Bamboo as a Cost effective Structural Material in Buildings

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Abstract— **Economy of projects is the most important considerations along with other considerations like lifespan and safety of the project. The consideration of investment becomes more important in cases of developing and underdeveloped societies. Nearly 25 percent of the world population cannot afford to have their own homes due to a very low income. Also one third of the world urban population lives in slums. These irritating figures on world economy tempted me to do research on "Looking for an alternative and cost effective Building and Structural material that can help in providing homes to more than a Billion homeless of the world". This research has been done with main thrust on reducing the cost factor in construction of buildings. The costs of raw materials for buildings these days are very high and it becomes near impossible for a common man to build his dream house. Use of bamboo in building construction working can reduce raw material costs to a huge extent. This research made a preliminary study of the relative economic condition of people and also of the feasibility of using bamboo for Building Construction. A comprehensive study on the subject resulted in the positive conclusion for introduction of this cheap, strong and aesthetically beautiful building material.**

Index Terms—**Economy of projects, Building and structural material, Bamboo, Cost effective**

I. Introduction

Bamboo has a long and well-established tradition as a building material throughout the world's tropical and sub-tropical regions. It is widely used for many forms of construction, in particular for housing in rural areas. Bamboo is a renewable and versatile resource, characterized by high strength and low weight, and is easily worked using simple tools. It is widely recognized as one of the most important non-timber forest resources due to the high socio-economic benefits from bamboo based products. It is estimated that there are 1200 species growing in about 14.5 million hectares area. Most of them grow in Asia, Africa and Latin America.

WHY BAMBOO:-Not only is bamboo the best eco-friendly alternative to building with timber from a green perspective, it actually performed better in University tests in my research that measured things like tensile and compression strength. And in real world events like hurricanes and earthquakes, well-constructed bamboo homes (like the ones we create) stood strong while conventionally built structures didn't.

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Here's a few reasons why building with bamboo is just plain better.

Strength- As strong as mild steel with the compression strength of concrete. Amazingly, one inch of bamboo can hold up to 7(1/2) tons of weight.

Hurricanes-Bamboo Living Homes surpass the toughest hurricane codes in the USA, and in 1995 withstood three back to back hurricanes with 173mph winds.

Earthquakes-Bamboo bends instead of breaks. In April 1991, twenty bamboo houses built for the National Bamboo Foundation in Costa Rica suffered no structural damage from a 7.5 Richter scale earthquake, despite being directly over the epicenter.

Termite action- Tests show that termites refuse to eat even untreated bamboo.

What considerations are must while building a structure like a building? *Economy, Serviceability and Safety!* The Bamboo is a wonder grass that can replace other costly building materials and provide homes at very low costs but not at the cost of the safety as it is safe enough to stand during Seismic Jerks, Hurricanes and other natural forces.

II. STRUCTURE OF BAMBOO

A young shoot of bamboo is protected by a series of sheaths, which fall off as the shoot grows into a mature culm. In many cases, these protective culm sheaths are covered with tiny hairs sharp enough to pierce human skin and, in several species, toxic enough to cause skin irritation. Most bamboos are hollow. In the hollow inner area, some horizontal partitions called 'diaphragms' .On the outside, these partitions are denoted by a ring around the culm. A diaphragm and the ring on the outside together form a "node". Branches grow from these nodes. The part between two nodes is called an "internode". The internodes of most bamboos are hollow; that is, they have a "cavity". The wall of the culm is called simply the "Culm wall".
The outside of the culm wall is dense, as can be seen from the dark color, and only about quarter of a millimeter thick. This layer contains much silica, a good material to protect the plant, but a nuisance for tools as silica blunts their sharp edges within a short time. The dark spots, decreasing from left to right in the cross-section, are cellulose fibers together with vessels. Cellulose acts as reinforcement, similar to steel bars

in reinforced concrete or glass fiber in fiber-reinforced plastic.

