STRUCTURAL PERFORMANCE OF SHORT MANGROVE REINFORCED CONCRETE COLUMNS

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ABSTRACT

This study investigates the structural behavior of concrete columns reinforced with mangrove poles. Eight small-scale short square columns having the same cross sections of 87 mm x 87 mm and 350 mm in height were variably reinforced with mangrove poles and tested under concentric loading to investigate strength capacity, deflection and failure patterns. A total of eight columns (a)four columns reinforced with four mangrove poles (b) three columns reinforced with single central mangrove pole and (c) a plain column (without any reinforcement) reinforced were tested. 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. Mangrove poles enhanced the ductility of columns compared to the plain concrete column. However, all columns failed in a similar pattern due to crushing of concrete. It was further noted that the mangrove poles showed no sign of slippage and remain unaffected even after concrete failure.

KEYWORDS: *Concrete column, mangrove, compressive strength, ductility, deflection*

I. INTRODUCTION

Different materials have been used for construction in various forms of structures; these materials include steel, soil, wood, plastic among others. The commonly used material for construction since ancient time till date is concrete reinforced with steel. Unfortunately steel is not produced widely leading to a higher cost of steel importations. The availability and production of construction material locally, saves a lot of construction cost and also in terms of energy [1]. In Africa, especially in the remote villages, people tend to use other forms of reinforcement option as steel reinforcement is very expensive and in some cases not possible to afford. In view of this, there is need for more economical and readily available substitute reinforcements for concrete. Mangroves have been seen as an alternative reinforcement in concrete [2]. Africa is blessed with several mangrove swamps such those in Kenya, Tanzania, Nigeria, Egypt and Madagascar coast lines. Nigeria has a large concentration of mangrove trees, spanning 36,000 km^2. 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.

Mangroves have very specialized adaptations that enable them to live in salt waters [3], they exist under very hostile and inhospitable conditions [4].Probably there are no other groups of plants with such highly developed adaptations to extreme conditions [5].Mangrove species can be categorized into true mangroves and mangrove associates [6]. 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 [7]; [8]. Plants that occur in the coastal environment and also within mangroves are considered as mangrove associates or non-exclusive species [8].

Mangrove found in the Kenya's coastal region was used for investigation in this study as compression reinforcement material in concrete. 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 along the Kilifi creek are found in areas of Maya, Kibokoni, Mnarani and Kidundu[9]. 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 [2].

In addition to providing a range of products that people need including building materials, firewood, tannins, fodder and herbal medicine, mangroves are of valuable 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.

Most of the benefits of mangroves are not generally appreciated or are sometimes camouflaged by only economic issue. Policy makers are traditionally viewed mangroves as wastelands with little or no value [10]. Although, experiences have shown that, the structural viability of using mangroves poles in the framing of roofs, general structural framing of lattice wall systems filled with adobe and as reinforcement material in floor slabs and beams with a lot of success in terms of structural performance, and integrity. A lot of harvestable benefits are get from mangrove forests: wood for fire, construction and furniture, a source for charcoal, tannin, paper, thatch, honey and incense, dyes and chemicals [11].Mangrove 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 [12].

This paper carries out an experimental investigation and evaluation of the use of mangrove as reinforcing bar in concrete as replacement for steel. After determining the properties of the materials, tensile test of mangrove, afterwards axial compressive test of columns with different reinforcement ratios were performed and their behaviors and strengths were compared to one another.

II. MATERIALS PROPERTIES

2.1 Coarse Aggregate

The selection and specification of coarse aggregate in this research was made in accordance with BS 882[13]. Crushed stone with triangular shape was used as coarse aggregates in columns samples. The maximum size of aggregate used for the columns was 10 mm. The coarse aggregate has been supplied from one of the local quarries in Kenya. The specific gravity and absorption test of coarse aggregate was undertaken according to ASTM C127 [14] and the values are 2.82 and 3.43 respectively.

2.2 Fine Aggregate

Local sand was used as fine aggregate. The specific gravity and absorption test of fine aggregate have been performed according to ASTM C128 [16] gave 2.56 and 0.96 respectively.

