EXPERIMENTAL INVESTIGATION AND ANALYSIS OF BAMBOO FRAME

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ABSTRACT

Bamboo as a material for building construction was assessed for its sustainability using data from secondary sources. It is a well - known fact that a sustainable material for building construction must be environmentally friendly, affordable, flexible in usage, and durable, which makes bamboo one because of these characteristics it possesses. Additionally, bamboo can be grown abundantly at a lower cost than other building materials, which makes it more economical. The concluded that bamboo could be used as a building material for various construction purpose such as foundation floor, walls and ceilings, doors, windows, scaffolding, trusses, and roofing. It also suggests the various preservation Techniques to be adopted in order to enhance its durability and lifespan for building construction purposes. However, the various problems which are associated with the use of chemical and non – chemical preservative treatments that enhances durability and lifespan.

Keyword: - *Bamboos, Compressive Strength, Tensile Strength, Deflection and Bending Moment etc….*

1.INTRODUCTION

This project relates to the use of bamboo in construction as structural elements, nonstructural elements and also for temporary works in structures or elements of structure, ensuring quality and effectiveness of design and construction using bamboo. The type of Bamboo used here is Dendrocalamus hamiltonii. Occurs in fine grained textured soil in semi-evergreen forests. As bamboo has less natural durability it requires chemical treatment for longer life. Bamboos have low natural durability (1 to 3 years) against attacks by fungi and insects. 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. As per IS 6874-2008 “Code of practice for Methods of Tests for Bamboo”, the physical and mechanical properties of bamboo are given as follows. Density is 792.91 kg/m3, ultimate compressive strength is 68.395N/mm^2, tensile strengths, which is 143.16 N/mm^2.

This analysis compared to experimental investigation Vs STAAD model.

2. REVIEWS OF ARTICLES

1.J. Goldsmith (2011) stated bamboo as the easiest, strongest, cheapest and the most durable construction material for building the structures of bamboo and also various new techniques for improving bamboo as a construction material and its uses in most of the innovative building.

2. *P. Sharma, et. al* (2014) stated the use of a bamboo as a top grade building material; its high valuedutilization not only promotes the economic development, but also saves forest resources to protectour ecological environment as a wood substitute. As an economic building material, bamboo’s rateof productivity and cycle of annual harvest outstrips any other naturally growing resource and its use in various structures such as roofs, scaffolding, walls, foundations etc. of different domestic building.

3. *T.Gutu* (2013) carried out study on the mechanical strength properties of bamboo to enhance itsdiversification on its utilization in which various tests were carried out to study the mechanical properties of bamboo. It was found that bamboo strength properties are suitable for use as an additional material and its strength properties are more than most of soft woods and some of the hard woods but the bamboo technology is not much in the country and bamboo is only used for weaved baskets, chair, mats in which few rural people benefits from that. It was concluded that bamboo the outer fibers of slim bamboo tubes have tensile strength of 40KN /cm2 allthe above makes bamboo a

very good material for all constructional works. Also, bamboo has higher tensile strength than alloys of steel and higher compressive strength than many mixtures ofconcrete .Bamboo has higher strength weight ratio than graphite and bamboo is used as a standard building material for majority of the world for hundreds of years and these structures have been withstand magnitude of earth quakes for so long ,also states that fencing using bamboo takes 30- 50 years without affected by any destructors as a result all the above support that bamboo is a verystrong material for use than most of the material that may be preferred.

4. *S. Bhalla*, (2013) carried out design and strength analysis of composite bamboo column elements in which they carried out un axial compressive test of various bamboo specimen of length 105mm, c/s area 1064mm2 , rate of loading 0.1 KN/mm2 and plotting the stress Vs strain graph . Then a bamboo composite column using many bamboos together with c/s area of about 15972 mm2 and similar test was conducted and the value of young modulus of elasticity was calculated in the end.

3. OBJECTIVES OF THE STUDY

Based on the literature review the following objectives are determined:

1. Study of mechanical properties of bamboo (Dendrocalamus hamiltonii).
2. Study of bending of bamboo frame using a bamboo frame model when subjected to verticalloading conditions.
3. Structural analysis of the bamboo frame model using a software tool STAAD Pro v8i.

