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Bamboo space frame

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Abstract

Recently, bamboo has been growing rapidly as a building material. This is because bamboo can be categorized as a sustainable building material. Bamboo can be used as a substitute material construction, for example space frame or space truss. The biggest challenge to use bamboo for space frames is in developing a connection system. Many architects and engineers have proposed joint designs that eliminate the eccentricity of force channelling. Apparently, bamboo cannot be treated as other material such as steel or timber because of its material features which influences the cost of its treatment. This paper will discuss the exploration of the bamboo space frame and how to create a more effective system for bamboo material.

Keywords Bamboo; Space; Frame

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1. Introduction

Space frame structure is a structural system composed of linear elements arranged and the loads transferred in three-dimensional way. In some cases, the constituent elements are two-dimensional. In macro spatial system often takes the form of a flat or curved surface. Spatial structure A space frame is usually arranged in a single, double, or multiplicative member arrangement. The main characteristics of space structure usually are grid construction and spread of load is omnidirectional as opposed to the linear transfer load in the ordinary framing system. Because of the transfer loads mainly by bending, for larger spans the bending stiffness increases most efficiently by changing to a double-layer grid (Fig. 1).

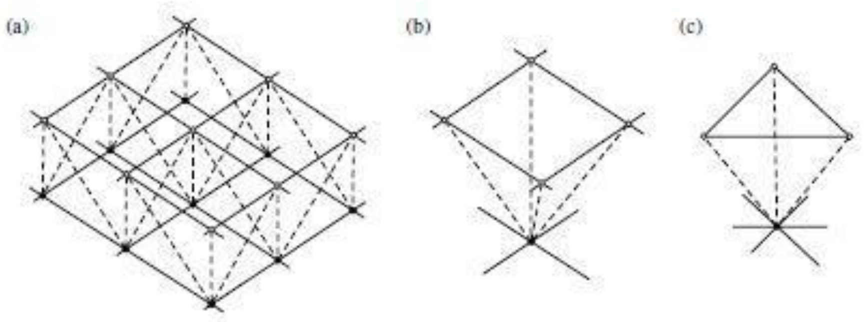


Fig. 1. Basic elements of double-layer grids (W.F. Chen, E.M. Lui (2005). Handbook of Structural Engineering. CRC Press LLC.)

The space frame structure was developed by Alexander Graham Bell around 1898 to 1908, based on tetrahedral geometry. Early interests of Alexander Graham Bell used geometry to be used in aeronautical engineering, with tetrahedral truss as one of his findings. Dr. Ing. Max Mengeringhausen developed a space grid system named MERO (*MEngeringhausen ROhrbauweise*) in 1943 in Germany, becoming the beginning of the use of space frame structures in the architectural world.

According to Engel (1997), space frame or space truss included in vector active structure. Vector active structure systems are structure systems of solid straight-line elements (bars and rods), in which the redirection of forces is affected through vector partition or multi-directional splitting of forces. The system members have either compression or tension. The typical features of this structure are triangulation and point connection. Because of these features, joints are very important to channelling the loads to bottom structure.

Bamboo has its own challenges to turn it into a space frame. Bamboo has a hard surface outside and each segment of the culm that is strong enough to withstand certain loads. However, the layer of the stem and hollow between the segment are two unique features in bamboo. These features need to be treated differently than other materials including in space truss. Bamboo can become a bar component in space truss, substitute timber or steel. The hollow feature in bamboo has similarity with hollow pipe steel. Usually, hollow steel material can be treated easily with a MERO joint by welding to a particular connection but it cannot be done for bamboo. This research develops bamboo as a space truss material. The main issue of this research is to find effective and low-cost bamboo joints in bamboo space truss.

2. Research Methodology

The method of this research is experimental of bamboo as a space frame. The study was carried out through the stages of building a test model to be tested for loading on the structure. This paper discusses how to improve systems that work on structural systems and look at the application of structural systems to permanent structures. The next stage is the analysis of the results of the test model data which is done by looking at the effectiveness of the connection system to be used and its potential development.

Bamboo is a material that is suitable for use in the structure of space when viewed from the physical and mechanical properties of bamboo. Type of bamboo was using local bamboo in Bandung, Indonesia. With the advantages provided by bamboo in terms of tensile and compressive forces, bamboo can be used for wide-span type structures such as spatial structures. Failures generated through testing this model are more focused on the part of the system that is connected to every corner of the structure that has only one support. This research was conducted to analyze and discuss related to the hypotheses submitted.

