"MODELING AND ANALYSIS OF A BAMBOO FRAME"

A

PROJECT

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Under the supervision of

Saurabh Rawat

(Assistant Professor)

By

Divakar Verma (121707)

Sachit Sharma (121709)

to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT SOLAN – 173234

HIMACHAL PRADESH INDIA

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CHAPTER 1: INTRODUCTION

1.1. General

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. Structural applications of indigenous materials such as bamboo are an integral part of sustainable development. The use of natural materials for construction, however, is often limited to cultural based traditions with little or no standardization. To develop sustainable construction materials, in both an engineering and cultural sense, one must evaluate the traditional building techniques in terms of engineering standards and develop equivalent design methodologies to assess and improve structural performance.(Bhavna Sharma, Kent A. Harries and Khosrow Ghavami, 2010)

1.2. Bamboo

The 16 commercially significant species of bamboo found in India are Bambusa balcooa, Bambusa bambos, Bambusa nutans, Bambusa pallida, Bambusa polymorpha, Bambusa tulda, Bambusa vulgaris, Dendrocalamus brandisii, Dendrocalamus hamiltonii, Dendrocalamus giganteous, Dendrocalamus strictus, Oxytenanthera stocksii, Melocanna bambusoides, Ochlandra travanvorica, Schizostachym dullooa, Thyrostachys oliveri.

The type of Bamboo used here is <u>Dendrocalamus hamiltonii</u>. Occurs in fine-textured soil in semi-evergreen forests. Grows abundantly and well in the North East and Himachal Pradesh. The culm is large, up to 30 m tall, dull green. The flowering cycle is 30-40 years commonly and periodically. Used as edible shoot, for roofing and construction purposes. (NMBA 2009)

1.3. Potential of Bamboo

1.3.1. Carbon-dioxide is one of the undesirable effluent of steel and cement industry. Cement, the main constituent of concrete, requires heating limestone and other ingredients to over 1,400^{o}C by burning fossil fuels. Producing one ton of carbon dioxide (CO_2) is released for energy. Roughly 5 to 10 percent of global CO_2 emissions are related to the manufacture and transportation of cement. Similarly, production of every ton of steel is accompanied with the release of over two tons of CO_2 in the atmosphere. On the other hand, usage of bamboo will help in reduction of emission of carbon dioxide and also other pollutants related to steel and cement plant industry. (Diwakar Bhagat, Mukul Gupta, Dr. Suresh Bhalla, 2013)

1.3.2. From structural engineering point of view, bamboo has competitive strength characteristics. Typically, the tensile strength, compressive strength and Young's Modulus of species like Dendrocalamus hamiltonii are comparable with mild steel which has an ultimate strength of 410 MPa, yield strength of 250 MPa and Young's modulus of 200 GPa. Concrete has much lower strength (compression/tension) 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. (Diwakar Bhagat, Mukul Gupta, Dr. Suresh Bhalla, 2013)

1.3.3. Bamboos can also tolerate extreme conditions that most plants can't. Some species can grow from sea level to up to 4000 m in the Andes and Himalayas withstanding temperatures well below -20°C. An extraordinary example of bamboo's resilience is the fact that it was the only plant to survive the radiation of the atomic bombings in Hiroshima, Japan in 1945. The incinerating heat destroyed all trees and other plant life, except for one bamboo grove. The grove has since been removed, but culms from the grove are preserved in a museum in Hiroshima. (Stéphane Schröder 2014)

1.3.4. It's cheap, it's easy to work with because it's so much more light weight than wood, concrete or steel. It has a huge strength to weight ratio advantage mainly because of the hollowness of its cylindrical shape. It's easily available, as a never ending source with one quarter of the grove harvestable each year. And, finally it's far less dangerous while building plus it is far less dangerous in the case of the storm or earthquake destroying a building so badly than its building materials wind up falling on its inhabitants. For Example, Excitement about the building with bamboo amplified when a 6.2 earthquake hit central Columbia in January 1999, and 70% of the recently built concrete and brick building failed while virtually all the older village buildings, of bamboo, stood strong and un-damaged.(Judith Goldsmith 2011)

1.4. Preservation and Treatment

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. They are very difficult to be treated by normal preservative methods in dry condition since their outer and to some extent inner membranes are impermeable to liquids. The treatment of bamboo is, therefore, best carried out in green conditions. The following are methods used for bamboo preservation:

1.4.1. Types of Preservatives

- *Coal Tar Creosote* -This is a fraction of coal tar distillate with a boiling point range above 200°C and is widely used admixed with fuel oil in the ratio of 50:50. The fuel oil ensures stability to creosote against evaporation and bleeding from the treated bamboos. Creosote has high performance; it is non-corrosive and provides good protection from termites.
- *Copper Chrome Arsenic Composition* **-** A typical composition of this preservative comprises of coppersulphate, arsenic pentoxide and sodium or potassium dichromate in proportion of 3: 1:4.
- *Copper Chrome Boric Composition*: A typical composition of the preservative comprises boric acid, copper sulphate and sodium or potassium dischromate in the proportion of 1: 5: 3: 4.
- *Copper Chrome Zinc Arsenic Composition* **-** A typical composition of this preservative comprises 28 parts of arsenic acid 25 parts of sodium arsenate, 17 parts of sodium dichromate and 30 parts of zinc sulphate.
- *Chromated Zinc Chloride* - This consist of zinc-chloride and sodium or potassium dichromate in the ratio of 81.5: 18.5.
- *Boric Acid Borax* - This has been used successfully against lyctus borers. A mixture of 2:5 percent of each is found more suitable.

1.4.2. Methods of Treatment

- *Surface Application*: this is done by brushing, spraying or dipping of timber in preservative solution for the required period.
- *Soaking process*: the debarked timber is submerged in the preservative solution for sufficient period till the desired absorption is obtained.

- *Hot & Cold process*: timber is preserved in the solution and then heated to temperature of about 90^0C and maintained at this temperature for suitable period and then cooled until required absorption is obtained.
- *Boucherie process*: it makes use of water soluble preservatives and hydraulic pressure.
- *Pressure process*: it can be employed to any type of preservative and is used where maximum absorption of the preservative is required.

  (Blogspot 2010)

1.5. Bamboo as a 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.

1.5.1. 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.

1.5.2. 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.

1.5.3. 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.

1.5.4. 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.

1.5.5. 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.

1.5.6. 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.

1.5.7. 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.

(Blogspot 2010)

1.6. Properties of Bamboo

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.

1.6.1. Physical Properties

- Moisture content

  The amount of water or moisture present inside bamboo and is calculated as loss in mass, expressed as a percentage of oven dry mass.

- Basic mass per volume or density

  Density or mass per volume of bamboo is calculated as oven dry mass, expressed as a percentage of green volume.

- Shrinkage

  Shrinkage percentage of bamboo is calculated along diameter, wall thickness and length which is calculated as difference in diameter, wall thickness or length of bamboo, expressed as percentage of initial diameter, wall thickness or length of bamboo.

1.6.2. Mechanical Properties

- Static bending strength

  It is calculated by using four point bending test. From which the bending strength can be calculated using the moment of inertia, maximum load, effective span, and the diameter of the bamboo.

- Compressive strength parallel to grain or axis

  The compressive strength can be calculated using a CTM or UTM. From which the maximum load is found out and using the cross sectional area of the specimen, the compressive strength can be calculated.

- Tensile strength parallel to grain or axis

  The tensile strength can also be calculated using UTM. From which the maximum load is found out and dividing it by the area of cross section of bamboo we can calculate the tensile strength.

- Shear strength parallel to grain or axis

  The shear strength is calculated using a suitable testing machines with the help of triangular blocks from which the maximum load is calculated and further dividing it by product of mean length and mean thickness we can calculate the shear strength of the bamboo. ("Code of practice for Methods of tests on Bamboo", IS 6874:2008)

1.7. Bamboo Connections

To make structural frame using bamboo it is necessary to study the type of bamboo connections to provide a strong connections at joints. Some types of bamboo connections are friction-tight rope connection, plug in/bolt connections, positive fitting connections, interlocking connections, combined connections and there can also be more than one type of connection at a particular joint.

The types of connections used in making the bamboo frame for this project are Bolted connections.

1.8. Bamboo Structures Worldwide

Today bamboo being a cheap, efficient, strong material and excellent properties as compared to steel and concrete in structures is being used in various famous structures throughout the world Some good examples are Nipa Hut in Philippines, the international K-12 school, in Bali Indonesia, Tiga Gunung building in Bali, Indonesia, German-Chinese House at the Expo 2010 in Shanghai, China, Vernacular Bamboo housing project in Haiti, Tree house restraint in New Zealand , and not only these many basic structures such as office buildings, bus stops etc. are also now a day's constructed using bamboo.(Tomas U. Ganiron Jr, 2014)

In India also buildings such as Cherai beach resort in Cochin, House of five elements in Banglore, Bamboo Museum in Palanapur, even a metro station at Banglore are made using bamboo as a construction material.(Neelam Manjunath, 2015)

1.9. STAAD.Pro

STAAD or (STAAD.Pro) is a structural analysis and design computer program originally developed by Research Engineers International at Yorba Linda, CA in year 1997. In late 2005, Research Engineers International was bought by Bentley Systems.

