deflection of loaded beams.

General slope formula: This formula expresses that the deflection can be computed by taking the double integral of the bending moment equation.

Deflection formula: This calculated by integrating the function that describes the slope of the member.

Content/Procedures/Methods/Illustrations

3.1 Identify structural elements based on the requirements

Structural elements have to do with the part of the building that is concerned with preserving the physical integrity (ensuring the structure satisfies the ultimate limit state and the serviceability limit state requirements) and continues to exist in the world as a physical object. Understanding the structure of a building requires an intuitive ability which depends on the knowledge of the functional requirements of the structure and the ability to differentiate between the non-structural and structural parts of a building.

The following are some of the structural elements:

i. Foundations – The foundation is a structural element that transmits load to the underlying soil or rock, the loads supported by the foundation and its self-weight in such a way that the soil is not overstressed or excessive settlement occurs.
ii. Columns- These are vertical members that majorly resist axial compressive loads.
iii. Beams- These are horizontal members that primarily carry vertical loads and resist failure in bending.
iv. Walls- A wall is a structure that demarcates the different spaces in a building as well as the external boundary. Some walls are load-bearing and carry the structural loads of the building.
v. Ties-This is a slender structural element that carries the loads in tension.
vi. Struts- This a structural member that carries the loads in compression only.
vii. Trusses-This a structure that is composed of a series of struts and is used to carry loads in compression.
viii. Frames- This type of structure is composed of beams and columns that are either pin or fixed connected.
ix. Slabs-This are horizontal structures built to provide a flat surface in buildings.

3.2 Design structural elements based on design codes

The design of members refers to the sizing of members to ensure they fit functional requirements during the ultimate limit state as well as the serviceability limit state. Design of structures in Kenya is the preserve of registered and licensed professional engineers, according to the Engineers Act (2011), however, graduate engineers and technologists (diploma holders) have an opportunity to contribute during the design phase under the guidance of the professional engineer.

The design of members is guided by design codes upon which reference is made during the design process. The following are some of the design codes currently in use in Kenya:

i. Design of reinforced concrete structures- BS 8110
ii. Design of steel-framed buildings- BS 5950
iii. Design of timber structures- BS 5628
iv. Design code on the occupancy load requirements of a building- BS 6399 Part 1.

The following is the procedure followed in the design of a beam according to BS 5950:

i. Determine the loading condition of the beam.
ii. Calculate the design load of the beam.
iii. Perform structural analysis to determine the design moment and the design shear.
iv. Perform a strength classification and section classification.
v. Choose a section based on its moment capacity equation.
vi. Perform a moment capacity check.
vii. Perform a shear capacity check.

viii. Evaluate whether it’s a low or high shear load.
ix. Perform a deflection limits check.
x. Perform a web bearing check.
xi. Perform a web buckling check.

3.3 Produce structural drawings based on the design.

Structural drawings have to be produced as the design process evolves since the drawings are required in the construction of the structure. Production of structural drawings takes place as follows:

i. The schematic architectural drawings are obtained from the architect. (Conceptual design phase)
ii. The engineer determines the loadings applied to the structure based on the drawings and performs design to size the members according to the forces applied to the building. (Developed design phase)
iii. As the design process evolves the engineer produces more detailed drawings, bar bending schedules, notes, specifications, details, and at the end of this stage we have construction ready documents. (Technical design phase)
iv. The drawings are included in a tender pack to be tendered together with drawings from other disciplines during the bidding and tendering process.

Conclusion

This learning outcome covered the structural elements of a building, design of steel, and production of structural drawings.

Further Reading

British Standards Institute. (2002). Design of reinforced concrete structures-BS 8810. BSI.
British Standards Institute. (2002). Design of steel structures-BS 5950. BSI.
British Standards Institute. (2002). Design of timber structures-BS 5628. BSI.

18.3.4.3 Self-Assessment

Written Assessment

1. Compare and contrast the following types of foundation
    a) Mat
    b) Isolated footing
    c) Combined footing
2. Which of the following is not a check done during the design of a reinforced concrete beam?
    a) Shear capacity check.
    b) Moment capacity check.
    c) Web buckling check.
    d) Deflection check
3. Which of the following is not a phase during the design of structures?
    a) Technical design
    b) Developed design
    c) Conceptual design
    d) Handover
4. Which of the following is not a structural element?
    a) Ties
    b) None
    c) Trusses
    d) Joists
5. Design a reinforced concrete beam of your choice according to the design code BS 8110.
6. Describe the various type of foundations and when should be used.
7. Describe the design principles that should guide an engineer during the design process.
8. Describe the main design theories.
9. Write an essay describing how an engineer with poor communication skills can lead to poor quality construction.

Project Assessment

Using a BIM software application of your choice obtain architectural drawings from the internet and develop a corresponding structural model.

Oral Assessment

Describe how you as a student pursuing a diploma of civil engineering can develop shop drawings for fabrication of steel members when requested by the professional engineer.

What skills have you gained as a result of performing the project assessment described above?

18.3.4.4 Tools, Equipment, Supplies and Materials

- Computers
- Rulers, pencils, erasers
- Drawing sheets
- Software
- Projectors
- Calculators
- Internet

18.3.4.5 References

W.H Mosley, R. Hulse, J.H Bungey (2012). Reinforced Concrete Design. Red Globe Press, New York.

N. Subramanian (2010). Steel structures design and practice. Oxford university press, New Delhi.

Abdy Kermani (2008) Structural timber design. Blackwell Science, London.

18.3.5 Learning Outcome No 4: Collect Wastewater Infrastructure Design Data
18.3.5.1 Learning Activities

Learning Outcome No 4: Collect Wastewater Infrastructure Design Data	
Learning Activities	**Special Instructions**
4.1 Map out areas to be surveyed 4.2 Prepare ***tools for data collection*** 4.3 Collect ***data and information***	• Group discussions • Demonstration by trainer • Online videos • Powerpoint presentation • Exercises by trainee

18.3.5.2 Information Sheet No 18/LO4: Collect Wastewater Infrastructure Design Data

Introduction to learning outcome

This learning outcome covers mapping out an area in preparation for wastewater data collection, tools, and methods to collect relevant data preparation and determination of relevant amounts and types of data to be collected from an area to better the wastewater management of the area.

Definition of key terms

Stabilization pond- These are large man-made water bodies that use natural processes in treating domestic water, sewage, and sludge as well as animal or industrial waste.

Detention time- this defines the time required for a known amount of wastewater to go through a tank at a set flow rate.

Scour Velocity- the speed of water that is required to dislodge settled solids from the stream bed.

Content/Procedures/Methods/Illustrations

4.1 Map out areas to be surveyed based on job requirements/specifications.

Wastewater management map is essential and assists in identifying where current wastewater servicing exits and where it is planned and also shows where servicing should be avoided. We can also use the map for supporting policies in the development plan, for example, when a plan needs new developments for connection to services where they are available, this can be shown on the map, it identifies how and where the development will connect and determines cost implications of accommodating development in areas with specific services. From a map, we can identify areas where ejectors and disposal fields are not allowed due to factors such as public health issues, soil limitations, environmental issues, policies or other reasons. The layering of wastewater system maps over land use designation maps will help integrate land use with wastewater management planning.

To map out an area for surveying we consider our topic which is wastewater and identify the various factors that we consider. These factors mainly focus on drainage and conservation of the environment. The main factors can be

- Infrastructure – in terms of crowding of buildings
- Population – population density is a major factor since a large amount of wastewater is expected
- Nearness to water bodies (rivers and streams) – conservation of the environment is important hence disposal of wastewater into them should be limited.
- Wildlife such as fish in water bodies
- Relocation plans for people living in areas where the wastewater treatment plant is expected to be developed.

4.2 Prepare tools for data collection (Stopwatch, Checklists, Questionnaires, Stationery, and Sampling equipment) based on information required.

In accordance with the study, we will use research methodologies to collect data on the area we have mapped out. Since water is a human resource we mainly focus on the population in terms of policies and essential needs by them. We are going to depend mainly on primary and qualitative data.

Primary data involves obtaining data directly from individuals and qualitative data is data we use for description without measurement.

Our data would be got by the following methods:

- Sample surveys
- In-person interviewing
- Telephone interviewing
- Mailed questionnaire
- Observations
- Case studies

4.3 Collect *data and information* (Population size and flow rate) based on tools prepared.

The data and information required in wastewater normally focus on the environmental and health issues, the goal is to better the hygiene of the general population and to ensure clean water is available for use by the population.

From the data tools and methodologies, we are expected to obtain the following information:

- The general population in the area
- What amount of the population have access to clean water
- Are there any rampant waterborne diseases in the mapped out area and if there are specify
- Understand and research the wastewater drainage system in the area.
- Public opinion in accordance with wastewater management in the area.

Conclusion

This learning outcome covered mapping the area, tools preparation, and quantity of wastewater data collection.

Further Reading

Read further

On wastewater infrastructure and data collection on

https://www.gov.mb.ca/mr/plups/pdf/wwg.pdf

18.3.5.3 Self-Assessment

Written Assessment

1. Summarize the reasons for mapping out an area.
2. From a map, we can identify where ejectors and disposal points can be placed, choose a factor that is not used to identify areas for disposal points and ejectors.
    a) Policies
    b) Soil limitation
    c) Health issues
    d) Water cleanliness

3. Which of the following is not a method of obtaining data
    a) using questionnaires
    b) sampling
    c) counting
    d) case studies
4. Predict the goal of data collection for wastewater treatment among the following
    a) To better hygiene of the public.
    b) To come up with systems
    c) Identifying new infrastructure
5. Explain the importance of mapping
6. Summarize the factors that can be used to identify disposal fields for wastewater treatment?
7. Outline the various method of data collection to obtain data which is helpful in wastewater treatment?
8. Explain the various methods of data collection?
9. Describe the types of information obtained for wastewater treatment?

Oral Assessment

1. Differentiate between primary and secondary data
2. Elaborate the term qualitative data?

Case Study Assessment

Briefly explain the impact of wastewater treatment in the area you currently stay **in.**

Oral Assessment

Construct questions that can be used to obtain data by using face to face interaction as a method of obtaining data?

Practical Assessment

In groups, use the questions you came up with to role play and practice on the face to face method of collecting data.

Project Assessment

Compose a questionnaire and hand them over to the public around your area then analyze and interpret the data obtained.

18.3.5.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras

- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

18.3.5.5 References

Water, Wastewater, and Stormwater Infrastructure Management, Second Edition (2012): Neil S. Grigg

Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low (2010): ...edited by Pay Drechsel, Christopher A. Scott, Liqa Raschid-Sally, Mark Redwood, Akica Bahr

Strategic Asset Management of Water Supply and Wastewater Infrastructures (2009): edited by Helena Alegre, Maria do Ceu Almeida

18.3.6 Learning Outcome No 5: Analyse Wastewater Infrastructure Design Data

18.3.6.1 Learning Activities

Learning Outcome No 5: Analyse Wastewater Infrastructure Design Data	
Learning Activities	**Special Instructions**
5.1 Arrange data and information 5.2 Clean data 5.3 Present data	• Group discussions • Demonstration by trainer • Online videos • Powerpoint presentation • Exercises by trainee

18.3.6.2 Information Sheet No 18/LO5: Analyse Wastewater Infrastructure Design Data

Introduction to learning outcome

This learning outcome covers categorizing population into various classes, analyzing and cleaning climatic and hydrological data, and producing topographical maps and ground profiles from survey data.

Definition of key terms

Hydrostatic bench- is a self-contained bench that is equipped with all apparatus needed for a comprehensive range of experiments on properties of fluids and hydrostatics.

Open Channel-defined as a design of flow enclosed in a conduit with a free surface commonly known as a channel.

Weirs- simply defined as a barrier across the width if a river to alter its flow.

Content/Procedures/Methods/Illustrations

5.1 Arrange data and information based on various themes.

In the middle of qualitative data analysis, we have another job of identifying themes, this can be done by reviewing literature and come from the phenomena being studied, already agreed-upon professional definitions, local common-sense constructs, and researchers.

Data can be arranged using various techniques, in modern trends and computing data is mostly arranged in Microsoft Excel for easier and faster interpretation and analysis.

Apart from Excel sheets data can also be grouped using;

- Pie charts
- Graphs
- Flow charts
- Tabulations

5.2 Clean data as per best practice.

After collecting and arranging data there is a need for it to be cleaned by a process known as data cleansing, this can be defined as a process of detecting and correcting inaccurate data from the database arranged. We shall focus on the quality of data, the quality can be assessed by the following factors:

- Validity
- Accuracy
- Completeness
- Uniformity
- Consistency
- Uniformity

Data cleansing also involves several processes i.e.

i. Data auditing by use of statistical methods
ii. Workflow specifications by removing anomalies
iii. Workflow execution where correctness is verified after the specification
iv. Post-processing and controlling by inspection of the results.

5.3 Present data based on various themes

Table 53: Data based on various themes

THEMES	PARAMETERS OF CALCULATION
Wastewater contamination extent	Data can be sorted into 3 main categories as municipal, agricultural, or industrial wastewater.
Geological data	Focusing on the vegetation in terms of infiltration and soil conditions.
Discharge requirements	Policies are a tool that can be used to come up with wastewater data this is based on requirements by bodies such as NEEMA and KEBS
Sizing of components	Here data is sorted as Primary, secondary and tertiary

Data presentation should be clear and easy to interpret it can be done by a graphical format or tabular, data can be in figures or textual.

The following are methods of presenting data

- Bar graph – used mainly for comparison
- Pie chart – shows percentages
- Line graph – useful in displaying data that changes over time
- Pictographs- uses small identical or figures of objects called isotopes in making comparisons.

Conclusion

This learning outcome covered categorizing population into various classes, analyzing and cleaning climatic and hydrological data, and producing topographical maps and ground profiles from survey data.

Further Reading

Read further areas:

https://www.slideshare.net/rubyocenar/presentation-of-data-37973327

18.3.6.3 Self-Assessment

Written Assessment

1. Data processing is a process of Quality of data can be assessed through the following except which one
    a) Completeness
    b) Validity
    c) Uniformity
    d) Presentation
2. Which of the following is not a method of presenting data?
    a) pie chart
    b) line graph
    c) creating models
    d) bar graphs
3. Explain the term data cleansing
4. Evaluate the sue of the hydrostatic bench.
5. Explain ways in which themes can be identified from a database?
6. explain various methods of data arrangements
7. Classify the modern techniques of arranging data

Oral Assessment

Explain the following processes:

a) Data auditing
b) Workflow specification

Case Study Assessment

Using hydrological data from your area, tabulate and interpret the data then present it

Oral Assessment

Briefly explain the following methods of data presentation.

1. Pie charts
2. pictograms

Practical Assessment

Give an example of a pictogram using data provided,

Project Assessment

Using hydrological data from your area, arrange clean, and present the data using your preferred method.

18.3.6.4 Tools, Equipment, Supplies and Materials

- Software
- Pencils
- Ruler
- T-square
- Scale rule
- Eraser
- Set square
- Drawing board

18.3.6.5 References

Analyzing, completing, and generating data for WWTP modeling: a critical review (2014). : CristinaMartinabPeter A.Vanrolleghema

Measuring the efficiency of wastewater services through data envelopment analysis (2015): A. Guerrini; G. Romano; C. Leardini; M. Martini

Water & Wastewater Infrastructure: Energy Efficiency and Sustainability (2013): Frank R. Spellman

18.3.7 Learning Outcome No 6: Calculate Wastewater Infrastructure Design Parameters

18.3.7.1 Learning Activities

Learning Outcome No 6: Calculate Wastewater Infrastructure Design Parameters	
Learning Activities	**Special Instructions**
6.1 Identify ***design Parameters*** to be calculated 6.2 Identify ***tools for parameter calculation*** 6.3 Calculate various wastewater infrastructure design parameters	• Group discussions • Demonstration by trainer • Online videos • Powerpoint presentation • Exercises by trainee

18.3.7.2 Information Sheet No 18/LO6: Calculate Wastewater Infrastructure Design Parameters

Introduction to learning outcome

This learning outcome covers Sizing of the pipes, Hydraulic flow in pipes, Depth of flow, Gradient, and Sizing of treatment units. Pipe sizing is a process in which various pipes are made concerning its diameter. The difference in pipe sizes affects the pressure and the velocities of the fluid flowing within the pipes. Narrow pipes result in higher velocities of flow.

Definition of key terms

BOD: (biochemical oxygen demand). This is the quantity of oxygen dissolved required by anaerobes to digest organic material in the water at a given temperature over a specified duration of time.

TSS :(total suspended solids). This is the dry mass of undissolved suspended particles in a given water sample that can be trapped and filtered such as silt.

Gradient: This is the inclination nature of a slope (upward or downward)

Content/Procedures/Methods/Illustrations

6.1 Identify *design Parameters* (Screening units, sedimentation tanks, grit chamber, trickling filters, stabilization ponds, activated sludge system) to be calculated based on the wastewater design manual.

There are many design parameters to be calculated based on the wastewater design manual. They include;

- Hydraulic load- wastewater influent expressed in per person per day.
- Mass load-indicator of water quality and pollution level
- BOD - (biochemical oxygen demand).
- COD-chemical oxygen demand.
- The volume of suspended solids

6.2 Identify *tools for parameter calculation* (Theodolite, Dumpy level, GPS, Total station, levelling staff, booking sheet, Soil sampler, Adequately equipped soil mechanics labouratory, Flow Measuring structures, and devices, Stopwatch, Questionnaires) based on the parameter to be calculated.

Tools used during the calculation of hydraulic load include; booking sheet, flow measuring structures, and devices and a stopwatch. Tools used during the calculation of Mass load. Mass load requires an adequately equipped soil mechanics lab to determine the pollution level.

BOD is measured by BOD analyzers

Table 54: Tools used during the calculation of Mass load

Tool Name	**Description**
Theodolite	Measures horizontal and vertical angles
Dumpy level	Measures points on the same horizontal plane
GPS	Global positioning system
Booking sheet	Tabulation of survey data
Stopwatch	Performs accurate timing
Soil sampler	Analyze soil samples

Pipe diameter size is required to determine the discharge and area of discharge at a given time to calculate the hydraulic load.

6.3 Calculate various wastewater infrastructure design parameters based on design codes.

How hydraulic load is obtained = (design flow in gal/day)/area in feet^2.

Mass load= total water flow* conc. Of substance required in mg/l).

Below is an example of how mass load is calculated;

EXAMPLE 1

Mass loading calculations:

Given:

Average flow rate Q=300l/min

Washing Day = 10hours

Washing span = 60 days/year

Average total phosphorous concentration = 0.4 mg/L

1 kg = 1000000 mg

Total water flow (TWF)

TWF = Q × WD × WS

300 L/min * 60 min/hr *10 hrs/day*260days/yr

46800000

Mass loading of phosphorous

MLP = TWF*TP

46800000 L/yr*0.4 mg/L

18720000 mg/yr

Convert to kilograms

MLP = 18720000 MG/YR&* 1kg/1000000mg

18.72 Kg/yr

Conclusion

This learning outcome covered Sizing of the pipes, Hydraulic flow in pipes, Depth of flow, Gradient, and Sizing of treatment units.

Further Reading

Read further on the measurement of BOD

18.3.7.3 Self-Assessment

Written Assessment

1. Which of the following is not a design parameter in wastewater analysis?
   a) Hydraulic load
   b) Lateral wind load
   c) suspended solids (TSS)
   d) mass loading

2. The indicator of the water pollution level is known as.

a) Mass load
b) Hydraulic load
c) BOD
d) COD

3. Which instrument measures horizontal and vertical angles?

a) Theodolite
b) Stopwatch
c) Dumpy level
d) Soil sampler

4. Discuss the following terms as used in the waste water analysis

a) Design parameter
b) Hydraulic load
c) Mass load

5. Calculate the hydraulic loading rate given: design flow is 12860 gallons per day, the area is $19.2m^2$
6. Discuss four parameters of wastewater analysis
7. Describe how suspended solids are removed in wastewater?
8. Discuss the effects of the variation of BOD in wastewater.
9. Sizing the pipe to be small is a necessary evil. Elabourate.

Oral Assessment

What were your observations during the visit to the nearby water treatment plant?
What conclusions can be made?

Practical Assessment

Experiment to determine the content of parameters in wastewater**.**
Illustrate the direction of the flow of wastewater in various stages.

18.3.7.4 Tools, Equipment, Supplies and Materials

- Software
- Pencils
- Ruler
- T-square
- Scale rule
- Eraser
- Set square
- Drawing board

18.3.7.5 References

CPL Grady et al (2011), Biological wastewater treatment. New York
Marcos Von Sperling, (2007), Basic Principles of wastewater treatment. Berlin.

18.3.8 Learning Outcome No 7: Draw Wastewater Infrastructure Units

18.3.8.1 Learning Activities

Learning Outcome No 7: Draw wastewater infrastructure units	
Learning Activities	**Special Instructions**
7.1 Identify and gather ***drawing tools, equipment, supplies, and materials*** 7.2 Draw ***wastewater infrastructure units*** based on the design parameters Draw ***wastewater infrastructure units*** 7.3 Submit wastewater infrastructure drawings for approval	• Group discussions • Demonstration by trainer • Online videos • Powerpoint presentation • Exercises by trainee

18.3.8.2 Information Sheet No 18/LO7: Draw wastewater infrastructure units

Introduction to learning outcome

This learning outcome covers drawing the different sections and profiles or different parts of the wastewater treatment unit and legal requirements. It also equips the learner with the knowledge of different chambers in the waste water treatment.

Definition of key terms

Equalization tank-A holding tank that ensures consistent flow and loading to subsequent processes over a given period

Rotating biological contactors- is a type of secondary (Biological) treatment process following the removal of grit sand and sediments that allows a biological film to come in contact with the wastewater to remove pollutants before discharge to the environment. It consists of a shaft with mounted rotating discs where biological degradation of pollutants takes place

Oxidation ditch-A circular trough installed with aerators used to purify wastewater by removal of pollutants via oxidation decomposition and adsorption

Content/Procedures/Methods/Illustrations

7.1 Identify and gather *drawing tools, equipment, supplies and materials*

Table 55: Drawing tools, equipment, supplies and materials

TOOL	FUNCTION
pencil	Sketching elements in a wastewater treatment plant
ruler	Draw straight lines
eraser	Delete errors that have been sketched
Drawing board	Provide a stable drawing surface
Masking tape	Mount the paper into place
Set square	Making right angles on the drawings

Identify and gather *drawing tools, equipment, supplies and materials*

The tools that are used in the technical drawing and design office include.

Software**,** Pencils**,** Ruler**,** T-square**,** Scale rule**,** Eraser**,** Set square**,** Drawing board**,** Supplies: Masking tapes**,** Materials: Drawing paper**,** Photocopying /printing papers**,** Equipment: Computer**,** Printer**,** Photocopiers) based on available resources and complexity of the design.

b. Draw *wastewater infrastructure units*

Sewer, Screen, Grit chamber-horizontal, aerated/spiral, Sedimentation tanks, Activated sludge system, Trickling filters(rock and plastic), Ponds, Oxidation ditch, Aerated lagoons, Stormwater drains, Equalization tank, Sequential Batch Reactor, Rotating biological contactors, Oil and grease trap) based on the design parameters.

