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Utilization of Tali Bamboo Reeds as Field Truss Components with the FRP Connection Method

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Abstract

Indonesian bamboo is widely used as a raw material for constructing simple houses and traditional pedestrian bridges, generally in rural areas. Bamboo is used for construction, furniture, household utensils, and crafts, and young bamboo is used as vegetable material. The main objective of this research is to obtain technical information about the strength and stiffness of bamboo Tali and their connections using FRP (Fiber Reinforced Polymer) as a simple planar frame structure component. This research aims to describe the advantages of bamboo Tali as a structural material in building structures in general, especially the strength and safety of FRP (Fiber Reinforced Polymer) joints on planar frames. The method used in this research is an experimental test method carried out at the Structural Laboratory, which is under the Soil and Concrete Mechanics Laboratory, Faculty of Engineering, Pakuan University. From the results, the 2-layer FRP connection is strong enough to withstand the maximum load and needs further testing. Continuation of the interframe connection. 3 Splicing with FRP (Fiber Reinforced Polymer) allows it to be used as bamboo Tali joints for field frames.

Keywords: *Tali Bamboo Reeds, Fiber Reinforced Polymer.*

INTRODUCTION

Indonesia uses bamboo to construct simple houses and traditional pedestrian bridges in rural areas. In addition to construction, bamboo is used for furniture, household appliances, and crafts, while young bamboo (shoots) are used as food and vegetable ingredients. (Artiningsih, 2012)

This is because bamboo is a cheap and easy-to-obtain material. Tali bamboo grows significantly in the tropics, forming small clumps in groups.(Mahdie & Rinaldi, 2007) (Leksono et al., 2020)

Bamboo as a building material is widely used in low-income rural areas, hence the emergence of a society that associates it with poverty. Meanwhile, in some communities, bamboo is widely used in restaurant buildings, villa buildings, and meeting places by being exposed because of its beauty to attract tourists. Not only in Indonesia but in several other countries, bamboo has been widely used as a building construction material. Using bamboo as a construction material has so far needed more support from scientific research to apply it. (Handoko et al., 2015)

Information regarding technical data regarding Tali bamboo as a structural component material for trusses is urgently needed, including connections on bamboo trusses. So far, the joints of bamboo trusses have used nails and connections of palm fiber Tali, rattan Tali, and some steel materials. Each of the several types of connection has its advantages and disadvantages. For this reason, an alternative connection is necessary to determine how far the connection with FRP (Fiber Reinforced Polymer) can be used as a cheap, practical, and robust connector.

In the context of utilizing Tali bamboo as a construction material, attention must also be paid to constraints such as the straightness of the bamboo, the non-homogeneous diameter, and the presence of books that vary in distance. Even so, bamboo as a construction material has several advantages: aesthetic value, high tensile strength, low density, and high elastic modulus. From some of these weaknesses and strengths, it is necessary to research the behavior of the structural review to the extent that the plane truss and its connections can withstand the applied loads in the form of tensile and compressive forces.

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Based on the issues above, this research aims to obtain technical data from relevant research sources. There has been extensive research on the physical and mechanical properties of bamboo, including tali bamboo, and the results of these studies are used as secondary data (Suriani, 2020). Then, a complete frame structure model is created to determine the strength of the joints and the tali bamboo frame. This frame model is subjected to loads at the joints until the test model breaks or fails. In testing the frame model, the assumption used at the connection points is a hinge. In addition to testing the strength of the model, deflection measurements are also taken. To compare the bar forces and deflections on the frame model, analysis is carried out using structural analysis software, specifically SAP2000.

The main objective of this research is to obtain technical information about the strength and stiffness of bamboo Tali and their connections using FRP (Fiber Reinforced Polymer) as a component of a simple plane frame structure. It is hoped that the results of this research can provide a general description of the benefits of Tali bamboo as a structural material for building construction in general and, in particular, can determine the strength and safety of FRP joints (Fiber Reinforced Polymer) on the field stem frame.

Utilization of Tali bamboo as an alternative material for constructing simple plane trusses, roof trusses of short-span buildings, pedestrian bridges, and others.

LITERATURE REVIEW

Bamboo

General Properties

Bamboo is a member of the *Bambusoideae* family, part of the grass family (*Gramineae*), which grows in tropical and subtropical regions. Bamboo generally has a hollow cylindrical shape and is divided into segments (internodes) separated by nodes. Its growth is very rapid, and its age needs to be considered for utilization, as the older the bamboo, the higher its specific gravity and the greater its mechanical strength. The maximum specific gravity of bamboo is reached at the age of 3 years, after which it no longer increases. Therefore, bamboo used for construction is typically between 3 and 6 years old. In Indonesia, one of the most commonly utilized types of bamboo is tali bamboo or *apus bamboo* (*Gigantochloa apus Kurz*), especially on the island of Java. Tali bamboo generally grows in dense clumps.

Research conducted by LPPM IPB in 2013 (Naresworo et al.) shows that the physical properties of the internode parts of tali bamboo are poorer than the node parts, contrary to ampel bamboo, where the internode parts tend to be better than the node parts. For all mechanical properties, the tali and ampel bamboo internode parts are better than the node parts. The modulus of elasticity of bamboo culms is 110% lower than bamboo strips, and the modulus of rupture of bamboo culms is 230% lower than bamboo strips. Conversely, the compressive stress parallel to bamboo culms' fibers (σtk//) is 15% higher than that of bamboo strips.