It can make use of various forms of analysis from the traditional 1st order static analysis, 2nd order p-delta analysis, geometric non linear analysis or a buckling analysis. It can also make use of various forms of dynamic analysis from modal extraction to time history and response spectrum analysis.

STAAD.Pro features a state-of-the-art user interface, visualization tools, powerful analysis and design engines with advanced finite element and dynamic analysis capabilities. From model generation, analysis and design to visualization and result verification, STAAD.Pro is the professional's choice of steel, concrete, timber, aluminium and cold-formed steel design of low and high rise buildings, culverts, petrochemical plants, tunnels, bridges, piles and much more.

STAAD.Pro consists of the following:

The STAAD.Pro Graphical User Interface: It is used to generate the model, which can then be analyzed using the STAAD engine. After analysis and design is completed, the GUI can also be used to view the results graphically.

The STAAD analysis and design engine: It is a general-purpose calculation engine for structural analysis and integrated Steel, Concrete, Timber and Aluminium design. (Bedabrata Bhattacharjee, A.S.V. Nagender, 2007)

CHAPTER 2: LITERATURE REVIEW

2.1. Bamboo as a Green Building Material

S. Kumar, et. al (1994) carried out a review on various bamboo preservation techniques which included study on properties of bamboo, methods of drying of bamboo, protection and treatment of bamboos and performance of those treated bamboos and their environmental aspects.

W. Liese ,et. al (2002) carried out study for preservation of bamboo for construction of houses for low income people in which the scientific and technical experience with preservation methods developed in Costa Rica by the Bamboo National Project (PNB) and the Bamboo Foundation (FUNBAMBU) were presented. Anatomical considerations as well as techniques for drying, storage and quality control are discussed. Performance of treated bamboo
structures used for the building of houses for low-income people, furniture, and other building components were commented.

K. Zalam and Z. Pongen (2008) identified 13 species of bamboo as recommended by NBM in their "Handbook of Bamboo", which told us their local names, habitat, distribution, flowering and fruiting, Identification features, Pest and diseases control and their uses.

*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.

S. Krötsch (2013) illustrated various examples of bamboo structures which show bamboo to be a very suitable and environmentally friendly substitute to construction materials like timber or steel in Kenya and at the same time is much more cost efficient. The light weight of bamboo construction allows prefabrication without special equipment. Repeating structural elements make it easier to design and to prefabricate the construction. If all parts of the bamboo structure are protected from wetness, a durable, long lasting construction can be established. Modern design for contemporary tasks can be realized. This way wildlife can be preserved, water catchment can be improved and local rural communities are able to benefit from natural, renewable resources.

D. K. Tamang, et. al (2013) carried out study on Bamboo Diversity, Distribution Patterns and its uses in Sikkim(India) Himalaya which included the study various different species of bamboo , their availability and various regions where they are found . There are 21 bamboo species found in tropical forests, 28 species in sub-tropical forests, 12 species in temperate forests, 6 species in sub-alpine forests and 3 species in alpine vegetation. In Sikkim, most of the bamboos are of sympodial type (6 genera) but 2 genera are of monopodial type of which 27 species (90.00%) under 6 genera constitute the first category while rest 3 species (10%) under 2 genera belongs to the other type. Dendrocalamus genera has the maximum number of species (8), followed by Bambusa and Sinarundinaria (6 each). Schizostachyum genera have 5 species, Phyllostachys has 2 and Arundinaria, Melocanna and Thamnocalamus has 1 species.

P. Sharma, et. al (2014) stated the use of a bamboo as a top grade building material; 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 an economic building material, bamboo's rate of 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.

A. Syeda and B. S. J. Kumar (2014) stated bamboo as the fastest growing plant and with highest Carbon Dioxide absorption. Bamboo is lighter in weight than bird but is stronger than steel. It takes carbon dioxide in and releases 30% more oxygen than tree. It grows a meter in one year and is mature in almost 3 years. Houses constructed using this bamboo are cool in summer and stays warm in winter and more over it can withstand earthquakes and can stand forever. The environmental and financial comparison demonstrates that bamboo can compete with building material. They also stated various bamboo structures used throughout the world, the preservation and treatments required for bamboo, its properties and its advantages and disadvantages.

2.2. Properties of Bamboo as a Structural Member

W.K. Yu, et. al (2003) carried out the study on column buckling of structural bamboo in which they studied the column buckling of bamboo scaffolds as it is considered to be one of the critical modes of failure in bamboo scaffolds, often leading to their overall collapse. The experiments were carried out on two species of bamboo with specimens of different length but one with same cross sectional areas and the other with varying cross sectional areas. The modified Slenderness Ratio and the Strength Reduction Factor were found out using suitable set of formulas which helped us in determining the change in strength of bamboo due to change in its length, slenderness ratio, Area of cross section. Hence, concluding that the proposed design method is shown to be structurally adequate in accordance with modern structural design philosophy, and it may be used effectively to design against column buckling of structural bamboo in bamboo scaffolds and other bamboo structures. With the availability of design data on the dimensions and the mechanical properties of structural bamboo together with the proposed column buckling design rule, structural engineers are encouraged to take the advantage offered by bamboo to build light and strong bamboo structures to achieve enhanced economy and build ability.

X. Li (2004) performed various tests to find out physical, chemical and mechanical properties of bamboo and its utilization potential for fiberboard manufacturing. The test performed found out the concentration of alcohol-toluene, hot water extractives, holocellulose and alphacellulose content, the varying concentration in different vascular bundles. The variation in specific gravity, compression properties and bending properties of bamboo with age, height and horizontal layers and strength properties of fiberboard.

S. Bhalla , et. al (2008) carried out study on bamboo as a green alternative to steel and concrete for modern structures in which they presented 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. It was concluded by 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 and the structure analyzed in a simple fashion, by considering the behavior 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 ferro cement 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

L. Hogan and G. C. Archer (2009) studied the development of long span bamboo trusses with the help of a new type of bamboo connection rather than old connections with the help of a steel gusset plate and steel rod which provided a proof of concept for a bamboo connection developed by roughening the inner surface of a bamboo member, filling a portion with mortar, embedding rebar and welding several of these members to a gusset plate. This connection can then be used to construct bamboo trusses that span moderate distances while providing a safe and predictable behavior. The connection developed bond stress between 258 kPa – 1710 kPa which translate to pullout capacities of up to 20 kN. These trusses also utilize a local and renewable resource for many areas around the world and their construction is easily accomplished using local labor thus stimulating local economies in developing regions.

M. Terai and K. Minami (2012) carried out the study on research and development of bamboo reinforced concrete structures in which the corrosive properties, mechanical properties and bond properties of bamboo were found out and then were tested with concrete in the form of slabs which concluded the feasibility of using bamboo and non-steel as the reinforcing material in concrete members. In order to investigate the fracture behavior and the mechanical properties of Bamboo Reinforced Concrete members, 9 pull-out and 4 slab specimens were constructed and the pull-out tests and 3 point bending test were carried out. The tensile strength filled with cement paste cured *w/c*=80% and 100% significantly increase with aging time. The behavior of pull-out test with bamboo is almost the same as the plain steel bar; however, the bond strength with bamboo was higher than the one with plain steel bar. It can be expected that the bond strength covering with full treatment shows the high value 1.2-1.35MPa. Bamboo reinforced concrete slab: When fresh concrete is poured, its water will moisten the bamboo; then, the concrete will harden and lose water so that the bamboo will again dry out. This drying process will completely break any bond between the bamboo and the concrete. It can be considered that underground humidity is high at any times therefore supply of water to the concrete can be accomplished.

H. Sakaray , et. al (2012) investigated on the properties of bamboo as a reinforcing material in concrete. They stated bamboo as an eco-friendly material and compared different species of bamboo in terms of occurrence. They also carried out various tests to find out physical and mechanical properties of bamboo. Brown coloured bamboo specimens were selected and the length, weight, diameter, nodes were determined as the physical properties. Mechanical properties of bamboo were determined by conducting the following tests: Tensile test, Modulus of Elasticity "E", Compressive test, Pull-out test, Shear test and Water absorption test. They also concluded that the constitutive relationship of the nodes differs from those of inter-nodal regions. Further the nodes possess brittle behavior and the inter-nodal regions possess ductile behavior. The average tensile strength of moso bamboo from present study is 125 N/mm^2, which is half the strength of mild steel. The compressive strength of bamboo is nearly same as the tensile strength of bamboo and this behavior is similar to steel. Bond stress of bamboo with concrete is very low compared HYSD steel bars, due to surface smoothness of bamboo. Water absorption of bamboo is very high and waterproofing agent is recommended. From the test conditions, bamboo can potentially be used as substitute for steel reinforcement.

