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Connections for Bamboo in Buildings - A Review

[1]G. Balaji*, [2]R. Vetturayasudharsanan, [3]E.Arul Reegan Raj, [4]S.Pranav kumar
[1*,2]Assistant professor, Department of Civil Engineering, M.Kumarasamy College of Engineering, Karur – 639 113, India
[3,4]Final Year Student, Department of Civil Engineering, M.Kumarasamy College of Engineering, Karur – 639 113, India

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Abstract:

This review paper has been carried out in order to study about the various connection used for connecting bamboo in buildings. It is also carried in order to learn about the ancient and modern methods of bamboo construction this investigation offers with bamboo as a reinforcement fabric in structural detail, with the intention to provide sustainable improvement through preserving the usage of iron ore. The principal goal is to reduce the quantity of steel through the usage of bamboo, which possess houses which include ductility, strength much like metallic and anti corrosive inside the non-load bearing regions. By the usage of bamboo reinforcement, the self-weight of the shape may be far bamboos have been used as longitudinal reinforcement alongside steel shear reinforcement, right here we are the use of bamboo for longitudinal and shear reinforcement. The stirrups have been provided at required spacing along longitudinal and transverse route. The research work is also carried out in order to study the load transfer during various connections. The outcome of this review is proposed to create a new idea for connecting bamboo in buildings.

Keywords: *Bamboo, Bamboo joints, Tensile strength, load transfer, construction*

1. Introduction

India is the second populated country in the world with a population growth of 0.99% per year. India is also a second country based on agriculture. Even though it is populated countries and most of the people were below the poverty line. In India the number of peoples who own houses was very than other countries. This variation is mainly due to the cost spent for the construction of house was very high. In order to minimize the cost of construction and to make the construction of house more affordable for others. We had made a replacement for steel in the structural members. As this material (steel) covers 25% of the material cost. When we use this alternative material for construction. The cost of construction will be reduced more proportionally. In this paper we have studied about the various joint which have been made for bamboo bars to use it as an reinforcement. We have also concluded this paper with new joint technique to connect bamboo to use it as a structural reinforcement.

2. Literature survey

2.1 Engineering properties of bamboo

Dr.Shakeel Ahmad et al (2014),have investigated that the mechanical properties of bamboo differs from species to species and from soil to soil anyway it has sufficient vitality making it reasonable for building reason. Bamboo is heavenly in strain and its rigidity fluctuates from species to species. A normal tractable intensity of half to 75% g of metal (or) every now and even extra might be seen in bamboo. The suddenness content in bamboo vacillates near to its height zone and enhancing period. It is viewed as one among the possible factors in discovering the way of life of bamboo. The top bit of bamboo has relatively lower dampness content material than the middle and the base segment at any scope of flavoring. Water assimilation is contrarily relative to the dampness content though dimensional adjustments, pliable and pressure vitality are promptly corresponding to dampness content material. The slippage in support by method for the holding between the solid and the reinforcing material. The dimensional changes of bamboo due to temperature and moisture version generally.

In general influence all the bond trails comprehensive of cement homes of the concrete network, pressure frictional powers showing up on the outside of fortifying bar on account of shrinkage of cement and shear obstruction of cement because

May – June 2020
ISSN: 0193-4120 Page No. 1946 - 1953

of surface structure harshly. The moving of fibre in cross – period of a bamboo shell differs with the thickness just as tallness fibre circulation are additional uniform at the base that the centre (on) the zenith. Likewise, it has been found that even though falls in part in the wooden claim family. However, it has power which is more prominent than limit of it relates. The bamboo has a high tensile strength corresponding to the fibers. Tensile strength of bamboo is impacted by the longitudinal fibers that make up around 40% cross section volume. The fibers are not impartially scattered in the culm divider; the outside bit of bamboo divider has a higher degree of fibers than does the internal divider part. This assessing of the cross segment achieves more important amazing culm quality and firmness than would be typical reliant on net segment properties. [35]