There are a total of 1,250 species of bamboo in the world, with around 159 species found in Indonesia. Of the 159 species in Indonesia, 88 are endemic to the country. According to Tribun Jabar, one of the founders of the Indonesian Bamboo Business Association (Perpubi) mentioned 40 types of bamboo in West Java, the most well-known being *betung bamboo, haur bamboo, gombong bamboo,* and *tali bamboo*. Tali bamboo can reach 22 meters in height, with internode lengths of 20 - 60 cm, a diameter of 4 - 15 cm, wall thickness of up to 15 mm, and leaves measuring 13 - 49 cm by 2 - 9 cm (Widjaya 2001 in Bachtiar (2008)

Physical and Mechanical Properties of Bamboo Rope

From previous research, several physical properties of tali bamboo have been extensively studied and published, such as in the Journal of Indonesian Agricultural Sciences 2013, for tensile tests, compressive tests without nodes, compressive tests with nodes, shear tests through compression, and shear tests through tension. Bamboo, as a natural material, has varying physical and mechanical properties due to species, growing conditions, and age. Additionally, there is variability within a single bamboo culm, both vertically (base, middle, tip) and horizontally (outer skin, inner part), as well as the influence of the nodes (Bachtiar, 2008). (Suriani, 2020)

Bamboo exhibits varying physical and mechanical properties influenced by species, growing conditions, and age as a natural material. Furthermore, within a single bamboo culm, there is variability both vertically (base, middle, tip) and horizontally (outer skin, inner part), as well as the influence of nodes. In designing bamboo as a component of space frame structures, it is necessary to calculate the forces acting on each bamboo culm as a component of the planned structure. A structural analysis program is used to calculate these forces accurately. Running this program requires input on the material's physical and mechanical properties, such as density, compressive strength, tensile strength, and modulus of elasticity.

The physical properties of tali bamboo were first tested for the density of 3-year-old tali bamboo from the Depok area, using air-dried volume and oven-dry weight. The results of the density tests on samples from the base and middle sections can be seen in the table below. The results show that the density of the middle section of bamboo is about 15% higher than the density of the base section (Bachtiar, 2008).

Table 1. Tali Bamboo Density

Sample	$P_{average}$(g/cm3)	ϱ_{max}(g/cm3)	ϱ_{min}(g/cm3)	SD	CV(%)	n
Middle	0,77	0,86	0,69	0,06	8,01	5
Base	0,66	0,78	0,60	0,07	11,02	5
combined	0,71	0,86	0,60	0,08	11,69	10

Source: (Bachtiar, 2008) (Note: SD = standard deviation, CV = coefficient of variation, n = number of samples)

The density value obtained is greater than the density value of the research by Syafi'i (1984) in (Surjokusumo & Nugroho, 1995), who obtained a density value of 0.65 g/cm3. Likewise, this compared with Nuryatin's research results, which obtained density values for the base and tip sections of 0.365 g/cm3 and 0.496 g/cm3, respectively. Syafi'i and Nuryatin's research used Tali bamboo samples from Dramaga, Bogor. Based on the research that has been done, the density at the base is smaller than the density at the top. The combined sample density value is used for structural calculations, namely 710 kg/m3 (equivalent to 0.71 g/cm3) (Bachtiar, 2008).

Based on the mechanical testing results, the mechanical properties of Tali bamboo were analyzed in the early stages by simple descriptive statistics and presented in tables and graphs. Furthermore, data that is considered to represent the population was analyzed based on AC 162 (Acceptance Criteria for Structural Bamboo) issued by ICBO (International Conference of Building Officials) in 2000 in California (Bachtiar, 2008)

Bamboo material data from various sources can be seen in the table below.

Table 2. Mechanical Properties of Tali Bamboo

Mechanical Properties	Wet		Air Dry	
	With Books	No Books	With Books	No Books
MOR (N/mm2)	102	71,5	87,5	74,5
Compressive Strength (N/mm2)	24	23,5	37,5	33,9
Shear strength r(N/mm2)	7,68	5,99	7,40	7,65
Tensile strength //(N/mm2)	294		299	

Source: Wijaya (1995) in Bachtiar, (2008)

Table 3. Physical And Mechanical Properties of Tali Bamboo Slats

Nature	Base	End	Average
Specific gravity	0,37	0,49	0,43
Thickness loss (%)	19,85	12,48	16,16
Width Shrink (%)	19,19	12,69	15,94
Compressive Strength //(Kg/cm2)	302,06	312,01	307,03
Tensile Strength //(Kg/cm2)	1312,79	1480,18	1396,48
MOE(kg/cm2)	123.598	153.385	138.492

Source: Suryatin (2000) in Bachtiar, (2008)

Table 4. Tensile strength and compressive strength of Tali bamboo

Part	Tensile Strength(Mpa)	Compressive Strength(Mpa)
Base	144	215
Middle	137	288
End	174	335

Source: Morisco (2005)

Table 5. Tensile Strength and Compressive Strength of Tali Bamboo

Mechanical Properties	Research Results (kg/cm²)	Permit voltage (kg/cm²)
tensile stress	1000-4000	300
Press Voltage	250-1000	80
bending stress	700-3000	100
MOE	100.000-300.000	100.000

Source: Purwito (2005)

Table 6. Tensile Strength and Elastic Modulus of Tali Bamboo

Magnitude	Average	
	With Books	No Books
Teg.bending limit(Mpa)	80	124
Tensile limit strain(x10-6)	7.099	8.885
Flexural modulus of elasticity (Mpa)	5.908	12.133
Tensile Elastic Modulus(Mpa)	8.908	15.225

Source: Morisco (2006)

Apus bamboo can grow in the lowlands and mountains, with a stem height of 8-13 m, an internodes distance of 45-65 cm, a diameter of 5-8 cm, and a thickness of 3-15 mm. The bark of Apus bamboo stems is dark green to black. This type of bamboo is intense, challenging, and straight, so it is suitable for building materials. Besides that, the long fiber and strength produce a stable weave. According to (Sulthoni, 1988), Apus bamboo is the most resistant to insects, even if it is not preserved because of its bitterness.

