BAMBOO AS GREEN ALTERNATIVE TO CONCRETE AND STEEL FOR MODERN STRUCTURES

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Received June 28, 2008 *Accepted November 21, 2008*

ABSTRACT

This paper presents the possible replacement of concrete and steel, production of every ton of which releases several tons of greenhouse gases in the atmosphere, by eco-friendly bamboo as a modern engineering construction material. In fact, growth of every ton of bamboo consumes nearly a ton of carbon dioxide besides releasing fresh oxygen into the atmosphere. In this paper, through structural analysis and design principles, it is demonstrated as to how modern engineered structures can be a real possibility using bamboo. A detailed structural analysis and design of a typical bamboo shed structure is presented in accordance with the Indian standard codes of practice. The columns are designed as battened columns with concrete bands as the ties. The roof is designed as a bamboo parabolic tied arch resting on the battened 'bambcrete' columns. Other elements such as purlins and bracings are also bamboo based. Two alternative designs are presented for connection of the bamboo columns with concrete pedestal projecting from the footing base. Not only the proposed structure is capable of withstanding the loads as prescribed in the codes of practice, its cost is several times less than the so called "modern structures" constructed using concrete and steel. The details presented in this paper set aside the conventional belief that only concrete and steel structures can be engineered. Modern structural analysis and design practices can be suitably applied upon bamboo elements for rational engineering design of buildings and other structures.

Key Words : Bamboo;, Concrete, Steel, Eco-friendly, Shed structure.

INTRODUCTION

There has been a furious construction activity in the developing world, especially India and China, for the last one and a half decades. Although not directly visible, construction industry is one of the most polluting industries in the world. Production of both concrete and steel cause considerable

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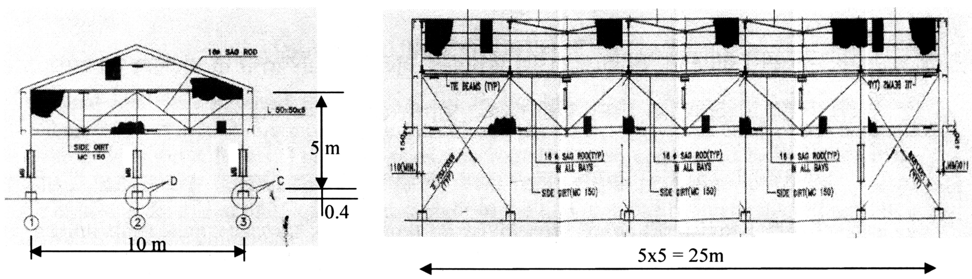
deterioration of the environment. Cement, the main constituent of concrete, requires heating limestone and other ingredients to over 1,400^{o}C by burning fossil fuels. Producing every ton of cement results in the emission of at least one ton of carbon dioxide (CO_2)[1]. Roughly 5 to 10 percent of global CO_2 emissions are related to the manufacture and transportation of cement[2]. Similarly, production of every ton of steel is accompanied with the release of over two tons of CO_2 in the atmosphere[3].

The developing economies need millions of houses for their growing population, a big part of which is homeless. Large population is forced to stay in slums in the big cities. People sleeping on the roadside is a very common sight in cities like Delhi, Mumbai and Beijing. Similarly, the fast growth rate necessitates infrastructure development in the form of suitable space for offices and industries. While acknowledging the need for building more structures, it is also most important to keep the environmental issues at the forefront. It is here that engineered bamboo can be of great value to civil engineers owing to several noteworthy features. From environmental consideration, production of every ton of bamboo consumes about a ton of the atmospheric CO_2, in addition to releasing fresh oxygen into the atmosphere. From structural engineering point of view, bamboo has competitive strength characteristics. Typically, species like dendrocallamus giganteus (DG) have tensile strength of about 120 MPa, compressive strength of 55 MPa and Young's modulus of 14 GPa. These figures do not compare badly with mild steel which has an ultimate strength of 410 MPa, yield strength of 250 MPa and Young's modulus of 20 GPa. Concrete has much lower strength than those of bamboo reported here. In addition, the low density of bamboo, which is typically 700 kg/m^3, results in much higher strength to weight ratio as compared to steel (density = 7800 kg/m^3) and concrete (density = 2400 kg/m^3). The only shortcoming with raw bamboo is susceptibility to termite attack which can be set aside by suitable chemical treatment.

