Bamboo as Construction Material and Bamboo Reinforcement

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Abstract: **The world timber demand is increasing at a rapid rate but the timber supply is depleting. It's been found through research that bamboo can suitably replace timber and other materials in construction and other works. Industrially treated bamboo has shown great potential for production of composite materials and components which are cost-effective and can be successfully utilized for structural and non-structural applications in construction. Bamboo is one of the oldest traditional building materials used by mankind.**

Through research it has been found that some species of bamboo have ultimate tensile strength same as that of mild steel at yield point and this coupled with other merits boosts the usage of bamboo as construction material. Bamboo is a versatile material because of its high strength-to-weight ratio, easy workability and availability. Bamboo needs to be chemically treated due to their low natural durability. It can be used in different ways for roof structure as purlins, rafters and reapers, for flooring, doors and windows, walling, ceiling, man-hole covers etc.

Keywords: **Bamboo, bamboo reinforcement, tensile strength, construction material, cost effective.**

1. INTRODUCTION

The use of bamboo as reinforcement in portland cement concrete has been studied extensively by Clemson Agricultural College. Bamboo has been used as a construction material in certain areas for centuries, but its application as reinforcement in concrete had received little attention until the Clemson study. A study of the feasibility of using bamboo as the reinforcing material in precast concrete elements was conducted at the U. S. Army Engineer Waterways Experiment Station in 1964. Ultimate strength design procedures, modified to take into account the characteristics of the bamboo reinforcement were used to estimate the ultimate load carrying capacity of the precast concrete elements with bamboo reinforcing.

Bamboo was given recent consideration for use as reinforcement in soil-cement pavement slabs in which the slabs behave inelastically even under light loads. For this case ultimate load analysis was shown to be more economical and suitable for use.The results of these investigations form the basis of the conclusions and recommendations presented in this report. Further studies will be required before complete confidence can be placed theoretical designs based on the material presented here.

The bamboo culm, or stem, has been made into an extended diversity of products ranging from domestic household products to industrial applications. Examples of bamboo products are food containers, handicrafts, toys, furniture, flooring, pulp and paper, boats, charcoal, musical instruments and weapons. Bamboo is quite common for bridges, scaffolding and housing, but it is usually used as a temporary exterior structural material. In many overly populated regions of the tropics, certain bamboos supply the one suitable material that is sufficiently cheap and plentiful to meet the extensive need for economical housing. It has been used in bicycles, windmills, scales etc. Its uses are broad and plentiful.

With the advancement of science and technology and the tight supply of timber, new methods are needed for the processing of bamboo to make it more durable and more usable in terms of building materials. Studies have been carried out on the basic properties and on processing of bamboo into various kinds of composite products. Bamboo has several unique advantages like ability to grow fast with a high yield and also it matures quickly. Additionally bamboo can be grown abundantly and that too at a lower cost which makes it more economical.

2. BAMBOO AS CONSTRUCTION MATERIAL

Through research it has been found that some species of bamboo have ultimate tensile strength same as that of mild steel at yield point and this coupled with other merits boosts the usage of bamboo as construction material. Bamboo is a versatile material because of its high strength-to-weight ratio, easy workability and availability. Bamboo needs to be chemically treated due to their low natural durability. It can be used in different ways for roof structure as purlins, rafters and reapers, for flooring, doors and windows, walling, ceiling, man-hole covers etc.

Bamboo Trusses: The bamboo has strength comparable to that of teak and sal. An experiment with the construction and testing of a 4m span truss made of round bamboo and different jointing techniques for web-chord connections gave results that were matching with the strength of timber.

Bamboo Roofs Skeleton: It consists of bamboo truss or rafters over which solid bamboo purlins are laid and lashed to the rafter by means of G.I.wire. A mesh of halved bamboo is made and is lashed to the purlins to cover the roof.

Bamboo walling/ceiling: As the bamboo material is light in weight it is more advantageous in earthquake prone areas as its chances of falling are very less and even if it falls it can be re-erected easily with less human and property loss with least efforts and minimum cost. Bamboo walls can be constructed in different modes like

- Whole stem, halved or strips of bamboo can nailed to one or both the sides of the bamboo frame
- Split bamboo mats can be fastened to the bamboo posts or mats can be woven, mud can also be applied to both sides of such mats
- Bamboo strips nailed to bamboo frame or posts for interior walling
- Cement or lime plastering can be done on the mud covering for better appearance and hygiene.

It has been found that the bamboo in the vertical position is more durable than in horizontal direction. For partition walls only single layer of bamboo strips are used.

Bamboo Doors and Windows: Bamboo frames can replace timber frames appropriate to function. Bamboo mat shutters fixed to bamboo frame or a panel of bamboo board fixed to the frame which is hinged to the wall can be used as door. Small framed openings hinged to the top in the wall can serve as windows.

Bamboo Flooring: Bamboo can be used as flooring material due to its better wear and tear resistance and its resilience properties. Whole culms act as frame work and the floor covering is done using split bamboo, bamboo boards, mats etc by means of wire lashing these to the frame.

Reed Boards: Reed boards are made by flat pressing the reed at high temperatures. These reed boards are used in elements like flooring, walls, ceiling and roofing. They can also be used for partitions, doors, windows etc.

Scaffolding: Bamboo poles lashed together have been used as scaffolding in high rise structures due to their strength and resilience. The timber planks can be replaced with bamboo culms and these can be lashed to the vertical culms.