2.2 Tensile strength of bamboo

Patil and Mutkekar (2014), have investigated that tensile strength of steel is lower than the tensile strength of bamboo. The tensile strength of bamboo will range from 140-280 MPa. The tensile strength of bamboo is very high when compared to normal wood like fir, pine, spruce[26]. Amada et al (1997); Amada et al (1996), said that the tensile strength of bamboo at inner region is 80 MPa which increases along the increase of the radius of bamboo[27]. Janssen (1981), said that the bamboos will have less tensile strength at perpendicular direction than the tensile strength of bamboo at the horizontal direction. The bamboo cannot withstand vertical force since the poission's ratio of bamboo is about 0.3[28].Patil and Mutkekar (2014), have investigated that the bamboo have more tensile strength than compared to compression strength of bamboo. They also concluded that the bamboo have high tensile strength at outer surface of bamboo.[26]

2.3 Compression strength of bamboo

Chung. K.F et al (2002), have investigated that the compression strength of bamboo will varies from one type of bamboo to another. The compression strength of bamboo was studied by author chung and yo in the year of 2000.He investigated that the compression strength of Bambara previable bamboo species is said to be as higher as 60KN at the bottom which reduces to 30 KN at the top of bamboo. The compression strength of Phyllostachys pubescenes is said to be 100KN at bottom and reduces to 50KN at the top of bamboo. The Bamboo with high moisture content fails at the bearing when it is tested. When the bamboo with low moisture content is tested the failure will take place in the form of only cracks.[29]

2.4 Elastic modulus of bamboo

Patil.S and Mutkekar.S (2014), have investigated that the bamboo have high elastic modulus, hence the bamboo can be used in the high earth quack prone region. The young's modulus of bamboo will vary from 5 to 35GPa from the bottom to the top of bamboo [26]. Janssen. J.J (2000), has investigated that the bamboos were with the cellulose in the form of fibre in order to increase the elastic modulus of cellulose.[30]

2.5 Flexural strength of bamboo

Janssen. J.J (2000), has investigated that the ultimate flexural strength of bamboo. He states that the bamboo fails during testing in the form of longitudinal splice but not in the form of fracture. The traverse strain of bamboo is said to be 0.0013 and the longitudinal strain of bamboo is said to be 0.00373. The ultimate bending stress of bamboo is said to be 62MPa.[30]

2.6 Shear strength of bamboo

Janssen. J.J (2000), has investigated that the bamboo is a hollow wooden pipe which has less resistant to withstand shear as compared to timber. The shear strength plays a virtual role in using bamboo in the construction site. The shear stress of bamboo along the neutral axis is said to be 2.2.[30]

2.7 Advantages of using bamboo as an construction material

Richard. M.J (2013), has investigated that the bamboo is one of the fastest growing wood plant it grows 3 times more than other plant and it takes only 3-6 years to harvest[31].Osorio. L., et al (2018), have investigated that the bamboo is a more ecofriendly material which treat carbon. The bamboo will treat 12 tons of Co_2 per hector [32]. Janssen. J.J (1981), has investigated that the bamboo is an economical material than compared with steel which is used for construction[28].Liese. W (1998), has investigated that the bamboo is also

TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 1946 - 1953

having high tensile strength as 193 MPa when compared with steel.[33]

2.8 Type of bamboo which can be used as reinforcement

Chandra S, et al (2013), have investigated that the bamboos are used for construction because which indicate a stated brownish green color. This will make certain that the plant is at the least three years as vintage and is matured. Selection is to be made in a way such that we get longest big diameter culms are quick and the thickness also reduces to at remenolous extent, for this reason culms from the base portion of the bamboo are preferable. Bamboo which are cut during spring (or) early summer seasons are to be avoided.[34]

2.9 Treatment which are to be made on bamboo

Chandra S, et al (2013), have investigated that the bamboo will be affected by inserts because of its nutrient content. In order to preserve the bamboo from the attack of insert. The Copper Chrome Boron (CCB) chemical is used in order to avoid insect attack. The chemicals which is used in the ratio of Boric acid: Copper Sulphate: Sodium Dichromate1.5:3:4. The chemical is used in the concentration of 8-10% for outdoor purpose [34]