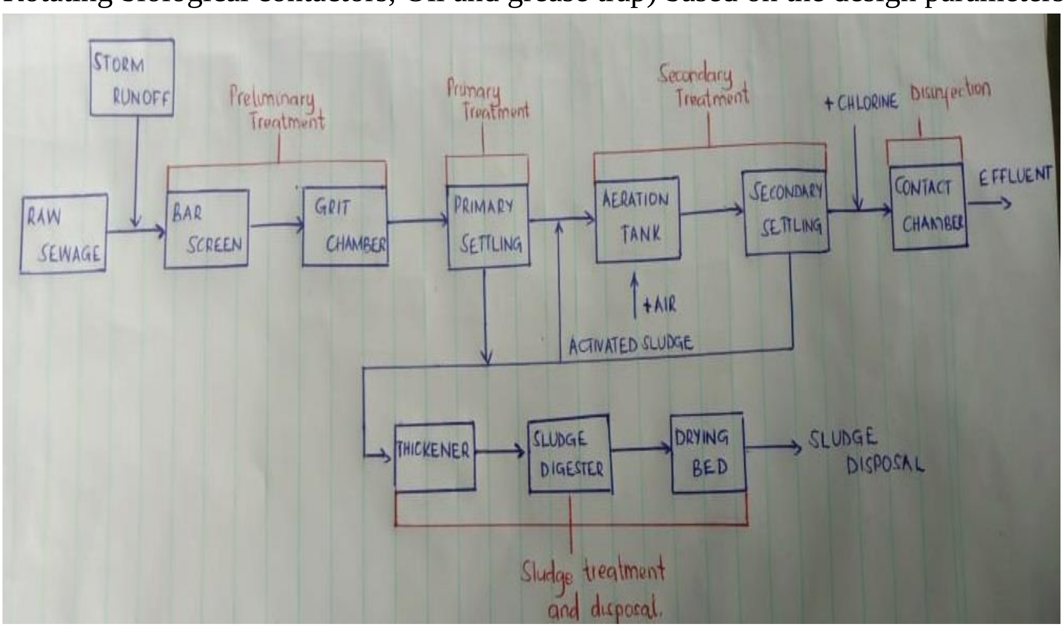


Figure 179: Draw wastewater infrastructure units

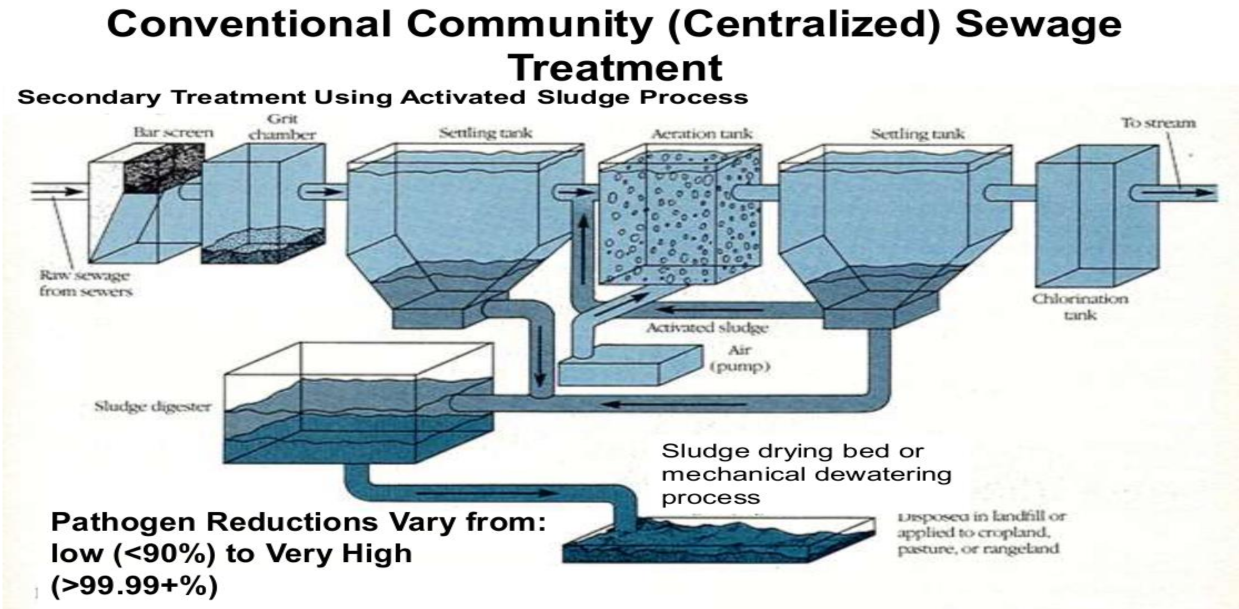


Figure 180: Sewage treatment
Source: Biological wastewater treatment (2011)

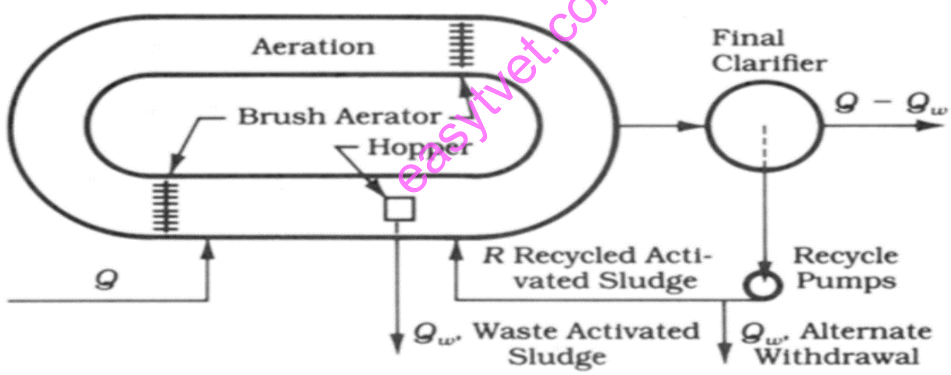


Figure 181: Oxidation ditch
Source: Biological wastewater treatment (2011)

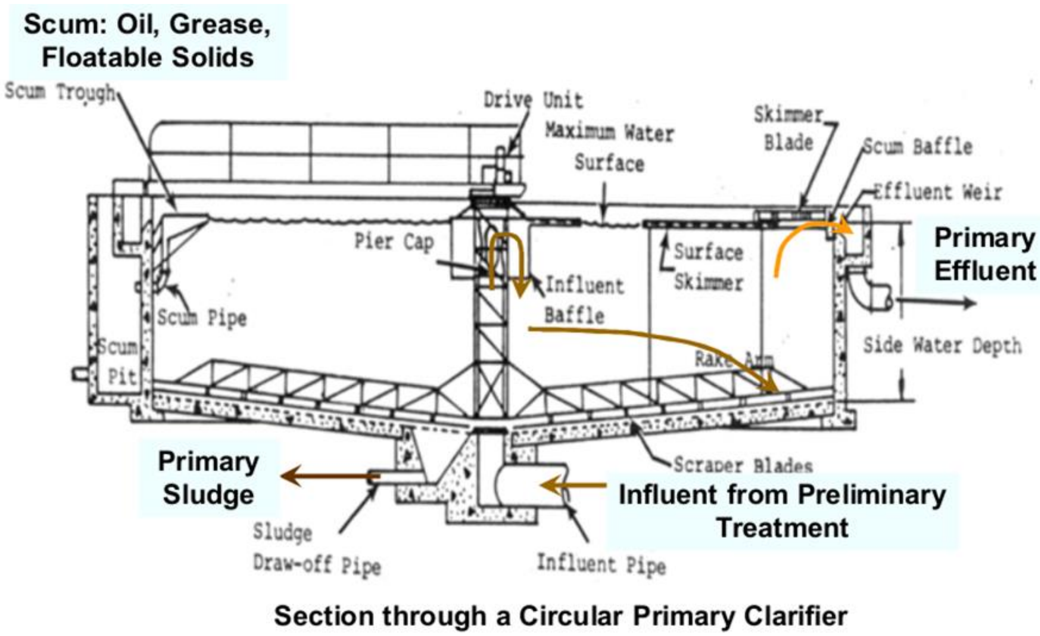


Figure 182: Circular primary clarifier
Source: Biological wastewater treatment (2011)

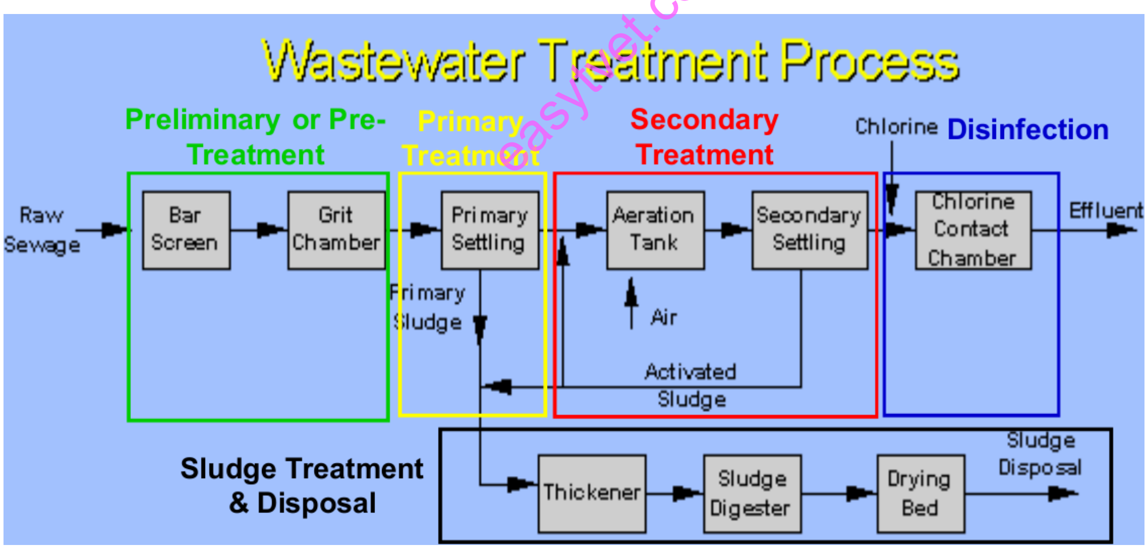


Figure 183: wastewater treatment process
Source: Biological wastewater treatment (2011)

c. Submit wastewater infrastructure drawings for approval as per legal requirements.

The various elements of a wastewater treatment plant work as follows;

1. Bar racks to remove large debris
2. Primary treatment were Type II sedimentation for flocculated particles. The SOR ranges from 25-60 m/d, td ranges from 1.5 to 2.5 hours.

3. Secondary treatment involving the use of microorganisms to remove BOD of any solids that pass primary treatment. Oxygen is limited and must be supplied. The most common secondary treatment process is activated sludge.
4. Secondary sedimentation to remove microorganisms from secondary treatment.
5. Disinfection to kill pathogens using chlorine (typically HOCl).

The legal requirements of wastewater infrastructure drawings must;

1. Be of sound engineering adhering to the technical standards put in place
2. Should be well planned to meet the future demands
3. The drawings must be approved by the relevant bodies to ensure it meets the standards in place
4. Should exhibit knowledge of the regulatory frameworks in place.
5. Stakeholders involved should stick to their roles.
6. The drawing must be able to cater for the future demand of the infrastructure

Conclusion

This learning outcome covered drawing the different sections and profiles or different parts of the wastewater treatment unit and legal requirements.
The legal requirements are contained in the water act of the constitution.

N/B Legal Requirements

Water quality Regulations, 2006

Further Reading

Read further on how wastewater treatment units can be made more efficient.
Read the water regulations act of 2006.

18.3.8.3 Self-Assessment

Written Assessment

1. Which chamber in a wastewater treatment plant traps solid material of sewage?
   a) Primary storage.
   b) Aeration zone
   c) Sedimentation tank
   d) Bar racks

2. Which one is not a microorganism in wastewater?
    a) Coliforms
    b) Aerobes
    c) Anaerobes
    d) Symplistica pteridophyte
3. What is the role of microbes in wastewater treatment?
4. State the importance of activated sludge?
5. Compare the composition of the influent and effluents of a wastewater treatment plant?
6. Describe how wastewater is treated?
7. As an engineer, what improvements can you make to a storm drain to improve its role and efficiency?
8. Describe the 3 main stages of wastewater treatment?
9. The activation chamber is the main section of treatment. Discuss.

Case Study Assessment

Given a city with a population of 50000 residents and a wet humid climate design a wastewater treatment plant to meet the demand of the city.

18.3.8.4 Tools, Equipment, Supplies and Materials

- Software
- Pencils
- Ruler
- T-square
- Scale rule
- Eraser
- Set square
- Drawing board

18.3.8.5 References

CPL Grady et al (2011), Biological wastewater treatment. New York.
Marcos Von Sperling, (2007), Basic Principles of wastewater treatment. Berlin.

18.3.9 Learning Outcome No 8: Compile Wastewater Infrastructure Design Report

18.3.9.1 Learning Activities

Learning Outcome No 8: Compile Wastewater Infrastructure Design Report	
Learning Activities	**Special Instructions**
8.1 Obtain design report format from the wastewater design manual. 8.2 Prepare a design report 8.3 Submit a design report to the client	• Group discussions • Demonstration by trainer • Online videos • Powerpoint presentation • Exercises by trainee

18.3.9.2 Information Sheet No 18/LO 8: Compile Wastewater Infrastructure Design Report

Introduction to learning outcome

This learning outcome covers technical report writing and legal requirements. The learner is also equipped with knowledge on how to design report based on the format from the waste water design manual.

Definition of key terms

Questionnaires: - Is an instrument used in research consisting of a series of questions which are intended for gathering information

Discharge: - Is the volumetric flow rate transported through a given cross-section

Sludge: - These are bio-solids that can be reused after stabilization processes such as composting and anaerobic digestion.

Content/Procedures/Methods/Illustrations

8.1 Obtain design report format from the wastewater design manual.

Title Page
Declaration
Dedication
Acknowledgment
Abstract
CONTENTS
LIST OF TABLES

8.2 Prepare a design report based on the identified format.

Abstract

To ensure that public health standards are upheld, it is imperative to dispose of human and industrial effluents so that they do not damage the natural environment or pose a danger to human health. Wastewater treatment process aims at removing contaminants from wastewater which is then converted into an effluent that can be recycled back to the water cycle rendering minimal impact on ecosystems.

Wastewater treatment technologies can be classified into mechanical systems, aquatic (Lagoons), and terrestrial treatment systems.

The non-conventional treatment was adopted as was adopted in this particular report because they are easily maintained, less energy-intensive, lower operational and maintenance costs, and is environmentally friendly.

CHAPTER 1 INTRODUCTION

Wastewater includes water and wastes released to the environment and originating from a variety of uses including commercial, residential, and industrial sources. Sewage is waste expelled from domestic dwellings such as commercial, institutional and residential establishments. The composition is expected to be organic because of the consistency of carbon composites.

These contaminants are toxic and dangerous to the environment and human health and thus should be treated prior to being released into the environment in the case when it is discharged back into the watercourse.

The treatment process employs physical, chemical, and biological processes to treat wastewater. The process occurs in a wastewater treatment infrastructure. The infrastructural design is dictated by the wastewater characteristics whereby each stage of treatment say mechanical treatment, biological and sludge treatment sections, are designed based on the wastewater characteristics and the organic loading.

CHAPTER 2 DESIGN

Waste stabilization ponds consist of three stages of treatment, namely,

Table 56: Waste stabilization ponds stages

Primary stage	Solids are separated
Secondary	Dissolved biological matter converted into a solid mass using water-borne bacteria
Tertiary	Biological solids are neutralized then disposed of and treated. Chemical disinfection is conducted at this stage

2.1 DESIGN PROCESS

Table 57: Design process

<table>
<tr><td></td><td>PRELIMINARY TREATMENT</td><td></td></tr>
<tr><td>REF</td><td>CALCULATION</td><td>REMARKS</td></tr>
<tr><td></td><td>BAR SCREEN DESIGN
Screens are used for the removal of coarse solids. Their design applies the following criteria.
<table>
<tr><th>Manual bar screens</th><th>Mechanical bar screens</th></tr>
<tr><td>Bar spacing range between 2- 5cm</td><td>Bar spacing range between 1.5 – 4 cm</td></tr>
<tr><td>Screen mounted at an angle of 30^0 - 45^0</td><td>Screens mounted at an angle of 30</td></tr>
<tr><td>Bar thickness is 1cm thick, 2.5cm wide.</td><td>Bar thickness is 1cm thick, 2.5cm</td></tr>
<tr><td>The minimum approach velocity is 0.45 m/s to avoid grit deposition.</td><td>Min approach velocity in the bars m/s to avoid a deposition.</td></tr>
<tr><td>Max velocity is 0.9 m/s to prevent washout of solids through the bars.</td><td>Max velocity is 0.9 m/s to washout of solids through the bars</td></tr>
</table></td><td></td></tr>
</table>

<table>
<tr><td></td><td>

Empirically described by the following equation

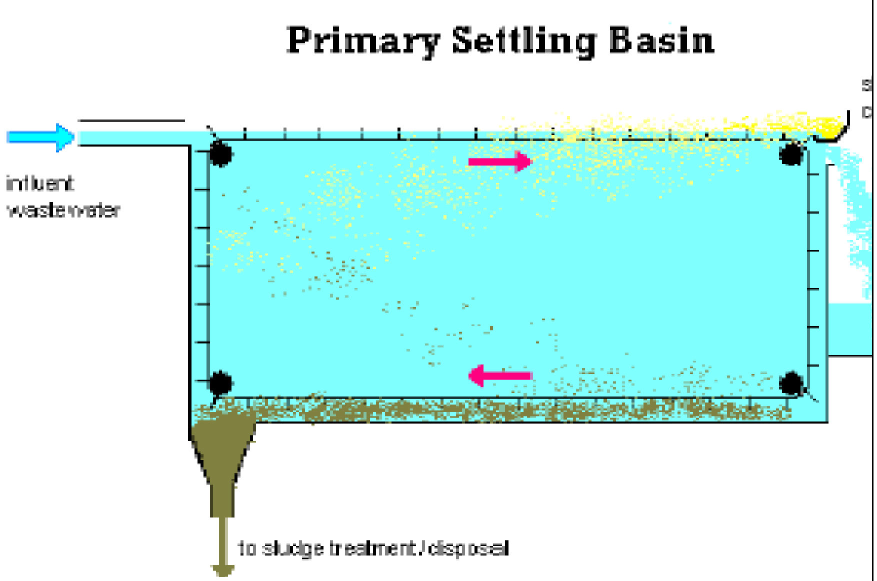
<table>
<tr><td>Q = AV or A = Q/V
Where
Q= design flow, m^3/s
A = bar screens cross-section
V = approach velocity of channel, m/s

Adopt rectangular channels with depth to width ratio = 1.5 for most efficient section</td><td>Head loss through the bar screen I
$$\frac{(V^2 - V'^2) \times 0.7}{2g}$$
Where:
H = head loss
V = velocity through the openings
V'= approach velocity, (m/s)
g = acceleration due to gravity</td></tr>
</table>

The typical head loss coefficient for a clean and clogged coarse screen is 0.8 and 0.5 respectively.
</td><td></td></tr>
</table>

<table>
<tr><td></td><td>PRIMARY TREATMENT</td><td></td></tr>
<tr><td>REF</td><td>CALCULATION</td><td>REMARKS</td></tr>
<tr><td></td><td>

The purpose of the primary stage is to remove sand and grit and other settleable organic solids that settle at the bottom and keep suspended organic matter in water.



Tchobanoglous and Schroeder, (1985).

Settling Theory
</td><td></td></tr>
</table>

$V_s = \sqrt{4g\frac{(\dot{\rho}-\rho)d}{3C\rho}}$ Where: V_s = settling velocity $\dot{\rho}$ = particle density ρ = liquid density d = particle diameter C = drag coefficient		$V_h = \sqrt{8\beta\frac{(\dot{\rho}-\rho)gd}{f}}$ Where: V_h = scour velocity B = friction face-off particles F = Darcy-weisbach friction factor

Particle density (Kg/m^3)		Settling Vs, (m/s)	
		0.1 mm	0.2mm
sand	2650	25	74
Organic matter	1200	3.0	12
Organic	1020	0.3	1.2

	GRIT CHAMBER	
REF	CALCULATION	REMARKS
	The purpose of the grit chamber is to remove organic matter with a higher density greater than 2000 Kg/m^3 and particle size 0.1 – 0.2 mm to protect pumps from abrasion and to prevent clogging of digesters. $A = W \times H = \frac{Q}{V}$ | $\frac{V"}{V} = \frac{H}{L}$ Where: A = grit chamber area H = Height of grit chamber W = width of grit chamber L = Length of grit chamber V" = Velocity of scouring V = settling velocity	

	SECONDARY TREATMENT	
REF	CALCULATION	REMARKS
	This stage is included to treat dissolved organic matter that forms the degradable biological content. The mechanism works by introducing micro-invertebrates into raw wastewater that aids in	

	the digestion of the organic matter. Three approaches exist in a fixed-film system, suspended film system, and lagoon system. The lagoons system is addressed in performing this design. Lagoons work by holding water for several months to allow the natural degradation of sewage. **Biological Treatment** The purpose of biological treatment is to capture solids that are unable to settle. The solids are trapped into a biological floc or biofilm. 2.2 LOADING This describes the amount to be applied to the treatment process 1. Population Loading The geometric growth model is used to determine the population increase over a specified design period is divided into three segments, initial year 5years, Basic year (10 years), and Final year (25 years). $$\mathrm{Pt} = \mathrm{P0}(1 + r)^{t}$$ Where: P_0 = initial population P_t = population after t years	

	SECONDARY TREATMENT	
REF	CALCULATION	REMARKS
	Waste Stabilization Ponds The most important design parameters for WSP include:	

Climate	Temperature, Net radiation, Solar insulation.
Flow	Normally 85% of the in-house water consumption.
BOD	Measured based on a 24hour flow weighted data.

Organic Loading

Biochemical oxygen Demand (BOD)

BOD loading is estimated from the following equation

$$\text{Li} = 1000\frac{B}{q}$$

Where

L_i = waste water BOD (mg/l)

B = BOD contribution (g/capita.day) Range (30-70g/capita.day)

Q = wastewater flow (L/capita.day)

Anaerobic Ponds

Continuous organic load of wastewater is received daily into the first stage of biological treatment which is a basin that is 3 – 5 m deep. The high wastewater loading depletes all oxygen and thus anaerobic conditions prevail.

At the bottom of the pond solids, settle and anaerobic digestion of sludge occurs

Anaerobic Pond Design

Designed based on volumetric loading $\lambda_{v,}$ (g/m^3/d)

$$\lambda\text{v} = \frac{\text{Li}Q}{\text{Va}}$$

Where:

L_i = influent BOD (mg/l), Q = flow rate (m^3/day)

V_a = anaerobic pond volume

	SECONDARY TREATMENT	
REF	CALCULATION	REMARKS

The recommended influent BOD loading is in the range of (100 – 400g/m^3.day.

Hydraulic retention time is then calculated as,

$$t = \frac{\mathrm{Va}}{Q}$$

Volumetric loading table

Temperature (℃)	Volumetric Loading (g/m^3.d)	BOD removal (%)
< 10	100	40
10-20	20T−100	2T+20
20-25	10T+100	2T+20
>25	350	70

Mara and Pearson, (1986).

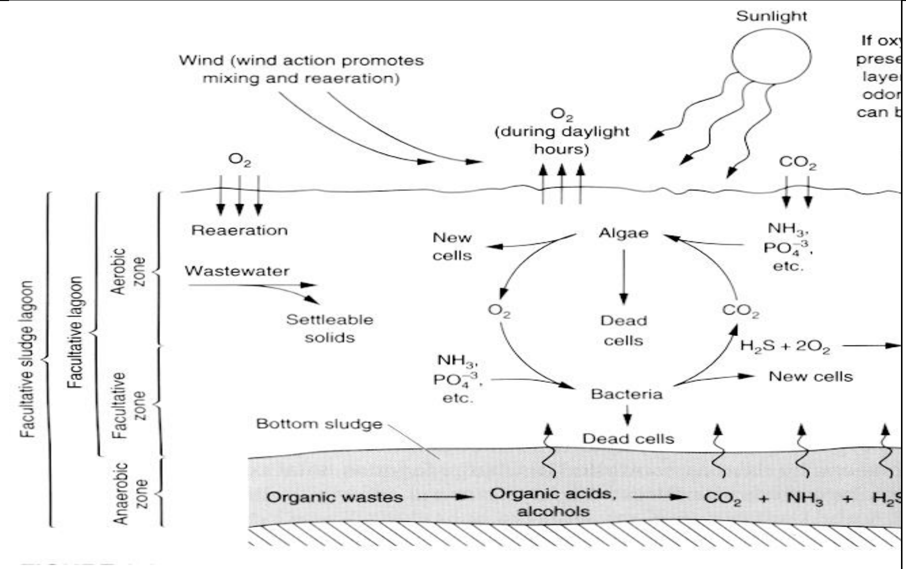
Mid depth area

$$\mathrm{A1} = \frac{\mathrm{V1}}{\mathrm{d1}}$$

Facultative Ponds Design

Allow shallow depths of basins (1.5 – 2m), to enable light penetration and photosynthetic production of oxygen, so that microbial action of decomposing organic material can be favored.