Table 7. MOE based on research by Idris et al (1981) in Haris (2008) in Rahmazudi (2014)

Bamboo	MOE (Kg//cm²)
Andong (Gigantochloa psedoarundina)	96.616 -121.395
Tali (Gigantochloa Apus Kurz)	57.515-121.334

For bamboo material data that will be used for the analysis process with the help of SAP2000 software as follows:

Other data physical properties bamboo Tali (Apus) MOE = 3.2 GPa and Poisson's ratio, v = 0.36 (Monalisa Manuputty & Pieter Th Berhitu, 2010)

For material data into SAP2000:

MOE= 138492 Kg/cm²

v= 0.36

MOR= 102000 kg/cm²

Voltage permission // =1396.48 kg/cm²

Berat volume = 0.59 – 0.67 g/cm³ = 670 kg/m³

Field Bar Frame

General Overview

Civil construction buildings require a wide span, especially roof structures in open spaces or simple bridges, canopies, and other buildings. A truss structure is required if using a single beam will result in large enough dimensions.

Truss construction comprises rods connected to hold external forces together. It can be a plane (flat) or two flat planes (space).

The truss construction is composed of several triangles, and this is because the triangular shape is the strongest compared to the other shapes. In the triangular shape, the change of place due to external forces is smaller than in other shapes, so this shape makes the triangular shape firmer and curry. The triangular shape is used as a component forming the truss construction.

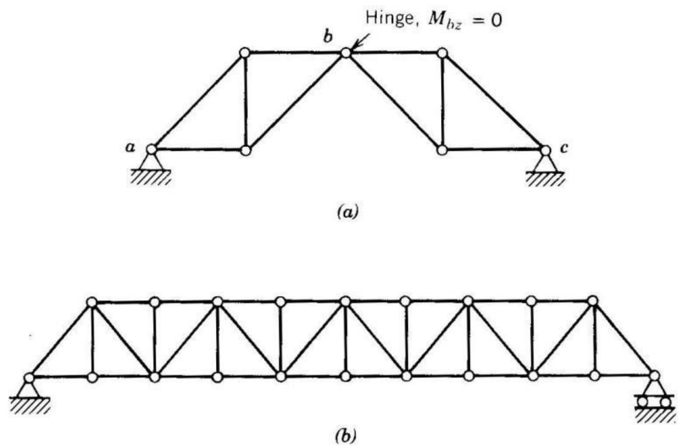


Figure 1. Field rod frame

Figure 2. Truss on the roof structure

Analysis of Bar Force on the Plane Truss Structure

The assumptions made in the analysis of the truss structure are as follows;

Perfect (frictionless) joints connect the rods at the ends.

Almost all elements are not connected by joints, such as welded or bolted. Even if a joint model is made, friction cannot be avoided. Nevertheless, this assumption oversimplifies a great deal and gives reasonably accurate results.

Loads and Reactions Only Work at the Joint Point

This assumption can be fulfilled by placing the substructure's supports at the joint points only so that the irregularly located loads are transmitted only to the joint points. However, this arrangement must often be fulfilled for practical/economic reasons.

The Longitudinal Axis of the Stem is Straight and Coincides with the Line Connecting the Joint Points

To prevent eccentricity, the axes of the sections connected at one joint point must intersect at one point.

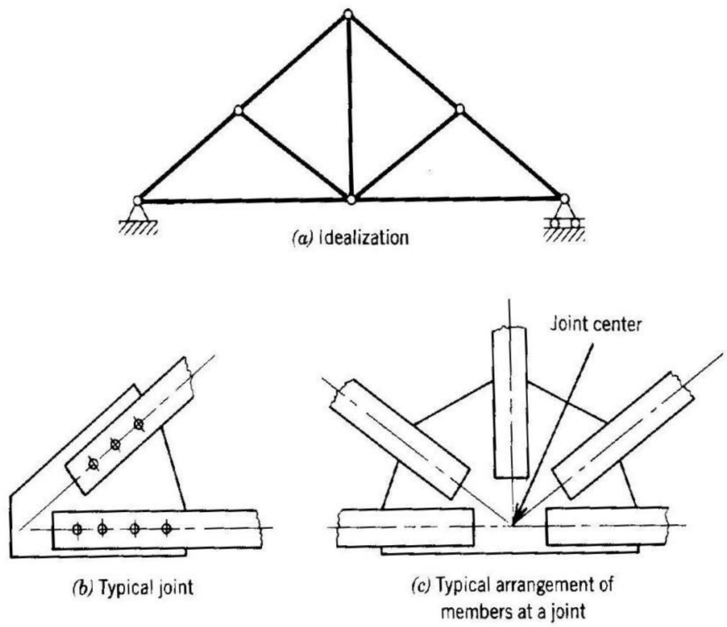


Figure 3. Assembling points on the trunk frame

From the assumptions above that have been fulfilled, the truss members only carry axial forces, and no bending moments or shear forces arise on the members in a truss. The style notation in the field bar frame can be seen in the image below;