3. Joint System in Space Truss

The early connection of space frame shown in MERO system. The MERO connection system, introduced about 50 years ago by Dr. Dryinghausen, proved to be very popular and has been used for many temporary and permanent buildings. The joint consists of a knot which is a round hot-pressed steel which is forged with flat sides and tapped holes. The trunk is a circular hollow section with a cone shaped steel forging welded at the end, which accommodates connecting bolts. The bolt is tightened using a hexagonal sleeve and a dowel pin arrangement, resulting in a complete connection. Up to 18 members can be connected on an eccentric connection. The manufacturer can produce knots of different sizes with diameters ranging from 46.5 to 350 mm, suitable bolts ranging from M12 to M64 with the maximum permissible strength of 1413 KN.

The typical space module of the Mero system is a square pyramid (half octahedron) with chords and diagonal members of the same length, 'a'; extended angle is 90 or 60°. Thus, the depth of the space module is / √2, and the vertical angle between the diagonal and chord members is 54.7° (Fig. 2).

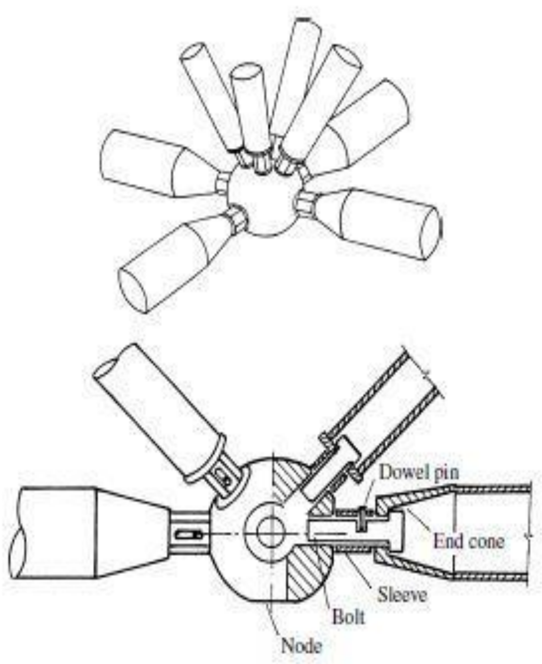
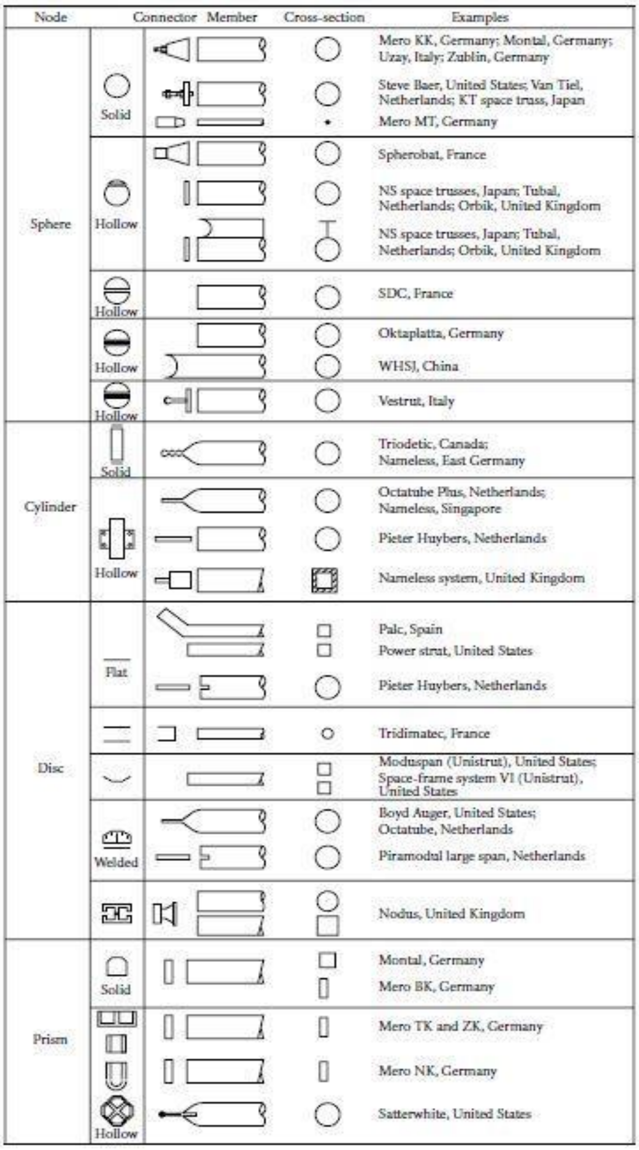