C. Sabnani, et. al (2013) compared the properties of bamboo with steel to replace steel as reinforcement in concrete with bamboo for key structural elements in a low cost house designed for urban poor. The possibilities of bamboo to be used as a reinforcing material in structural elements such as beams, columns and beam column slabs are checked. In the end it is established that bamboo can replace steel for modest housing for the urban poor who live close to bamboo growing regions. The reason why it is not a favorable proposition arises not due to the material's inherent limitations, but the procedural methods required for its treatment before it is actually used as a structural material, The reason for its non popularity can be attributed to the Precautions that have to be used during the design and construction of the structural elements.

T.Gutu (2013) carried out study on the mechanical strength properties of bamboo to enhance its diversification 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 Strong extremely – strong wood fibers can resist up to 5 KN/ cm^2 and steel can resist at most 37 KN/ cm^2 and bamboo the outer fibers of slim bamboo tubes have tensile strength of 40KN /cm^2 all the 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 of concrete .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 very strong material for use than most of the material that may be preferred.

K. Disén and P. L. Clouston (2013) explained the historical usage of bamboo structures and various types of bamboo connections used in bamboo structures and further technological advancements required for a more stable structure. The availability and flexibility of bamboo as material make it ideal for use in disaster relief or quick-build housing situations. Using the techniques pioneered by bamboo-growing societies and adapting the discoveries made using modern materials, it is possible to create a technique-based building system using bamboo which can be utilized to build quick, strong, safe structures with varying levels of permanence and divergent needs. Give and take between accessibility and strength/permanence; simple lashed connections are weaker than concrete/metal connections, but for the purposes of building a strong structure quickly and efficiently, splitting culms with bolts or pins is not a viable option. Complexity of structures was and is not limited by connection type, but skilled craftsmanship and time-intensive material selection make traditional methods of connection more costly.

S. Bhalla, et. al (2013) carried out design and strength analysis of Composite Bamboo Column Elements in which they carried out unaxial compressive test of various bamboo specimens of length 105mm, cross-sectional area 1064 mm^2, rate of loading 0.1 kN/mm^2 and plotting the Stress vs Strain graph. Then a Bamboo composite column using many bamboos together with cross sectional area of about 15972 mm^2 and similar test was conducted and the value of Young's Modulus of Elasticity was calculated in the end.

A. Sethia, V. Baradiya (2014) carried out experimental investigation on behavior of bamboo reinforced concrete member in which various tests were conducted to check the properties of bamboo and then the bamboo was used a reinforcing member in concrete in the form of a beam and tests were carried out which concluded that bamboo possesses low modulus of elasticity compared to steel. So, it cannot prevent cracking of concrete under ultimate load. But from the flexural test of bamboo reinforced beam, it has been seen that using bamboo as reinforcement in concrete can increase the load carrying capacity of beam having the same dimensions. For bamboo reinforced concrete beam, the load carrying capacity increased about 3 times that of plain concrete beam having same dimensions. The maximum deflection of bamboo reinforced concrete beam is about 1.5 that of plain concrete.

K. N. N. Prinindya and L. Ardiansyah (2014) studied the effect of chemical substance and the immersion time of Dendrocalamus asper as chemical preservation treatment which concluded that chemical preservatives increase the tensile strength of bamboo betung. Optimum increasing of tensile strength acquired at borax and 60% boric acid preservative. Immersion time increase the tensile strength of bamboo betung. Optimum increasing of tensile strength acquired at 24 hours of immersion time. Tensile strength of bamboo betung has not optimum decreased during the 3 days of weathering.

2.3. Bamboo Structures

S. Iyer (2002) studied the possibility of building bamboo-reinforced masonry in earthquake prone areas in India. She studied that the best way to seismically strengthen masonry structures is to reinforce them that is using steel bars but as steel bars are costly bamboo is preferred and it is possible to use bamboo splints as reinforcing for masonry structures. Thought the tensile strength of bamboo is about 1/3rd that of steel, this is sufficient for masonry structures and provides a more economical and environment-friendly alternative that is accessible to every section of the society.

K. Ghavami, et. al (2010) carried out the pushover test of Bamboo Portal Frame Structure in which a prototype frame structure was made using four culm column base connections and different types of bamboo connections. The frame was instrumented using linear variable displacement transducers (LVDTs), placed at the top of both
columns below the lateral members, at the peak of the roof truss and at mid-height of both columns. The test helped in studying the behavior of column bases and joint regions.

P. Susira (2013) carried out the study of design and structural potential of Bamboo practical joints and frame truss system which is the pilot project for "Kashiihama House for All". He further carried out the compression and tension test of the bamboo and then the type of Bamboo Joint Connection to be used in which two types of joints were tested NFB (Joints with Nothing infill Bamboo) and CFB (Joints with Concrete-mortar infill bamboo), Then the frame truss system was formed with the help of bolted joint system with/without concrete mortar infill and tests were carried out on the frame which concluded that using bamboo as structural material for KHFA project by utilizing bolted with/without concrete mortar infill provide strength rigidity. Further, the frame truss system is certainly appropriate for bamboo as structural material since it effectively prevent bamboo from bending and buckling in the middle of the culm.

T. U. Ganiron Jr (2014) studied the investigation of the physical properties and the use of Lumumpao Bamboo Species as wood construction material in which he illustrate various architectural structures made up of bamboo followed by physical properties of lumumpao bamboo and its availability.

N. Manjunath (2015) carried out study on contemporary bamboo architecture in India and its acceptability , in which she mentioned the traditional use of bamboo in foundations, structures, walls, roofs, doors and windows, the various problems and solutions to traditional bamboo houses and acceptability of bamboo architecture due to its material limitations, Academic, research and development issues, Legal, financial and policy issues, Social issues and Execution issues and the systematic solution to all the above.

2.4. Analysis of Bamboo Structures

B.Bhattacharjee and A.S.V.Nagender (2007) carried out computer aided analysis and design of multi-storeyed buildings using STAAD.Pro in which the explained various fundaments of the software STAAD.Pro and carried out proper analysis of a whole structure considering all possible factors.

2.5. Research Significance

Numerous studies and researches are being carried out on bamboo to make it a more efficient material and using it in place of steel to make the structure more economic, feasible and durable. The research carried out above helps us to understand the use of bamboo as a green building material being eco-friendly, less CO_2 emissions, sustaining earthquake and extreme temperature conditions and its properties similar to that of steel can be used as a structural member in place of steel. Also treating and preserving bamboo with proper means to improve its mechanical properties. Not only these, the research also helped us to understand the failures caused in bamboo such as buckling, and to modify the mechanical properties of bamboo to calculate the change in strength of bamboo due to change in its length or cross section. Also bamboo can also be used a reinforcing member in concrete which provides strength almost equal to that of steel. The research also showed various structures of bamboo built throughout the world and their stability.

2.6. Summary of Literature Review

The above literature review helped us in understanding the use of bamboo as the cheapest , strongest , durable construction member with its properties similar to that of mild steel used in construction. It also showed the potential of bamboo as a less CO_2 emitting, temperature resistant, and highly earthquake resistant material. The various ways of preserving or treating bamboo so as to attain the maximum mechanical properties. Also understanding various physical and mechanical properties of bamboo and various tests conducted to calculate those properties. Also the use of bamboo as a structural material in various structures, be it bamboo itself or as a reinforcing material and failures caused in bamboo such as buckling when load is applied on bamboo structures and to calculate the change in strength caused due to such using various factors such as strength reduction factor or modified slenderness ratio. Hence, allowing us to use bamboo as a green building material in various structures allowing structures to be more economic and better durability.

2.7. 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 vertical loading conditions.

3. Structural analysis of the bamboo frame model using a software tool STAAD Pro v8i.

2.8. 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.

CHAPTER 3: METHODOLOGY

3.1. Mechanical properties of bamboo

The material testing of bamboo is carried out using the UTM (Universal Testing Machine). The experiment carried out to study the density, compressive strength and tensile strength of bamboo are explained below.

3.1.1. Density

The density of the bamboo is calculated by taking a regular bamboo specimen and measuring its weight, W using a weighing machine and its volume, V using green volume method by dipping the bamboo specimen in a water filled container and measuring the volume of the water and finally dividing the two.

$\rho = \frac{W}{V} = \frac{95.15}{120}$ g/ml = 0.79291 g/ml = 792.91 kg/m^3.

3.1.2. Compressive Strength

The compressive strength of the bamboo used in the project was carried out as per IS 6874:2008 "Code of practice for methods of test for bamboo". In this experiment the specimens for compressive strength tests were taken from the undamaged ends of specimens used in static bending tests. The test specimens shall be from internode. The end planes of the specimen shall be perfectly at right angles to the length of the specimen; the end planes shall be flat, with a maximum deviation of 0.2 mm. Outer diameter and wall thickness are measured.

After this various specimens of length L are prepared, and are tested uniaxially under UTM and the value of F_{ult}, which is the maximum load is obtained and ΔL, which is the deflection, is obtained from UTM as shown in Fig1 and Fig 2.

And, finally the ultimate compressive strength is calculated using the formula, $\sigma_{cult} = \frac{F_{ult}}{A}$ and the value of Young's Modulus of Elasticity, E is further calculated by plotting the Stress vs. Strain Curve.