4. SCOPE OF THE STUDY

In the present study, the behavior of a bamboo frame is carried out only under vertical loading. However, the bamboo frame can also be studied for sway analysis. The stability of bamboo frame under dynamic loading can also be an interesting field for the upcoming researchers. The variation in response of bamboo frame with different types of joints can also be carried out to study the use of bamboo as a structural member.

5. MATERIALS USED FOR EXPERIMENTAL ANALYSIS

1. Bamboo
2.Steel plate
3.Bolts & nuts
4.Steel angle

6. MECHANICAL PROPERTIES OF BAMBOO FRAME

Table -1

S.NO	DENSITY	COMPRESSIVE STRENGTH	TENSILE STRENGTH
1.	792.91 Kg/m3	68.395 N/mm2	143.16 N/mm2

7. EXPERIMENTAL SETUP

The project is carried in a series of steps. First of all, Planning of size and shape of the structure is carried out which is to be constructed. Secondly, Gathering of resourced and materials such as bamboo, steel plate, steel angles, bolts etc. is carried out which are to be used in the modeling of the structures. Thirdly, the material testing of physical and mechanical properties of bamboo such as compressive strength, tensile strength and as well as the modeling of the bamboo structure both digitally and mechanically is carried out simultaneously. Finally the analysis of structure is carried out using the UTM as well as the software STAADPro v8i. The literature review of the project is carried throughout the project and various assumptions and conclusions are made using the data collected from various papers

Fig -1: Bamboo frame modeled in real

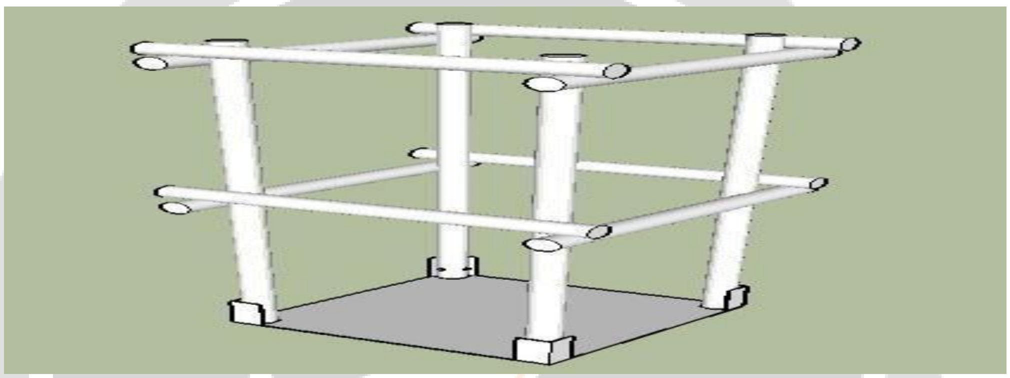

Fig -2: Bamboo frame model using software

8.EXPERIMENTAL ANALYSIS OF THE BAMBOO FRAME

The experimental analysis of the bamboo frame used in the study is carried out using steel plate on the top of the bamboo frame to apply vertical loading condition with UTM so as to divide the load to the four bamboo columns. The deflection in each direction is calculated using dial gauges When placed under UTM and failure due to application of load in bamboo frame is illustrated as shown in Fig 4. The following readings were calculated by placing the frame under vertical loading conditions using UTM with the help of arrangements given in the Fig 3.

Fig -3: Arrangement of Frame **Fig. 4.** Failure after load

The two dial gauges provides the deflection in X and Y direction and the deflection along Z- Axis is given using UTM. After the test the failure occurred is shown in **Fig.4**. and the readings and graphs were calculated .The experimental analysis of bamboo frame was carried out by placing the bamboo frame in an UTM and tested under vertical loading conditions. The magnetic dial gauges were used to calculate the deflection of members and the corresponding load carrying capacity was obtained from the UTM. The observed load and the corresponding deflections are given in **table 2.**

Table -2 Observations from UTM.

