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BAMBOO REINFORCED CONCRETE

by

H. G. Geymayer

F. B. Cox

January 1970

Sponsored by

Office, Chief of Engineers

U. S. Army

Conducted by

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

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FOREWORD

The investigation on which this paper is based was sponsored by
the Office, Chief of Engineers (RDT&E), and reported in the Waterways
Experiment Station Technical Report No. C-69-3, February 1969.

This paper was prepared at the request of Mr. Robert E. Wilde,
Assistant Secretary, American Concrete Institute, for publication in
the Journal of the American Concrete Institute. The paper has been
reviewed and approved for publication by the Office, Chief of Engineers.

Preparation of the paper was accomplished at the Concrete Division,
U. S. Army Engineer Waterways Experiment Station, under the direction
of Mr. Bryant Mather, Chief, Concrete Division.

Colonel Levi A. Brown, CE, was Director of the Waterways Experiment
Station during the preparation of this paper and Mr. F. R. Brown was
Technical Director.

Bamboo Reinforced Concrete

by H. G. Geymayer and F. B. Cox

In many underdeveloped areas steel reinforcing bars for concrete are scarce, very costly, or not available, even though cement may be locally produced and readily at hand. Thus, there is a need for indigenous materials that can be used as expedient reinforcement for temporary or secondary concrete structures. Many of the areas in question are located in or near tropical and subtropical zones where bamboo is generally cheap and plentiful.

The idea of using bamboo as an expedient reinforcement for concrete is not new. More than 30 years ago, Datta[2] and DeSimone[3] experimented with bamboo reinforcement, and since then, about a dozen investigators, among them most notably Glenn[4] at Clemson University, have conducted research on the subject. These studies made it clear that bamboo reinforcement is feasible, but problems exist concerning bond, volume changes, and possible decay. Bamboo reinforcement was used during World War II by U.S. and Japanese armed forces in expedient military construction on isolated Pacific islands.

Military construction activities in Southeast Asia have recently caused renewed interest in bamboo reinforcement and an investigation of the use of bamboo as expedient reinforcement for concrete was begun at the U. S. Army Engineer Waterways Experiment Station. The more important results and conclusions are summarized here.

Properties of Bamboo

Bamboo, of which approximately 550 species have been described, is a perennial grass found in almost all tropical, subtropical, and many temperate zones. Two species, A. tecta (small cane) and A. gigantea (southern cane), are common in the United States.[4] A summary of pertinent physical properties of bamboo is given in table 1. The properties determined on Mississippi small cane were generally somewhat inferior to those reported in the literature for

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most other species, hence, the conclusions and methods described below
are believed to be reasonably conservative. Bamboo has a fairly high tensile
strength. Values as high as 53,000 psi (3726 kg/cm^2) have been reported.
An average tensile strength of about 15,000 psi (1055 kg/cm^2) was found for
local A. tecta. The modulus of elasticity of bamboo is relatively low, usually
less than 1/10 of that of steel reinforcement. This leads to large deflections
and wide cracks when bamboo reinforced flexural members are loaded to capacity.
Both tensile strength and elastic modulus vary greatly with the type and
environmental conditions of the specimen tested. The tensile strength of bam-
boo under sustained loads appears to be considerably lower than its static
strength, a reduction of up to 50 percent was found on local specimens of
A. tecta. Creep of seasoned specimens of the same species after 1 year under
tensile stresses of 4000 and 8250 psi (201.2 and 580.0 kg/cm^2) amounted to
about 40 percent of the elastic elongation under the respective load.

The Swelling-Shrinkage-Bond Problem

The principal problems associated with bamboo reinforcement, however, are
not its strength and deformation under tensile loads, but volume changes and
bond. Bamboo culms have been observed to undergo diameter changes in the
order of 5 percent and length changes up to about 0.05 percent with variations
in the moisture content. Diameter changes of such magnitude can obviously
result in serious cracking of the concrete cover due to expansion and/or an
almost complete loss of bond due to shrinkage of the culms. In addition, the
coefficient of thermal expansion of bamboo can be as low as 1/3 that of con-
crete longitudinally and as high as 10 times that of concrete diametrally.
These differences will also contribute to cracking of the concrete cover and
to a loss of bond, particularly if the member is exposed to large temperature
variations. Results of tests on A. tecta are given in table 1.

