STRUCTURAL PERFORMANCE OF MANGROVE REINFORCED CONCRETE BEAM AND COLUMN ELEMENTS

KALLENAMA AZÉ KERTÉ

MASTER OF SCIENCE IN CIVIL ENGINEERING

(STRUTURAL ENGINEERING OPTION)

PAN AFRICAN UNIVERSITY INSTITUTE FOR BASIC SCIENCES, TECHNOLOGY AND INNOVATION

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Kallenama Azé Kerté

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DECLARATION

This thesis is my original work and has not been submitted to any other University for examination.

Signature .... Date 05/11/2014

Kallenama Azé Kerté

This thesis has been submitted for examination with our approval as university supervisors.

1. Signature .... Date 05/11/2014

   Dr. Eng. Timothy Nyomboi

   PAUISTI/KURA

2. Signature .... Date 05/11/2014

   Eng. Prof. Walter Oyawa

   JKUAT

DEDICATION

This work is dedicated to my father, my mother, my brothers, my sisters and my friends …

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SYMBOLS

a: Span of Beam

A_c: Area of Concrete

A_g: Gross Area of the Cross Section

A_s: Area of Reinforcement

A_{sc}: Area of Reinforcement in Compression

b: Breadth or Width

d: Depth of Beam

E: Modulus of Elasticity

f_c: Compressive Strength of Concrete Cylinder

f_y: Yield Strength of the Reinforcement

Gsa: Apparent Specific Gravity

Gsb: Bulk Specific Gravity (Oven-Dry)

Gsb SSD: Bulk Specific Gavity (Saturated, Surface-Dry)

h: Depth of Column

K_a: Reduction Factor

L: Length

L_{ex}: Effective Height in Respect of the Major Axis

L_{ey}: Effective Height in Respect of the Minor Axis

M_{cr}: Moment at Crack

M_u: Moment at Ultimate Load

n: Number of Samples

P_{cr}: Load at Crack

P_{max}: Maximum Load

P_o: Maximum Load Provided by ACI318-05

P_u: Ultimate Load of Column

P_y: Load at Limit of Proportionality

R6: Mild Steel of 6 mm of Diameter

S: Slump Test

S_d: Design Strength

SD: Standard Deviation

S_k: Characteristic Strength

S_r: Raw Strength

t: t-value of the Statistic Table

u: Allowable Bond Stress

V_1: Volume

W_o: Oven-Dry Weight

W_1: Weight of Sample at Test

X: Strength

@: Shear Links Spacing

Δ': Deflection at Mid Length at Limit of Proportionality of Mangrove

δ_u: Deflection at Ultimate Load

δ_y: Deflection at Limit of Proportionality of Column

μ: Ductility

ρ: Reinforcement Ratio

σ: Allowable Tensile Stress

\$: Dollar

$\bar{X}$ **:** Strength Mean

% Abs.: Absorption in Percent

ABBREVIATIONS

ACI: American Concrete Institute

ASTM: American Society for Testing and Materials

BR4MPΦ30C30: Beam Reinforced with Four Mangrove Poles of 30 mm of Diameter of Concrete Class C30

BR4MPΦ25C30: Beam Reinforced with Four Mangrove Poles of 25 mm of Diameter of Concrete Class C30

BR4MPΦ20C30: Beam Reinforced with Four Mangrove Poles of 20 mm of Diameter of Concrete Class C30

BR4SBΦ10C30: Beam Reinforced with Four Steel Bars of 10 mm of Diameter of Concrete Class C30

BR4MPΦ30C25: Beam Reinforced with Four Mangrove Poles of 30 mm of Diameter of Concrete Class C25

BR4MPΦ25C25: Beam Reinforced with Four Mangrove Poles of 25 mm of Diameter of Concrete Class C25

BR4MPΦ20C25: Beam Reinforced with Four Mangrove Poles of 20 mm of Diameter of Concrete Class C25

BR4SBΦ10C25: Beam Reinforced with Four Steel Bars of 10 mm of Diameter of Concrete Class C25

BR4MPΦ30C20: Beam Reinforced with Four Mangrove Poles of 30 mm of Diameter of Concrete Class C20

BR4MPΦ25C20: Beam Reinforced with Four Mangrove Poles of 25 mm of Diameter of Concrete Class C20

BR4MPΦ20C20: Beam Reinforced with Four Mangrove Poles of 20 mm of Diameter of Concrete Class C20

BR4SBΦ10C20: Beam Reinforced with Four Steel Bars of 10 mm of Diameter of Concrete Class C20

BR2MPΦ30C20: Beam Reinforced with Two Mangrove Poles of 30 mm of Diameter of Concrete Class C20

BR2MPΦ25: Beam Reinforced with Two Mangrove Poles of 25 mm of Diameter of Concrete Class C20

BR2MPΦ20: Beam Reinforced with Two Mangrove Poles of 20 mm of Diameter of Concrete Class C20

BS: British Standard

CR4MP: Column Reinforced with Four Mangrove Poles

CRSCMP: Column Reinforced with Single Central Mangrove Pole

CR4MPΦ14C30: Column Reinforced with Four Mangrove Poles of 14 mm of Diameter of Concrete Class C30

CR4MPΦ11C30: Column Reinforced with Four Mangrove Poles of 11 mm of Diameter of Concrete Class C30

CR4MPΦ8C30: Column Reinforced with Four Mangrove Poles of 8 mm of Diameter of Concrete Class C30

CR4SBΦ8C30: Column Reinforced with Four Steel Bars of 8 mm of Diameter of Concrete Class C30

CR4MPΦ14C25: Column Reinforced with Four Mangrove Poles of 14 mm of Diameter of Concrete Class C25

CR4MPΦ11C25: Column Reinforced with Four Mangrove Poles of 11 mm of Diameter of Concrete Class C25

CR4MPΦ8C25: Column Reinforced with Four Mangrove Poles of 8 mm of Diameter of Concrete Class C25

CR4SBΦ8C25: Column Reinforced with Four Steel Bars of 8 mm of Diameter of Concrete Class C25

CR4MPΦ14C20: Column Reinforced with Four Mangrove Poles of 14 mm of Diameter of Concrete Class C20

CR4MPΦ11C20: Column Reinforced with Four Mangrove Poles of 11 mm of Diameter of Concrete Class C20

CR4MPΦ8C20: Column Reinforced with Four Mangrove Poles of 8 mm of Diameter of Concrete Class C20

CR4SBΦ8C20: Column Reinforced with Four Steel Bars of 8 mm of Diameter of Concrete Class C20

CRSCMPΦ24C20: Column Reinforced with Single Central Mangrove Pole of 24 mm of Diameter of Concrete Class C20

CRSCMPΦ20C20: Column Reinforced with Single Central Mangrove Pole of 20 mm of Diameter of Concrete Class C20

CRSCMPΦ16C20: Column Reinforced with Single Central Mangrove Poles of 16 mm of Diameter of Concrete Class C20

FAO: Food and Agriculture Organization

F.S: Fiber Stress

IDEAS: Iniciativa Para el Desarollo Ambiental Sustentable

IUCN: The World Conservation Union

L.P: Limit of Proportionality

M.L: Maximum Load

MOE: Modulus of Elasticity

MOR: Modulus of Rupture

NDS: National Design Specification

NSG: Nominal Specific Gravity

PCCC30: Plain Concrete Column of Concrete Class C30

PCCC25: Plain Concrete Column of Concrete Class C25

PCCC20: Plain Concrete Column of Concrete Class C20

PFL: Leadwire-Intergral Polyestyer Gauge

PFLW: Wood-Long Term Strain Gauge

PL: Polyester Wire Strain Gauge

PMC: Percentage – Moisture Content

OD: Oven-Dry

SGT: Specific Gravity at Test

UNEP: United Nations Environment Programme

US: United States

ABSTRACT

More often, steel is used as reinforcement in concrete because of its high tensile strength. Unfortunately steel is not produced in all parts of the world hence leading to a higher cost of steel that has to be imported from abroad, resulting in higher cost for housing. This study evaluates the potential to utilize mangrove as reinforcement in concrete structural members.

A total of three singly mangrove reinforced beams (beams reinforced with two mangrove poles) and nine doubly mangrove reinforced beams (beams reinforced with four mangroves) of 1100 mm length having 150 mm width and 250 mm depth reinforced variably were tested in flexure and compared with steel reinforced concrete control beams. Flexural test on mangrove reinforced beams demonstrated that using mangrove as reinforcement in concrete can increases the load carrying capacity of reinforced concrete beam having the same dimensions.

Besides, 18 small-scale short square columns having the same cross section of 87 x 87 mm and 350 mm in height with different types of reinforcement were tested under concentric loading to investigate strength capacity, deflection and failure patterns. The results showed that the load carrying capacity of the column increased with decrease in percentage of mangrove reinforcement for columns reinforced with four mangrove poles and the increase is not proportional to the percentage of reinforcement. It is also determined that mangrove poles have enhanced the ductility of columns compared to the plain concrete column.

CHAPTER 1

INTODUCTION

1.1 Background Information

Generally, concrete is a widely used construction material which has relatively high compressive strength and is used largely because it is economical, has good fire resistance and is a readily available material. It has low tensile strength hence requiring reinforcement. The modulus of elasticity of concrete is a very important parameter reflecting the ability of concrete to deform elastically (Misba et al., 2014). Since, concrete is weak in tension it is necessary to reinforce it with some other materials to strengthen it in tension. One of the more popular reinforcing bars (rebar) for concrete is steel. Steel has a relatively high tensile strength and is used to complement the low tensile strength of concrete. Although it is available and affordable in developed countries it is still considered an expensive construction material in most of the developing countries. In Nigeria and other developing countries, the cost of steel has limited the proportion of citizens who can afford their own house to about 30% (Musbau et al., 2012). There exists a need for more economical and readily available substitute reinforcements for concrete. Availability of construction material in a near vicinity and use of locally produced material saves a lot on construction cost and also in terms of energy (Pawar, 2012). Therefore in order to provide shelter to economically deprived persons of the society it is necessary to go either for alternative construction materials with conventional construction technique or to adopt conventional materials with alternative construction technique to reduce the cost of structure (Khan, 2014).

The increase in the cost and general shortage of reinforcing steel recently in many parts of the world particularly in Africa has led to increasing interest in the possible use of alternative locally available materials for the reinforcement of concrete such as mangrove poles, bamboo, etc. For example natural plant fibers reinforced polymeric composite materials have been used in many fields of our lives to save the environment (Zakikhani et al., 2014). This study therefore focuses on the technical capabilities of mangrove (Rhizophora) as reinforcement in concrete. Rhizophora is one of the dominant plants of mangrove communities throughout the world, with each genus having several closely related species (Ellison, 1993).

Africa abounds in important mangrove swamps in Kenya, Tanzania and Madagascar, with the latter even admixing at the coastal verge with dry deciduous forests (Diana, 2010). Nigeria is the Africa's country where one can find a large concentration of mangrove trees, spanning 36,000 km^2 (Kathiresan, 2002). Oil spills and leaks have destroyed many of them in the last fifty years, damaging the local fishing economy and water quality. Along the coast of the Red Sea, both on the Egyptian side and in the Gulf of Aqaba, mangroves consist primarily of Avicennia Marina and Rhizophora Mucronata grow in about twenty eight stands that cover about 525 hectares. Almost all Egyptian mangrove stands are now protected.

Mangrove forests in Kenya are found along the coastal strip in the tidal estuaries, creeks and the protected bays, between latitudes 1° 40’N and 4° 25’S and longitudes

41° 34’E and 39° 17’W. The largest mangrove forests in Kenya are mainly found in Lamu and the Tana River counties along the coastal strip. There are also less extensive mangroves forests found in Mida, Kilifi, Mombasa and Gazi-Funzi areas, which border Tanzania. Mangroves in Kenya may be divided into two main blocks; area north and south of River Tana. Mangroves forests found in the north of Tana River Delta are structurally more complex than those found in the south largely due to the influence of river Tana as well as due to the East African Coastal Currents (Maguriu et al., 2013).

In addition to providing a range of products that people need including building materials, firewood, tannins, fodder and herbal medicine, mangroves are of invaluable local and global ecologic, environmental and social importance. Mangroves serve as breeding grounds for many species of fish, molluscs, crustaceans and birds. Being at the edge of the sea, mangroves protect shoreline from coastal erosion. There are nine species of mangroves in Kenya among them is: Ceriopstagal, Rhizophora mucronata, and Aviccenia marina. Mangroves along the Kilifi creek are found in areas of Maya, Kibokoni, Mnarani and Kidundu (Diana, 2010).

Mangrove poles have been used in Kenya for composite structures (i.e. structures framed using mangrove poles in conjunction with other building materials such as coral, concrete, soil, etc). They have been used as reinforcement for structural elements such as beams and slabs for a long period since early of fifteenth century. Mangroves have been proven as high integrity materials for concrete reinforcement. In the olden and modern structures, mangrove poles have been used as reinforcements for floor slabs and beam elements consisting of coral rag prepared from lime mortar mixed with coral aggregate/hardcore and some soil (Manguriu et al, 2013).

The structural members studied in this project are beams and columns. Actually, beams and columns can be found in infinite variety of sizes, shapes and orientations. A beam is a structural member whose length is large compared to its cross sectional area which is loaded and supported in the direction transverse to its axis. Lateral loads acting on the beam cause the beam to bend or flex, thereby deforming the axis of the beam into a curved line. Reinforced concrete beam design consists primarily of producing member details which will adequately resist the ultimate bending moments, shear forces and torsional moments (Mehmet et al., 2012). At the same time serviceability requirements must be considered to ensure that the member will behave satisfactorily under working loads. It is difficult to separate these two criteria; hence the design procedure consists of a series of interrelated steps and checks (Khosrow, 2004). These steps are shown in detail in chart of BS 8110-3:1985, but may be condensed into three design stages: (1) preliminary analysis and member sizing; (2) detailed analysis and design of reinforcement; (3) serviceability calculation.

A column is defined as a member that carries loads in compression. Usually it carries bending moments as well, about one or both axes of the cross section. The bending action may produce tensile forces over a part of the cross section. Despite of the tensile forces or stresses that may be produced, column is generally referred to as compression member (Kenneth and Simon, 2000) because the compression forces or stresses dominate their behavior.

In some parts of the world mostly in Africa’s villages, people have constructed many buildings only with concrete or mud-bricks. This seems to be very dangerous in case where seismic activity occurs. These buildings will not be able to stand the activity of an earthquake (Satjapan, 2010). Steel reinforcement would be an ideal solution, but the high cost of steel causes a considerable problem. Scientists and engineers are constantly looking for new local materials or alternatives for structural systems instead of steel; the idea of using mangrove as possible reinforcement is getting popular.

1.2 Statement of Problem

Africa abounds in many local materials that can be used in construction of buildings and bridges. Many people in Africa use none or very little steel reinforcement in construction owing to the high cost of steel. Indeed there exists a need for more economical and readily available substitute reinforcements for concrete.

Despite the prolonged usage of mangrove poles in Civil Engineering for construction as reinforcement of floor slabs and beam elements, there seems to be limited documented work regarding engineering design data although the existing historical and modern structures testify to their structural integrity and environmental benefits (Maguriu et al., 2013). Most of the benefits of mangroves are not generally appreciated or are sometimes camouflaged by only economic issue. Policy makers have traditionally viewed mangroves as wastelands with little or no value (Mohammed, 2009). Due to the high price and unavailability of steel in some Africa’s countries such as Nigeria, Cameroon, Chad, etc., this project seeks alternative reinforcement for in the form of mangrove poles. The idea is to promote the use of mangroves, change the strategy of construction and materials, and classify them among the reinforcement materials of construction in Civil Engineering.

1.3 Research Questions

1. Is there any link between the mechanical properties of mangrove and steel?
2. How does beam reinforced with mangrove behave under flexural as compared to that reinforced with steel?
3. How does column reinforced with mangrove behave under compression and what is its strength as compared to the column reinforced with steel?

1.4 Objectives

1.4.1 General Objective

The general objective of this study is to determine the feasibility of using mangrove poles as alternative reinforcement for concrete beams and columns.

1.4.2 Specific Objectives

1. To determine the mechanical properties of mangrove and steel.
2. To compare the flexural properties of beams reinforced with mangrove and steel.
3. To compare the compressive behavior and strength of columns reinforced with mangrove and steel.

1.5 Justification

This study is undertaken to help people who live in places where local materials are readily available for their activities of construction. It comes to encourage people to make use of local materials when they are available. Researchers have proven that mangrove is strong enough than many woods and can be used as reinforcement in beams, columns and slabs. The objective is not to demonstrate that mangrove poles and steel bars have the same tensile strength which is not admissible because the tensile strength of steel is almost three times to that of mangrove according to the result obtained by Maguriu et al. (2013) in their study on mechanical properties of mangrove. The idea is to facilitate people who live in extreme poverty or do not have an opportunity to get steel bars for their construction to use what they can easily get to construct their simple modest buildings. This study contributes also to the generation of knowledge, policy makers and materials of construction.

1.6 Scope

This study investigates structural performance of mangrove embedded in a beam and column elements. The main response parameters are deflection of a beam, compressive strength of a column subjected to axial compressive loading and tensile strength of mangrove poles. The scope of this study is: (1) determination of some mechanical properties of mangrove poles and steel; (2) a number of 15 beams of 150 mm x 250 mm x 1100 mm will be cast and tested; (3) a total of 18 columns square of 87 mm x 87 mm x 350 mm will be cast and tested as well.

1.7 Limitations

Since there are a wide variety of types of mangroves and from different regions, the one that was chosen in this study is Rhizophora sourced from Mtwapa which is located in Kenya’s Kilifi County. Usually some pull out tests with treated and untreated mangrove poles embedded into concrete, beams and columns reinforced with treated mangrove poles tests were planned to be carried out. Due to time granted, financial means and lack of equipments, treated mangrove poles will not be used in this study and nor will pull out tests carried out.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter focuses on recent contributions related to the use of local materials more precisely this of mangrove in Civil Engineering and other areas if possible and past efforts most closely related to the needs of the present work. Mangrove pole has been used as a construction material in certain areas for centuries, but its application as reinforcement in concrete has received little attention until the present day. Lack of reliable technical information about the local materials makes the consumers use mainly industrialized materials for which the information is freely available (Khosrow, 2004). Mangrove poles have been used as reinforcement for structural elements such as walls (Figure 2.1 and 2.2), beams, slabs (Maguriu et al., 2013). As for steel bars, mangrove poles are to be used to provide tensile strength and probably some of the shear strength while concrete, strong in compression, protects the mangrove poles to give durability and fire resistance.

Figure 2.1: Mangrove Poles Used as Reinforcement for Walls Made with Adobe

Figure 2.2: Mangrove Poles Used as Reinforcement for Walls Made with Stones

2.1 Ecological Characteristics of Mangroves

A mangrove is a tree and bush species group that possesses adaptation abilities, and that colonizes flooded lands that are impacted by saltwater intrusions (IDEAS, 2007). Mangroves forests are plants in tropic and subtropic regions that can withstand highly saline water conditions. The first thing to think about the establishment of mangroves is the stabilization of mud-flats. When mangroves grow, the submerged banks are completely stabilized; after this, mangroves slowly come to the climax vegetation stage. Mangroves have very specialized adaptations that enable them to live in salt waters (Khan, et al., 2011). Probably there are no other groups of plants with such highly developed adaptations to extreme conditions (Kathiresan, 2002). Their leaves, roots, and reproductive methods have adapted to survive in a harsh, dynamic environment of soft, low-oxygen soils and changing salinity. Their special adaptations to resist and survive in salt water allow these plants to live in an environment only a few species of flowering plants can.

Almost all mangroves have two common reproductive strategies: dispersal by means of water and vivipary. The development and composition of mangrove communities depend largely on temperature, soil type, salinity, duration and frequency of inundation, accretion of silt, tidal and wave energy and such aperiodic factors as cyclone or flood frequencies (Lugo and Snedaker, 1974; Hutchings and Saenger, 1987). Extensive mangrove communities seem to correlate with those areas where the water temperature of the warmest month exceeds 24°C, and they are absent from those waters that never exceed 24°C throughout the year (Blasco et al., 1996). They exist under very hostile and inhospitable conditions (Khan et al., 2009). Many tests have been performed with mangrove seeds and it has been proven that they grow even quicker and taller in fresh water compared to salt water only if competition with other species is reduced. Prior to water uptake, a big quantity of the salt may be eliminated but a certain quantity of salt often enters the plants and could potentially provoke damage if not taken care of. Rhizophora species for example is able to carry salt ions to old leaves. It should be noted also that, mangroves developments vary substantially in their geomorphologic characteristic (Endah et al., 2012).

Briefly, there are three important abiotic characteristics in mangrove ecosystems: salinity, temperature, and oxygen. As for salinity, mangroves have adapted several different ways to prevent salt intake. Some expel salt through their leaves, and some have root systems that are too small for salt particles, but just big enough for water to pass through. Temperatures are referred to the temperatures of water which are usually tropical temperatures and are just right for the mangroves. Lastly, since there is a lack of oxygen where the mangroves are located, black mangroves have created a system of adaptation known as a pneumatophore, which is a root protrusion coming from the water or the soil. Since there is poor oxygen intake anywhere, these pneumatophores collect and store oxygen for times when the oxygen is needed.

2.2 Importance of Mangroves

Commercially, mangroves are very important and provide many benefits to the environment and are attractive to tourists because of the fauna that inhabit these forests. Probably no other distinct plant community has attracted as much curiosity and scientific attention for as long as have the mangrove forests of the tropical and subtropical tideland (Lugo, 1980). By assessing the importance of mangrove ecosystems from a scientific perspective, it can be said that the values of mangroves can be divided into ecological, community and economic. They represent an important source livelihood for many poor people across the world (Mohammed, 2009; IUCN, 2006), specially to people living near tropical and sub-tropical coasts as wood and food resources and for coastal protection and are also important from the global view point of the earth's natural environment (Yoshihiro et al., 2003). Mangroves support the natural food chain by forming a link between the land and the sea. They serve as the sanctuary for both aquatic and terrestrial wildlife (Baldevarona, 2001). One hectare trees of mangrove produces up to 3 tons of litter fall annually and one hectare of healthy mangrove ecosystem produces about 1.08 tons of fish per year (Schatz, 1991). Many researchers have established that mangrove forests reduce impact of Tsunami and cyclones. Strong typhoons and tsunamis have caused very serious damage to human beings and their properties in South Asian and South East Asian. However, where natural mangroves are well conserved or there are wide belts of planted mangroves, the damage was substantially reduced (Yoshihiro et al., 2003). Usually, mangrove trees grow ubiquitously as a relatively narrow fringe between land and sea (Ivan et al., 2001), and support a wealth of life, from starfish to people, and are probably more important to the health of the planet than we ever imagined such as substrate for primary producers, prevention of coastal erosion, and they act as buffers against storms, cycle nutrients and filter heavy metal and excess organic materials (UNEP, 2006).

A lot of harvestable benefits are obtained from mangrove forests, namely: wood for fire (Figure 2.3), construction (Figure 2.1, 2.2, 2.4 and 2.5) and furniture (Figure 2.6), a source for charcoal, tannin, paper, thatch, honey and incense, dyes and chemicals (Kathiresan, 2002). Mangrove plants provide food for livestock and are used for traditional medicine. Some researchers have found that some diseases such as skin disorders and sores, including leprosy may be treated with ashes or bark infusions of certain species of mangrove. In the Philippines, it is estimated that the value of a complete mangrove ecosystem ranges from US$500 to US$1,550 per hectare per year (Dixon, 1989). Mangroves are seen as one of the nursery areas of the sea, where young fish is able to get food from them and shelter there from predators. By trapping of nutrients and sediments from drainage, they protect coral reefs, sea grass meadows and coastal waters in general. They preserve water quality and reduce pollution by filtering suspended material and assimilating dissolved nutrients. Despite their obvious economic value, mangroves have often been considered as wastelands and converted to other forms of land use (Vannucci, 1989). Briefly, the benefits of mangroves can be summarized as fellow: stabilize shorelines, building up land, flood protection, recycle nutrients, protect the coral reef, act as a natural sewage treatment plant, provide home and shelter for fish, serves as a home for many animals.

Figure 2.3: Mangrove Used as Firewood in Mtwapa

Figure 2.4: Shed Made with Mangrove Poles in Malindi

Figure 2.5: Fences Made with Mangrove Poles in Malindi

Figure 2.6: Beds Made with Mangrove Woods in Malindi

2.3 Family and Species of Mangroves

Mangrove forests are composed of one or more of the species indicated in Tables 2.1 and 2.2 of plants called mangroves and include approximately twenty families. The tables give the number of species of mangroves in each listed plant genus and family. Mangrove species can be categorized into true mangroves and mangrove associates (Selvam, 2007). True mangroves are exclusive species, which are the largest group, comprising around sixty species, adapted to the mangrove habitat, and do not extend into other terrestrial plant communities (Saenger et al., 1983; Shigeyuki et al., 2013). Plants that occur in the coastal environment and also within mangroves are considered as mangrove associates or non-exclusive species (Shigeyuki et al., 2013). This group of plants is not restricted to the typical mangrove environment and is often found within drier, more terrestrial areas.

