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Stiffness and Ductility of Bolted Connection Laminated Veneer Lumber (LVL) Paraserianthes Falcataria

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Abstrak

Kayu sengon dapat digunakan sebagai alternatif pengganti kayu solid walaupun jenis kayu ini memiliki sifat mekanik yang rendah, namun seiring berkembangnya teknologi dapat diolah menjadi produk kayu rekayasa yaitu LVL (Laminated Veener Lumber). Selanjutnya yang menjadi permasalahan adalah mencari tahu bagaimana mekanisme sambungannya, mengingat hal ini sangat mempengaruhi kestabilan struktur pada saat kayu LVL diaplikasikan dalam perancangan struktur. Penelitian ini difokuskan untuk mengkaji parameter penyambung kayu LVL Sengon menggunakan baut untuk memprediksi tingkat kekakuan dan daktilitas sambungan, dimana kegagalan kayu mengarah pada kegagalan getas. Pengujian Kayu berdasarkan ketentuan ASTM 5652-95 dengan jarak satu baut 5d dan untuk jarak dua baut 5d (d = diameter baut). Hasil pengujian menunjukkan nilai kekakuan sambungan dipengaruhi oleh sistem gaya pengikat sambungan baut yang akan meningkatkan tahanan selip. Dengan bertambahnya jumlah baut maka nilai kekakuan sambungan akan semakin besar, hal ini disebabkan bertambahnya daya dukung kayu LVL akibat gaya aksial baut. Nilai daktilitas sambungan semakin berkurang seiring bertambahnya jumlah baut. Hal ini disebabkan oleh faktor aksi kelompok sambungan, sambungan baut luar akan menekan kayu yang akan mempengaruhi nilai slip sambungan dan mengurangi sudut tekuk baut.

***Kata Kunci** : paraserianthes falcataria; sambungan; kekakuan; daktilitas*

Abstract

Sengon wood can be used as an alternative to solid wood, although this type of wood has low mechanical properties, as technology develops, it can be processed into engineered wood products, namely LVL. Furthermore, the problem is finding out how the connection mechanism is, considering that this greatly affects the stability of the structure when the LVL Sengon wood is applied in structural design. This research is focused on examining the parameters of LVL Sengon wood joints using bolts to predict the level of stiffness and ductility of the joints, where wood failure leads to brittle failure. Wood Testing based on ASTM 5652-95 provisions with a distance of one bolt is 5d and for a distance of two bolts is 5d (d = bolt diameter). The test results show that the value of the joint stiffness is influenced by

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the bolt connection binding force system which will increase the slip resistance. With the increase in the number of bolts the value of the joint stiffness will be greater, this is due to the increased bearing capacity of LVL wood due to the axial force of the bolts. The ductility value of the joint decreases as the number of bolts increases. This is due to the group action factor of the joint, the outer bolt connection will compress the wood which will affect the value of the joint slip and reduce the bending angle of the bolt.

Keywords : paraserianthes falcataria, connection, stiffness, ductility

A. INTRODUCTION

The development of processed wood in Indonesia is currently experiencing significant. For example, use of wood LVL Sengon as an alternative to solid, wood considering sengon wood is wood species relatively quickly growth which can be harvested 4-6 years. LVL Sengon can be produced in various sizes and shapes such as beams, columns, shear walls, element truss, and web or flanges on I-joist. The generally low mechanical properties of sengon wood can be improved through wood engineering products namely LVL. From the results of the tests carried out, Sengon wood LVL has the value of parallel to grain strength and perpendicular to grain with a bolt diameter of 12 mm is 21.93 MPa and 12.10 MPa. The difference in the average strength value of the fulcrum parallel to the fiber and perpendicular to grain between before and after the sengon wood is done by engineering lamination shows that wood lamination engineering is more effective to improve the quality of Sengon wood that has a low quality (Palaeowati, Awaludin, & Siswosukarto, 2014). Furthermore, the problem is figuring out how mechanism connection greatly affects the stability of the structure when LVL Sengon is used in the design of the structure.