The following readings were calculated from the conducted test on bamboo. Various samples (without any nodes) of length approximately L are taken as diameter varies along the length The following setup was made as shown in the figure below the specimen was kept at the UTM and was made intact by fixing it with the upper plate of UTM and a magnetic dial gauge was connected to measure the change in diameter.

Fig. 1. Experimental Setup

Fig. 2. Specimen after test

Table 1. Compressive Strength of Bamboo

Sample No.	Ultimate Load, F_{ult} (kN)	Area of cross-section,A (mm^2)	Compressive Stress,σ_{cult} (N/mm^2)	Length of Specimen, L (mm)	Deflection, ΔL (mm)	Diameter of Specimen, D (mm)	Change in diameter, ΔD (mm)
1.	67.2	1071.29	62.73	102	8.7	42	0.81
2.	69.8	942.47	74.06	98	5.2	40	0.84
3.	68.3	998.684	68.39	98	6.8	41	0.83

The mean of all compressive strength is taken as the ultimate compressive strength, which is 68.395 N/mm^2.

Poisson's Ratio, n = $\frac{\varepsilon T}{\varepsilon L} = \frac{0.0201}{0.0692}$ = 0.29 which is the ratio of transverse strain and longitudinal strain which is same as that of steel whose poisson's ratio ranges between 0.27-0.30 and close to stainless steel whose lies between 0.30-0.31.

3.1.3. Tensile Strength

As per IS 6874:2008 "Code of practice for methods of test for bamboo".

As shown in Fig 3, the specimens for tensile strength test shall be taken from the undamaged ends of specimens used in static bending tests. The test specimens should be with one node in the centre. The general direction of the fibres should be parallel to the longitudinal axis of the test specimen. The length of the specimen should be 60 mm and the width shall be 10 to 20 mm, so that the test specimen is more or less flat. The thickness of the specimen should be that of the wall thickness or less, depending on the diameter of the culm. All the dimensions should be measured to an accuracy of 0.1 mm, It should be permitted to use test pieces with laminated ends for better grip.

The grips of the testing machine should ensure that the load is applied along the longitudinal axis of the test piece, and should prevent longitudinal twisting of the test piece. The grips should press the test specimen perpendicular to the fibres and in radial direction.

The load should be applied continuously and the movable head of the testing machine should travel at a constant rate of 0.01 mm/s as shown in Fig 4.The maximum load, F_{ult} should be recorded. And, finally the tensile strength is calculated using the formula,$\sigma_{tult} = \frac{F_{ult}}{A}$, in N/mm^2.

The following readings given in Table 2 were calculated from the conducted tests on bamboo. The specimens were taken long enough so as to provide a better grip to the specimen using UTM and about 15 to 20 mm thick, and following readings were calculated.

Fig. 3. Test specimen

Fig. 4. Test Specimen in UTM

Table 2. Tensile Strength of Bamboo

Sample No.	Ultimate Load , F_{ult}(kN)	Area of cross-section,A (mm^2)	Tensile Stress, σ_{tult} (N/mm^2)	Deflection, ΔL (mm)	Strain, ε_L
1.	27.6	200	138	8.4	0.01378
2.	29.8	197	151.3	6.2	0.01017
3.	28.6	204	140.2	7.3	0.01197

The ultimate tensile strength is taken as the mean of tensile strengths, which is 143.16 N/mm^2.

Modulus of Elasticity, E = $\frac{\sigma tult}{\varepsilon L}$ = 11956.57 N/mm^2 which is less than and comparable to that of steel, that is 20000 N/mm^2 which means that the deflection of bamboo will be higher as compared to that steel.

Now, from E and n we can calculate, Shear modulus, G = $\frac{E}{2(1+n)}$ = 4598.68 N $/mm^2$ which again is very less as compared to that steel meaning that the deflections caused in transverse direction are also more.

3.2. Bamboo Frame

The various materials used in constructing the bamboo frame are:

3.2.1. Bamboo

The type of Bamboo used here is Dendrocalamus hamiltonii as shown in Fig 5. Occurs in fine-textured soil in semi-evergreen forests. Grows abundantly and well in the North East and Himachal Pradesh. The culm is large, up to 30 m tall, dull green. The flowering cycle is 30-40 years commonly and periodically. Used as edible shoot, for roofing and construction purposes. The length of bamboo used is approximately 2ft. for vertical members and approcimately1ft. for horizontal members in the model. For testing, the length specified in the experimental setup of given tests were used.

Fig. 5. Bamboo used (Dendrocalamus hamiltonii)

3.2.2. Steel Plate

Two Steel plates, one of dimension 254 x 254 x 2 mm^3 is used to provide the base of the model and other of dimension 254 x 254 x 10 mm^3 as the medium of applying point loads on the four corners of the model at the top as shown in Fig 6.

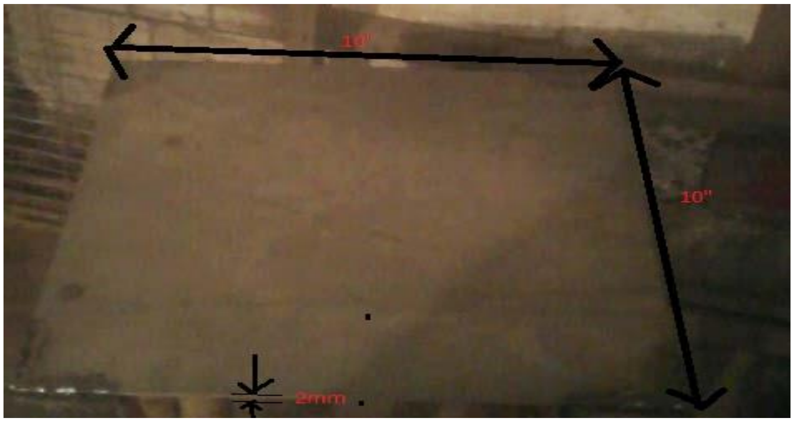


Fig. 6. Steel Plate

3.2.3. Steel Angles

Four steel angles are welded at the four corners of the steel plate on both top and bottom so as to provide a fix joint to the bamboo with the plate as shown in Fig 7. Each Steel Angle is of the dimension 25.4 x 38.1 x 5 mm^3 per plane.

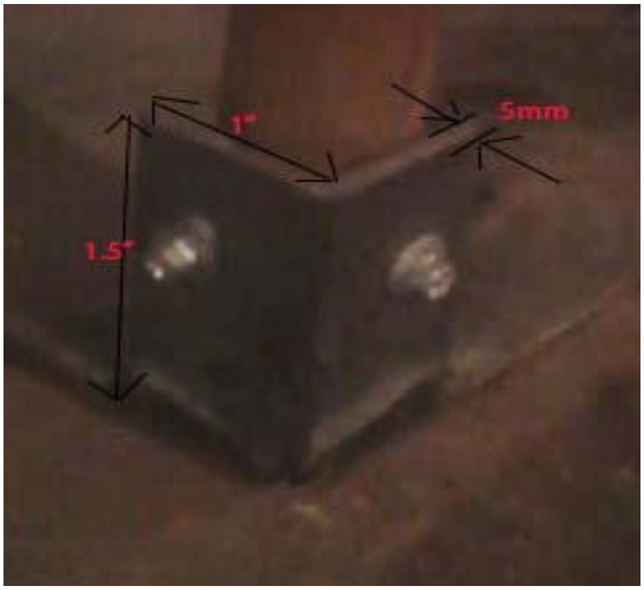


Fig. 7. Steel Angles

3.2.4. Bolts

Bolts are used to provide connections to the bamboo at joints used to connect bamboo to bamboo or bamboo to steel plate. Each bolt is of 5mm dia as shown in Fig 8.

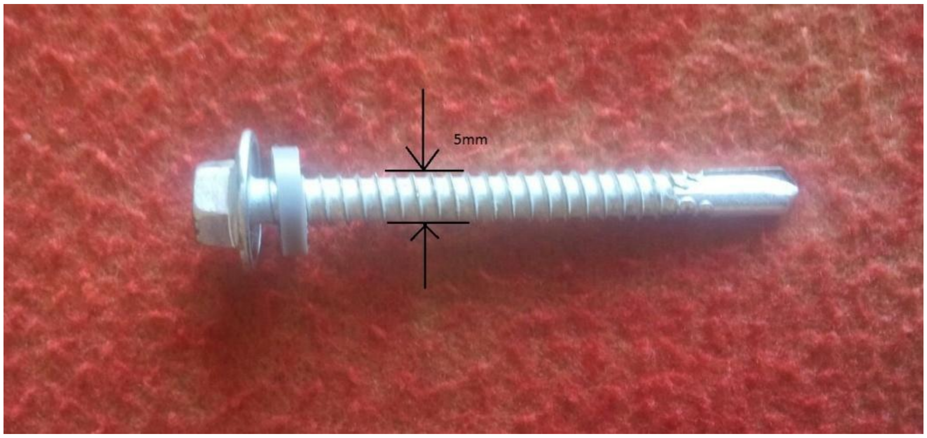


Fig. 8. Steel Bolts

3.2.5. UTM

UTM or Universal Testing Machine as shown in Fig 9 is the main requirement for any test carried out on bamboo as well as the structure to find out the compressive strength, tensile strength and as well as the Young's Modulus of Elasticity of Bamboo from the Stress vs. Strain graph obtained from testing.