Table 2.1: Major Components of Mangroves

Nº	Family	Genus	Number of Species	Common Name
1	Acanthaceae, Avicenniaceae or Verbenaceae (family allocation disputed)	Avicennia	9	Black Mangrove
2	Combretaceae	Conocarpus; Laguncularia; Lumnitzera	1; 11; 2	Button Wood, White Mangrove
3	Arecaceae	Nypa	1	Mangrove Palm
4	Rhizophoraceae	Bruguiera; Ceriops; Kandelia; Rhizophora	6; 2; 1; 8	Red Mangrove
5	Lythraceae	Sonneratia	5	Mangrove Apple

The term mangrove is more applied to four species of trees. They are red mangrove, black mangrove, white mangrove, and buttonwood. Each species of mangrove can tolerate specific environment conditions which the others cannot. These four species of mangrove are classified as fellow:

1. The tallest of all local species is the red mangrove. It can grow up to 80 feet tall (25 m). It has large broad leaves and terminates with a blunt point. The leaves are waxy, dark green above and pale green below. The trunk and limbs have grey bark that covers a dark red wood. The key characteristics of the Red mangrove are the prop roots derived from the trunk and from the branches.
2. Black mangrove is the second tallest species grows up to over 65 feet (20 m) height. The elliptical, green leaves can reach lengths of 4 inches (10 cm) and are always encrusted with salt. The bark is dark and scaly. The key characteristics of

the black mangroves are the aerial roots known as pneumatophores born from underground horizontal cable roots.

3. The smallest species is the white mangrove existing as a tree or shrub with maximum heights of 50 feet (l5 m). Broad is the leaf shape, flat oval rounded at both ends. Leaf lengths approach three inches (7 cm). When growing in oxygen deprived sediment the white mangrove all the times develop peg roots which are similar to pneumatophores except they are shorter and stouter physically.
4. The Buttonwood is known as an associate of the community, but is more frequently found in the upland transitional zone. Rough bark exists on older trees which are always covered with epiphytes (plants which live on other plants). Rather than producing seedlings that germinate on the parent tree, button woods flower with the formation of a button-like seed case.

Table 2.2: Minor Components of Mangroves

Nº	Family	Genus	Number of species
1	Acanthaceae	Acanthus; Bravaisia	1; 2
2	Bombacaceae	Camptostemon	2
3	Cyperaceae	Fimbristylis	1
4	Euphorbiaceae	Excoecaria	2
5	Lecythidaceae	Barringtonia	6
6	Lythraceae	Pemphis	6
7	Meliaceae	Xylocarpus	2
8	Myrsinaceae	Aegiceras	2
9	Myrtaceae	Osbomia	2
10	Pellicieraceae	Pelliciera	1
11	Plumbaginacea	Aegialitis	2
12	Pteridaceae	Acrostichum	3
13	Rubiaceae	Scyphiphora	1
14	Sterculiaceae	Heritieria	3

Different mangrove species have different wood and bark properties, making some more suitable than others for specific uses (FAO, 1994). Plants of the mangrove community belong to many different genera and families, most of which are not closely related to one another phylogenetically (Blasco et al., 1996). What they do have in common is a variety of morphological, physiological and reproductive adaptations that enable them to grow in a particular kind of rather unstable, harsh and salty environment (Saenger, 1982; Tomlinson, 1986). At the generic level, Avicennia and Rhizophora are the dominant plants of mangrove communities throughout the world, with each genus having several closely related species in both the east and the west (Macnae, 1968; Tomlinson, 1986; Ellison, 1993). At the species level, however, only a few species occur in both hemispheres (Blasco etal., 1996).

2.4 Physical and Mechanical Properties of Mangrove and Steel

2.4.1 Mangrove

To evaluate the physical properties of the mangrove, Manguriu et al. (2013) have determined the moisture content of every sample considered and measured before the tests have been performed by weighing the specimens before and after putting them in an oven. They have used BS 373-1957 to carry out the tests on mechanical properties of the mangrove. The diameter chosen of mangrove poles ranged between 120 and 140 mm. The choice of this range of diameters was to ensure that clear samples for the various tests are obtainable from the poles. The poles were converted into rectangular pieces of timber as the test samples.

From the experimental results and the analysis of the materials used by Manguriu et al. (2013), it is concluded that the results found from their study confirm the structural viability of using mangrove poles as reinforcement for light weight concrete beams. Afterward, they have performed torsion tests of beams reinforced with mangrove poles. In this study, after determining the mechanical properties of mangrove poles, flexural tests of beams reinforced with mangrove poles and compression tests of columns reinforced with mangrove poles will be performed and compared to those reinforced with steel bars. Manguriu et al. (2013) have concluded that: the basic physical and mechanical (strength) characteristics of mangrove poles present suitable levels for use as reinforcement in concrete beams. The compressive strength is determined as 79.96 N/mm^2, the bending tensile strength as 100.62 N/mm^2, and tensile strength as 158.91 /mm^2, the shear strength as tangential 23.01 N/mm^2 and radial 18.04 N/mm^2. The strength values are much higher than that of ordinary structural timber. Mangrove is an eco-friendly material which has a high strength to weight ratio which can be used to replace steel as reinforcement and help reduce the carbon emission problem associated with the production of steel.

2.4.2 Steel

Steel is arguably the world's most advanced material. It is a very versatile material with a wide range of attractive properties which can be produced at a very competitive production cost (Enda, 2004). The properties of structural steel result from both its chemical composition and its method of manufacture , including processing during fabrication. Although the behavior of steel is greatly affected by its chemical composition, heat treatment and the method of manufacturing, there are some physical properties that determine the behavior of reinforcement for concrete such as yield strength, ultimate strength, Young’s modulus of elasticity, Poisson’s ratio and percentage elongation (Charles, 2002). Product standards define the limits for composition, quality and performance and these limits are used or presumed by structural designers. The major constituent of steel is iron; the addition of very small quantities of other elements can have a marked effect upon the properties of the steel. The strength of steel can be increased by the addition of alloys such as manganese, niobium and vanadium. However, these alloy additions can also adversely affect other properties, such as ductility , toughness and weldability (Owens, 1992).

The use of high tensile steel can reduce the volume of steel needed but the steel needs to be tough at operating temperatures, and it should also exhibit sufficient ductility to withstand any ductile crack propagation. Therefore, higher strength steels require improved toughness and ductility, which can be achieved only with low carbon clean steels and by maximizing grain refinement. The influence of high strength steel on cracking and deflection of structural concrete members led to a series of studies in the past into the service behavior of such steel (Base et al., 1966). Yield strength is the most common property that the designer will need as it is the basis used for most of the rules given in design codes. The product standards also specify the permitted range of values for the ultimate tensile strength (UTS).

Other mechanical properties of structural steel that are important to the designer include:

1. Modulus of elasticity, $E = 210{,}000\ N/mm^2$
2. Shear modulus, $G = E/[2(1 + \nu)]\ N/mm^2$, often taken as $81{,}000\ N/mm^2$

3. Poisson's ratio, $v = 0.3$
4. Coefficient of thermal expansion, $\alpha = 12 \times 10^{-6}/°C$ (in the ambient temperature range).

2.5 Flexural of Concrete Beam

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending (Richard and Norm, 1991). The flexural strength is expressed as modulus of rupture (MR) in MPa and is determined by standard test methods. When a beam is subjected to a pure bending moment, originally plane transverse sections before the load was applied, remain plane after the member is loaded. Even in the presence of shear, the modification of stress distribution in most practical cases is very small so that the Engineer's Theory of Bending is sufficiently accurate. Research on the use of high strength steel as reinforcement for reinforced concrete members has been ongoing for some time. The flexural behavior of concrete beams reinforced with high-strength reinforcing bars has been investigated experimentally by a number of researchers (Yotakhong, 2003). In the design of reinforced concrete flexural members, to apply the higher resistance factor φ of 0.9, a member should exhibit desirable behavior. At service load, small deflections and minimal cracking are desired. At higher loads, however, the member should exhibit large deflections and/or excessive cracking to provide warning before reaching nominal strength. Both deflection and cracking are primarily a function of steel strain near the tension face of the member (Robert et al., 2009).

2.6 Compression of Concrete Column

Columns are defined as members that carry loads in compression. Usually they carry bending moment as well, about one or both axes of the cross section. The bending action may produce tensile forces over a part of the cross section (Kenneth and Simon, 2000). Despite of tensile forces or stresses that may produce, columns are generally referred to as: compression members because the compression forces or stresses dominate behavior (Ibrahim, 2002). In addition to the most common type of compression members (vertical elements in structures), compression members include: arch ribs; rigid frame members inclined or otherwise; compression elements in trusses; shells. More recently, compressive strengths approaching 138 MPa have been used in cast-in-place buildings. Concrete compressive strength higher than 65 MPa is referred to as high-strength concrete in this study (Hany, 2014).

The strength of a column and the manner in which it fails are greatly dependent on its effective length. A very short stocky steel column may be loaded until it reaches its yield point, and perhaps the strain hardening range. In essence it can support about the same load in compression that it can in tension (Ibrahim, 2002). The effects of high compressive stress in columns have to be considered especially under seismic loading (Xiaozhen et al., 1988).

2.7 Reinforced Concrete Structures

Performance-based design needs a reliable system for predicting structural responses and examining the safety, serviceability, and durability of structures. Significant progress in mechanical and durability performance of concrete has been worked out through a combination of new chemical admixtures and mineral addition during the last decade (Mehmet et al., 2012). Reinforced concrete is also known as a composite material but many people refer composite structures in engineering construction as a member comprising either of a concrete encased hot-rolled steel section or a concrete filled tubular section of hot-rolled steel.

One of the most important properties of concrete that must be specified by the structural designer with respect to structural design is the compressive strength. Generally, the specified compressive strength of the concrete ranges from 3,000 to 10,000 psi (pounds per square inch), this of yield strength of the reinforcing steel is normally 60,000 psi (pounds per square inch) and the one of timber varies from one type to another type of timber and according to the region. Beams as composite elements with wood and steel received attention beginning more than 30 years ago (Kenneth and Simon, 2000). Composite action of any reinforced concrete member is only possible if sufficient bond strength exists between them. Bond behavior of reinforcing bars to concrete is one of the most important mechanisms that should be properly designed to ensure satisfactory performance of reinforced concrete structures (Raafat et al., 2006). Bond strength is a function of compressive strength of concrete and hence high strength concrete has higher bond strength (Ahmedet al., 2007). The load transfer is considered to as bond and is idealized as a continuous stress field that develops in the proximity of the reinforcement in regions in the concrete where tension is expected. The main factors which affect the bond between the reinforcing bar and concrete are: adhesive properties of the cement matrix, the compression friction forces appearing on the surface of the reinforcing bar due to shrinkage of the concrete and the shear resistance of concrete due to surface form and roughness of the reinforcing bar (Khosrow, 2004).

The major structural design concept of reinforced concrete is the placement of steel or timber or any kind of reinforcement before the placement of concrete. Concrete is relatively strong in compression, it is weak in tension. Its tensile cracking strength is very low (approximately 10% of its compressive strength) comparing of its compressive strength. To overcome this problem, steel or timber reinforcement is used to resist tension; if not, the structure will crack excessively and may fail. Ideally, the fact that one combine reinforcement and concrete results of a strategic of composite material that has high strength and retains the versatility and economic advantages of concrete.

The design objectives of the structural engineer for any reinforced concrete structure mainly consist of the following:

1. To set up a workable and economical structural system. That's the selection of the appropriate structural types and laying out the locations and arrangement of structural elements such as columns and beams. Therefore, designs that replicate member sizes and simplify reinforcement placement to result in easier and faster construction will usually result in being more economical than a design that achieves minimum material quantities.
2. To choose structural dimensions such as depth and width, of individual members, and the concrete cover.

3. To identify and determine the required reinforcement, both longitudinal and transverse. A structure must always be designed to serve its intended function as specified by the project requirements.
4. To provide the reinforcement with all possible details such as development lengths, hooks, and bends.
5. To satisfy serviceability requirements such as deflections and crack widths. Structural systems and member must be designed with sufficient margin of safety against failure. Safety in structural design is typically addressed by considering uncertainties in both the structure and the expected loads and introducing safety factors in the design process (Wei-Jian et al., 2008). For ductility design, it is important to precisely evaluate ductility capacity of beams and columns as well as their strength (Hideyuki and Setsuro, 2004).

Many of the mangrove studies were based on ecological characteristics of mangrove. However, Manguriu et al (2013) in their study have determined the mechanical properties of mangrove and the properties of concrete beam reinforced with mangrove subjected to torsion. So the current study will be focused on the performance of mangrove poles used as reinforcement for beams subjected to flexural and columns to compression.

CHAPTER 3

MATERIALS AND METHODS

3.0 Introduction

This chapter covers information on the determination of properties of aggregates, properties of mangrove poles, tensile test of steel bars used for the beams specimens. Compressive test of mangrove reinforced concrete columns and three-point bending load test of mangrove reinforced concrete beams were performed. Tensile test of mangrove poles involve specimen preparation, test set-up and instrumentation. Beam and column testing include beam and column design, concrete mix design, mangrove poles or reinforcement preparation, formwork preparation, concrete casting, and the conduction of tests. The beam and column tests with mangrove poles as reinforcements were compared with the beams reinforced with steel bars and plain concrete columns. The beams, columns tests setup and instrumentation are explained in detail. At the end, the loading history and testing procedure are presented.

3.1 Determining the Mechanical Properties of Mangrove Poles and Steel

3.1.1 Study Site

All the tests of the project were performed in two different laboratories that is Jomo Kenyatta University of Agriculture and Technology (JKUAT) Civil Engineering Structural Laboratory for the beams and columns tests and the determination of sand

and coarse aggregate properties; Kenya Forestry Research Institute Forest Products Laboratory (KEFRI) for mangrove poles tests.

3.1.2 Aggregates

The selection and specification of coarse aggregate in this study was made in accordance with BS 882. Crushed stone with triangular shape was used as coarse aggregates in beams and columns samples. The maximum size of aggregate used for the beams and columns were 20 and 10 mm, respectively. The coarse aggregate was supplied from one of the local quarries of Kenya. The specific gravity and absorption test of coarse aggregate were performed according to ASTM C127; those for fine aggregate according to ASTM C128.The test method for sieve analysis of fine aggregate was performed according to ASTM C33.

3.1.3 Mangrove

The species of mangrove poles were sourced and purchased from Mwtapa along the Kenya coast. Harvested mangrove poles with age range between 15 to 25 years were selected. The mangrove poles selected were those already dried and their application did not require further moisture reduction processed. The tests on mechanical properties of mangrove poles were performed at Kenya Forestry Research Institute Forest Products Laboratory (KEFRI) as mentioned above. The tests carried were as referred to in BS 373-1957 and the machine used was the Universal Strength Testing Machine (Figure 3.1). For each test, a number of approximately 18 samples were considered and different accessories were fitted on the machine. For all the tests, samples were labeled appropriately, dimensions and weights taken before testing commenced and the room temperature and humidity were recorded as well. All different tests on mangrove were performed in one day, the average room temperature recorded was 22 ^{o}C and this of relative humidity was 80%. The mechanical properties of mangrove poles determined are: compression parallel to grain, shear parallel to grain, static bending – centre point loading, janka hardness.

Figure 3.1: Universal Strength Testing Machine for Mechanical Timber Test

a) Compression Parallel to Grain Test of Mangrove

Twenty specimens measuring 20 mm x 20 mm x 60 mm were used in test. They were prepared to have end faces truly parallel to each other and at right angles to the long axis (Figure 3.2). Compression platen was fitted to the under side of the moving cross-head of the machine and test specimens held in compression cage assembled on the machine table as shown in Figure 3.3.

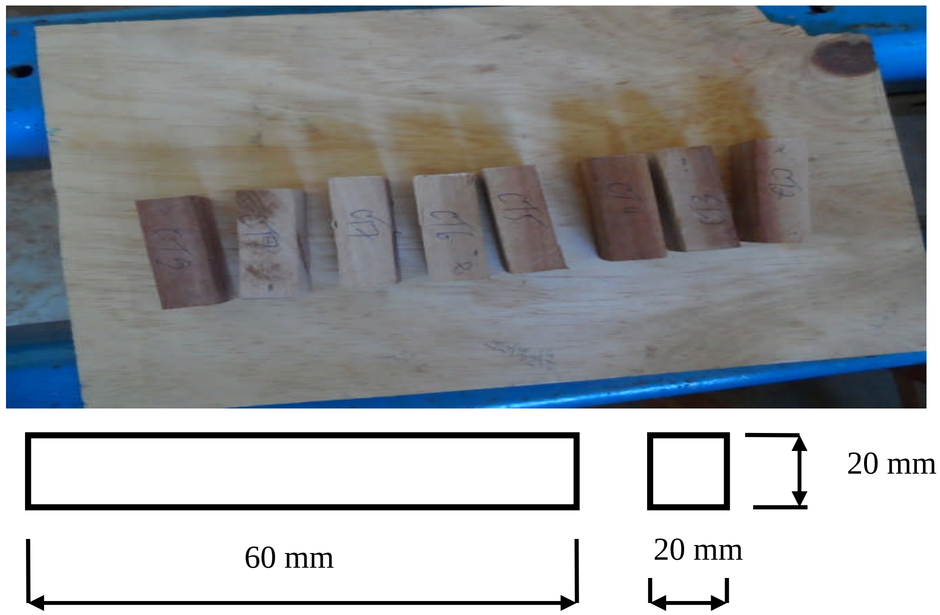


Figure 3.2: Test Pieces for Compression

The load was applied continuously throughout the test at a rate of 0.6 mm per minute cross-head motion. At the point of maximum load and failure, the pointer retreated to the zero position. When test was completed, the maximum load of each specimen was recorded.

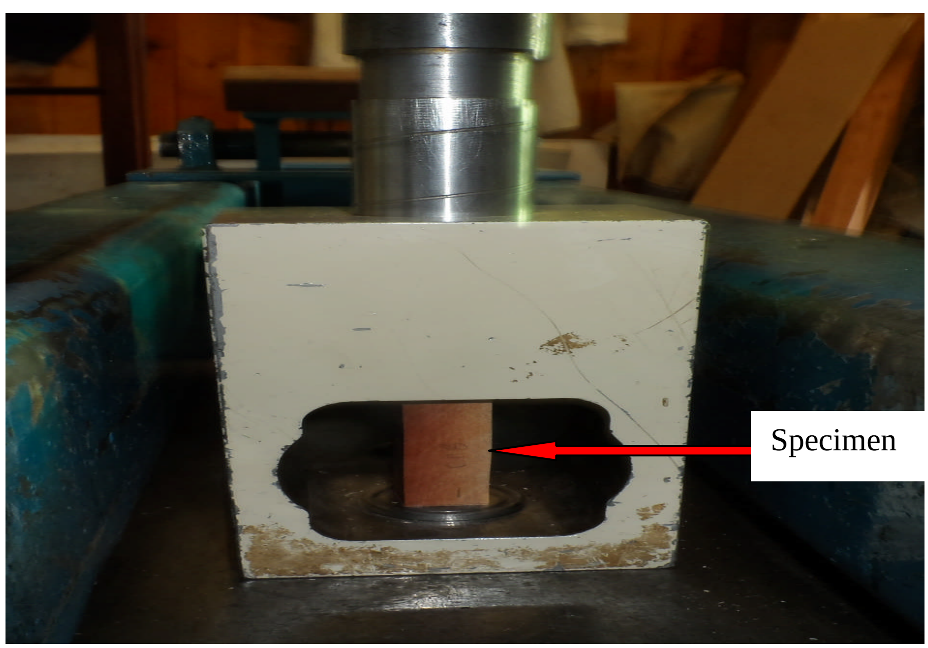


Figure 3.3: Compression Parallel to Grain Test

b) Shear Parallel to Grain Test of Mangrove

Test specimens were 20 mm cube of dimensions (Figure 3.4). Twenty four samples were considered for this test, twelve were sheared radially and the rest tangentially. Compression platen was attached to the underside of the moving cross-head of machine and the shear tool fitted on the machine table as shown in Figure 3.5. The load was applied continuously throughout the test at cross-head motion rate of 0.6 mm per minute. At the end of testing, the maximum load of each specimen was recorded.

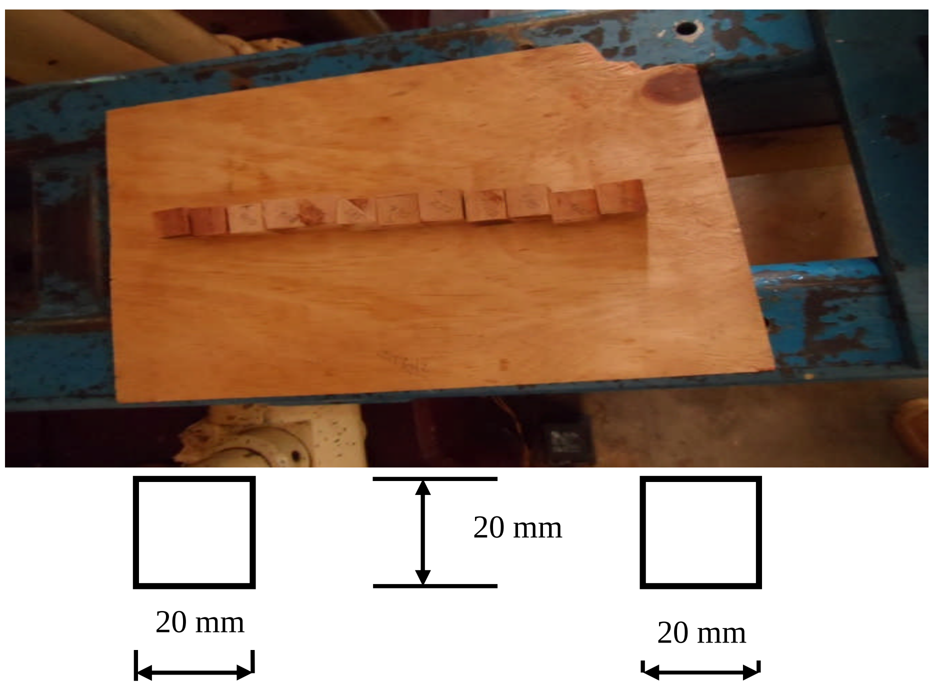


Figure 3.4: Test Pieces for Shear Parallel to Grain

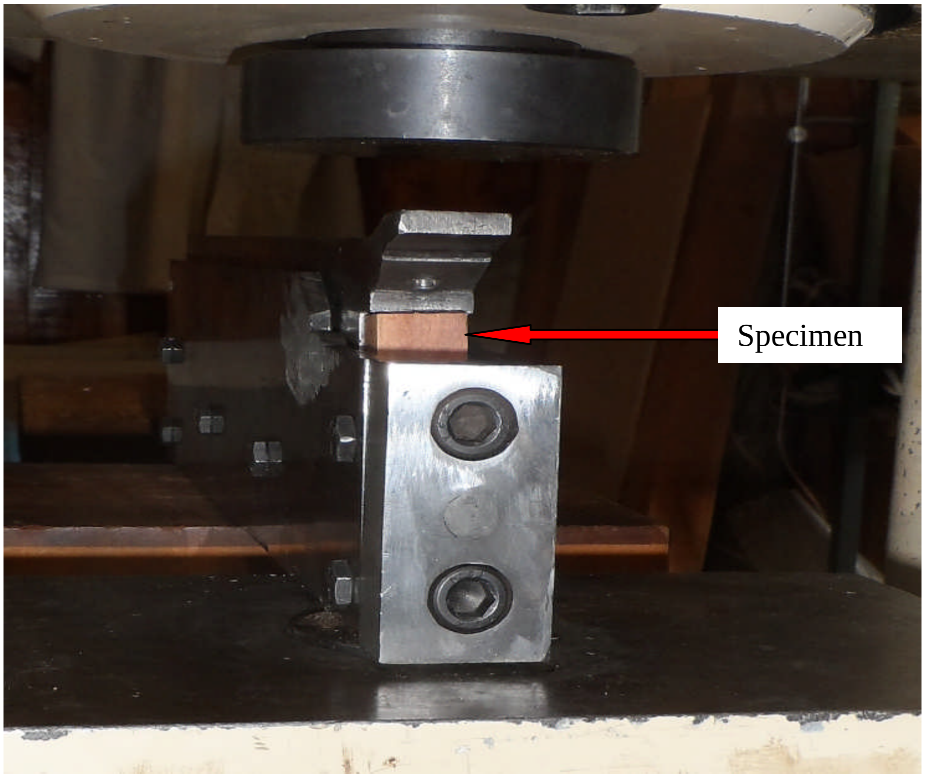


Figure 3.5: Shear Parallel to Grain Test

c) Static Bending – Centre Point Loading of Mangrove

Twenty specimens measuring 20 mm x 20 mm x 300 mm were considered. After dimensions and weights were taken, three small nails were driven perpendicular to one tangential face in the neutral plane at the centre and 140 mm from the centre (Figure 3.6). The bending knee was attached to the underside of the moving cross-head and trunnion supports fitted on the machine table. The cross-head was lowered sufficiently to near touching the specimens, the deflection yoke supported on the end nails and adjusted to measure deflection of the centre point of the neutral axis (Figure 3.7).