	UTM reading		Dial gauge reading	
Time (sec)	Ultimate load, Fult (kN)	Deflection al Y-Axis, ΔY (mm)	Deflection alo Z-Axis,ΔZ (mm)	Deflection alo X-Axis, ΔX (mm)
10	11.9	0	0	0
20	28.4	0	0	0
30	31.9	-0.2	0.01	0
40	35	-0.4	0.01	0
50	37.5	-0.6	0.01	0
60	39.7	-0.8	0.01	0
70	42.4	-1	0.01	0.01
80	45	-1.2	-0.01	0.04
90	47.9	-1.4	-0.04	0.04 i
100	50.8	-1.5	-0.11	0.04
110	54	-1.7	-0.19	0.035
120	57.2	-1.9	-0.24	0.035
130	60.8	-2.1	-0.28	0.035
140	64.7	-2.3	-0.33	0.035
150	68.8	-2.5	-0.37	0.035
160	72.7	-2.7	-0.37	0.035
170	77	-2.9	-0.37	0.035
180	81.3	-3.1	-0.37	0.035
190	87.3	-3.4	-0.36	0.035
200	91.7	-3.6	-0.33	0.035
210	94.8	-3.7	-0.22	0.035
220	96.7	-3.9	-0.11	0.035
230	100.8	-4.1	-0.02	0.01
240	104.7	-4.3	0.06	0.01

250	108.5	-4.5	0.18	0.01
	UTM reading		Dial gauge reading	
Time (sec)	Ultimate load, Fult (kN)	Deflection al Y-Axis, ΔY (mm)	Deflection alo Z-Axis, ΔZ (mm)	Deflection alo X-Axis, ΔX (mm)
260	112.1	-4.7	0.32	0.01
270	115.5	-4.9	0.51	0
280	119.3	-5.1	0.73	-0.06
290	122.7	-5.2	1.02	-0.09
300	124.7	-5.4	1.39	-0.14
310	127.3	-5.6	1.70	-0.24
320	129.8	-5.8	1.98	-0.33
323	130.2	-5.9	2.04	-0.36
330	128.2	-6	2.17	-0.44
340	128.1	-6.2	2.17	-0.44
350	130	-6.4	2.18	-0.43
360	131.6	-6.7	2.20	-0.43
370	132.6	-6.9	2.23	-0.43
375	132.7	-6.9	2.23	-0.43
380	132.3	-7	2.20	-0.43
390	130.6	-7.2	1.79	-0.43

Hence, the ultimate load, Fult obtained is 132.7 kN at which the bamboo frame failed with the deflection of -6.9 mm along Y-Axis, 2.23 mm along Z- Axis and -0.43 along X- Axis which is very large amount of load which proves bamboo structures can take huge amount of load. It was also observed that the deflection along Z-Axis was zero at time between 230 and 240 seconds which means that the frame was bending inwards along Z-Axis initially and then start bending outwards. Similarly, the deflection along Y-Axis was zero at time 270 seconds which means the frame was bending outward along Y-Axis initially and then started bending inwards.

9.SOFTWARE ANALYSIS OF BAMBOO FRAME USING STAAD.PRO

The software analysis of the bamboo frame is carried out using STAAD.Pro v8i. First of all the bamboo frame is modeled in the software as shown in Fig 04. The load applied on the frame can be depicted with the help of figure below also depicting the the nodal numbers and the member numbers.