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Previous investigators[2,3] have warned that, due to shrinkage, untreated, green or presoaked culms, experience a drastic loss of bond in continuously dry cured specimens. Evidence to this effect was found on pullout specimens in which the protruding ends of the culms were not sealed and could, therefore, freely exchange moisture with the environment. However, in beams in which the concrete cover prevented the culms from readily losing moisture, we did not observe a significant loss of bond. The extent to which such a loss may occur depends primarily on the degree of saturation of the culm upon hardening of the concrete, the extent and rate at which the embedded culm is able to dry and shrink, the relative roughness of the culm or its protrusion:diameter ratio and the range of temperature fluctuations in the member.

There are six approaches to overcome the shrinkage bond problem.

a. To use seasoned (dry) culms that will continue to swell after the concrete has set up, in the hope that this swelling will compensate for subsequent shrinkage. This method is not recommended here because it frequently results in intolerable cracking of the concrete cover.

b. To coat seasoned culms with some type of moisture barrier (e.g. varnish, asphalt emulsion,[4] paint, etc.) to slow the rate of moisture changes in the culms. This method appears to have promise (provided the coating has no lubricating effect) and should be used if suitable materials are at hand. Some investigators[3,4] have also warned that coatings may aggravate the decay problem.

c. To coat seasoned culms with a material such as epoxy or polyester resins that firmly adheres to the bamboo surface. To ensure positive bond with concrete, sand should be sprinkled on the fresh resin coat to produce a rough surface.

d. To saturate seasoned culms with a liquid that will neither evaporate nor adversely affect bond or treat them with a hydrophobic substance.

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<u>e</u>. To rely on mechanical interlocking between bamboo and concrete through protrusions that are large enough to be relatively unaffected by shrinkage. The use of split culms rather than whole culms is strongly recomended (in addition to any other bond improvement method that may be used) since splitting results in a much higher contact area between concrete and bamboo and should afford better decay protection.

<u>f</u>. There is no shrinkage-bond problem when the culms do not lose significant amounts of moisture because the relative humidity remains above 80 percent.

The total anchorage force of a culm does not increase linearly as the embedment length increases. It appears more realistic to assume that beyond a certain embedment length, the pullout force will be fairly constant. Figure 1 shows that the bond strength computed from pullout tests on specimens with an embedment length of 6 in. was almost twice as high as the bond strength computed for specimens with 12, 18, and 24 in. embedment length. Similar results were found in beam tests.

Consequently, the concept of an allowable average bond stress perhaps should be abandoned altogether, or at least modified considerably. It could be replaced by the concept of a graduated allowable bond stress, such as allowing a relatively high bond stress value, U_1, for the first 6 in. (15.24 cm) of embedment length, a lower bond stress, U_2, for the next 6 in. (15.24 cm), and a very low value, U_3, for the remainder (if any) of the embedment length up to about 3 ft (0.9144 m).

Tests of Structural Members

About 30 simply supported beams with different cross sections, reinforcement ratios, and culm treatments, and six 2-way slabs have been tested. Typical test results and crack patterns of bamboo reinforced beams and slabs are shown in fig. 2-4. The results of these tests led to the following conclusions.

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Volume Stability, Bond, and Decay

In order to improve the bond of bamboo reinforcement, it is advantageous to use split culms rather than whole culms. When using split bamboo culms as reinforcing members, the concave side of the culms should be oriented so that air will not be entrapped. The culms have a tendency to float toward the top of the member especially during vibration of the concrete; therefore, special precautions are necessary to assure proper positioning of the reinforcement. To insure a fairly uniform cross-sectional area of reinforcement, care should be taken to alternate the basal and distal ends of the bamboo culms.

The maximum size aggregate in the concrete should be restricted to about 3/8 in. (9.53 mm) to avoid difficulties in placing and consolidating the concrete in members with high reinforcement ratios.

Special measures are necessary to prevent or reduce the absorption of water from the fresh concrete by the bamboo culms. If suitable materials are available, they may be used as a moisture barrier. However, caution is necessary with regard to materials that may have a lubricating effect. An expedient method of eliminating the swelling (but not the shrinkage) problem is to soak the bamboo culms (coated or uncoated) in water for 2 to 3 days prior to their embedment in the concrete. The use of some wood preservative (if available) rather than plain water to presoak the culms would appear to be desirable from the viewpoint of decay, but attention must be given to the influence of the preservative on bond (i.e. lubricating effect).