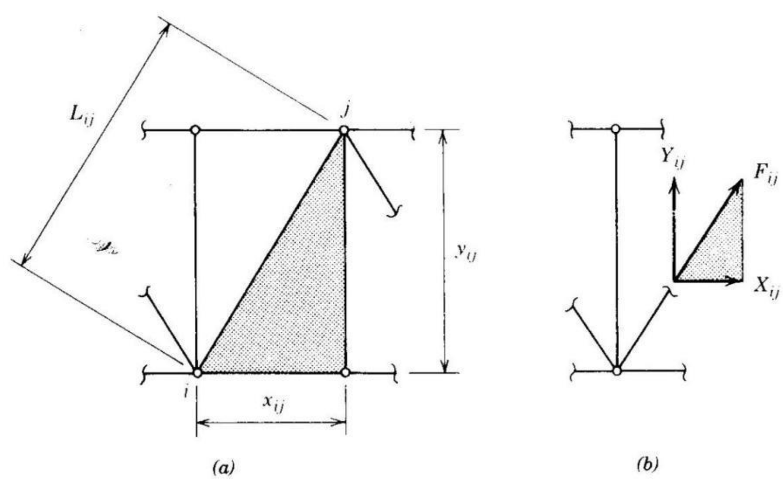


Figure 4. Style on the Truss

The axial force acts in the direction of the rod so that it can be broken down into components based on the direction/angle of the rod, namely the shape of a triangle of forces similar to the triangle of the rod.

Figure 5. Tensile and compressive forces at the collection point

Force analysis on plane trusses can use manual analysis or the SAP2000 structural analysis program (*Structural Analysis Program*).

Analysis of Strength and Stiffness of Plane Truss

Strength analysis on truss is divided into two parts, namely tensile strength analysis;

$$\sigma_{tr} = \frac{N}{A_{netto}} \leq \sigma_{ijin}$$

N = is the tensile force of the rod

Anetto = net cross-sectional area of the stem

For the analysis of compression rods, the stress that occurs is influenced by the buckling factor of the truss

$$\sigma_k = \frac{N_k}{A} \leq \sigma_{ijin}(tekan)$$

So that the stress due to bending of the rod, becomes;

$$\sigma_{tk} = \varpi \frac{N}{A} \leq \sigma_{ijin}(tekan)$$

where w = is the buckling factor

$$\sigma_{cr} = \frac{P_{cr}}{A}$$

$$P_{cr} = \frac{\pi^2 EI}{L_k^2}$$

$$P_{cr} = \frac{\pi^2 EAi^2}{L_k^2}$$

$$\sigma_{cr} = \frac{\pi^2 EAi^2}{AL_k^2}$$

$$\sigma_{cr} = \frac{\pi^2 E}{(L_k / i)^2}$$

So that

E = Modulus of Elasticity of Bamboo

A = cross-sectional area of bamboo

i = radius of inertia

Llk = bending length of the stem

I = moment of inertia

For the stiffness of the truss, it is affected by the magnitude of the deformation of each member where the deformation of the truss is used by Hooke's formula:

L= Initial length

D_l = rod deformation

Bamboo Connection

Traditional joints on bamboo trusses in rural areas use traditional connections, generally using nail connections, rattan fiber Tali and pegs. The use of bamboo nails is easy to split, unless the bamboo is drilled first. This connection relies on shearing between the bamboo and the Tali so that in general rota, palm fiber or Tali are made of bamboo skin, so the shrinkage affects the strength of the connection.

Connections at this time based on research results, several types of connections have been made, such as connections with steel plates, connections with steel tape or tape *fiberglass*. (HELMI, 2020)