Figure 3.6: Samples Prepared for Bending Test

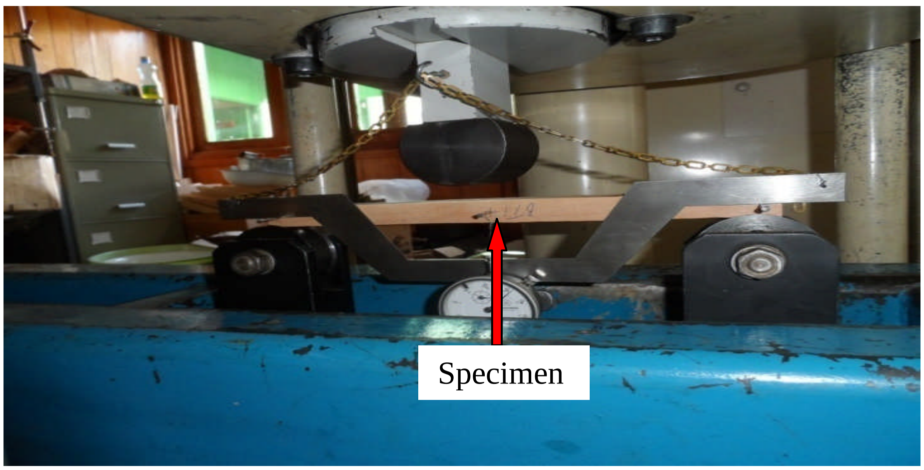


Figure 3.7: Static Bending – Centre Point Loading Test

Since the machine was not fitted with plotting accessories, to facilitate load-deflection curve tracing, the load was read at predetermined deflection intervals. The load was applied continuously at cross-head motion rate of 1 mm per minute. This was maintained till the specimens failed and then the maximum load was recorded. The following equations give:

Fiber stress at limit of proportionality (F.S. at L.P.):

$$3P_yL / (2bh^2) \quad (3.1)$$

Equivalent fiber stress at maximum load (F.S. at M.L.) or modulus of rupture (MOR):

$$3P_{max}L / (2bh^2) \quad (3.2)$$

Modulus of elasticity (MOE):

$P_y L^3 / (4\Delta' bh^3)$ (3.3)

P_{max} is the maximum load in Newton; P_y the load in Newton at limit of proportionality; Δ' the deflection in millimeter at mid length at limit of proportionality; b the breadth in millimeter; h the depth in millimeter.

d) Janka Hardness of Mangrove

Eighteen specimens of 20 mm x 20 mm x 100 mm were used for the test (Figure 3.8). The janka indentation tool was fitted to the underside of the moving cross-head of the machine and specimen holder placed on the machine table. Specimens are pressed firmly between two blocks of timber making a composite block. The two timber blocks were preferably of the same species as test specimen. The load was continuously applied at cross-head motion rate of 6.4 mm per minute and removed immediately the bell sounds. Two indentations were made, one on the radial face and the other on the tangential face. The specimens were placed in holder such that the indentation was 20 mm end and not closer than 30 mm to the other indentation (Figure 3.9). The maximum load for each indentation is recorded.

Figure 3.8: Test Pieces for Janka Hardness

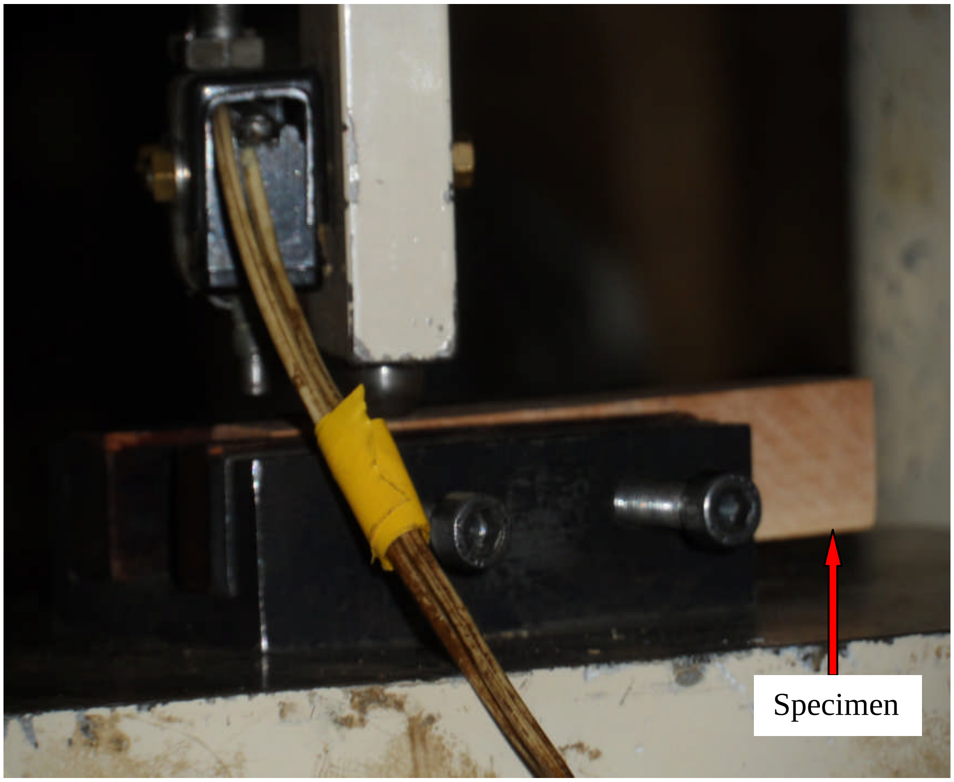


Figure 3.9: Janka Hardness Test

e) Tensile Test of Mangrove

The resistance to tension of mangrove was determined parallel to the grain. The form and dimensions of the test piece used for determining the tension parallel to grain strength were as illustrated in Figure 3.10. The test piece was so orientated that the direction of the annual rings at the cuboidal section was perpendicular to the greater cross-sectional dimensions. The actual dimensions at the minimum cross-section were measured. The load was applied to the 2 cm face of the ends of the test piece by special toothed plate grips which were forced into the wood before the test piece commenced as shown in Figure 3.11. These grips were designed so as to give axial load. The load was applied to the test piece at a constant head speed of 0.05 in./min.

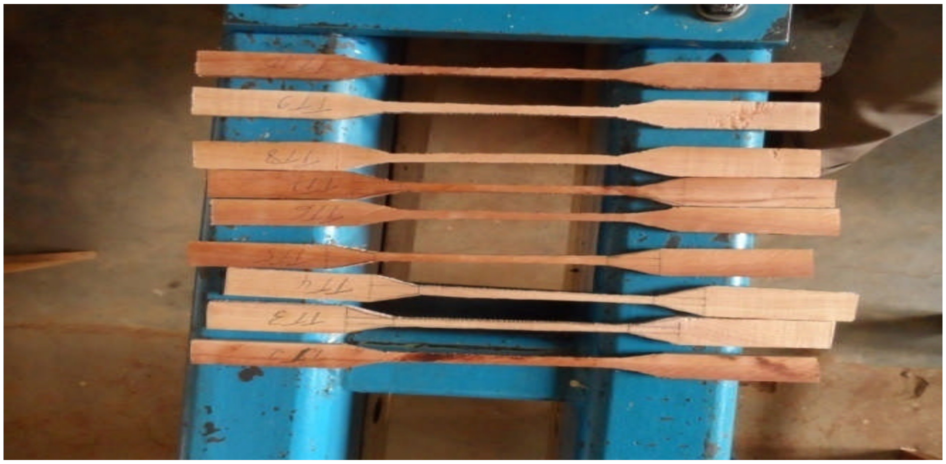


Figure 3.10: Test Pieces for Tension Parallel to Grain Test

Figure 3.11: Tension Parallel to Grain Test

f) Moisture Content and Specific Gravity of Mangrove

Immediately after each mechanical test was conducted, a small sample for determination of moisture content was taken from each test piece except these of bending and tensile. The sample consisted of a transverse section from near the point of fracture. The sample was weighed (Figure 3.12) and then dried in an oven at a temperature of 103 ± 2 °C (217 ± 4 °F) until the weight was constant. The loss in weight expressed as a percentage of the final oven-dry weight was taken as the moisture content of the test piece.

Figure 3.12: Weight of Samples to Determine the Moisture Content

The parameters calculated are:

1. The percentage – moisture content:

$$PMC = ((W_1 - W_o) \div W_o) \times 100 \quad (3.4)$$

2. The specific gravity at test:

$$SGT = W_1 \div V_1 \quad (3.5)$$

3. Nominal specific gravity, oven-dry:

$$NSG, OD = W_o \div V_1 \quad (3.6)$$

Where W_1 is the weight of sample at test in gram; W_o the oven-dry weight of sample in gram; V_1 the volume of sample in centimeter cube.

And the density at test and nominal density, oven-dry were obtained by multiplying Equation (3.5) and Equation (3.6) with (PMC + 100)/100 where PMC is the percentage moisture content.

Read on the use of characteristic strengths and design strength which uses a lesser strength value than actual in order to be within safe limits for design, raw data obtained from the mangrove poles tests from the laboratory were used to determine the standard deviation SD of the strength Equation (3.8) of each test after having determined the sample strength mean $\bar{X}$ Equation (3.7) of each test performed.

$$\bar{X} = \frac{1}{n}\sum_{n=1}^{i} Xi \tag{3.7}$$

$$\mathrm{SD} = \sqrt{\frac{\sum_{n=1}^{i}(X-\bar{X})^2}{n-1}} \tag{3.8}$$

X, and n are the strength of each sample and number of samples respectively for the test considered.

Tabulated design values are based on 5% exclusions value of the clear-wood strength values with a reduction factor or strength ratio of less than 1.0 to allow for the effects of strength-reducing characteristics such as knot size, slope, splits, checks and shakes (NDS, 2005).

Characteristic strength S_k of each test of the mangrove poles is obtained by the following Equation (3.9):

$$S_k = \bar{X} - t.\mathrm{SD} \tag{3.9}$$

$\bar{X}$ and S are as defined above and t is the value obtained from the statistic table.

Therefore the design strength S_d is obtained by Equation (3.10):

$$S_d = K_a.S_k \tag{3.10}$$

K_a is the reduction factor given in BS 5268 Part 2.

3.1.4 Steel

In this test, three specimens were prepared suitably for gripping into the jaws of the testing machine. The specimens used were approximately uniform over a gage length (the length within which elongation measurements are done**).** The steel used was of 10 mm of diameter with original length of 500 mm. Before the test commences, gauge length was marked, the weight of specimen measured and then fixed in the Jaws of Universal Testing Machine as shown in Figure 3.13. Tensile load was being applied until rupture. Elongation was measured at regular interval of applied tensile load. During the applying tensile load (as pulling proceeds), the change in the gauge length of the sample is measured from a sensor attached to the sample (called an extensometer).

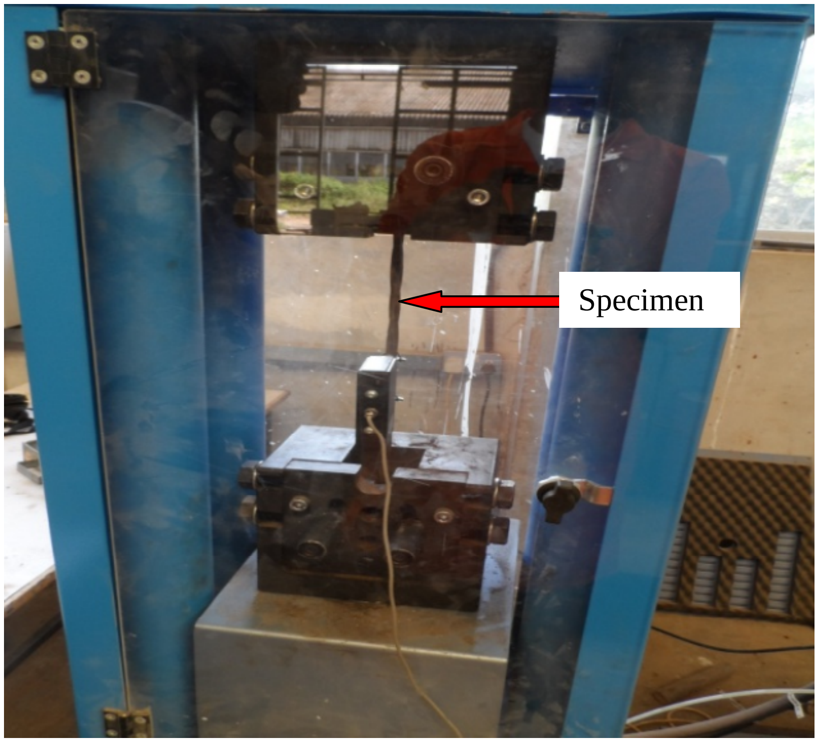


Figure 3.13: Tensile Test of Steel

3.2 Comparing the Flexural Properties of Beams Reinforced with Mangrove and Steel

3.2.1 Beam Design

Beam designs were in accordance with BS 8110 standards and specifications. The first step was to determine the beam sizes, after evaluating the laboratory conditions and desired testing set-up, a beam of 150 mm x 250 mm x 1100 mm was chosen (Figure 3.14). After that, three different diameters of the mangrove reinforcements were also chosen; they were 30 mm, 25 mm and 20 mm because of the unknowns associated with the behavior of mangrove reinforced concrete. Designated diameters were obtained by measuring each one of the mangroves at seven marked points distant of 170 mm from one another (Figure 3.16) with a caliper as shown in Figure

3.15 along the length of the mangrove pole and then the average of the values measured from each mangrove was calculated. Steel reinforcement, 10 mm in diameter was chosen for beams destined for control.

The clear cover, i.e, the distance from the outside of the beam to the reinforcement was 20 mm for both mangrove poles and steel reinforced concrete beams according to BS 8110 Part1, clause 3.3. The shear links of all beams were made with mild steel of 6 mm of diameter. The clear spacing between shear links was 170 mm according to BS 8110 Part1 clause 3.4.5.5 (which stipulates that spacing of links in the direction of the span should not exceed 0.75d, where d is the effective depth of the beam) as shown in Figure 3.30 and 3.31 and the maximum aggregate size was 20 mm as mentioned above.

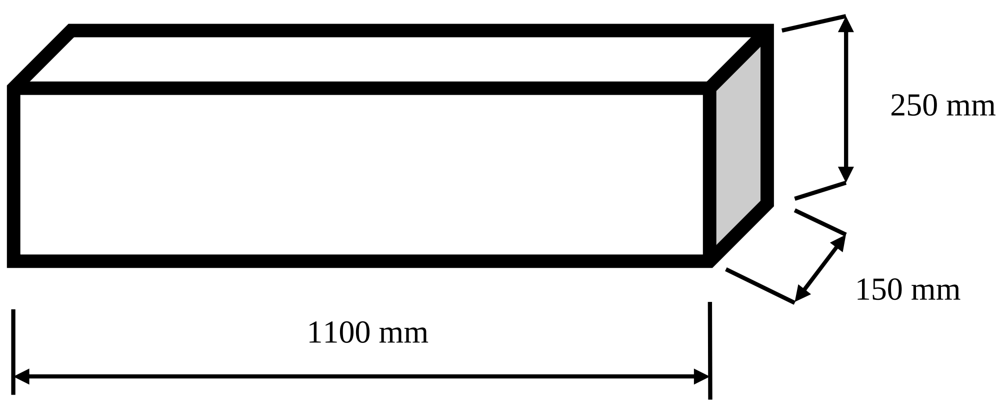


Figure 3.14: Dimensions of Beam Sample

3.2.2 Variables of Beams

The variables used for the beams were: (1) three reinforcement ratios with different sizes of mangrove diameters (30, 25 and 20 mm); (2) three target classes of concrete strengths for the beams samples (30, 25 and 20 N/mm²); (3) two reinforcement modes: beams reinforced with four mangrove poles (doubly reinforced beams) as shown in Figure 3.30 and 3.31and beams reinforced with two mangrove poles (singly reinforced beams) as shown in Figure 3.32.

3.2.3 Preparation of Beams Reinforcement

As it bas been said earlier in the literature review that there is very limited information in literature regarding mangrove poles reinforced concrete for the design and construction of the actual reinforcement. Therefore it was the aim of this research to design the process of fabricating the reinforcement for the beams. For their use as reinforcements in beams, the poles were first shaped into round bar shapes. A caliper was used to determine the values of the designated diameters as mentioned above (Figure 3.15). The following criteria were considered in the selection of mangrove poles for use as reinforcement in concrete: (1) use of a mature plant with no voids in the middle trunk; (2) minimal defects where possible; (3) seasoned mangrove.

The reinforcement ratio is defined by the following Equation (3.11):

$$\rho = 100A_s / A_c \tag{3.11}$$

Where A_s and A_c is the area of reinforcement and concrete respectively.

In the absence of any standard specifications for incorporating mangrove in concrete, reference was made to clauses 3.12.5 and 3.12.6 in BS 8110 Part1, which stipulate a minimum of 0.8% gross sectional area for reinforcement in beam and neither the maximum area of tension reinforcement nor the area of compression reinforcement should exceed 4% of the cross-sectional area of the concrete.

Figure 3.15: Measure of the Diameter of Mangrove Reinforcement

The original length of mangrove reinforcement was 1060 mm which is lesser than the length of beam. This is to provide cover on either side of reinforcement. The original length of steel was 1260 mm including the hook length. As the mangrove reinforcement is a tough material and cannot be bent no hook has been made (Figure 3.16) while hook of 100 mm has been made with steel reinforcement (Figure 3.17).

Figure 3.16: Mangrove Pole Reinforcement

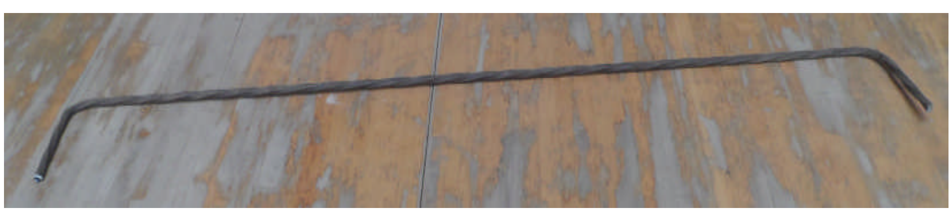


Figure 3.17: Steel Bar Reinforcement with Hook of 100 mm

Shear reinforcement, 6 mm diameter mild steel was provided at 170 mm centre-to-centre spacing throughout the length of the doubly and singly reinforced beams as shown in Figure 3.30, 3.31 and 3.32 respectively. Rebar ties were used to tie the longitudinal reinforcements to the transverse reinforcements.

Figure 3.18: Mangrove and Steel Reinforcements of Beam

Figure 3.19: Mangrove Reinforcement Destined for Tension Zone of the Beam

Once the reinforcements bound together the use of strain gauges were done rationally. For each beam for example one strain gauge was stuck on one of the tension reinforcements (Figure 3.31 and 3.32). Only reinforcements for the beams C25 where two strain gauges were used: one on the compressive reinforcement and another on the reinforcement tension (Figure 3.30). The strain gauges were preferably stuck at the middle of the reinforcements where the bending is supposed to be critical as shown in Figure 3.30, 3.31 and 3.32. As the middle of the longitudinal reinforcements of the beams coincided with the shear links of the middle, those shear links were removed to facilitate an easy sticking of the strain gauges for not to be pressed by the shear links which might cause their damage. Before the strain gauges were stuck on the reinforcements, grease, rust for steel, paint or any kind of impurities were removed from the bonding surface of the reinforcements by using a chisel (Figure 3.20) and after that they were lightly polished with an abrasive paper (Figure 3.21), wiped with acetone and marked gauge installation position. The strain gauges were fixed using super glue (Figure 3.22) afterward they were covered with wax and then tied with a self adhesive tape or bandage as shown in Figure 3.23 to protect them from both impact and moisture during the pouring of concrete. Once the strain gauges fixed, they were connected to the strain meter (data logga) which in turn was connected to a source of power to check whether the strain gauges work or not before proceeding to the casting of beams. The types of strain gauges used are: (1) PFL-10-11 for steel; (2) PFLW-30-11 for wood. Both of the strain gauges types have a gauge factor of 2.12 ± 1%.

Figure 3.20: Removal of Impurities in Steel Reinforcement

Figure 3.21: Removal of Impurities in Mangrove Reinforcement

Figure 3.22: Use of Super Glue for Fixing the Strain Gauge

Figure 3.23: Strain Gauges Already Fixed on the Reinforcements

3.2.4 Formworks Preparation of Beams

Formworks were made of 19 mm x 122 mm x 244 mm plywood supported by timber battens to contain the fresh concrete placed into them, mangrove and steel reinforcements of the beams as shown in Figure 3.24. The formworks were designed in such a way that their internal sizes gave the beams sizes.

Figure 3.24: Formworks of Beams

3.2.5 Mix Design, Casting of Beams and Cylinders

The concrete used for casting the columns was made using Portland Pozzolana cement as per Kenya standards, crushed stone with triangular shape as coarse aggregate with a maximum size of 20 mm, and natural sand supplied from one of the local rivers as fine aggregate. Three different classes of concrete strengths were used for the beams, which are C30, C25 and C20 with different water-cement ratios of 0.6, 0.55 and 0.5 respectively. The mixes were designed for twenty eight day strength. The concrete mix proportions were 1:1:2.2 for C30, 1:1.2:1.8 for C25 and 1:1.75:2 for

C20 (cement: fine aggregate: coarse aggregate) with a slump value of 50 ± 5 mm to insure consistency concrete. A typical beam had the dimensions of 150 mm x 250 mm x 1100 mm as shown in Figure 3.14 and the volume of 41250000 mm³. The mixe for a 41250000 mm³ beam is shown in Table 3.1.

Table 3.1: Ingredients for Concrete Mixture (One Beam)

Class of Concrete	Cement(kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)
C30	26.27	26.27	57.80	15.76
C25	26.27	31.53	47.29	14.45
C20	21.02	36.78	42.04	10.51

Beams of the same class of concrete were cast from the same batch of concrete. After mixing the concrete for each class, it was taken to the formworks. Reinforcements were well positioned by the use of 20 mm thick concrete spacer blocks tied under the reinforcements of the tension zone in contact of the bottoms of formworks and laterally between the reinforcements and lateral part of the formworks to control the clear cover during casting. Concrete was then placed into the formworks and around the mangrove or steel reinforcements. A poker vibrator was used to compact the concrete and ensure there was homogeneity. When all the concrete was added to the formworks, the tops were made smooth with a trowel. The specimens were demoulded after 24 hours and were cured for 28 days where they were continuously kept under wet conditions by the use of sacks absorbent as shown in Figure 3.27. Cylindrical 100 mm diameter and 200 mm height compressive and tensile strength specimens were also cast from the same concrete mix and demoulded after 24 hours and cured by in a water tank for 28 days. Figure 3.28 shows a concrete cylinder.


Figure 3.25: Beams and Cylinders Recently Cast


Figure 3.26: Beams Cast After 24 Hours

Figure 3.27: Beams Dressed with Sacks Absorbent to Keep Humidity

Figure 3.28: Concrete Cylinder

3.2.6 Test Set-Up of Beams, Instrumentation and Data Acquisition

The test set-up began with preparing the beam by pasting an angle iron as shown in Figure 3.29 on one of lateral-central faces of the beam at the midspan from supports to facilitate the fixing of the transducer and protect it during test. White painting was applied on the both lateral surfaces along the length of the beam to display clearly cracks during the applying load. After that, a steel support beam in I-shaped were put on the lower frame of the testing machine and then the rollers for the supports were placed on the top of it at the measured location of 900 mm inside from center to center of the supports (Figure 3.33). Next the beam was picked up with the forklift and carefully placed between the upper and the lower frames of the Testing Machine on the supports as shown in Figure 3.33.

Figure 3.29: Angle Iron Fixed on One of the Lateral-Center Faces of the Beam for Transducer

Instrumentation consisted of a displacement transducer which was placed at the lateral-center of the beam (Figure 3.29) to measure the deflections at each applied load, a load cell of 50 tons of capacity to measure the load transferred through it and electrical strain gauges to measure strain.

Besides the strain gauges placed on the reinforcements, another of type PL-60-11 with gauge factor of 2.13 was placed in the center-bottom side of the beam which is supposed to be the critical zone (point of maximum deflection). Before placing the strain gauge, the surface of the concrete where it must be placed was cleaned with an abrasive paper, wiped with acetone and marked gauge installation position and then strain gauge was fixed using super glue. Figure 3.30, 3.31 and 3.32 show the location of strain gauges on reinforcements and at the concrete of the beams.