Preliminary test results and theoretical considerations indicate that the shrinkage of embedded, split culms will be a very slow process as long as a sufficiently thick, dense concrete cover protects the culms from the environment, or as long as the humidity of the environment stays above about 80 percent. However, if the concrete develops large cracks, as it will if the member is heavily loaded, or if the environment is constantly at a low humidity, shrinkage of the bamboo could become a very serious problem.

Of all the methods tested to date only two (other than splitting) were effective in increasing the bond between bamboo and concrete. Unfortunately, both have only limited value for field application. The two methods were:

_a._ The use of presoaked, split culms with 8-in.-long (20.32 cm) whole end sections to provide end anchorage.

_b._ The use of seasoned, split culms brush-coated with an epoxy or polyester resin that firmly adheres to the bamboo. To improve bond, sand was sprinkled on the fresh resin coat.

Flexural Strength, Cracking, and Deflections

For rectangular beam sections, the optimum reinforcement ratio (i.e. area of bamboo to total beam cross-sectional area) appears to be between 3 and 4 percent. Higher percentages result in overcrowded cross sections, and lower percentages give unsatisfactory strengths and large deformations. The use of inverted T sections rather than rectangular sections (fig. 5) results in a moderate increase of the ultimate moment capacity for the same total cross sectional area.

Rectangular beams reinforced with presoaked split bamboo (about 3.5 percent) are capable of developing about three times the flexural strength of unreinforced beams with identical cross sections (assuming the tensile strength of concrete to be 1/10 its compressive strength). If any of the previously mentioned methods of increasing bond are used, the flexural strength can be more than four times that of unreinforced beams.

Bamboo reinforcement does not substantially affect the cracking load of flexural members over that of unreinforced members. Upon cracking, flexural members develop large cracks and high deflections. Due to the poor bond, cracks are usually not numerous but are wide, extending close to the compression face of the member, thus indicative of the very high position of the neutral axis (fig. 2 and 6).

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Tentative Design Procedures

Based on the results to date, the following recommendations are made for the design of bamboo reinforced concrete members:

Beam Design

Expedient field design for rectangular cross sections. The simplest procedure and the one most suitable for field applications is:

    _a._ Neglect the bamboo reinforcement and design as an unreinforced beam permitting the concrete to carry an allowable tensile stress equal to $8\sqrt{f_c'}$ psi $(2.12\sqrt{f_c'}$ kg/cm$^2)$.

    _b._ Use 3 to 4 percent split, presoaked culms (preferably treated) as tensile reinforcement to ensure an overall safety factor of 2 to 2.5.

More Refined Design Procedures

For a more refined flexural design of beams reinforced with 3 to 4 percent split bamboo, the following modifications of the working stress design and the ultimate strength design as outlined in ACI Code 318-63 are suggested.

Elastic design. A regular straight-line elastic design according to the working stress design procedures of ACI Code 318-63, but tentatively using the following allowable stresses: [*]

Elastic modulus of bamboo (in tension)	$E_b = 2.0 \times 10^6$ psi $(140,614$ kg/cm$^2)$ (or $E_b = 1.25 \times 10^6$ psi $(87,884$ kg/cm$^2)$ for deflection analysis)
Elastic modulus of concrete (normal weight concrete)	$E_c = 57,500\sqrt{f_c'}$ psi or $15,246\sqrt{f_c'}$ kg/cm^2
Extreme fiber stress of concrete (in compression)[**]	$f_c = 0.8\ f_c'$
Tensile stress in bottom bamboo culms	$f_{b_{max}} = 5000$ psi $(351.54$ kg/cm$^2)$
Shear stress in concrete (use $\dfrac{V}{bh}$ rather than $\dfrac{V}{bd}$)	$V_c = 1.1\sqrt{f_c'}$ psi or $0.292\sqrt{f_c'}$ kg/cm^2

[**] Allowance for higher stresses than given in the ACI Code is made due to large strain gradients in bamboo-reinforced beams.