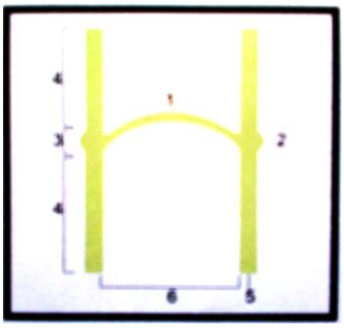

Fig. 1 The parts of a culm (1 = diaphragm; 2 = outside ring ; 3 = node; 4 = internode ; 5 = culm wall; 6 = cavity

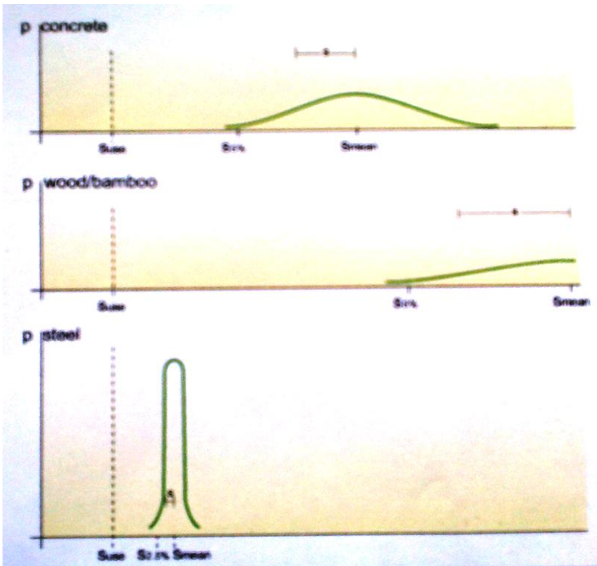

Fig. 2 A comparison of safety of bamboo with steel and concrete

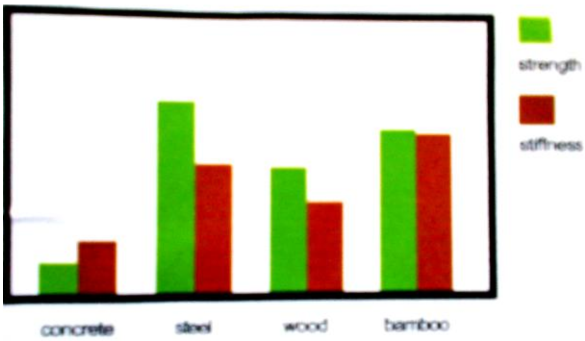

Fig.3 Strength and stiffness comparison between Bamboo and various materials

These fibers are concentrated near the outside. The stiffness (the resistance against bending) that this distribution pattern creates is ten percent more than the one that a more even distribution pattern could offer – an excellent example of the structural design acumen of Mother Nature (imagine a steel tube with high tensile steel on the outside and normal mild steel on the inside!). The vessels take care of the transport of liquids during the life of the bamboo. The material between the dark spots is called "parenchyma", and it is the matrix in which the fibers are embedded (like the concrete between the steel bars). Approximately, a bamboo Culm has 40% fibers, 10% vessels and 50% parenchyma. While inspecting the structure of bamboo, one aspect readily catches my attention: bamboo does not have any "rays" like the ones present in wood (best seen in woods like beech as dark spots on the surface of a sanded plank). Rays are places for the transport and storage of food, mostly sugar, but they weaken the material. Consequently, bamboo is stronger than wood, especially in shear.

III. COMPETETIVENESS OF BAMBOO

There are several plantations in bamboo-growing countries where bamboo is harvested just like timber .However can one expect bamboo to be as economically competitive? A simple calculation will explain this. Assume the approximate price of an 8-meter bamboo Culm to be US$ 1.50. If the volume of woody material in the culm taking into account only the culm wall and not the cavity inside – is calculated, this price would be US$ 105 per cubic meter. It has been verified that, because of its hollowness, bamboo's effectiveness as a beam is 1.9 better than a wooden beam. Hence, for wood to be economically as competitive as bamboo, it should not cost more than US$ (105 / 1.9) = US$ 55 per cubic meter. However, wood used for beams costs much more than this, emphasizing the competitiveness of bamboo in structural use.