Fig. 2. MERO System (Chen and Lui, 2005)

The connection system is a very important part of the space frame design. Effective solutions to these problems are fundamental to the success of design and construction of space frame structure. The type of connection mainly depends on the connecting technique, whether it is bolting, welding, or applying special mechanical connectors. It is also influenced by the shape of the trunk. This usually involves different connecting techniques depending on whether the part is a hollow or square section or a rolled steel part. The effort expended for research and development of connection systems is enormous, and many types of connectors have been proposed in the last few decades.

The connection of space frame developed into many types according to its form whatever its bar material. Chen and Lui (2005) categorized connection in three system. There are connection types with node, connection type without node, and connection types with Prefabricated Units (Fig. 2 and 3).



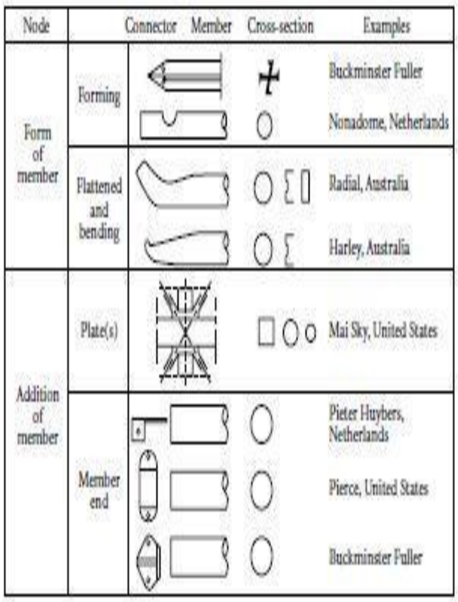


Fig. 3. Connection types with a node (left) and without node (right) (Chen and Lui, 2005)

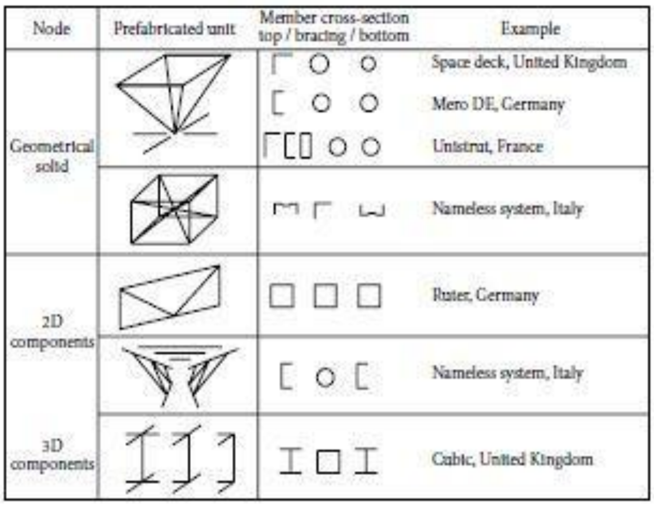


Fig. 4. Connection types with Prefabricated Units (Chen and Lui, 2005)

Connections for space frames are more important than ordinary framing systems because more than two members are connected into one point connection. In addition, members are located in three-dimensional space, and hence the mechanism of force transfer is more complex. The role of the connection in the spatial structure is so significant that most successful commercial spatial frame systems use an exclusive connection system. Thus, connections in a space frame are usually more sophisticated than connections in a planar structure, where a simple plate is sufficient. In designing a connection system, the variables that must be considered are the joints must be strong and rigid, structurally and mechanically simple, and easily made without advanced technology. These variables have been decided in early research to create connection that is low cost and can be assembly every labour. The eccentricity of the connection must be kept to a minimum, but the connection details must provide the necessary tolerance that may be required during construction. Finally, the space-frame joints must be designed to be easy and low maintenance. Connection production costs are one of the most important factors affecting the final economic structure. Typically, connector steel consumption will reach 15 to 30% of the total. Therefore, a successful prefabrication system requires a connection that must be repeated, mass produced, easy to make, and capable of transferring all the forces in the interconnected structure of the connection. All connectors can be divided into two main categories: custom made connections and exclusive connections used in industrial construction systems. Specially made connections are usually used for wide span structures where the application of exclusive standard connections is limited.