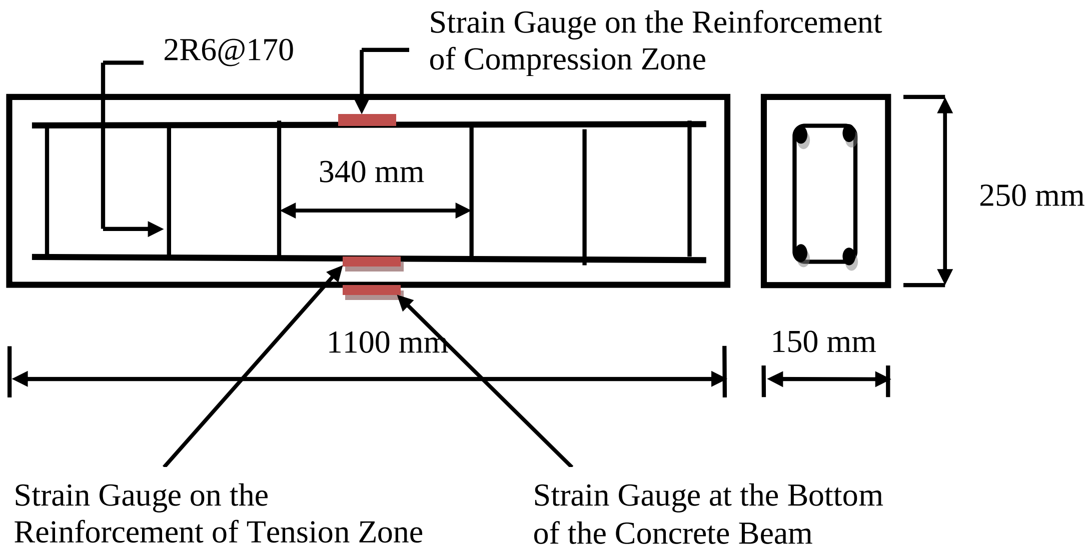


Figure 3.30: Longitudinal and Cross-Section of BR4MPΦ30C25, BR4MPΦ25C25, BR4MPΦ20C25 and BR4SBΦ10C25

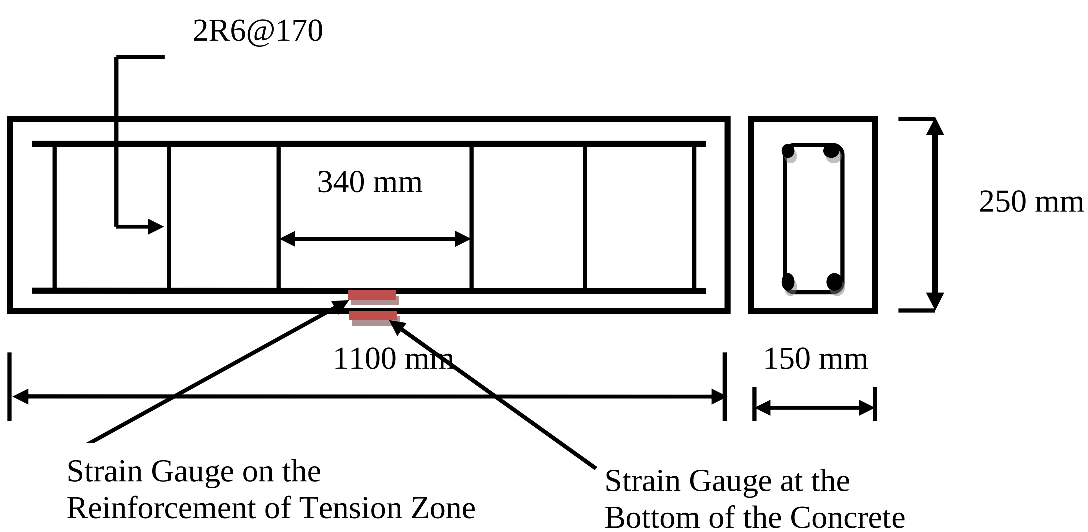


Figure 3.31: Longitudinal and Cross-Section of BR4MPΦ30C30, BR4MPΦ25C30, BR4MPΦ20C30, BR4SBΦ10C30, BR4MPΦ30C20, BR4MPΦ25C20, BR4MPΦ20C20 and BR4SBΦ10C20

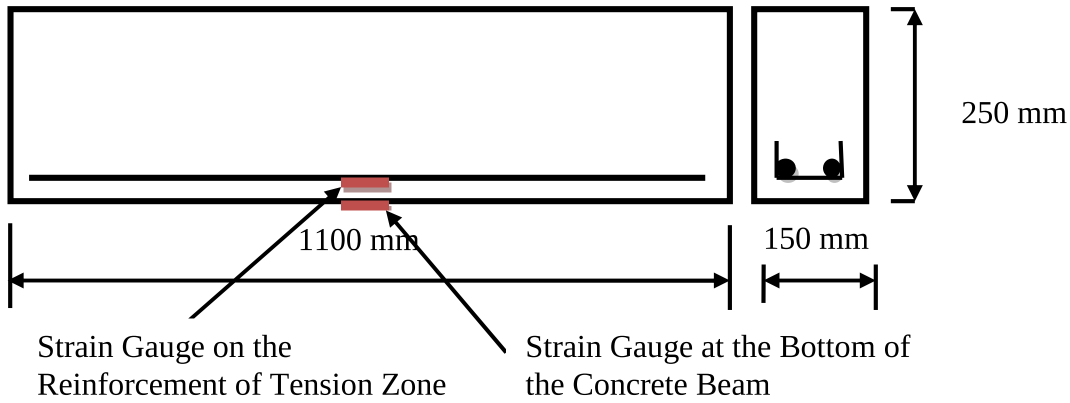


Figure 3.32: Longitudinal and Cross-Section of BR2MPΦ30C25, BR2MPΦ25C25 and BR2MPΦ20C25

Once the beam was placed between the frames of the Testing Machine and ready for the test, it was subjected under three point bending test as shown in Figure 3.33 and load was applied gradually by controlled pumping unit till failure. The deflection of the beam at midspan was measured at regular interval of loading.

Figures 3.33: Three Point Bending Test of the Beam Specimens

The data acquisition system consisted of instrumentation to collect, digitize, and process sensor and signal inputs for the purpose of monitoring and analyzing the failure process. The equipments used for measurements from the beam were connected to a strain meter or data logger shown in Figure 3.34 which displayed the measurements and printed them at each applied load up to failure. The results of the beams tests were used to plot the load-deflection curves and load-strain curves of reinforcements. Cracks propagation and failures mode were also recorded and examined in detail at the same time.

Figure 3.34: Printing of Data From a Data Logga

3.3 Comparing the Compressive behavior and Strength of Columns Reinforced with Mangrove and Steel

3.3.1 Short Column Design

This part of study intends to compare compressive strength and behavior of short concrete columns reinforced with mangrove poles to the concrete columns reinforced by conventional steel reinforcement and unreinforced columns. The design of the short column was referred to clauses 3.8.1.5 in BS 8110Part 1, which stipulates that an unbraced column may be considered as short when both the ratios:

$$L_{ex} / h < 10 \text{ and } L_{ey} / b < 10 \tag{3.12}$$

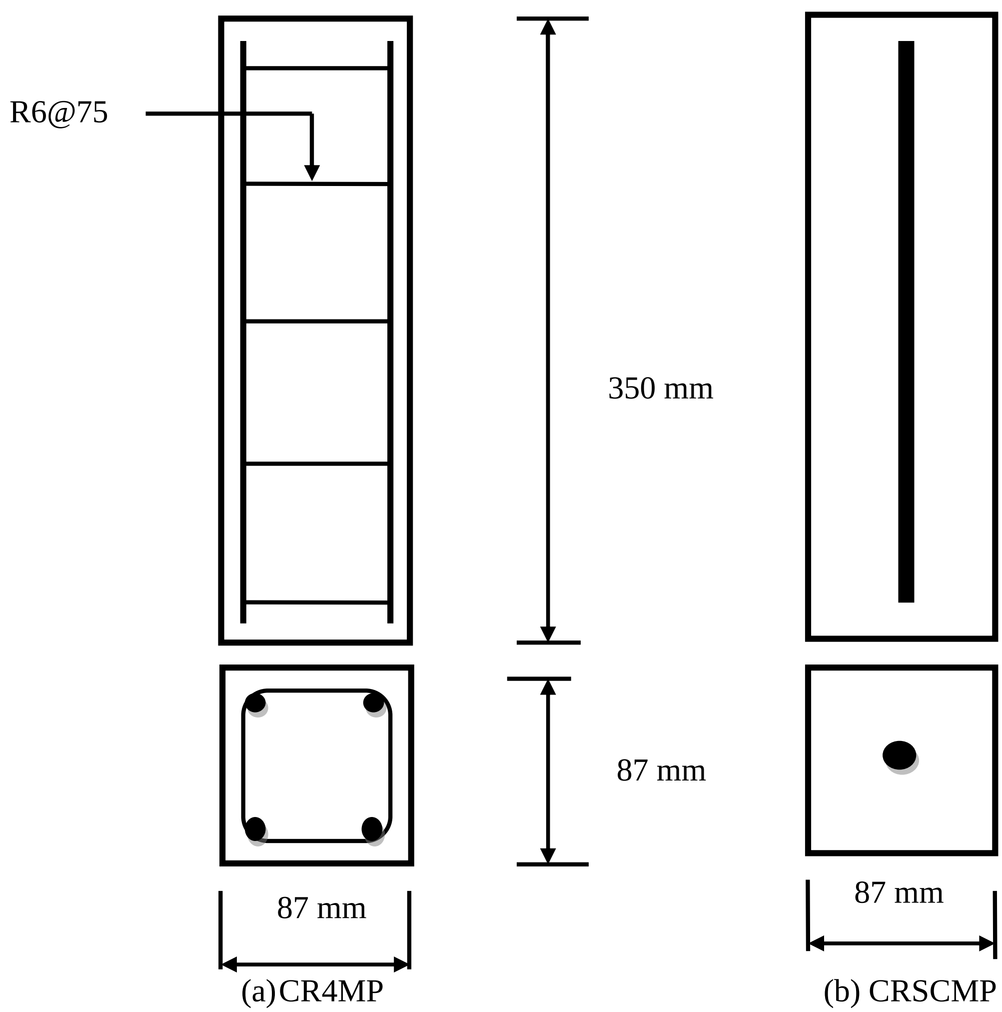
L_{ex}, L_{ey}, h and b are effective height in respect of the major axis, effective height in respect of the minor axis, depth of cross-section measured in the plane under consideration and width of the column respectively.

Design of the column started with the determination of the column sizes. After evaluating the laboratory conditions and desired testing set-up, a square column of 87 mm x 87 mm and 350 mm of height was chosen. The next step of the design was to choose the diameters of the mangrove reinforcements. Mangrove poles reinforcements for columns were measured at five equidistant points (75 mm) with a caliper along the length of the mangrove and then the average of the values measured from each mangrove was calculated to obtain the designated diameters values of mangrove reinforcement. Steel reinforcement, 8 mm in diameter was chosen and could be easily cut and bent to required length for columns destined for control. Plain columns were cast too for control purpose as well.

The clear cover was 10 mm (Figure 3.35.a) for both mangrove poles and steel reinforced concrete column according to BS 8110 Part 1, clause 3.3. All columns with four reinforcements have the same transverse reinforcement made with of 6 mm in diameter. The clear spacing between transverse reinforcements center to center was 75 mm as shown in Figure 3.35.a and the maximum aggregate size was 10 mm as mentioned above.

3.3.2 Variables of Columns

Variables used for columns were: (1) six reinforcement ratios with different sizes of mangrove diameters: 8, 11, 14, 16, 20 and 24 mm; (2) three target classes of concrete strengths: 30, 25 and 20 N/mm²; (3) two modes of reinforcement: beams with four reinforcements (Figure 3.35.a), beams with single central reinforcement (Figure 3.35.b). Besides these two modes of reinforcement, plain concrete column was used as control.



Figures 3.35: Type of Reinforcement of Columns

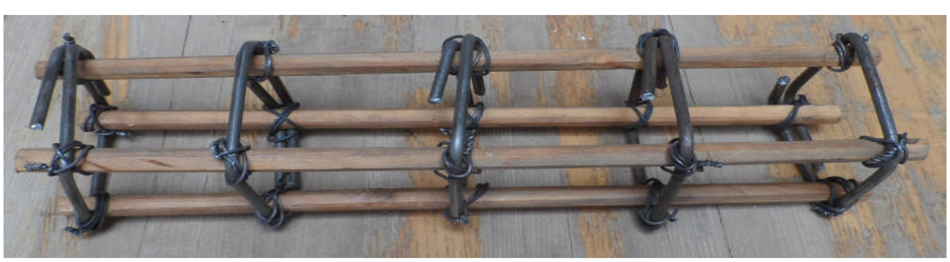
3.3.3 Preparation of Columns Reinforcement

The mangrove poles selected were those already dried and their application did not require further moisture reduction processed. Once they were shaped approximately to the sizes required, their diameters were measured at five marked points at a distant of 75 mm from one another with a caliper along the length of the mangrove poles and then the average of the values measured from each mangrove was determined as the designated respective diameter. The reinforcement ratio was defined by the formula similar to that of beam:

$$\rho = 100A_{sc} / A_g \tag{3.13}$$

A_{sc} and A_g is the area of reinforcement in compression and concrete respectively.

Reinforcement of columns were referred to clause 3.12.5 and 3.12.6 in BS 8110, which stipulate a minimum of 0.4% and a maximum of 8% gross sectional area for reinforcement in column. The reinforcements of columns were tied together at each corner of the transverse reinforcements of 67 x 67 mm square made with round steel bars of 6 mm of diameter (Figure 3.36 and 3.37). The distance from one transverse reinforcement to another was 75 mm center to center as shown in Figure 3.35.a and rebar ties were used to tie the longitudinal reinforcements to the transverse reinforcements (Figure 3.36 and 3.37).



Figures 3.36: Tying Mangrove Longitudinal Reinforcements with Transverse Reinforcements

Figures 3.37: Tying Steel Longitudinal Reinforcements with Transverse Reinforcements

3.3.4 Formworks Preparation of Columns

Formworks were made of 19 mm x 122 mm x 244 mm plywood to support the fresh concrete placed into them, the mangrove and the steel reinforcements of the column, as shown in Figure 3.39 and 3.40. The formworks were designed in such a way that their internal sizes gave the column sizes. They have been made according to the vertical standing or direction of the columns (Figure 3.38).

Figure 3.38: Columns Formworks

3.3.5 Mix Design, Casting of Columns and Cylinders

The maximum aggregate used for concrete was 10 mm. Three batches concrete were mixed, where each batch corresponds to a specific class of concrete that is C30, C25 and C20 corresponding to water-cement ratios of 0.6, 0.55 and 0.5 respectively. The mixes were designed for twenty eighth day strength. The concrete mix proportions were 1:1:2.2 for C30, 1:1.2:1.8 for C25, 1:1.75:2 (cement: fine aggregate: coarse aggregate) with a slump value of 50 ± 5 mm to insure consistency concrete. A typical column had the dimensions of 87 mm x 87 mm x 350 mm and the volume of 2649150 mm^3. The mixes for a 2649150 mm^3 column is shown in Table 3.2.

Table 3.2: Ingredients for Concrete Mixture (One Column)

Class of Concrete	Cement(kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)
C30	1.69	1.69	3.71	1.01
C25	1.69	2.03	3.04	0.93
C20	1.35	2.36	2.70	0.68

After mixing the concrete for each class, it was taken to the formworks. Steel rebar ties were employed to control the cover by hanging up the reinforcements; they were attached to the top shear links of the columns and to the nails fixed near the opened edges of the formworks as shown in Figure 3.39. Single central reinforcements (Figure 3.40) were fixed with nails placed at the bottoms of the formworks.

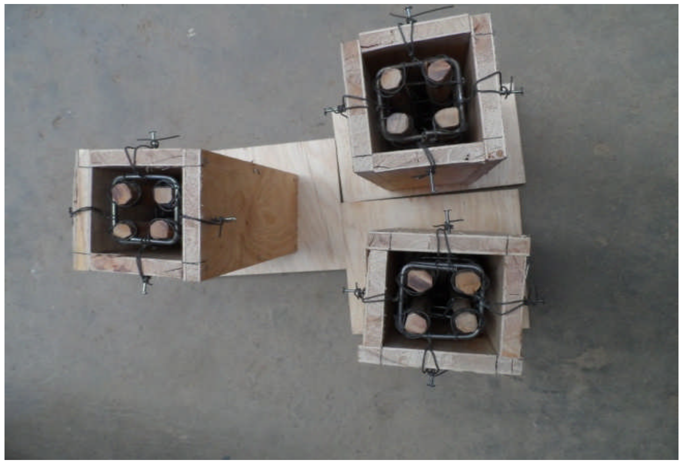


Figure 3.39: Reinforcements Suspended by Steel Rebar Ties Inside the Formworks

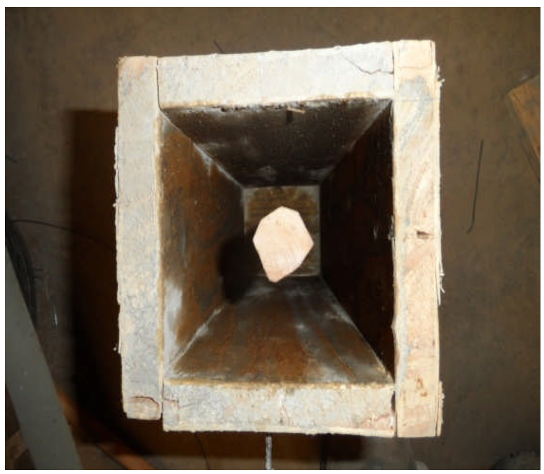


Figure 3.40: Single Central Reinforcement of Column

After mixing the concrete for each class, the concrete was then poured in the formworks containing the mangrove or steel reinforcements. A Poker vibrator was used to push the concrete down and compact it in between the reinforcements as well as in the more open areas to help ease out air pockets. On filling the formwork, the concrete tops were made smooth with a trowel. The specimens were demoulded after 24 hours and transferred into a curing tank containing clean water for curing for a period of 28 days. Cylinders of 100 mm x 200 mm were also prepared and cured according to ASTM standards and tested on the 28th day in compression and splitting tensile.

Figure 3.41: Columns and Cylinders Recently Cast

3.3.6 Test Set-Up of Columns, Instrumentation and Data Acquisition

On the 28th day, compression tests were carried out on the specimens (both cylinders and columns). The column specimen was set up on the Universal Testing Machine, and steel bearing plates were put at the top end of specimen as shown in Figure 3.42. Axial deformation of the column was measured using a displacement transducer attached with a magnetic base frame. After testing set up was ready, compression force was gradually applied to specimen using a load cell of 50 tons of capacity until failure. Column behavior was observed throughout the loading process and the values of deflection corresponding to the applied gradual loading at an interval of 5 kN were recorded. Cracks pattern propagation and failure modes were also noted and examined in detail.

Figure 3.42: Test Set-Up of Column Specimen Subjected to Axial Load

CHAPTER 4

RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter presents the results of all the tests performed. These are mechanical properties of mangrove poles, the tensile test of steel, the three point bending beam test and column compressive test. Test results were compared and a comparative analysis was made and discussed in detail in this chapter. Load-deflection, failure modes and cracking behavior have been dwelt in detail. Test designations were based on percentage ratio or diameter of reinforcements and concrete strength as well.

4.1 Mechanical Properties of Mangrove Poles and Steel

4.1.1 Aggregates

Table 4.1 gives the results of specific gravity and absorption of coarse and fine aggregate found from the laboratory tests and Figure 4.1 shows the grading curve obtained from the sieve analysis of fine aggregate.

Table 4.1: Results of Specific Gravity and Absorption of Aggregates

Designation	Gsb	Gsb SSD	Gsa	% Abs.
Coarse aggregate, maximum size 20 mm	2.72	2.82	3.01	3.44
Coarse aggregate, maximum size 10 mm	2.71	2.80	2.99	3.43
Fine aggregate	2.54	2.56	2.60	0.96

By observing the Figure 4.1 below that displays the result of the sieve analysis of fine aggregate, it can be seen that the fine aggregate (sand) tested in lab meets the ASTM specifications for all the points fit between the high and low boundaries.

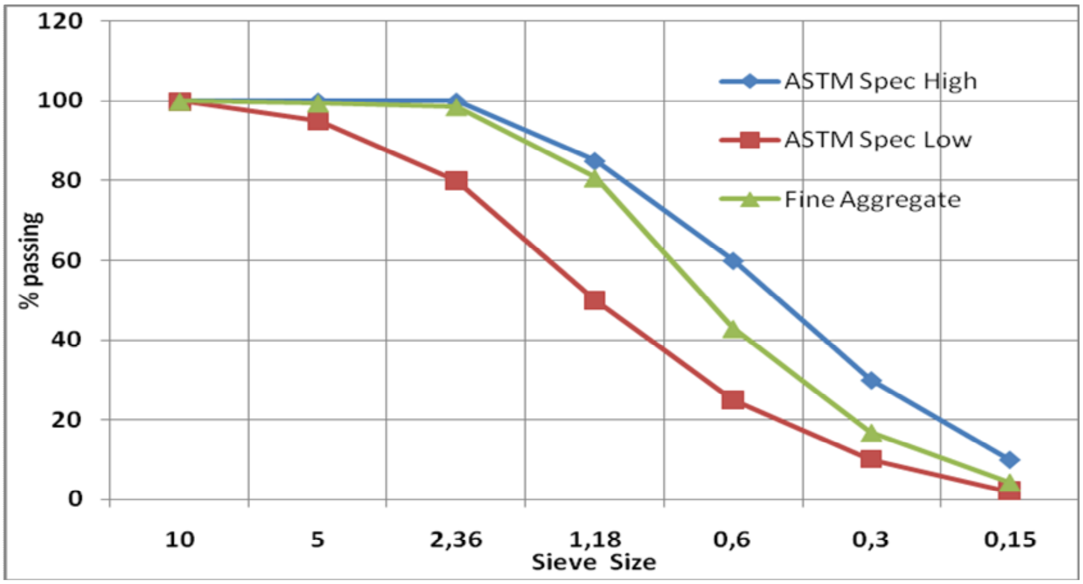


Figure 4.1: Fine Aggregate Sieve Curve

4.1.2 Mangrove

Table 4.2 gives the average raw strengths, characteristic strengths and design strengths of the mechanical properties of mangrove poles.

Table 4.2: Design Strengths of Mechanical Properties of Mangrove

Test	N^o of Samples	t	K_a	S_r(N/mm^2)	S_k (N/mm^2)	S_d (N/mm^2)
Compressive Parallel to Grain	20	2.086	0.6	73.31	63.32	37.99
Shear Parallel to Grain Tangential	12	2.179	0.9	20.50	15.42	13.88
Shear Parallell to Grain Radial	12	2.179	0.9	18.25	13.46	12.11

Modulus of Rupture (MOR)	20	2.086	0.8	140.53	117.48	93.98
Tension Parallel to Grain	25	2.060	0.8	192.95	66.33	53.07
Modulus of elasticity (MOE)	25	2.060	0.8	16504.78	12217.80	9774.24

Comparing the actual results (unfactored results) of mechanical properties of mangrove poles found to the results obtained by Manguriu et al (2013) mentioned in section 2.4.1, the gaps between the results are within the range. This confirms that the mangrove poles in this study can be used as reinforcement in structural concrete elements. However the Janka Hardness of mangroves tangential and radial have an average of 11.163 kN and 11.166 kN, respectively, which provide mangrove poles a good resistance to impact loading and good quality as structural timber. Figure 4.2 shows a typical curve of mangrove static bending test obtained from the laboratory test, while Figures 4.3 the mode of failure of each mangrove test performed.