3. STRENGTH PROPERTIES OF BAMBOO

Experimentally it has been found that the ultimate tensile strength of some species of bamboo is comparable to that of mild steel and it varies from $140N/mm^2$- $280N/mm^2$. This together with other properties has made Bamboo a more visible option as a construction material. It has also been found that bamboo acts very well in buckling but due to low stresses than compared to steel and due to it not being straight it may not be very good.

Further, it has been established that in seismic zones the failure of bamboo is very less as the maximum absorption of the energy is at the joints. Cellulose is the main component present in bamboo which is the main source of mechanical properties of bamboo.

Some specific properties of Bamboo are as given below:

Specific gravity - 0.575 to 0.655

Average weight - 0.625kg/m

Modulus of rupture - 610 to $1600kg/cm^2$

Modulus of Elasticity - 1.5 to $2.0 \times 10^5 kg/cm^2$

Ultimate compressive stress- 794 to 864kg/cm^2

Safe working stress in compression - 105kg/cm^2

Safe working stress in tension - 160 to 350kg/cm^2

Safe working stress in shear- 115 to 180kg/cm^2

Bond stress - 5.6kg/cm^2

4. SELECTION AND PREPARATION OF BAMBOO

Selection:

The following factors should be considered in the selection of bamboo culms (whole plants) for use as reinforcement in concrete structures:

1. Use only bamboo showing a pronounced brown color. This will insure that the plant is at least three years old.
2. Select the longest large diameter culms available.
3. Do not use whole culms of green, unseasoned bamboo.
4. Avoid bamboo cut in spring or early summer. These culms are generally weaker due to increased fiber moisture content.

Preparation:

Sizing. Splints (split culms) are generally more desirable than whole culms as reinforcement. Larger culms should be split into splints approximately 3/4 inch wide. Whole culms less than 3/4 inch in diameter can be used without splitting.

1. Splitting the bamboo can he done by separating the base with a sharp knife and then pulling a dulled blade through the culm. The dull blade will force the stem to split open; this is more desirable than cutting the bamboo since splitting will result in continuous fibers and a nearly straight section. Table II shows the approximate net area provided by whole culms and by 3/4-inch-wide splints, as well as the cross-sectional properties of standard deformed steel bars and wire mesh.
2. Seasoning: When possible, the bamboo should be cut and allowed to dry and season for three to four weeks before using. The culms must be supported at regular spacings to reduce warping.
3. Bending: Bamboo can be permanently bent if heat, either dry or wet, is applied while applying pressure. This procedure can be used for forming splints into C-shaped stirrups and for putting hooks on reinforcement for additional anchorage.
4. Waterproof Coatings: When seasoned bamboo, either split or whole, is used as reinforcement, it should receive a waterproof coating to reduce swelling when in contact with concrete. Without some type of coating, bamboo will swell before the concrete has developed sufficient strength to prevent cracking and the member may be damaged, especially if more than 4 percent bamboo is used. The type of coating will depend on the materials available. A brush coat or dip coat of asphalt emulsion is preferable. Native latex, coal tar, paint, dilute varnish, and water-glass (sodium silicate) are other suitable coatings. In any case, only a thin coating should be applied; a thick coating will lubricate the surface and weaken the bond with the concrete.

Construction principles

In general, techniques used in conventional reinforced concrete construction need not he changed when bamboo is to be used for reinforcement

Concrete Mix Proportions

The same mix designs can be used as would normally be used with steel reinforced concrete. Concrete slump should be as low as workability will allow. Excess water causes swelling of the bamboo. High early-strength cement is preferred to minimize cracks caused by swelling of bamboo when seasoned bamboo cannot be waterproofed.

Placement of Bamboo

Bamboo reinforcement should not be placed less than 1-1/2 inches from the face of the concrete surface. When using whole culms, the top and bottom of the stems should be alternated in every row and the nodes or collars, should be staggered. This will insure a fairly uniform cross section of the bamboo throughout the length of the member, and the wedging effect obtained at the nodes will materially increase the bond between concrete and bamboo.

The clear spacing between bamboo rods or splints should not be less than the maximum size aggregate plus 1/4 inch. Reinforcement should be evenly spaced and lashed together on short sticks placed at right angles to the main reinforcement. When more than one layer is required, the layers should also be tied together. Ties should preferably be made with wire in important members. For secondary members, ties can be made with vegetation strips.

Bamboo must be securely tied down before placing the concrete. It should be fixed at regular intervals of 3 to 4 feet to prevent it from floating up in the concrete during placement and vibration. In flexural members continuous, one-half to two-thirds of the bottom longitudinal reinforcement should be bent up near the supports. This is especially recommended in members continuous over several supports. Additional diagonal tension reinforcement in the form of stirrups must be used near the supports. The vertical stirrups can be made from wire or packing case straps when available; they can also be improvised from split sections of bamboo bent into U-shape, and tied securely to both bottom longitudinal reinforcement and bent-up reinforcement. Spacing of the stirrups should not exceed 6 inches.

