

Experimental study on strength and stiffness connection of wooden truss structure

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Abstract. Scarcity of wood is hindering the use of wood materials that have large dimension and high quality. Thus, wooden truss is expected to be a solution for this problem. However, the use of this system is not complemented with adequate research of its strength and behavior. In this study, wooden truss would be examined experimentally. The specimen is a wooden truss joist supporting the floor slab for typical residences with two connection type variations which are nail and glue. These specimens has dimension of 185 cm in length and 36 cm in height with 3 layers of a wooden board in width, and were produced by using Sengon wood with elasticity modulus of 2867 MPa, and specific gravity of 0.4. Destructive and non-destructive test were performed. From the result, we obtained a higher proportional strength for glue type connection truss which at 1123.34 kg compared to nail type connection truss which at 767.07 kg. However, unlike the nail type connection, the glue type connection has a brittle behavior. Moreover, the stiffness connection study resulted with partial fixity value of 0.07 for nail type and 0.98 for glue type connection. Furthermore, these results have also been validated using numerical model analysis

1 Introduction

These days, wood as a construction material is gaining its fame, especially with the recently high demand of green material. One of the reasons is the low amount of energy to produce those wood materials compared to other construction materials. Moreover, the wood materials are getting more demand with the latest development of fast growing wood species [1]. These eventually lead to the issues of the lack of dimension and quality of wood as structural member.

In this study, these woods with lack of dimension and quality are engineered for use in the wooden truss joist supporting a residential floor slab with connection type variations. The truss type structure is chosen because this type of structure is more likely to be the best for optimizing the use of wood with small dimension. In addition, it has more esthetically values.

To fully understand this type of structure behavior, experimental test is required and conducted in this study. This test is also conducted to obtain strength and stiffness value as part of its behavior. Furthermore, structural analysis with numerical program is also conducted and validated with the experimental results obtained previously. This is intended for practical uses in future design.

2 Experimental details

2.1 Test specimen

Wood species used in this study is Sengon (*Albizia chinensis*). Its mechanical properties were tested based on ASTM D2395-02 [2] and obtained the bending modulus of elasticity and specific gravity which at 2847 MPa and 400 kg/m³. This wood species is classified as a low quality of wood according to SNI 7933-2013 [3].

These specimens has dimension of 185 cm in length and 36 cm in height with 3 layers of a wooden board in width. Each board is made with 6 cm x 2 cm of dimension. This board is used in the specimen as vertical, horizontal, and diagonal bar for tension and compression. The specimen configuration and dimension can be seen in the Figure 1.

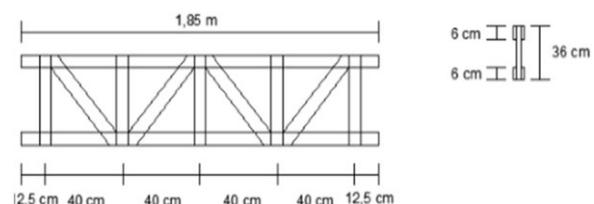


Fig. 1. Specimens' configuration and dimension

These specimens were arranged from two horizontal bars as top and bottom of the truss. For the middle part, it consists of vertical and diagonal bars. Figure 2 shows the assembly of the specimen

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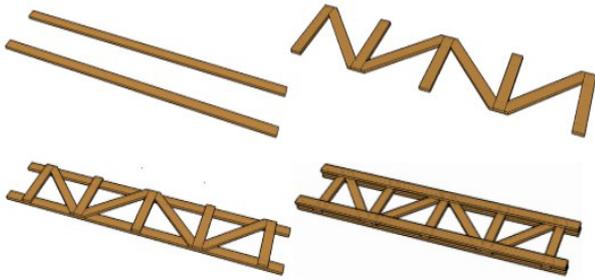


Fig. 2. The assembly of the specimen

2.2 Specimens' test specimen

Two connection types, which are nail and glue type connections, were observed in this study. These types of connection are the most common connection for practical uses in construction.