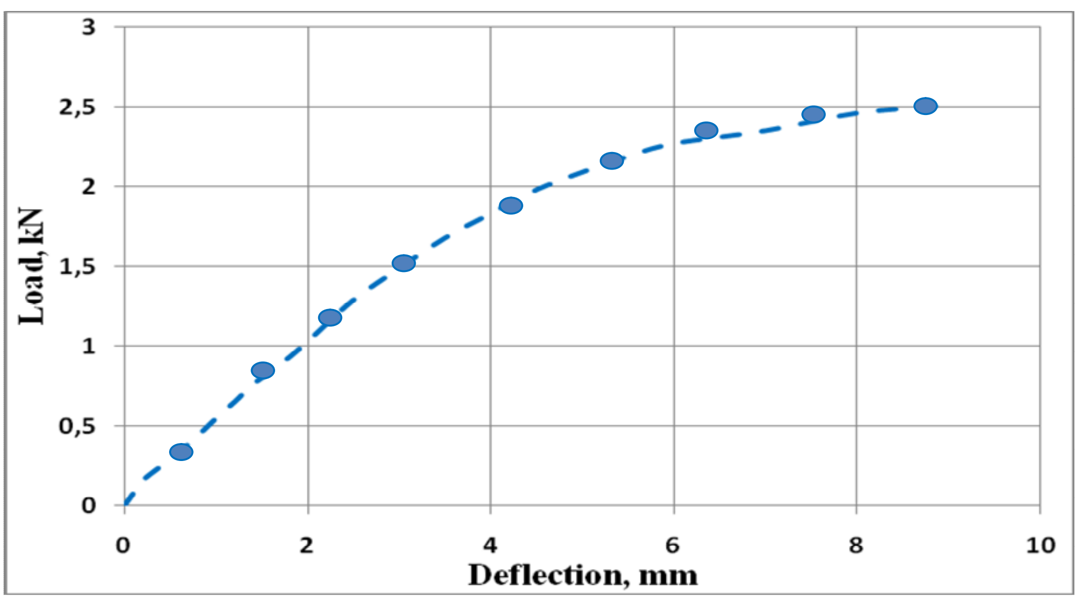


Figure 4.2: Load-Deflection Curve of Static Bending Test of Mangrove

The result shows that the average moisture content for the mangrove specimens was found to be approximately 12.3%. The strength properties of wood are influenced by its moisture content. The moisture content obtained indicates that the mangrove poles used in this study are classified among the strongest timber, for the moisture content of strongest timbers range within 12 to 15%.

The average density of mangrove at test and nominal density, oven-dry were experimentally established to be 1.17 and 1.04 g/cm^3, respectively, which are within the range of the density of hardwoods. The specific gravity of the mangrove species used in this study both at test and oven-dry are 1.04 and 0.92, respectively. The values are within the range which affects the ease with which the mangrove can be worked with hand tools for the lower the specific gravity the easier the cutting of the wood with sharp tools (Manguriu et al., 2013).

It is noted that the tensile strength of mangrove is much lower than that of steel as given in Section 4.1.3, approximately seven times less than that of steel. In terms of percentage, the tensile strength of mangrove is around 14.6% of that of steel. None the less, its usage may still be applicable particularly where loadings regimes can be accommodated within the mangrove strength.

(a) Compression Parallel to Grain Test, Mode of Failure Small Cracks

(b) Shear Parallel to Grain Test, Mode of Failure True Shearing

(c) Static Bending – Centre Point Loading, Mode of Failure Oblique Shear

(d) Janka Hardness, Mode of Failure Dents

(e) Tensile Test, Failure Occurred Near the Edge Prepared For the Grip

Figures 4.3: Mode of Failures of Mangrove

4.1.3 Steel

From the three tensile tests performed on steel bars of 10 mm of diameter it was found that the average maximum load carried by steel was 35.1 kN, the average maximum design tensile strength was obtained by multiplying the tensile strength obtained from the laboratory test by the safety factor of steel equal to 1.15. Following this step mentioned above, it was found that the value of design tensile strength of steel is 363.2 N/mm² and the elongation at break was approximately 12.6%.

The results shows the average tensile strength of the steel used to reinforce the control specimens is about 363.2 N/mm^2, which is established to be lower than the specified strength for high yield steel strength as provided for in the standards as approximately 460 N/mm^2. None the less the objective of the test was to establish the steel tensile strength as used in the control beams to allow for comparisons with that of mangrove as discussed previously.

4.2 Comparison of Mechanical Properties of Beams Reinforced with Mangrove and Steel

The results of the beams and curves are given by class of concrete strength. The beams of C30 and their control were compared among one another, the beams of C25 and their control were compared among one another and those of C20 and their control were compared among one another as well. It is important to note that beams of C20 have two types of reinforcement, some reinforced with four mangrove poles (doubly reinforced) and other reinforced with only two mangrove poles (singly reinforced) at the tension zone of the beams samples. Both of them have the same control.

4.2.1 C30 Reinforced Concrete Beams

a) Compressive and Tensile Strength of Cylinder C30 for Beams

Results of compressive and tensile strength of concrete cylinder of 100 mm diameter and 200 mm height for 28 days are given in Table 4.3. The target of compressive strength of concrete cylinder in this part of study was 30 N/mm^2. However, both the average of the result found was 29.1 N/mm^2 which is slightly below the target, while the tensile strength was 3.25 N/mm², which clearly confirms the poor tensional strength of concrete.

b) Flexural Strength of Beams C30

A total of three doubly mangrove reinforced beams (beams reinforced with four mangrove poles) of class C30 whose sizes are 150 mm x 250 mm x 1100 mm (see Figure 3.14) reinforced variably were tested in flexure and compared from steel reinforced concrete control beam of the same sizes and class of concrete. Comparison of the flexural behavior of mangrove reinforced concrete beams and steel reinforced control concrete beam was as shown in Figure 4.6.

From the results it is noted that mangrove concrete beams reinforced with larger diameter of mangrove poles (BR4MPΦ30C30) showed higher ultimate load of 79 kN with a lower deflection of 5.3 mm. This is higher than that of the control steel reinforced beam (BR4SBΦ10C30) which had ultimate strength of 67 kN and a deflection of 17.6 mm. A review of the other mangrove reinforced beams reinforced with smaller diameters of mangrove poles show lower ultimate load at failure with a corresponding much lower deflection levels. One common characteristic of the mangrove reinforced concrete beams is that even though the physical failure mode (see Figures 4.4 and 4.5) shows flexure and combined flexure and shear failure mode, the results shown in Figure 4.6 a more semi brittle failure as compared to the control beam. The brittle failure in the mangrove beams that exhibited flexural cracking but with sudden failure may be attributed to the existence of defects such as knots in the poles. Obviously steel reinforced control beam exhibited a more ductile characteristic due to the intrinsic elastic properties of steel as compared to that of the mangrove reinforced beams as illustrated by the doted lines in Figure 4.6. It is evident that the load carrying capacity and deflection capacity depends on the reinforcement ratio of the mangrove: the higher the reinforcement ratio of the mangrove, the higher the load carrying and deflection capacity.

(a) Failure Pattern of BR4MPΦ30C30

(b) Failure Pattern of BR4MPΦ25C30

(c) Failure Pattern of BR4MPΦ20C30

Figures 4.4: Failure Pattern of Beams C30

Figure 4.5: Failure Pattern of BR4SBΦ10C30 (Control Beam)

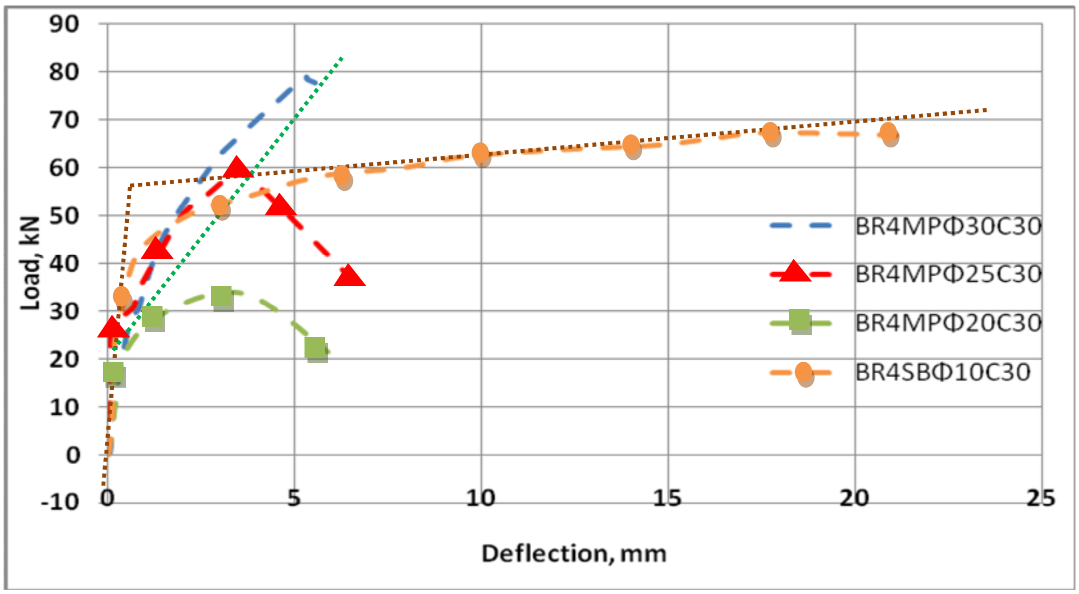


Figure 4.6: Load-Deflection Curves of Beams C30

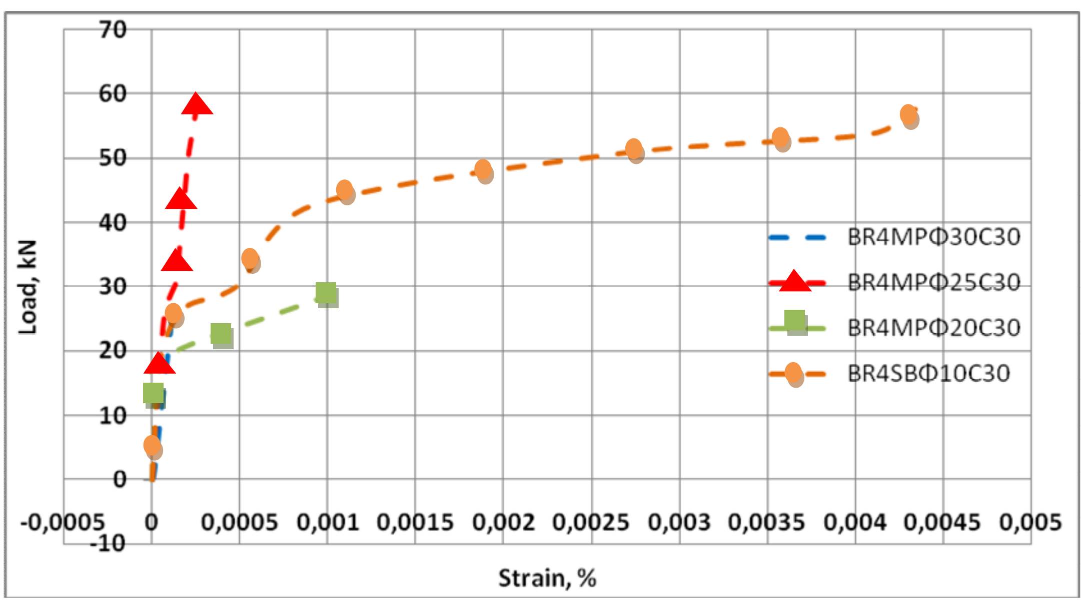


Figure 4.7: Load-Stain Curves of Reinforcements in Beams C30

From Figure 4.7, it can be seen that there is linear elastic strain behavior until first crack whereby nonlinear behavior is noted. The strain in the steel is much higher than this in the mangrove.

c) Beams C30 Failure Modes

The test results from Table 4.3 shows that the beam with 7.8% mangrove reinforcement ratio (BR4MPΦ30C30) failed in flexure accompanied by shear cracks near the support on the right side as seen in Figure 4.4.a. This could be as a result of a higher reinforcement ratio and thus ability to carry more load than the other beams including the control beams. Beam BR4MPΦ2530 failed in bending accompanied by one shear crack to the left as shown in Figure 4.4.b. Beam BR4MPΦ20C30 had failed in pure bending by only one vertical crack at the center from the bottom to the beam to the top as shown in Figure 4.4.c. BR4SBΦ10C30 failed also in bending with high ductility. During test, two vertical cracks occurred on BR4SBΦ10C30 equidistant from each other from the center and from which small cracks occurred as shown in Figure 4.5.

The results also show that the load carrying capacity depends on the reinforcement ratio of the mangrove: the higher the reinforcement ratio of the mangrove, the higher the load carrying capacity. From Figure 4.6 and Table 4.3 it can be seen that the maximum deflection of a beam reinforced with mangrove did not depend on the reinforcement ratio. It was noted that during testing all the beams reinforced with mangrove poles failed suddenly accompanied by a loud deep sound due to mangrove cracking and failed at the maximum load, while the beam reinforced with steel shows a ductile failure behavior.

4.2.2 C25 Reinforced Concrete Beams

a) Compressive and Tensile Strength of Cylinder C25 for Beams

Table 4.3 gives the results of compressive and tensile strength test of concrete cylinder of 100 mm diameter and 200 mm height for 28 days. The target of compressive strength of concrete cylinder in this part of study was 25 N/mm^2. Average compressive strength is slightly below the target strength although within and error margin of + or – 1 N/mm^2, while the tensile strength clearly confirms the poor tensional strength of concrete.

b) Flexural Strength of Beams C25

Three doubly mangrove reinforced beams (beams reinforced with four mangrove poles) of class C25 having 1100 mm length, 150 mm width and 250 mm depth reinforced variably were tested in flexure and compared from the steel reinforced concrete control beam of the same sizes and class of concrete. Comparison of the flexural behavior of mangrove reinforced concrete beams and steel reinforced control concrete beam was as shown in Figure 4.10.

From the results it is noted that mangrove concrete beams reinforced with larger diameter of mangrove poles (BR4MPΦ30C25) showed higher ultimate load of 96 kN and with a lower deflection of 8.5 mm. This is higher than that of the control steel reinforced beam (BR4SBΦ10C25) which had ultimate strength of 67 kN and a deflection of 16.5 mm. In Figure 4.10, a review of the other mangrove reinforced beams reinforced with smaller diameters of mangrove poles show lower ultimate load at failure with a corresponding much lower deflection levels. One common characteristic of BRMPΦ25C25 and BRMPΦ20C25 is that even though the physical failure mode (see Figure 4.8.b and 4.8.c) shows flexure, the results show in Figure 4.10 a more semi brittle failure as compared to the control beam (BRSBΦ10C25). The brittle failure in the beam that exhibited flexural cracking but with sudden failure may be attributed to the existence of defects such as knots in the poles. As illustrated by the doted lines, Figure 4.10 also indicate a lower elastic stiffness of the mangrove reinforced beams as compared to that of the control steel beam attributable to the lower modulus of elasticity of mangrove poles. However, the post-elastic stiffness of mangrove reinforced beams seems to be higher than that of steel reinforced beams.

(a) Failure Pattern of BR4MPΦ30C25

(b) Failure of BR4MPΦ25C25

(c) Failure Pattern of BR4MPΦ20C25

Figures 4.8: Failure Pattern of Beams C25

Figure 4.9: Failure Pattern of BR4SBΦ10C25 (Control Beam)

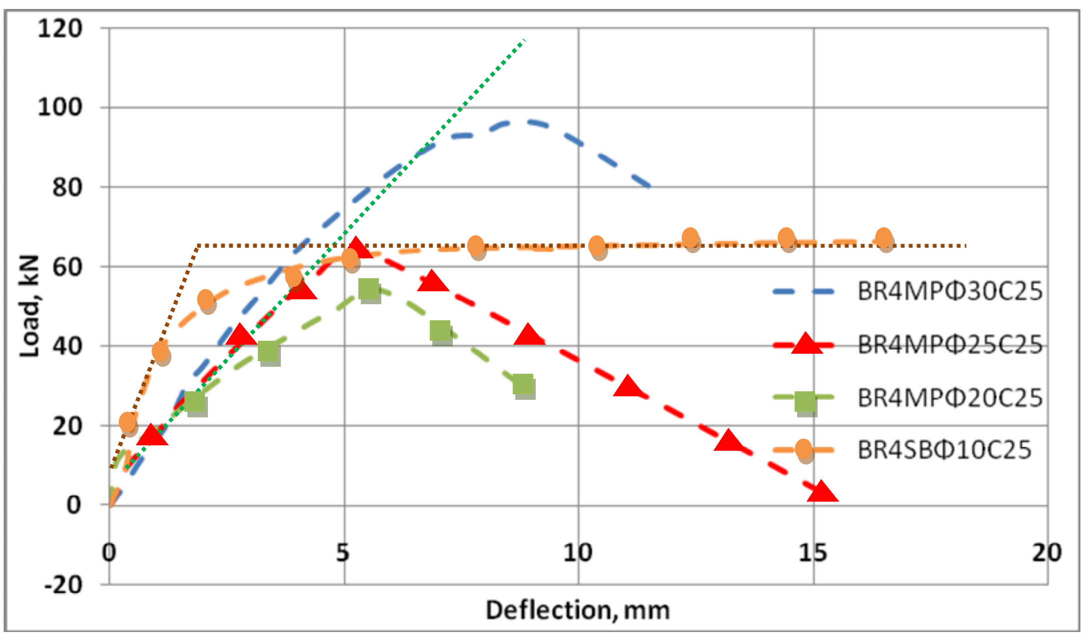


Figure 4.10: Load-Deflection Curves of Beams C25

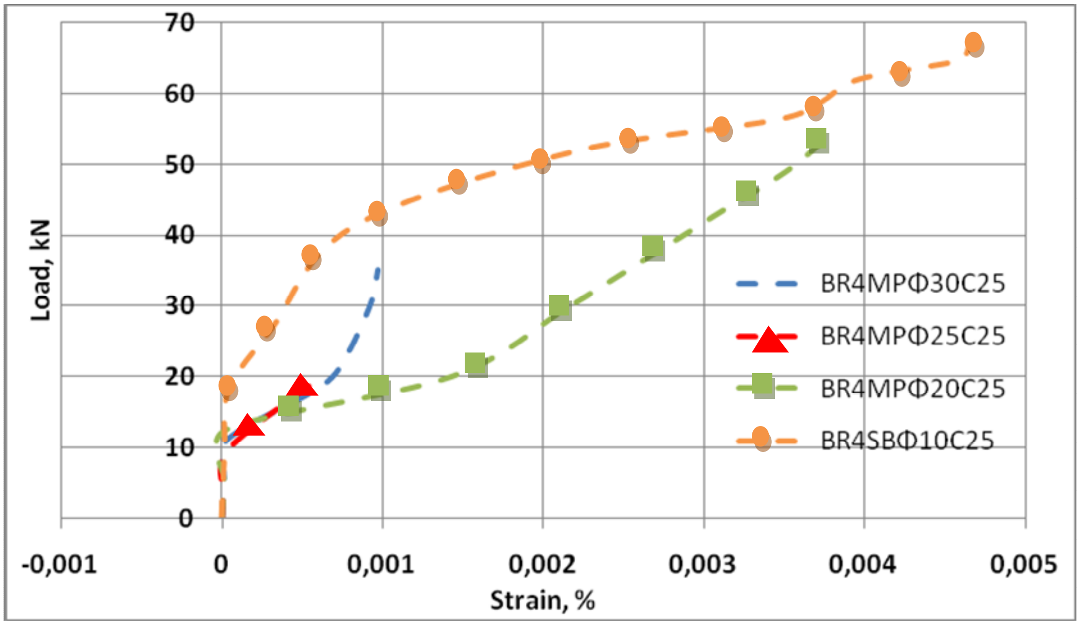


Figure 4.11: Load-Stain Curves of Reinforcements in Beams C25

From Figure 4.11, it can be seen that there is linear elastic strain behavior until first crack where by nonlinear behavior is noted. The strain in the steel and mangrove pole of 20 mm of diameter is almost the same and much higher than this of mangrove of 30 and 25 mm of diameter.

c) C25 Failure Modes

The test results from Table 4.3 shows that the beam with 7.9% mangrove reinforcement ratio (BR4MPΦ30C25) failed in flexure accompanied by more shear cracks near the supports on the left sand right side as seen in Figure 4.8.a. This can be explained by the fact that the reinforcement ratio was higher in that beam and the beam was able of carrying more loads than the other beams including the control beams. Beams BR4MPΦ25C25, BR4MPΦ20C25 and BR4SBΦ10C25 failed in pure bending as shown in Figure 4.8.b, 4.8.c and 4.9 respectively. These three beams (BR4MPΦ25C25, BR4MPΦ20C25 and BR4SBΦ10C25) had the same failure mode;

they have only one crack occurred at the center of the beam, more or less vertical from the bottom to the top as shown in Figure 4.8.b, 4.8.c and 4.9 respectively.

In general, the results show also that the load carrying capacity depends on the reinforcement ratio of the mangrove: the higher the reinforcement ratio of the mangrove, the higher the load carrying capacity. From Figure 4.10 and Table 4.3 it can be seen that the maximum deflection of a beam reinforced with mangrove did not depend on the reinforcement ratio. It was noted that during testing all the beams reinforced with mangrove poles failed suddenly accompanied by a loud deep sound due to mangrove cracking and failed at the maximum load, while the beam reinforced with steel shows a high ductile behavior.

4.2.3 C20 Reinforced Concrete Beams

a) Compressive and Tensile Strength of Cylinder C20 for Beams

The target compressive strength of cylinder of 100 mm diameter and 200 mm height was 20 N/mm². However, the 28 days average compressive strength of concrete was 19.3 N/mm², while the average tensile strength was established to be 2.3 N/mm².

b) Flexural Strength of Beams C20

For class C20, two type of beams reinforcement mode were used according to the number of reinforcements namely: doubly mangrove reinforced beams (beams reinforced with four mangrove poles) and singly mangrove reinforced beams (beams reinforced with only two mangrove poles). A total of three singly mangrove reinforced and three doubly mangrove reinforced beams of 1100 mm length having

150 mm width and 250 mm depth reinforced variably were tested in flexure and compared from the same steel reinforced concrete control beam.

Comparison of the flexural behavior of mangrove reinforced concrete beams and steel reinforced control concrete beam is as shown in Figures 4.15 and 4.16. From the results, it is noted that mangrove concrete beams reinforced with larger diameter of mangrove poles (BR4MPΦ30C20) showed slightly higher ultimate load of 82 kN but with a lower deflection of 7 mm. This is higher than that of the control steel reinforced beam (BR4SBΦ10C20) which had ultimate strength of 75 kN and a deflection of 15 mm. A review of the other mangrove reinforced beams reinforced with smaller diameters of mangrove poles show lower ultimate load at failure with a corresponding much lower deflection levels. One common characteristic of the mangrove reinforced concrete beams is that even though the physical failure mode (see Figures 4.12 and 4.13) shows flexure and combined flexure and shear failure mode, the results shown in Figure 4.15 and 4.16 indicate a more semi-brittle failure as compared to the control beam. The brittle failure in the mangrove beams that exhibited flexural cracking but with sudden failure may be attributed to the existence of defects such as knots in the poles. Obviously steel reinforced control beam exhibited a more ductile characteristic due to the intrinsic elastic properties of steel. It is evident that the load carrying capacity and deflection capacity depends on the reinforcement ratio of the mangrove: the higher the reinforcement ratio of the mangrove, the higher the load carrying and deflection capacity. As illustrated by the doted lines, the Figures also indicate a lower elastic stiffness of the mangrove reinforced beams as compared to that of the control steel beam attributable to the lower modulus of elasticity of mangrove poles. However, the post-elastic stiffness of mangrove reinforced beams seems to be higher than that of steel reinforced beams.