Anchorage and Splicing of Reinforcements

Dowels in the footings for column and wall reinforcement should be imbedded in the concrete to such a depth that the bond between bamboo and concrete will resist the allowable tensile force in the dowel. This imbedded depth is approximately 10 times the diameter of whole culms or 25 times the thickness of 3/4 inch wide splints. In many cases the footings will not be this deep; therefore, the dowels will have to be bent into an L-shape. These dowels should be either hooked around the footing reinforcement or tied securely to the reinforcement to insure complete anchorage. The dowels should extend above the footings and be cut so that not more than 30 percent of the splices will occur at the same height. All such splices should be overlapped at least 25 inches and be well tied. Splicing reinforcement in any member should be overlapped at least 25 inches. Splices should never occur in highly stressed areas and in no case should more than 30 percent of the reinforcement be spliced in any one location.

5. DESIGN PRINCIPLES

Bamboo reinforced concrete design is similar to steel reinforcing design. Bamboo reinforcement can be assumed to have the following mechanical properties:

Table I. Mechanical properties of bamboo reinforcement

Mechanical Property	Symbol	Value (psi)
Ultimate compressive strength		8,000
Allowable compressive stress	□	4,000
Ultimate tensile strength		18,000
Allowable tensile stress	□	4,000
Allowable bond stress	u	50
Modulus of elasticity	E	2.5×10^{6}

Design of Bamboo Reinforced Beam

Design a bamboo reinforced concrete beam to span 8 feet and to carry a uniform dead load plus live load of 500 pounds per linear foot and two concentrated loads of 12,000 pounds each symmetrically located 2 feet each side of the center line of span. Assume the ultimate strength of the concrete is 2500 psi; the allowable compression stress is 0.45 f'_c or 1125 psi. Allowable unit diagonal tension stress, v, in the concrete is 0.03 f'_c or 75 psi. Allowable tension stress, □, in the bamboo is 4000 psi; the allowable unit bond stress between bamboo and concrete is 50 psi.

1. At the intersection of the allowable stress curves (Figure 1) for concrete and bamboo, find R = 115 and p = 3.1 percent.

2. Maximum bending moment, M, is given by:

$$M = \frac{500\,(8)^2\,(12)}{8} + 12{,}000\,(2)\,(12) = 336{,}000 \text{ in.} - \text{lb.}$$

3. From $R = \frac{M}{bd^2}$

bd^2 = 336,000/115 = 2920 $in.^3$

4. If b = 8 in. is chosen, then d = $(2920/8)^{1/2}$ = 19.1 in.

5. Bamboo reinforcement = pbd = 0.031(8)(19.1) = 4.75 sq in.

6. Use 3/4-inch-thick splints, area = 0.563 sq in. (from Table II). Number required = 4.75/0.563 = 8.4; round up to 9. Space evenly in three rows. Bend up top row randomly in the outer one-third ends of the beam.

7. Check the bond stress. Maximum shear at the support, V, is determined as:

$$V = \frac{500\,(8)}{2} + 12{,}000 = 14{,}000 \text{ lb.}$$

The perimeter of one splint is 4(3/4) or 3 in.; the total perimeter of the longitudinal reinforcement, Σo, is 9(3) = 27 in. The value of j = 0.925 is taken from Figure 1 for 3.1 percent reinforcement. The bond stress, u, is calculated from:

$$u = \frac{V}{\Sigma o\, j\, d} = \frac{14{,}000}{27\,(0.925)(19.1)} = 29 \text{ psi}$$

This is less than the allowable bond stress of 50 psi.

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

$$V' = v\,b\,j\,d = 75\,(8)\,(.925)\,(19.1) = 10{,}600 \text{ lb.}$$

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

9. Try 1/4-inch-thick splints for stirrups. The area provided by one stirrup bent into a U-shape, A, is 2(0.1875) = 0.375 sq. in. Maximum spacing, s, is given by:

$$s = \frac{A\,\sigma\,j\,d}{V - V'} = \frac{0.375\,(4000)\,(0.925)\,(19.1)}{14{,}000 - 10{,}600} = 7.8 \text{ in.}$$

Common practice is to include two additional stirrups past the point where diagonal tension reinforcement is not needed.

Replacement of a Steel Reinforced Beam with a Bamboo Reinforced Beam

Construction drawings call for the beam given in the sketch below. Replace it with a bamboo reinforced beam. There are no objections to deepening the member.

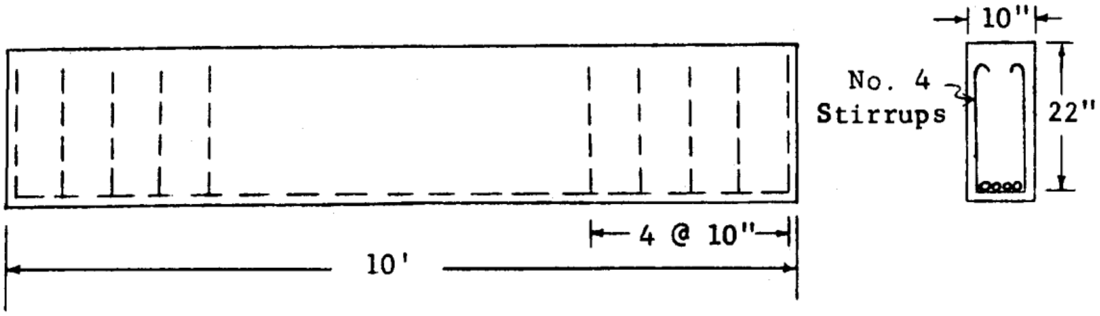


Figure-1

1. Select the cross-sectional dimensions from Figure 2a. Avoid using sections with depth to width ratios greater than 4 for reasons of stability. Try width of 1.0b or 10 in. and a depth of 1.32d or 29.0 in. The area is 290 sq in.