Anchorage force per culm (for minimum embedment length of 12 in. (30.48 cm)

F = 250 lb per in x P, where P = perimeter of culm, in.

lb (N)

(437.8N per cm x P, where P = perimeter of culm, cm)

Ultimate Strength Design

The ultimate strength design procedures specified by the ACI must be modified to account for failure by loss of bond rather than by yield of the reinforcement. A detailed discussion of this approach can be found in the report.[1]

Slab Design

In slabs, it is generally impractical to place 3 to 4 percent bamboo reinforcement. The following expedient field design procedure is suggested for slabs containing less than 3 percent reinforcement:

<u>a</u>. Use a minimum slab thickness of 3 in. (7.62 cm) even for small panels to ensure sufficient cover and efficiency of the bamboo reinforcement.

<u>b</u>. Neglect the contribution of the bamboo to the strength, and design the slab as an unreinforced slab, using $6\sqrt{f_c'}$ psi ($1.59\sqrt{f_c'}$ kg/cm^2 in the metric system) as the allowable concrete tensile stress. (For allowable shear stress see ACI Code).

<u>c</u>. Maintain a minimum reinforcement ratio (relative to the total cross-sectional area) of 1.5 to 2.5 percent to ensure a safety factor of approximately two. Culms should be split and presoaked (and preferably treated).

<u>d</u>. For two-way or continuous slabs provide additional corner and/or negative reinforcement where necessary.

The more refined design considerations outlined for beams are also suitable for two-way, bamboo-reinforced slabs.

Current and Future Tests

To obtain a better understanding of the shrinkage-bond mechanism, a number of tests are currently under way to investigate the bond strength and decay behavior in beams and pullout specimens after long-term exposure to various

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environments. The behavior of prototype beams under sustained loads and field exposure conditions is under study (fig. 6) and new methods of splicing culms, improving bond, and preventing culm shrinkage and decay, as well as the use of bamboo as shear reinforcement are being investigated. Future tests will include field tests of complete structures under both, long-term and dynamic (blast) loads. Eventually, final design and construction procedures will be recommended for incorporation into an engineering manual on bamboo reinforced concrete structures.

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3. De Simone, D., "Norme, Materiali e Strutture per la Limitazione dell'impiego del Ferro nelle Costruzioni," Annali dei Lavori Publlici, Vol. 77, No. 12, Dec 1939, pp 1189-1223; English translation by A. Holme, "Substitutes for Steel in Reinforced Concrete," Royal Engineers Journal, Vol. 54, June 1940, pp 237-244.

4. Glenn, H. E., "Bamboo Reinforcement in Portland Cement Concrete," Bulletin No. 4, May 1950, Clemson Agricultural College, Clemson, S. C.

Note: This is an ACI Summary Paper. It presents the major important material from "Expedient Reinforcement for Concrete for Use in Southeast Asia," Report No. 1 "Preliminary Tests of Bamboo," USAEWES TR C-69-3 February 1969, copies of which may be obtained from the Director, U. S. Army Engineer Waterways Experiment Station, P. O. Box 631, Vicksburg, Mississippi, 39180 for $2.25 each by check or money order payable to the Treasurer of the United States, Vicksburg, Mississippi. Copies of TR C-69-3 will be maintained permanently on file at the American Concrete Institute Headquarters and when copies are no longer available from USAEWES, xerographic or similar reproductions may be obtained from ACI at a charge equal to the cost of reproduction plus handling at the time of the request.