When considering a material for structural use, the first question that arises is about its safety. Fig.2 shows a comparison between bamboo, timber, steel and concrete in terms of their behavior under stress. The stresses, with the symbol "s" (pronounced "sigma"), are plotted on the horizontal axis. To make stresses between these different materials comparable, the value of the stress in the material when the building is in normal use is taken as the unit. This is indicated by the term "s use" (also called the "allowable stress") and is about 140 N/mm2 for steel and 10 N/mm2 for timber. In each of the three diagrams in Fig. 2, a formation like a hill can be seen. This is the area of stresses at failure during tests, the middle part of the "hill" indicating the mean stress at failure (denoted by "s mean"). Each hill also shows an "s" value, which is the standard deviation indicating whether the results of a test are widespread or not. We consider the stress under which 5% or 2.5% of the specimens fail as the limit, and the allowable stress shall be at a safe distance below this limit. These limits are indicated as s5% or s2.5%. On the vertical axis, we see the value "p", which is the chance that a stress will occur. If a hill is wide and flat, the "p" is low; if a hill is narrow and steep, the "p" is high. The lowest diagram is for steel, a material that is produced using a very Controlled process and hence, bad specimens are very rare. It shows a narrow and steep hill, indicating that failure under stress occurs in a narrow range indicated by a small value for "s". This means that the allowable stress ("s use") can be at a short distance from the stress at failure. The diagram in the middle for wood and bamboo, which are natural materials, shows a wide variety of stresses around the mean stress at failure. In these materials, specimen quality varies widely from very bad to very good. Because of this uncertainty, one finds a large distance between the stress at failure and the allowable stress. The top diagram is for concrete, which is between the other two as far as safety is concerned. In normal circumstances, the use of steel is economical because of the short distance between allowable stress and stress at failure, signifying the optimum use of the material. The use of timber and bamboo, on the other hand, is less optimal since the allowable stress is very low when compared with stress at failure. In the case of a disaster like a hurricane or an earthquake, however, the stresses will get multiplied. They may become double the allowable stress. In such cases, stresses in steel will come into the area of failure, but not in timber and bamboo. This means that steel structures will suffer much damage, while most structures of timber or bamboo will remain in good condition**. A bamboo house is a good place to stay during a hurricane or an earthquake (provided the house has been built with proper care)**.Another comparison between the materials is shown in Fig. 3. Two questions are dealt with here – how much strength and how much stiffness (resistance against deformation) does concrete, steel, timber or bamboo give? The diagram shows that, as far as strength is concerned, concrete is the worst, followed by timber (the green bars in the diagram are calculated as the strength divided by the mass per volume or the density). Steel is the best and bamboo the second best**. In terms of stiffness, the fourth place is for concrete, third for timber, second for steel and the first place is for bamboo** (the brown bars in this diagram are calculated as the E-modulus divided by the mass per volume or the density).

IV. SOLID TIMBER VS HOLLOW BAMBOO

Fig.4 Bamboo and a Timber Piece (Same Cross-section)

Fig. 4 above shows a piece of bamboo and a piece of timber with the same cross-section area. As can be seen, the bamboo on the left is hollow tube, while the timber on the right has a massive structure. How do their respective structures affect the efficiency of these materials? Or, expressed in technical terms, what effect does this structural difference mean for the ratio between the moment of inertia(I) and the cross section(A)?

For bamboo, the following formulas are valid:

I (Moment of Inertia)
= π*(D^4-d^2) / 64 and A = π * (D^2 –d^2) / 4, in which:

π= 3.14

D = external diameter
d = internal diameter (for most bamboos d = 0.82D)
t = wall thickness (evidently D = d + 2t)

If we take for d the value of 0.82D, and we work out the formulas with this value, we get:
I = 3.14 (1 – 0.824) D^4/ 64 = 0.03D^4.