2. The amount of reinforcement can be selected from Figure 2b. Assume that 3/4-inch-thick splints will be used. The number of splints required for 200 sq in. is determined at 11. This number is multiplied by the ratio 290/200 to get 16 splints. These should be-distributed evenly in four rows.

3. Determine the vertical stirrups required. The No. 4 steel stirrups have a cross-sectional area of 0.2 sq in. (Table II). These stirrups are spaced at 10 in. which provides (12/10)(0.2)= 0.24 sq in. of reinforcement in a 12-inch length. Four times this area should be used for bamboo stirrups or 0.96 sq in. per foot of length. From Figure 4, select 3/8-inch-thick splints spaced at 4-inch centers.

4. The top two rows should be bent up randomly in the outer one-third sections of the beams to assist the vertical stirrups in resisting diagonal tension.
The final design is shown in the following sketch.

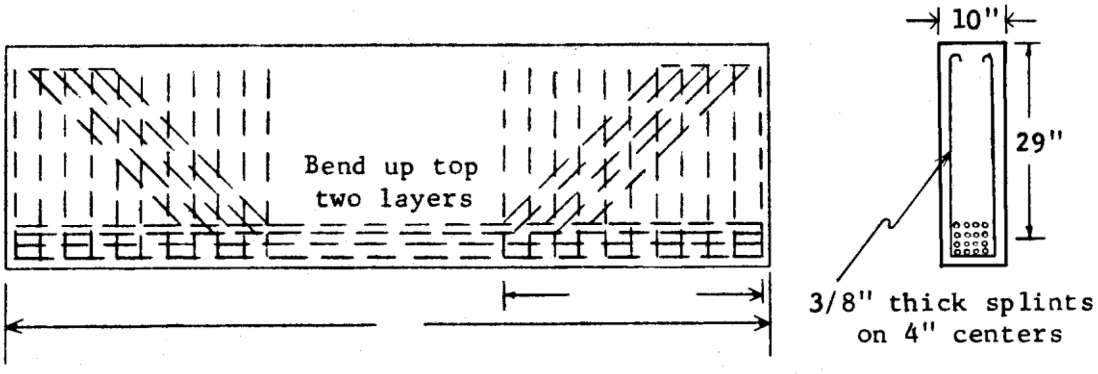
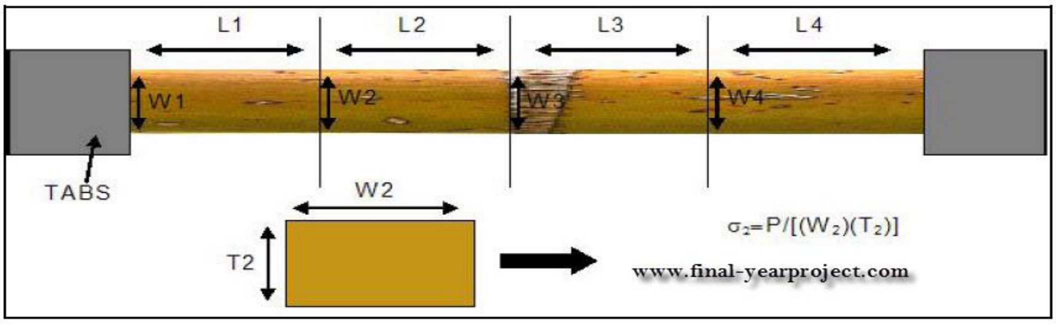


Figure-2



Dimensioning of Tensile Sample

Figure-3

Square Bamboo Reinforced Column Design

Determine the cross section and bamboo reinforcement of a column required to carry an axial load of 70,000 lb. Ultimate compression strength of the concrete, f'_c, is 2500 psi.

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:

$$A_g = \frac{70{,}000}{0.8\,(0.225)\,(2500)} = 155.5 \text{ sq. in.}$$

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

$b = (155.5)^{1/2} = 12.47$ in., say 12.5 in.

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4. The amount of vertical reinforcement should be 4 percent of the concrete area and can be obtained from Figure 4. Try 3/4-inch-thick splints. The number required is 8.8 for an area of (12.5)(12.5) = 156 sq in. However, Figure 2 provides only 3-percent reinforcement; thus 8.8 should be multiplied by (4/3) to get 11.7. Thus, 12 splints should be used; these should be spaced evenly around the perimeter with 1-1/2 in. of cover. Lateral ties should be arranged as shown in the following figure to provide each vertical splint with a 90-degree corner (or smaller).

