Third International Conference on Structural Engineering Analysis & Modelling (SEAM3) 1993.

Behaviour of Fan-Palm Reinforced Concrete On-Way Slabs Subjected to Flexural Loading

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Abstract

Laboratory tests were carried out on fan-palm reinforced concrete one-way slabs to determine the effects of variation of percentage of fan-palm reinforcement, effects of preload, repeated cyclic load and alternate wet and dry cycles on their flexural strength and cracking behaviour. The results were compared with that of steel reinforced slabs under similar loading. Three analytical methods were used in computing the theoretical future loads.

Flexural strength of the slabs increased with increase in fan-palm reinforcement but large deflections and wide cracks occurred at capacity loads. Failure was by tension in fan-palm coupled with concrete crushing in some cases. To prevent failure by concrete crushing, percentage of reinforcement should be limited to 4. To develop the same flexural strength, the area of fan-palm reinforcement was found to be four times the area of steel in a slab of equal dimensions. Computing the failure load by the elastic analysis of an uncracked section will give a factor of safety of 2 to 3 against collapse.

Keywords: fan-palm, concrete slabs, reinforcement, flexural strength, cracking.

1.0 Introduction

In developing countries, the high cost and scarcity of steel as a building material has motivated the research for alternative cheap and locally available materials as substitute for steel in the reinforcement of concrete. Reinforcement is normally provided in concrete structures primarily to take up primarily to take up tensile stresses, which conrete cannot take adequately and to supplement the inherent shear and compressive strengths of concrete. Bamboo has been extensively studied as an alternative reinforcing material for concrete (1-5) and recently a study was done on date palm, commonly found in desert oasis (6).

Another material that is currently under study as an alternative reinforcing material is fan-palm (7,8). Fan-palm (borassus aethiopian)is a tree belonging to the palmaceae family and grows in the savannah regions of West Africa and in other tropical countries. In some areas, it is naturally heavily forested and, traditionally, it has been used in building construction as beams, posts, and roof-trusses. The matured fan-palm tree is felled and the hard and fibrous outer-core (with the bark) of the stem is sliced into strips when fresh and then left to air dry before use. This hard and fibrous outer-core is known to have high tensile strensth, varying between 59.20 N/mmxxx and 229.44 N/mmxxx; dimensionally stable in moist environment; and has inherent high resistance to rot decay and termites or insect infestations (7).

This paper reports tests on fan-palm reinforced concrete one-way slabs subjected to flexural loading. The aim of the study is to determine the effects of variation of percentage of fan-palm reinforcement effects of preload, repeated cyclic load and alternate wet and dry cycles on the flexural strength and cracking behaviour of the slabs. The results were compared with those of steel reinforced concrete and plain (unreinforced) slabs under similar loading.

2.0 Experimental Details

2.1 Fan-palm reinforcement

The fan-palm used were obtained were obtained from local timber dealers in Ilorin and the marketable sizes were sliced into rods of different lengths and cross-sections for reinforcement purposes. Only matured fan-palm were used. Practical cross-sectional dimensions that can be sliced easily is 12mm (minimum). Because of lubricating oil used when saw-slicing, the oil stains were removed in order not to inpair the bond with concrete. The reinforcing rods were tied with stripped ...ile or steel tie wire at right angles. The percentage of steel reinforcement for the control slab ... Tables 1 and 2 show the properties of fan-palm used and details of reinforcement, ...ively.

Concrete materials

...ncrete was made from ordinary portland cement, natural dug-out sand and gravel of 10mm ...um size. The mix proportion was done to obtain a concrete grade of 15 N/mmxxx at the 7th ...d gave a mix ratio of 0.5:1:1.53:2.11 by weight of water, cement, fine aggregate and coarse ...ate. Mixing was done ina rotating drum tilting concrete mixer.