A dedicated team of researchers at the Indian Institute of Technology Delhi (IIT Delhi) has recently initiated a comprehensive research program to scientifically design, build and test engineered bamboo structures so that conventional wisdom can be integrated with scientific knowledge. The initiative is funded by World Bank through National Agricultural Innovation Program (NAIP). It is in this endeavour that a thorough structural analysis and design of a typical bamboo shed structure, 10x25m in plan and 5m high, is carried out and the results presented in this paper.

Structural details and basic bamboo elements

Bhalla et al.[4] recently covered the wind analysis of a bamboo shed 6x6m in plan and 2.4m in height. The present study aims to go ahead and provide an alternative design for a much larger steel shed structure, 10x25m in plan and 5m in height, using engineered bamboo. The structure is assumed to be situated in Delhi region. **Fig. 1** shows the front and the side elevations of a conventional industrial shed made of steel. In the alternative design presented here, the steel columns shall be replaced by battened bamboo columns, of the type shown in **Fig. 2,** where bamboo elements serve as struts and ferrocement bands as battens. The roof steel roof truss shall be replaced by bamboo tied arch of the type shown in **Fig. 3.** The arch has a crown height of 1.7m and span of 10m. Both the columns and the bamboo arch have been recently conceived at IIT Delhi[5,6] and are classified as 'bambcrete' elements, to signify the combination of bamboo with concrete. Both the column as well as the arch prototypes are currently under test in the Heavy Structures Laboratory (HSL), of the Structural Engineering Laboratories (http://web.iitd.ac.in/~strlab), Department of Civil Engineering, IIT Delhi. The forthcoming sections provide details of the design philosophy, detailed structural analysis and the design of various components.



(a) (b)

Fig. 1 : Details of typical industrial shed aimed to be replaced with bamboo. (a) Front elevation. (b) Side elevation.

Fig. 2 : Bambcrete column.

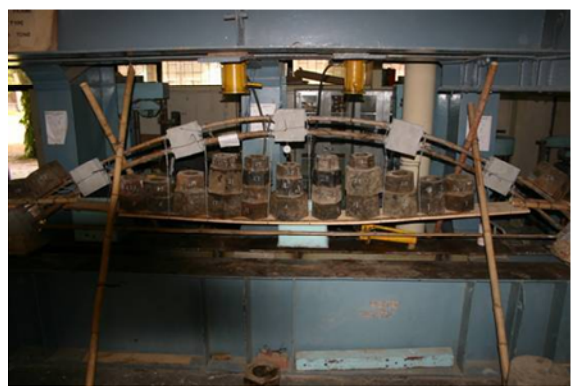


Fig. 3 : Bamboo bow beam for supporting roof.

Design philosophy and allowable stresses

The design covered in this paper is assumed to use the species dendrocallamus giganteus (DG) of bamboo, for which the tensile strength and the compressive strengths are reported as 121.5MPa and 55.55 MPa respectively[3]. The proposed approach follows the working stress design method and assumes that bamboo behaves linearly elastic in the working stress range. Being natural product, and expecting a large variation of strength characteristics, a large factor of safety of four is considered in the proposed approach. Hence, the allowable stress in tension works out to be 30 MPa. For compression, taking the factor of safety as well as elastic critical load analysis, the allowable compressive stress works out to be 13 MPa for a slenderness ratio of 80. Each bamboo element is considered to have an external diameter of 40mm and a wall thickness of 10mm.

Dead loads and imposed loads

Dead load and imposed load analysis of the structure are straightforward since these loads do not induce any moment on the column due to flexible connection of the bamboo arch with the columns. For dead loads, the roof has been considered to be covered by galvanized iron (GI) sheeting. Together with bamboo purlins, these are considered to impose a dead load of 15kg/m^2. The weight of the tied arch has been considered as 200kg and that of the columns as 40kg/m. In accordance with IS 875 part 2[7], an imposed load of 75kg/m^2 has been considered for the roof. The dead loads and the imposed loads result in an axial force of 6.75 kN and 18.75 kN respectively at the base of the column.

WIND LOADS

In this study, the structure is analyzed for wind forces in accordance with IS: 875 Part 3[8]. For Delhi region, this code recommends a basic wind speed V_b of 47m/s. This study has considered the value of the probability factor (risk coefficient) k_1 as1.0 assuming a mean probable life of 50 years. The terrain, height and size factor k_2 of 1.0 has been considered since the proposed structure belongs to class A and category 2 as per IS 875 part 3[8]. Finally, the topography factor k_3 has been chosen as 1.0. These factors result in a design wind speed $V_Z (=k_1\, k_2\, k_3\, V_b)$ of 47m/s , thereby resulting in a design wind pressure of 1.325 kNm^{-2} . The external and internal pressure coefficients on the wall and roof in accordance with IS 875 part 3[8] are shown in **Fig. 4** for two wind directions- normal to the ridge and parallel to the ridge. An internal wind pressure of ±0.7 has been considered taking into account the large opening area, somewhat more than 20% of the wall area. In overall, following wind cases have been analyzed

1. Wind normal to ridge, inside suction.
2. Wind normal to ridge, inside pressure.
3. Wind along ridge, inside suction.
4. Wind along ridge, inside pressure.