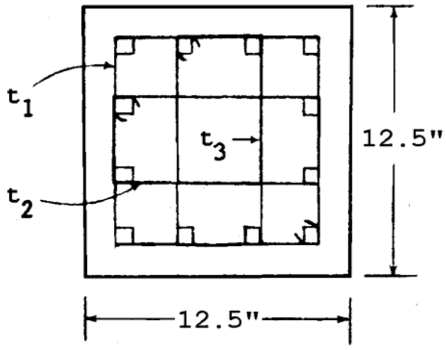


Figure-4

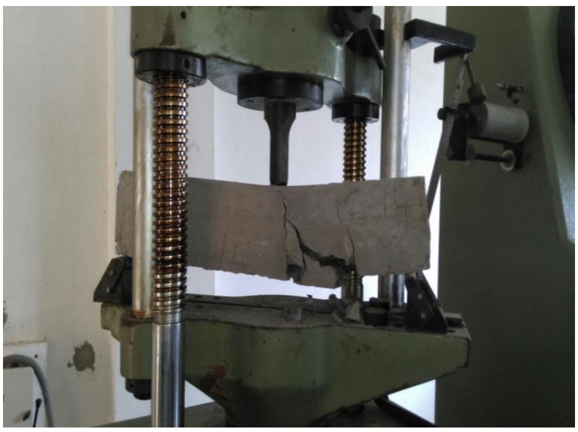
Tie reinforcement size should be 2 percent of the total area of the vertical bars confined by it. Each tie confines four vertical bars or an area of 4(3/4)(3/4) = 2.252 sq in. The cross-sectional area of the ties should be at least 2 percent of this or 0.02(2.252) = 0.045 sq in. Try 1/4-inch by 1/4-inch splints. The cross-sectional area is (1/4)(1/4) = 0.063 sq in. and therefore is adequate. The least dimension of the column is 12.5 in., and 16 times the thickness of the vertical reinforcement is 16(3/4) = 12.0 in.; therefore, spacing of the lateral ties is restricted to a maximum of 12 in.

Observation table with comparison

Table 2. Average cracking and ultimate loads of bamboo reinforced concrete columns

COLUMN CHARACTERISTICS	**Types of Reinforcement**					
	No reinforcement (Plain)	**Bamboo Reinforced Concrete**				**Steel Reinforcement**
		4No. Bamboo Strips	6No. Bamboo Strips	8No. Bamboo Strips	12No. Bamboo Strips	4No. 12mm Steel reinforcemen
Cracking Load (kN)	160	276	240	227	200	280
Ultimate Failure Load (kN)	160	332	357	270	243	428
Central Defl. at cracking load (mm)	2.0	6.0	11.0	11.0	16.0	8.0
Central Defl. at failure load (mm)	2.0	6.0	11.0	11.0	22.00	17.0

Pictures



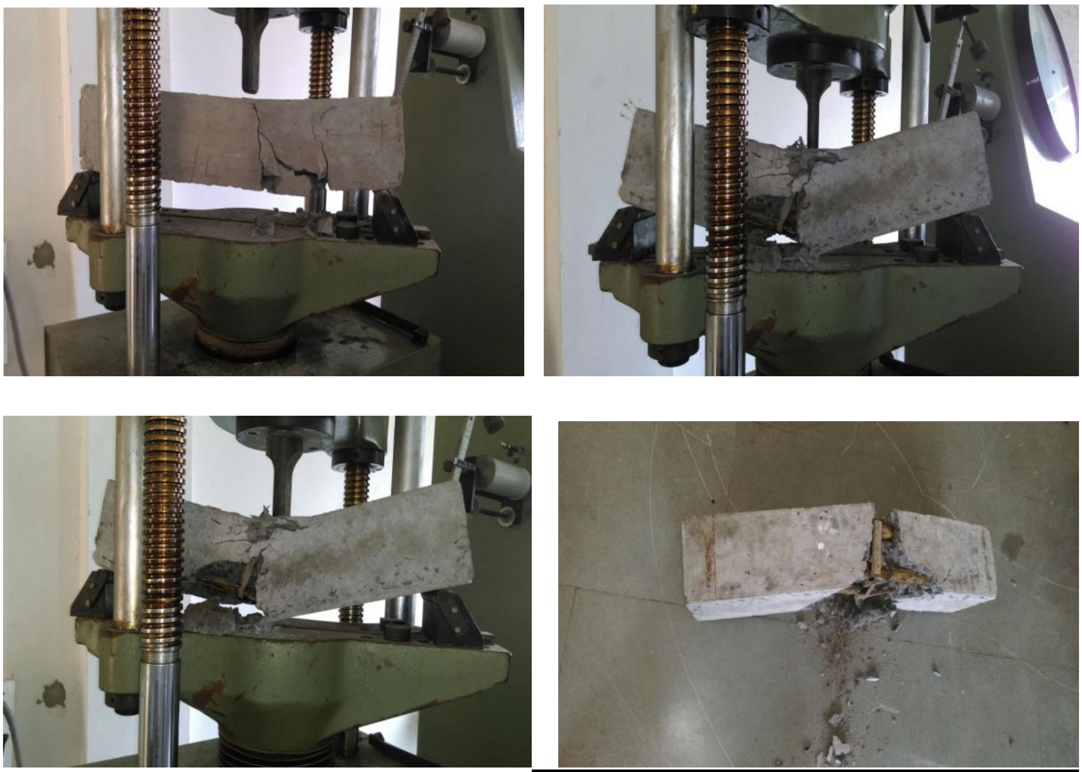


Table 3. Load-deflection values for unreinforced, bamboo reinforced and steel reinforced column