...1: **Properties of fan-palm (borassus aethiopum) (Air dried, matured outer-core, m.c. 9-10%)**

Property	Value	Remarks
Specific gravity	1.2	-
Ultimate tensible strengh (mean)	151.91N/mm^2	range is from 59.20 to 229.44N/mm^2
Modulus of elasticity (in tension)	15.13kN.mm^2	initial tangent modulus
Modulus of rupture in flexure (mean)	143.80N/mm^2	range is from 86.64 to 218.43N/mm^2
Modulus of elasticity (in flexure)	22.61kN/mm^2 (mean)	range is 18.97 to 26.06kN/mm^2
Characteristic strength (in flexure)	73.28 N/mm^2 63.94 N/mm^2	at failure at proportional limit

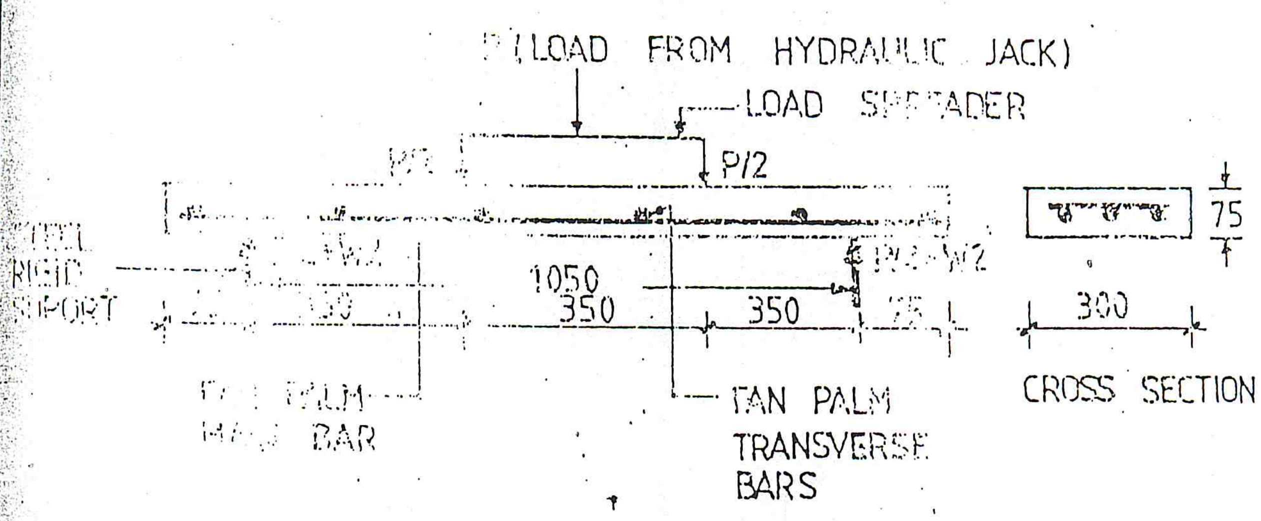

Fig. 1: LOADING ARRANGEMENT AND REINFORCEMENT DETAIL.

2.2 Casting and curing of slabs

Rectangular timber frames, made from quality hardwood, were constructed for moulding the slabs. The internal dimensions were 1200mm long, 300mm wide and 75mm deep. Bracings were provided to keep the formwork rigid. For control cubes, 100mm steel cube moulds were used.
Sixteen slabs comprising two plain, twelve fan-palm reinforced and two steel reinforced concrete slabs each 1200mm long, 300mm wide and 75mm deep were cast. Span-effective depth ratio was kept constant at 23. Casting of slab started by placing the wooden mould in a paper spread on a flat smooth floor and internal surface of the mould oiled to prevent adhesion of concrete on to it. Concrete was poured into the mould and compacted to obtain the required cover of 15mm. The reinforcement fan-palm or steel, was then placed on the 15mm concrete cover and more concrete poured until the wooden mould was filled. Further compaction was done by vibration and the surface was levelled and finished using a trowel.

Form work was struck off the second day and identification marks were made on the slabs. The slabs were moist cured continuosly by wetting until tested. Before the test, each slab was surface- dry and white-washed for easy detection of cracks during test.
100mm concrete control cubes were cast along with the slabs. Table 3 shows the slab details.