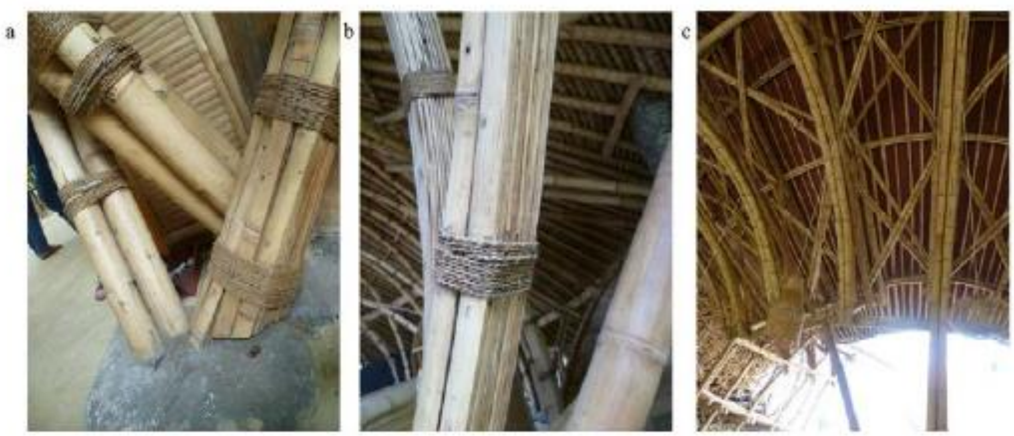


Figure 6. Bamboo connection using Tali

Figure 7. Bamboo connection using Tali

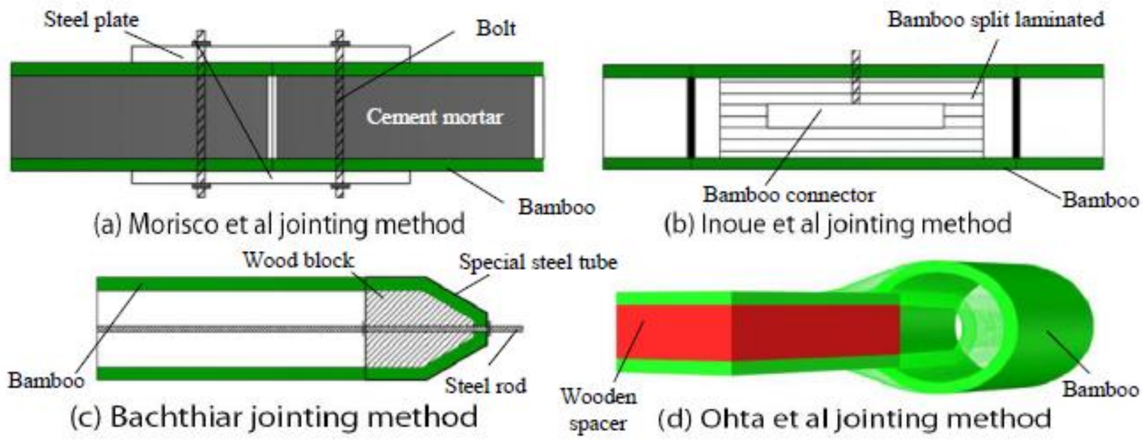


Figure 8. The bamboo connection uses a steel plate

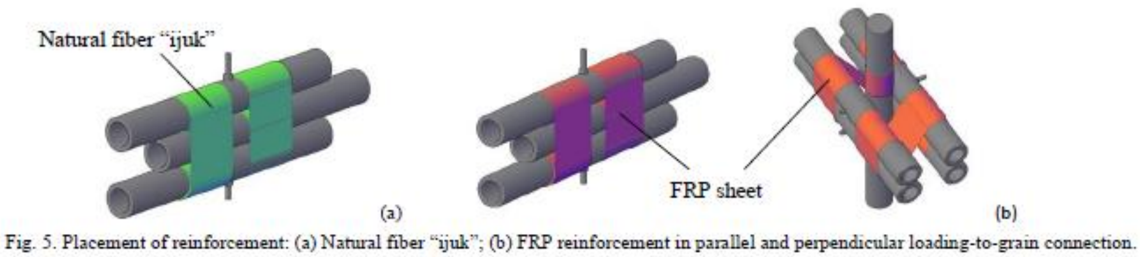


Figure 9. The bamboo connection uses palm fiber and FRP

Figure 10. The bamboo connection uses FRP

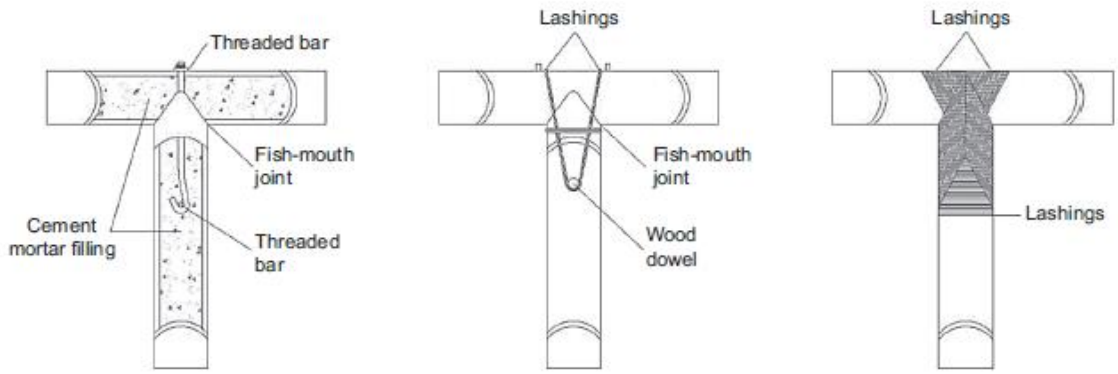


Figure 11. Connection with reinforcing steel

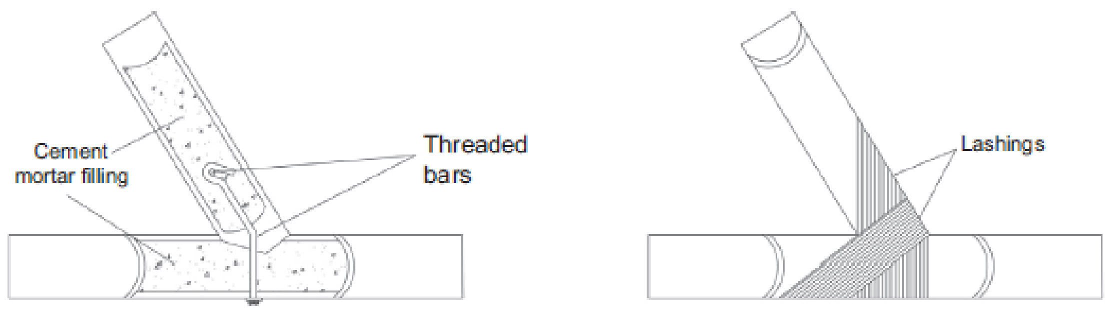


Figure 12. Connection with reinforcing steel and cement filler

Fiber Reinforced Polymer (FRP)

FRP is lightweight, has a very high tensile strength (7-10 times higher than steel), and is easy to implement. FRP can be made of 3 (three) composite materials, namely Carbon, Glass, and Aramid. The reinforcement of the truss connection is planned to use glass fibre material with a combination of epoxy resin so that it becomes a composite material.

FRP is more straightforward to implement in the field because there is no need to dismantle existing structural elements so that it can speed up construction work (Pangestuti, 2009).