Load (kN)	Average deflection (mm) at centre of column					Unreinforced Concrete
	Bamboo strip reinforced concrete with				Steel reinforced concrete with 4Y12	
0					-	
40	2.0				-	
60	2.0	6.0			-	
80	3.0	6.0	1.0		4.0	
100	3.0	6.0	4.0	7.0	5.0	
120	3.0	7.0	8.0	10.0	5.5	-
140	3.0	7.5	10.0	12.0	6.0	-
160	4.0	9.0	10.5	14.0	6.5	-
180	4.0	9.0	10.5	14.0	7.0	-
200	4.0	9.0	11.0	14.0	7.0	-
220	4.0	10.0	11.0	15.0	7.5	1.0
240	4.5	10.5	11.0	15.0	8.0	1.5
260	5.0	11.0	11.0	16.0	8.0	2.0
280	6.0	11.0	11.0	16.0	8.0	
300	6.0	11.0	11.0	22.0	10.0	
320	6.0	11.0	11.0	22.0	12.0	
340	6.0	9.0	11.0		15.0	
360		9.0			17.0	
380					17.0	
400						

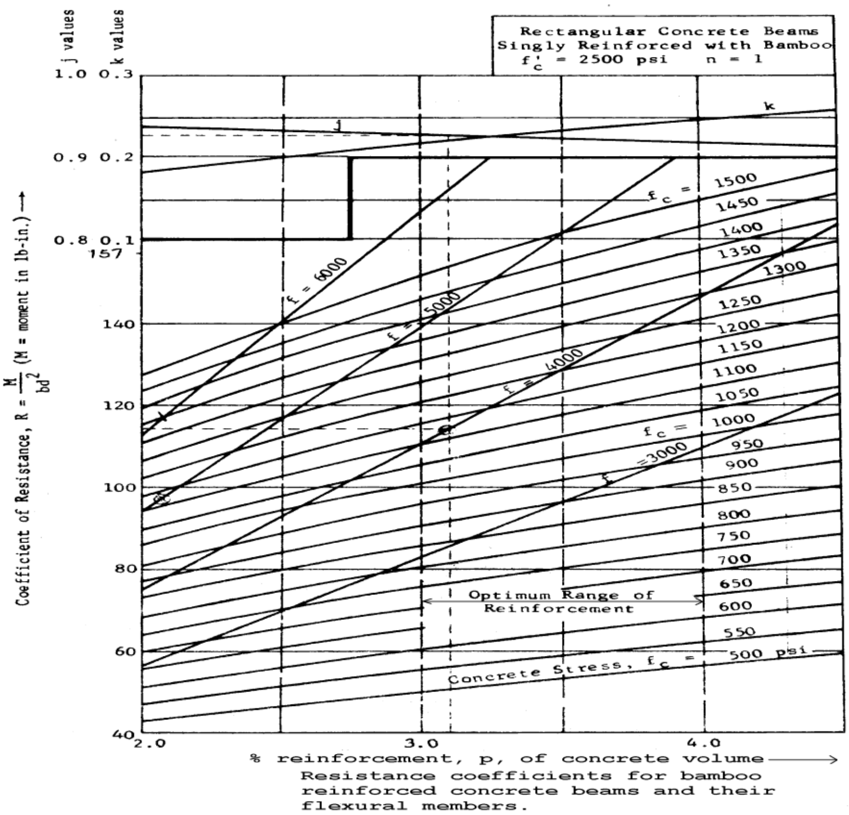


Figure 5. Resistance coefficients for bamboo reinforced concrete beams and their flexural members