Table 1

|	As Reported in the Literature for Various Species	As Obtained in This Investigation for Ar. tecta. (Southern Small Cane)	
	Range	Average	Range
Dimensional changes due to moisture variation (swelling and shrinking)			
diameter change %	Not reported	--	approximately 5%
length change %	Not reported	--	approximately 0.05%
Approximate coefficient of thermal expansion			
diagonally 10^{-6}/F	32.00×10^{-6}-61.00×10^{-6}	26.0×10^{-6}	20.74×10^{-6} 31.90×10^{-6}
10^{-6}/C	57.60×10^{-6}-109.8×10^{-6}	46.8×10^{-6}	37.33×10^{-6} 57.42×10^{-6}
longitudinally 10^{-6}/F	3.00×10^{-6}-9.00×10^{-6}	2.00×10^{-6}	0.80×10^{-6} 2.87×10^{-6}
10^{-6}/C	5.40×10^{-6}-16.2×10^{-6}	3.60×10^{-6}	1.44×10^{-6} 5.17×10^{-6}
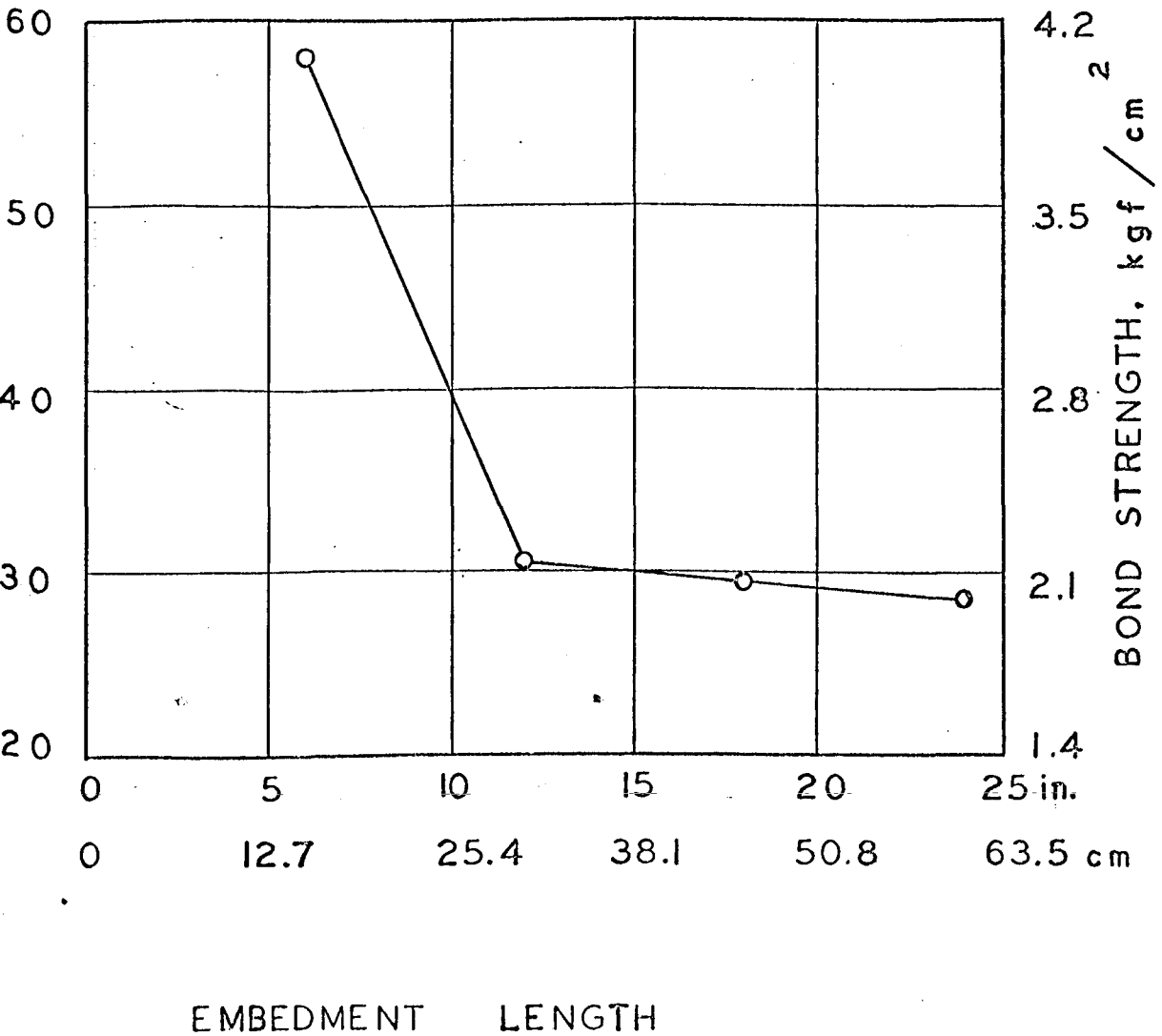
EMBEDMENT LENGTH