2.10 Bamboo construction

Andry Widywaijatnoko and Kent A.Harries, have investigated that the bamboos can be used in construction as an structural or architectural element. The building constructed by using bamboo have been classified into two types they are conventional bamboo construction and substitutive bamboo construction. Conventional bamboo construction is a type of bamboo construction in which bamboo is used in the construction based on the specification of the bamboo Substitutive bamboo construction is a type of construction in which bamboo is used as an replacement material for structural elements[36]

2.11 Traditional method of bamboo construction

Arboleda. G (2006), has investigated that the traditional method of construction the well-seasoned bamboo have been used for construction. A strapped fish mouth joint have been made in order to connect the bamboos for the structural joint. This Joint is also called as “original joint”. This joint is very simple when compared with other joints and the efficiency of the joint is higher than compared with other joint. In the traditional bamboo construction, the supporting structure is formed from straight full-section bamboos subject to only compressive or bending stresses. the major drawback of the older method is that the bamboo does not process high strength at joints. The strapped fish mouth joint is shown in figure. 2.1[1]

Fig.2.1 This picture indicates traditional method pf bamboo construction.

2.12 Conventional method of bamboo construction

Arboleda. G (2006), has investigated that the conventional method of bamboo construction the joints between the bamboo were made by bolt with or without mortar. In this method multiple bamboos were connected to a single bamboo by means of single bolt. In this type of construction, the bamboos are mainly subjected to the bending stress and they will not be subjected to tensile stress mostly. In this type of construction, the loading at the joint will be in the form of eccentrical Loading. The joint strength of the bamboo is increased by the combination of both bolted joint along with fish mouth joint[1].

2.13 Substitutive method of bamboo construction

Arboleda. G (2006),has investigated that the bamboo is used as an replacement material in order to reduce the cost of bamboo . The bamboo can also be used as an alternative material due lack of particular material[1]

3. Connection for bamboo in buildings

3.1 Bamboo joint

Janssen. J.J (2000) and Widyowijatnoko, et al (2011), have investigated that the bamboo joint is more important for transferring load from one bamboo to another. The bamboo joints are primarily classified based on the load transfer from one bamboo to another. The primary classification of

TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 1946 - 1953

bamboo are based on mapping of the edges of bamboo and how the bamboos are connected are 1) The bamboos connected from outer to outer, The bamboos connected from inner to inner 2) The bamboos connected perpendicular to each other. There are different types of joint in connecting bamboos, they are 1) A two bamboos are connected with each other either by contact between full cross section 2) By transferring the force from one bamboo to another by a connecting element. The forces can transfer from inside to inside or from outside to outside. The joining element can be used to join the bamboo can be connected in parallel or perpendicular to each other.[3,4]

3.2 Transfer of compression load from one bamboo to another by connecting the bamboo through contact with the whole section

Janssen. J.J (1981), has investigated that the ends of the bamboo were made in the shape of fish mouth in order to connect one bamboo with another. The fish shape joint will help in effective transfer of load from one bamboo to another. This type joint is mainly used to connect one column with another.[5]

3.3 Transfer of load from one bamboo to another bamboo by creating friction between outer surface of two bamboos

Garzon and Diaz (1996), have investigated that this type of joint. In this type of joint the bamboos are connected by the contact of outer surface of two bamboo. In this type of joints the load transfer through friction[6].Farbiarz (2001),has investigated that the bamboo filled with mortar and having a 12.7 mm rod will transfer more tensile load than the bamboo transferring tensile load by friction. Load bearing capacities of these type of bamboo will be five times higher than the bamboo transferring load by friction[7].Mitch (2010), has investigated that the tensile strength of bamboo with no rod inserted on it will be less than 1 kN but when rod of diameter 12.7mm and 15.9mm have been inserted in the bamboo the tensile strength will increases to 13 kN[8]. Sharma et al., (2011); Trujillo, (2007); Forero, (2003), have investigated that this method will create slip in bamboo. this slip is avoided by inserting bars. This bar will act as shear reinforcement. The slip will causes punching shear failure.[9,10,11].Arce, (1993); Widyowijatnoko, (2012), have investigated that the slip resistance can be provided for beam by giving the bamboo an epoxy coat .while adding epoxy coat to bamboo all the bamboo powder remains inside the bamboo should be removed.[2,12]