In a similar way we get for A the value 0.26D^2. We need a comparison between I and A, but I is related to D^4 and A to D^2 . So we take the square of A, A^2= 0.07D^4.
This allows us to calculate the ratio between I and A as:
A: I = 0.40. Timber mostly has a rectangular cross section: h = 2*b. From this ratio, and because;
I = b* h^3 /12 and A =b*h, it follows that: I = 0.16*A^2; a difference of 2.5 in favor of bamboo. If numerical values, D = 100 mm and d = 82 mm, are substituted, then for bamboo:

I = 2.69 *$10^6 mm^4$ and A = 2570 mm^2 (For Bamboo)

If the same cross-section is considered for timber, then:

For a beam of 36*72 mm, I = 1.12 *10^6 mm^4 (For timber)
For a column of 51* 51 mm, I = 0.56 *10^6 mm^4

In both cases, the value of I (Moment of Inertia) for timber is much less than that for bamboo*. *This indicates that the structural efficiency of bamboo is very good. This brings up a question: why do most engineers think that the tube-like bamboo cannot be used as a beam? The tube material they are accustomed to is the steel tube, which is very expensive. Consequently, engineers always use I-shaped profiles for beams.

Fig.5 Cross-section of Bamboo and Comparison with an I-Profile

Now consider Fig.5 in which the cross-section of a bamboo culm is on the left. ***Imagine that the material from both sides are pushed horizontally towards the vertical axis of symmetry, and see what happens. The result is something about the same as a steel beam profile!***

V. BAMBOO-A NATURE'S STRUCTURAL DESIGN

The cellulose fibers in bamboo act as reinforcement similar to reinforcing steel bars in concrete or glass-fiber in polyester-resin. The distribution of these fibers increases from the inside to the outside .The E-modulus for cellulose is 70 000 N/ mm^2 and about 50% of the cross-section ofthe fiber is cellulose; the E of the fiber is 35 000 N/mm^2. A rule of thumb for bamboo is: E = 350 * % of fibers. In most bamboos, fibers constitute about 60% on the outside and 10% on the inside. Hence:

Outside E = 350 * 60 = 21000 N/ mm^2
Inside E = 350 * 10 = 3500 N/mm^2
It is clear from this data that EI for the culm is more (by about 10%) because of the non-uniform fiber distribution – another example of the efficient structural design of bamboo and of optimum material use.

VI. BAMBOO: BETTER IN BENDING OR IN SHEAR?

Is bending strength determined by bending stress orby shear? This depends on the length of the free span: in case of a short free span, the bamboo does not act as a beam but as an arch, and transversal forces are the first reason for failure. If the free span is long, and if a four-point bending test is being run, pure bending stresses will determine the strength. Evidently, there must be a boundary below which shear is the limit and above which bending is the limit.
After many calculations **L(crit.)** is found to be:-

Lcrit. = 26 D (or 30D, to be on the safer side)
Where; L =span and D= Diameter of culm.

If the free span is less, the bamboo will fail in shear (transversal force); so a bending test is run only with a longer free span. Many misunderstandings follow from a lack of knowledge on this phenomenon. In a real bending test, the nodes with the diaphragms act like a plastic hinge, resulting in more deformation. But in a test with a short free span, they strengthen the arch-like behavior of the beam, resulting in less deformation. Several researchers have come to wrong conclusions because they were unaware of this. Bending tests have to be carried out with wooden saddles between the steel parts of the bending machine and the bamboo itself. These saddles should rest on the nodes, to avoid crushing of the internodes.
Several researchers have tried pre-stressing. It is only positive if the bamboo is perfectly circular, which is rarely the case. Consequently, most of the time, the outcome was disappointing. Creep (which is increased deformation under long-term loading) is negligible in bamboo; the permanent plastic deformation is only 3-5% of the immediate elastic deformation!