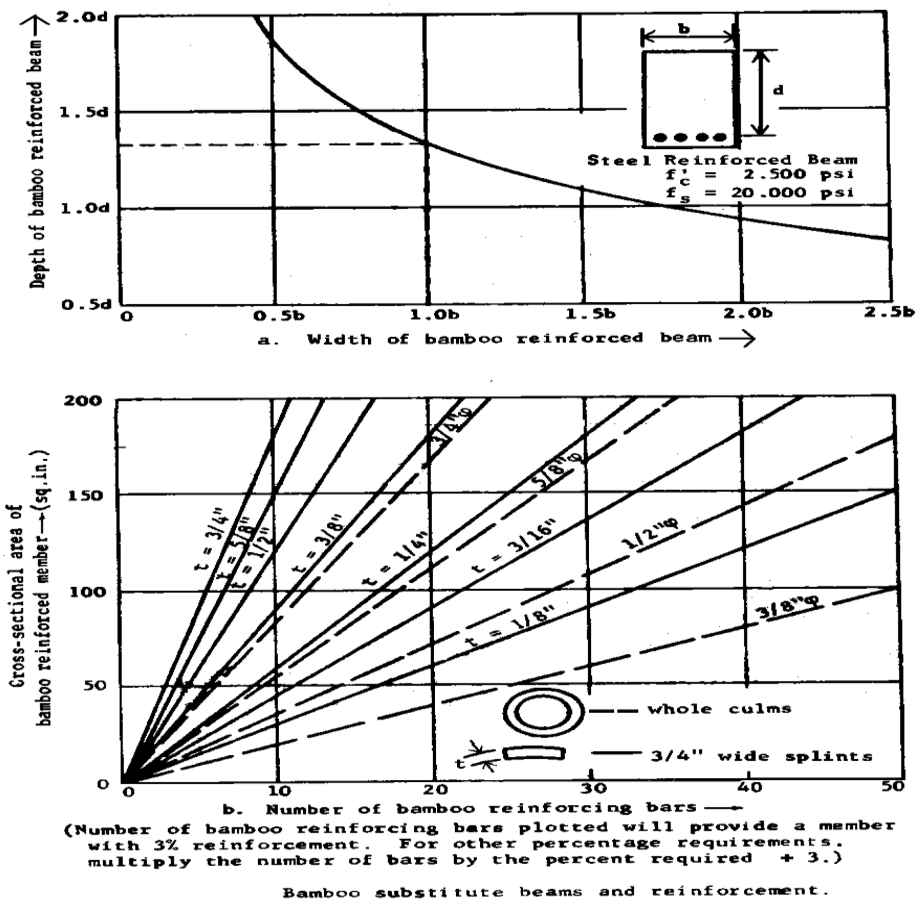


Figure 6. Bamboo substitute beams and reinforcement

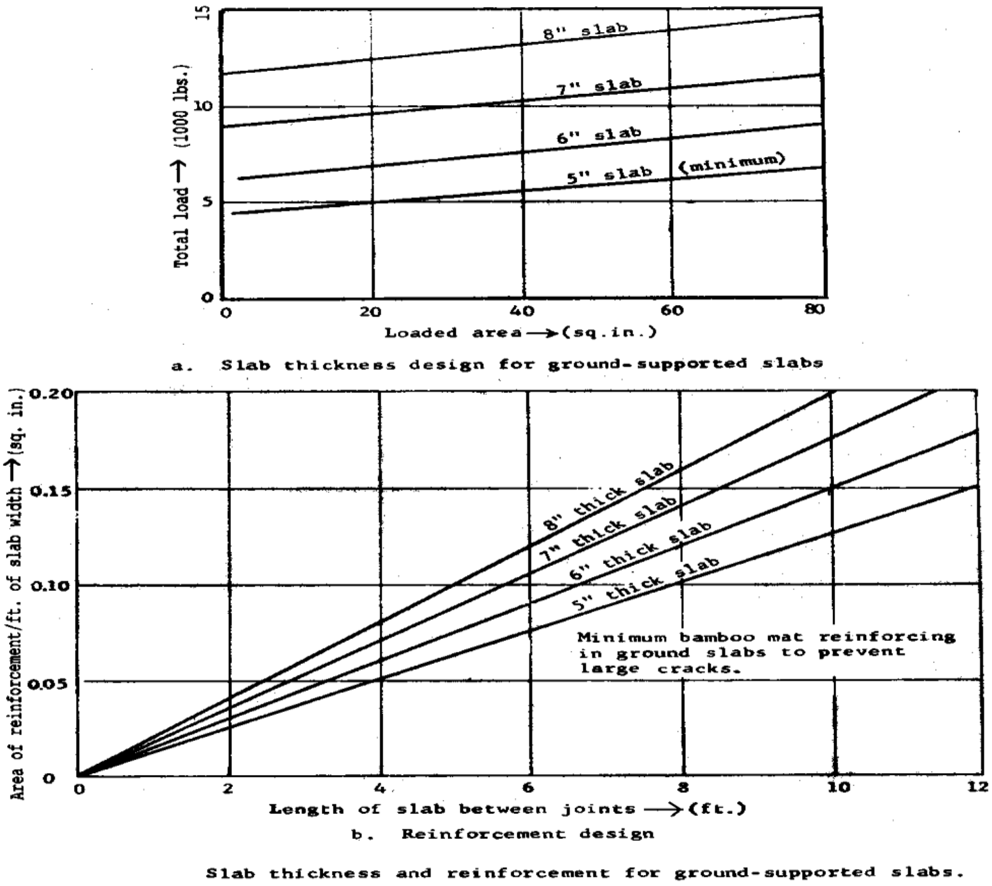


Figure 7. Slab thickness and reinforcement for ground supported slabs.