An anaerobic state exists at the bottom of the pond where settleable solids are degraded.



Tchobanoglous and Schroeder, (1985).

	SECONDARY TREATMENT	
REF	CALCULATION	REMARKS

<u>Facultative pond design</u>

Their design assumes they are completely mixed reactors in which BOD5 removal, adheres to first-order kinetics.

$$\frac{\mathrm{Le}}{\mathrm{Li}} = \frac{1}{(1 + \mathrm{K1t})}$$

$$\mathrm{t} = \frac{(\mathrm{Le}/\,\mathrm{Li} \;\; - 1)}{1/\,\mathrm{K1}}$$

the mid area depth

$$A = \frac{Qt}{D}$$

Facultative ponds are designed on the based on surface loading ,λ_s,

$$\lambda\mathrm{s} = \frac{10\mathrm{Li\ Q}}{\mathrm{Af}}$$

where:

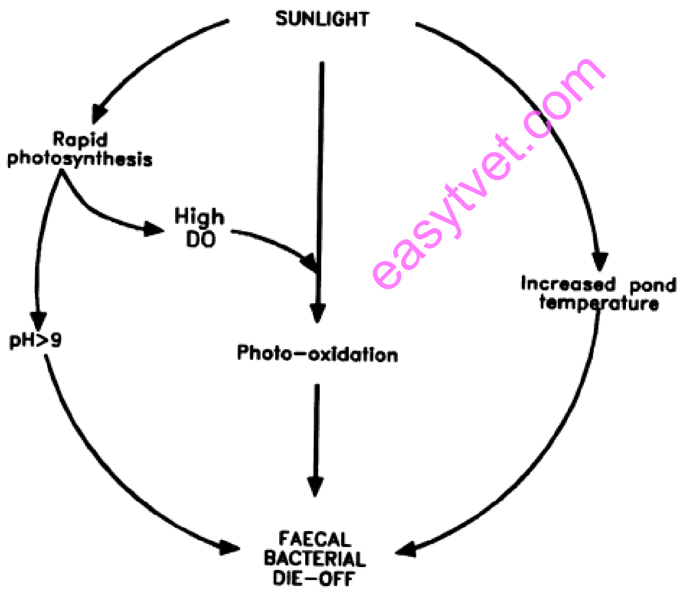
Li = the influent sewage concentration (mg/L)

A_f = Facultative pond area (m^2)

Surface loading value is given by: $\lambda_s = 20T - 120$

Retention time θ_f ,(days)

	$\theta f = \frac{AfD}{Qm}$ Where: Q_m = mean flow, (m^3/day) D = pond depth usually 1.5m).	

	TERTIARY TREATMENT	
REF	CALCULATION	REMARKS
	Maturation pond The objective of maturation ponds is to remove pathogenic microbes in the wastewater. The removal process occurs due to sunlight in the water column. Basin depth ranges between (0.8 – 1.5m).  Figure 3.4 Conceptua mechanisr faecal coli off in pond Tchobanoglous and Schroeder, (1985). <u>Design of Maturation Ponds</u> They are designed based on first-order kinetic models as in a completely-mixed reactor. $Ne = \frac{Ni}{1 + KT\theta}$ The maturation ponds are normally arranged in series $Ne = \frac{Ni}{[(1 + t1\ KT)(1 + t2KT)(1 + t3\ KT)n]}$	

	$$KT = 2.6(1.19)^{T-20}$$ $$V3 = Q \times t3$$ Mid area depth $$A3 = \frac{V3}{d3}$$	

	TERTIARY TREATMENT	
REF	CALCULATION	REMARKS
	Where: Ne and Ni = number of faecal coliform per 100mlin the effluent and influent KT = first-order rate constant for faecal coliform removal per day Θ = retention time (day). CONCLUSION In non-conventional treatment design, the selection of treatment processes depends on the wastewater quality. In case the wastewater is found not to contain pathogenic microorganisms then the engineer can decide the design for only three stages of treatment say Preliminary, primary, and secondary excluding maturation ponds. Other designers may exclude preliminary treatment when the wastewater has no or minimal, large objects. The design methodology presented applies to all non-conventional treatment system. Variations my occur only in the selection of data to be used.	

8.3 Submit a design report to the client as per best practice

The report is presented in the form of slides that explain the design process. The engineer must be conversant with all the processes so that the slides only assist him to plan the presentation.

The seven rule applies in preparing the slides that is seven slides, seven sentences and seven words per sentence

TITLE SLIDE
PROJECT TITLE
NAME
SPECIALITY

PROBLEM STATEMENT

- The need for the waste treatment plant
- Challenges in implementing the project
- Solutions to the above challenges
- Future changes in trends

METHODS AND MATERIALS

- Design criteria
- Materials required for design
- Tools, equipment, and machinery required

DATA COLLECTION

- Types of data
- Methods of collection of data
- Data transfer and storage

DATA ANALYSIS

- Empirical and numerical modeling
- Design codes referencing
- Design software applications

RESULTS AND RECOMMENDATIONS

- Design report presented
- Sizes of infrastructure decided upon
- Approval of the project

CONCLUSIONS

Conclusion

This learning outcome covered technical report writing and legal requirements.

Further Reading

Arrhenius equation and its application
Linear growth models and exponential growth models

18.3.9.3 Self-Assessment

Written Assessment

1. In characterizing wastewater which of the terms doesn't describe wastewater source.
    a) Industrial sources
    b) Underground sources
    c) Residential sources
    d) Commercial sources
2. Wastewater treatment process is grouped into three, mechanical treatment, biological treatment, and chemical treatment, which of the following is not included in mechanical treatment.
    a) Removal of large objects
    b) Removal of sand and grit
    c) Primary sedimentation
    d) Faecal coliform removal

3. Which of the following is true about detention time?
    a) Oxidation pond detention time range = (3 – 5) days
    b) Facultative pond detention time range = (25 – 180) days
    c) Aerated pond detention time range = (7 – 20) days
    d) Storage pond/HCR pond detention time range = (100 – 200)
4. Which one is the odd one out?
    a) Activated sludge
    b) Trickling filter
    c) Rotating biological contactors
    d) Grit chamber
5. Tertiary treatment is also called high-rate secondary treatment. Which one of the following is not removed at this stage?
    a) Nitrogen
    b) Phosphorous
    c) Refractory organics
    d) Non dissolved solids

6. Why is it important to pre-treat industrial wastewater before releasing it to the treatment plant?
7. Discuss the chemicals used in wastewater treatment
8. Which are the regulatory bodies which control the quality of effluent discharged into the environment.
9. Describe the mechanism of treatment in an activated sludge system
10. Analyse the types and operational principles of conventional systems

Practical Assessment

In your university labouratory perform tests for BOD_5 by conducting an experiment using samples from your school kitchen.

Oral Assessment

Make a slide presentation describing the geotechnical procedures conducted on a proposed wastewater treatment site and present to your class.

Project Assessment

Design a suspended growth system using OPENMDELICA software application

18.3.9.4 Tools, Equipment, Supplies and Materials

- Software
- Pencils
- Ruler
- T-square
- Scale rule
- Eraser
- Set square
- Drawing board

18.3.9.5 References

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Hakanen, J., Sahlstedt, K., & Miettinen, K. (2013). Wastewater treatment plant design and operation under multiple conflicting objective functions. modeling & software, *46*, 240-249

CHAPTER 19: CONSTRUCT WASTEWATER INFRASTRUCTURE

19.1 Introduction of the Unit of Learning

This unit covers the competencies required to construct wastewater infrastructure. It involves analysis of soil properties, construction of the wastewater infrastructure units, organization of the construction site, and preparation of construction schedule
This standard applies in the water industry.

19.2 Performance Standard

Analyse soil properties, prepare construction schedule, organized the construction site, construct the wastewater infrastructure based on available resources and the tests to be conducted, standard procedures, soil classification, and results.

19.3 Learning Outcomes

19.3.1 List of Learning Outcomes

a) Analyse soil properties
b) Prepare construction schedule
c) Organize the construction site
d) construct the wastewater infrastructure

19.3.2 Learning Outcome No 1: Analyse Soil Properties

19.3.2.1 Learning Activities

Learning Outcome No 1: Analyse Soil Properties	
Learning Activities	**Special Instructions**
1.1 Identify and gather ***soil analysis tools, supplies and materials*** 1.2 Identify engineering properties of soils 1.3 Analyse properties of soils 1.4 Prepare soil analysis report	• Use of Online videos • Power point presentation • Exercises by trainee

19.3.2.2 Information Sheet No 19/LO1: Analyse Soil Properties

Introduction to learning outcome

This learning outcome covers analysis of soil properties based on standard procedures as well as how to prepare a soil analysis report.

Definition of key terms

Moisture Content - Moisture content is the amount of water present in a given soil mass.

PI index - Plasticity index is a measure of the range of water in which the given soil remains in plastic state

Sieve Analysis – Sieve analysis is a procedure for classifying soils using standard sieves to determine the particle size distribution.

Content/Procedures/Methods/Illustrations

1.1 Identify and gather *soil analysis tools, supplies and materials* (Sieve analysis, PI index, Moisture content, CBR, Proctor, Triaxial test, Oedometer tests, Casagrande, Cone penetrometer, Sand Replacement, California Bearing Ratio) based on available resources and the tests to be conducted

The following explains the gathered soil analysis tools, supplies and materials based on tests to be conducted:

- **CBR Test-** This refers to California Bearing Ratio which is a penetration test used for **classification of soil sub grade and base coarse materials** especially for design of flexible pavements and was developed by California State Highway Department in U.S.A.
  It shows the ratio of force per unit area needed to penetrate a given mass of soil at a rate of 1.25mm/min, to the corresponding penetration of a standard material.
- **Proctor Test-** This is a compaction test that is carried out to determine the **optimum moisture content** at which a given soil in question achieves maximum dry density through air removal.
- **Triaxial Test-** This test is done to measure the mechanical properties such as **shear strength** of soil hence it is often known as triaxial shear strength. It is performed by subjecting stress on a given soil sample in a way that the resultant stress in one direction is different in perpendicular direction.
- **Oedometer Test-** This test is done to determine **consolidation** which is an engineering property of soil. This is determined by measuring the vertical displacement of the soil being tested when it is subjected to vertical loading
- **Casagrande Test-** This is an atterberg limit test used to measure the **liquid limit** of a given soil sample. The term casagrande is used because the test apparatus was designed by Arthur Casagrande.
- **Cone penetrometer-** This is used in testing soil properties at the site because one is able to map out the soil profiles and determine properties such as **relative density of soil.**
- **Sand Replacement Test-** This test is used to determine the **dry density** of soil at the site. One needs to dig a hole first then proceeds to fill it with sand of a known density hence the term sand replacement. From this, one can determine the volume of the hole.

1.2 Identify engineering properties of soils based on the soil classification

Engineering properties of soils are the characteristics that soils possess that make them suitable for use in the engineering field. They range from one soil to another and in that way soil has to be classified into different categories as shown below

a) AASHTO classification system

This system is based on the plastic characteristics and particle size of soil. The soil is divided into seven categories and even further when considering the group index as shown in the classification chart below:

General Classification	**Granular Materials (35% or less passing the 0.075 mm sieve)**							**Silt-Clay Materials (>35% passing the 0.075 mm sieve)**			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis, % passing											
2.00 mm (No. 10)	50 max	…	…	…	…	…	…	…	…	…	…
0.425 (No. 40)	30 max	50 max	51 min	…	…	…	…	…	…	…	…
0.075 (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 0.425 mm (No. 40)											
Liquid Limit	…		…	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min
Usual types of significant constituent materials	stone fragments, gravel and sand		fine sand	silty or clayey gravel and sand				silty soils		clayey soils	
General rating as a subgrade	excellent to good							fair to poor			

Note: Plasticity index of A-7-5 subgroup is equal to or less than the LL - 30. Plasticity index of A-7-6 subgroup is greater than LL - 30

In the AASHTO system:

- **gravel is material** smaller than 75 mm (3 in.) but retained on a No. 10 sieve;
- **coarse sand is material** passing a No 10 sieve but retained on a No. 40 sieve; and fine sand is material passing a No. 40 sieve but retained on a No. 200 sieve.
- Material passing the No. 200 sieve is **silt-clay** and is classified based on Atterberg limits.

Figure 184: AASHTO classification
Source: Bello, Afeez. (2013). Introductory Soil Mechanics I.

b) Unified soil classification system

This system classifies soil into three categories: Organic soils, Coarse grained and fine grained soils. This is determined depending on how much soil passes standard sieve sizes.

c) **Grain size classification system**

This system classifies soils based on the grain size only hence it is not very significant. The soil can be classifies as either silt, sand or clay depending on the particle size.

d) **Textural classification**

This is an improved system from the grain size system because it considers the grain size distribution as a percentage.

From the above classification systems, the following engineering properties can be identified as shown:

- **Shear Strength-** This refers to soil resistance to deformation when subjected to shear stress. It is important in geotechnical engineering because it helps in determining the bearing capacity of foundation.
- **Consolidation-** This according to (Terzaghi & Peck, 2013), consolidation is "any process which involves a decrease in water content of saturated **soil** without replacement of water by air".
- **Liquid Limit-** This shows the amount of moisture present when a given soil sample transitions from plastic state to liquid state such that the soil can flow. This helps classify the soil in terms of how fine it is and it is important to an engineer as they can calculate the allowable bearing capacity of foundation as well as its settlement.
- **Dry Density** – This in simple terms is the density of soil when dry and is calculated by subtracting the moisture content from the wet density. It is used to give an idea of extent of compaction of soils whereby a high dry density indicates an increased compaction.
- **Relative Density-** This property is dimensionless and shows how dense a cohesionless soil is, that is the difference between void ratios when loose and in natural state, compared to its maximum density i.e. the difference in void ratio when loose and dense state.

1.3 Analyse properties of soils based on the standard procedures

The following standard procedures are used in analyzing engineering properties of soils: They are divided into two main categories:

i. **In-situ Testing Procedures:** This involves field tests carried out at site of proposed location and may include but not limited to:

a) **Standard Penetration Test**

This test is done in accordance to **IS -2131:1963**. A bore hole is drilled to a desired depth after which a standard split spoon sampler is driven into the soil using a dropping hammer weighing 63.5kg it is dropped at a rate of 30 blows per minute over a height of 0.75m. The aim of this test is to determine the **relative density** of soil.

b) **Sand Replacement Test.**

This test aims at determining the **dry density** of the soil in question and it is based on **IS 2720 part 28**. The in situ compacted soil is removed and replaced with sand of known density to determine the volume of the hole after the weight of sand needed to fill the hole is determined.

ii. **Labouratory Tests:** This cannot be done at site hence the soil sample is taken to the labouratory for analysis. They include but not limited to:

a) **Sieve Analysis**

This test is used to determine the **particle size distribution** of soil using the standard procedure outlined in **ASTM C136 (AASHTO T-27)**. The sample soil is passed through a number of standard sieves and the retained soil in each sieve measured for analysis in determining the soil gradation.

b) **Atterberg's Limits Tests**

This involves a number of tests that are carried out to determine the **critical water content** in fine graded soils. The tests are carried out as outlined in **ASTM D4318** and include: liquid limit test, plastic limit test and shrinkage limit test.

1.4 Prepare soil analysis report based on the results.

A soil analysis report is a report prepared by an engineer that shows the soil properties of the area where an infrastructure is likely to be constructed showing whether the soil conditions are suitable on not. It is important because it tells the viability of proposed project before it is started.

The following is the procedure for preparing a soil analysis report:

i. One is first required to know the client's expectations on the proposed project for instance the location where they want the project to be among others.

ii. The next step is carrying out both field and labouratory tests of the soil on the chosen location to determine its engineering properties. The tests and soil properties have been highlighted in **1.3** and **1.2** respectively.

iii. The results from the tests are the analysed to determine if the soil has suitable engineering properties thus a decision can be made whether the site is safe for engineering works.

iv. The Geotechnical engineer will then provide a detailed report of existing conditions to the client as well as give recommendations where necessary which helps in knowing if the proposed are safe and viable and what can be done incase otherwise.

Conclusion

This learning outcome covered analysis of engineering soil properties in terms of what they are, how they can be tested together with relevance in engineering field and how a soil analysis report can be prepared.

Further Reading

Research more on how soil tests are done to determine whether they possess required engineering properties by watching tutorials on You Tube.

https://www.aboutcivil.org/soil-geotechnical-investigation-report.html use this link to learn more on how to prepare a soil analysis report.

19.3.2.3 Self-Assessment

Written Assessment

1. The following are labouratory tests in soil analysis except one:
    a) Standard Proctor Test
    b) Penetration test
    c) Triaxial Test
    d) Odometer Test
2. Soil analysis is important in engineering works. Which if the following is not an engineering property of soil:Shear Strength
    a) Plastic Limit
    b) Consolidation
    c) Water quality
3. What is an **in-situ** testing procedure? Give three examples of in-situ tests in soil analysis
4. Elabourate 4 Atterbergs Limits
5. Discuss 4 engineering properties of soil
6. Compare and contrast between density of soil and relative density of soil?
7. Proctor test is used to determine the optimum moisture content of soil. Briefly explain how the proctor test is done and its significance in the engineering field.

Case Study Assessment

Your sister was watching construction videos on you tube and came across the term **Soil Analysis Report.** She approached you to explain what a soil analysis report is and why it is crucial in the construction industry. What would you tell them?

Project Assessment

A client has approached you with the intention of consulting you on whether their preferred location for their project is suitable or they need to switch to another area. Prepare a soil analysis report that you will give them including your recommendations based on your findings. Use soil samples from the school field.

Oral Assessment

What contents are you going to include in your **Soil Analysis Report**?

19.3.2.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet

19.3.2.5 References

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19.3.3 Learning Outcome No 2: Prepare Construction Schedule

19.3.3.1 Learning Activities

Learning Outcome No 2: Prepare Construction Schedule	
Learning Activities	**Special Instructions**
2.1 Interpret engineering drawings 2.2 Identify ***construction activities*** 2.3 Prepare project management timelines	• Demonstration by trainer • Power point presentation • Exercises by trainee

19.3.3.2 Information Sheet No 19/ Lo 2: Prepare Construction Schedule

Introduction to learning outcome

This learning outcome applies to the Interpretation of work drawings, Construction activities (Concrete works, Steel works, Earth work, Form works, site clearance, Trenching and excavation, Backfilling) based on scope of work and Preparation of Project management timelines based on project specifications.

Definition of key terms

Earthworks: Earthworks are operations that involves digging, transporting and compacting the surface of the earth at a particular site.

Backfilling: Backfilling is the process of placing the soil back into a trench or base after the excavation has been completed.

Trenching and **excavations**: according to Occupational Safety & Health Administration (OSHA), excavation is defined as any human-made hole, cavity, or depression in the earth's surface created by the removal of the soil, while the trench is defined as a narrow underground excavation that is narrower than the wide one and is no longer than 15 feet (4.5 meters) wide.

Content/Procedures/Methods/Illustrations

2.1 Interpret engineering drawings based on the engineering codes

Engineering drawings are a rich and detailed outline that demonstrates all the details and specifications required for the manufacture of an object or product. It's more than just drawing, it's a graphical language that communicates ideas and details. Engineering drawing provides far more detailed details and specifications, including: dimensions, geometry, tolerances, material type, finish and hardware according to www.makeuk.org.

An illustration of an engineering drawing

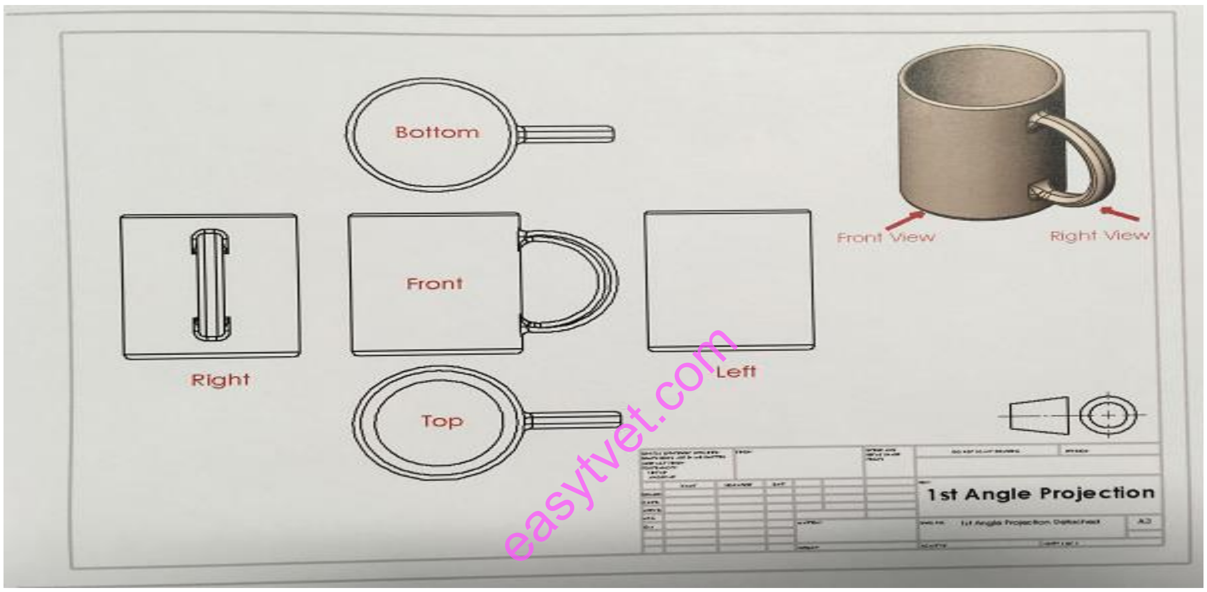

Figure 185: Illustration of an engineering drawing
Source: www.makeuk.org.

2.2 Identify *construction activities* (Concrete works, Steel works, Earth work, Form works, site clearance, Trenching and excavation, Backfilling) based on scope of work.

Construction activities shall mean any clearing, grading, excavation, grubbing, filling or other operation which results in the disturbnace of land.

Concrete works: Concrete works involves the following processes: preparation of the concrete mixture; delivery of the mixture to the construction site; feeding, distribution and compaction of the mixture in the formwork (molds); curing of the concrete while it is hardening; and quality control of the concrete work.

Steel works: Steel works is the assembly of steel components into a frame on site. This is achieved by lifting and placing components into position then connecting them together through bolting or site welding.

Earth work: Earthwork includes the loosening, removal and handling of earth amounts in the course of construction refer to a Guide to the Training of Supervisors-Trainees' Manual/Part1 (ILO, 1981,269 p.)

Form works: Formworks are temporary molds used to shape the concrete structure. Refer to the Building Construction Handbook by Roy Chudley & Roger Greeno.

Site clearance**-** According to Building Construction Handbook by Roy Chudley, site clearance involves removal of vegetation, surface soil, and levelling and land preparation for planned construction work.