2.3 Mangrove

The species of mangrove poles used in this research were sourced from Mwtapa, along the Kenya coast. Harvested mangrove poles with age range between 15 to 25 years were selected. For their use as reinforcements in beams, the poles were first shaped into round bar shapes. The following criteria were considered in the selection of mangrove poles for use as reinforcement in concrete: (a) use of mature plant with no voids in the middle trunk (b) minimal defects (c) seasoned mangrove.

III. SAMPLE PREPARATION

3.1 Mangrove Poles

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. In order to conduct the tensile strength test, it was necessary to prepare the mangrove sample as referred to in BS 373 [17].

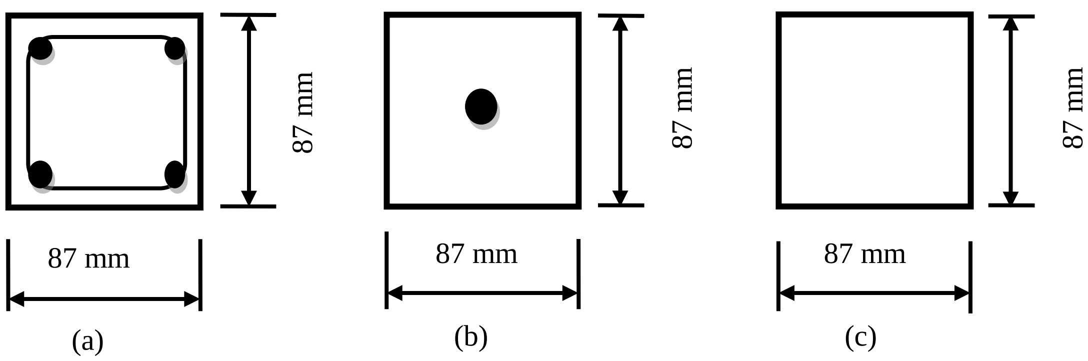
3.2 Concrete Mix Design

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 10 mm, and natural sand supplied from one of the local rivers as fine aggregate. The mixes were designed for 28 days cylinder strength of 20 N/mm² with a water-cement ratio 0.5. The concrete mix proportions was 1:1.75:2 (cement: fine aggregate: coarse aggregate) with a slump value of 50 ± 5 mm to ensure consistency of the concrete mix.

3.3 Column Specimen

In this Study, three types of columns were used according to the number of reinforcements namely: (a) columns with four reinforcements (Figure 1.a), (b) columns with single central reinforcements (Figure 1.b) and (c) plain concrete column (Figure 1.c). Tie reinforcements of 6 mm diameter mild steel was provided at 75 mm centre-to-centre spacing. Details of diameters of reinforcement and reinforcement ratio are given in Table 1.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 28^{th} day in compression and splitting tensile. For ease of columns specimen description, the following notations were applied and are used throughout this paper:

CR4MPΦ14:	Column Reinforced with Four Mangrove Poles of 14 mm of Diameter.
CR4MPΦ11:	Column Reinforced with Four Mangrove Poles of 11 mm of Diameter.
CR4MPΦ8:	Column Reinforced with Four Mangrove Poles of 8 mm of Diameter.
CR4SBΦ8:	Column Reinforced with Four Steel Bars of 8 mm of Diameter.
CRSCMPΦ24:	Column Reinforced with Single Central Mangrove Pole of 24 mm of Diameter.
CRSCMPΦ20:	Column Reinforced with Single Central Mangrove Pole of 20 mm of Diameter.
CRSCMPΦ16:	Column Reinforced with Single Central Mangrove Poles of 16 mm of Diameter.
PCC:	Plain Concrete Column.



(a) Case of CR4MPΦ14, CR4MPΦ11, CR4MPΦ8 and CR4SBΦ8(Height = 350 mm)

(b) Case of CRSCMPΦ24, CRSCMPΦ20 and CRSCMPΦ16(Height = 350 mm)
(c) Case of PCC(Height = 350 mm)

Figure 1: Cross-Section of Sample Concrete Column

IV. EXPERIMENTAL PROGRAM

Compressive and tensile strength of cylinders, tensile strengths of mangrove and axial compressive strength of the mangrove and steel reinforced concrete columns was investigated in the experimental program. The testing procedures are as summarized in the section below.

4.1 Tensile Strength Test of mangrove

In order to conduct the tensile strength test, it was necessary to prepare the mangrove sample as referred to in BS 373 [17]. The resistance to tension of mangrove was determined parallel to the grain. 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. 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. 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.