CFRP is carbon fibre which is defined as a fibre that contains at least 90% carbon by weight. Carbon fibre does not show corrosion or crack at room temperature. The function of reinforcement with the CFRP system is to increase strength or provide increased flexural, shear, axial and ductility capacities. The way to install CFRP is by wrapping it around the perimeter surface of the reinforced structural elements using an epoxy resin adhesive. The working system is the same as conventional transverse reinforcement.(Achmad et al., 2013)

Fiber Reinforced Polymer (FRP) is lightweight, non-corrosive, and can withstand high tensile strength. FRP can be made of 3 (three) composite materials, namely Carbon, Glass, and Aramid. This research used fibre glass Fiber Reinforced Polymer (FRP).

The principle of using FRP is the same as Steel Plate, some materials with terms on the market are as follows, the FRP material used is:

Carbon FRP (CFRP)

Aramid FRP (AFRP)

Glass FRP (GFRP).

CFRP is generally used in reinforcement with consideration of tensile strength,

stiffness, durability and creep Properties.

CFRP is available in the form of: Plate (strip), Fabric (wrap), Rod (reinforcement), below is a stress and strain comparison chart for several FRP materials.

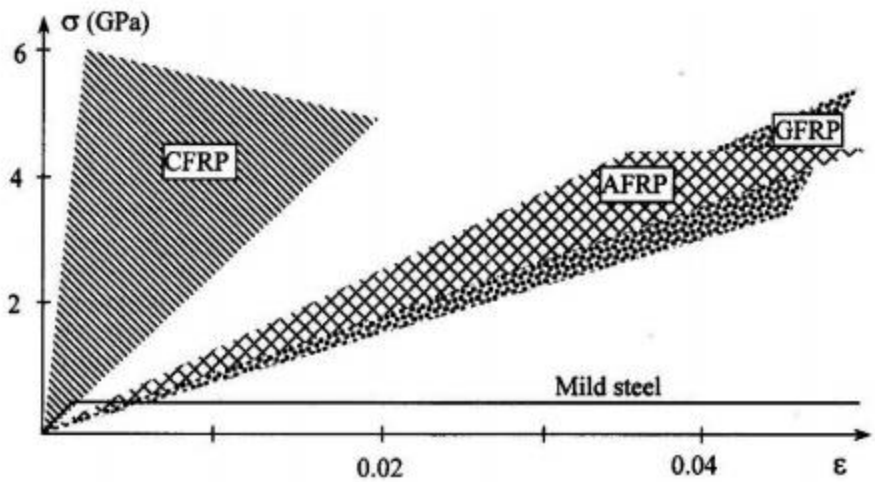


Figure 13. Stress - Strain Diagram

For adhesive materials, adhesive glue is used on the market. Nowadays, various types of adhesive glues and methods are produced according to their uses, such as acrylic, epoxy, melamine, polyester and others.

Epoxy resin cannot be a good choice from an economic point of view because the price is relatively high compared to the price of polyester resin. However, it is straightforward to use and durable in terms of strength. Therefore, the price of goods made from epoxy is higher than those made from polyester resin.

Epoxy resin, which has a much clear yellowish colour, adheres well and firmly to wood surfaces and will not require a final coat (finishing), unlike polyester resin. Not only on wood, but this epoxy resin also has a strong bond on almost all surfaces, including the surface of polyester resin, making it suitable for finishing materials.

The hardiness and elasticity of epoxy resin, which exceeds other resins, makes it popular in the defense sector, such as making kevlar and even bullet-proof glass, and is even more popular in the shipping industries. Many forums discuss using epoxy resin as essential in shipping, although some choose to use polyester resin. However, it is better to use epoxy resin because it is safer and more practical, of course, at a high cost.

Another characteristic of epoxy resin is that it does not have a strong odour like polyester resin, making it safer and more comfortable indoors. Of course, interior items made from epoxy resin are better than polyester resin, such as table wood veneer eat, coffee tables, countertops in the kitchen, and other decorations. This clear epoxy resin is also very much marketed for jewelry crafts such as elegant frames, key chains, necklace eyes, and even artificial ring stones, which have been so popular in Indonesia for some time.

METHODS

The method used in this research is an experimental testing method, which will be carried out in the structure laboratory, which is in one activity under the soil and concrete mechanics laboratory, Faculty of Engineering, Pakuan University. In this research, the object used is a plane truss structure with joint joints laminating of FRP material (*Fiber Reinforced Polymer*) *woven roving* WR 400 and adhesives using adhesives *Polyvinyl Acetate (PVAc),* or adhesive epoxy *resin Non. Sag*, where the adhesive is a polymer with powerful Properties, is often used as a base material to manufacture glue for fabric, paper and wood. PVAc is odorless, non-flammable and solidifies faster. Tests performed with center-point *loading test,* namely test 1 (one) vertical load on the plane truss model.