Two millimeter diameter nails with 40 mm length were used in the nail type connections. The nail has 107 kg of maximum shear strength. For the glue type, epoxy type adhesive was selected. The glue has 4.18 MPa of maximum shear stress and was applied in the specimen with 0.95 mm thickness.

Three nail type connection specimens, named A-1, A-2, and A-3, and also three glue type connection specimens, named B-1, B-2, and B-3, were produced for this study.

2.3 Destructive and non – destructive test

Destructive tests were conducted using UTM (Universal Testing Machine) in order to obtain wooden truss' strength. Three millimeter per minute speed rate was suggested by ASTM D143-94 [4]. The proportional, ultimate, and rupture condition of load and displacement can be found and then analyzed to determine the strength and behavior of the specimens. Figure 3 shows the test setup of specimens.

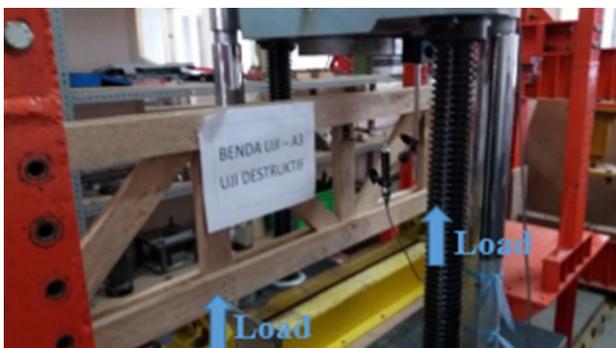


Fig. 3. Destructive test specimen

Non-destructive tests were also conducted in order to obtain the stiffness of specimens. The test gave the relation between load and displacement which was measured using LVDT (transducer). The load excitation used weight plates that increased gradually. Non-destructive testing from the specimen is shown in Figure 4.



Fig. 4. Non-destructive testing specimen

2.4 Experimental test result

Figure 5 – Figure 10 shows the load-displacement curve for each specimen obtained from destructive test. Three points shown in the graph represent the specimen's design, proportional, and ultimate load. Design load refers to maximum load for joist supporting residential floor slab design which equal to 266.5 kg [5]. Proportional and ultimate point is used to describe the specimen behavior.