(a) Failure Pattern of BR4MPΦ30C20

(b) Failure Pattern of BR4MPΦ25C20

(c) Failure Pattern of BR4MPΦ20

(d) Failure Pattern of BR2MPΦ30C20

(e) Failure Pattern of BR2MPΦ25C20

(f) Failure Mode of BR2MPΦ20C20

Figures 4.12: Failure Pattern of Beams C20

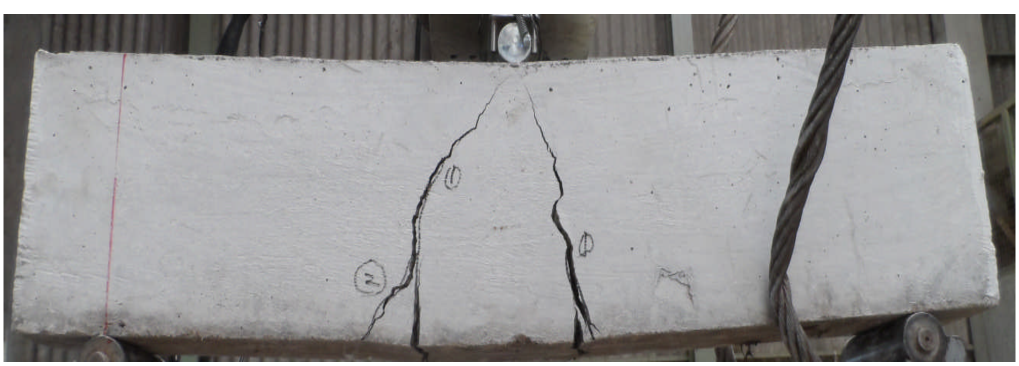


Figure 4.13: Failure Pattern of BR4SBΦ10C20 (Control Beam)

Figure 4.14: Crack of Mangrove Pole inside the Beam

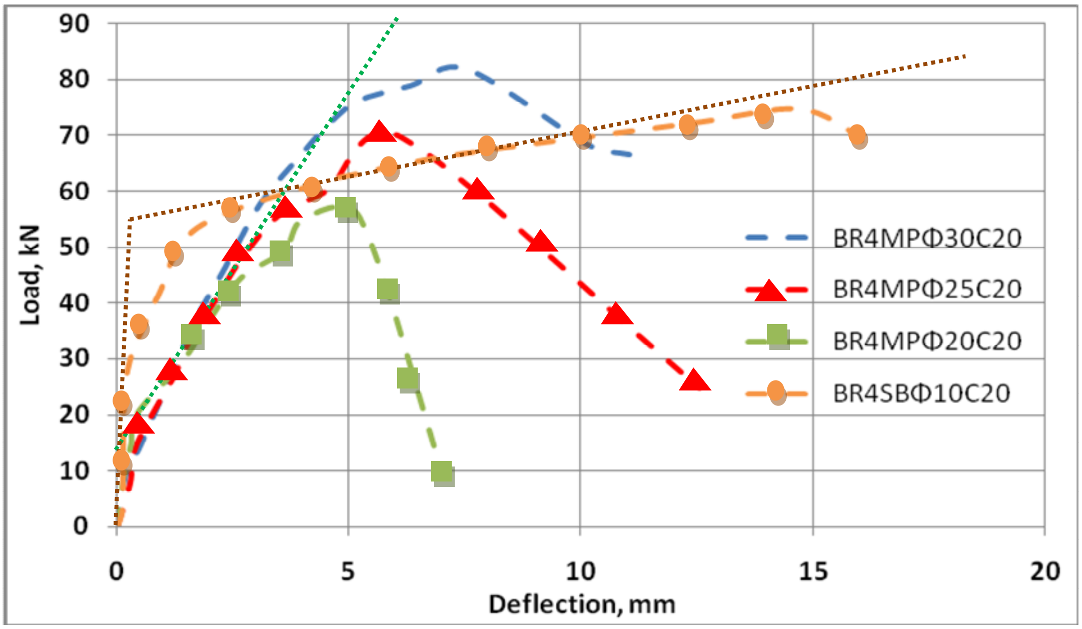


Figure 4.15: Load-Deflection Curve for Doubly Mangrove Reinforced Beams C20

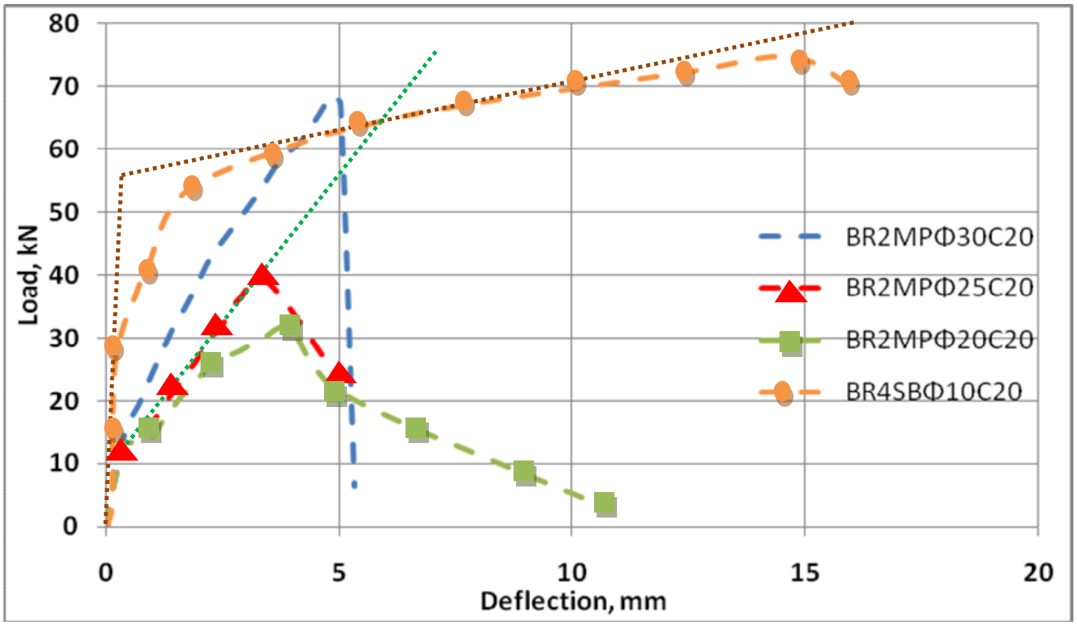


Figure 4.16: Load-Deflection Curve for Singly Mangrove Reinforced Beam C20

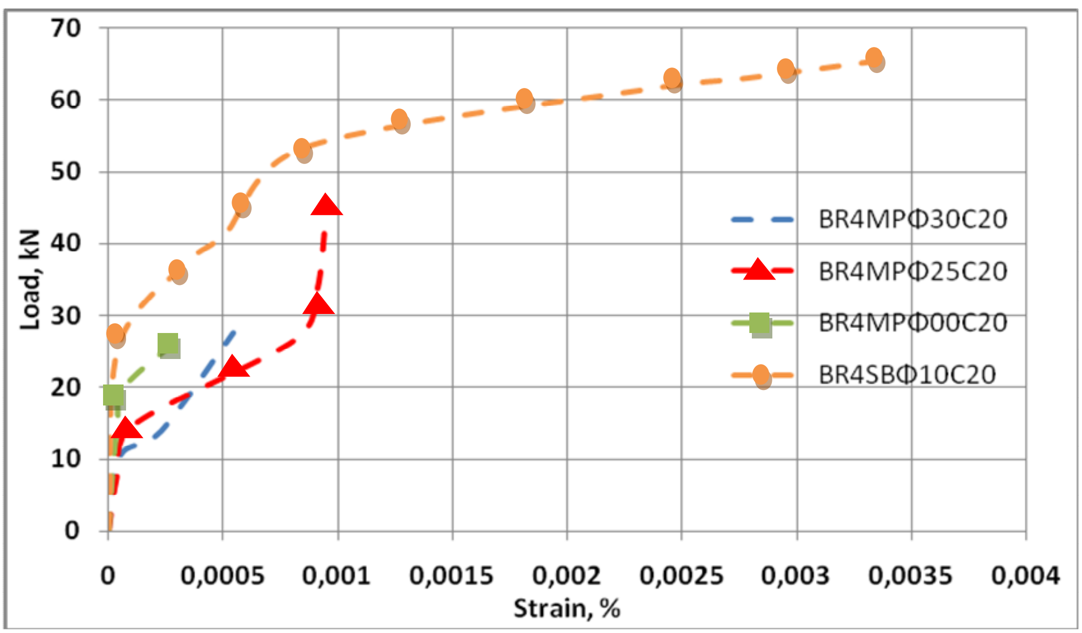


Figure 4.17: Load-Stain Curves of Reinforcements in Beams C20 Doubly Reinforced

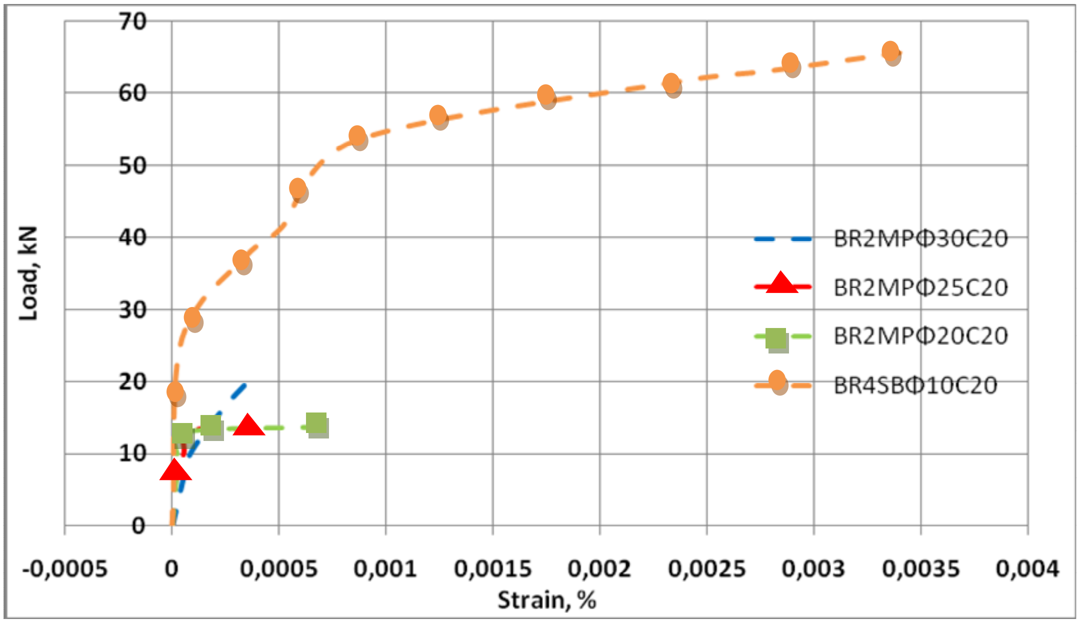


Figure 4.18: Load-Stain Curves of Reinforcements in Beams C20 Singly Reinforced

From Figure 4.17 and 4.18, it can be seen that there is linear elastic strain behavior until first crack where by nonlinear behavior is noted. The strain in the steel is much higher than this in the mangrove.

c) Beam C20 Failure Modes

The test results from Table 3 shows that the beams with 7.80% mangrove reinforcement ratio (BR4MPΦ30) failed in flexure accompanied by more shear cracks near the support on the left side as seen in Figure 4.12.a. This could be as a result of a higher reinforcement ratio and thus ability to carry more load than the other beams including the control beams. Beams BR4MPΦ25C20 and BR4MPΦ20C20 failed in bending accompanied by one shear crack near the support on the right side as shown in Figure 4.12.b and 4.12.c respectively. These two beams (BR4MPΦ25C20 and BR4MPΦ20C20) had almost the same failure mode; the only difference is that the first bending crack of BR4MPΦ25C20 did not occur exactly at the center of the beam but a bit more to the left giving way to a second crack opposing it to the right near the center as well (see Figure 4.12.b). While the first crack of BR4MPΦ20C20 occurred at the center of the beam and vertically from the bottom to the top as shown in Figure 4.12.c, BR2MPΦ30C20 failed in bending by a central vertical crack accompanied by small cracks both on the left and right side of the beam as shown in Figure 4.12.d. It is noted in Figure 4.12.d that a piece of concrete fell out from the lower section of the beam, revealing a nearly perfect imprint of the mangrove reinforcement. This suggested a poor bonding between the concrete and mangrove, leading to bond failure. Upon examining the beam at the region of failure crack (Figure 4.14) the mangrove pole in tension seemed to be broken, leading to the assumption that the beam failed in due to existence of knot defect. However, failure pattern of BR2MPΦ25C20 and BR2MPΦ20C20 are similar, both of them failed in bending by only one vertical crack more or less at the center from the bottom to the top of the beam. While BR4SBΦ10C20 failed in bending with high ductility. During test, two vertical cracks occurred on BR4SBΦ10C20 equidistant from each other from the center as shown in Figure 4.13. It was noted that during testing all the beams reinforced with mangrove poles failed suddenly accompanied by a loud deep sound due to mangrove cracking and failed at the maximum load, while the beam reinforced with steel shows a ductile failure behavior.

4.2.4 Summary of Beams Results

Figure 4.19 gives the bar chart for ultimate loads of beams and Table 4.3 summarizes the results of all beam tests performed for the research namely: cracking loads and their moments, ultimate loads carrying capacity and their moments and the maximum deflections of singly reinforced beams and doubly reinforced beams cured at 28 days. It also shows the compressive and tensile strengths of concrete cylinder, the results of the slump tests, and the reinforcement ratio of every beam.

The targets of compressive strengths of concrete cylinder in this study are 30, 25 and 20 N/mm^2. However, the results are slightly different as shown in Table 4.3 because of different variables which are parameters of material properties, mixing procedure and curing condition in the laboratory. Average of compressive strengths are slightly below the target strengths although within and error margin of + or – 1 N/mm^2, while the tensile strength clearly confirms the poor tensional strength of concrete.

From Table 4.3, it can be seen that for each class of concrete the carrying capacity of the beam depended on the reinforcement ratio. As much bigger the reinforcement ratio is more loads the beam was able to carry. But the load carrying capacity of the beam did not depend on the class of concrete. The change of the load carrying capacity may be explained by the variation of diameter throughout the mangrove poles which cause them to break at the weak points and the defects on mangroves such as number and size of knots, splits, etc. However the usage of mangrove can be applicable particularly where loadings regimes can be accommodated within the mangrove strength.

Table 4.3: Summary of Beams Results

Specimen	δ_u (mm)	f_c(N/mm²)	f_t (N/mm²)	S (mm)	P_{cr}(kN)	M_{cr} (kNm)	P_u (kN)	δ_u (mm)	M_u (kNm)	Failure Mode
BR4MP Φ30 C30	5.3				31	7.0	79	5.3	17.8	Flexure + Shear
BR4MP Φ25 C30	3.5				26	5.9	60	3.5	13.5	Flexure + Shear
BR4MP Φ20 C30	3.6	29.1	3.3	54	19	4.3	34	3.6	8.7	Flexure
BR4SB Φ10 C30	17.6				27	6.1	67	17.6	15.1	Flexure
BR4MP Φ30 C25	8.5				19	4.3	96	8.5	18.0	Flexure + Shear
BR4MP Φ25 C25	5.5				17	3.8	64	5.5	14.4	Flexure
BR4MP Φ20 C25	5.9	24.5	2.7	47	20	4.5	54	5.9	12.2	Flexure
BR4SB Φ10 C25	16.5				27	6.1	67	16.5	15.1	Flexure
BR4MP Φ30 C20	7.5				11	2.5	82	7.5	18.5	Flexure + Shear

BR4MP Φ25 C20	6.1				15	3.4	70	6.1	15.8	Flexure + Shear
BR4MP Φ20 C20	5.2				20	4.5	55	5.2	12.4	Flexure + Shear
BR4SB Φ10 C20	14.7				41	9.2	75	14.7	16.9	Flexure
BR2MP Φ30 C20	4.8	19.3	2.3	51	17	3.8	69	4.8	15.5	Flexure
BR2MP Φ25 C20	3.5				16	3.6	39	3.5	8.8	Flexure
BR2MP Φ20 C20	4.0				14	3.2	31	4.0	7.0	Flexure

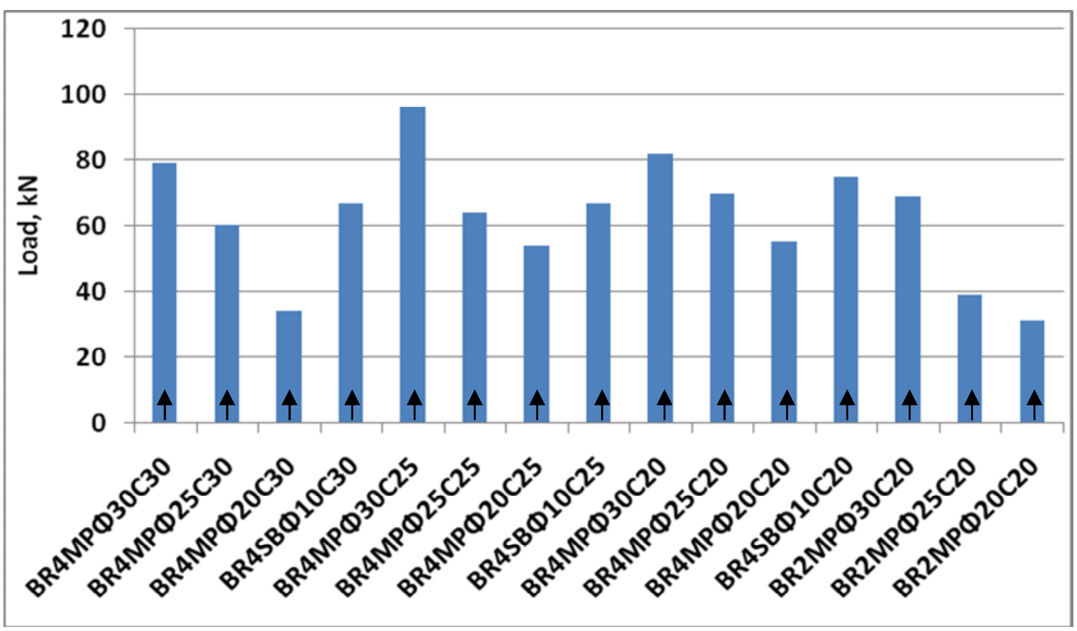


Figure 4.19: Bar Chart for Ultimate Load (P_u) of Beams

It is also important to point out that the entire beams reinforced with mangrove poles had some defects in them which are cracks before the test commenced. These defects can be explained by the dimensional variation of untreated mangroves due to water absorption which has caused micro and even macro cracks in cured concrete as shown in Figures 4.20. During the casting and curing of concrete, reinforcing mangroves have absorbed water and expanded. The swelling of mangroves have pushed the concrete away. Then at the end of the curing period, the mangroves have lost the moisture and shrunk back almost to their original dimensions leaving voids around themselves which lead to cracks appearing on the beams. The dimensional changes of mangrove due to moisture variation will surely influence the bond characteristics severely. The sizes and the number of cracks vary according the sizes of the reinforcements or reinforcement ratio: the bigger the reinforcement ratio of the mangrove poles the bigger and numerous the cracks appeared on the beam, the smaller the reinforcement ratio of the mangrove poles the lesser and smaller the cracks appeared on the beam.

(a) Cracks on the Top Surface of the Beam

(b) Cracks on the Lateral Surface of the Beam

Figures 4.20: Longitudinal Cracks on the Beam before Test

4.3 Comparison of Compressive Strength of Columns Reinforced with Mangrove and Steel

4.3.1 C30 Reinforced Concrete Columns

a) Compressive and Tensile Strength of Cylinder for ColumnsC30

The target of compressive strength of concrete cylinder in this part of study was 30 N/mm². However, twenty eight day average compressive strength of concrete was 28.3 N/mm², while the average tensile strength was established to be 3.1 N/mm².

b) Cracking Behavior of Mangrove Reinforced Concrete Columns C30

During the test of columns C30 reinforced with mangrove poles, the cracks started from the top to the center, went beyond the center towards the bottom at around one third of the columns height for CR4MPΦ11C30 and CR4MPΦ8C30 (see Figure 4.21.b and 4.21.c), and reached the bottom for CR4MPΦ14C30 (see Figure 4.21.a). The size of the cracks is proportional to the volume of reinforcement ratio, the bigger the reinforcement ratio the more the cracks appear on the concrete. Figure 4.21 shows the spalling of the concrete constituting the cover and the mangrove pole and shear link inside the concrete column of CR4MPΦ11C30 can be seen (Figure 4.21.b). After the test was completed, an investigation of crack patterns was done on the columns and it was found that mangrove poles have remained unaffected. Control column reinforced with steel (CR4SBΦ8C30) has its cracks started from the top, extending to the centre (see Figure 4.22.a) where its failure load occurred with less cracks as compared to the columns reinforced with mangrove poles. However the failure of plain concrete column (PCCC30) was sudden at the maximum load where the majority of cracks appeared. This shows a brittle behavior of the plain column for there will not be visible cracks up to about 90% of the applied; most of the cracks were appeared at the maximum load. Using such material for buildings is too risky. Figure 4.22.b shows the mode of failure of the plain concrete column (PCCC30).

c) Axial Load Capacity of Mangrove Reinforced Columns C30

From Figure 4.23, the capacity of the columns (strength) is independent on the mangrove reinforcement for the maximum axial load carried by the plain column (PCCC30) is higher than those carried by the columns reinforced with mangrove poles. However, the ductility of the columns depended on the mangroves reinforcement since there is remarkable difference between the cracking load and the ultimate failure load in all the different percentages of mangroves reinforcement unlike the plain concrete column, which has both its cracking and failure load at 241 kN. The curves from Figure 4.23 show that the increase in the percentage volume of mangrove in the concrete section resulted in reduction of load carrying capacity and ductility. The load carrying capacity of the steel reinforced control beam definitely has higher load capacity which is noted to be approximately 252 kN (Figure 4.23: CR4SBΦ8C30) while that of the pole mangrove reinforced columns, apparently is lower with the highest being 208 kN (CR4MPΦ8C30) and lowest being 129 kN

(CR4SCMPΦ14C30). Although unreinforced concrete column (PCCC30) showed also remarkable compressive load caring capacity, none the less, the usage of the columns reinforced with mangrove is preferable to the plain concrete columns because of their ductility behavior and cost reductions and in any case the mangrove can only be applied where loadings regimes can be accommodated within the mangrove strength.

(a) CR4MPΦ14C30 (b) CR4MPΦ11C30 (c) CR4MPΦ8C30

Figures 4.21: Failure Mode of Columns C30

(a) CR4SBΦ8C30 (b) PCCC30

Figures 4.22: Failure Mode of Control Columns C30

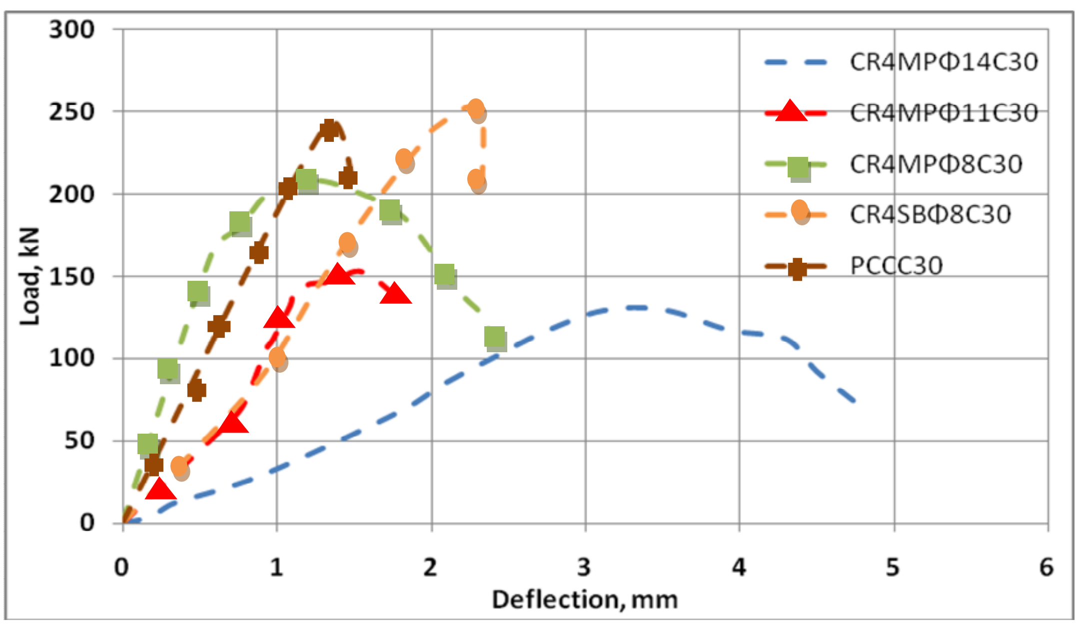


Figure 4.23: Load-Deflection Curves of Columns C30

4.3.2 C25 Reinforced Concrete Columns

a) Compressive and Tensile Strength of Cylinder for Columns C25

The target of compressive strength of concrete cylinder of 100 mm diameter and 200 mm height in this part of study was 25 N/mm². However, twenty eight day average compressive strength of concrete was 24.2 N/mm², while the average tensile strength was established to be 2.9 N/mm².

b) Cracking Behavior of Mangrove Reinforced Concrete Columns C25

Columns of class C25, have their cracks starting from the top to the center and reached the bottom for all columns except the plain concrete column (PCCC25) where the cracks reach around two third of the height of the column towards the bottom (see Figure 4.25.b). Columns CR4MPΦ14C25 and CR4MPΦ11C25 have more cracks than CR4MPΦ8C25 and CR4SBΦ8C25. This might be caused by the effect of shrinkage of mangrove poles inside the concrete which has created larger voids between the concrete and the mangrove poles for bigger reinforcement ratio and lesser voids for columns reinforced with smaller reinforcement ratio vice versa. Plain concrete column (PCCC25) has a brittle behavior for it did not show any post yielding behavior before failure as shown in Figure 4.26. Columns reinforced with mangrove poles had more ductility than the control column reinforced with steel.

c) Axial Load Capacity of Mangrove Reinforced Columns C25

Figure 4.26 shows the load-deflection curves of columns of concrete class C30. The load carrying capacity of the steel reinforced control beam definitely has higher load capacity which is noted to be approximately 214 kN (CR4SBΦ8C25), while that of the mangrove reinforced columns, apparently is lower with the highest being 166 kN

(CR4MPΦ8C25) and lowest being 112 kN (CR24SCMPΦ14C25). The capacity (strength) of the column C25 is independent on the mangrove reinforcement for the maximum capacity load of plain concrete is higher than those of the columns reinforced with mangrove poles, whereas ductility of the columns depended on the mangrove reinforcement (Figure 4.26). The Figure 4.26 shows that the increase in the percentage volume of mangrove poles in the concrete section resulted in reduction of load carrying capacity. Although unreinforced concrete column showed also remarkable compressive load caring capacity, none the less, the usage of the columns reinforced with mangrove is preferable to the plain concrete columns because of their ductility behavior and cost reductions and in any case the mangrove can only be applied where loadings regimes can be accommodated within the mangrove strength.