Trenching and excavations: according to Occupational Safety & Health Administration (OSHA), excavation is defined as any human-made hole, cavity, or depression in the earth's surface created by the removal of the soil, while the trench is defined as a narrow underground excavation that is narrower than the wide one and is no longer than 15 feet (4.5 meters) wide

Backfilling: According to theconstructor.org/geotechnical, backfilling is the process of replacing or reusing the soil that is removed during construction to strengthen and support the foundation of a structure or any other structural component.

2.3 Prepare project management timelines based on project specifications

Project management timetable is where you take all the details you have about your project, including the start date, the deliverables, the end date, and how you're going to set a plan for when everything is going to be finished.

5 key steps in developing a project schedule

i. Define activities
ii. Sequence activities
iii. Estimate activity resources
iv. Estimate activity durations
v. Develop schedule

An illustration of a construction work schedule

Table 58: Illustration of a construction work schedule

	Activity	2019	2019	2019	2020	2020	2020	2020	2020
No.	Name	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	Visitor center								
2	Submitted								
3	Site grading/ utilities								
4	Foundations								
5	Concrete walls								
6	Steel								
7	Envelop								
8	Interior finish								
9	Mech/Elec								
10	Commissioning/final								

Conclusion

This learning outcome has prepared the student to be able to Interpret work drawings, Construction activities. Project planning and how to prepare a project management timeline.

Further Reading

Read more on:

1. Steel works as illustrated by BS EN 1090-2:2018, Execution of steel structures and aluminum structures. Technical requirements for steel structures, BSI.
2. Watch a video on excavation and backfilling in construction

19.3.3.3 Self-Assessment

Written Assessment

1. Which of the following is not a construction material?
    a) Tape measure
    b) Steel
    c) Cement
    d) Blocks
2. The following are construction activities. Which one is not?
    a) Concrete works
    b) Earth works
    c) CBR
    d) Form works
3. Which of the following is not a pre-tender work?
    a) Pre-tender program
    b) Cost implication
    c) Plant schedule
    d) Security
4. Which of the following is not a construction tool?
    a) Pipe wrenches
    b) Hammer
    c) Tape measure
    d) Timber

5. The following are site infrastructures. Which one is not?
    a) Site office
    b) Site store
    c) Ablution block
    d) Proctor
6. The following are considerations that should be taken by the builder when tendering. Which one is false?
    a) Access to site
    b) Labour
    c) Services
    d) Filling
7. Differentiate between trench and excavations.
8. Describe the process of backfilling.
9. Before any building work can commence, the area covered by the building must be leveled. Discuss using illustrations, the methods used.

Oral Assessment

1. Project management important? Justify
2. Are you able to differentiate the various construction activities? Differentiate

Practical Assessment

Conduct a site visit and prepare a project schedule upon commencement of the construction.

Oral Assessment

Why is it important to prepare a project schedule?

19.3.3.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

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19.3.4 Learning Outcome No 3: Organize the Construction Site

19.3.4.1 Learning Activities

Learning Outcome No 3: Organize the Construction Site	
Learning Activities	**Special Instructions**
3.1 Clear and secure site 3.2 Identify and mobilize human resources construction plant and equipment 3.3 Put in place ***site infrastructures***	• Group discussions • Demonstration by trainer • Power point presentation

19.3.4.2 Information Sheet No 19/ Lo 3: Organize the construction site

Introduction to learning outcome

This learning outcome covers clearance of site based on the contract document, site layout and organization, resource mobilization, contract documents site infrastructures (site office, site store, ablution block, fence, signage/safety signs, hoarding) based on contract document and legal requirements and legal requirements.

Definition of key terms

Ablution block: Ablution Block is a washroom built on site location.

Site Office: The site office is a temporary administrative center where the building project operations are carried out.

Hoarding: Hoarding are closed boarded fences or barriers erected adjacent to a highway or public footpath.

Content/Procedures/Methods/Illustrations

3.1 Clear and secure site based on the contract document.

It is advisable, during clearing and grubbing, to involve the removal of any dead branches or the trimming of low hanging branches on the trees, so as to interfere with the growth. All pruning should be carried out in compliance with appropriate nursery practices. In the case of any harm to private property, the contractor shall be responsible for the costs involved in restoring the site to its previous state. A professional arborist should be consulted to make recommendations for the restoration or replacement of vegetation.

Figure 186: Preparation of the construction site
Source: Preparation of the construction site fao.org

3.2 Identify and mobilize human resources construction plant and equipment based on the contract document

The main contractor sets out certain requirements for the selection of its subcontractors. Such requirements may include previous experience of the subcontractor, technological ability to conduct work, mobilization ability in terms of human resources and plant equipment, financial capacity, quality of work carried out in the previous, records in terms of working relationships with the main contractor, record of work safety and workers' welfare.

3.3 Put in place *site infrastructures* (site office, site store, ablution block, fence, signage/safety signs, hoarding) based on contract document and legal requirements.

- The arrangements for office accommodation should be provided on site as it a matter of choice for each individual contractor according to the Act 1963.
- There should be site store for provision of adequate space, protection and control for building materials.
- There should be sanitary facilities such as an ablution block separate male and female if possible.
- There should be a fence with a minimum height of 1.8 m with minimum access points and lockable gate or barrier.
- The safety signs/ signage should there and positioned well
- Hoarding should be provided to prevent unauthorized persons obtaining access to the site.

Conclusion

This learning outcome has prepared the student to be able to understand clearing of the site, site infrastructures, site layout and organization, resource mobilization, contract documents and legal requirements.

Further Reading

Read more on:

Contract documents, resource mobilization and legal requirements as illustrated on the Construction Project Management Theory and Practice by Kumar Neeraj page 137.

19.3.4.3 Self-Assessment

Written Assessment

1. The following falls under clearing of the site. Which one is does not?
    a) Demolition of existing buildings
    b) Grubbing out of bushes and trees
    c) Removal of soil with vegetable matter
    d) Builder's square
2. The following are methods used to reduce the levels in the slopping sites. Which one is not?
    a) Cut and fill
    b) Cut
    c) Fill
    d) Clear site
3. Which of the following does not fall under site work and setting out?
    a) Clearing the site
    b) Establishing a datum
    c) Setting out the building
    d) Hoarding
4. Which one of the following is not a site layout consideration?
    a) Storage
    b) Access
    c) Datum
    d) Plant

5. Which of the following is not a safety sign?
    a) Red
    b) Yellow
    c) Black
    d) green
6. Discuss three types of contract documents
7. Differentiate between fencing and hoarding.
8. Discuss the aspect to be considered when carrying out site layout considerations.
9. Describe site organization structure
10. Why do you think when a builder is tendering for a given job, he must first visit the site before filling in his unit rates in the bill of quantities?

Oral Assessment
1. Briefly explain factors to be considered when tendering?
2. Discuss the activities should be carried out in pre-tender work?

Practical Assessment
Conduct a construction site visit and prepare the site organization structure.

Oral Assessment
Site organization structure important?Justify

19.3.4.4 Tools, Equipment, Supplies and Materials
- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos
- Wooden pegs
- Nails
- Hammer

19.3.4.5References

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19.3.5 Learning Outcome No 4: Construct the Wastewater Infrastructure

19.3.5.1 Learning Activities

Learning Outcome No 4: Construct the Wastewater Infrastructure	
Learning Activities	**Special Instructions**
4.1 Source and mobilize ***construction materials and tools*** 4.2 Set out infrastructure 4.3 Construct ***wastewater infrastructure units*** 4.4 Do labour payments 4.5 Prepare and submit as built drawings 4.6 Prepare payment certificate 4.7 Prepare completion certificate 4.8 Observe site personal health and safety	• Group discussions • Demonstration by trainer • Power point presentation • Exercises by trainee

19.3.5.2 Information Sheet No19/Lo 4: Construct the Wastewater Infrastructure

Introduction to learning outcome

This learning outcome covers Constructional details of onsite sanitation facilities and Construction plant and equipment. It also equips the learner with labour payment knowledge.

Definition of key terms

Trickling filters - These are a wastewater treatment system made up of crushed rocks in a tank of a depth of about 2 metres and a diameter of about 60 metres that is used to remove organic pollutants .

Sedimentation tanks – These are part of a waste water treatment system where waste water is filled and allowed to settle for a while so as to remove suspended particles that are in the wastewater.

Grit chambers – These are tanks that are long and narrow and are used to remove inorganic solids from waste water by reducing the speed of the flowing wastewater.

Content/Procedures/Methods/Illustrations

4.1 Source and mobilize *construction materials and tools* (Cement, Aggregates (course and fine), Steel, Stones /blocks, Timber, Tape measure, Hack saws, Pipe wrenches, Levelling tools e.g. Hammer, Set of protective) gear based on the bill of quantities

A bill of quantities entails the construction materials, tools, labour and their costs. It also includes the quantities required.it is usually prepared after specifications have been set and the design of the infrastructure has been done.

It will be used as a guide to obtain the specific quantities of construction materials needed. Sourcing of construction materials involves balancing between the cost of materials and their quality.

Material sourcing for construction involves the following activities:

1. **Deciding on possible suppliers.**
   Based on the materials that are required, you can choose a supplier for example a hardware store or a wholesaler with the required materials.

2. **Checking the availability of materials.**
   You could call the viable suppliers to check whether the required materials are in stock. Also in this step you could confirm the quality of the materials in stock.

3. **Requesting quotes from the suppliers.**
   This is done so as to find a supplier with the most economical price. The quote can be obtained via email or by going to the supplier.
   After obtaining the quotes a price comparison is done to decide the final supplier.

4.2 Set out infrastructure based on the engineering drawings.

Setting out infrastructure is a process of transferring an engineering drawing onto the site/actual ground so as to establish the necessary structural parts. It enables construction to be carried out as it has been planned.

Setting out is done by using the following methods:

a. Using the peg and rope method
b. By using a dumpy level.

The procedure for setting out is as follows:

i. The building line for the waste water infrastructure is first set out.
ii. The baseline for the infrastructure is then set out.
iii. The first right angle to the base line is set out next.
iv. The second right angle to the base line is set out.
v. The final back line is set out.

vi. The set out for the infrastructure is then checked to confirm the measurements.
vii. Profiles are then set up on corners and ranging lines attached.

4.3 Construct *wastewater infrastructure units* (Screen, Grit chamber-horizontal, aerated/spiral, Sedimentation tanks, Activated sludge chamber, Trickling filters, Ponds, Oxidation ditch, Aerated lagoons, Storm water drains, Equalization tank, Sequential Batch Reactor, Rotating biological contactors, Oil and grease trap) based on the design drawings

Waste water infrastructure units are the units that are systematically used to purify water so that it can be recycled back.
Construction of these units is done in with reference to the engineering drawings and bill of quantities on the site where they have been set out.

4.4 Do labour payments based on the progress report and attendance.

A progress report is a report that details the activities that have been carried out, those that have been completed, those that are in progress, any problems that may have been faced and how the construction project is proceeding.
The progress report facilitates labour payments, called progress payments. These are partial payments made to cover the amount of work that has been done at a particular stage or by what percentage of work that has been done.

4.5 Prepare and submit as built drawings based on the actual construction.

As-built drawings are revised drawings that are prepared and submitted by the contractor after the project has been completed.
They usually indicate all the adjustments made while building the project.
The method of preparing is built drawings is as follows:

1. **Preparation of the as built drawings by the contractor.**
   The contractor incorporates all changes made to the original design in accordance with official notes regarding such changes. The contactor is also supposed to visit the site to ensure all the changes are reflected in the drawing.
   After preparing the drawings, they are submitted to the Engineer overseeing the construction.

2. **Approval of the as built drawing by the engineer.**
   The engineer verifies the drawings with the official notes time to time according to how much construction has been done.
   They will also go to the site and check the drawings against the constructed facilities.
   If satisfied, the engineer will accept the drawings and keep a record of them in their office.

4.6 Prepare payment certificate based on progress report.

A payment certificate in construction is a document that gives an account of the work that has been completed. It is approved by the contractor.

They are issued either on a regular basis or when a project reaches a particular milestone.

Some types of payment certificates include: certificate of non-completion, interim certificate, practical completion certificate and final certificate.

4.7 Prepare completion certificate based on the legal requirements.

A completion certificate is also called a final certificate. It is usually submitted when the project has been completed successfully at the end of the contract. The construction has to have met required specifications outlined by Building regulations stipulated by the Kenyan Government.

4.8 Observe site personal health and safety as per the OSH Act and site regulations.

OSH Act is a set of rules meant to ensure the safety and wellbeing of employees by employers by protecting them from hazards.

These regulations help in the identification, reduction and elimination of hazards that are related to construction work.

The employers and employees must adhere to the set standards of safety to avoid getting injured due to the top four construction hazards which include:

1. Falls
2. Struck-By
3. Caught-In/Between
4. Electrocutions

Conclusion

This learning outcome covered Constructional details of onsite sanitation facilities and Construction plant and equipment.

Further Reading

Read more on the various types of payment certificates, how to come up with as-built drawings and go through the OSH Act.

19.3.5.3 Self-Assessment

Written Assessment

1. Which of the following is not a waste water infrastructure unit?
    a) Activated sludge chamber
    b) Trickling filter
    c) Pit latrine
    d) Grease trap
2. Which one is not a type of payment certificate?
    a) Final certificate
    b) Certificate of non-completion
    c) Independent certificate
    d) Interim certificate.
3. One of the following better defines an as built drawing. Which one is it?
    a) The drawing of the building before construction.
    b) The revised drawing of the building after construction.
    c) A sketch drawing
    d) None of the above.
4. A completion certificate is also called?
    a) Interim certificate
    b) b) Project certificate
    c) c) Final certificate
    d) d) None of the above
5. What does OSH Act stand for and what does it entail?
6. Define a progress report.
7. Discuss 4 wastewater infrastructure units?
8. Write a short essay outlining the basic steps that are followed in material sourcing and their significance.
9. Discuss what a payment certificate is and expound on the various types of payment certificates.

Oral Assessment

Demonstrate various waste water infrastructure units.

Examine the steps followed while sourcing materials for construction?

Practical Assessment

Design an engineering drawing of a trickling filter and practice setting out its infrastructure.

Oral Assessment

Mention the challenges faced in the process of designing the trickling filter.
What are the major steps followed while setting out infrastructure?

19.3.5.4 Tools, Equipment, Supplies and Materials

- Computers
- Software
- Cameras
- Construction manuals
- Projectors
- Flip charts
- Calculators
- Rulers, pencils, erasers
- Charts with presentations of data
- Drawing sheets
- Internet
- Relevant videos

19.3.5.5 References

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CHAPTER 20: DESIGNING ONSITE SANITATION FACILITIES

20.1 Introduction of the Unit of Learning

This unit covers the competencies required to design onsite sanitation facilities**.**
It involves Collection and analysis of onsite sanitation design data, calculation of onsite sanitation design parameters, drawing onsite sanitation units, designing shit flow diagram and compilation of onsite sanitation design report.
This standard applies in water industry.

20.2 Performance Standard

Collect onsite sanitation design data, analyse onsite sanitation design data, calculate onsite sanitation design parameters, draw onsite sanitation units, design shit flow diagram, and compile onsite sanitation design report based on job requirements/specification and tools prepared.

20.3 Learning Outcomes

20.3.1 List of Learning Outcomes

a) Collect onsite sanitation design data
b) Analyse onsite sanitation design data
c) Calculate onsite sanitation design parameters
d) Draw onsite sanitation units
e) Design shit flow diagram
f) Compile onsite sanitation design report

20.3.2 Learning Outcome No 1: Collect Onsite Sanitation Design Data

20.3.2.1 Learning Activities

Learning Outcome No 1: Collect Onsite Sanitation Design Data	
Learning Activities	**Special Instructions**
1.1 Map out area to be served 1.2 Prepare ***tools for data collection*** 1.3 Collect data and information	• Demonstrate how to correctly map out an area and prepare tools needed • Elabourate on the data collection process

20.3.2.2 Information Sheet No.20/LO1: Collect Onsite Sanitation Design Data

Introduction to learning outcome

This unit focuses on collection of onsite sanitation design data for a mapped out area and using prepared tools as per the job specification. Data collection tools are also discussed

Definition of key terms

Tools for data collection – these include the instruments or methods that are employed so as to obtain data, interpret it and present it.

Onsite sanitation facility – this is a sanitation facility that treats the wastewater at the place where it has been generated.

Content/Procedures/Methods/Illustrations

1.1 Map out area to be served based on job requirements/specification.

The area to be served by the on-site sanitation system is mapped using already existing base maps and by employing the use of GPS and GIS to acquire more accurate data. To acquire these maps a team made up of individuals with a range of different skills will be employed.

Mapping is important for the following reasons:

1. It enables the site to be charted and this helps in having a better understanding that will aid in planning the sanitation facility.
2. It aids in marking the boundaries of the site
3. It prevents the occurrence of overlaps as a result of miscalculation.

1.2 Prepare *tools for data collection* (Questionnaires, Stationery, GPS, Cameras, Check list, Sampling equipment, Maps, Measuring instruments, Safety equipment, Safety box, First aid kits) based on *onsite sanitation facility (*septic tanks, bio-digesters, anaerobic baffled reactors, latrines. Soak pits, ecosan toilets, imhoff tank) to be designed.

Tools for data collection are the instruments or methods that are employed so as to obtain data, interpret it and present it.

They include:

Interviews, questionnaires, reporting, existing data, observation, focus groups and combination research.

The necessary preparations that have to be made include:

i. Making logistical arrangements at the site of the sanitation facility
ii. Preparing the questionnaire by doing a pre-test of the questions to be asked
iii. Selecting and preparing the required equipment at the site
iv. Rechecking the questionnaires

After the data can proceed to be collected for subsequent analysis.

1.3 Collect data and information based on tools prepared.

The data that is expected falls into two categories:

Quantitative data; which is data that can be expressed as values that indicate quantity. It is expressed numerically. It is usually then interpreted and presented in tables or graphs.

Qualitative data; which is data that is descriptive and describes qualities. It answers questions like “why?” and “how?” It explains the values obtained as quantitative data.

Data is collected from the site using the tools of data collection i.e.: Interviews, questionnaires, reporting, existing data, observation, focus groups and combination research and analysed. This information will then be used to design the onsite sanitation facility.

Data collection aids in design in the following ways:

1. It enhances the research by verifying its integrity.
2. It reduces arising of errors.
3. It is important in decision making since data will be used to have a better understanding
4. It saves time and costs that would have been lost if decisions were made without a better understanding

Conclusion

This learning outcome served collection of onsite sanitation design data to meet the need for wastewater disposal and within a legal framework.

Further Reading

Do some further research on mapping and the various data collection tools?

20.3.2.3 Self-Assessment

Written Assessment

1. Which of the following is not a method of data collection?
    a) Interviews
    b) Questionnaires
    c) Observations
    d) Experiments
2. While doing preparations for the data collection tools, which among the following must be rechecked?
    a) The site
    b) Questionnaire
    c) First aid kits
    d) Sampling equipment
3. Which of the following fits the description "Collection of data by the use of questionnaires alongside other methods"
    a) Survey
    b) Interviews
    c) Mapping
    d) Sampling
4. Define tools for data collection.
5. What is an on-site sanitation facility?
6. Expound on the preparations that have to be made on tools for data collection.

Practical Assessment

Come up with a simple questionnaire on construction of an on-site sanitation facility to be used within your locality. Use them to collect data from individuals living in that area.

Oral Assessment

1. Mention various tools of data collection.
2. Mention various challenges faced while collecting data using questionnaires.

20.3.2.4 Tools, Equipment, Supplies and Materials

- Questionnaires
- Stationery
- GPS
- Cameras
- Check list
- Sampling equipment
- Maps
- Measuring instruments
- Safety equipment
- Safety box
- First aid kits

20.3.2.5 References

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20.3.3 Learning Outcome No 2: Analyse Onsite Sanitation Design Data

20.3.3.1 Learning Activities

Learning Outcome No 2: Analyse Onsite Sanitation Design Data	
Learning Activities	**Special Instructions**
2.1 Arrange data and information 2.2 Present data	• Utilize excel software to analyze the collected data

20.3.3.2 Information Sheet No20/LO2 Analyse Onsite Sanitation Design Data

Introduction to learning outcome

This unit aims to arrange and present collected data and information based on the onsite sanitation facility to be designed.

Definition of key terms

Arrangement of data – this is where data is put into tables so as to have it organized according to similarities. It is also referred to as classification of data.

Presentation of data- this involves organizing data in such a manner that it is summarized and is attractive so as to be able to easily interpret it.

Content/Procedures/Methods/Illustrations

1.1 Arrange data and information based on onsite sanitation facility to be designed.

Data arrangement involves classifying the data collected using tools for data collection into groups. This is done by checking the similarities of the raw data that has been gathered. This is done so as to aid in the understanding of data before it is finally analysed. Also, suitable comparisons can be made. The data for the design of the onsite sanitation facility from the various data collection tools such as: questionnaires, reporting, existing data, observation, focus groups and combination research, is classified so that it is easier to be able to further understand it.

Classification of data is done according to the following basis:

a. **Qualitative classification.**
This is where data is put into categories based on qualities. For example, data collected from a population can be classified according to employment where there would be the unemployed and those that are employed.

b. **Quantitative classification.**
This is putting data into classes in the basis of characteristics that can be measured such as: length, width etc.

c. **Chronological classification.**
It is also called temporal classification. This involves putting data in clusters in accordance to time, either in descending or ascending order. Time could be in weeks, months, years etc.

d. **Geographical classification.**
It is also called spatial classification. This is classifying data according to geographical locations such as counties, countries, cities etc.

After the data for designing the onsite sanitation facility has been classified then analysis and presentation can be done.

1.2 Present data based on onsite sanitation facility to be designed.

Presentation of data is done so as to allow for decisions to be made. The data collected in the previous outcome after it has been classified needs to presented for it to aid in designing the onsite sanitation facility.

There are various methods of presenting data, called tools of data presentation. These include:

a. **Textual presentation.**
This is where data comprising of texts and values is written and then read.

b. **Tabular presentation.**
This involves putting data systematically in rows and columns. This makes up a statistical table.

c. **Graphical presentation.**
This is where statistical data is presented in the form of lines or curves plotted on coordinated points.
Examples of graphs: bar graph, pie chart, line graph etc.

A suitable method of data presentation should be selected from the above list to present the data needed to design the onsite sanitation facility.

Conclusion

This learning outcome served arrangement and presentation of data and information collected from the previous outcome.

Further Reading

Read more on the various classifications of data and the methods of presenting data.

20.3.3.3 Self-Assessment

Written Assessment

1. Which of the following is not a method of data classification?
    a) Temporal classification
    b) Spatial classification
    c) Graphical classification
    d) Quantitative classification.
2. One of the following is not a method of presenting data?
    a) Textual presentation
    b) Graphical presentation
    c) Chronological presentation
    d) Tabular presentation
3. Give three reasons why data classification is important.
4. What are the three data presentation tools?
5. Write an essay highlighting the process of arranging and presenting the data for the onsite sanitation facility and specify what methods you used in both.

Oral Assessment

Mention types of graphs.

Mention the 4 types of data classification.

Practical Assessment

Arrange and present the data for designing the onsite sanitation facility. Use excel to generate the graphs.

Oral Assessment

Mention the observations you have made from the presented data.

20.3.3.4 Tools, Equipment, Supplies and Materials

- Software e.g. Excel

20.3.3.5 References

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20.3.4 Learning Outcome No 3: Calculate Onsite Sanitation Design Parameters

20.3.4.1 Learning Activities

Learning Outcome No 3 Calculate Onsite Sanitation Design Parameters	
 **Learning Activities**	**Special Instructions**
3.1 Identify ***design parameters*** to be calculated 3.2 Identify ***tools for design parameter calculation*** 3.3 Calculate various onsite sanitation facility design parameters	• Present design parameters and tools for their calculation through a power point presentation.