Fig. 9. UTM (Universal Testing Machine)

3.2.6. Magnetic Base Dial Gauge

These dial gauge as shown in Fig 10 are used to calculate the deflection during the analysis of bamboo frame under vertical loading conditions in X and Y direction.

Fig. 10. Magnetic Base Dial Gauge

3.3. 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.

3.4. Modeling of Structure

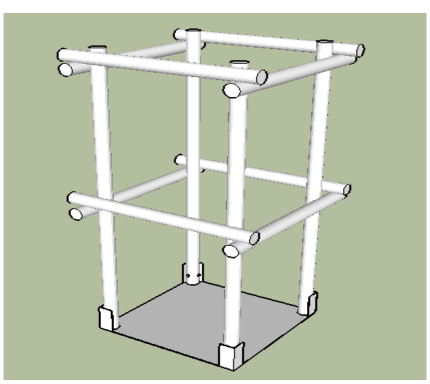
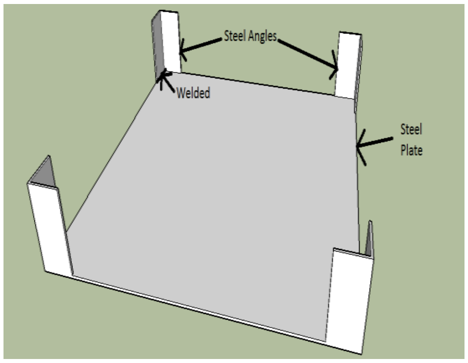


Fig. 11. Bamboo frame modeled using software

Fig. 12. Bamboo frame modeled in real

First, A steel plate of dimension 254 x 254 x 2 mm^3 is taken and four angle joints of dimension 38.1 x 38.1 x 5 mm^3 per plane each are welded at the four corners of the steel plate. As shown in Fig. 13.



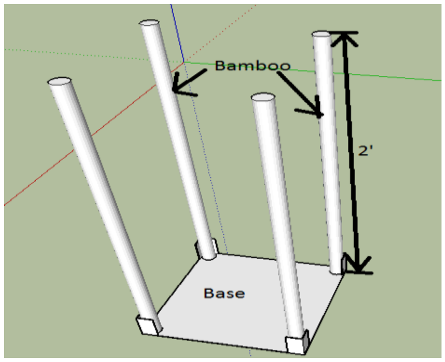
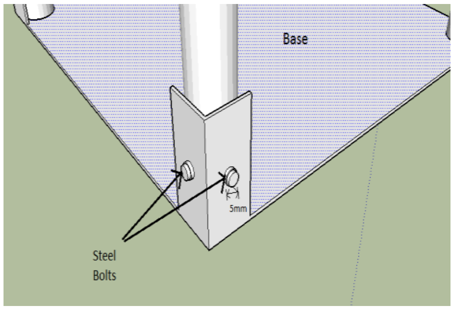


Fig. 13. Welding of Steel Angles to Steel Plate

Fig. 14. Connection of bamboos to steel plate

After that four bamboos of height approx. 0.6096 m are bolted at four angle joints with the bolts of 5 mm dia fixing them to the steel plate as shown in Fig. 14 and 15.



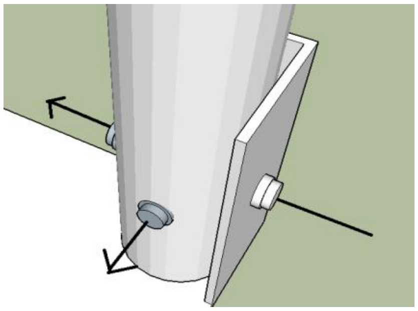
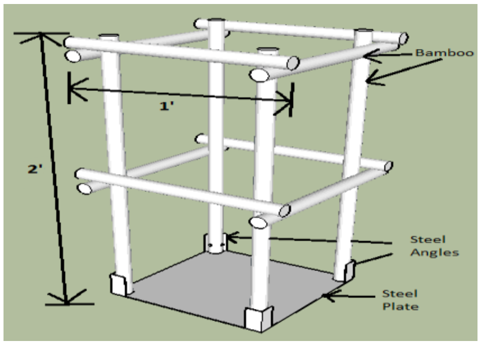


Fig. 15. The bolted connection of angles with bamboo

After this is done , four bamboos of length approx. 0.3048 m are attached along the horizontal plane to the four bamboos at a height of approx. 0.3048 m and similarly four bamboos of same length at the top using bolted connections as shown in Fig. 17.



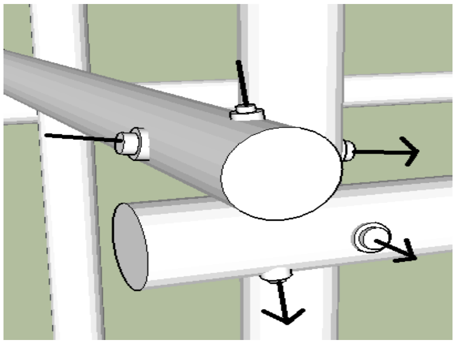


Fig. 16. The connection of eight bamboos to make first and second storey

Fig. 17. The bolted connections of bamboo with each other

Finally, resulting in a bamboo model as illustrated in Fig. 11, Fig. 12 and Fig. 16.The method of applying load is shown in Fig. 18.

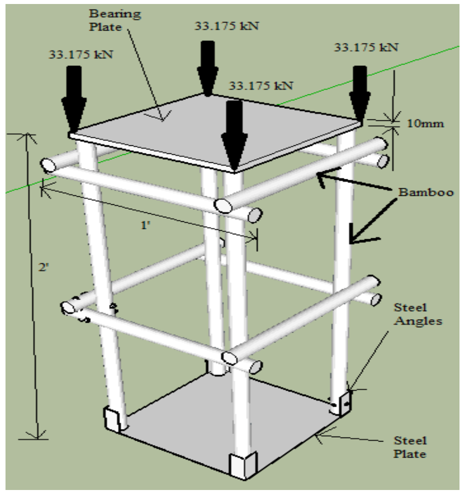


Fig. 18. Application of load on frame.

3.5 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 as shown in Fig. 19. The deflection in each direction is calculated using dial gauges as shown in Fig. 19. When placed under UTM and failure due to application of load in bamboo frame is illustrated as shown in Fig 20.

The following readings were calculated by placing the frame under vertical loading conditions using UTM with the help of arrangements given in the Fig 19.

Fig. 19. Arrangement of Frame

Fig. 20. 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. 20. 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 3.

Table 3. Observations from UTM.

	UTM reading		Dial gauge reading	
Time (sec)	Ultimate load, F_{ult} (kN)	Deflection along Y-Axis, ΔY (mm)	Deflection along Z-Axis, ΔZ (mm)	Deflection along 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
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, F_{ult} (kN)	Deflection along Y-Axis, ΔY (mm)	Deflection along Z-Axis, ΔZ (mm)	Deflection along 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, F_{ult} 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 started 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.

3.6 Software Analysis of Bamboo Frame using STAADPro

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 21. 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.

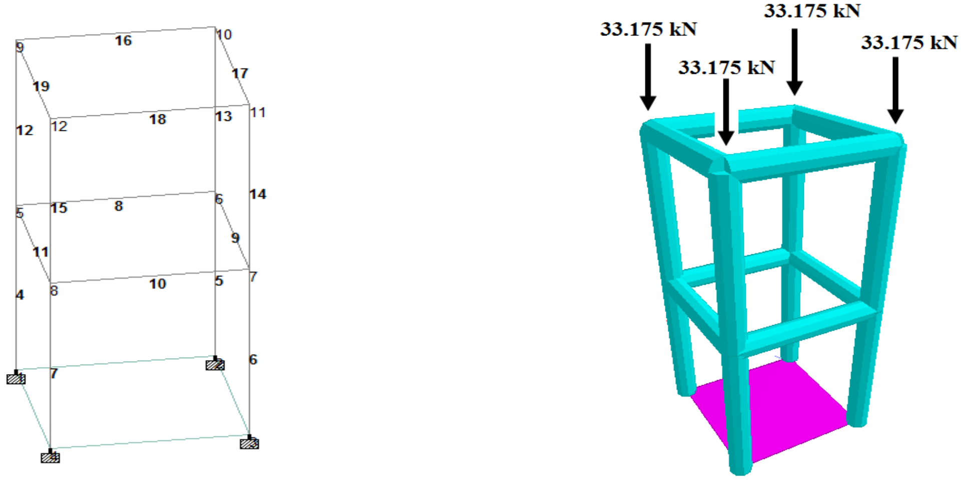


Fig. 21. Modeling and application of load on bamboo frame in STAADPro

Secondly, the geometrical properties of bamboo and the steel plate, such as their shape, diameter and thickness are defined along with the support reaction as shown in Fig 22.