(a) CR4MPΦ14C25 (b) CR4MPΦ11C25 (c) CR4MPΦ8C25

Figures 4.24: Failure Mode of Columns C25

(a) CR4SBΦ8C25 (b) PCCC25

Figures 4.25: Failure Mode of Control Columns C25

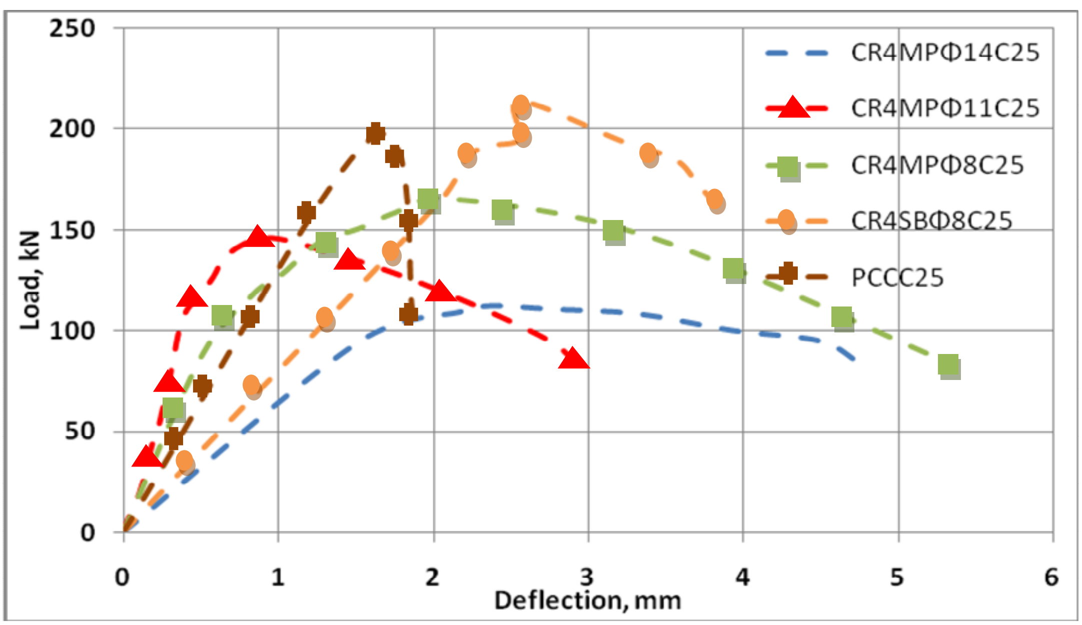


Figure 4.26: Load-Deflection Curves of Columns C25

4.3.3 C20 Reinforced Concrete Columns

a) Compressive and Tensile Strength of Cylinder for Columns C20

The target of compressive strength of concrete cylinder in this part of study was 20 N/mm². Twenty eight day average compressive strength of concrete was 18.7 N/mm² for the batch of concrete used to cast columns reinforced with four mangrove poles and 19.2 N/mm² for the batch of concrete used to cast columns reinforced with single central mangrove pole. While their average tensile strengths were established to be 2.6 N/mm² and 2.5 N/mm² respectively.

b) Cracking Behavior of Mangrove Reinforced Concrete Columns C20

There are two types of reinforcement mode of columns C20: columns with four reinforcements and columns with single central reinforcement as shown in Figure 3.34. Failure modes of columns reinforced with four mangroves poles (Figures 4.27: CR4MPΦ14C20, CR4MPΦ11C20 and CR4MPΦ8C20) occurred with more cracks as compared to the control column reinforced with steel (CR4SBΦ8). Columns reinforced centrally with single mangrove pole (Figures 4.28: CRSCMPΦ24C20, CRSCMPΦ20C20, CRSCMPΦ16C20) had majority central cracking along the four faces of the columns. First cracks started from the top extending to the bottom at ultimate failure with concrete spalling as shown in Figure 4.27 (a-c). Failure of the Control columns (Figures 4.29: CR4SBΦ8 and PCC) appear to crush with cracks limited to the upper quarter part of the columns. The vertical cracks running through the columns height are noted to be absent; an indication that the cause for the same in the mangrove poles reinforced columns is by the presence of the mangrove poles. The likely reason for this phenomenon could be attributed to the poor bonding characteristics between the concrete and the mangrove poles. Generally cracking was noted to be depended on the reinforcement ratio and position of the of mangrove pole in the column. It was established that the higher the reinforcement ratio the more and wider the cracks. It was noted the first cracking for the four mangrove poles reinforced columns occurred at about 70-90% while that of central singly mangrove pole reinforced columns was within 50-60% of the maximum axial load.

c) Axial Load Capacity of Mangrove Reinforced Columns C20

Figure 4.30 and 4.31show the load-deflection curves of columns reinforced with four mangrove and single central mangroves poles respectively. The load carrying capacity of the steel reinforced control column definitely has higher load capacity which is noted to be approximately 152 kN (CR4SBΦ8C20), while that of the four pole mangrove reinforced columns, apparently is lower with the highest being 138 kN (CR4MPΦ11C20) and lowest being 104 kN (CR24SCMPΦ14C20). Same trend is noted in the single centrally reinforced mangrove reinforced columns where the highest load is 137 kN (CRSCMPΦ20C20) against a lower value of 106 kN (CRSCMPΦ24C20). The trend confirms a decreasing load carrying capacity with increasing mangrove reinforcement ratio. Conversely, it is noted that ductility is determined by the position of the mangrove poles and reinforcement ratio in the columns. Four mangrove reinforced columns (Figures 4.30: CR4MPΦ8C20, CR4MPΦ11C20, CR4MPΦ14C20) show generally higher displacement values as compared to that of single central mangrove reinforced columns (Figures 4.30: CRSCMPΦ16C20, CRSCMPΦ20C20, CRSCMPΦ24C20). Although unreinforced concrete column showed also remarkable compressive load caring capacity, none the less, the usage of the columns reinforced with mangrove is preferable to the plain concrete columns because of their ductility behavior and cost reductions and in any case the mangrove can only be applied where loadings regimes can be accommodated within the mangrove strength.

(a) CR4MPΦ14C20 (b) CR4MPΦ11C20 (c) CR4MPΦ8C20

Figures 4.27: Failure Mode of Columns C20 Reinforced with Four Mangroves

(a) CRSCMPΦ24C20 (b) CRSCMPΦ20C20 (c) CRSCMPΦ16C20

Figures 4.28: Failure Mode of Columns C20 Reinforced with Single Central Mangroves

(a) CR4SBΦ8C20 (b) PCCC20

Figures 4.29: Failure Mode of Control Columns C20

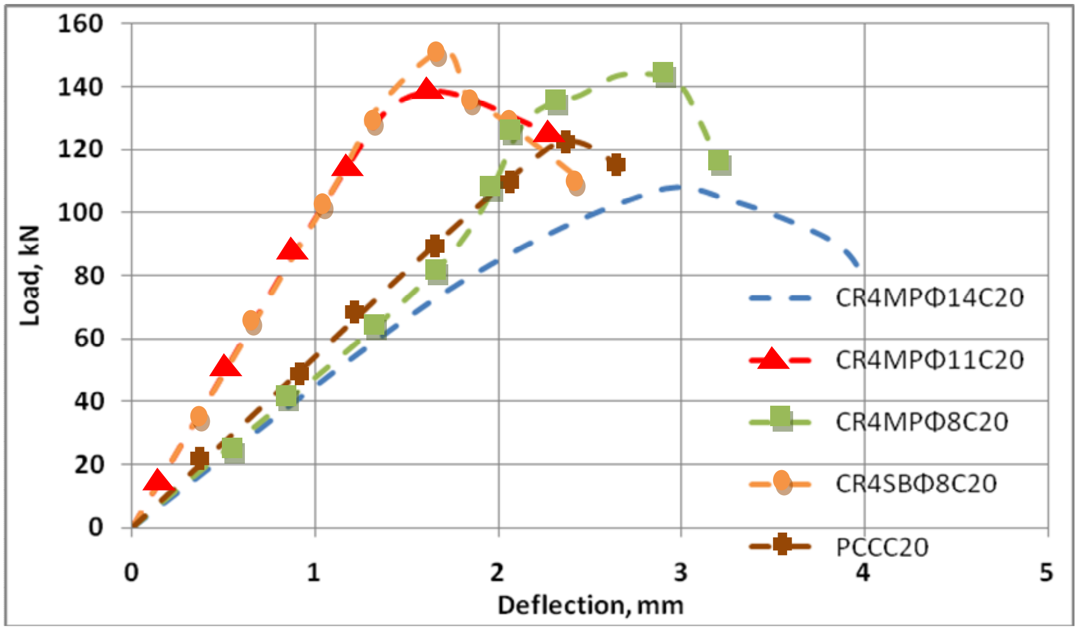


Figure 4.30: Load-Deflection Curves of Columns C20 Reinforced with Four Mangroves

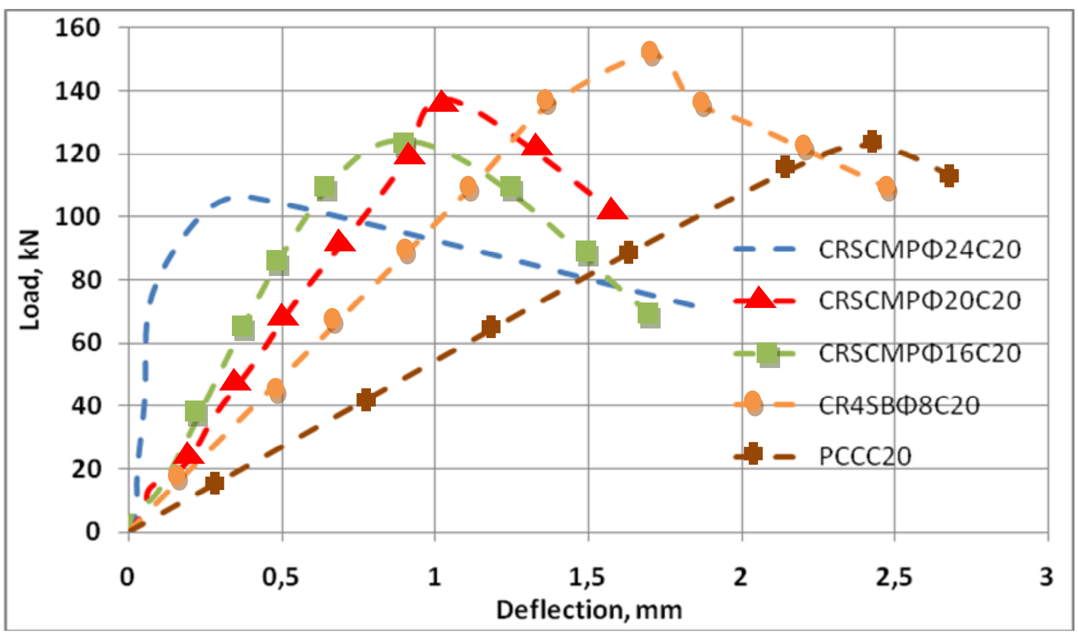


Figure 4.31: Load-Deflection Curves of Columns C20 Reinforced with Single Central Mangrove

4.3.4 Comparison of Theoretical and Actual Results of Columns

An American concrete Institute ACI318-05 equation on axial load capacity has been applied by other researchers on bamboo reinforced columns Satjapan et al. (2010). It is noted that the yield load or the axial maximum load of reinforced concrete column is the sum of yield strength of the reinforcement plus the strength of concrete. Consequently Equation (4.1) below has been used to determine the theoretical maximum load of axially loaded columns in this study.

$$P_o = 0.85f_{cu} (A_g - A_{sc}) + A_s f_y \quad (4.1)$$

Where A_g is the gross area of the cross section, A_{sc} is the total area of longitudinal reinforcement in the column section, f_{cu} is the compressive strength of a concrete cylinder, and f_y is the yield strength of the reinforcement whether steel or mangrove. Most of the times, equation (4.1) is widely used for reinforced concrete columns with conventional steel reinforcements. In the case of this study, not only columns reinforced by steel reinforcement were compared with Equation (4.1), but columns reinforced by reinforcing mangrove were investigated and compared as well.

Comparison of the experimental values obtained was compared with those obtained from equation (4.1) above were as shown in Table 4.4. It is can be observed from the results that all columns with the ratio of the maximum load, P_{max} to the maximum load provided by ACI318-05, P_o (P_{max}/P_o) is on average 0.9, with most of the mangrove reinforced columns results yielding ratios equal or more than 1.0. This confirms the applicability of the equations in design in the case where mangrove reinforcements are to be applied in concrete column. Moreover, theoretical results also qualify experimental results obtained in the research as far as mangrove reinforcement is concern. Those columns are CR4MPΦ8C30, PCCC30, CR4MPΦ8C25, PCCC25, CR4MPΦ11C20, CR4MPΦ8C20 and CRSCMPΦ20C20. But PCCC30 and PCCC25 are advised not to be used in construction because they are considered as brittle material. From the results, it can be seen that most of the columns C20 have satisfied both experimental and theoretical conditions. Thus the use of mangrove as reinforcement in columns might be recommended with low concrete strength.

4.3.5 Summary of Columns Results

Figure 4.32 gives the bar chart for ultimate loads of columns. Table 4.4 shows the results of compressive and tensile strength test of concrete cylinder of 100 mm diameter and 200 mm height for 28 days. The target of compressive strength of concrete cylinder in this part of study was 20 N/mm². Three different target compressive strengths of concrete cylinders for casting columns were determined. These were 30, 25 and 20 N/mm². After testing the cylinders the results were slightly different as shown in Table 4.4 because of variable parameters of material properties, mixing procedure and curing condition in the laboratory. However, average compressive strengths are slightly below the target strength although within and error margin of + or – 2 N/mm^2, while the tensile strength clearly confirms the poor tensional strength of concrete.

The test results of the entire axial compressive tests of columns are summarized in Table 4.4. Columns with four reinforcements had most of their cracks at about 70 - 90% of the maximum axial force. This range decreases as the volume of reinforcement increases. Columns reinforced with single central mangrove have most of their cracks visible at around 50 – 60% of the maximum axial force. From Table 4.4 it can be seen that the maximum load and ductility increase as the reinforcement ratio of mangrove poles decrease. Columns reinforced with steel and plain concrete columns for each class of concrete have carried more loads except PCCC20 where CR4MPΦ11C20 and CR4MPΦ8C20 have carried more load. Because of the ductility the plain concrete columns are advised not to be used in construction. While most of the columns reinforced with mangrove poles have good ductility some of them have their ductility higher than this of steel reinforced column of the same class of concrete (columns C25 and C20). The absorption of water by mangrove poles during the period of casting and curing had caused weak bond characteristic between them and concrete. However their applicability is advised where loadings regimes can be accommodated within the mangrove strength rather than plain concrete column.

Table 4.4: Experimental and Theoretical Results of Columns

Specimen	**δ_u (mm)**	**f_c(N/mm^2)**	**f_t (N/mm^2)**	**S (mm)**	**P_u(kN)**	**P_y (kNm)**	**P_o (kN)**	**P_u/ P_o**	**δ_u (mm)**	**δ_y (mm)**	**$\mu = \delta_u/\delta_y$**
CR4MP Φ14C30	8.2				129	125	200	0.65	3.30	2.00	1.65
CR4MP Φ11C30	5.1				153	75	193	0.79	1.60	0.8	2.00
CR4MP Φ8C30	2.7	28.3	3.1	52	208	100	188	1.11	1.2	0.55	2.18

CR4SB Φ8C30	2.7				252	85	256	0.98	2.31	0.90	2.57
PCC C30	0				241	241	182	1.18	1.31	1.31	1.00
CR4MP Φ14C25	8.1				112	80	176	0.64	2.37	1.80	1.32
CR4MP Φ11C25	5.0				146	112	168	0.87	0.92	0.50	1.84
CR4MP Φ8C25	2.7	24.2	2.9	49	166	75	162	1.03	2.08	0.70	2.97
CR4SB Φ8C25	2.7				214	162	230	0.93	2.56	2.10	1.22
PCC C25	0				196	196	156	1.26	1.59	1.59	1.00
CR4MP Φ14C20	8.2				107	100	143	0.75	2.84	2.70	1.05
CR4MP Φ11C20	5.1				139	130	135	1.03	1.68	1.30	1.29
CR4MP Φ8C20	2.6	19.3	2.3	51	144	80	128	1.13	2.68	1.70	1.58
CR4SB Φ8C20	2.7				152	128	195	0.78	1.70	1.30	1.31

PCC C20	0				120	120	121	0.99	2.28	2.28	1.00
CRSCP Φ24C20	6.1				106	68	140	0.76	0.40	0.15	2.67
CRSCP Φ20C20	4.2	19.2	2.5	54	137	120	135	1.02	1.05	0.90	1.17
CRSCP Φ16C20	2.7				123	100	131	0.94	0.82	0.60	1.37

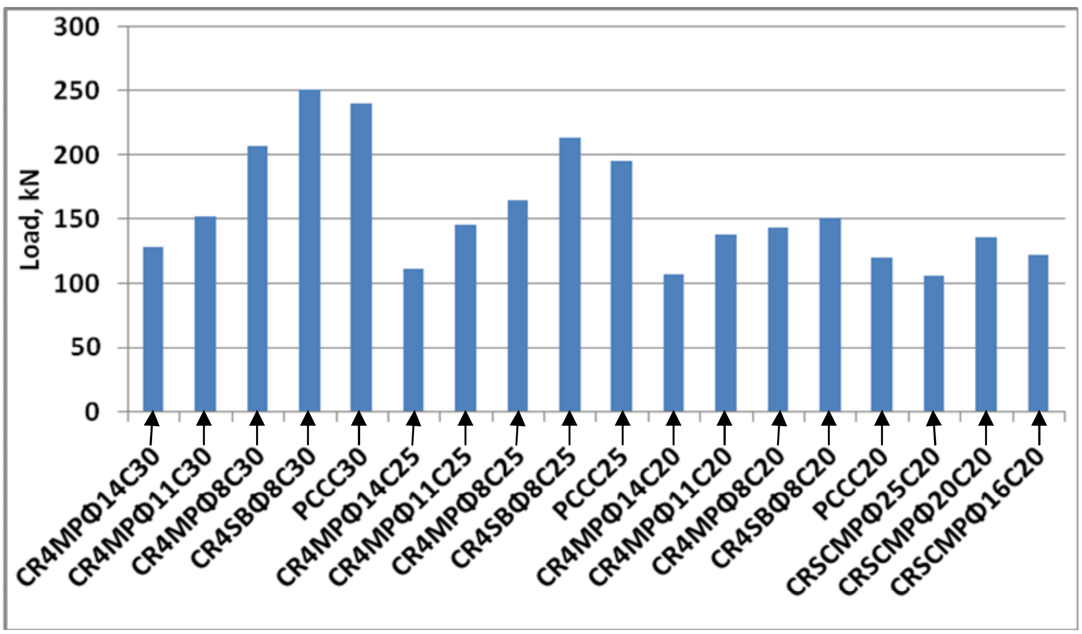


Figure 4.32: Bar Chart for Ultimate Load (P_u) of Columns

The results of the columns are given by class of concrete strength i.e the columns of class C30 are compared with one another and so are those of C25 and C20. There were two types of reinforcement mode of Columns with class of concrete C20 namely: columns reinforced with four mangrove poles and columns reinforced with single central mangrove poles and of them had the same controls (CR4SBΦ8 and PCCC20). The columns reinforced with mangrove poles presented some cracks before the test begun. This might be explained by the water absorbed by mangrove poles and had caused a weak bonding characteristic between mangrove poles and concrete during the period of curing of concrete. However, columns reinforced with mangrove poles of 24 mm and 20 mm of diameter (CRSCMPΦ24C20 and CRSCMPΦ20C20), had wider cracks before they were subjected to test as shown in Figure 4.33. During test, the first cracks of columns are mostly dependent on the strength of the concrete, while the ultimate failures correspond to the loads at which the columns refused to take more loads due to the failure of the composite materials, that is, additional loads after the cracking is taken by the reinforcement.

Figure 4.33: Crack of Column Reinforced with Mangrove Pole Before Test

CHAPTER 5

CONCLUSIONSAND RECOMMANDATIONS

5.1 Conclusions

This study evaluated the feasibility of using mangrove pole as a potential reinforcement in concrete structural members. To achieve this objective preliminary tests on mechanical properties of mangrove were done followed by three point bending tests of concrete beams reinforced with mangrove and axial compressive tests on mangrove reinforced columns in order to characterize the performance of mangrove as reinforcement. Beams reinforced with mangroves were compared with the control steel reinforced concrete beams; columns reinforced with mangroves were compared with the control steel reinforced concrete columns and plain concrete columns. Based upon the tests conducted, the following conclusions are drawn:

1. It is determined from material property tests that mangrove poles possess lower tensile strength than that of steel, approximately 14.6% of that of steel.

2. From the flexural test on mangrove reinforced beams, it is demonstrated that using mangrove as reinforcement in concrete increases the load carrying capacity of reinforced concrete beam having the same dimensions. For doubly mangrove reinforced concrete beams, the load carrying capacity increased by about 1.6 times than that of singly mangrove reinforced concrete beam having same dimensions. Flexural test results further show that the deflection at ultimate load of doubly reinforced beam is about 1.5 times than that of singly reinforced beam.

It is also determined that the sizes and the number of cracks vary according the sizes of the reinforcements or reinforcement ratio: the higher the reinforcement ratio of the mangrove poles the bigger and numerous the cracks appeared on the beam. Mangrove does not improve the post cracking ability of the concrete.

3. Increase in reinforcement ratio of mangrove reinforcement in the concrete columns does not lead to corresponding increase in ultimate load carrying capacity. However, the location and the mangrove reinforcement ratio lead to enhanced ductility of concrete column.

5.2 Recommendations

In view of what has been established in this research, the following recommendations on future research are proposed:

1. Pull-out tests should be conducted with treated and untreated mangrove poles as well as with different waterproofing agents and bonding applications should investigated in order to establish the necessary conditions for better bonding between the concrete and mangrove.

2. In this study, mangroves used for the beams reinforcement were untreated, that has caused cracks to appear on the surfaces of concrete. However, it is suggested to treat the mangrove poles by using different waterproofing agents and accommodating bonding applications to investigate the necessary conditions for better bonding between the concrete and mangrove.

3. However, mangrove cannot be utilized in heavily loaded structural elements which ordinarily would use steel of larger reinforcement ratio. Applicability of mangrove would be more in less loaded structural elements such as in beams such as those found in load bearing structural walls.

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APPENDICES

Mangrove reinforced concrete design is similar to steel reinforcing design. By lack of any specific document on mangrove reinforced concrete, design method will be as indicated in work done by Brink and Rush (1966) on the design principles on bamboo reinforced concrete elements. From the results obtained in this study, it can be concluded that mangrove reinforcement has the following mechanical properties:

Table A.1: Mechanical Properties of Mangrove Reinforcement

Mechanical Property	Symbol	Value (N/mm^2)
Ultimate compressive stress		73
Allowable compressive stress		38
Ultimate tensile stress		193
Allowable tensile stress	σ	53
Modulus of elasticity	E	9774

As it is with bamboo, when design handbooks are available for steel reinforced concrete, the equations and design procedures can be used to design mangrove reinforced concrete if the above mechanical properties are substituted for the reinforcement.

Due to the low modulus of elasticity of mangrove, flexural members will nearly always develop some cracking under normal service loads. If cracking cannot be tolerated, steel reinforced designs or designs based on unreinforced sections are required.

A.1. Example of Design of a Mangrove Reinforced Beam

Design a mangrove reinforced concrete beam to span 3000 mm and to carry a uniform dead load plus live load of 7.5 kN/m and two concentrated loads of 55 kN each symmetrically located 500 mm each side of the center line of span as shown in Figure A.1. Assume the ultimate strength of the concrete is 20 N/mm²; the allowable compression stress is 0.45 f_c = 9 N/mm². Allowable unit diagonal tension stress, υ, in the concrete is 0.03 f_c =0.6 N/mm². Allowable tension stress, σ, in the mangrove is 53 N/mm²; the allowable unit bond stress between mangrove and concrete, u is assumed to be 1 N/mm².