Fig. 5 shows the steps involved in the analysis of a typical transverse frame, which supports the wind load on a tributary length of 5m of the building, for the case of wind load normal to ridge with pressure inside. The structure is analyzed as the superposition of two cases- (A) and (B), shown in the figure. The columns are idealized as propped cantilevers for case (A). The wind force acting on the walls induces moment on the columns while that on the roof simply result in axial force. **Table 1** summarizes the final forces in the columns for all the four cases listed above. It can be clearly observed that case (i) and (ii) would be most critical and shall govern the column design for the load combination DEAD LOADS + WIND LOADS.

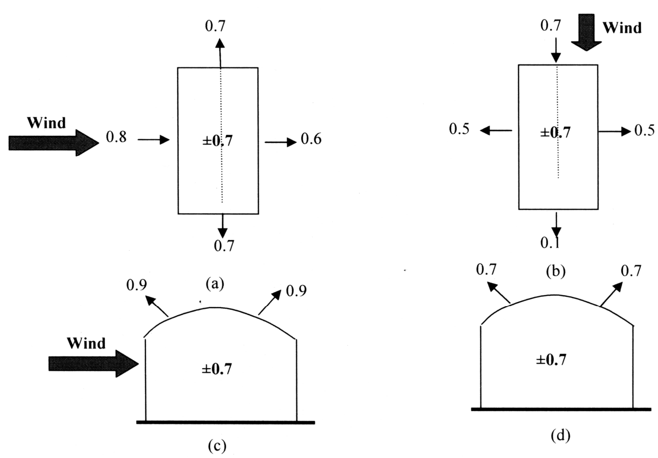


Fig. 4 : Wind pressure coefficients in accordance with IS 875 part 3
(a) Walls : Wind normal to ridge, (b) Walls : Wind along ridge
(c) Roof : Wind normal to ridge, (d) Roof : Wind along ridge

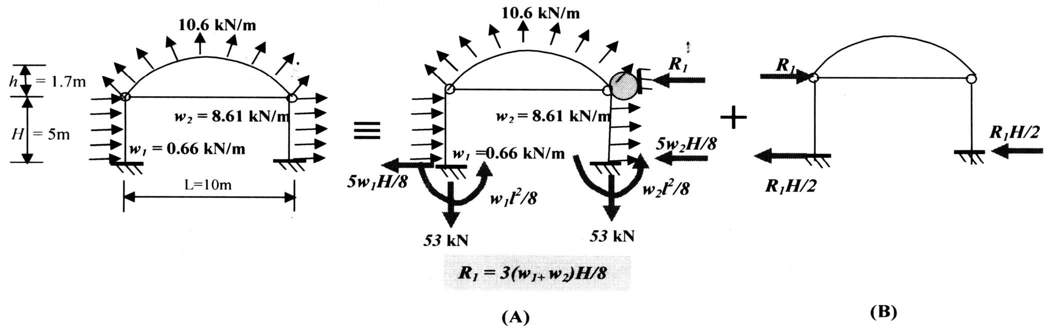


Fig. 5 : Analysis of transverse frame for wind normal to ridge, inside

Table 1 : Summary of forces at bottom of column for four wind conditions

S. No.	WIND CASE	TENSILE FORCE (kN)	MOMENT (kNm)	HORIZONTAL FORCE (kN)
1	Wind normal to ridge, inside suction	3.2	74.5	39.8
2	Wind normal to ridge, inside pressure	53	70.5	35.6
3	Wind along ridge, inside suction	0	4.2	4.2
4	Wind along ridge, inside pressure	46.3	4.2	4.2