Neienhuys (1978), has invented a connection by connecting two bamboos with the internal anchor bolts.[13]

3.4 Transfer of load between two bamboos by creating friction at the outer surface of bamboo

Brusnowitz (1988), has invented a new connecting clamp to connect one bamboo with another. The image of the clamp is shown in Figure. 3.1 [14]

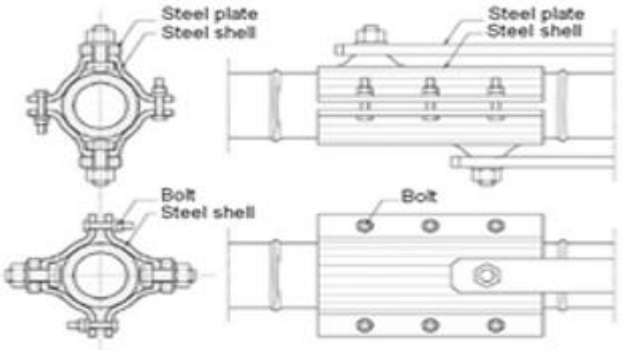

Figure.3.1 this image shows the clamp invented by Brusnowitz

Vahanvati(2015),has altered the connecting clam in such a way that four bamboos can be connected together. The image of the connecting clamp with four provision for connecting bamboo is shown in Figure. 3.2 [15]

Figure. 3.2 This figure shows the clamp invented by the Vahanvati

3.5 Transferring of load from one bamboo to another by connecting two bamboo with a perpendicular element

Clavijo and Trujillo, (2000); Janssen, (2000),have investigated that the shear failure will occurs on the bamboo in the direction parallel to bamboo which will result in crushing of bamboo.[16,17].Clavijo and Trujillo (2000), have investigated

TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 1946 - 1953

that the Smaller diameter pin elements are mainly used for connecting one bamboo with another as they will control the bearing, crushing that take place in bamboo and transfer the load-induced from one bamboo to another. The shear capacity of bamboo is very low . The pinned connections will the bamboo to arrest the shear failure[16]. Trujillo and Malkowska (2018), have investigated that the screws can be attached at the circumference of bamboo before connecting one bamboo with another. This will increase the efficiency of connection and allows several bamboos to connect with a single bamboo.[18].Davies (2008), has investigated that the pin joint on the bamboo will causes the failure that affect the bamboo by splitting it into two half . in order to avoid this failure he had used plywood gusset plate joints to connect one bamboo with another which resist their bending, shear and tensile strengths[19].Forero (2003), has investigated a new joint by using a hybrid gusset plate for connecting one bamboo with another .the two gusset plates are used at either side of the bamboo and connected with pins at the circumference of bamboo. Two pins were used in this joint are main pins and smaller pins. These pins are responsible for load transfer.[20]

3.6 Transferring load from one bamboo to another by perpendicular contact of one bamboo with another

Morisco. F and Mardjono.F (1996),have investigated that this type of joint the bamboos are connected perpendicular to each other by making the edges of bamboo in the shape of fish mouth. Bearing of one culm on another spots in any event the supporting culm in flexure. At the point when the bearing is constrained to a 'point load' at just a single area on the culm boundary, except if that heap is correspondent with a node, The culm divider is likewise put in flexure bringing about complex inside powers prone to bring about devastating of the culm divider underneath the heap or pulverizing of the whole cross segment. The most widely recognized event of these associations is the association between rooftop purlins and their supporting rafter or truss harmony. To boost contact territory around a culm outline, fish mouth joints are utilized. These are additionally helpful in verifying the culms from parallel development.[21]

3.7 Combination of joints in order to connect one bamboo with another

Popovic Larsen (2008), has investigated that the structures made of bamboo are like the frame and has the same load transfer mechanism. he also said that the only difference is in the framed structures are in direct contact but in bamboo structures the bamboos are tied to each other[22].