The results showed that the bolt end distance of 5*d* LVL Sengon produces an ideal lateral resistance, although the provisions according to Eurocode 5 and SNI 7973-2013 are 7*d*, (Awaludin, Ali. D.N., 2017). This basis will be reviewed by the author in determining the stiffness and ductility of LVL Sengon connections. Often the connection is deliberately made as a fuse as the weakest point in a structure. This is to ensure that the structure failed ductile or brittle in the connection system due to the load received. Wood structures are fragile elements, in contrast to steel structures and reinforced concrete structures, where the connections are designed as rigid elements. Wood joints have very complicated provisions the fact that wood is heavily influenced by several factors such as geometry including the number and placement of joints, slenderness ratio, type of jointing tools, moisture content, duration of load, density and density of the wood. The influence of several factors must be considered and taken into account when designing wood connections. Deformation, stiffness, and ductility will occur perfectly if the influencing factors can be controlled and overcome perfectly (Kiwelu, Smith, & Asiz, 2014). Analysis results for the past 15 years. shows that the ductility ratio (μ) is very dependent on the melting point and displacement calculation. So the calculation of the connection ductility needs for clicking estimate of the melting point of connection and deformation tools continued. In Eurocode 5 there is an equation to analyze the stiffness of the bolt connection is not enough to predict

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the initial stiffness of the wooden connection. due to the fact it that equation Eurocode 5 is only considering wood density and bolt diameter (Mohammad, Toro, Quenneville, & Salenikovich, 2010)

This study focuses on reviewing the parameters of the LVL Sengon wood joint using bolts to predict the level of stiffness and ductility of the joint. In response to that failure leads to a wooden structure over brittle failure and generally not well understood.

B. LITERATURE REVIEW

1. Initial Stiffness And Ductility

The increase in the carrying capacity of the joints in applying the initial fastening force on the bolts is caused by increased friction resistance. Friction or friction inhibits slippage between wood and bolts because bolts rest on the wood when deformation occurs at the joint. (Petersson, 2005) make finite element modeling to calculate the stress distribution and contact area on the connection by assuming the value of the friction coefficient μ between 0.0 - 0.7. The model is subjected to compressive forces along the symmetry axis of the bolt hole with values $\mu = 0$ and $\mu = 0.7$ which indicate that the friction effect only occurs along the 0.7*d* from the edge of the bolt hole (*d* = bolt diameter). Based on this, that friction has a great influence on the stresses that occur and must be included in a wooden connection.

The monotonic test results on the wood connection obtained the force and slip curve of Initial stiffness (K_0), melting load (P_y), yield displacement (D_y), maximum load (P_{max}), and energy dissipation up to 0.8 from maximum load. Initial stiffness is defined as a line passing through a point on the curve that corresponds to 0.1 and 0.4 of the maximum load. With the 5% offset method (ASTM D-5652, 2000), the initial stiffness line is shifted as far as 5% of the bolt diameter

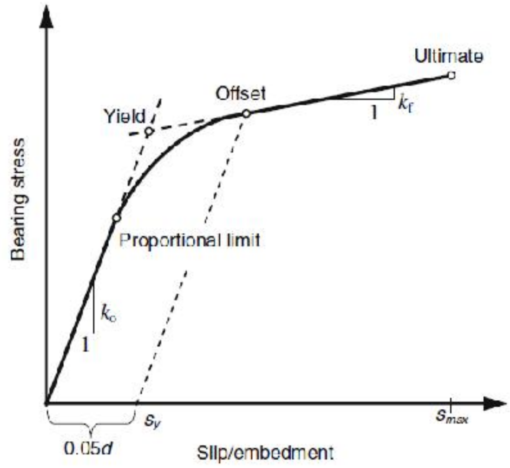

Figure 1. The curve relationship proportional limit stiffness k_o; stiffness after proportional limit k_f (ASTM D-5652, 2000)

Ductility value is obtained from the ratio between deflection of 0.8 P_{max} with deflection (δ_y). Yield load is the intersection between the lines with curves load-displacement. Yield displacement is the displacement in figure 2 curve load-displacement which is associated with a load of yielding.

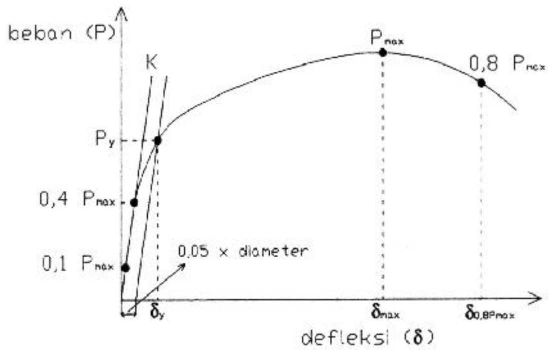

Figure 2. Curves initial stiffness and ductility of connection

2. Parallel to grain connection type steel-wood-steel

Some Research proposes an analytical equation to determine the effective number n_{ef} are used to evaluate the connection bolt in a row to get a perfect stiffness and ductility. The relationship is based on analytical and theoretical results using the same parameters.