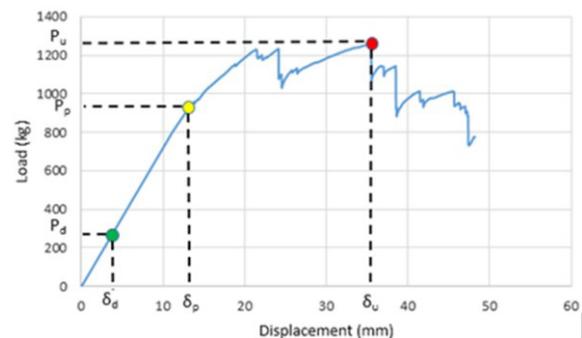


Fig.5. Load-displacement curve specimen A-1

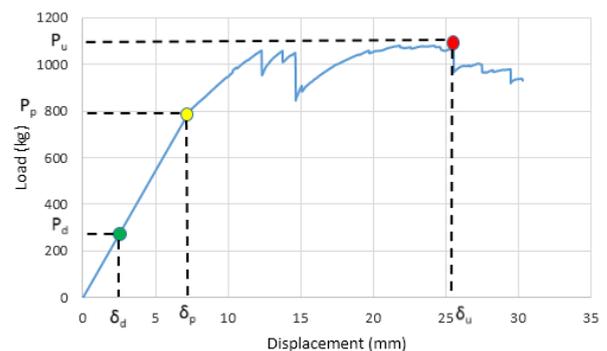


Fig.6. Load-displacement curve specimen A-2

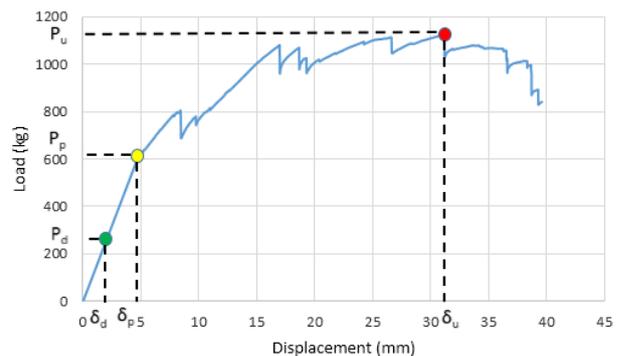


Fig.7. Load-displacement curve specimen A-3

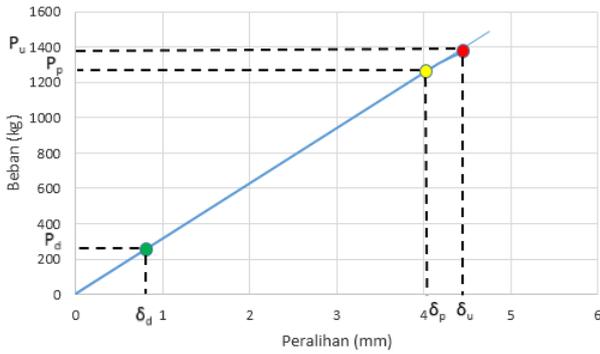


Fig.8. Load-displacement curve specimen B-1

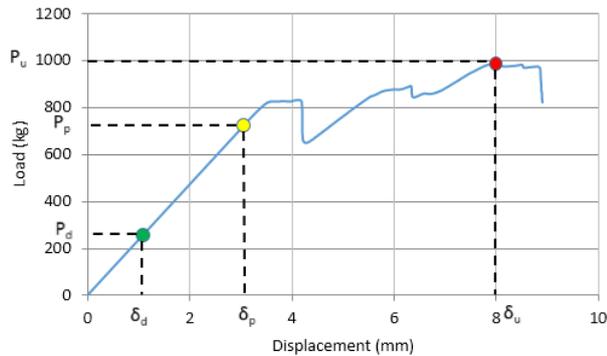


Fig.9. Load-displacement curve specimen B-2

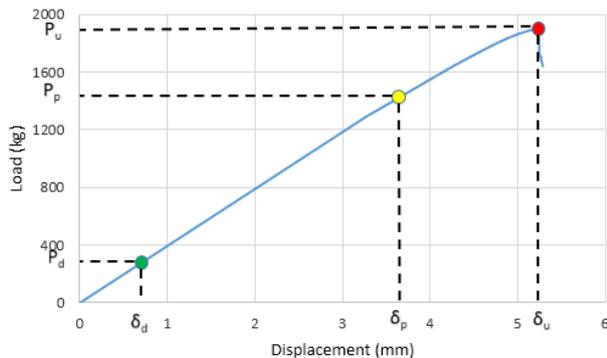


Fig.10. Load-displacement curve specimen B-3

Figure 11 shows the relation between load and displacement of the specimens obtained from non-destructive test. The allowable displacement of structural beam that refer to the latest code ($L/300$ which equal to 5.33 mm) [3] is also added to the curve in Figure 11