2.3 Testing Equipment/Facilities

The slabs were tested in a purpose-built steel frame. Accessories used were hydraulic jack for load application, rigid support facilities, load spreader. Deflections were measured by dial gauges placed 10mm from the edges at midspan.
The slabs were simply supported with an effective span of 1050mm and line loading was applied at the third points. A schematic diagram of the loading arrangement is shown in Figure 1.
The mode of load application depended on the parameter under investigation, as follows:-

i) For finding the effect of increase in percentage of fan-palm reinforcement, the slabs were loaded directly to failure.

ii) For the determination of the effect of preload, the slab wasfirst subjected to a load to cause first crack; the load was released and the slab reloaded directly to failure.

iii) For the effect of repeated load, the slab was first subjected to twenty cycles of half of the first crack load (about 5kN). The process was repeated five times allowing twenty four hours interval. At the end of the fifth twenty load cycles the slab was loaded directly to failure.

Table 2: Details of reinforcement

	Longitudinal Fanpalm			Transverse Fanpalm		
Slab	No	Size (mm x mm)	Spacing (mm)	No	Size (mm x mm)	Spacing (mm)
1SL2	2	16 x 16	254	6	16 x 16	230
2SL2	2	16 x 16	254	6	16 x 16	230
1SL3	2	18 x 18	126	6	16 x 16	230
2SL3	2	18 x 18				
1SL4	2	18 x 18	126	6	16 x 16	230
2SL4	2	18 x 18				
1SL5	2	20 x 20	83	6	16 x 16	230
2SL5	2	20 x 20				
			CONTROL SLABS			
1ST	3	8 dia	131	6	8 dia	232
2ST	3	8 dia	131	6	8 dia	232
1PL	-	-	-	-	-	-
2PL	-	-	-	-	-	-
PRSL1	2	16 x 18	254	6	16 x 16	230
PRSL2	2	16 x 8	254	6	16 x 16	230
RPSL	2	16 x 8	254	6	16 x 16	230
WDSL	2	16 x 8	254	6	16 x 16	230

iv) For the effect of wet and dry cycles, the slab was first subjected to first crack load and later subjected to alternate soaking in water and drying in open air each for twenty four hours. The wet and dry process was repeated five times at the end of which the slab was loaded directly to failure.

3.0 Theoretical Considerations

3.1 Flexural Theory

The ultimate flexural load (including self weight) for the slabs under study when subjected to concentrated live load at the third points is given by (8,9).

$$P\ (kN) = \frac{M-0.075}{0.175} \qquad (1)$$

Where P is the theoretical maximum load and M is the moment of resistance of the section in kN-m. The moment of resistance of the fan-palm reinforced concrete slabs were evaluated by elastic analysis of uncracked and cracked sections, respectively, using a triangular stress distribution and also by limit state analysis of the section using a rectangular-parabolic stress distribution.

Substituting the expression for the moment of resistance of section otained by the three methods of analysis into equation (1). will give the theoritical ultimate loads as follows:.

$$P\ \text{uncracked} = 0.334\left\{\frac{75-x}{3} + 0.6r\,\frac{(d-x)}{75-x}\left(d-\frac{x}{3}\right)\right\} - 0.43 \qquad (2)$$

$$\text{where } x = \quad x = \frac{75 + 1.2rd}{1.2r + 2} \qquad (2)$$

Details of the calculations can be found in refernce (8)..

For the reinforced concrete, the critical moment, M_{cr} based on the modulus of rupture is given by $M_{cr} = f_{tc}bh^2/6$ in which f_{tc} is the tensile strength in bending, b is the width of the slab and h the overall thickness. Using $f_{tc} = 2.6N/mm^2$, b = 300mm and h = 75mm, the failure load will be 3.74 kN for the unreinforced concrete slab.

4.0 Theoretical and Experimental Results

Figures 2 and 3 show the load deflection curves for the slabs plotted from test data. The curves are linear up to the appearance of the first crack, which invariably occured at the bottom within the middle third of the span. After the first crack, the greadients of the curve decreased while the cracks widened and multiplied until failure. There were more cracks in slabs with higher percentage of fan-palm.