(Gattesco & Toffolo, 2004) concluded that increasing the number of bolts in a row the ductility value decreases, even though the distance and distance between the connecting devices is considered. The equation value used by the experiment to calculate the effective number of bolts is the joint equation using the European wood design (EC5). The following is a graph of the relationship between the number of bolts and the effectiveness of the parallel fiber joint in one row in Figure 3

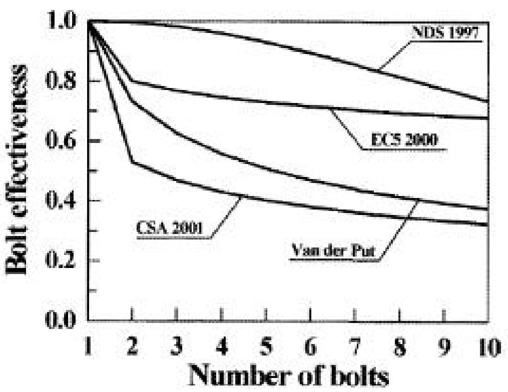

Figure 3. Graph of the relationship between the number of bolts and the effectiveness of parallel fiber joints in one row

3. Lateral resistance based on FEM (Finite Element Method) beam on elastic foundation

A beam that is located on an elastic surface can be modeled as a beam that is located on a series of springs along the beam. A practical example found in civil engineering is the track foundation, where the foundation is modeled as a beam on an elastic foundation because the soil is assumed to be an elastic material.

In fig.4, the bolt is likened to an elastic-plastic beam on top of the wood which is likened to having a series of springs as an elastic foundation.

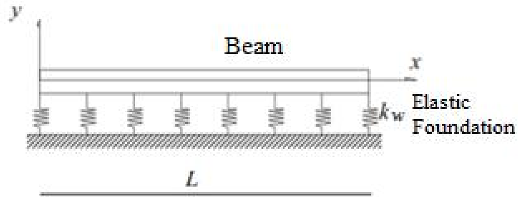

Figure 4. Beam on Elastic Foundation

Finite Element Modeling was carried out by Tsujino (1983) from the modified Hirai constant modified using the principle of beam on elastic foundation (Edward Friedman Pesudo, 2012) Program modification is in determining the wood bearing strength coefficient which is influenced by specific gravity. The different density in each layer causes a different coefficient of support in each layer. The order of the layers of wood from the outer layer will affect the strength of the joint. Changes were also made to the program termination requirements, in the Hirai program the program termination requirement is a momentary slippage that exceeds 2.5 cm, but in this program, the program termination requirement is if the bearing constant is less than the minimum bearing constant of wood, this indicates a failure in the wood. There are two assumptions that elasto-plastic bolts are flexible after the melting point, the first is that the bolts have perfect plasticity and the second is that the bolts experience constant strain hardening. In the assumption of perfect plasticity, the yield strength of the bolts does not increase until failure occurs, so the second stiffness ratio is considered zero. The assumption of constant strain hardening is a ratio of second stiffness after yield.

4. Load carrying capacity SNI 7973-2013 and Johansens's Yield Model

Provides geometric planning provisions in connection with the bolt and there are several provisions in the planning of such a connection is, terms and conditions within the terminals

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within instrument dial in a row for the category of quality solid wood with low wood namely the end distance of bolted connection 7d and the bolt spacing 4d. (SNI 7973-2013, 2013) provides planning provisions in load carrying capacity (Z) of the connection wood using connecting steel-wood-steel briefly described:

Table 1. Planning for lateral resistance (Z) of the timber bolt connection type stell-wood-stell wrote SNI 7973-2013

SNI I_m	SNI III_s
$\frac{D\,\ell_m F_e}{R_d}$	$\frac{2\,k_3 D\,\ell_s F_e}{(2+R_e R_d}$

Fig. 5 shows the possible failure modes for steel-wood-steel bolted timber joints. The failure is either characterized by reaching the embedding strength of the timber or by simultaneously reaching the bending capacity of the bolt