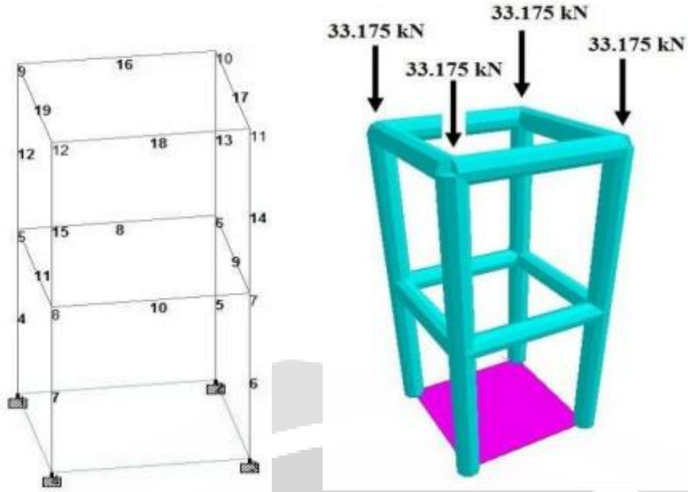

Fig. 05. Modeling and application of load on bamboo frame in STAADPro

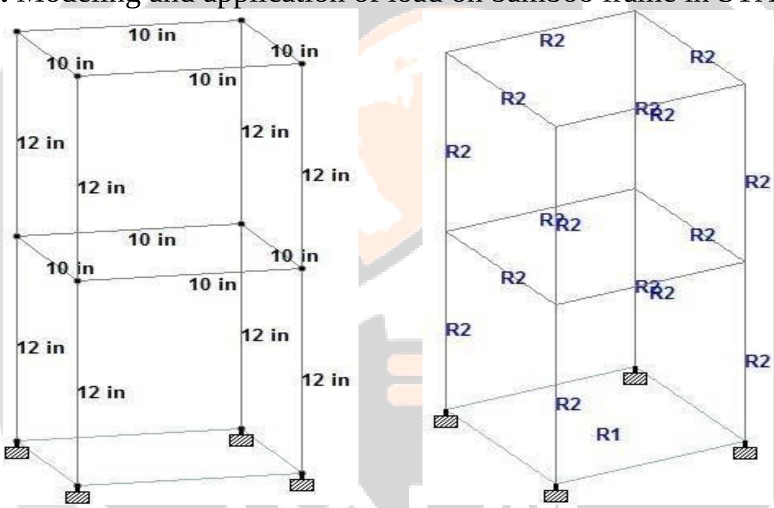

Fig. 06. Defining Geometrical Properties

Thirdly, the load is applied by equally distributing the load at which the frame failed at the four corners of the of the frame and material properties of bamboo were defined using the value of modulus of elasticity, poisson's ratio, density, shear modulus obtained from the test conducted andwere applied on the structure as shown in Fig06 and Table 02 .

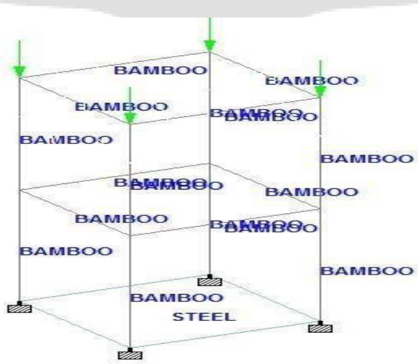

Table 3. Properties of Bamboo STAAD.pro

Parameters	Values	Units
Young's Modulus, E	11956.6	N/mm^2
Poisson's Ratio, n	0.30	-
Density, ρ	792.91	kg/m^3
Thermal Coefficient, a	0.0000360694	$/^oF$
Critical Damping	0.05	-
Shear Modulus, G	4598.68	N/mm^2

And, finally the analysis is carried out using STAADPro v8i which uses the principles of 1st order static analysis and STAAD analysis and design engine for structural analysis and integrated steel,concrete, timber and aluminium design. Here in this case only steel and self defined material, that is bamboo using the values of material properties obtained from the test conducted thus calculatingthe deflection, stresses, strain and force on each member after the application of load using the principle of 1st order static analysis used to determine the nodal displacements, the element deflections together with the element forces, moments and stresses.This is the most common form for the analysis of building structures. Now, as per the material properties defined above in STAADPro using the values obtained from the tests conducted and by the application of load following results were obtained after running the analysis on the software.illustrates the bending of the frame after the application of load at failure along with the strain diagram of the frame which illustrates deflection at various points of the member of the beamafter the application of load, that is at failure thus illustrating the amount of bend caused in the beam at different locations of the members of the bamboo frame. At point A, the strain is maximum, thus the deflection because of the application of load at that point. At point B, the strain is opposite indicating frame is bending inwards. At point C, the strain is zero indicating frame is bending inward to outwards.