4. Bamboo Nodal Joint

Bamboo space frame is part of substitutive bamboo construction according to the structural classification by Widyowijatnoko (2012). In this connection bamboo is used as a substitute for metal pipes which are the main elements of this structure. The main problem arises is how to connect the bamboo, so their force lines meet at one point without eccentricity. Traditionally bamboo is joined using ropes and pegs. This connection system makes it difficult to connect bamboo without the eccentricity of channelling force. Therefore, in traditional or vernacular bamboo construction, only buildings with short spans can be reached. The development of traditional construction towards engineered construction is basically done by strengthening building elements. One example is in traditional construction, it is very common to use bamboo with a larger size as a column, while smaller bamboo as a beam mounted with a positive-fitting connection, which bamboo for the column is perforated so that bamboo for the beam can penetrate. This will greatly reduce the strength of the column. In engineered construction, it can be used more than one stem bamboo as a column and beam. This form can be done by using bolted joint. By using bolted joints several bamboo stems can be combined into a solid unit, either as a column or a block or for other elements. The use of bolted joints has changed massively bamboo architecture throughout the world. In spite of this, this connection system still cannot eliminate eccentricity in channelling force. A certain connection system is still needed so bamboo can be used as main material in space frame structure. In general, bamboo space frames have been created by using expensive nodal joints. This basically only replaces the space frame element stem with bamboo, while the nodal joint system (such as mero joint) is still in use. In this context, a major effort was made to connect bamboo to the nodal joint. The most effort made to solve this problem is to connect the bamboo tip with bolt using concrete or resin injection into bamboo. This connection principle is in accordance with the principle of Group 2, transferring force through friction on the inner surface or compression to the diaphragm (Widyowijatnoko, 2012). To solve those problems, it used a particular connection by using a T-joint and Hub Connector. The T-joint uses a 5mm thick iron plate for connecting to the Hub Connector and is locked with M12 bolts. On this iron plate section is given room to tolerate the different lengths of members of each bamboo stick. The binder on the bamboo uses an M12 threaded rod with eyenut attached to the inside end.


Fig. 5. T Joints design

In Hub Connector, the iron plate has 5mm thickness with a cross section size of 90x90mm below. Hub Connector is a connection system that is made through the process of laser cutting iron plate material which is then combined with the welding process. The weight of one Hub Connector is around 550 grams.

Fig. 6. Hub Connector

The connection system is designed to be used with varying degrees of tilt. That way the slope can be adjusted according to the module size specified. This system also prioritizes the ease of assembling bamboo space frames.

Fig. 7. Bamboo connection in Bamboo Space Frame

Bamboo space frame applications are generally exactly the same as space frame applications with steel rods. The stems are cut short as needed. Usually there are two main dimensions, namely the horizontal bar and the diagonal bar. For steel pipe material, the length of the truss space truss can be cut anywhere as needed. When this is applied to bamboo material, a problem arises because it becomes difficult to obtain bamboo stems for space truss frames that have nodes at both ends. Even though bamboo can be 12 meter long. This problem becomes greater if the bamboo tip connection system relies heavily on the presence of nodes. The implementation of this structural system is applied to residential buildings in Parongpong, Bandung, Indonesia. The size of the bottom area of the bamboo space frame structure is 9x12 meters with the use of a 3x3 meter module. The duration of this structure work process is around 15 days starting from the connection fabrication and assembly process in the field. The roof covering used transparent polycarbonate roof. The process of the building construction was done by builders. Builders do not need a long time to understand the technical installation of connection system. The assembly process is directly carried out at a predetermined height.

Fig. 8. Implementation of Bamboo Space Frame

Conclusion

Bamboo material is a material that has very good strength to be implemented in various types of structures. Exploration of bamboo to be used in structural systems needs to be continued to increase the popularity of bamboo. The bamboo space frame is still very open to the possibility of deeper exploration of how bamboo can be used effectively and can reduce the economic value of the use of this structural system. In this research process, the type of bamboo and optimum diameter of bamboo are not really considered as the main variables. There is still so much opportunity for improvement of space frame connection to get the most effective structural system. Bamboo have possibility to be used in permanent structural systems. Based on the process of implementing bamboo as space frame structure, the challenges are relatively small. However, there are some important aspects that need to be improved. The horizontal bamboo connection needs to be designed more effectively as solution to combine two bamboos because of the limited length of bamboo available on the market. This development can increase utilization of this structural system with a larger area. Further research also needs to be done to understand the behaviour of structural systems when receiving wind loads for implementation at certain heights.

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Conflict of Interest

The authors declare there is no conflict of interest

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