Fig. 1   Bond Strength vs. Embedment Length
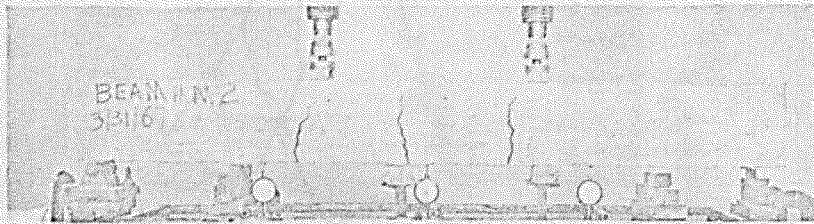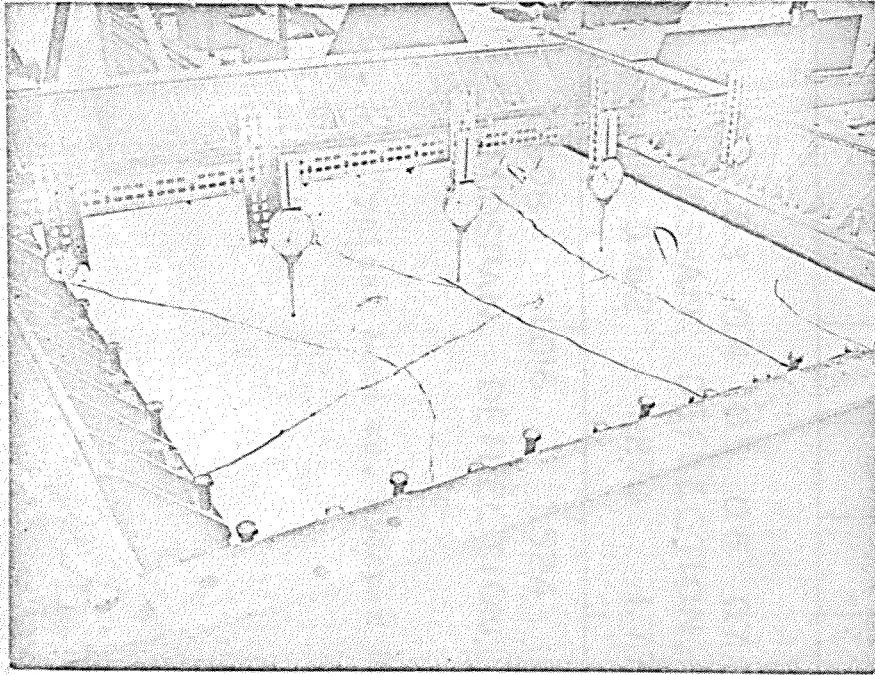
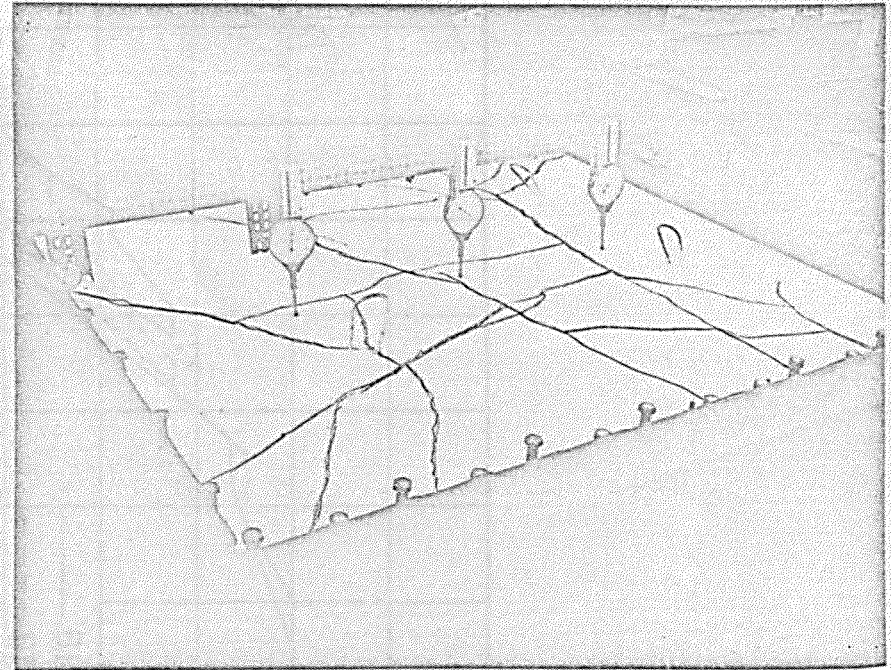Total load = 1500 lb (680.4 kg)
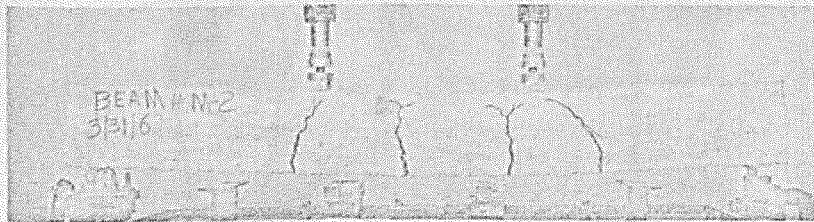
Total load = 4000 lb (1814.4 kg)
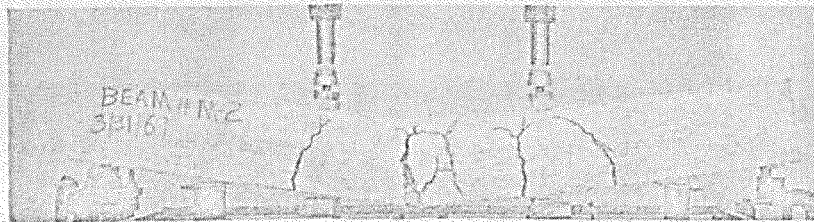
Total load = 4000 lb (1814.4 kg), failure