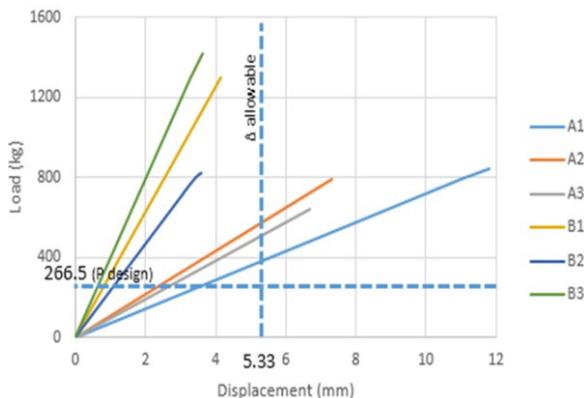


Fig.11. Non-destructive test result

3. Numerical model validation

Numerical model validation is required to obtain wooden truss connection stiffness. In addition, it can be used to validate experimental results for structural analysis design. The numerical analysis was modeled using SAP2000. All of its properties required for the analysis (except for connection stiffness) were taken from the actual experimental test. Connection stiffness was found by using trial and error value of partial fixity.

The connection stiffness was evaluated using Romstad and Subramanian equation (1) [6] below:

$$Sc = \lambda 4EI / L \quad (1)$$

where Sc is connection stiffness and λ is partial fixity value of connection. The partial fixity represents the structural connection condition. Three type of partial fixity value that usually used on numerical model are rigid frame ($\lambda = 1$) that assumes the connection have sufficient rigidity to hold virtually unchanged the original angles between intersecting member, simple framing ($\lambda = 0$) that assumes insofar as gravity loading is concerned, ends of beams and girders are connected for shear only and are free to rotate under gravity load, and lastly semi-rigid framing ($0 < \lambda < 1$) that assumes the rigidity of connection in degree between rigid and simple framing condition. Figure 12 shows the modelling of partial fixity condition.

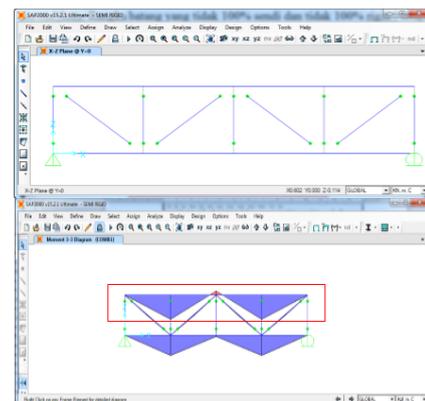


Fig.12. Test model validation

After several trial value of partial fixity, the graph in Figure 13 summarizes the relation between partial fixity and displacement. Displacement from experimental test is fitted to find partial fixity value for both type of wooden truss connection.

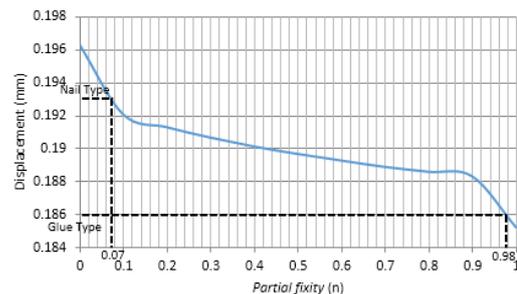


Fig.13. Relation between partial fixity and displacement

From the trial and error, it is concluded that the partial fixity is 0.07 and 0.98 for nail type and glue type connection respectively as shown in figure above.

4. Analysis and discussion

4.1 Destructive test result

The table 1 show the summary of proportional and ultimate condition for both type connections obtained from load-displacement curves.

Table 1. Destructive test result

Type	Pp (N)	δp (mm)	Pu (N)	δu (mm)
A-1	8442.8	11.82	12364.74	35.49
A-2	7843.3	7.31	10562.51	30.31
A-3	6265.9	6.70	11007.40	31.18
B-1	12714.84	4.13	13446.46	4.44
B-2	6420.43	3.58	9636.88	8.01
B-3	13861.71	3.63	18582.13	5.23

As shown in Table 1, proportional load for nail type connection ranges from 6000-8500 N which is smaller than the proportional load for glue type connection that ranges from 6000-14000 N. Likewise, this condition is also applied to specimens' ultimate load.