Research Flow Diagram

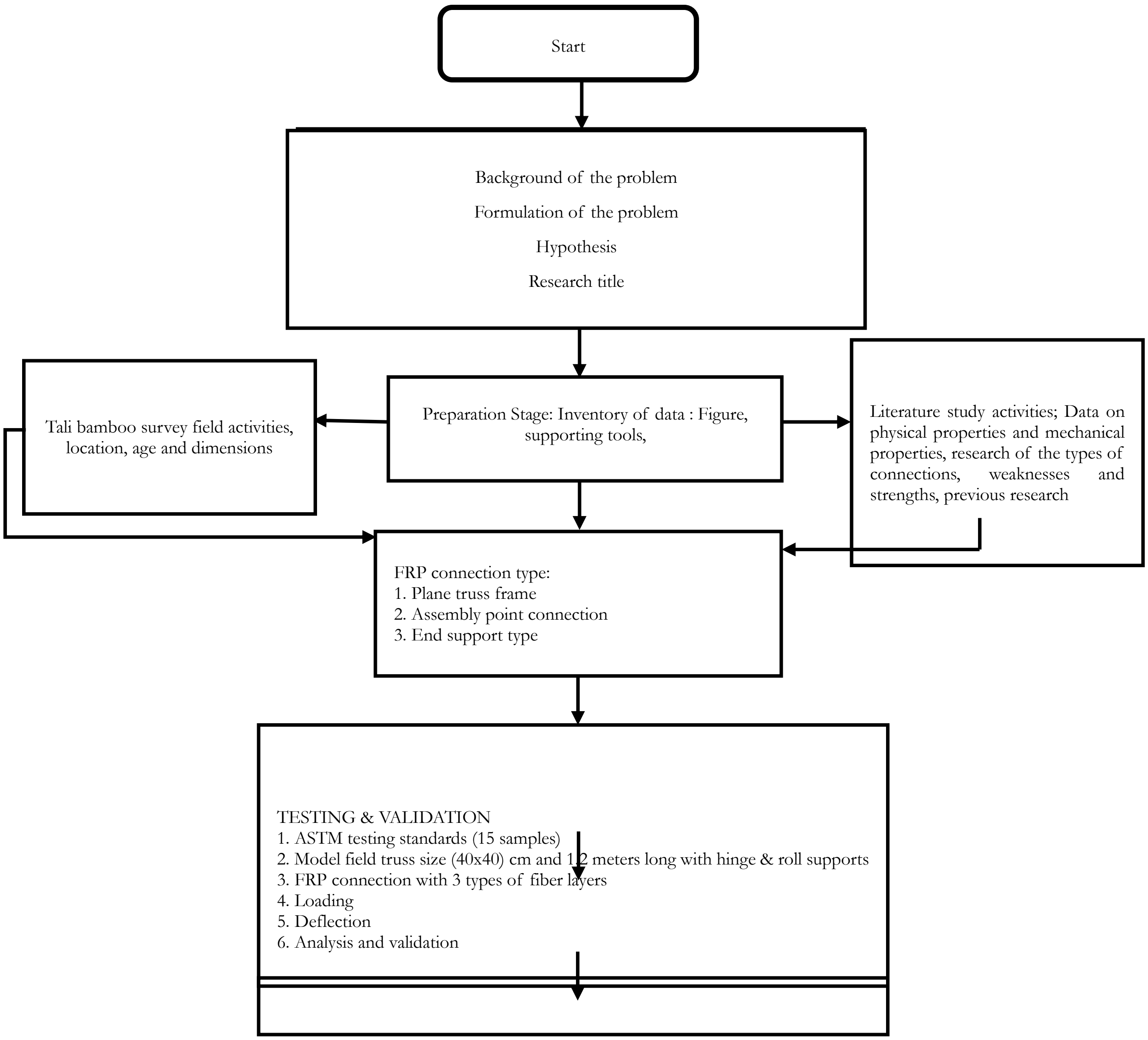
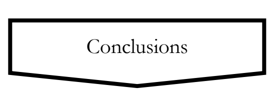


Figure 14. Research flow chart

This research used 3 (three) plane truss models, each consisting of 3 (three) sample specimens. In one type of model 1, the test object uses a laminated connection type with 1 (one) layer of FPR, type 2 uses 2 (two) layers of FRP lamination, and type 3 uses 3 (three) layers of FRP lamination.