20.3.4.2 Information Sheet No20/LO3: Calculate Onsite Sanitation Design Parameters

Introduction to learning outcome

This learning outcome involves the calculation of design parameters based on wastewater design manual, calculation of design parameters already identified based on required design codes and calculation of various onsite sanitation facility design parameters based on the design codes.

Definition of key terms

Design parameters: Design parameters are aspects of a system that are required to make something happen according to www.igi-global.com/dictionary.

Tools for design parameter calculation: The tools for design parameter calculation are tools that assist in coming up with the required system design to function well.

Content/Procedures/Methods/Illustrations

3.1 Identify *design parameters* to be calculated based on wastewater design manual.

Design parameters: Design parameters are aspects of a system that are required to make something happen according to www.igi-global.com/dictionary.

The design manual is intended to serve as a guide for those already in the field who may use it for cross-checking purposes and as a starting point for those interested in wastewater and would like to be involved in the design of works (Freese, 2009)

Design parameters in wastewater design:

- Maximum quantity of sewage
- Volume of sewage

- Surface area
- Detention period
- Depth
- Diameter
- Free board

Design parameters for settling tank

Types of settling	Overflow rate m^3m^2/day		Solids loading $kg/m^2/day$		Depth	Detention time
	Average	Peak	Average	Peak		
Primary settling only	25-30	50-60	-	-	2.5-3.5	2.0-2.5
Primary settling followed by secondary treatment	35-50	60-120	-	-	2.5-3.5	
Primary settling with activated sludge return	25-35	50-60	-	-	3.5-4.5	-
Secondary settling for trickling filters	15-25	40-50	70-120	190	2.5-3.5	1.5-2.0
Secondary settling for activated sludge (excluding extended aeration)	15-35	40-50	70-140	210	3.5-4.5	-
Secondary settling for extended aeration	8-15	25-35	25-120	170	3.5-4.5	-

Figure 187: Design parameters for settling tank
Source: www.slideshare.com by Bibhabasu Mohanty.

3.1 Identify *tools for design parameter calculation* (laptops, calculator, stationery, and software) based on the parameter to be calculated.

The tools for design parameter calculation are tools that assist in coming up with the required system design to function well. These tools are explained below:

Laptops: Laptop is a portable computer that can be conveniently transferred and used in a number of locations that run software and access the same type of files according to edu.gcfglobal.org/computer basics.

Calculator: Calculator is a tool that performs mathematical arithmetic operations as stated by whatis.techtarget.com/calculator.

Stationery: Stationery is a type of writing material, such as paper, envelopes, pens, pencils and books according to Cambridge Advanced Learner's dictionary.
Software: Software is a series of programs designed to perform a well-defined purpose according to www.tutorialspoint.com/software.

3.2 Calculate various onsite sanitation facility design parameters based on design codes.

On-site sanitation facilities: are wastewater systems designed to treat and dispose of effluent on the same property that produces wastewater in areas not covered by public sewage infrastructure (Tkgd2007, 2008).

Design procedure

In designing a sanitary sewer system, the designer commences by:
Step 1: Establishing the boundaries of the specific area to be serviced
Step 2: Obtaining mapping as required
Step 3: Breaking the defined area into units
Step 4: Determining the existing and proposed land use
Step 5: Deciding on an ultimate population to be attached to each unit
Step 6: Determining the design flow for the population of each unit
Step 7: Determining a design allowance for infiltration.
After the proposed sewer routing is established and the necessary profiles obtained, the designer will proceed to calculate sewer pipe sizes and grades.
The design of the latrine is driven both by customer preferences and by public health requirements. While basic design factors (pit length, septic tank retention time, etc.) remain the same, local circumstances and specifications influence the factors that regulate the final cost of the latrine.

Pit latrine design

Step 1: Size of the pit

Three conditions must be met when determining the size of a pit latrine opening:

- The pit will have ample storage space for all sludge that accumulates during its operating life or prior to its expected emptying according to (R Franeys, 1992).
- When the service life of the pit is finished, enough space will still be left for the contents to be enclosed.
- Appropriate wall space should be available at all times so that any liquid in the pit can enter the surrounding soil (R Franeys, 1992).

Step 2: Capacity to store

Adequate capacity should be accounted for when designing the pit's operating life according to (R Franeys, 1992)

Step 3: Depth of soil seal

This is usually taken as 0.5 m (R Franeys, 1992). In the case of the double pit latrines, the depth is to the bottom of the inlet drain.

Step 4: Zone of penetration

A significant amount of water can reach the pit in communities where people use water for anal cleaning or bathing in the toilet. When the soil pores below the sludge surface are believed to be blocked, additional wall areas must be allowed to penetrate the liquids above the sludge (R Franeys, 1992)

Step 5: Depth of pit

According to R Franeys, (1992) total depth of the pit shall be calculated as follows:

Pit depth = sludge depth + infiltration depth + depth of soil seal

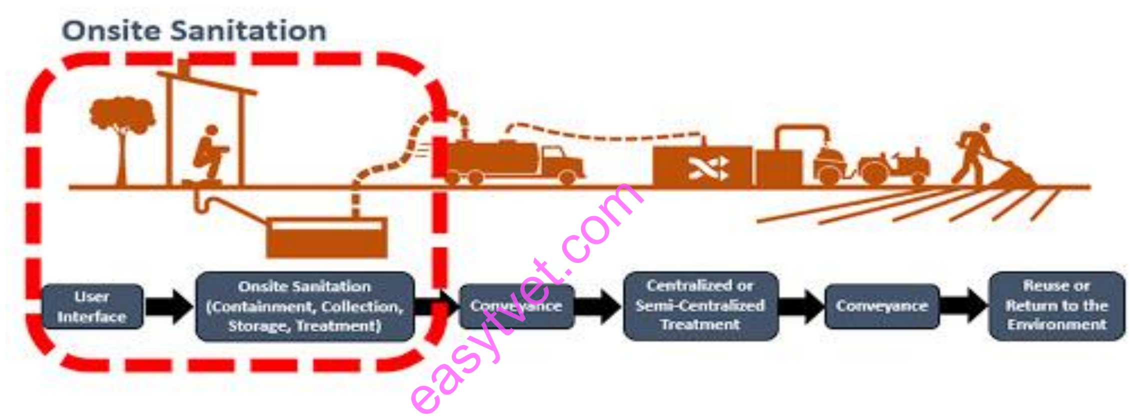

Figure 188: Pit latrine design

Source: Pit toilets (Latrines)/ Global Water Pathogen Project

Conclusion

This learning outcome has covered calculation of onsite sanitation design parameters such as wastewater estimation and population projection, tools for design parameters and design of onsite sanitation facilities based on design codes.

Further Reading

Read more on:

1. Design of onsite sanitation facility: Engineering Design Manual by Sudbury, C. o. (2012). On-site Sanitation facility. *Engineering Design Manual*.
2. Watch a video on Design criteria (https://slideshare.com/slide/4326901)

20.3.4.3 Self-Assessment

Written Assessment

1. Which one of the following is not an onsite sanitation facility to be designed?
    a) Latrines
    b) Stationery
    c) Septic tank
    d) Site office
2. Which one is not a tool for design parameter calculation?
    a) Software
    b) Stationery
    c) Design manual
    d) Laptop
3. Define design parameters
4. Differentiate the tools for design parameter calculation
5. Determine various onsite sanitation design parameters
6. Discuss the importance of calculating onsite sanitation design parameters

Oral Assessment

Outline the tools for design parameter calculation.

State the technical skills an individual need to have in calculation of onsite sanitation design parameters.

Project Assessment

Design a septic tank suitable for 120 users assume a flow of sewage 100l/h/day and a retention period of 24 hours assume any other necessary information.

20.3.4.4 Tools, Equipment, Supplies and Materials

- Laptops
- Calculator
- Stationery
- CAD Software
- Internet

20.3.4.5 References

Mehraban Sadeghi, H. H. (2012). Design Parameters. International Journal of Environmental Health Engineering.

Sudbury, C. o. (2012). On-site Sanitation facility. Engineering Design Manual.

Tkgd2007. (2008). Onsite sanitation facility. Scratch in Adobe illustrator.

20.3.5 Learning Outcome No 4: Draw Onsite Sanitation Units

20.3.5.1 Learning Activities

Learning Outcome No 4: Draw Onsite Sanitation Units	
Learning Activities	**Special Instructions**
4.1 Identify and gather drawing 4.2 Draw onsite sanitation facilities 4.3 Submit onsite sanitation facility drawings for approval	• Facilitate group discussions and provide online videos on how to draw the sanitation facilities. • Provide exercises to the trainees for submission

20.3.5.2 Information Sheet No20/LO4 Draw Onsite Sanitation Units

Introduction to learning outcome

This units aims to ensure the trainees are able to draw chosen onsite sanitation facilities based on the design parameters calculated.

Definition of key terms

Drawing tools -these are instruments to help the learner draw a required design.

Supplies -these are the available items that are provided.

Materials -objects which the drawing will be put down to help in visualization.

Content/Procedures/Methods/Illustrations

4.1 Identify and gather *drawing tools,* (software, pencils, ruler, T-square, scale rule, eraser, set square, drawing board) *supplies* (masking tapes, software) *and materials* (drawing paper, photocopying/printing papers, and stationery) based on available resources and complexity of the design.

Drawing tools

Pencils-an instrument used for writing or drawing made from a thin piece of granite
Ruler-a straight piece of wood or plastic which is marked and used for measuring distances
T-square-an implement used for drawing horizontal lines or testing angles

Scale rule-instrument used to measure and transfer length
Eraser-a piece of rubber used to wipe out unwanted writings
Set square-an instrument used for drawing lines at certain degrees
Drawing board-a table used for drawing or writing
Supplies
Masking tape-tape used to cover unwanted painting areas
Software-instructions set on a computer that are used carry out certain tasks
Materials
Drawing paper-paper used for drafting finished work
Photocopying paper-a plain paper used for printing
Stationery –a collection of writing materials

4.2 Draw onsite sanitation facilities based on the design parameters.

Onsite sanitation facility -this is where the waste is collected and treated on the same facility

Design parameters –these are the considerations needed before starting something.

- The demand for sanitation
- Project definition
- Background information
- Comparison and selection of systems

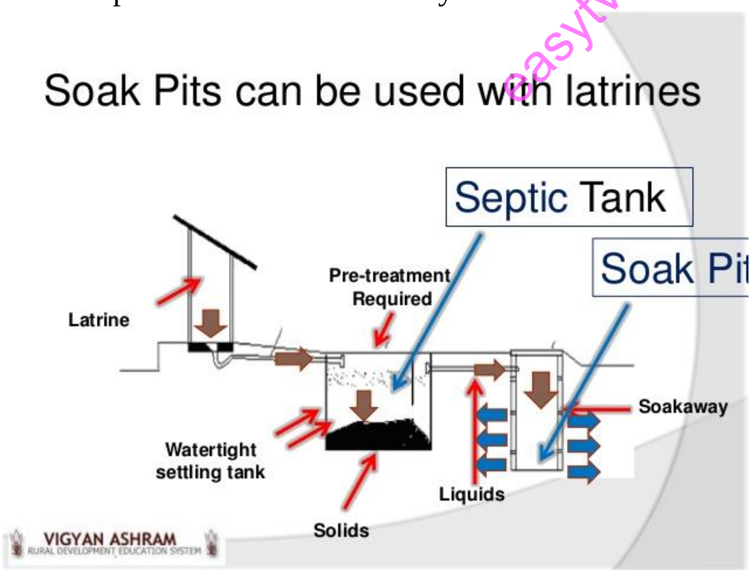

Figure 189: Soak pit

Source: Vigyan Ashram, Introduction to Water, Rural Development Education System, https://slideshare.net/mobile/vigyanashram/day-1-recycle-grey-water

4.3 Submit onsite sanitation facility drawings for approval as per legal requirements

Legal requirements –protocols put in place by the government that needs to be fulfilled and act as guidelines.

Should be readily available to the community.

Local government to include onsite sanitation plans to reduce expenditures.

The health sector should play a part in ensuring the safety of the public's health

Inspection of sanitation systems to avoid exposure of excretes materials and endangerment of people's health.

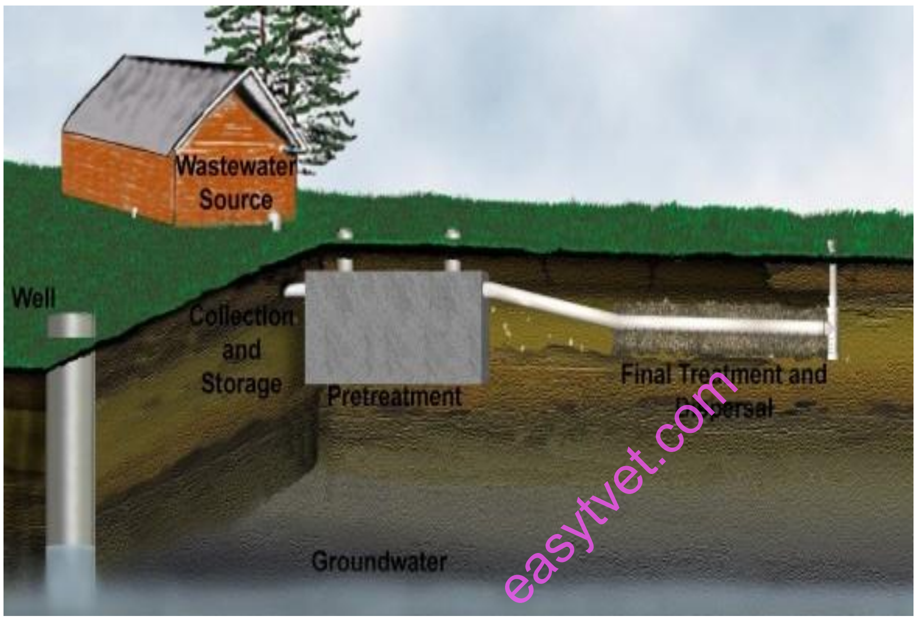

Figure 190 : Onsite sanitation facility drawings

Source: Texas A&M Agrilife Extension, Onsite Wastewater Treatment Systems (OWTS), https://ossf.tamu.edu/onsite-wastewater-treatment-systems-owts/

Conclusion

This learning outcome served the drawing of onsite sanitation units using available resources and based on the complexity of the design. The learner should be able to comfortably define terms related to the onsite sanitation and implementing the knowledge taught.

Further Reading

Read more on the design parameters of onsite sanitation facility.

20.3.5.3 Self-Assessment

Written Assessment

1. Identify a factor which doesn't affect waste disposal in onsite sanitation
    a) Ground conditions
    b) Human waste
    c) Insects and vermin problems
    d) Significance of pollution
2. In planning of onsite sanitation facility different considerations are taken into account. Give a factor with least consideration.
    a) Mode of transport
    b) Need for sanitation
    c) Financial aid
    d) Background information
3. Define onsite sanitation.
4. Give the objective of onsite sanitation
5. In relation to onsite sanitation give two examples.
6. Describe the preparation for an onsite sanitation facility.

Case Study Assessment

While on an attachment you're asked by your supervisor to help with the ongoing onsite sanitation facility construction, which design criteria will you use to help them draw the facility?

Oral Assessment

Which design criteria did you use?

Practical Assessment

In your class identify and name the different tools and materials available.

Oral Assessment

What are the tools used for?

20.3.5.4 Tools, Equipment, Supplies and Materials

Tools:

- Software
- Pencils
- Ruler
- T-square
- Scale rule
- Eraser
- Set square
- Drawing board

Supplies:

- Masking tapes
- Software

Materials:

- Drawing paper
- Photocopying /printing papers
- Stationery

Equipment:

- Computer
- Printer
- Photocopiers
- Calculator

20.3.5.5 References

Texas A&M Agrilife Extension. (2019). Onsite Wastewater Treatment Systems. Texas. Agrilife Bookstore.

WHO. (2018). WHO Guidelines on Sanitation and Health. Geneva. World Health Organization

20.3.6 Learning Outcome No 5: Design Shit Flow Diagram

20.3.6.1 Learning Activities

Learning Outcome No 5: Design Shit Flow Diagram	
Learning Activities	**Special Instructions**
5.1.Identify data required for SFD preparation 5.2.Identify methodology for data collection 5.3.Identify and gather tools, supplies and materials 5.4.Collect, sort and analyze data 5.5.Prepare SFD	• Utilize the available resources to gather the data requires for designing a shot flow diagram.

20.3.6.2 Information Sheet No20/LO5 Design Shit Flow Diagram

Introduction to learning outcome

The objective of this unit is to design a shit flow diagram by first collecting the required data using the available resources and as per the standards needed. The learner should be able to understand and work with a shit flow diagram.

Definition of key terms

Shit flow diagram –a diagram that shows how excrete flows in an urban or rural setting.

Fecal Sludge management –it is the collection, transportation, and treatment of the fecal sludge

Content/Procedures/Methods/Illustrations

5.1 Identify data required for SFD preparation according to standards

- Boundary of area-political and administrative boundaries may differ with the areas sanitation boundaries.
- Population -using census data to know the area population.
- Types of sanitation systems and how they operate.
- The key geographical features to know the areas climate and topography.
- Policies or regulations of the area for easier sanitation delivery.
- Co-ordinates to locate service chain components.

5.2 Identify methodology for data collection as per the standards

Methodology is a way of gathering information.

- Questionnaire- a set of questions written on paper and given to people to answer them.
- Interviews- meeting held by two parties to gather information by asking questions.
- Pictures- captured images by use of an instrument called a camera.
- Identifying the stakeholders- stakeholders are the relevant authority that gives permission for a project to start.
- Relevant identification documents and introduction letters- these are used to show the institution you come from and your intentions.

5.3 Identify and gather tools, supplies and materials based on available resources

Tools: Safety equipment-these are tools or materials used to protect an individual from harm

Measuring instruments-they are used to estimate distance

Cameras-it is an instrument used to capture an object

Stationery- a collection of writing materials

Map- a tool that assists in locating or finding a place

GPS- an instrument used to find the location of a place

Supplies: Software- instructions set on computer that are used to carry out certain tasks

Materials: Drawing paper- a factory made light material used in artwork or writing.

5.4 Collect, sort and analyze data based on methodology identified

- Data collection will be through questionnaires which will be dropped and picked from the responders after filling them. Pictures will be taken by form of cameras while interviews will be carried out on one on one basis.
- Sorting will be done through: numbering of pictures that will act as proof of location.
- Questionnaires will be numbered and the questions coded.
- Analysis will be done by compiling all the data and feeding it into the SFD graphic generator.

5.5 Prepare SFD based on the data collected

Shit flow diagram- a diagram that shows how excrete flows in an urban or rural setting.

Preparation

Identify the stakeholders to ensure you get the necessary permission from relevant authorities and mark out the sanitation boundary.

Questionnaires will give you a better understanding of the sanitation situation in the area and other related issues.

Population of the area will give the measurements one needs to know for the possible best containment system to use for a certain amount of people.

Pictures will be a form of proof of the existing sanitation systems around the area.

The data will be fed into the into the SFD graphic which will be generated from the SFD matrix using the online graphic generator.

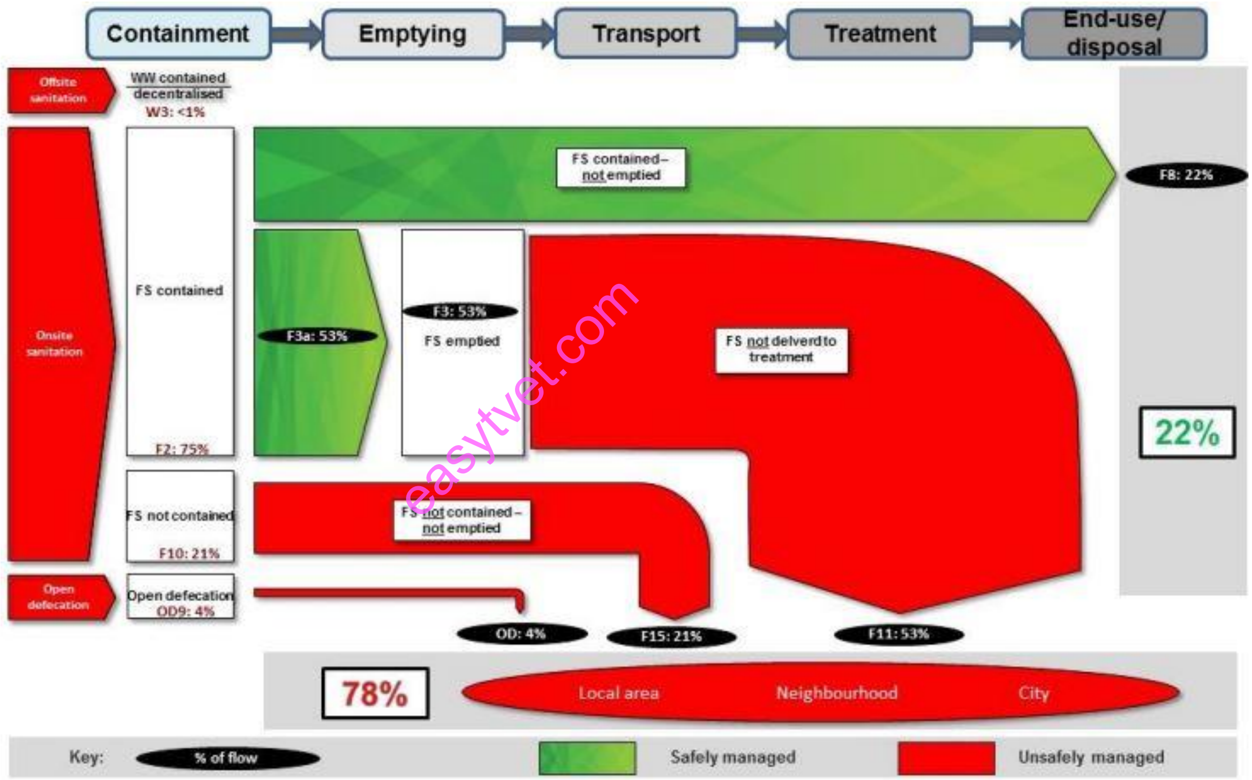

Figure 191: SFD Promotion Initiatives Updates

Source: African Water Association , 2017, SFD Promotion Initiatives Updates, USAID, https://www.afwakm.com/sfd-promotion-initiative-updates/

Conclusion

This learning outcome served the preparation, designing of an SFD for fecal sludge management and teaching the basics in collecting and analyzing raw data.

Further Reading

Read further on the steps of fecal sludge management

20.3.6.3 Self-Assessment

Written Assessment

1. Which area is fecal sludge management preferred the most?
    a) Cluster settlement
    b) Dense settlement
    c) Sparse settlement
    d) Stratified settlement
2. Name the mode of transport used in fecal sludge management.
3. After treatment of the fecal sludge management, what is the byproduct given?
4. List the advantages and disadvantages of fecal sludge management.
5. Differentiate between onsite sanitation and fecal sludge management.
6. Describe how social and cultural practices affect fecal sludge management.
7. Fecal sludge management is proving to be a necessary way of waste water treatment.

Oral Assessment

What was the most advantageous quality of fecal sludge management?

Case Study Assessment

On your way home, you pass by a school with a failed sewerage system. Advise the school principal on fecal sludge management and design a shit flow diagram for the school.

Practical Assessment

In groups of two find the system used to ensure a proper fecal sludge management in your area.

Oral Assessment

Which way of disposal is used in fecal sludge management?

20.3.6.4 Tools, Equipment, Supplies and Materials

Tools:

- Software
- Pencils
- Ruler
- T-square
- Scale rule
- Eraser
- Set square
- Drawing board

Supplies:

- Masking tapes
- Software

Materials:

- Drawing paper
- Photocopying /printing papers
- Stationery

Equipment:

- Computer
- Printer
- Photocopiers
- Calculator

References

Bhitush Luthra. (2019). Shit Flow Diagram. New Delhi. Global and Indian Experience.