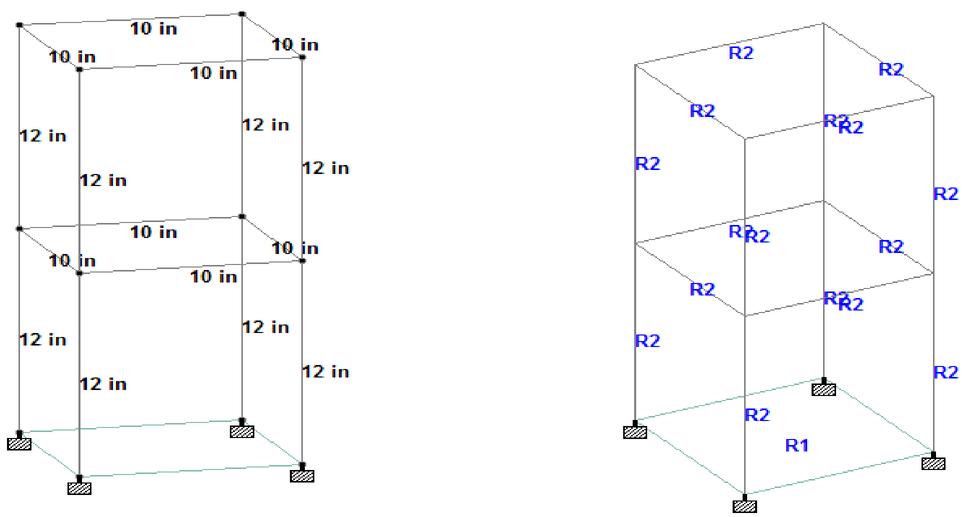


Fig. 22. Defining Geometrical Properties

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 and were applied on the structure as shown in Fig 23 and Table 4.

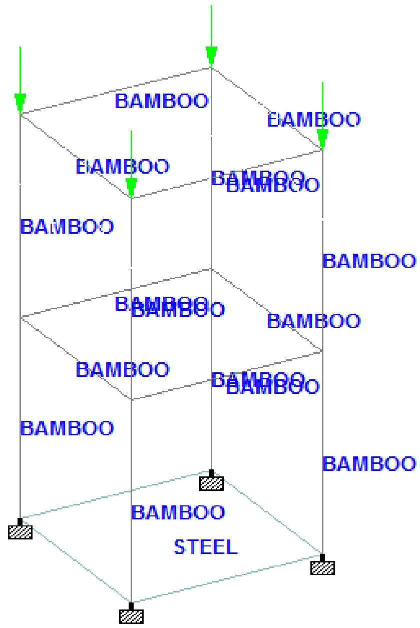


Fig. 23. Defining Load and Material Properties

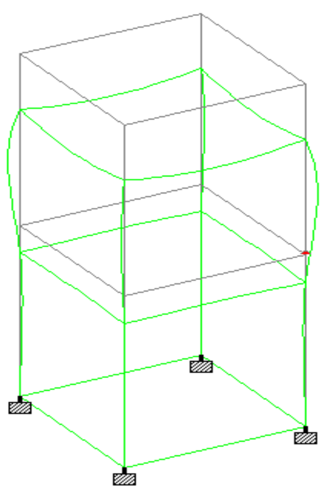
Table 4. Properties of Bamboo defined in STAADPro.

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 calculating the 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.

Fig 24. 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 beam after 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.



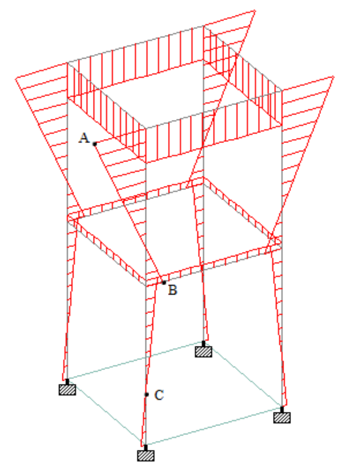


Fig. 24. Bending of frame after application of load and the strain diagram

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.

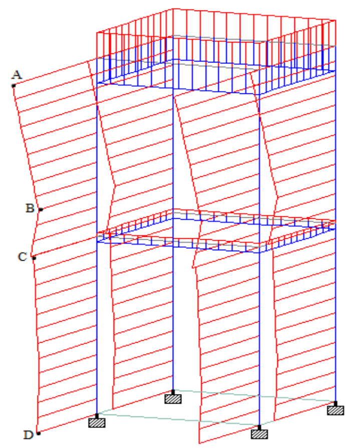


Fig. 25. Stress diagram after the application of the load

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 5. Peak nodal displacements in the frame

		Horizontal	Vertical	Horizontal	Resultant	Rotational		
	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
Max Rst	9	0.002	-1.346	0.002	1.346	0.003	0	-0.003

Table 5 gives 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 critical deflection. 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 rotation caused 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 the load 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 6. Maximum Beam Forces

	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 7. 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 be no moment along Y-Axis either as the loading is only vertical and no moment is applied but due to buckling caused by the failure of bamboo which leads to eccentric loading on the bamboo frame the moment is generated.

Now, 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 starting node 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.

CHAPTER 4: RESULT AND DISCUSSIONS

4.1. Mechanical Properties of Bamboo

4.1.1. Density

The density of bamboo is 792.91 kg/m^3 which is similar to that of density of oak wood, timber etc. thus proving bamboo to be a light material compared to that of steel whose density is 8000 kg/m^3.

4.1.2. Compressive Strength

The mean of compressive stress of all the samples is 68.395 N/mm^2 which is the amount of compression that can be taken by bamboo before failing which can be taken as the ultimate compressive stress of the bamboo used.

4.1.3. Tensile Strength

The Tensile Strength of bamboo is found out to be 143.16 N/mm^2 which is the amount of tension that can be taken by bamboo which can be taken as the ultimate tensile stress of the bamboo used.

4.2. Analysis of Bamboo Frame

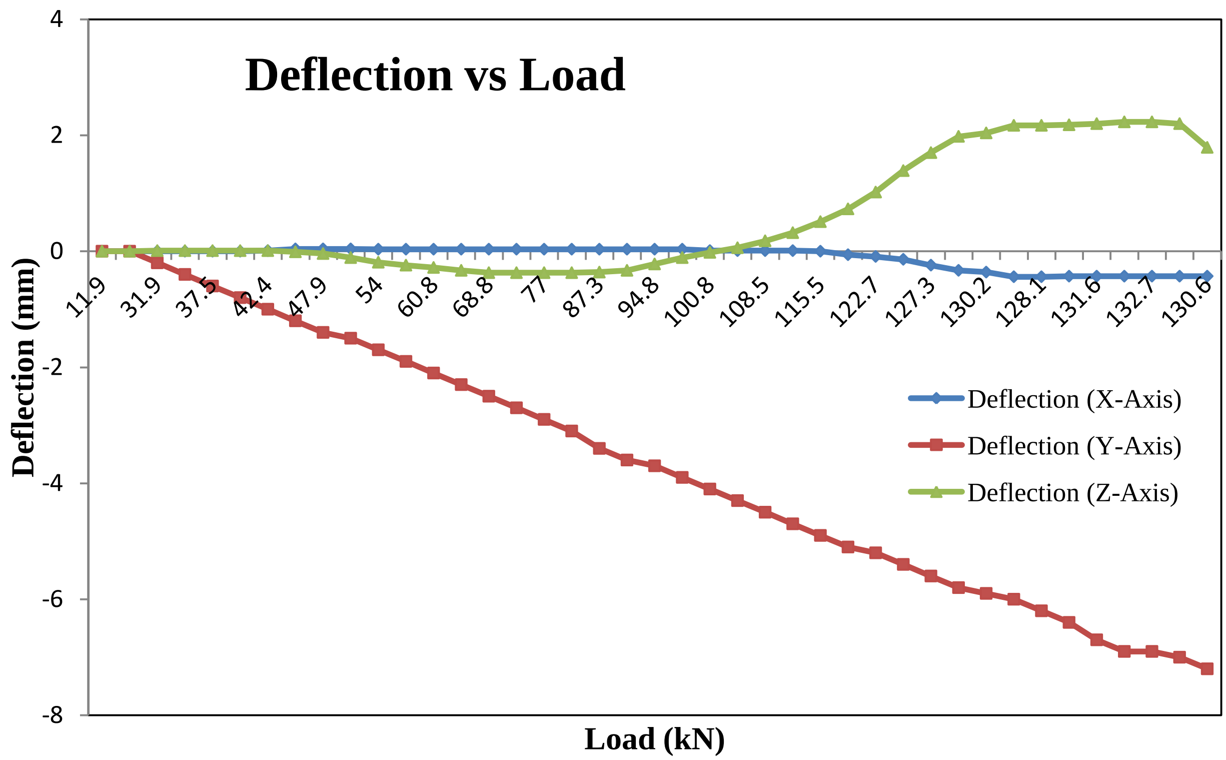
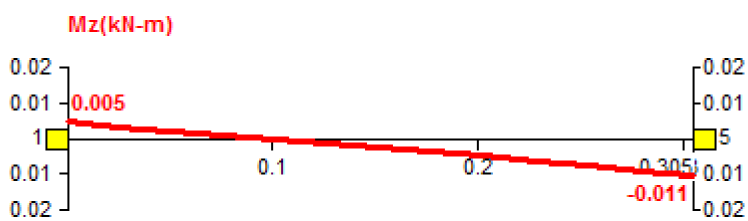