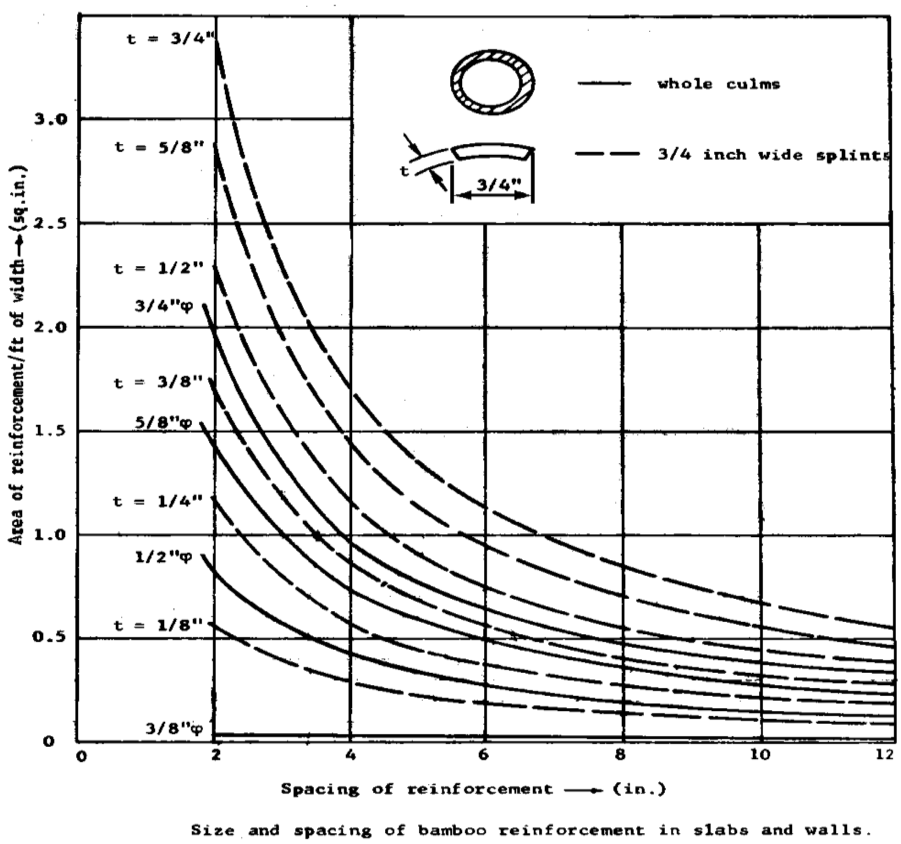


Figure 8. Size and spacing of bamboo reinforcement in slabs and walls

Table 4 . Properties of bamboo

Whole Culms		3/4 Inch Wide Splints	
Diameter (in.)	Area (sq. in.)	Thickness (in.)	Area (sq. in.)
3/8	0.008	1/8	0.094
1/2	0.136	1/4	0.188
5/8	0.239	3/8	0.282
3/4	0.322	1/2	0.375
1	0.548	5/8	0.469
2	1.92	3/4	0.563

Table 5: Steel reinforcing

Nominal Dimensions - Round Sections		
Bar Designation No.	Nominal Diameter (in.)	Cross Sectional. Area (sq. in.)
2	0.250	0.05
3	0.375	0.11
4	0.500	0.20
5	0.625	0.31
6	0.750	0.44
7	0.875	0.60
8	1.000	0.79
9	1.128	1.00
10	1.270	1.27
11	1.410	1.56

Table 6: Steel wire

AS&W Wire Guage Numbers	Diameter (in)	Area (sq. in.)	Weight (lb/ft)
0000	0.3938	0.12180	0.4l36
000	0.3625	0.10321	0.3505
00	0.3310	0.086049	0.2922
0	0.3065	0.073782	0.2506
1	0.2830	0.062902	0.2136
2	0.2625	0.054119	0.1838
3	0.2437	0.046645	0.1584
4	0.2253	0.039867	0.1354
5	0.2070	0.033654	0.1143
6	0.1920	0.028953	0.09832
7	0.1770	0.024606	0.08356
8	0.1620	0.020612	0.07000
9	0.1483	0.017273	0.05866
10	0.1350	0.014314	0.04861
11	0.1205	0.011404	0.03873
12	0.1055	0.0087417	0.02969
13	0.0915	0.0065755	0.02233
14	0.0800	0.0050266	0.01707
15	0.0720	0.0040715	0.01383
16	0.0625	0.0030680	0.01042

6. CONCLUSIONS AND RECOMMENDATIONS

In this work, strips of coated seasoned bamboo of cross-section 8x10mm were used as reinforcement in concrete column. Different percentage volume of the bamboo reinforcement was considered with unreinforced and steel reinforced column. Based on the experimental observation, the following can be deduced:

1. The tensile stress of seasoned bamboo is about 70N/mm2, about one-third of that of steel, with low ductility and a total strain of 5% compared with an average strain in steel of 12%.
2. The use of bamboo-strip as reinforcement in concrete column increased the load carrying capacity of the column compared to unreinforced concrete. It also improves the post cracking ability of the concrete but not as pronounced as in steel-reinforced column. Increase in volume content of bamboo strip reinforcement in the concrete section does not correspond to increase in the ultimate strength but only enhanced the ductility of the section.
3. Failure mode is independent of the materials used for reinforcement but rather on the strength of the reinforcement/concrete matrix. Hence, attention should be on enhancement of the reinforcement/concrete matrix bond.
4. The bamboo-strip reinforced column shows excessive cracking and deflection especially those with 12No.-strips.

In conclusion, the use of bamboo strips as reinforcement in column should not be for the purpose of imparting compressive strength but rather to induce elasticity in the concrete section, which in turn guide against sudden failure. Secondly, bamboo strips lack grips in concrete and deteriorate with age. The application of impervious surface coating like bitumen makes it more resistance to deterioration and sand coating further increase the bonding, which in turn translates to good strength. Therefore, the bamboo reinforced concrete column is recommended for lightly loaded structures and low rise constructions. However, it may not be suitable in water retaining structures because of the large deflection accompanying its failure. It is recommended that further investigation be carried out on bamboo strip reinforced concrete design, focusing on the determination of the optimum percentage of reinforcement.

REFERENCES

[1] H. E. Glenn. "Bamboo reinforcement in portland cement concrete," Engineering Experiment Station, Clemson Agricultural College, Clemson, South Carolina, Bulletin No. 4, May 1950.

[2] U. S. Army Engineer Waterways Experiment Station. Technical Report No. 6-646: "Precast concrete elements with bamboo reinforcement," by E. F. Smith and K. L. Saucier. Vicksburg, Mississippi, May 1964.

[3] S. R. Mehra and R. G. Ghosh. "Bamboo-reinforced soil-cement," Civil Engineering and Public Works Review, Vol. 60, no. 711, October 1965; vol. 60, no. 712. November 1965.

[4] "Concrete floors on ground," Portland Cement Association Concrete Information, ST-51.

[5] American Concrete Institute. "Building code requirements for reinforced concrete," (ACI 318-56). May 1956.

[6] Department of the Navy, Bureau of Yards and Docks. Design Manual NAVDOCKS DM-2, Structural Engineering. October 1964.