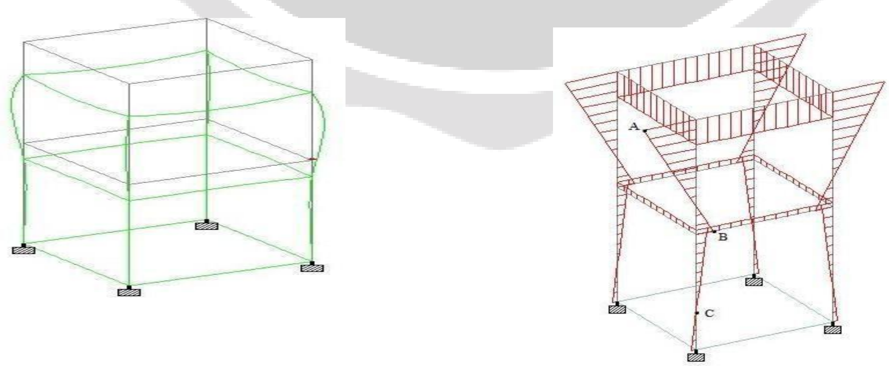

Fig. 08. Bending of frame after application of load and the strain diagram

The stress diagram of the frame after the application of load at failure is shown below in Fig 25 which illustrates the amount of stress and its direction at different location of the members of the bamboo frame after the application of load at failure. At points A and D, the stress is maximum whereas at point B, the stress is minimum and is same for all vertical members and positive.However, both positive and negative stresses are seen at all horizontal members.

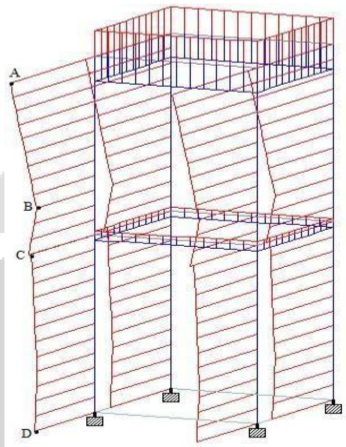

Fig. 25. Stress diagram after the application of the load

The following tables give us the values of the peak nodal displacements, maximum beam forces, and maximum beam stresses on the basis of which above figures were obtained.

Table 4. Peak nodal displacements in the frame

		Horizont al	**Vertic al**	**Horizont al**	**Resulta nt**	**Rotation al**		
	Node	X mm	Y mm	Z mm	Mm	rX rad	rY rad	rZ rad
Max X	6	0.002	-0.673	-0.002	0.673	-0.001	0	-0.001
Min X	5	-0.002	-0.673	-0.002	0.673	-0.001	0	0.001
Max Y	1	0	0	0	0	0	0	0
Min Y	9	0.002	-1.346	0.002	1.346	0.003	0	-0.003
Max Z	7	0.002	-0.673	0.002	0.673	0.001	0	-0.001
Min Z	5	-0.002	-0.673	-0.002	0.673	-0.001	0	0.001
Max rX	9	0.002	-1.346	0.002	1.346	0.003	0	-0.003
Min rX	11	-0.002	-1.346	-0.002	1.346	-0.003	0	0.003
Max rY	1	0	0	0	0	0	0	0
Min rY	9	0.002	-1.346	0.002	1.346	0.003	0	-0.003
Max rZ	10	-0.002	-1.346	0.002	1.346	0.003	0	0.003
Min rZ	9	0.002	-1.346	0.002	1.346	0.003	0	-0.003

Table 5 give us the values of peak nodal displacements at various nodes after the application of load on the bamboo frame structures these deflections at different nodes add up to give the criticaldeflection. Now, all the deflections at node 1 are zero because node 1 is at the fixed support and as the bamboo structure is fixed at node 1 therefore there will be no kind of deflection or rotationcaused at that point and as the deflection in frame is along the negative Y-Axis so the maximum deflection along the Y- direction will be 0, that is at node 1. Further, as theload is being applied vertical along negative Y- axis so there will be no rotation caused along Y- axis and only along X- axis and Z-axis which is caused due to eccentric loading and moment generated due to buckling .