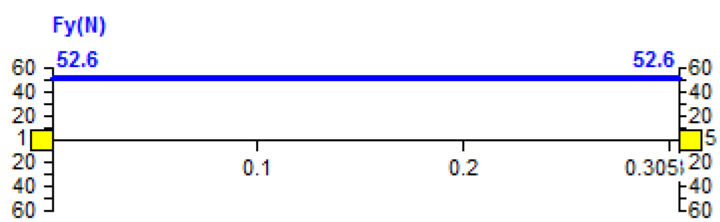
Fig. 26. Deflection vs Load Graph

Hence, the ultimate load, F_{ult} 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 before failing and can be applied in real life use also to take on huge amount of load, no doubt the deflection caused due to such load is significant and more than that in case of steel structures but bamboo as cheap, naturally occurring material can be used in place of steel in different areas of construction and as an eco friendly source of construction.

Fig. 26 illustrates the deflection along X-Axis,Y-Axis and Z-Axis along with the increase in load and the deflection obtained at the critical loading of 132.7 kN , that is -0.43 mm which is along the negative X- direction, that is towards inside of the frame as seen from the graph, the pattern moves from positive to negative which means that the frame bended from outwards to inwards along X- direction, -6.9 mm which is along the negative Y- direction, that is towards compression or inside of the frame as seen from the graph, the pattern stays negative and decreases uniformly indicating the due to vertical loading there was no deflection upward but only downward along Y- direction and 2.23 mm which is along the positive Z- direction, that is towards outside of the frame as seen from the graph, the pattern moves from negative to positive which means that the frame bended from inwards to outwards along Z-direction.

The following graphs were obtained by the analysis on STAADPro which illustrate the amount of shear force, axial force and moment taken by the each member of the frame.





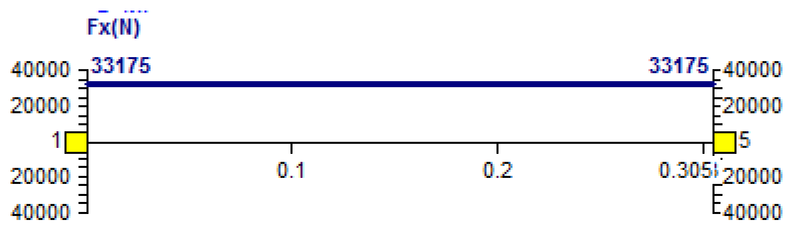
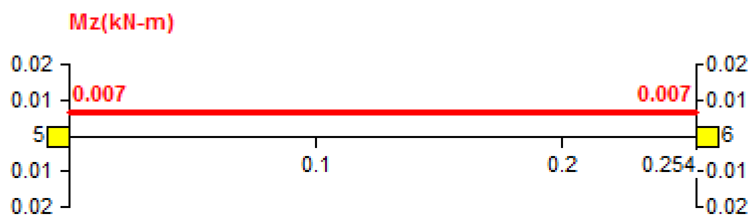
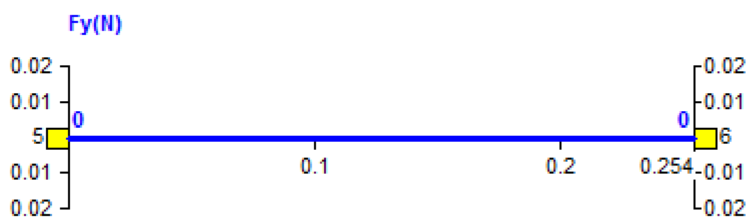


Fig. 27. Graph of M_z, F_y and F_x of beam 4 at failure.

Fig. 27 above tells us the moment, axial and shear force along the length of the vertical beam 4 from its starting node 1 to its ending node that is 5.Because of buckling and eccentric loading we see variation of moment along the length and shear force on this beam. Moment M_z varies from 0.005 kN-m at node 1 to -0.011kN-m at node 5, whereas F_x and F_y remain constant throughout the length of the beam, that is 33175 N and 52.6 N respectively. As the loading is symmetrical along the four vertical sections so we will get same graphs for beam 5, 6 and 7 as well.

Similarily, Fig. 28 below tells us the moment, axial force and shear force along the length of the horizontal beam 8. Now, because of symmetrical loading, we will obtain same graph for beams 9, 10 and 11 as well. Here, as we can see there is no vertical loading taken by these beams which means the vertical load acting on the frame passed straight through the vertical beams, therefore F_y is zero. However, constant moment, M_z of 0.007 kN-m from node 5 to 6 and constant axial force, F_x of -289 N from node 6 to 5 is observed in these beams due to buckling.





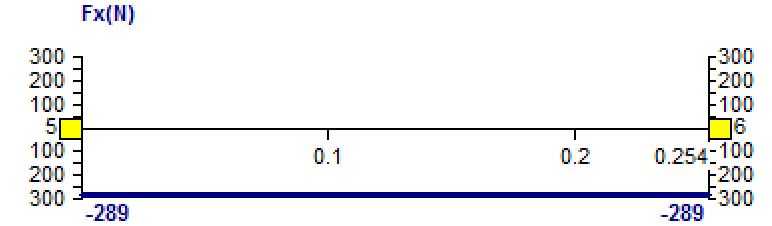


Fig. 28. Graph of M_z, F_y and F_x of beam 8 at failure

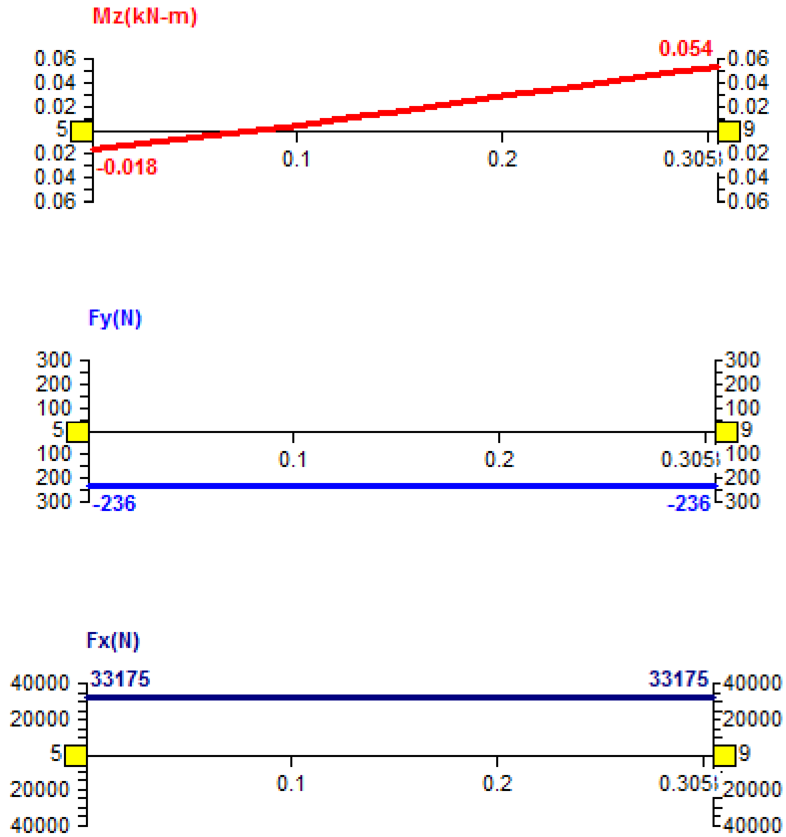


Fig. 29. Graph of M_z, F_y and F_x of beam 12 at failure

Similar to Fig. 27, Fig. 29 gives us the moment, shear force and axial force along the length of the vertical beam 12 which is above beam 4, which is same as that of beams 13, 14 and 15 due to symmetrical loading. Due to buckling and eccentric loading, the moment, M_z varies from -0.018 kN-m at node 5 to 0.054 kN-m at node 9 and a constant shear force, F_y of -236 N in the beam.

However, the axial force, F_x remains same that is 33175 N which passes along to beam 4 and then to support.

Similarly, Fig. 30 gives us the moment, shear force and axial force along the length of the horizontal beam 16 at the top, which is same as that of beams 17, 18 and 19 due to symmetrical loading. Again, as no load is taken by these beams, the axial force, F_y is zero throughout the beam. But due to buckling we observer constant moment, M_z of -0.037 kN-m and shear force, F_x of 236 N throughout the beam.