Center for Science and Environment. (2019). Methodology for Data Collection. New Delhi. Center for Science and Environment.

Ian Ross, Rebecca Scot, Ana Mujica, Zach White, Mike Smith. (2016). Fecal Sludge Management: Diagnostics for Service Delivery in Urban Areas. Leicestershire. World Bank Group.

20.3.7 Learning Outcome No 6: Compile Onsite Sanitation Design Report

20.3.7.1 Learning Activities

Learning Outcome No 6: Compile Onsite Sanitation Design Report	
Learning Activities	**Special Instructions**
6.1 Obtain design report format from the wastewater design manual. 6.2 Prepare design report 6.3 Submit design report to the client	• Utilize the provided design report format from the wastewater design manual.

20.3.7.2 Information Sheet No20/LO6 Compile Onsite Sanitation Design Report

Introduction to learning outcome

This unit summarizes the design of onsite sanitation facilities because a trainee is expected to submit a design report to the client as per best practice.

Definition of key terms

Onsite sanitation entails dealing with the waste on the location where it is collected and deposited with regard to drainage and disposal of sewage and refuse from houses, examples include; septic tanks, use of latrines and many others to be obtained from the waste water manual

Onsite sanitation design report is a written guide record that is in place to show how engineers use the design process to arrive at the destined design of onsite facilities

Content/Procedures/Methods/Illustrations

6.1 Obtain design report format from the wastewater design manual.

- It can be obtained from the government catalog of ministry of water and irrigation or on the Internet by downloading from Google scholar websites
- The design report format outlines the following;
    a. Existing sanitation technology
    b. Existing conditions of onsite sanitation
    c. Selection of sanitation technology
    d. Selection of rural or urban sanitation
    e. Cost comparison and alternatives and decision making

f. Planning, design considerations and parameters of the chosen method construction
g. Implementation phase

6.2 Prepare design report based on identified format.

A design report is prepared by conducting studies on the following basis;

a. Existing sanitation technology in Kenya include onsite and offsite sanitation
b. Grasping sewerage conditions for onsite treatment systems i.e climatic and site conditions, population, sociocultural factors and institutional framework in place
c. The minimum criteria for selection is the service level of water supply, population density, ground permeability and water table
d. Use of septic tanks, latrines are both considered in the rural and urban sanitation variations being land and water use
e. The method with the minimum cost and maximum benefits is picked
f. Conceptualization of the plan, actualization of drawings design data analysis and computation with respect to design principles and parameters to come up with dimensions
g. Availability and gathering of resources and materials involved such as land, workmanship and thereafter construction

More information on the detailed design report to be found in
Ministry of Water and Irrigation draft practice manual for Sewerage & Sanitation Kenya. JUNE (2008)

6.3 Submit design report to the client as per best practice.

- The design report is submitted to client through a legal framework involving a third party where the document is reviewed and dully signed by both parties involved in the contract agreement
- The terms and conditions of monitoring and evaluation of the works are also agreed
- The client is made known to the risks, costs and maintenance measures to be put in place after project completion

An illustration below to show how sanitation technologies are designed to work

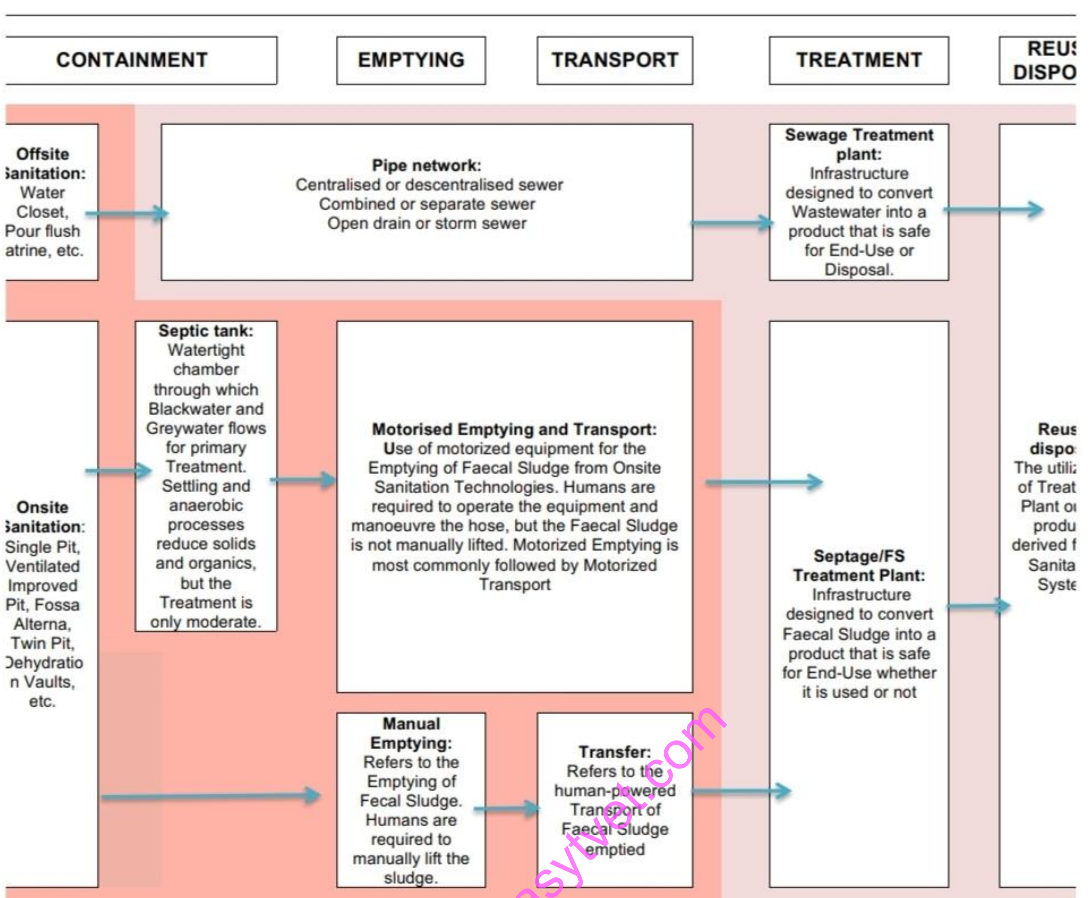

Figure 192: Sanitation technologies

Source: Using the shit flow diagrams by Lara Fernandez Martinez, Loughborough University

Conclusion

This learning outcome served the preparation and submission of an onsite sanitation design report and enlightened the learner about waste water design manual.

Further Reading

Learners should read more on design of onsite sanitation and be able to compute analysis questions on onsite sanitation, their design principles and consideration.

Go through other sections of the waste water design manual to familiarize yourself with other methods of sanitation.

20.3.7.3 Self-Assessment

Written Assessment

1. Which one of the following cannot be termed in existing condition of sanitation technology?
    a) Population
    b) Cost
    c) Planning
    d) Management
2. Septic tanks are adopted conveniently in?
    a) Rural areas
    b) Urban areas
    c) Both
    d) Low density residential areas
3. Where can one obtain a design report format?
    a) Internet
    b) Waste water design manual
    c) Review journals
    d) Onsite facility
4. Briefly define online sanitation
5. What is an online sanitation design report?
6. List two online sanitation methods practiced in a Kenya

Essay question

With reference to the waste water design manual, describe the preparation of a design report

Oral Assessment

Is online sanitation reliable in our country? If yes or no why?

Case Study Assessment

A client in Machakos has hired your consultant company to prepare a design report format for his residential houses sewerage system. Adopt the design with a suitable method of sanitation

20.3.7.4 Tools, Equipment, Supplies and Materials

- Computer
- Internet
- Printer
- Work Station
- Photocopying /printing papers

20.3.7.5 References

Republic of Kenya Ministry of water and Irrigation draft practice manual for Sewerage and Sanitation Services.

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The american water works association. (2012). waste water treatment plant design.fifth edistion. colorado: mcgraw hill professional

CHAPTER 21: CONSTRUCTION OF ONSITE SANITATION FACILITIES

21.1 Introduction of the Unit of Learning

This unit covers the competencies required to construct onsite sanitation facilities. It involves preparing construction schedule, organizing the construction site and construction of the various onsite sanitation facilities. This standard applies in water Industry.

21.2 Performance Standard

Prepare construction schedule, organize the construction site, and construct the various onsite sanitation facilities based on engineering codes, scope of work, and project specifications.

21.3 Learning Outcomes

21.3.1 List of Learning Outcomes

a) Prepare construction schedule
b) Organize the construction Site
c) Construct the various onsite sanitation facilities

21.3.2 Learning Outcome No 1: Prepare Construction Schedule

21.3.2.1 Learning Activities

Learning Outcome No 1: Prepare Construction Schedule	
Learning Activities	**Special Instructions**
1.1 Interpret engineering drawings 1.2 Identify ***construction activities*** 1.3 Prepare project management timelines	• Trainer guidance on the application of engineering codes • Use of updated engineering codes

21.3.2.2 Information Sheet No21/LO1: Prepare Construction Schedule

Introduction to learning outcome

This section deals with the necessary steps taken for the construction of the onsite sanitation facilities. Scheduling construction activities involve distributing the construction tasks available over a specified time frame to ensure its timely delivery and a high quality output of the final product. Sanitation has always been neglected during water supply. However, there has been a tremendous development s in the innovation of better and low-cost sanitation facilities. Therefore, preparation of a construction schedule is necessary in realizing an appropriate supply of clean and potable water and sanitary disposal of human wastes towards improvement of the health of the people in the society.

Definition of key terms

Construction activities: involve the tasks that are undertaken during the implementation of the actual building of the structure.

Content/Procedures/Methods/Illustrations

1.1 Interpret engineering drawings based on the engineering codes

Different engineering codes are available for the design of different engineering structures in order to meet certain minimum standards. These codes include but not limited to: Euro codes, British Standard Codes, Kenyan standards among others and are all essential in any engineering design.

Interpretation of engineering drawings involve converting them into forms of CAD representation using different forms of softwares for example Auto CAD, Prokon, Revit Technology among others that convey different meanings including representing a 3-D structure. .

There are three levels of interpretation of engineering drawings namely:

a. Lexical level
b. Syntatic level
c. Semantic level

At the syntactic level, there are tasks utilized in generally recognizing annotations and dimensioning in particular. This dimensioning can be in form of linear or angular dimensioning. It is essential to always start by reading and understanding the title block of every drawing as they contain important features including dimensioning units, scales among others. Section views show the hidden features of an object so that the contractor or the site engineer is able to understand that during construction. Reading and understanding different symbols used in the drawings is also key to interpreting the drawing and meeting its demands fully and therefore it is important to understand a few basics of symbols. The most common symbols used are and not limited to rectangles, triangles, circles and polygons. Architectural symbols for instance doors, windows, cars and electrical installations are normally generally notated. Engineering drawings are a graphic representation of a structure/object and produced by the engineer or technician. It is important that they are done according to the specifications of the relevant engineering codes. Any contractor or a site engineer must therefore be able to interpret any technical drawings given to him or her at the site in order to deliver a project that meets the expected design standards and specifications. Consultation in engineering is necessary. At the site, it is essential to consult with other colleagues and especially the engineer that designed and produced the drawing.

1.2 Identify *construction activities* (Surveying, excavation, laying and jointing) based on scope of work.

Different construction activities are all put together chronologically in order to achieve the desired output of the construction. Preliminary surveying for instance for site understanding and easier clearance to pave way for the actual construction is important.

Surveying is the process of analyzing and obtaining the general characteristics of a land area proposed for construction. The most preferred surveying instruments include the theodolite and the total station. There are several categories of surveying namely:

a. Cadastral surveying
b. Topographical surveying
c. Geodetic surveying
d. Aerial surveying
e. As Built surveying

Excavation involves the removal of soil or rocks from a site using tools and machinery. Excavation and trenching is common for the construction of all sanitary facilities as they are vital for the construction of deep foundations. However, these methods of foundations differ for foundations, underground openings or slopes. These foundation methods include: bracing excavation methods, zoned excavation among others.

Laying and jointing is done especially for pipes for instance concrete pipes or plastic pipes. Pipes are generally laid below the ground or even sometimes on the ground. These pipes are laid in the following ways:

a. Initially prepare a detailed map showing the topographical features of the area including lanes, roads among others.
b. The Centre line of the proposed pipework be transferred from the map to the actual ground and marked in equal intervals.
c. Excavation of the trenches commences.
d. Pipes are laid on the ground by use of derricks for heavy pipes or manually for lighter pipes.
e. Testing of these pipes for leakage and pressure begin immediately after the pipes are laid in position.
f. After it has passed the above immediate test, backfilling using soil or rock is done.

1.3 Prepare project management timelines based on project specifications

The success of a project often is also defined by completing the project within the budgeted timeframe. This will be achieved by developing a realistic and working plan and effective management of the created plan. Different construction activities and stages will be given specified time limits to which they should be completed for example site clearance, excavation, setting out works, actual construction to completion and official handing over will be given different dates in the same order. This is also made possible through the work breakdown structure. The following steps are to be followed in order to develop or prepare project management timelines:

a. Write the scope of the project for instance for the construction of a 3-bedroom house that will occupy an area of 20 sq. feet.
b. Develop a work breakdown structure. This will help in breaking down the construction of the house into small sub-units for example construction of foundation, exterior walls, partition walls, partition walls, roofing.
c. Each work package is broken down into tasks
d. The total time required for each task is estimated. Sufficient time for curing is given for concrete works.
e. Identify the available resources required to be input into the specific works and allocate them appropriately.
f. Using all the above gathered information, assemble them to obtain the final project management timeline

Conclusion

This learning outcome covered the preliminary construction techniques, scheduling and management of the onsite sanitation facilities.

Further Reading

Read more on the project cycle and methods of excavation

21.3.2.3 Self-Assessment

Written Assessment

1. Which is the most applicable engineering code in any design by engineers
    a) British standards
    b) Kenyan standards
    c) Euro codes
2. Onsite sanitation facilities include the following except one, identify
    a) Aqua-privy
    b) Pit latrine
    c) Swamp
3. Which one of the following is not a construction activity
    a) Surveying
    b) Excavation
    c) Trenching
    d) Playing
4. Do poor waste disposal pollute groundwater
5. Is provision of clean water the solution to the problem of poor sanitation
6. Which is the most common form of waste disposal in Kenya
7. Is waste segregation at the production site important in controlling pollution
8. Is project plan important in ensuring a timely delivery of the project

Essay question

Scheduling of work is important in ensuring the completion of the project in time, discuss

Oral Assessment

Why is excavation one of the most important stage in onsite sanitation facilities construction?

Are low-cost construction techniques the solution to the problem to the deficiency of sanitation facilities in third world countries?

Case Study Assessment

Malawi has made great improvements in ensuring an improved water supply rates to its citizens (56.3%). However, like other sub-Saharan countries, continue to suffer under the burden of an increasing population and hence a higher demand for more sanitation facilities. Using this knowledge, discuss what the government should do to improve the livelihoods of the people in your area.

Oral Assessment

What are the likelihoods that improved sanitation will impact positively on the improvement of the health of the people of the society?

Project Assessment

Conduct a research (questionnaire) on how poor maintenance of sanitation facilities lead to the poor sustainability of the already established facilities

21.3.2.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Standard operating procedures
- Ordinary Portland Cement
- Surveying instruments
- Laying pipes
- Wheelbarrow
- Excavators

21.3.2.5 References

Strande, L. (2014). The global situation (pp. 1-18). IWA Publishing, London.

Harada, H., Strande, L., & Fujii, S. (2016). Challenges and oppotuniteis of faecal sludge management for global sanitation. Towards future earth: challenges and progress of global environmental studies. Tokyo (Japan): Kaisei Publishing, 81-100.

Tiimub, B. M., Forson, M. A., Obiri-Danso, K., & Rahaman, I. A. (2009, May). Pointed gaps in the provision, quality, patronage and management of toilet facilities in Bawku East District. In Water, Sanitation and Hygiene: Sustainable Development and Multisectoral Approaches, Proceedings of the 34th WEDC International Conference, United Nations Conference Centre, Addis Ababa, Ethiopia (pp. 18-22).

21.3.3 Learning Outcome No 2: Organize the Construction Site

21.3.3.1 Learning Activities

Learning Outcome No 2: Organize the Construction Site	
Learning Activities	**Special Instructions**
2.1 Clear and secure site 2.2 Identify and mobilize human resource, construction plant and equipment 2.3 Put in place ***onsite infrastructure***	• Strict and transparent bidding and tendering process • All measurements adhered to

21.3.3.2 Information Sheet No21/LO2 Organize the Construction Site

Introduction to learning outcome

This is a very important and the most crucial step towards implementation of the proposed facility. Visiting the actual site and mobilizing the human resource to provide labour and providing the necessary equipment for the actual construction is essential.

Definition of key terms

Onsite infrastructure: This can be defined as the supporting infrastructure that is provided within the specified perimeter of a project site and is directly or indirectly related to the same project. Examples include, but not limited to, onsite sanitation units, administrative offices, roads, residences, and power substations

Content/Procedures/Methods/Illustrations

2.1 Clear and secure site based on the contract document.

The procedure of clearing and securing the site varies depending on several factors, such as project size and how remote the site is. The procedure for clearing the site should be clearly highlighted in the contract document. In most cases, this is done by the contractor. The first step is usually grubbing and standard clearing. The works included in this step are removing any existing tree stumps, bushes, buildings, and any other obstruction to site preparation. The terrain is then leveled to the surveyor's specifications using the surveyor's instruments. The ground beyond the site is also leveled to facilitate future works of maintenance. The trees and shrubs that stand on the right of way of the project are also trimmed as per the contract document.

Grubbing is done in all areas where deep excavation is to be done. Note that all tree clearances and excavations are done according to the engineer's specifications, as stipulated in the contract drawings. At this stage, it's easier to design the onsite facilities depending on the orientation of the cleared site.

2.2 Identify and mobilize human resource, construction plant and equipment based on the contract document.

This step is carried out by the contractor before work commencement, and once the site is ready for work. According to the Fidic Redbook, the contractor shall carry out all the manufacture of the plant, the production of materials, and all other executions of the stipulated work. Depending on the nature of work, the contractor should be able to identify the type of labour that is needed for the execution of the works and also the equipment. These are organized and arranged on site. Examples of human resources needed in a site are masons, technicians, supervisors, and plumbers. Examples of equipment that should be availed to the site are wheelbarrows, excavators, pipes, and trowels. Identify the available labour and compare with what is needed. If there is a need for more, then more mobilization is paramount.

2.3 Put in place onsite infrastructure (stores, site offices, fences) based on contract document and legal requirements.

The contract document should indicate the necessary onsite infrastructure that is to be built. Once site clearance and mobilization of equipment are complete, then this step can commence. The first thing to do is appropriately fence the site as per the contract document. The administrative offices can then be constructed so as to accommodate the administrative staff that is crucial for project management. The stores are then constructed. These are important in facilitating the movement of material and equipment. Stores are also important in safeguarding materials such as cement. On completion of this step, the site should be ready for the commencement of the main works

Conclusion

This learning outcome covered the full organization of the construction site in order for the actual construction works to commence.

Further Reading

Discuss other ways which the suitable alternatives can be utilized to replace onsite sanitation facilities.

21.3.3.3 Self-Assessment

Written Assessment

1. Which one of the following is not an onsite infrastructure facility?
    a) Toilet
    b) Wheelbarrow
    c) Pavement
    d) Power substation
2. Which one of the following is not an activity in site clearing?
    a) Design of culverts
    b) Tree cutting
    c) Demolitions
3. Identify the human resource that is involved in site clearance
    a) Painters
    b) Drivers
    c) Masons
    d) Excavator operators

Oral Assessment

1. Identify and explain two documents that are necessary in putting into place onsite infrastructure.
2. Explain, in detail, the process from site clearing to commencement of the main works

Case Study Assessment

Organize with your lecturer, and visit a nearby construction site. Request for entry and identify all the existing onsite infrastructures. Draw sketches of the site outline that capture the infrastructure.

21.3.3.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Standard operating procedures
- Ordinary Portland Cement
- Surveying instruments
- Laying pipes
- Wheelbarrow
- Excavators
- GPS

21.3.3.5 References

Bunni, N. G., & Bunni, N. G. (2005). The FIDIC forms of contract (Vol. 284). Oxford: Blackwell Publishing.

Totterdill, B. W. (2001). FIDIC User's Guide: A Practical Guide to the 1999 Red Book. Thomas Telford.

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21.3.4 Learning No 3: Construct the Various Onsite Sanitation Facilities

21.3.4.1 Learning Activities

Learning Outcome No 3: Construct the Various Onsite Sanitation Facilities	
Learning Activities	**Special Instructions**
3.1 Source and mobilize ***construction materials*** 3.2 Set out onsite sanitation facilities 3.3 Construct ***onsite sanitation facility units*** 3.4 Do labour payments 3.5 Prepare and submit as-built drawings 3.6 Prepare substantial completion certificate 3.7 Prepare payment certificate 3.8 Prepare completion certificate	• A correct bill of quantities • Construction done according to the approved engineering drawings

21.3.4.2 Information Sheet No21/LO3: Construct the Various Onsite Sanitation Facilities

Introduction to learning outcome

Onsite sanitation facilities will be constructed using several methods for instance the "project cycle" approach in order to improve on sanitation standards in the society. This approach seeks to address all the project complexities through all its stages and, at the same time, maintaining the alignment with the objectives and strategies. The construction phase is a very important one in project management.

Definition of key terms

Construction materials: These are items or supplies, most of which are naturally occurring that are used to form the components of the structure. Naturally occurring materials include stones, sand, and timber. Some materials are made in the factory from naturally occurring minerals. A good example is cement.

Onsite sanitation facility units: are units designed and constructed to handle, store, and treat the waste generated within the same property that produces it. In most cases, the onsite treatment facilities are used in areas that are not yet covered with public sewers. A typical example is the septic tank.

Content/Procedures/Methods/Illustrations

3.1 Source and mobilize construction materials (cement, bricks, stones) based on the bill of quantities.

Before the commencement of the project, there is proper documentation that specifies all the materials to be used in the necessary quantities. This document is called the bill of quantities. The contractor uses this document to know and decide on the best way of acquiring the materials. The document specifies the number of bags of cement that are required for each construction stage. Bricks and stones are measured in terms of kilograms or tons. In that case, the contractor will be able to interpret the document and order the required amount of the same. Preferably, these materials should be sourced from closer sources to save on the cost of construction. For example, the stones and bricks could be sourced from a nearby quarry. Once these have been obtained, the construction of the facilities can commence. Read and understand the bill of quantities, on the materials section. Make or organize how orders of the same materials will be made. Also, organize for delivery of the same to the site. Identify the ordered materials on arrival, and perfom a thorough inspection to check on quantity and quality. Write a report on the same. Also, document this in the invoice and sign the delivery documentation. Lastly, organize how the delivered materials shall be stored. This is to make sure they are protected from quantity and quality manipulation.

3.2 Set out onsite sanitation facilities based on the engineering drawings.

Setting out is a very important stage in construction. It is the stage that determines the orientation of the construction and whether the plan will be followed accordingly. For this step, the engineers or surveyors may make use of sophisticated instruments. Examples are GPS, computers, and surveyors' equipment. The setting out is done following the drawings. Centerlines of the structures are interpreted from the drawings and transferred to the ground. Excavation lines are also plotted on the ground during setting out. . Interpreted the drawings, and draw the appropriate centerlines. Mark them using a visible marker, preferably a string. This shall aid in accurate excavation.