Table 5 .Maximum Beam Force

	Beam	Node	Fx N	Fy N	Fz N	Mx kN-m	My kN-m
Max Fx	4	1	33175.01	52.612	-52.612	0	0.005
Min Fx	8	5	-289.016	0	0	0	0
Max Fy	13	6	33175.01	236.404	236.404	0	-0.018
Min Fy	12	5	33175.01	-236.404	236.404	0	-0.018
Max Fz	12	5	33175.01	-236.404	236.404	0	-0.018
Min Fz	14	7	33175.01	236.404	-236.404	0	0.018
Max Mx	12	5	33175.01	-236.404	236.404	0	-0.018
Min Mx	11	8	-289.016	0	0	0	0
Max My	12	9	33175.01	-236.404	236.404	0	0.054
Min My	14	11	33175.01	236.404	-236.404	0	-0.054
Max Mz	12	9	33175.01	-236.404	236.404	0	0.054
Min Mz	13	10	33175.01	236.404	236.404	0	0.054

Table 6. Maximum beam stresses

		Max Compressive Stress		Max Tensile Stress	
Beam	**Length m**	**Stress N/mm2**	**Dist m**	**Stress N/mm2**	**Dist m**
4	0.305	28.847	0.305	0	0
5	0.305	28.847	0.305	0	0
6	0.305	28.847	0.305	0	0
7	0.305	28.847	0.305	0	0
8	0.254	0.86	0	-1.32	0
9	0.254	0.86	0	-1.32	0
10	0.254	0.86	0	-1.32	0
11	0.254	0.86	0	-1.32	0
12	0.305	38.631	0.305	0	0
13	0.305	38.631	0.305	0	0
14	0.305	38.631	0.305	0	0
15	0.305	38.631	0.305	0	0
16	0.254	6.093	0	-5.717	0
17	0.254	6.093	0	-5.717	0
18	0.254	6.093	0	-5.717	0
19	0.254	6.093	0	-5.717	0

Now, Table 6 gives us the maximum and minimum forces at different members of the bamboo frame and moment at different nodes after the application of load on the bamboo frame from UTM.Now as the loading is only along vertical direction so there is no moment generated about X-Axis.Now assuming the ideal case, there should beNow, Table 7 below gives us the maximum compressive stress and the maximum tensile stress caused at different members of the bamboo frame structure at the given distance from the startingnode of the beam. Now, due to vertical loading conditions on the entire vertical member, that is 4,5,6,7,12,13,14 and 15 experienced compression only and no tension due to direct vertical load. However, horizontal members of the bamboo frame, that is 8,9,10,11,16,17,18 and 19 due to deflection and buckling experienced both compressive and tensile stress

10.COMPARISON OF EXPERIMENTAL AND ANALYTICAL RESULTS

Table 7. Comparison of Experimental and Analytical Results

Parameters	Experimental	Using STAAD .Pro
Deflection along X-Axis, ΔX	-0.43 mm	0.002 mm
Deflection along Y-Axis, ΔY	-6.9 mm	-1.346 mm
Deflection along Z-Axis, ΔZ	2.23 mm	0.002 mm

11.CONCLUSIONS

From the experimental and analytical studies carried out on the bamboo frame the followingconclusions can be derived:

- From the material testing of bamboo the young's modulus of elasticity obtained was 11956.57 N/mm^2 which is less as compared to that given in literature review that is 20000N/mm^2 which is also the modulus of elasticity of steel which maybe caused due to less rigidity of bamboo as compared to steel.
- The poisson's ratio obtained was 0.3 which is similar to that of steel whose poisson's ratioranges from 0.27 to 0.3. which signifies deflection in transverse direction is less than that in longitudinal direction due to less rigidity of bamboo.
- The density of bamboo was found to be 792.91 kg/m^3 which is similar to that of oak woodand is very less to that of steel, which is 8000 kg/m^3 thus proving that bamboo is very lightmaterial as compared to that of steel.
- The deflection of bamboo frame obtained from the experimental analysis, that is -6.9 mm along Y-Axis,-0.43 mm along X-Axis and 2.23 mm along Z-Axis were much higher than that compared to the results obtained from STAAD.Pro analysis from the application of same load symmetrically on the frame, that is -1.346 mm along Y- Axis, 0.002 mm along X-Axis and 0.002 mm along Z- Axis which was caused to difference in the modeling of bamboo connection and joints in real to that compared to bamboo frame modeled in STAAD.Pro. From the above graphs, that is Fig. 27 to Fig. 30. It was also observed that some amount ofmoment and shear force were present in the members of the bamboo frame, in spite of vertical axial loading which was because of buckling caused in bamboo frame due to eccentric loading after the application of load on it from UTM.

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