The observed cracking and failure loads are presented in table 4 which also shows the theoretical failure loads calculated from equations (2) to (4). From the table, it can be seen that there is little variation in the ratios of the theoretical crack load as given by equation 2 to the experimental first crack load. The average is about 0.8 which is close to 1. The difference in the two values could be attributed to the difficulty in detecting thre first crack, which was taken as the first visible cracks. The ratios of the ultimate loads to the experimental failure loads, $\frac{P_{cr}}{P_{ult}}$ and $\frac{P_{ult}}{P_{ult}}$ show little variation from their average values of, 0.71 and 0.80 respectively. The factors of safety against experimental failure loads are 1.4 for the elastic failure load and 1.25 for the ultimate (limit state) load, P_{ult}.

The corresponding values for the steel reinforced slabs are 2.4 and 1.59.
Considering the shear capacity of the slabs using CP 110 procedures (10), it is found that the experimental first crackloads were less (about 0.6) than the design shear strength of the slab, if fan-palm reinforcement was neglected. This is an indication that the first cracks were not shear cracks but caused by flexure. In fact, the failure of the slabs was primarily by flexure rather than by shear as the experimental failure loads were less than the designed shear resistance with fan-palm reinforcement considered.

5.0 Discussion of Results

The excessive deflections and wide cracks of fan-palm reinforced slabs at failure compared to the steel reinforced slabs can be attributed to the low elastic modulus of fan-palm (initial modulus) of 15.13 kN/mm²) which is less than 10% of the steel modulus. Clearly, the serviceability limit state of cracking and deflections should govern the design to avoid wide cracks and large deflections. Consideration should be given to the elastic design method than to the limit state.

The modes of failure of the fan-palm reinforced slabs were tension failure in the fan-palm for fan-palm reinforcement up to 3.5% and a combination of tension and crushing of concrete in the compression zone for percentage fan-palm ranging from 4 to 5.3. The crushing failure is not a desirable form of failure, except that it was accompanied by tension failure. It might mean that, to avoid compression failure, the percent fan-palm reinforcement should not exceed 4.

None of the slabs tested showed any evidence of bond failure and no special surface treatment was given to the fan-palm before use, except to wash off any lubricant used during slicing and surface roughening of some of the rods.

The behaviour of slabs subjected to different load regimes showed that preloading a slab to produce first crack, removal of the load and subsequent loading to failure did not reduce significantly the failure (ultimate) load when compared to slab without a preload. For repeated application of loads lower than the first crack load as a normal slab and the ultimate failure load was also not appreciably affected. Subjecting the slab to wet and dry cycles after the first crack and later testing to failure also gave a failure load close to that of the normal slab.

For purpose of comparison, costs were compared for steel- and fan-palm--reinforced concrete slabs designed to carry an ultimate load of 14.0 kN. The slabs are of the same dimensions as tested in this study. Using limit state design, the reinforcement areas required were 960mmxxx and239mmxxx for fan-palm and steel, respectively. On the basis of unit material prices prevailing in Nigeria at the time of this work, the cost of fan-palm reinforcement was one-fifth of steel, although the amount of fan-palm required was about four times that of steel.