Fig. 2 Typical Beam Crack Patterns

792 psf (3866.9 kg/m²)

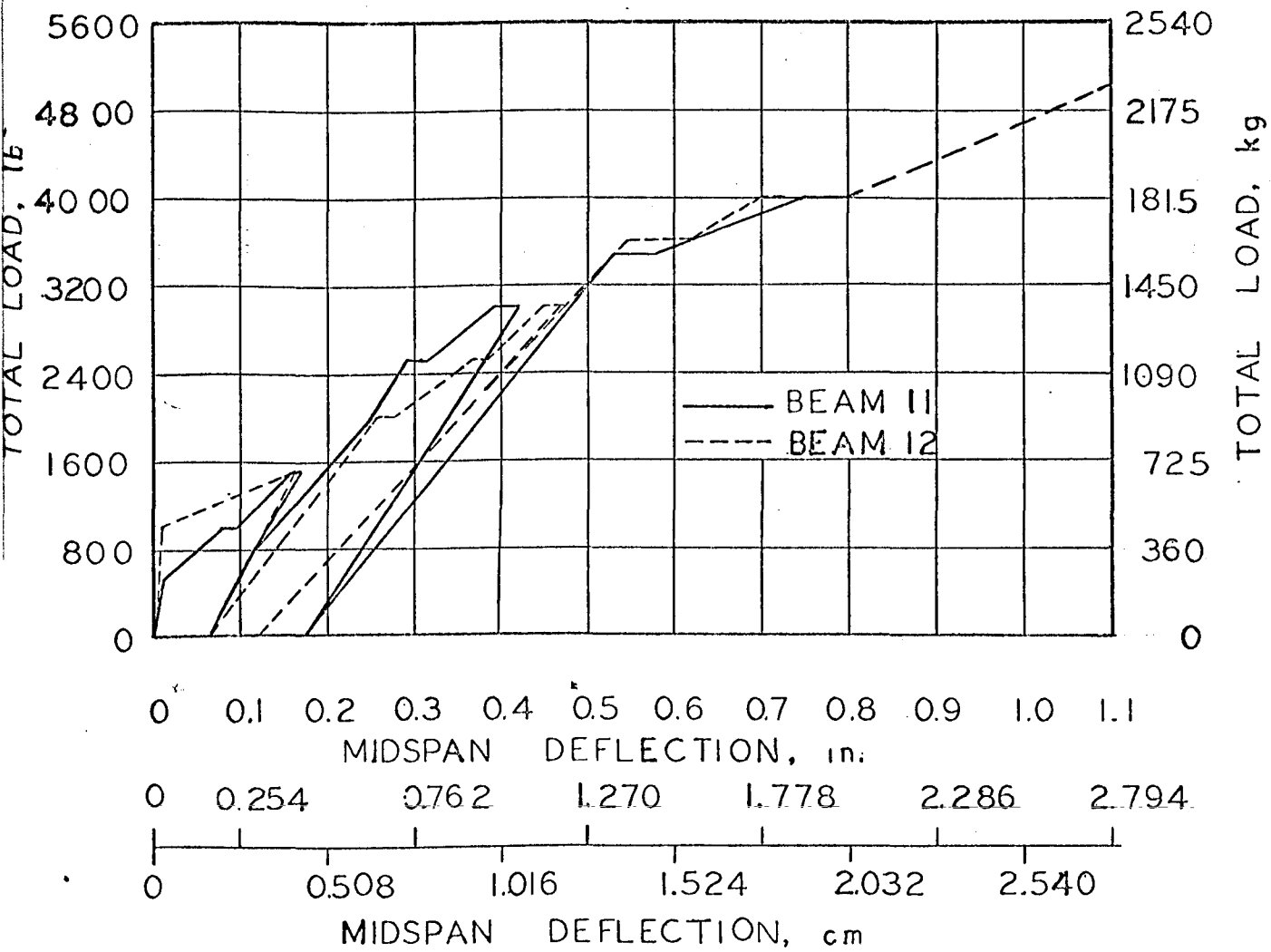1296 psf (6327.6 kg/m²)
Failure

Fig. 3 Typical Slab Test

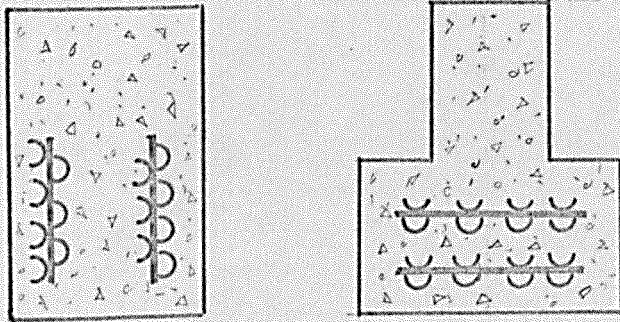Fig. 4   Typical Load vs. Midspan Deflection