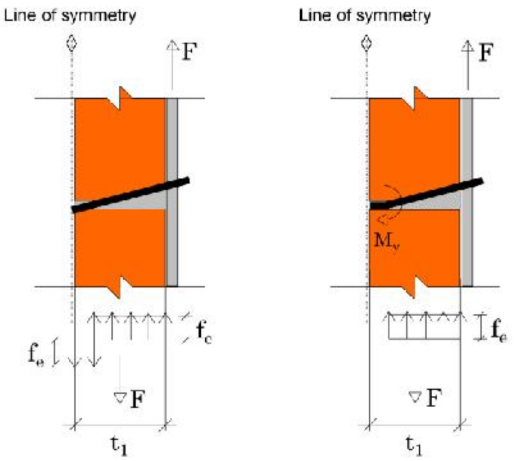

Figure 5. Failure modes for steel-wood-steel bolted timber joints (steel plate thickness < 0,5 bolt diameter)

Lateral resistance equation for timber joints for one wood shear plane with steel plates, based on the *Yield Model* theory (Johansen, 2019) described below mode yielding.

Table 2. Johansen's yield theory for steel-wood-steel bolted timber joint

EYM I_m	EYM III_s
$Z = 0.4\ F_{em} D t_m$	$Z = \sqrt{2 M_y F_e}\ D$

C. Material and Methods

Wood connection strength testing is carried out based on ASTM 5652-95 by applying compressive loads in the direction parallel with Hydraulic jack until it reaches the maximum load. The dimensions of LVL are 120 mm^2 x 80 mm^2 x 300 mm^2.

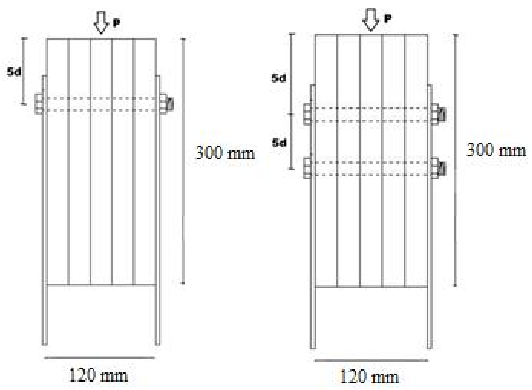

Figure 6. Sample of testing material LVL

The test specimen consists of 10 specimens, 5 specimens for one bolt and 5 specimens for multi bolts. Testing using bolt Ø 10 with ultimate stress (F_u) of 400 MPa and yield stress (F_y) of 240 MPa, to measure lateral deviations using 2 units of LVDT. The load cell used to measure the size of the force that carried out the test specimen capacity of 20 ton, a data logger is used to recorded relationship force and deviation occur. The making of LVL specimens using one bolt with an end distance of 5*d* (*d* = bolt diameter), and two bolts with a bolt spacing the connection 5*d* (Awaludin, Ali. D.N., 2017). Fig. 7 is the setting up of the LVL specimen.

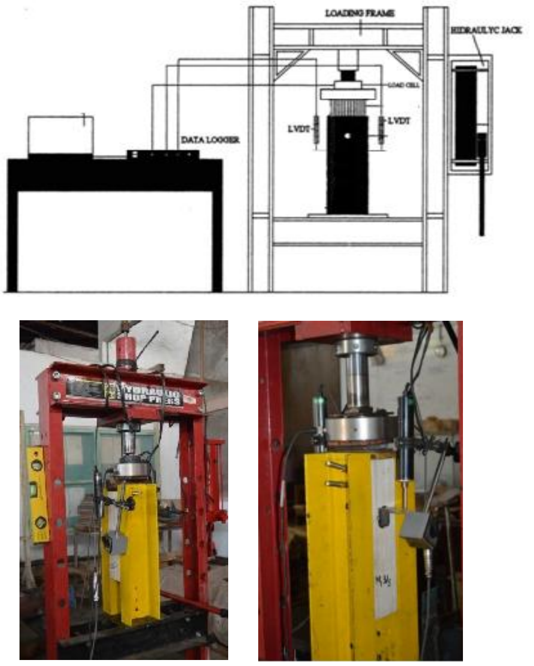

Figure 7. Setting up LVL specimen

D. Results and Discussions

The LVL test results of Sengon wood (ASTM D-4442, 2016) have a water content of 11.23 % and a density of 3 16.09 kg/m ^{3} at a standard moisture content of 15% with a specific gravity of 0,28. The results of the strong support of 10 mm parallel to grain with the (ASTM D-5764-97a, 2002) obtained an average of 20.07 MPa. The results of the 2005 NDS bolt flexural strength test obtained the value of the melt load (Py) and the maximum load (P_{max}) by the 5% *offset* diameter method, which is equal to the value of the melt load (P_y) 2390 N. The value of the bending moment (M_{yb}) 65725 Nmm. Experiment results are displayed fig.8 between the load and slip single bolt.