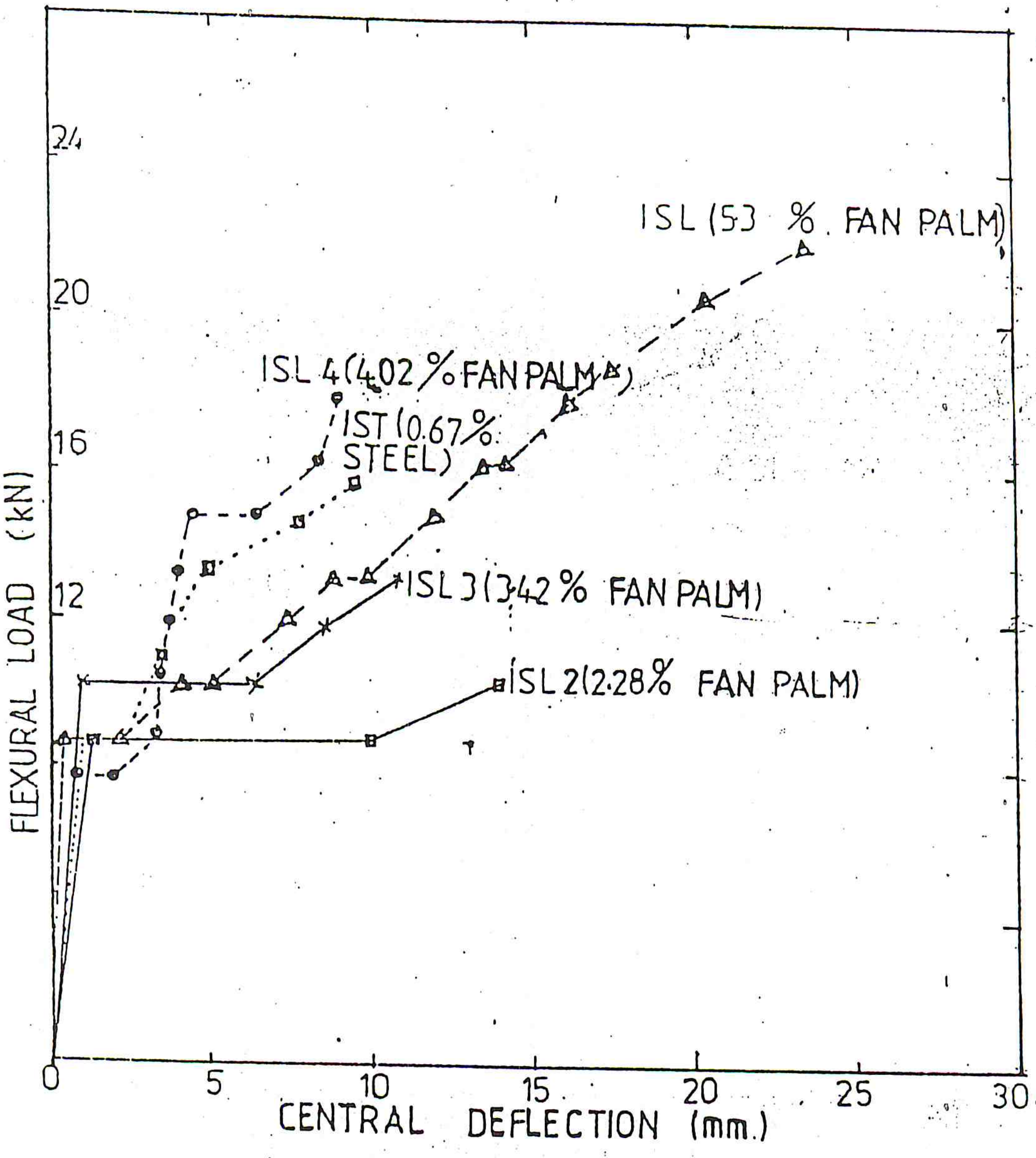

Fig . 2 : FLEXURAL LOAD—DEFLECTION CURVES FOR TEST SLABS

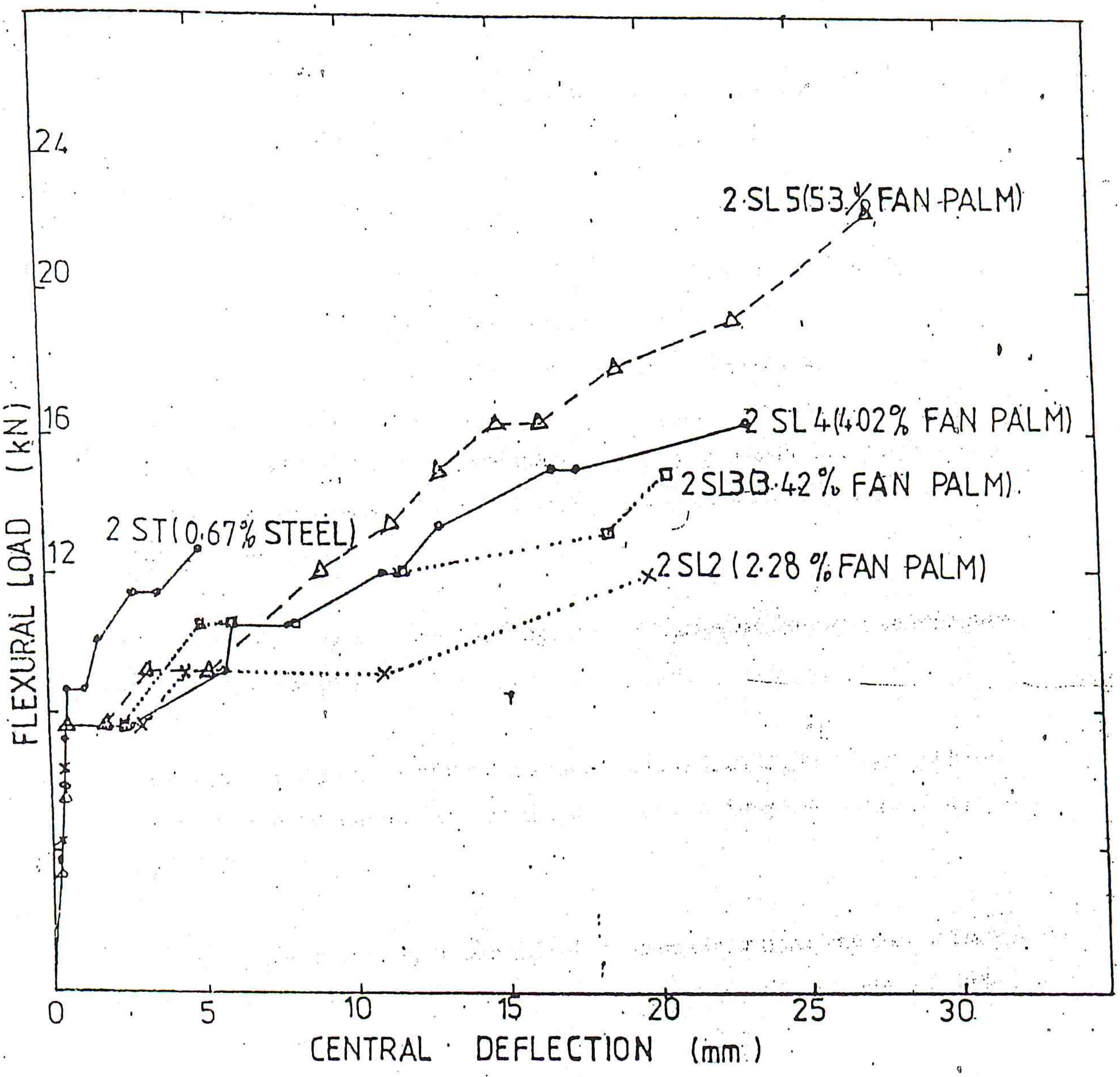

Fig. 3 : FLEXURAL LOAD — DEFLECTION CURVES FOR TEST SLABS

6.0 Conclusions

On the basis of tests carried out on one-way simply-supported palm reinforced concrete slabs, the following conclusions can be made;

(1) The first crack load seem not to be appreciably affected by the reinforcement as there was little variation in the first crack loads of the plain (unreinforced) slab and the fan-palm- and steel-reinforced slabs.

(2) Fan-palm has a fairly high tensile strength and modulus of rupture, but its low modulus of elasticity (which is less than one-tenth that of steel) leads to large deflections and wide crack when fan-palm reinforced slabs are loaded to capacity. To avoid large deflections after initial crack, it may be necessary to restrict the permissible load to that which cause failure found by the elastic found by the elastic analysis of an uncracked section. This will give a factor of safety of about 2 to 3.0 against collapse.

(3) To avoid failure by concrete crushing, the percentage of fan-palm reinforcement should be limited to 4.

(4) On the basis of the results of the different short term loan regimes reported here, no evidence of bond failure between the concrete and fan-palm reinforcement was observed.

(5) To develop the same strength in a slab of the same dimensions, the cost of fan-palm reinforcement was one-fifth that of steel, although the amount of fan-palm reinforcement required was about four times that of steel.

Acknowledgement

The financial support of UNICEF, Lagos, Nigeria (WATSAN division), through a research sponsorhip on the use of local materials for the construction of VIP latrines is gratefully acknowledged. The tests were carried out at the Structures and Concrete laboratories of the University of Ilorin.

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