Table 1 also shows both of the proportional and ultimate displacement of the specimens that would be used to determine its ductility. The ductility is calculated from the ratio between ultimate and proportional displacement. It shows the ability of the specimen to resist load after yield point. Displacement ductility of both specimens has significantly large differences as shown figure in table 2.

Table 2. Average ductility

Type	Displacement Ductility	Average Ductility
A-1	3.00	3.94
A-2	4.15	
A-3	4.66	
B-1	1.08	1.58
B-2	2.24	
B-3	1.44	

From Table 2, it can be concluded that wooden truss with nail type connection is more ductile than the other type. Its ductility value ranges from 3 – 5 while the glue type connection has ductility value less than 2.5. On the other hand, specimen with glue type connection has greater strength than nail type connection.

4.2 Non – destructive test result

The glue type connections have better stiffness than nail type connections as shown in Figure 11. It is related with the ductility behavior of specimen. Based on the graph in Figure 11, it shows that allowable displacement for glue type is not in elastic condition. Therefore, the design for glue type connection is limited by proportional load

unlike the nail type connection that is limited by allowable displacement

4.3 Safety factor

The ratio between ultimate and proportional load against design load give safety factor for both specimen type. Design load for this study is obtained from calculation of a 0.85 meter joist supporting a residential floor slab (=2665.6 N).

Table 3. Safety factor

Type	Pd (N)	Pp (N)	Pu (N)	SF (Pp / Pd)	SF (Pu / Pd)
A-1	2665	7845.29	12364.7	2.75	4.24
A-2		7843.23	10562.5		
A-3		6265.95	11007.4		
B-1	2665	12714.8	13446.5	3.99	5.21
B-2		6420.43	9636.88		
B-3		12735.8	18582.1		

Safety factor for nail type connection is lower than glue type connection as shown on table 3. It is 2.75 and 4.24 in proportional and ultimate condition respectively for nail type connection. As for the glue type connection, the safety factor is 3.9 and 5.21 in proportional and ultimate condition respectively. Overall, safety factor from both connection types is quite large and adequate.

4.4 Failure characteristic

From the previous test, failure characteristic from both specimens is quite different. The failure type that happened on the specimen is ductile failure on nail type connection as shown in Figure 14. The ductile failure is indicated by cracks on the element that developed gradually. This failure is totally different from brittle failure that experienced by glue type connection. In brittle failure, cracks suddenly developed as shown on figure 15

There is no connection failure in both type of specimen. It's caused by maximum shear stress of nail and glue hasn't been exceeded. It is also proven experimentally by visual checks of nail and glue condition after test.

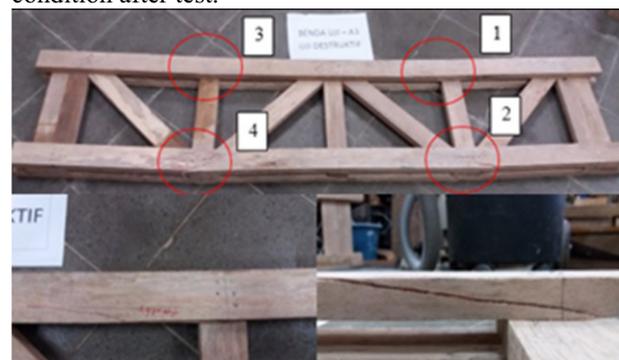


Fig.14. Ductile failure on nail type connection specimen



Fig.15. Brittle failure on glue type connection specimen

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5. Conclusion

Wooden truss with nail and glue type of connection have adequate safety factor for a residential floor joist design which range from 2.75 – 4.00.

It's also observed that the specimen with nail type connection has lower stiffness value than the glue type connection. It's also proven by model validation that resulted the partial fixity value of 0.07 and 0.98 for nail and glue type of connection respectively.

Failure characteristic of specimen is ductile for nail type of connection unlike the other specimen that experienced more brittle failure. Although the glue type connections have a brittle failure, it has 30% higher strength than the nail type connection.

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