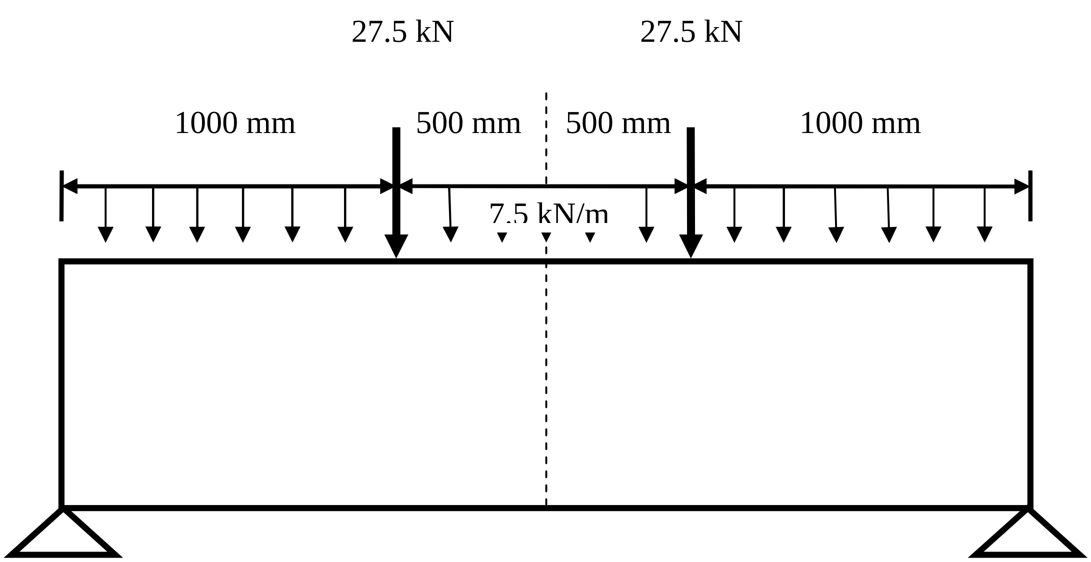


Figure A.1: Loading of Beam Reinforced Mangrove with Supports

1. Referred to Figure A.7, at the intersection of the allowable stress curves for concrete and mangrove, find R = 170 and ρ = 2.3 percent.
2. Maximum bending moment, M, is given by:

M = ((7.5) x (3²))/8 + (55) x (0.5) = 36 kNm (318627 in.-lb)

$R = M/bd^2$

3. From

   $bd^2 = 318627/170 = 1874$ in.^{3} (30709358.07 mm^3)

4. If b = 180 mm is chosen, then $d = (30725745.13/180)^{1/2} = 413$ mm.
5. Mangrove reinforcement = $\rho bd = (0.025) \times (180) \times (413) = 1858.5$ mm^2.
6. Use 25.4 mm of diameter of mangrove, area = 353.526 mm^2 from Table A.2. Number required = 1858.5/353.526 = 5.3; round up to 6.
7. Check the bond stress. Maximum shear at the support, V, is determined as:

   $V = (7.5 \times 3)/2 + 55 = 66.25$ kN

   The perimeter of one mangrove poles is (12.7) x (3.14) or 40 mm; the total perimeter of the longitudinal reinforcement, $\sum o$ is (6) x (40) = 240 mm. The value of j = 0.93 is taken from Figure A.7 for 2.3 percent reinforcement. The bond stress, u, is calculated from:

   $u = V/ (\sum o jd) = 66.25/ (240 \times 0.93 \times 413) = 0.00072$ N/mm^2

This is lesser than the allowable bond stress of 1 N/mm^2.

8. Calculate the shear, V', taken by the concrete from:

   $V' = \upsilon bjd = (0.6) \times (180) \times (0.93) \times (413) = 41481.72$ N/mm^2.

   Where υ is the allowable diagonal tension stress of the concrete.

9. Take 6 mm of diameter of steel for shear links. BS 8110 Part 1clause 3.4.5.5 stipulates that spacing (S) of links in the direction of the span should not exceed 0.75d, where d is the effective depth of the beam.

   $S = (0.75) \times 413 = 309.75$; take S = 200 mm.

Number of shear links for the beam = (3000 – 40)/200 = 15.8; round it up to 16. 40 in the calculation is the summation of cover on the both longitudinal end side of the beam.

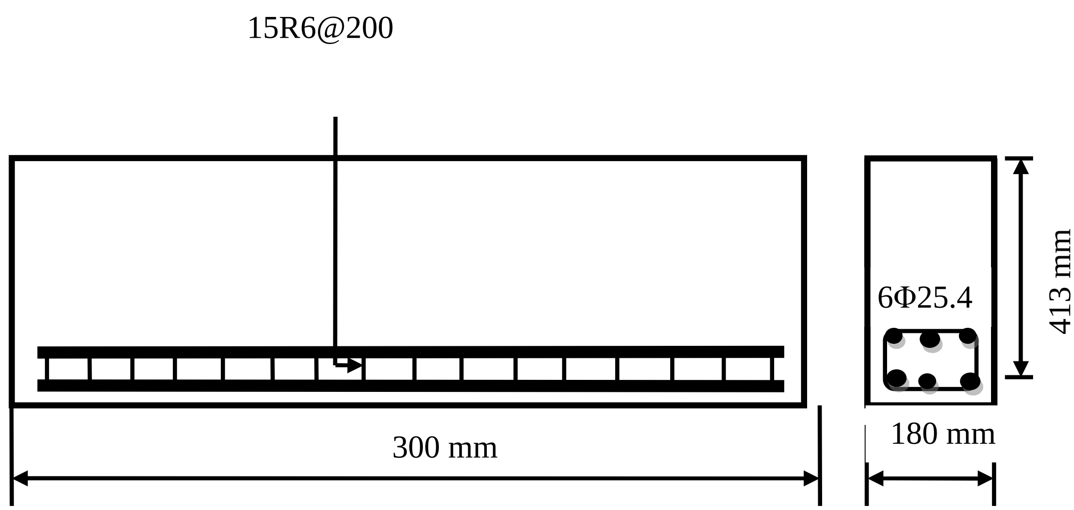


Figure A.2: Longitudinal and Cross-Section of the Mangrove Reinforced Concrete Beam

A.2. Example of Replacement of a Steel Reinforced Beam with a Mangrove Reinforced Beam

Construction drawings call for the beam given in the sketch below (Figure A.3). Replace it with a mangrove reinforced beam. There are no objections to deepening the member.

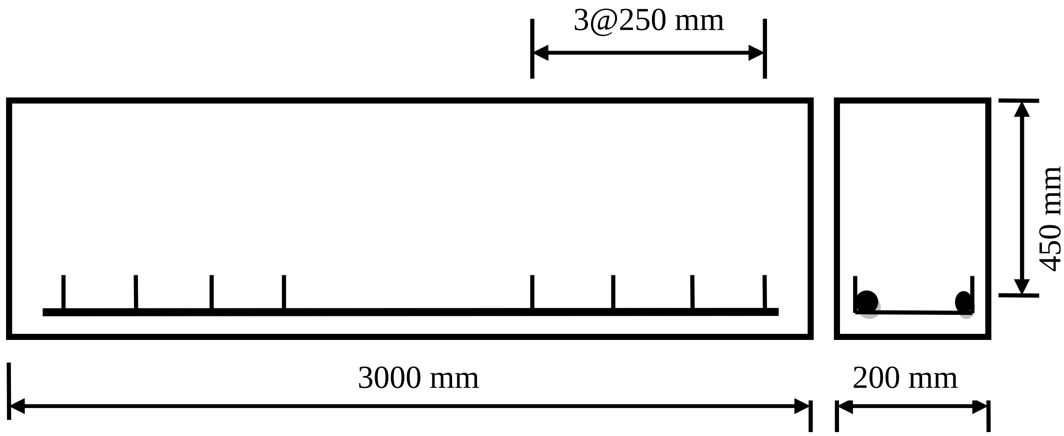


Figure A.3: Longitudinal and Cross-Section of the Steel Reinforced Concrete Beam

1. Select the cross-sectional dimensions from Figure A.8.a. Avoid using sections with depth (d) to width (b) ratios greater than 4 for reasons of stability.

   d/b = 450/200 = 2.25, ok

   Try width of 0.8b or 160 mm and a depth of 1.4d or 630 mm. The area is 100800 mm².

2. The amount of reinforcement can be selected from Figure A.8.b. Assume that 19.05 mm of diameter of mangrove poles will be used. The number of poles required for 100800 mm² is determined at around 20. This number of reinforcements should be-distributed evenly in five rows.

3. Take 6 mm of diameter of steel for shear links. Keep the same spacing of vertical shear links for the steel reinforced beam as that of the mangrove reinforced beam. The final design is shown in the following sketch (Figure A.4):

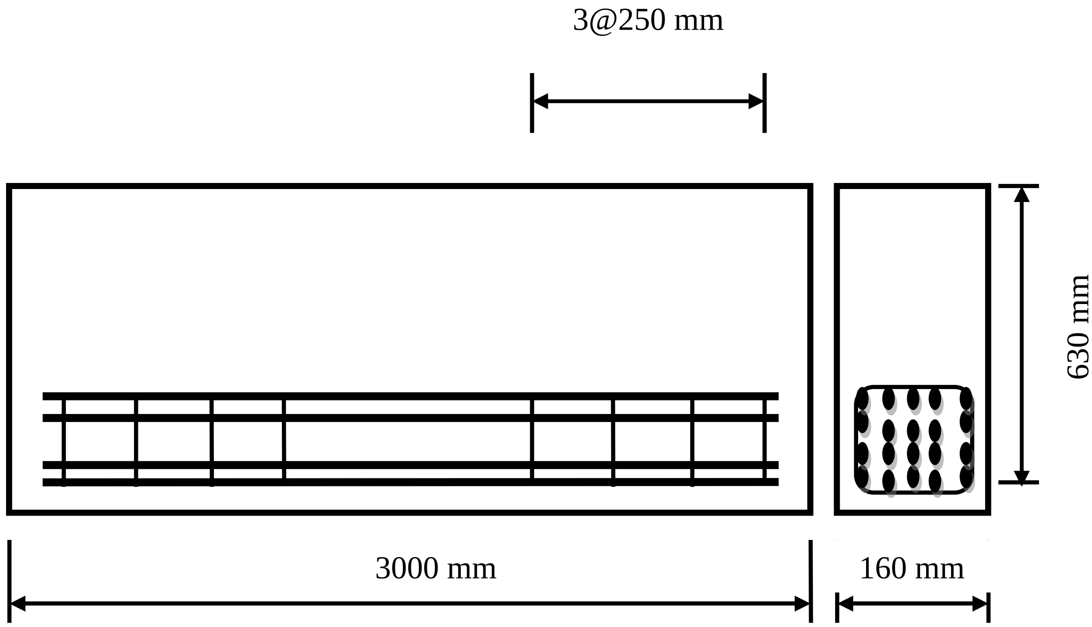


Figure A.4: Longitudinal and Cross-Section of the Mangrove Reinforced Concrete Beam Substituting Steel Reinforced Concrete Beam

A.3. Example of Square Mangrove Reinforced Column Design

Determine the cross section and mangrove reinforcement of a column required to carry an axial load of 250 kN. Ultimate compression strength of the concrete, f is 20 N/mm².

1. For an unreinforced rectangular column the safe axial load, P, is given by:

   $P = 0.8A_g\ (0.225\ f_c)$

   where A_g is the cross-sectional area of the concrete column.

2. The column should have a cross-sectional area of: A_g = (250000)/ ((0.8) x (0.225) x (20)) = 69444.4 mm².

3. If a square column is chosen, it will have face dimensions of:

   $b = (69444.4)^{1/2} = 264$ mm

4. The cross-sectional area is 69444.4 mm². Use 4 percent of the concrete area as vertical reinforcement. Figure A.8.b is used to determine the size and number of mangrove reinforcement. 19.05 mm of diameters of mangrove poles will be used. For a concrete area of 69444.4 mm², the number of these poles required is 13. Since Figure A.8.b provides 3 percent reinforcement, the number of poles should be multiplied by the ratio (4/3) to get 17.3. Thus, 18 poles should be used; these should be spaced evenly around the perimeter with 20 mm of cover. Lateral ties should be arranged as shown in Figure A.5.

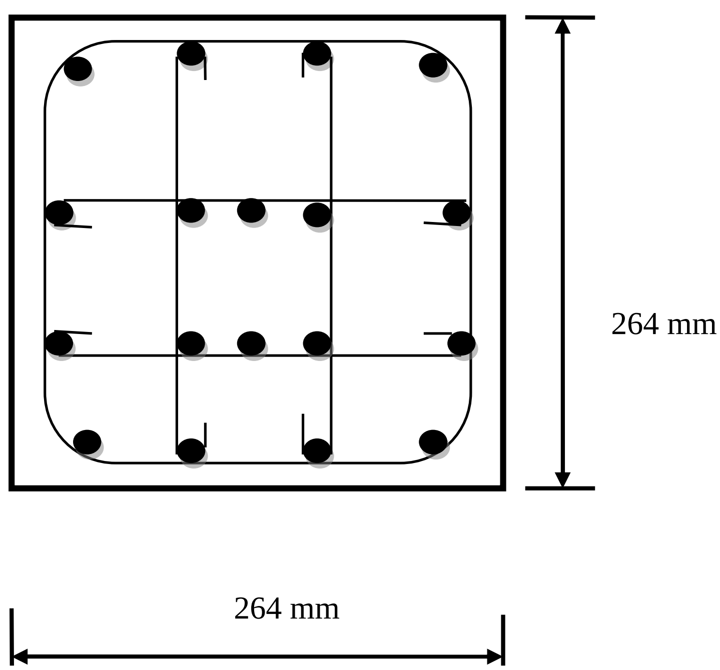


Figure A.5: Cross-Section of the Mangrove Reinforced Concrete Column

5. Shear links will be made with steel of 6 mm of diameter and the calculation is the same as indicated in BS 8110.

A.4. Example of Replacement of Steel Reinforced Square Column Design with Mangrove Reinforced Square Column

Construction drawings call for a 200 mm x 200 mm concrete column reinforced with 12 No. 6 steel reinforcing bars. Three No. 2 ties on 200 mm centers are required. Replace this column with a square column reinforced with mangrove.

1. The face dimensions should be increased by 50 percent. The mangrove reinforced column will have sides of 1.5(200) = 300 mm
2. The cross-sectional area is 300 x 300 = 90000 mm^2. Use 4 percent of the concrete area as vertical reinforcement. Figure A.8.b is used to determine the size and number of mangrove reinforcement. Assume 19.05 mm of diameter of mangrove poles will be used. For a concrete area of 90000 mm^2, the number of these poles required is 18. Since Figure A.8.b provides 3 percent reinforcement, the number of poles should be multiplied by the ratio (4/3); it should also be multiplied by the ratio (324/200) as a correction factor for concrete area. These multiplications indicate that 39 poles should be used.
3. Lateral ties should be arranged as shown in Figure A.6. The Determination for tie size and spacing are referred as to BS 8110.

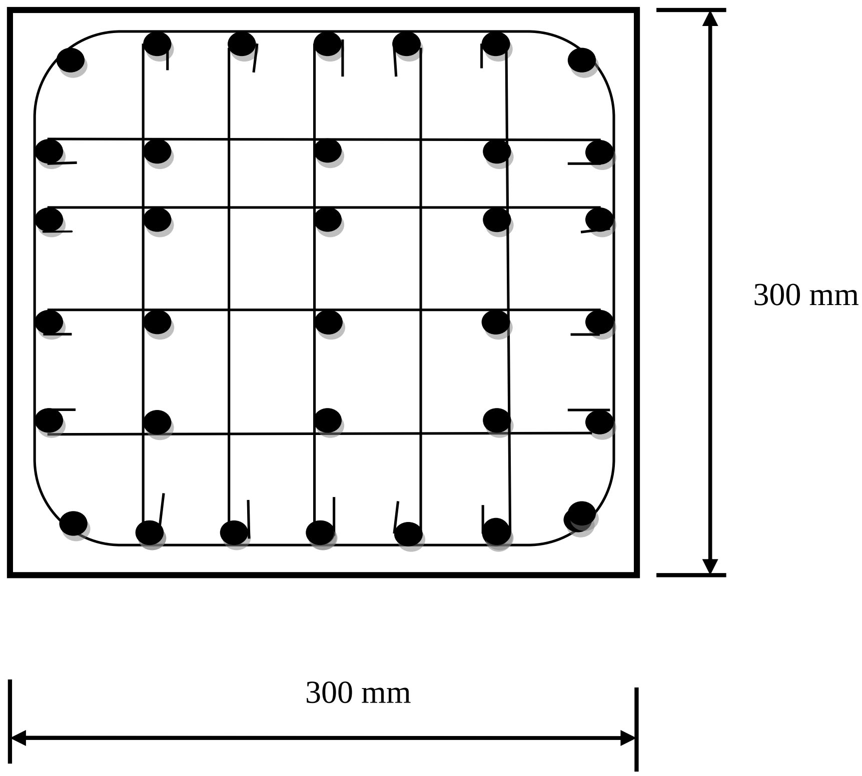


Figure A.6: Cross-Section of the Mangrove Reinforced Concrete Column Substituting Steel Reinforced Concrete Column

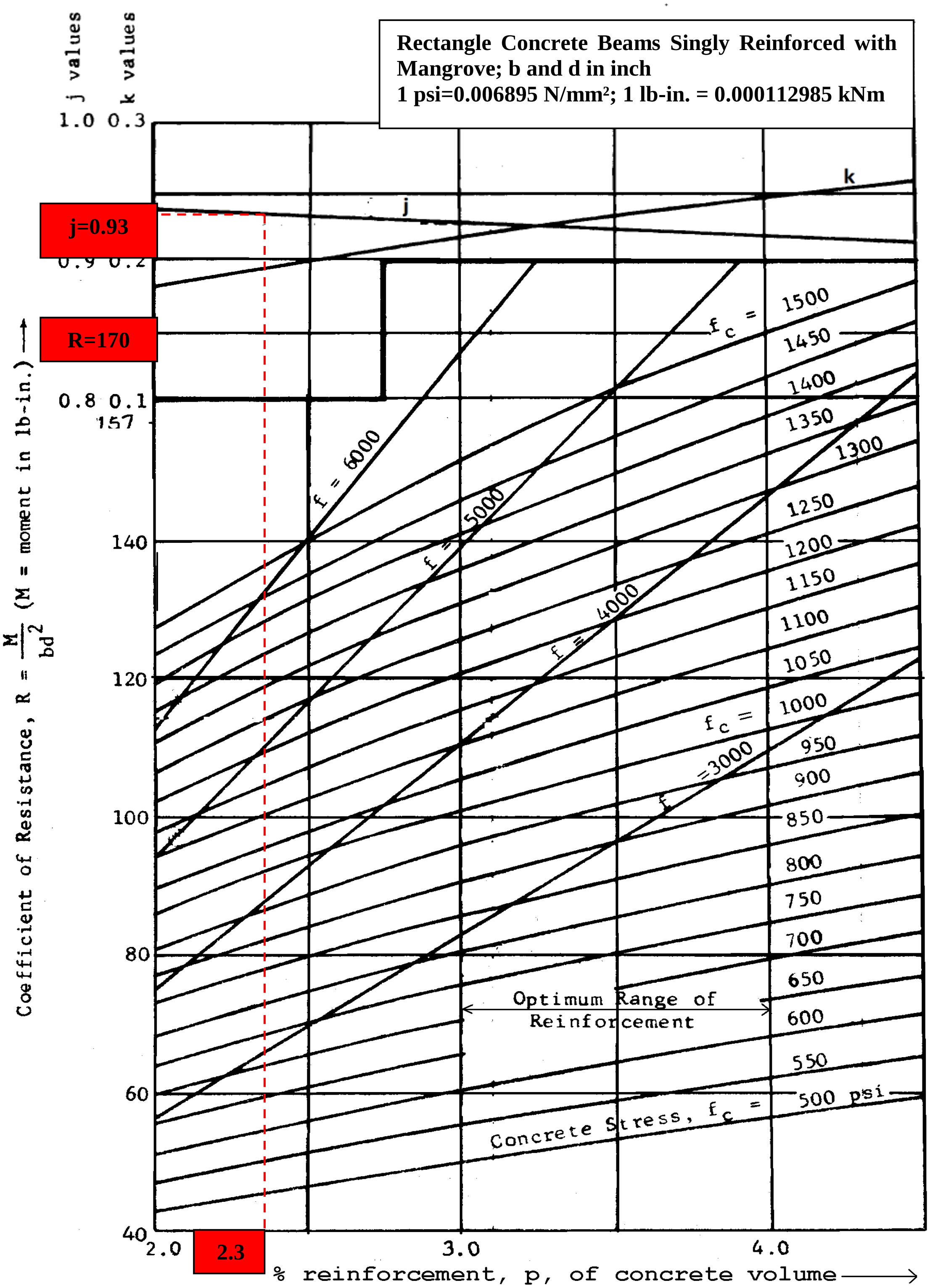
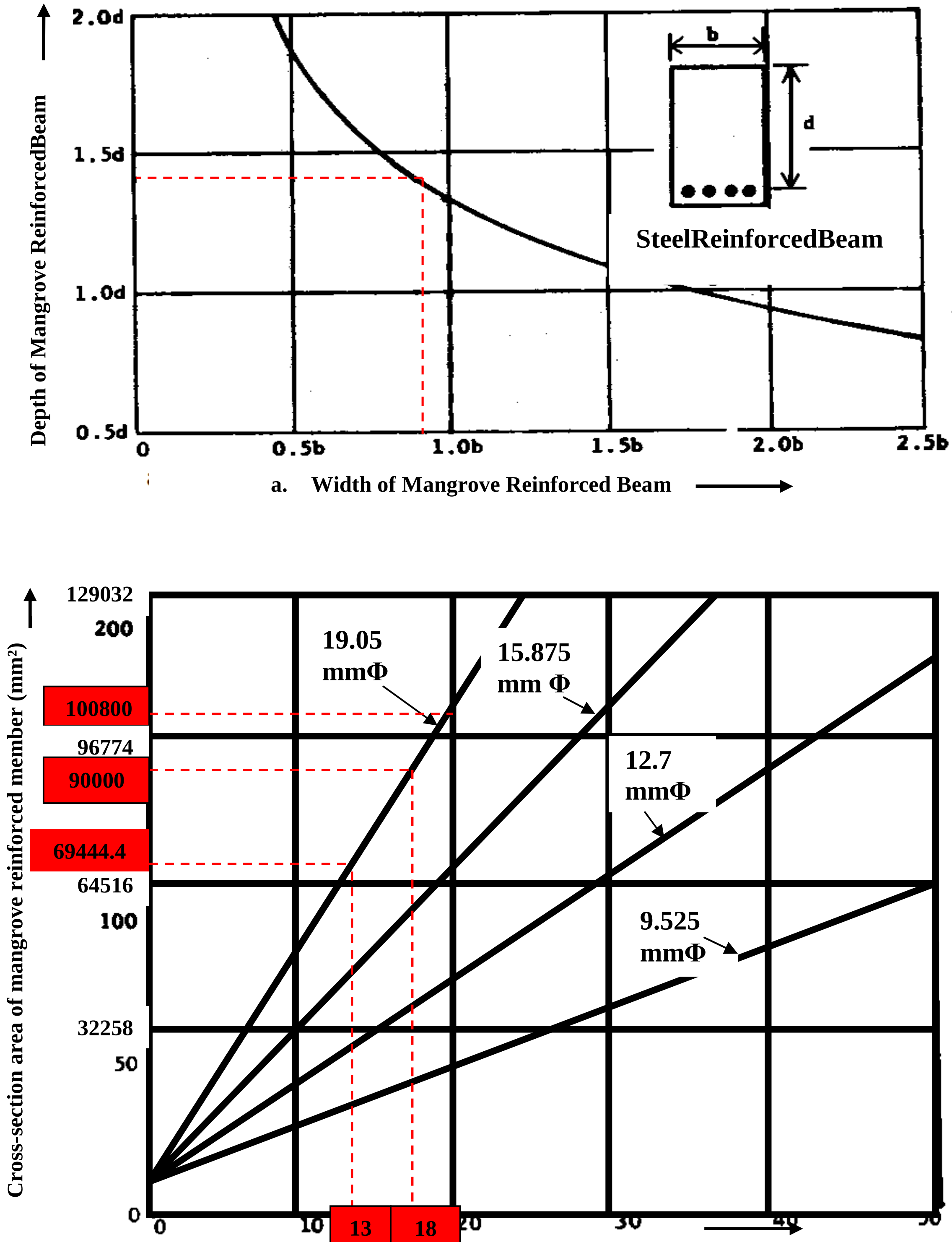


Figure A.7: Resistance Coefficients for Mangrove Reinforced Concrete Beams and their Flexural Members



(Number of mangrove reinforcing bars plotted will provide a member with 3% reinforcement. For other percentage requirements, multiply the number of bars by the percent requirements + 3.)

Figure A.8: Mangrove Substitute Beams and Reinforcement

Table A.2: Properties of Mangrove Poles

Round shape	
Diameter (mm)	Area (mm^2)
9.525	5.161
12.7	87.736
15.875	154.184
19.05	207.729
25.4	353.526
50.8	1238.63

Table A.3: Properties of Steel Reinforcing Bars

Nominal Dimensions - Round Sections		
Bar Designation No.	Nominal Diameter (mm)	Cross Sectional. Area (mm^2)
2	6.35	32.258
3	9.525	70.9676
4	12.7	129.032
5	15.875	199.9996
6	19.05	283.8704
7	22.225	387.096
8	25.4	509.6764
9	28.6512	645.16
10	32.258	819.3532
11	35.814	1006.4496