3.3 Construct *onsite sanitation facility units* (Septic tanks, bio-digesters, soak pits) based on the design drawings

Septic tanks. The drawings will determine whether the tank will be a single or two-compartment tank. The excavation is also done following the setting out procedure. The best materials to use for the floors and walls of the septic tank are concrete and plastic. The floor should have a slight slope towards the outlet. All these details are specified in the structural drawings. Bio-digesters. These are facilities fed with generated organic waste, and in return, create useful gases such as methane. This is the right way of recycling waste. Just as in the septic tanks, the specifications are well illustrated in the structural drawings provided in the contract document. Soak pits. These are covered holes, whose walls are made of porous materials to allow fed in waste to soak into the soil slowly. In most cases, the soak pit is connected to the septic tank. Its design is a bit easier. The depth of the soak pit, the position of the inlet, and the material to be used should be specified in the drawings. The details should be followed keenly.

3.4 Do labour payments based on the progress report and attendance list.

Unless stated otherwise, it's the responsibility of the contractor to mobilize and pay for labour. The easiest way is to have a complete list of all the involved labour. In such a case, an attendance list is necessary to make sure everyone is paid for what he/she has worked for. It is important to observe the regulations that have been set for rates of wages and working conditions. Organize the labourers on the payroll into manageable groups. This is if the payments are to be made in cash. Have group heads to help in distributing their dues. Organize them to sign a document on receiving the payment. Lastly, write a report and submit to the management.

3.5 Prepare and submit as-built drawings based on the actual construction works.

These drawings are prepared based on what is going on on the ground. They are very important as they cater to the changes that might have occurred during the construction. Changes in construction might be a result of various forces such as nature, politics, and financial constraints. Built drawings as necessary in making further construction plans. This can be done by the use of computer software such as AutoCAD. These drawings are then submitted to the relevant authorities for approval before construction commences. They have to meet certain minimum criteria in terms of design.

3.6 Prepare substantial completion certificate based on FIDIC regulations.

A substantial completion certificate is a document between the owner of an ongoing construction and a contractor. This certificate is prepared upon completion of the initially proposed work when the contractor has handed over the structure to the owner and the owner now becomes liable for anything that happens to the structure. The Fidic Redbook states that reporting of progress of works shall continue until the respective contractor has completed all the planned works. Before total completion, the contractor should submit relevant results that capture a description of the progress of works at each stage of design. This can be done via charts, graphs, photos, and videos. A certificate is then offered for completion of a stage

3.7 Prepare payment certificate based on progress report.

The payment certificate captures the amount that the contractor is entitled to and it depicts the importance of cash flows in determining the success of a project. This will depend on the amount of progress on the works. The report of progress should be accompanied by supporting documents that will validate the necessity of payment being demanded. These payments can therefore be set periodic payments or stage payments. Any variations from the contract price should be clearly indicated. If all is clear, the payment certificate is issued

Table 59: payment certificate based on progress report

Type	Cost (Kshs)
Preliminaries	5 000 000
Foundation	23 000 000
Internal works	30 000 000
External works	15 000 000
Total	73 000 000

3.8 Prepare completion certificate based on the legal requirements.

The completion certificate is issued once whole works or sections (if any) have been completed within the agreed time of completion. Once the progress has been agreed on, taking over certificate application is issued by the engineer to the employer. At that point, the contractor ceases to be responsible for any works ongoing on the site.

Conclusion

Constructing a public sewer is quite expensive. On-site sanitation facilities are, therefore, important for the improvement of sanitation standards of a society. More importantly, in areas where there is no access to a public sewer. There is, therefore, a need to construct more onsite sanitation facilities. However, the performance of these facilities will depend on how well the construction is done. For the best results, proper design and construction procedures are paramount.

Further Reading

Read more on the construction of septic tanks

21.3.4.3 Self-Assessment

Written Assessment

1. Which of the following is not a certificate captured in the Fidic Redbook?
    a) Certificate of completion
    b) Payment certificate
    c) Structural drawings
    d) Taking over certificate

2. Which one of the following is not a part of a contract?
    a) Contractor
    b) Employer
    c) Engineer
    d) Politician
3. Which one of the following is not an onsite treatment facility?
    a) Septic tank
    b) Soak pit
    c) Bio digester
    d) Waste stabilization pond

Oral Assessment

1. Explain your choices of onsite treatment methods
2. Briefly describe five documents captured in the Fidic Redbook.

Case Study Assessment

Visit any public institution and identify the present onsite treatment facilities and give detailed report on their management and sustainability of these facilities

Practical Assessment

Draw and label a simple septic tank. Use your own dimensions and if possible, draw a connected soak pit

21.3.4.4 Tools, Equipment, Supplies and Materials

- Computers
- Stationery
- Standard operating procedures
- Ordinary Portland Cement
- Surveying instruments
- Laying pipes
- Wheelbarrow
- Excavators
- Trowels
- Tape measure

21.3.4.5 References

Glover, J., & Hughes, S. (2011). Understanding the FIDIC Red Book: A Clause by Clause Commentary. Sweet & Maxwell.

CHAPTER 22: CIVIL ENGINEERING PROJECT MANAGEMENT

22.1 Introduction of the Unit of Learning

This unit describes the competencies required to manage civil engineering projects. It involves managing project time, managing construction project quality, managing project site safety, health and security, managing construction project cost, managing project labour, managing project contracts and managing construction materials, plant, tools and equipment.

22.2 Performance Standard

Manage project time, construction project quality, project site, safety, health and security, construction project cost, project labour, project contracts, and construction materials, plant and tools and equipment based on project specifications.

22.3 Learning Outcomes

22.3.1 List of Learning Outcomes

a) Manage project time
b) Manage construction project quality
c) Manage project site, safety, health and security
d) Manage construction project cost
e) Manage project labour
f) Manage project contracts
g) Manage construction materials, plant, tools and equipment

22.3.2 Learning No 1: Manage Project Time

22.3.2.1 Learning Activities

Learning Outcome No 1: Manage Project Time	
Learning Activities	**Special Instructions**
1.1 Prepare work schedules and time programs 1.2 Monitor and evaluate project timelines 1.3 Control project time schedules 1.4 Prepare and disseminate project timeline reports	• Group discussions • Demonstration by trainer • Online videos • Power point presentation • Exercises by trainee

22.3.2.2 Information Sheet No22/LO1: Manage Project Time

Introduction to learning outcome

This learning outcome deals with project time management and this can be achieved through the knowledge of various aspects such as; preparation of work schedules and time programs, monitoring, evaluation and control of project timelines and schedules. All this is based on the project specifications.

Definition of key terms

Work schedule: Ronald (2015) defines schedules in project management as a process of identifying deliverables, milestones, and activities in chronological order with a start and end date and time. Therefore, work schedules can be defined as an organization of activities, deliverables, and project milestones to ensure that inputs are transformed into outputs in a project at a stipulated time.

Project timeline: The project timeline can be defined as the process of showing the chronological order of events in a project.

Content/Procedures/Methods/Illustrations

1.1 Prepare work schedules and time programs based on the project specifications

The process of preparing work schedules and time programs can be complex since different projects have varied approaches and challenges. However, there are six steps simplified steps that can be applied in all projects regardless of the project nature.

a. **Identify and Write down the project tasks**

The most crucial step in project management allows the project manager to understand the project nature. Moreover, it determines how activities will be well-coordinated within the project stipulated time.

b. **Define the various relationships between the tasks.**

Once the project tasks have been written down, it is crucial to identify the existing relationship between the various events.

c. **Develop various Milestones**

Project milestones indicate the event that allows the end of a particular project activity and allows the beginning of another activity. The steps involve allocating the relevant tasks that will facilitate the achievement of the set milestones.

d. **Allocate time for the identified milestone**

After the milestone development, the next step now becomes identifying the available time and allocating accordingly. The time allocation should be balanced and clearly stated. Moreover, it should have an allowance to avoid inconveniences.

e. **Allocate resources**

After the project's milestones have been identified, it is crucial to understand the various roles and resources allocation basis. The project success depends on this step since the progress and results will be dependent on the product mix on this stage.

f. **Review and Revise the schedule regular**

The first attempt might not provide the most feasible option; therefore, it is necessary to adjust the program. However, the revision should be aligned with the project's goals, objectives, and allocated time and resources.

1.2 Monitor and evaluate project timelines based on the project specifications

Project monitoring and evaluation (M&E) is the process of gathering and interpreting data to check if the project is moving towards the stipulated direction. Monitoring is carried to measure progress and performance for decision-making purposes at the different stages of the projects. On the contrary, evaluation is carried out for general data assessment purposes of understanding the extent at which the specified goal is achieved. It is crucial to understand the direction and the impact that a particular project, therefore the need to carry out monitoring and evaluation activities. Furthermore most projects are time bound, and evaluation and monitoring help in maintaining the specified timing.

1.3 Control project time schedules based on the project specifications

For easier control project time schedules, data collection plays a crucial role. The data collection varies with the project nature; thus, the project managers need to identify the sustainable data collection method. From the data collected, the resource and responsibility allocation is identified with the time being a factor of consideration. The information helps in operational and strategic management, and controlling the project becomes an easy and straight leader.

1.4 Prepare and disseminate project timeline reports based on the project specifications.
After the data is collected, the need for compiling and analysis arises. Therefore, the project manager collabourates with the research team members and selects the various tools required to analyse the data collected logically and acceptably. After analysis, the data organized and prepared in an official document that will be used for reporting purposes. The data collected should be organized in such a way that it allows objective and strategic adjustments.

Conclusion
This learning outcome covered project time management

Further Reading

Read more on project timelines and project time control

22.3.2.3 Self-Assessment

Written Assessment
1. Work schedule can be defined as
    a) the various expectations that show the project's success
    b) process of identifying deliverables, milestones, and activities in chronological order with a start and end date and time
    c) A document that shows a chronological order of events in a project.
    d) Organization of activities, deliverables, and project milestones to ensure inputs are transformed into outputs in a project at a stipulated time.
2. Which one of the following does not explain the purpose of carrying out monitoring and evaluation in a project?
    a) Capacity building
    b) Clarification
    c) Accountability
    d) Strategic management

3. Which one of the following explains the meaning of monitoring a project?
    a) The document prepared during the process can be used for explanation purposes to the project donors and stakeholders about the utilization of the various resources in the program.
    b) Information acquired at the different project levels can be used to change the project approach due to the objective and strategies adjustment.
    c) Process of measuring progress and performance for decision-making purposes at the different stages of the projects
    d) Provides information that is required for the coordination and management of the various resources for project improvement purposes.

Short answer question

Identify the tools required to analyse and report the collected data?

Essay question

Describe the process of monitoring and evaluate project timelines based on the project specifications

Case Study Assessment

The county board of directors has selected you in the short-list on their project manager in a county development project. Prepare a document that you will present on the interview day to demonstrate your ability to organize, manage, and report the project at the various project stages.

Project Assessment

Write a report on the management of the post-modern library being constructed in your school

22.3.2.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Relevant reference materials
- Stationeries
- Design Software
- Computer lab
- Relevant practical materials
- Labouratories (chemical, biological & soils)
- Internet
- Manuals and guidelines
- Project management software
- Measuring and drawing tool
- Printer/plotting device
- Codes of practice

22.3.2.5 References

Eng. Ssempebwa Kibuuka Ronald. (2015). Project Schedule Management. Hawaii. Research Gate.

Hu, X., Cui, N., Demeulemeester, E., & Bie, L. (2016). Incorporation of activity sensitivity measures into buffer management to manage project schedule risk. European Journal of Operational Research, 249(2), 717-727.

Susser, B. S. (2012). How to Effectively Manage IT Project Risks. Journal of Management & Business Research, 2(2).

22.3.3 Learning No 2: Manage Construction Project Quality

22.3.3.1 Learning Activities

Learning Outcome No 2: Manage Construction Project Quality	
Learning Activities	**Special Instructions**
2.1 Develop construction project quality plans 2.2 Develop construction project methodology 2.3 Acquire construction project resources 2.4 Undertake construction project quality control 2.5 Prepare construction project quality reports	• Group discussions • Demonstration by trainer • Online videos • Power point presentation • Exercises by trainee

22.3.3.2 Information Sheet No22/LO2: Manage Construction Project Quality

Introduction to learning outcome

This learning outcome deals with development of construction project quality plans, methodology, and undertaking of project quality control together with preparation of project quality reports.

Definition of key terms

Contract: This is an agreement creating and defining obligations between parties. It is an agreement enforceable at law made between two or more persons by which rights are acquired by one or more to act on the part of the other or others.

Contract specifications: These are the rules of the contract. They are the agreed upon set of requirements that provide the necessary details about specific requirements.

Content/Procedures/Methods/Illustrations

2.1 Develop construction project quality plans according to the contract specifications

Construction project quality plan is a written plan detailing how one will manage quality on a construction project. Project quality plans vary depending on the type of construction project one undertakes; however, they are limited in scope. Quality plans are written to make the clients know how you going to control the quality of your projects, so it is necessary that when developing a quality plan, one should make clear how and when you would control quality in your project. A construction quality plan should be prepared in such a way that your headings match up with your client's specifications.

Essential elements of a construction project quality plan include

i. Project personnel in charge of the project quality. Has the overall responsibility
ii. Quality communications to ensure quality work is done.
iii. Quality assurance surveillance-Monitoring overall project quality.
iv. Project quality specifications-Where one makes sure compliance with the projects contract specifications.
v. Inspections and tests-To inspect phases of works to ensure they are up to the required quality.
vi. Control of nonconformance-The quality control plan should outline how to handle situations that go wrong.

2.2 Develop construction project methodology according to the contract specifications

Construction Project methodologies are processes that assist project managers with guidance and the steps to take to bring a project to completion.

Depending on contract specifications, there are a number of methodologies that are crucial to getting the job right. The choice of methodology will depend entirely on the project with their set of rules, principles, processes and practices.

- **Agile**

This is one of the most recognizable methodologies where demands and solutions evolve through the cross functional teams and their customers.

- **Lean**

This type of construction methodology promotes maximizing customer value while minimizing waste.

- **Waterfall**

In this methodology, processes flow downwards in one direction like a waterfall. One is able to move onto the next phase of development once the current phase has been completed as illustrated by Winston W George in an article written in 1970.

- **PMI/PMBOK**

  PMI stands for project Management Institute which is a non-profit membership association, project management certification and standard organization.

  PMI produces the PMBOK which is a guide detailing the set standards that characterize project management.

2.3 Acquire construction project resources according to the contract specifications
Construction resources in a construction project might include:

i. Products and material
ii. Human resources
iii. Space and facilities
iv. Finances
v. Construction plant, tools and equipment.
vi. Subcontractors.

Construction Project resources vary depending on cost, duration, quality and safety as the construction project industries are diverse and contains subcontractors, contractors, consultants, architects, owners and others. Acquiring resources needs an understanding of what resources are needed, what resources are available, where the resources are located and the ability to reschedule those resources accordingly.

2.4 Undertake construction project quality control according to the contract specifications
Construction quality control is or are measures to ensure that a project conforms to the quality as indicated in the specifications.
To ensure quality, a number of steps are employed in a construction project.

i. Organizing for Quality-Have a group that will have an overall responsibility of ensuring that the project quality is adhered to.
ii. Inspectors and quality assurance personnel will be involved in day to day quality check of the project.
iii. Work and material specification. -This documentation includes special provisions of the design project facility as well as references to generally accepted specifications to be used in construction.
iv. Quality control by statistical methods-This involves testing all the material on a particular project. Such as non-destructive techniques or an onsite inspector can witness the appropriateness and adequacy of construction methods.

2.5 Prepare construction project quality reports according to the contract specifications
Construction quality report is an account generated that is given to the customer of the materials used in the project together with a description of its technical characteristics.
The reports details how the quality plans were followed to ensure quality is attained.

Conclusion
This learning outcome covered management of construction project quality

Further Reading

Read more on construction project methodologies on

Kolarić, S., Pavlović, D., & Vukomanović, M. (2015). Developing a methodology for preparation and execution phase of construction project. Organization, technology & management in construction: an international journal, 7(1), 1197-1208.

22.3.3.3 Self-Assessment

Written Assessment

1. Quality control is...
   a) The graphic display of data that illustrates results of a process
   b) Measures to ensure that a project conforms to the quality as indicated in the specifications.
   c) Processes that assist project managers with guidance and the steps to take to bring a project to completion.
2. Which of the following is not an essential element of a construction project quality plan?
   a) Quality communications
   b) Control of nonconform aces
   c) Project submissal
3. Quality control plan must address
   a) Quality control of the project
   b) Quality assurance of the Project
   c) All of the above
4. Which statement is true?
   a) The choice of methodology will depend entirely on the project with their set of rules, principles, processes and practices.
   b) Construction Project methodologies are processes that assist project managers with guidance and the steps to take to bring a project to completion
   c) All of the above
5. Summarize the different methodologies in a construction project.
6. With reference to quality control, outline three quality standards in a construction project.
7. Summarize quality control plans.

Essay question

With reference to construction project plan outline and explain in details what one would consider then planning for a construction project.

Oral Assessment

1. Outline the factors to include in a construction resource
2. Evaluate the elements of a construction project

Case study assessment

A road is to be constructed in your area and your firm has been contracted to do it. As the project manager present your project plan for approval by the relevant authorities.

4.3.2.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Relevant reference materials
- Stationeries
- GPS
- Design Software
- Computer lab
- Relevant practical materials
- Labouratories (chemical, biological & soils)
- Internet
- Manuals and guidelines
- Project management software
- Measuring and drawing tool
- Printer/plotting device
- Codes of practice

22.3.3.5 References

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22.3.4 Learning No 3: Manage Project Site, Safety, Health and Security

22.3.4.1 Learning Activities

Learning Outcome No 3: Manage Project Site, Safety, Health and Security	
Learning Activities	**Special Instructions**
3.1 Develop project health, safety and security guidelines 3.2 Conduct site health, safety and security inspections 3.3 Coordinate and monitor project site security	• Group discussions • Demonstration by trainer • Online videos • Power point presentation • Exercises by trainee

22.3.4.2 Information Sheet No22/LO3: Manage Project Site, Safety, Health and Security

Introduction to learning outcome

This learning outcome deals with development, coordination and monitoring of project health, safety and security guidelines. The health and safety of people places of work deals with development, coordination and monitoring of project health, safety and security guidelines. These provisions are enhanced by legal regulations which introduce measures to improve the health and safety of workers through minimizing the risks they go through at their places of work.

Definition of key terms

Occupational safety and health: is an essential sector that deals and ensures the safety, health and welfare of the workers.

Content/Procedures/Methods/Illustrations

3.1 Develop project health, safety and security guidelines in line with the OSH Act

Health and Safety Project is planned to assist in the monitoring of operations and promote a risk-based approach to the prevention of dangerous actions that may lead to accidents or illnesses or severe workplace incidents. The following are guidelines in line with the OSH Act (2007):

i. There should be registration of work places applied before any persons occupy or uses any premises as a work place
ii. There should be training and supervision of inexperienced works
iii. There should be supervision, employment of persons below eighteen years, apprentices and indentured learners
iv. Protective clothing and appliances
v. There should be cleanliness in the workplace
vi. Proper ventilation should be provided

vii. Proper lighting should be provided

There should be evacuation procedures

3.2 Conduct site health, safety and security inspections in line with the OSH Act

i. Initial environmental audit- OSHA identifies and understands all legal and other requirements for workers within the site or work places according to environmental aspects
ii. Environmental policy – whether the employees and employers are observing their responsibilities on observing safety and health measures
iii. Planning – OSHA formulates their policies to be put in day to day practice
iv. Implementation – by allocating functions and responsibilities, motivating employees and training them to be accountable in the delivery of their duties diligently.
v. Training – OSHA clarifies the impact, beware of the task and responsibility within work places and consequences of the non-compliance workers
vi. Communication – OSHA do their best to communicate using various ways such as visits, open door events, the legislation, conferences to ensure safety and security of workers and employees
vii. Auditing – by assessing performance (monitoring operations and track frame) identify problems and correct them, keeping records performances and documented files

3.3 Coordinate and monitor project site security in line with the OSH Act

There should be proper coordination and monitoring among the employer and the workers in the project site. The employer and the workers should be aware of:

i. Types of hazards that may occur from work being performed on-site by employees hired by contractors, subcontractors or staffing agencies.
ii. Procedures or measures necessary to prevent or control exposure to such hazards.
iii. How to contact the manufacturer, subcontractor or personnel department if they have a health issue.
iv. Past work undertaken and the types of risks that might still be present at the job site.

Conclusion

This learning outcome has prepared the student to be able to apply the general and particular legislation and regulations of Health and Safety at work, understand management of project site, safety, health and security

Further Reading

Read further on safety, health and security as illustrated on the Occupational Safety and Health Act, 2007.

22.3.4.3 Self-Assessment

Written Assessment

1. Which of the following is not a provision of health and safety?
    a) Permit to work
    b) Fire prevention
    c) Project site
2. Can you interpret the following as used in OSHA?
    a) Act
    b) Prevention
3. Summarize the application of OSHA guidelines
4. Are you able to interpret OSHA guidelines?
5. Summarize the health and safety general provisions.
6. State health and safety general provisions
7. Summarize importance of project management

Essay question

1. Discuss the basic aspects of targeted by OSHA.

Oral Assessment

1. Evaluate the importance of OSHA in a project
2. Summarize on skills necessary for project management on site.

Project Assessment

An elevated road is being constructed at Maji ya Chumvi along Nairobi-Mombasa Highway to fly over the railway line. Prepare the project report.

22.3.4.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Relevant reference materials
- Stationeries
- GPS
- Design Software
- Computer lab
- Relevant practical materials
- Labouratories (chemical, biological & soils)
- Internet
- Manuals and guidelines
- Project management software
- Measuring and drawing tool
- Printer/plotting device
- Codes of practice

22.3.4.5 References

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www.osha.gov, (2016), Occupational Safety and Health Administration

22.3.5 Learning No 4: Manage Construction Project Cost

22.3.5.1 Learning Activities

Learning Outcome No 4: Manage Construction Project Cost	
Learning Activities	**Special Instructions**
4.1 Prepare project budget 4.2 Procure, allocate and monitor site resource utilization 4.3 Control project cost variation 4.4 Prepare project financial report	• Group discussions • Demonstration by trainer • Online videos • Power point presentation • Exercises by trainee

22.3.5.2 Information Sheet No22/LO4: Manage Construction Project Cost

Introduction to learning outcome

This learning outcome deals with project budget preparation, procurement, allocation and monitoring of site resource utilization and the control of project cost variation.

Definition of key terms

Project scope: Project scope is the part of project planning that deals with determining project goals, the project methods such as labour and materials, project timeline, functions and project fixed costs. These are parts which are needed to deliver and achieve a project to its completion.

Cost variation: Cost variation is the difference between the earned value of a project and its actual cost (McMullen, 2010)

Content/Procedures/Methods/Illustrations

4.1Prepare project budget according to the scope of the project

The project budget is the total cost that has been projected to complete the project within a specified period of time for instance payments, operating costs, starting capital among others.

Table 60: Project budget according to the scope of the project

Sample Project Budget			
Activity	**Direct cost**	**Budget Overhead**	**Total cost**
Survey	1,500	500	2,000
Planning	6,000	500	6,500
Foundation	4,000	1,000	5,000
Materials	8,000	1,500	9,500
Building	10,000	2,000	12,000
Plumbing and electrical	4,000	500	4,500
Cumulative			**39,500**

4.2 Procure, allocate and monitor site resource utilization according to the project scope

Procurement of construction materials and resources is vital to ensuring the success of the project. It involves the following important steps:

i. Particularization. This is the first step as it involves the coordination of the project manager and the purchasing department in order to buy the required materials and items required to complete the project.
ii. Choosing. This is where the client or the purchasing firm selects the potential suppliers of materials before and during the construction period.
iii. Contracting. The purchasing department coordinates with the suppliers on when and how the materials will be delivered to the site and they must lie within the budget of the project.
iv. Management control. How these materials will be utilized and controlled will determine the successful completion of the project. This will be done by the management team of the project.
v. Measurement. This is the last step of procurement as it represents the accountability of the team that ensured the accomplishment of the project. There are several measurement indicators in project management that have to be adhered to and their criteria met after the project has been handed over to the client.