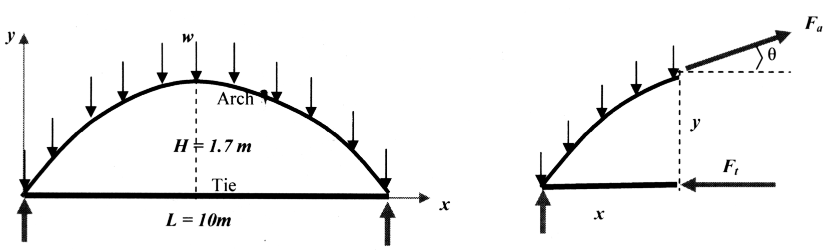


Fig. 6 : Analysis of bamboo tied arch

DESIGN OF BAMBOO TIED ARCH

Fig. 6 shows the idealized model of the bamboo tied arch. The arch is assumed to follow a parabolic profile as given by

$$y = \frac{4H}{L^2}\left(Lx - x^2\right) \qquad (1)$$

where H is the crown height and L the span of the arch. In general, under a uniformly distributed load w (acting downwards), the force in the arch (F_a) and the tie element (F_t) can be derived, using equilibrium of forces, as

$$F_a = \frac{w\sqrt{L^4 + 16H^2(L-2x)^2}}{8H} \qquad \text{(Compressive)} \qquad (2)$$

$$F_t = \frac{wL^2}{8H} \qquad \text{(Tensile)} \qquad (3)$$

Table 2 summarizes the maximum forces induced in the tie and the arch components under the load combinations DEAD LOADS + LIVE LOADS and DEAD LOADS + WIND LOADS. Wind case 2 **(Table 1)** offers the maximum upward load on the arch element has been considered in the above combinations.

Table 2 : Summary of forces in the arch components

S. No.	Load Combination	Force In Arch (kN)	Force In Tie (kN)
1	DEAD LOADS + LIVE LOADS	45 (C)	37 (T)
2	DEAD LOADS + WIND LOADS	78 (T)	64 (C)

'C' denotes compression and 'T' denotes tension

By trial and error, a section consisting of four bamboo struts (40mm diameter and 10 wall thickness), positioned at the corners of a 200mm square, as shown in **Fig. 7(a),** is found to have the compressive as well as tensile stresses within the permissible limits, both for the arch as well as the tie element. The tie will be a bambcrete element of the type shown in **Fig. 2.** Concrete bands shall be spaced at an interval of 1200 mm to limit the slenderness ratio of each strut to 80. This is lower than the overall slenderness ratio of 100 for the tie. For the arch element, the intermittent support by purlins at a spacing of 1200mm would result in an overall slenderness ratio of 80.

Design of columns and other components

From **Table 1,** wind cases 1 and 4 are found to exert maximum axial force and the moment in the column. **Table 3** shows the total axial force and the moment at the column base for the three wind cases of **Table 1** in combination with the dead loads. By trial and error, a cross section shown in **Fig. 7(b)** works out to be adequate from the point of view of the permissible stresses. **Fig. 7(c)** shows the section of the members for vertical bracing system, and the horizontal bracing. The loads are computed as illustrated in reference[9]. The vertical bracing shall be provided in the longitudinal frames in the two end bays, similar to that of the steel building shown in **Fig.1(b).** The horizontal bracings shall also be provided in the same bays but at the level of the tie member of the bamboo arch. The bamboo struts are tied by concrete bands spaced 1200mm.

The last component to left to be designed is the purlin. A spacing of 1200mm is considered for the purlins. The combination DEAD LOADS + WIND LOADS shall govern the design of the purlin and will typically subject an element to biaxial bending. By trial and error, a section shown in **Fig. 7(d)** is found to be suitable. The bamboo struts are tied by concrete bands at a spaced 1200mm.

Table 3 : Summary of design forces in columns

S. No.	Load Combination	Axial force (kN)	Bending moment (kNm)
1	DEAD LOADS + WIND CASE 1	4 (C)	75 (T)
2	DEAD LOADS + WIND CASE 4	47 (T)	70 (C)