4.2 Compressive test of column

28 days compressive strength tests were carried out on the specimens (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 2. Axial deformation of the column was measured using a displacement transducer attached to a magnetic base frame. After set up was complete, axial compressive force was gradually applied to specimen using a load cell of 50 tones 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 5kN were recorded. Crack pattern and failure modes were also noted and examined in detail.

Figure 2: Test set-up of column specimen subjected to axial load

V. RESULTS AND DISCUSSIONS

5.1 Compressive and tensile strength of concrete

Twenty eight days average compressive strength of concrete was 19.1 N/mm², while the average tensile strength was established to be 2.5 N/mm².

5.2 Tensile Strength of Mangrove

The tensile strength of the mangrove was found to be variable due to the natural defects inherent in the material e.g presents of minor knots, splits, etc. Taking the defects into account, average stress has been reduced by a safety factor of 0.8 which is the coefficient of safety of wood as provided for in BS 5268[9]to obtain the characteristic tensile strength approximately equal to 153 N/mm². It is noted that the tensile strength of mangrove in comparison to that of steel is approximately three times less. However, its usage may still be applicable particularly for ductility purpose and where loadings regimes can be accommodated within the mangrove strength.

5.3 Cracking Behavior of Mangrove reinforced Concrete Columns

Failure modes of columns reinforced with four mangroves poles (Figure 3.a, b, c: CR4MPΦ14, CR4MPΦ11 andCR4MPΦ8) occurred with more cracks as compared to the control column reinforced with steel (CR4SBΦ8). Columns reinforced centrally with single mangrove pole (Figure 3.d, e, f: CRSCMPΦ24, CRSCMPΦ20, CRSCMPΦ16) had majority central cracking along the four faces of the column. First cracks started from the top extending to the bottom at ultimate failure with concrete spalling as shown in Figure 3.a, b, d, e and f. Failure of the Control columns (Figure 4:CR4SBΦ8 and PCC) appear to crush with cracks limited to the upper quarter part of the column. The vertical cracks running through the column height is noted to be absent, an indication that the cause for the same in the mangrove poles is caused 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 pole 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.

(a) (b) (c) (d) (e) (f)

(a) CR4MPΦ14; (b) CR4MPΦ11; (c) CR4MPΦ8; (d)CRSCMPΦ24; (e) CRSCMPΦ20;

(f) CRSCMPΦ16.

Figure 3: Failure Mode of Columns

(a) (b)

(a) CR4SBΦ8; (b) PCC.

Figure 4: Failure Mode of Control Columns

5.4 Axial Load Capacity of Mangrove Reinforced Columns

Figure 5and 6show the load-deflection curves of columns reinforced with four mangrove and single central mangrove poles respectively. The load carrying capacity of the steel reinforced was higher, which is noted to be approximately 152kN (Figure5:CR4SBΦ8, while that of the four pole mangrove reinforced columns, apparently was lower with the highest being 138kN (CR4MPΦ11)and lowest being 104kN(CR24SCMPΦ14). Same trend was noted in the single centrally reinforced mangrove reinforced column where the highest load is 137kN (CRSCMPΦ20) against a lower value of 106 kN (CRSCMPΦ24).The trend confirms a decreasing load carrying capacity with increasing mangrove reinforcement ratio. Conversely, it was noted that ductility is determined by the position of the mangrove poles and reinforcement ratio in the column. Four mangrove reinforced columns (Figure 5: CR4MPΦ8, 11, 14) shows generally higher displacement values as compared to that of single central mangrove reinforced columns (Figure 6: CRSCMPΦ16, 20, 24).Although unreinforced concrete column showed also remarkable compressive load caring capacity, none the less, the usage of the columns reinforced with mangrove showed better resistance than the plain concrete columns because of their ductility behavior. In any case, mangrove can only be applied where loadings regimes can be accommodated within the mangrove strength.