Allocation of resources involves scheduling the available resources appropriately required to complete the project.

The following steps will ensure a good resource-allocation to ensure that the project is completed within the estimated duration and does not exceed the budgeted cost.

i. The project is divided into different steps
ii. The available resources are assigned
iii. The different aspects of the resources are actuated.
iv. Resources are resolved and allocated as required
v. Ways of resource utilization are utilized.

Table 61: Procure, allocate and monitor site resource utilization according to the project scope

Month	From	To
June	Survey	Planning
July	planning	Foundation
August	Foundation	Materials & Building
Sep	Building	Other Finishes

4.3 Control project cost variation as per SOPs

The cost variation of the project is the numerical difference between the value of the project earned and the actual cost of the project.

From the Sample Project budget

Value of the Project = 39,500

Actual cost of the Project $= 42{,}000$

Then, Cost variation $42{,}000 - 39{,}500 = \ 2{,}500$

4.4 Prepare project financial report

The Project Financial Statements Report provides an Income Statement, Cash Flow and a Balance Sheet for individual projects as they provide credibility and accountability on the expenditure breakdown of the project's allocated finances. This provides you with useful data for tracking financial information related to individual projects according. The diagram below is an illustration of project financial report

Program/Project Financial Report

Council on Library and Information Resources
Cataloging Hidden Special Collections and Archives Program
Financial Reporting Template

To be completed and signed by the financial officer responsible for project funds, then uploaded into the Hidden Collections Annual Report Form.

NOTE: Everything in this document must be explained within your narrative report in the section titled Financial Narrative. All numbers cited in the Financial Narrative must exactly match those in this document. All numbers in the Budget columns of the Expenditures table must match the numbers listed in your original application.

Organization: Lorem Ipsum University

Award period: 01/01/2013 -- 01/01/2015
Report period: 01/01/2014 -- 01/01/2015

This entire document refers to grant funds only. Cost sharing funds should not be included.

Income

Grant amount:	$329,000.00
Interest credited to date:	$620.00
Total Income:	$329,620.00

If no interest has been credited, send CLIR a letter explaining why interest is not being earned on the grant. You only need to submit this letter once. Interest earned should be included in the Expenditures table below.

Expenditures

	Current Period			Total Project		
Categories	Budget	Actual Expenses	Variance *(must be explained in the annual report form)*	Budget	Cumulative Expenditures	Balance
Salaries and Wages	$126,374	$119,784	$6,590	$272,000	$269,723	$2,277
Fringe Benefits	$23,894	$29,123	-$5,229	$50,000	$51,397	-$1,397
Consultant and Training Fees	$3,000	$3,000	$0	$4,000	$4,000	$0
Supplies and Materials	$1,620	$1,620	$0	$2,620	$2,500	$0
Services	$500	$500	$0	$500	$500	$0
Other Costs	$0	$0	$0	$0	$0	$0
Totals	$\boxed{\$155,388}$	$\boxed{\$154,027}$	$1,361	$\boxed{\$329,620}$	$\boxed{\$328,120}$	$1,500

Budget and actual expenses for current Report Period only. (In this case, 01/01/2014-01/01/2015)

Figure 193: Project financial report
Source: www.blackbaud.com

Conclusion

This learning outcome covered management of construction project cost, project budget, project cost variation and project financial report.

Further Reading

Read further on project financial report

22.3.5.3 Self-Assessment

Written Assessment

1. What is not part of the earned value calculations?
    a) Unknowns that are known
    b) Unknowns that are not known
    c) Amount of work completed
    d) Budget of the project
2. Which one of the following does not contribute to the success of a project
    a) Procurement
    b) Resource allocation
    c) Monitoring of the project
    d) Resource vandalism
3. In project management, speed and dependability objectives are generally called?
    a) Dependence
    b) Vision
    c) Time
    d) Range
3. Summarize the various steps in ensuring a good resource allocation
4. Explain how uncertainties in project management are minimized.

Essay questions

Discuss the various ways of managing project costs

Case Study Assessment

Visit a nearby construction facility within your school and prepare a project management financial report

Practical Assessment

From the visited construction facility within your school determine the tasks and the estimated costs of each stage of construction

22.3.5.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Relevant reference materials
- Stationeries
- GPS
- Design Software
- Computer lab
- Relevant practical materials
- Labouratories (chemical, biological & soils)
- Internet
- Manuals and guidelines
- Project management software
- Measuring and drawing tool
- Printer/plotting device
- Codes of practice

22.3.5.5 References

Mullen, A. (2010). Chron small business.

Imbeah, W., & Guikema, S. (2009). Managing construction projects using the advanced programmatic risk analysis and management model. Journal of Construction Engineering and Management, 135(8), 772-781.

Iyer, K. C., & Jha, K. N. (2005). Factors affecting cost performance: evidence from Indian construction projects. International journal of project management, 23(4), 283-295.

Hwang, B. G., & Ng, W. J. (2013). Project management knowledge and skills for green construction: Overcoming challenges. International journal of project management, 31(2), 272-284.

22.3.6 Learning No 5: Manage Project Labour

22.3.6.1 Learning Activities

Learning Outcome No 5: Manage Project Labour	
Learning Activities	**Special Instructions**
5.1 Develop project labour guidelines 5.2 Establish labour levelling plan 5.3 Allocate staff 5.4 Manage labour welfare 5.5 Prepare project labour report	• Group discussions • Demonstration by trainer • Online videos • Power point presentation • Exercises by trainee

22.3.6.2 Information Sheet No22/LO5: Manage Project Labour

Introduction to learning outcome

This learning outcome deals with management of project labour through the development of project labour guidelines, allocation of staff and management of labour welfare to ensure smooth implementation of work stages.

Definition of key terms

Project labour. This can be defined as the human resource that is employed in the project to implement the idea portrayed in the designs and drawings. They include technicians, masons, plumbers, electricians and drivers.

Content/Procedures/Methods/Illustrations

5.1 Develop project labour guidelines in line with Labour laws and FIDIC regulations

Labour guidelines are rules or guides that are developed to ensure the labourers work in harmony, and towards one goal. Labour guidelines are crucial in a project as they affect how the employees feel about their jobs. The labour laws and Fidic are statutory bodies that have set and defined rules and regulations to ensure that any guidelines developed in a project protect the workers' rights. According to the Fidic Redbook, the contractor is the one that organizes, houses, and compensates any human resource employed in a project.

Developing labour guidelines is easy. You have to set rules that will favor the progress of the project but, at the same time, withhold the rights of the human resource. The best way to develop these guidelines is to involve all the workers to make sure you capture what would lead to maximum productivity.

Remember that you should pay the right wages and observe the conditions of labour every time. The rates of labour that are to be paid should not be lower than the industry's average rates.

The contractor should also comply with all the labour laws applicable to his personnel, including those that relate to the employees' health, safety, and environment. Movement and welfare. The employees are also required to adhere to all set laws concerning the project.
Work should only be carried out on the recognized days of work unless stated otherwise in the agreement. The extra hours worked should be recognized and overtime and compensated.
There are many rights of employees that are to be considered by the managers when developing a project labour guideline. Consult the Fidic Redbook for more.

5.2 Establish labour levelling plan

A labour leveling plan can be defined as a plan according to which start and finishing dates are adjusted depending on labour limitation to create a balance between the demand of the labour and the available supply. Creating this plan calls for a proper understanding of progress monitoring. Since different people perform different tasks in a project, planning is key.
First, identify the number of activities that are supposed to be done in a specified time. Also, have in mind the amount of workforce you have. Also, identify how many people and how much time each task will need to complete. Once you have all that in mind, you can develop a histogram based on the earliest start time of any activity to balance the labour resource. This tends to spread the available workforce on the available tasks. It ends up rearranging the tasks according to the available labour which we call levelling.
The final result of this is a plan that will show all tasks assigned with an equal balance between available labour and demand for the same, arising from the tasks.

5.3 Allocate staff

This is quite easy. However, there is a lot to consider. For you to do this effectively, you need to have in mind. Have the tasks to be done, preferably have a list. Also, on the same list indicate the skills demanded by that task and the number of staff it would require to implement. On the other hand, have a list of the available workers and the skills possessed by each. What should follow next is matching the tasks and the appropriate employees. In the process, you should remember to consider the staff's availability of the interests of the task. Also, remember to observe the labour guidelines stated by the statutory bodies fully.

5.4 Manage labour welfare

Labour welfare means the services, benefits, and facilities that the employer avails to the human resource. They include accommodation and health services. They are provided to improve the productivity of the labourers. Therefore, labour welfare management entails the coordination of aspects carried out to ensure the comfort of the labour force is improved.
Managing the welfare of the employees is easy. All you need to do is have a clear understanding of their individual needs. Ensure that they have been provided with proper housing, proper medical services, and safety equipment at work.

The Fidic Redbook also dictates that the following should be done to the employees.
Supply of quality foodstuffs and clean water. Also, the management should work to ensure the cultural and religious beliefs of all employees are upheld.
Last but not least, the employer should not employ any forced or compulsory labour.

5.5 Prepare project labour report

A labour report is a detailed report prepared to show all the labour charges attached to the project. They include regular time, overtime, and also, the total number of work hours per employee. This report also captured the employee number, name, and the task performed.
To prepare this report, you need all the mentioned details. You can create a simple spreadsheet with a name column that corresponds to worked ours and total charges. Alternatively, you can use the vision planning software. This uses data from the project to generate a detailed report.

Conclusion

This learning outcome covered project labour management. . From this outcome, the students should be able to properly coordinate the human resource involved in a given project. Also, the student should be able to prepare a number of reports concerning the human resource.

Further Reading

Read further on labour resource management from the Fidic Redbook of 1999 and the labour laws of Kenya document. These two resources are available online for free.

22.3.6.3 Self-Assessment

Written Assessment

1. Which one of the following is not a document that safeguards the rights of employees?
   a) The Fidich Redbook
   b) The labour laws of Kenya
   c) Traffic regulations act
2. Which one of the following is a right of employees in accordance with the Fidic redbook.
   a) Right to food and clean water
   b) Right to practice religious and cultural beliefs
   c) Right to drugs and alcohol

3. Briefly explain how a labour report is prepared
4. Explain, in details, any five clauses of the Fidic redbook, that are concerned with labour management

Oral Assessment

Explain how inaccuracy of the labour report could affect project progress

Case Study Assessment

Visit a nearby construction site, and consult on their labour guidelines. List down the rights that the management has considered.

Oral Assessment

From your visit to the site, how would you advice the management to improve the welfare of the employees?

Practical Assessment

Prepare a detailed labour report for the day you visited the named site

22.3.6.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Relevant reference materials
- Stationeries
- GPS
- Design Software
- Computer lab
- Relevant practical materials
- Labouratories (chemical, biological & soils)
- Internet
- Manuals and guidelines
- Project management software
- Measuring and drawing tool
- Printer/plotting device
- Codes of practice

22.3.6.5 References

Angell, R. L., & Kraemer, J. R. (2017). U.S. Patent No. 9,734,464. Washington, DC: U.S. Patent and Trademark Office.

Dayarathna, Dushar. (2019). Employee Welfare Management.

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22.3.7 Learning No 6: Manage Project Contracts

22.3.7.1 Learning Activities

Learning Outcome No 6: Manage Project Contracts	
Learning Activities	**Special Instructions**
6.1 Manage project documentation 6.2 Engage project stakeholders 6.3 Inspect construction project works 6.4 Manage project information 6.5 Prepare project implementation report	• Group discussions • Demonstration by trainer • Online videos • Power point presentation • Exercises by trainee

22.3.7.2 Information Sheet No22/LO6: Manage Project Contracts

Introduction to learning outcome

This learning outcome deals with management of project contracts through various aspects such as management of project documents, information, reports and inspection of project works. By completing this outcome, the students should be able to manage a civil engineering project to completion.

Definition of key terms

Project implementation report: The project implementation report is a written document, usually prepared by a project manager, whose purpose is to capture the progress of a given project. This report seeks to guide the implementation of design ideas into reality.

Content/Procedures/Methods/Illustrations

6.1 Manage project documentation

Document management is very important for any project. Not just for its implementation but also for future reference for future projects. The success of a project also depends on how well the involved documentation is managed. Project document management is, therefore, defined as applying practices and procedures used to produce, store, and distribute various types of project documents. To manage project documents successfully, there are a few things that need to be done. Number one is that project documents should be treated with the utmost care and respect. A proper organizational structure for the document folders will be vital. Also, naming the documents using meaningful conventions will help keep the documents in order. There should also be a clear rule on how documents are shared. Access of documents should only be granted to necessary parties.

And once the time to return comes, there should be a clear protocol on how they are returned to prevent mix-ups. Lastly, you should ensure that the specified practices are adhered to in all aspects according to the capabilities and needs of the project.

6.2 Engage project stakeholders

Project stakeholders are the people who have a direct interest towards the ongoing project. In short, these are the members of the project management team. They include, but not limited to, project sponsors, users, managers, and engineers. These are mainly the people who have a direct investment in the project, and their input can directly affect the outcome of the same project. There is a need to come up with a stakeholder engagement plan. This is a plan that helps the manager identify strategies and engagements required to bring active involvement of the stakeholders in the execution of the project. To engage the stakeholders, the plan should advise you to identify them as early as possible. It is not possible to engage stakeholders that you don't know of. Before you even initiate the project, make sure you identify the stakeholders first.

Find a way of bringing the stakeholders together and get them talking. Invite them to important project meetings. This will also help to solve any conflicts that may arise in the future. It would be best if you always tried to understand others before being understood. This simply means that you should always have the other people's perspective first before considering your own. For this to work, you have to be a very great team player. To manage them, you need to be a keen listener. It would be best if you learned to listen before talking. Lastly, learn how to communicate courteously. The best way of doing this is by developing a good communication plan that involves all the stakeholders.

6.3 Inspect construction project works

Inspection of the works simply means monitoring and documenting the progress to ensure it aligns with the plan in terms of timely and quality completion. For a successful inspection, there are a few steps that need to be followed. Number one is to prepare fully for the inspection. Identify and write down the topics that need to be covered during the inspection. Also, identify the premises that you intend to inspect. It would be best if you remembered to inform the team on site of your intention to visit for inspection. Once preparation is done, you can now visit the site. On the site, the following should be done. One is to put on protective gear. This is to protect yourself from any risks. Carefully inspect the progress of the work and note every step-in detail. This data will help in report preparation. Besides monitoring the work, inspect and note down the following; the welfare of the workers, housekeeping issues, readiness for emergency procedures, employee relationships, wages and compensations, working hours, rest periods, and any other necessary issue related to the project. Upon completion, close the inspection, and most importantly, prepare a detailed progress report.

6.4 Manage project information

To successfully manage project information, you need to come up with a proper project information management plan. This is a document that outlines the responsibilities and actions involved in information management. The plan should capture the following.

- It should define which information is available to who and when
- It should define how the information on the project is collected
- It should define who has access to any information.
- Should define the responsibilities and qualifications of all the personnel involved in collecting information.

6.5 Prepare project implementation report (Daily, Monthly, Project progress report)

You should be able to complete project implementation reports.

Daily report. This report captures daily construction progress. At the end of the closure of the day's business, you should check on how much work was done and how much work remains. This report aims at informing the management of the deliverables and milestones. Remember to focus on the day's results other than activities. Make use of charts, graphs, tables, pictures, videos, and graphics. Use short sentences and instead use data points.

Monthly report

This captures the monthly progress report. The procedure for preparing this report is just like that of the daily report. However, the monthly report should also capture the combined daily progress.

Project progress report

Just as it sounds, this document explains how far you have gone towards implementing the project. Start by writing the heading of the progress report. This will capture the writer's name, the position of the recipient, and the report subject.

Write the introductory paragraph. This is a brief composition that explains the project. It talks about its purpose. Then proceed to the "works completed "part where a description of the works done is captured. Any findings should be mentioned.

In the next section, you should capture any problems encountered by the Implementing team. Prepare another section that highlights what your team intends to do moving forward. Finish with a summary of the report.

Conclusion

This learning outcome covered project contracts management. The student is now confident on the procedures and documents involved in monitoring progress of a civil engineering project.

Further Reading

Read further on project management from
http://www.uredjenazemlja.hr/UserDocsImages/dokumenti/oprojektu_dokumenti/Annual_Report_2012_v.1.0.pdf

22.3.7.3 Self-Assessment

Written Assessment

1. Which one of the following is not done during inspection?
    a) Inspect works progress
    b) Take pictures
    c) Write the report
2. Which one of the following is not captured in the progress reports?
    a) Structural Drawings
    b) Images
    c) Videos
    d) Tables
3. Which one of the following is not a possible stake holder in a project
    a) Politicians
    b) Engineers
    c) Investors

Oral Assessment

Explain the reason for your choices of stakeholders.

Case Study Assessment

Visit a nearby ongoing project, with permission from the necessary authorities, do an inspection and prepare a daily progress report.

Practical Assessment

Visit a nearby ongoing project, with permission from the necessary authorities, do an inspection and prepare a daily progress report.

22.3.7.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Relevant reference materials
- Stationeries
- GPS
- Design Software
- Computer lab
- Relevant practical materials
- Labouratories (chemical, biological & soils)
- Internet
- Manuals and guidelines
- Project management software
- Measuring and drawing tool
- Printer/plotting device
- Codes of practice

22.3.7.5 References

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22.3.8 Learning No 7: Manage Construction Materials, Plant, Tools and Equipment

22.3.8.1 Learning Activities

Learning Outcome No 7: Manage Construction Materials, Plant, Tools and Equipment	
Learning Activities	**Special Instructions**
7.1 Prepare site storage facility 7.2 Prepare **construction materials** (Roofing, Walling, Flooring, Finishing, and Reinforcing) schedule 7.3 Prepare **construction equipment** (Excavation, Lifting, and Transporting) schedule 7.4 Procure construction materials and equipment 7.5 Issue construction materials and equipment	• Group discussions • Demonstration by trainer • Online videos • Power point presentation • Exercises by trainee

22.3.8.2 Information Sheet No22/LO7: Manage Construction Materials, Plant, Tools and Equipment

Introduction to learning outcome

This learning outcome deals with management of construction materials through the preparation of site storage facilities, preparation of material schedules, equipment schedules, and the procurement of materials and inspection.

Definition of key terms

Construction materials: Also known as building materials, these are materials that are added to the constructed structure. Examples include concrete, sand, cement, steel, aggregates bricks etc.

Construction equipment: These are machinery, structures, materials, tools or systems designed for carrying out/executing construction works.

Content/Procedures/Methods/Illustrations

7.1 Prepare site storage facility

These are facilities for keeping civil construction equipment and even machines safely.
All engineering items are properly stored and managed under the stock management department. This will for instance determine the storage volume and subsequently the amount of space required. The store of these goods should be selected properly based on its accessibility, size and proximity among other factors. Inspection by the store keeper must be done upon supply and delivery of these goods.

They are also piled and properly managed for ease of removal whenever need arise.
Safety precautions through the use of precaution guidelines must be adhered to.
All civil engineering materials require proper handling, storage and usage for instance when carrying them manually to work sites, stacking bricks and building stones or driving trucks loaded with concrete. Given the number of hazards the employees face during storage such as falling objects, improperly stack objects among others, training and education is necessary.
Factors to consider on preparation of site storage facility include:

- physical properties,
- organization
- security
- costs
- control
- Protection.

7.2 Prepare construction materials (Roofing, Walling, Flooring, Finishing, and Reinforcing) schedule

Table 62: Construction materials

	Construction materials	Uses
Roofing	Timber Glass Iron sheets	Roofing. After the building is complete.
walling	Concrete Stone Brick Steel sheets Timber Clay blocks	Construction wall building
Flooring	Cement Brick Wood	Floor construction:
Finishing	Terrazo Tiles Rubber Wood Glass and cork stones	Construction work finishing
Reinforcing	Steel bars BRC mesh	Absorbs tensile and shear and stresses

7.3 Prepare construction equipment (Excavation, Lifting, and Transporting) schedule

Table 63: Construction equipment

	Construction Equipment	uses
Excavation	Excavators Graders Loaders Backhoe Bulldozers	Earth moving equipments. Excavating large volumes of mass.
Lifting	Equipment Crane Conveyors Hoists Forklifts	Material handling-lifting
Transporting	Tippers Dumpers Trailers Tankers	Transporting construction materials and equipments into and out of site. Also moving wastes out of site.

7.4 Procure construction materials and equipment

Procurement of construction materials is normally done through a logical order. One first plans what to contract then how to do it. You need to think of all the work that one will do so as to plan for any purchases and acquisitions. Procurement procedures are followed.

i. **Choosing of Suppliers to be invited to tender.**
   A client carefully chooses the list of suppliers to be invited to apply for the available tenders for example when procuring construction materials and equipment.
ii. **Request, appeal and tender submission**
   Tender request is delivered to potential suppliers and they carry the terms and conditions of the tender contract. They are then required to submit back the proposals.
iii. **Technical Evaluation.**
   Technical proposals is evaluated before the opening of the financial proposal so as to ensure that it conforms to the conditions and requirements that was set.
iv. **Process of negotiation and Awarding of contract:**
   Contract price is negotiated and other terms and conditions listed among tenderers.
v. **Delivery, Inspection and Payment.**
   Equipment are delivered as agreed in the contract. Inspection is done to ensure the entire delivered equipment meet the requirements.

7.5 Issue construction materials and equipment

Lee and Dobler define materials management as "a confederacy of traditional materials activities bound by a common idea-the idea of integrated management approach to planning, acquisition, conversion, flow and distribution of production materials.

Inspection

This can happen in two ways

- Pre-dispatch inspection
- Receipts from internal divisions.

The inspector inspects to inspect all the materials delivered to the site prior to being used in the work.

Conclusion

This learning outcome covered management of construction materials, plant, tools and equipment.

Further Reading

Read further on construction equipment as illustrated in Construction Equipment Management Book by Giovanni Ciro, October 1998.

22.3.8.3 Self-Assessment

Written Assessment

1 Which equipment is used to remove earth?
   a) Elevator
   b) Crane
   c) Excavator

2 The following are construction equipment, which among them is used to level the ground and spread loose material.
   a) Excavator
   b) Grader
   c) Tractor

3 Which of the following is not a flooring material?

a) Timber
b) Tiles
c) Concrete
d) Glass

4 Discuss the procedure for procuring construction materials and equipment
5 Distinguish the equipment and materials used to construct a slab.
6 Evaluate factors to consider for site storage facilities.

Essay question

Construction activities have an effect to the environment. With reference to road and building construction, discuss. (20mks)

Oral Assessment

Why is it important to study how construction activities affect the environment?

Case Study Assessment

Make a visit to the nearest facility being constructed in your area and prepare a report on how they manage their construction materials on a daily basis.

Practical Assessment

Make a visit to the nearest facility being constructed in your area and prepare a report on how they manage their construction materials on a daily basis indicating the financial allocation in each stage of construction.

22.3.2.4 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Relevant reference materials
- Stationeries
- GPS
- Design Software
- Computer lab
- Relevant practical materials
- Labouratories (chemical, biological & soils)
- Internet
- Manuals and guidelines
- Project management software
- Measuring and drawing tool
- Printer/plotting device
- Codes of practice

22.3.8.5 References

Said, H., & El-Rayes, K. (2011). Optimizing material procurement and storage on construction sites. Journal of Construction Engineering and Management, 137(6), 421-431.

Patel, K. V., & Vyas, C. M. (2011, May). Construction materials management on project sites. In National Conference on Recent Trends in Engineering & Technology (pp. 1-5).

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