VII. EARTHQUAKE RESISTANCE OF BAMBOO

Bamboo is a perfect material for earthquakes: it is lightweight, and the hollow form gives much stiffness. But how to assess whether a bamboo house would survive an earthquake of a given intensity? A dynamic test on a full-scale house is extremely expensive. At the National Bamboo Project of Costa Rica, only typical walls were tested, using a static test. The wall was fixed on a steel frame and using a hydraulic jack, a horizontal force was applied at an upper corner and in the plane of the wall. Different walls have been tested: with and without diagonal, with and without mortar, etc. The results were more than satisfactory.
From this report the bamboo housing system can be assessed as earthquake-resistant.
"The real proof came in April 1991, when about 20 bamboo houses survived quite near to the epicenter of a 7.5 Magnitude earthquake."

VIII. BAMBOO AS REINFORCEMENT

Bamboo as a reinforcement in concrete structures has not been employed to the satisfying proportions till date.
The bamboo as a reinforcement has been found to have the following mechanical properties
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Mechanical Property	Value (mpa)
Ultimate compressive strength	55.158
Allowable compressive stress	27.579
Ultimate tensile strength	124.105
Allowable tensile stress	27.58
Allowable bond stress	0.3447
Modulus of elasticity	17236.89

Fig.6 Mechanical properties of bamboo reinforcement

For bamboo reinforced concrete beams, the deformation is approximately half that of steel. The allowable bending moment in a concrete beam with bamboo reinforcement is about 78% compared with steel reinforcement. In bamboo reinforced concrete, bamboo shrinks more than concrete as it loses moisture, completely breaking any bond between the bamboo and the concrete. This effect can be overcome by applying melted bitumen together with coarse sand, nails, coconut fibre rope or twisted bamboos. In bamboo reinforced concrete, the high alkalinity of concrete destroys the pectin, which sticks the cellulose fibers of the bamboo together. Consequently over time the bamboo separates into loose cellulose fibres. Again this can be overcome with the use of bitumen coatings. Ideally 5-6% of bamboo reinforcement is required, but in practice it is difficult to achieve more than 4% reinforcement. Due to the low modulus of elasticity of bamboo, flexural members will nearly always develop some cracking under normal service loads. If cracking cannot be tolerated, steel reinforced designs or designs based on unreinforced sections are required. **Our tests showed that split bamboo performs better than whole culms when used as reinforcing.** Better bond develops between bamboo and concrete when the reinforcement is-split in addition to providing more compact reinforcement layers. Large-diameter culms split into 3/4-inch- wide splints are recommended.

IX. CONCLUSION

This study has finally concluded that Bamboo, "**THE WONDER GRASS"** can be used as an economical building and structural material in buildings. Since time immemorial, bamboo has played an important role in the development of mankind. It is used for a wide range of day-to-day purposes, both as a woody material and as food. It has been the backbone of much of the world's rural life and will remain so as the population increases. Bamboo will continue to play an important part in the development of enterprises and the transformation of rural environments, in all regions of the developing world where it grows.

On account of the enforcement of our natural forest protection project, wood is becoming increasingly scarce. The realization that bamboo is the most potentially important non-timber resource and fast-growing woody biomass, has evoked keen interest in the processing, preservation, utilization and the promotion of bamboo as an alternative to wood. The properties as top grade building material and increased availability of bamboo in our country makes it possible to use, bamboo in the field of construction extensively. Its high valued utilization not only promotes the economic development, but also saves forest resources to protect our ecological environment as a wood substitute.

As a very economic building material, bamboo's rate of productivity and cycle of annual harvest outstrips any other naturally growing resource, if today you plant three or four structural bamboo plants, then in four or five years later you will have mature clumps, and in eight years you will have enough mature material to build a comfortable, low cost house.

This research can help in deciding the use of Bamboo as a Structural and Constructional material in Buildings. Still there are many things to be worked upon so that this wonder grass can be made into a cost effective strength material in future.

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