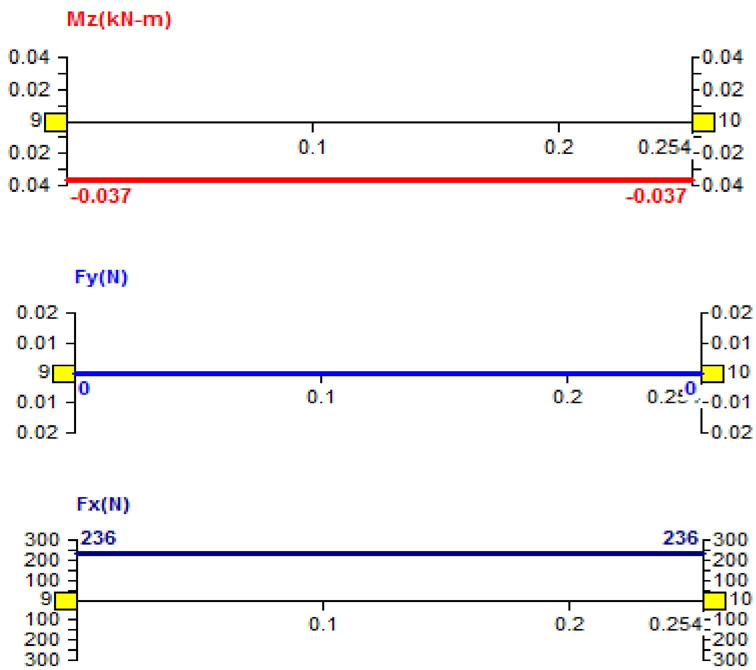


Fig. 30. Graph of M_z, F_y and F_x of beam 16 at failure

The above figures, tables and graphs give us the necessary data that is forces, stresses and deflection pattern of each member of the frame after the application of load on the frame using UTM at failure.

4.3. Comparison of Experimental and Analytical Results

Table 8. Comparison of Experimental and Analytical Results

Parameters	Experimental	Using STAAD
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

Now, the deflections in the bamboo frame obtained at the critical loading of 132.7 kN during the experimental analysis, that is -6.9 mm along Y-Axis,-0.43 mm along X-Axis and 2.23 mm along Z-Axis are much higher than that compared to the results obtained from STAADPro 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 is almost equal to zero along X and Z-Axis. This may be because of several reasons, one of which is due to the buckling caused in the bamboo frame due to eccentric loading. Secondly, the bamboo connections used in the real frame, that is bolted connections, could not be implemented on STAADPro which took bamboo connections as just normally continued sections without any joints which could have been one of the reasons for such difference in deflection. Another reason can be that the material properties of bamboo such as the thermal coefficient and the critical damping may vary in real.

CHAPTER 5: CONCLUSIONS

From the experimental and analytical studies carried out on the bamboo frame the following conclusions 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 20000 N/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 ratio ranges 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 wood and is very less as compared to that of steel, which is 8000 kg/m^3 thus proving that bamboo is very light material 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 STAADPro 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 STAADPro.
- From the above graphs, that is Fig. 27 to Fig. 30. It was also observed that some amount of moment 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.

REFRENCES

- "Construction with Bamboo – Bamboo Connections", <http://bambus.rwth-aachen.de/eng/PDF-Files/Bamboo%20Connections.pdf> , (Oct. 27, 2002).
- Yu, W.K., Chung, K.F., Chan, S.L. (Dec. 4, 2002). "Column buckling of Structural bamboo", Department of Civil and Structural Engineering, the Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, China.
- Iyer, S. (2002). "Guidelines for building bamboo-reinforced masonry in Earthquake prone areas in India", University of Sourthern California.
- Liese, W., Gutiérrez, J., and González, G. (2002). "Preservation of bamboo for the contruction of houses for low income people",1-11.
- Li, X. (2004). "Physical, Chemical, and Mechanical Properties of Bamboo and its utilization potential for Fireboard Manufacturing", Lousiana State University and Agricultural and Mechanical College.
- Bhattacharjee, B. and Nagender, A.S.V., "Computer aided analysis and design of multi-storeyed buildings", National Institute of Technology, Rourkela (2007).
- IS 6874:2008,"Code of practice for Methods of tests on Bamboo", ICS 79.060.20, Bureau of Indian Standards (2008).
- Bhalla, S., Gupta, S., Sudhakar, P., and Suresh, R. (2008), "Bamboo as green alternative to concrete and steel for modern structures" Proc., *International Congress of Environmental Research,* Goa, 18-20 December 2008.
- Salam, K., and Pongen, Z. (2008) *Handbook on Bamboo,* M. L. Choudhary, Chief Editor. S. K. Sarma, Editor.
- Hogan, L., and Archer, G.C. (2009), "Development of Long Span Bamboo Trusses**",** Architectural Engineering, California Polytechnic San Luis Obispo, USA.
- NMBA (2009), "Species - National Mission on Bamboo Applications (NMBA)", <http://www.bambootech.org/subsubtop.asp?subsubid=77&subid=22&sname=BAMBOO&subname=SPECIES>, (2009)
- Sharma, B., Harries, K.A., and Ghavani, K. (2010). "Pushover test of bamboo portal frame structure." Proc., *ASEES North Central Sectional Conference,* University of Pittsburgh, Pittsburgh, PA.

- Blogspot (2010), “Use of Bamboo as a Construction Material”, <http://civil-resources.blogspot.in/2010/06/use-of-bamboo-as-construction-material.html?m=1> , (June 9, 2010).
- Judith Goldsmith (2011),“Bamboo: A great building material gets even better”, <http://permaculturenews.org/2011/03/09/bamboo-a-great-building-material-gets-even-better/>, (Mar. 9, 2011)
- Sakaray, H., Togati, N.V.V.K., and Reddy, I.V.R. (2012). “Investigation on Properties of Bamboo as reinforcing material in concrete”, *International Journal of Engineering Research and Application(IJERA),* 2(1), 77-83.
- “Chapter 4 – Bamboo”, *Bangladesh National Building Code (2012)*,6/227-6/246.
- Terai, M., and Minami, K. (2012), “Research and Development on Bamboo Reinforced Concrete Structure”, Fukuyama University, Japan.
- Bhagat, D., Gupta, M., and Bhalla, S. (2013). “Design and Strength Analysis Of Composite Bamboo Column Element”, *IOSR Journal of Engineering (IOSRJEN),* 3(6), 31-36.
- Sabnani, C., Latkar, M., and Sharma, U. (2013) ,”Can Bamboo Replace Steel as Reinforcement in Concrete, for the key Structural Elements in a Low Cost House, Designed for the Urban Poor?”, *International Journal of Chemical, Environmental & Biological Sciences (IJCEBS),* Volume 1, Issue 2 (2013) ISSN 2320 –4087 (Online).
- Tamang, D.K., Dhakal, D., Gurung, S., Sharma, N.P. and Shrestha, D.G. (2013). “Bamboo Diversity, Distribution pattern and its uses in Sikkim (India) Himalaya”, *International Journal of Scientific and Research Publications,* Volume 3, Issue 2, February 2013 1 ISSN 2250-3153.
- Disén, K., and Clouston, P.L. (*2013*). “Building with bamboo: A review of culm connection technology” *by Journal of Green Building: Fall 2013,* Vol. 8, No. 4, pp. 83-93.
- Susira, P. (2013). “The Study of Design and Structural potential of Bamboo Practical joints and Frame Truss System”, 27/1-27/4.
- Gutu, T. (2013). ”A Study on the Mechanical Strength Properties of Bamboo to Enhance Its Diversification on Its Utilization”, *International Journal of Innovative Technology and Exploring Engineering (IJITEE),* ISSN: 2278-3075, Volume-2, Issue-5, April 2013.
- Ganiron, T.U. (2014),”Investigation on the Physical Properties and Use of Lumampao Bamboo Species as Wood Construction Material”, *International Journal of Advanced*

Science and Technology, Vol.72 (2014), pp.49-62, Te Roopu Taurima O Manukau, Otahuhu, Auckland.

- Prinindya, K.N.N. and Ardiansyah, L. (2014),"The Effect of Chemical Substance and Immersion Time of Dendrocalamus as per as Chemical Preservation Treatment", *International Journal of Advances in Materials Science and Engineering (IJAMSE)*, Vol.3, No.1,January 2014, Materials and Metallurgical Department, Faculty of Industrial Technology, Sepuluh Nopember Institute of Technology, Sukolilo, Surabaya 60111, Indonesia.
- Sethia, A., Baradia, V. (2014). "Experimental investigation on behaviour of bamboo reinforced Concrete member", *International Journal of Research in Engineering and Technology (IJRET)*, 3(2), 344-348.
- Stéphane Schröder (2014), "Amazing Facts about Bamboo", <http://www.guaduabamboo.com/facts/amazing-facts-about-bamboo> , (Nov. 9, 2014).
- Manjunath, N. (2015), "Contemporary Bamboo Architecture in India and its Acceptability" Proc., *10th World Bamboo Congress, Korea 2015*, Center for Green Building Materials and Technology, Bangalore, India.