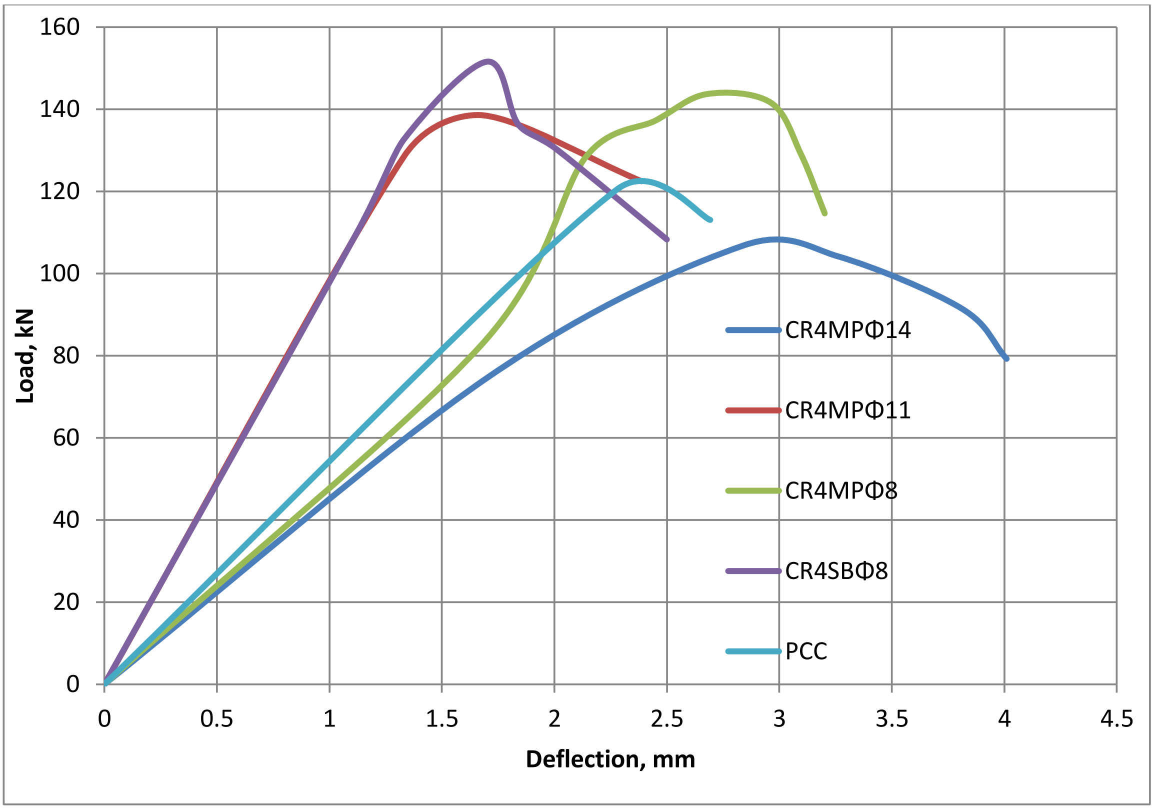


Figure 5: Load-Deflection Curves of Columns Reinforced with Four Mangroves

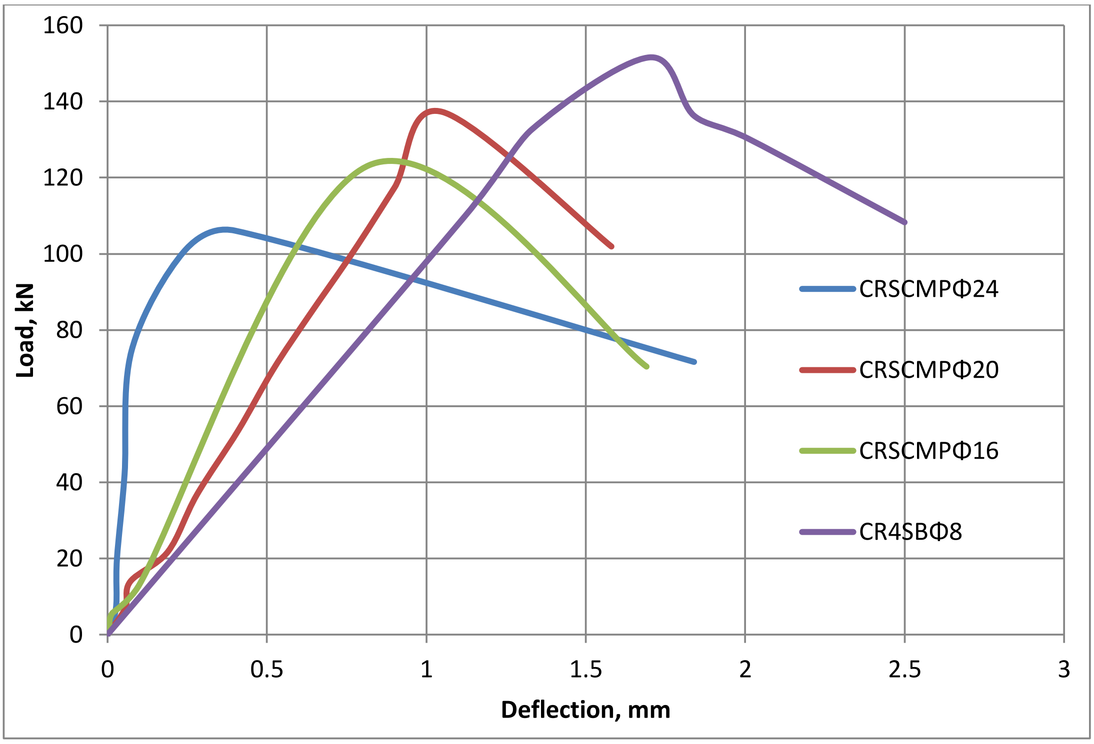


Figure 6: Load-Deflection Curves of Columns Reinforced with Single Central Mangrove

5.5 Comparison of theoretical and experimental results of columns

An American concrete Institute ACI318-05 [18] equation on axial load capacity has been applied by other researchers on bamboo reinforced columns [19]. 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 [19]. Consequently equation (1) below has been used to determine the theoretical maximum load of axially loaded columns in this paper.

Po= 0.85fcu (Ag – As) + Asfy (1)

Where Po is the maximum load, Ag is the gross area of the cross section, As is the total area of longitudinal reinforcement in the column section, fcu is the compressive strength of a concrete cylinder, and fy is the yield strength of the reinforcement (mangrove or steel). Equation (1) is used both with column reinforced by steel reinforcement and columns reinforced by mangrove poles.

Comparison of the experimental values obtained was compared with those obtained from equation (1) above were as shown in Table 1. 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, Po (P_{max}/Po) 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 CR4MPΦ11, CR4MPΦ8 and CRSCMPΦ20, PCC. But PCC is advised not to be used in construction because it is considered as a brittle material.

Table 1: Summary of columns results

		Axial load				**Axial deformation**		