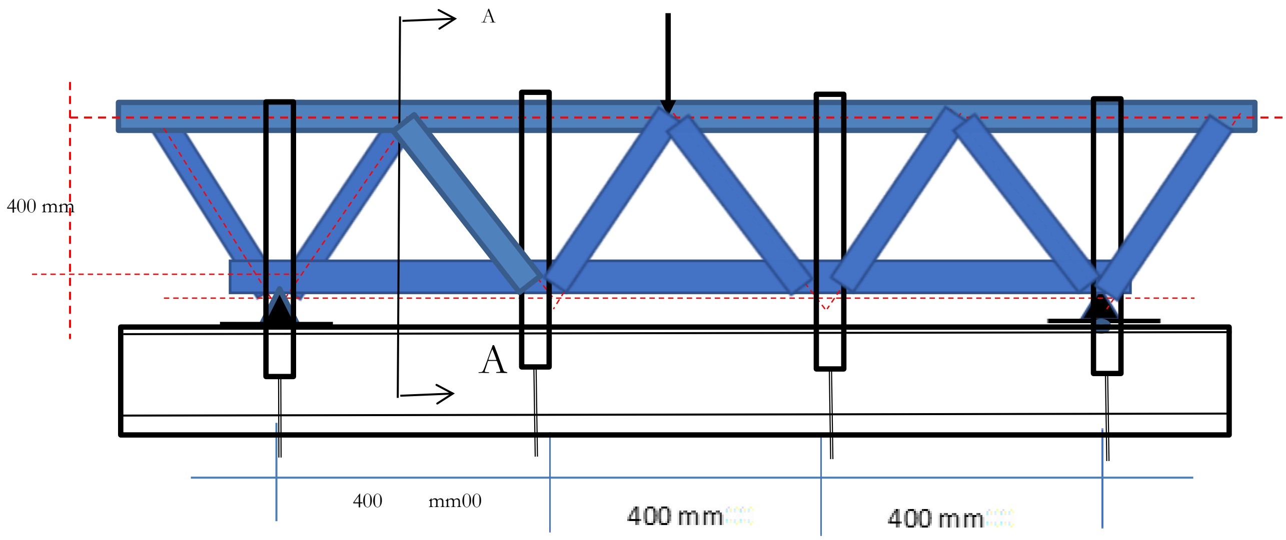


Figure 15. Test object with concentrated load

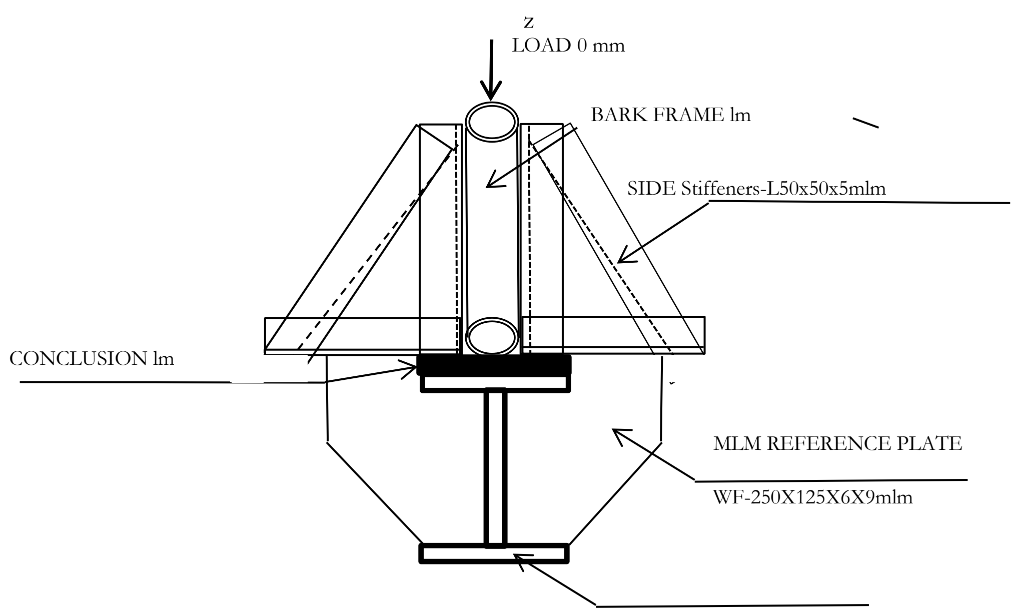


Figure 16. A-A cut

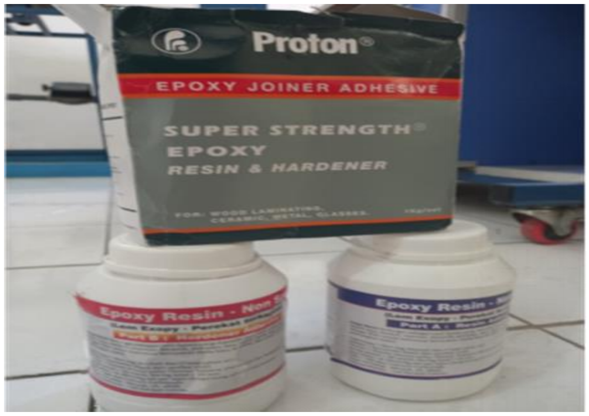


Figure. Experimental testing method Figure. Epoxy resin

RESULT AND DISCUSSION

Test Results for Bamboo Stem Frames with FRP Connections

In the experimental test of bamboo Tali truss with a centric meeting point and the connection method with several layers of FRP, the sample specimens of the truss consisted of 3 types of truss, namely 1-layer, 2 layer and 3-layer FRP connections for each type of truss totaling 5 objects trials. In the loading test on the truss with left and suitable side stiffeners, the twisting effect does not occur. The distance between the trusses is 40 cm with the loading using a bending testing machine *Digital Compression Machine* ASTM C-39 23 2000 kN capacity with reading *Dial Gauge* done at every 5 kN load increase.

Table 8. Test Results of Truss with 1 layer FRP Connection.

Test Objects	Maximum Load (kN)	Maximum Deflection (cm)
S1	18	2,5
S2	15	2,5
S3	20	3,0
S4	18	3,0
S5	14	2,0
Average		

Source: test results

Table 9. Test Results of Truss With 2 Layers of FRP Connection

Test Objects	Maximum Load (kN)	Maximum Deflection (cm)
E1	27	3,5
E2	24	3,0
E3	22	2,5
E4	23	2,5
E5	30	4,0
Average		

Source: test results

Table 10. Results Of Truss Testing With 3 Layers of FRP Connections

Test Objects	Maximum Load (kN)	Maximum Deflection (cm)
F1	25	3,5
F2	28	4,0
F3	26	3,5
F4	20	2,5
F5	20	2,0
Average		

Source: Test Results

CONCLUSION

The research results show that the physical properties of the bamboo Tali section are worse than those of the book section, in contrast to Ampel bamboo, which tends to be better. In part of the book section. For all mechanical properties, Ampel and bamboo Tali were better than books. The elastic modulus value of bamboo culms is 110% smaller than that of bamboo slats, and the modulus value of bamboo slats is 230% smaller than that of bamboo slats. In comparison, the compressive stress parallels to the fibers (?tk).//) is 15% greater than that of bamboo slats". 1. Connections using FRP (Fiber Reinforced Polymer) can be used as joint connections on bamboo Tali for plane trusses. 2. From the results obtained, the 2-layer FRP connection is strong enough to withstand the maximum load. 3. Need further testing for the frame-to-frame connections.

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