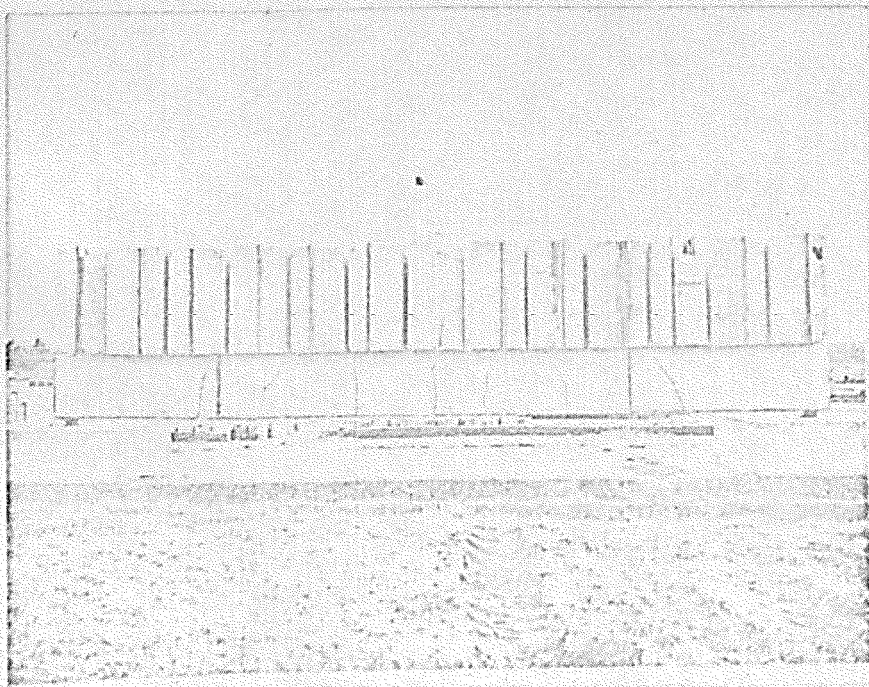Fig. 5   Typical Cross Sections
Of Bamboo Reinforced Beams

Fig. 6   Field Test of a 7x15x180 in. Beam
Under a Sustained Load of 650 lb/ft.

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