Specimen	**Reinforcement ration (ρ) in %**	**Max. load (P_{max}) inkN**	**Ult. load (P_u) in kN**	**ACI318-05 load (P_o) in kN**	**Pu/Po**	**Deformation at P_{max}, (δu) in mm**	**Deformation at P_u, (δy) in (mm)**	**Ductility (δu/δy)**
CR4MP Φ14	8.2	107	100	143	0.8	2.8	2.7	1.1
CR4MP Φ11	5.1	139	130	135	1.0	1.7	1.3	1.3
CR4MP Φ8	2.6	144	80	128	1.1	2.7	1.7	1.6
CR4SB Φ8	2.7	152	128	195	0.8	1.7	1.3	1.3
PCC	0	120	120	120	1.0	2.3	2.3	1.0
CRSCMP Φ24	6.1	106	68	140	0.8	0.4	0.2	2.7
CRSCMP Φ20	4.2	137	120	135	1.0	1.1	0.9	1.2
CRSCMP Φ16	2.7	123	100	131	0.9	0.8	0.6	1.3

VI. CONCLUSION AND RECOMMANDATIONS

Based on experimental observations, it was determined from material property tests that mangrove poles possess low tensile strength as compared to that of steel. The use of mangrove as reinforcement in concrete column increased the load carrying capacity of the column compared to plain concrete. Mangrove does not improve the post cracking ability of the concrete and increase in reinforcement ratio of mangrove reinforcement in the concrete section also does lead to corresponding increase in ultimate load carrying capacity. However, the location and the mangrove reinforcement ratio lead to enhanced ductility. It is therefore recommended that:

a) Technically, applicability of mangrove exists, however in lightly loaded structural columns of low rise structures.
b) A study on the bonding characteristics of mangrove in concrete should be undertaken.
c) Prototype scale columns are suggested for further research.

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