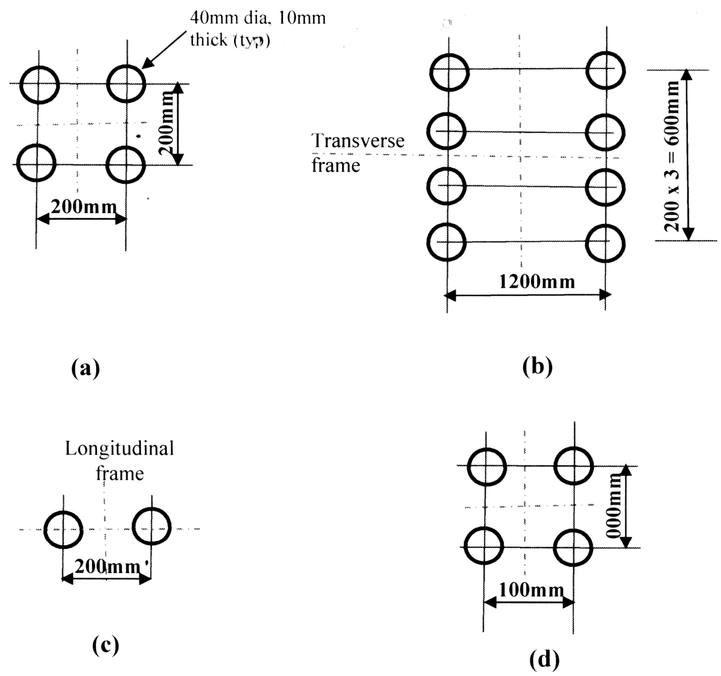


Fig. 7 : Cross section of various components worked out by design principles.
(a) Arch and tie element. (b) Columns. (c) Vertical and bottom chord bracing. (d) Purlins.

End connection of column

In his study, two possible types of base connections have been conceived. In the first type, shown in **Fig. 8,** the bamboo components are embedded inside concrete of the pedestal up to a length which is sufficient to provide an adequate force through bond with the surrounding concrete. From the above analyses, the maximum axial force in tension in the bamboo component of the column would be 16 kN. The required length of embeddment for the maximum force F = 16 kN can be calculated as

$$L = \frac{F}{\pi D \tau} \qquad (4)$$

where τ is the bond strength between bamboo and concrete, to be determined in the laboratory through a pullout test and D the outer diameter of the bamboo. This type of connection is the simplest type. Further laboratory tests are needed to evaluate τ for bamboo-concrete combination. **Fig. 9** shows the second type of base connection. In this type of connection, eight mild steel tubes of internal diameter 50mm and 8mm wall thickness are first embedded inside concrete and suitable length left projected above the top of pedestal. The tubes have a centre to centre spacing as in **Fig. 7(b)** for the bamboo struts. The development length can be easily computed using Eq. (1), taking τ = 1.4 Nmm^2 (limit state) as per IS 456 (2000) for M 25 concrete. This comes out to be 115mm for a force of 1.5 x 16 kN. Hence, the steel tubes are embedded 150mm inside concrete. After the pedestal is ready, the bamboo components of the bambcrete column can then pushed inside these steel tubes and secured by bolts.

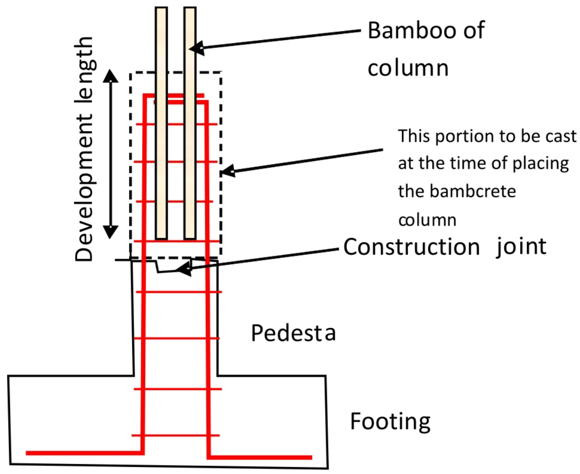


Fig. 8 : Type I base connection.

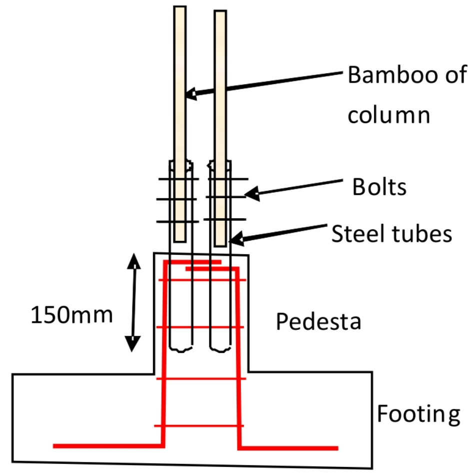


Fig. 9 : Type II base connection

CONCLUSION

This paper has covered the analysis and the conceptual design of a typical bamboo based shed structure under various loads and their combinations. Wind loads have been considered as per IS 875 part 3[7] and the structure analyzed in a simple fashion, by considering the behaviour of a typical frame in the transverse direction. The roof is supported by bamboo tied arches and the columns are designed as battened bamboo members tied by ferrocement ties. The proposed structure aims to provide an alternative environment friendly construction for a steel industrial shed, typically 10m in span and 5m in height. It can serve multiple purposes, such as workshop for a cottage industry, warehouse, and other medium industries. Not only is the structure light compared to conventional steel, it is at the same time several times cheaper and eco friendly. Such structures can pave way for sustainable industrialization of the rural sector in India and other developing nations.

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