3.8 Space structure connection

Arce (1993), has invented a new joint by using wooden plug. In this type of joint tension force is transmitted by the adhesion.[2] . Widyowijatnoko (2012), has invented that this connection can be made by replacing the wooden plug with a dowel or pin[12] . The Figure. 3.3 represent the image of space structure connection

Fig. 3.3 This image indicate the space structure constructed by using bamboo

3.9 Column base connection Mortar filled gusset joint

Morisco. F and Mardjono.F (1996),have investigated that this type of connection is mainly used for connecting two columns. In this type of connection two bamboos are connected by means of a common base. This common base is made up of concrete or soil pedestal.

In modern method several alternative methods have been developed in order to connect several bamboos to connect at the single concrete base. In this method several reinforcement bars are laid from the concrete base. These Reinforcement bars are tied to the bolt attached to the bamboo Which hold the bamboo at a single concrete base. Fig. 3.4 represent the column base connection[21]

May – June 2020
ISSN: 0193-4120 Page No. 1946 - 1953

Fig. 3.4 This image indicate the bamboo connected by using a single base connection

3.10 Tee joint connection

Morisco and Mardjono (1996), have investigated this type of joint are mainly used for connecting bamboos at right angle. In this type of joint the edges of bamboo were made in the shape of fish mouth which will be more effective for transferring load from one bamboo to another. In this connection the fish mouth joint has been made by using dowel and tenon. In modern construction this dowel and tenon is replaced by through -culm bolt and hook bolt. The tee joint is represented in Fig. 3.5[21]

Fig. 3.5 This image indicate the bamboo connected by T -joint

Morisco and Mardjono (1996) has invented a joint which uses gusset plate and perpendicular bolt to connect two bamboos. This type of joint is mainly used for connecting complex structure.[21] This type of joint is mainly used for the complex joint which cannot be connected by the other joint. In this joint a gusset plate and a perpendicular bolt have been used. Clavijo and Trujillo (2000) had said an improvement to the mortar-filled joint. Notwithstanding the essential pin embedded through the grounded inter node, numerous little width pins are embedded in a helical path. This array of reinforcing pins draws in the mortar plug with direct contact (instead of through grating alone) and transmits some power to the culm divider away from the essential pin connection. The mortar filled gusset joint is shown in figure. 3.6 [23]

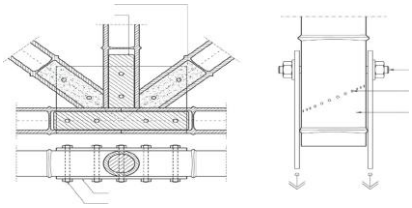

Fig. 3.6 this figure indicate the mortar filled gusset joint

3.10.1 Splice connection

Jayanetti and Follet, (1998), have investigated that the splice connection. This type of connection is like the lap joint and butt joint in steel connection. The bamboos are bolted by placing one over the. The bamboos in can also be connected by placing one bamboo adjacent to another and connecting them with a connecting element. The Fig 1.8 represent the splice connection of bamboo [24] Inoue et al (2004), has investigated that this connection by combining the pasture and the ground filled interior wedge element [25]

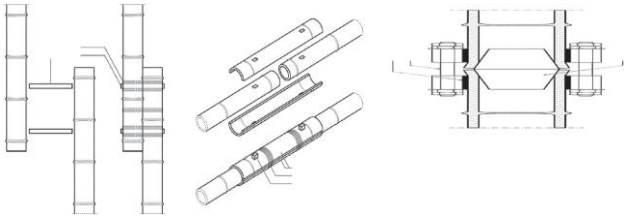

Fig. 3.7 This picture indicate the slip connection made on bamboo

Fig. 3.8 This picture indicate the interlocking system used for connecting bamboo.

4. Conclusion

From the above said papers, I have concluded some points for connections in bamboo buildings. I have come to know that there were several bamboo joints were available in the market. We have also come to know the various properties of bamboo like engineering and mechanical properties. We have also come to know about the

May – June 2020
ISSN: 0193-4120 Page No. 1946 - 1953

compression, Tensile, flexural, shear strength of bamboo .We have also leant about traditional and modern methods of bamboo construction.

Based upon the type of the joint that we use to connect one bamboo with another the load distribution between two bamboos will varies. The path of load transfer from one bamboo to another bamboo have also been studied.

From the information gathered from various journals we have invented a new system to connect one journal with another. This system is known as interlocking system. (Refer Fig. 3.8)

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