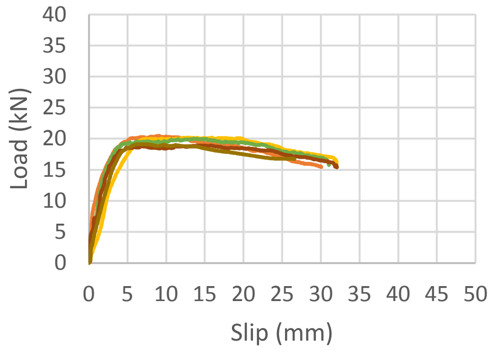

Figure 8. Load and slip single bolt connection

The connection experiment results are displayed Fig. 9 between the load and

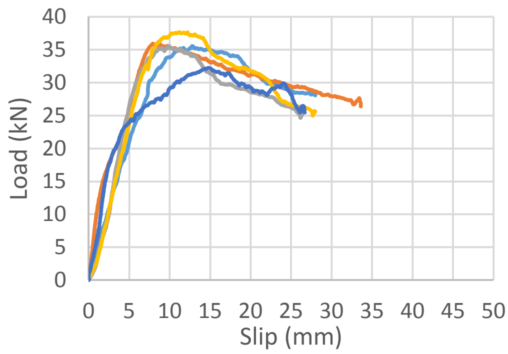

Figure 9. Load and slip multi bolt connection

From the above Fig 8 and Fig 9 then analyzed to find the value of lateral resistance. lateral resistance values connection with the method of 5% offset diameter Table 3:

Table 3. Lateral resistance values single bolt connection

Object	Single-bolt connection	
	Pmaks (kN)	Py (kN)
1	20.46	18.99
2	20.17	18.23
3	19.98	18.74
4	18.93	18.54
5	19.12	18.31
Average	19.73	18.56

The result of a single bolt connection experiment shows the value of lateral resistance (Py) of the

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connection is 90% of the Pmax value, with a range of minimum values up to a maximum of 67% - 97%.

Table 4. Lateral resistance values multi bolt connection

Object	Multi bolt connection	
	Pmaks (kN)	Py (kN)
1	33.26	30.64
2	35.92	34.89
3	35.57	31.67
4	37.67	32.35
5	32.24	24.36
Average	34.93	30.78

The results of the multi bolt connection experiment show a lateral resistivity (Py) value of 78% of the Pmax value, with a range of minimum values up to a maximum of 67% - 97%.

Calculation of reference lateral resistance (Z) based on **analysis of SNI 7973-2013**

SNI I_m

$$Z = \frac{D\ell_m F_e}{R_d} \qquad = 4.0 \text{ kN}$$

SNI III_s

$$Z = \frac{2k_3 D\ell_s F_e}{(2 + R_e)R_d} = 3{,}65\ k$$

Based on SNI calculations, the lateral resistance of the connection is 3.65 kN (minimum value of the two failure modes, III_s), then the lateral resistance of the connection is 2 x 3.75 = 7.3 kN.

Analysis of EYM :

EYM I_m

$$Z = 0.4\ F_{em} D t_m = 6{,}42 \text{ kN}$$

EYM III_s

$$Z = \sqrt{2M_y F_e \quad D} = 5{,}14 \text{ kN}$$

From the EYM calculation, the lateral resistance is 5.14 (the minimum value of the two failure modes, III_s), then the lateral resistance according to the EYM calculation is 5.14 x 2 = 10.28 kN.

Analysis of FEM :

Data analysis on the Matlab program that has been sent by (Edward Friedman Pesudo, 2012), 8 cm thick wood, 1 layer of wood, sengon wood with a specific gravity of 0.34 (light wood with a specific gravity of 0.24 ~ 0.49), The number of review elements is 10 elements, the diameter of the bolts used is 1.0 cm, and the results show elastoplastic bolts (perfect plastic bolts), while the load and displacement outputs are shown in Fig. 10

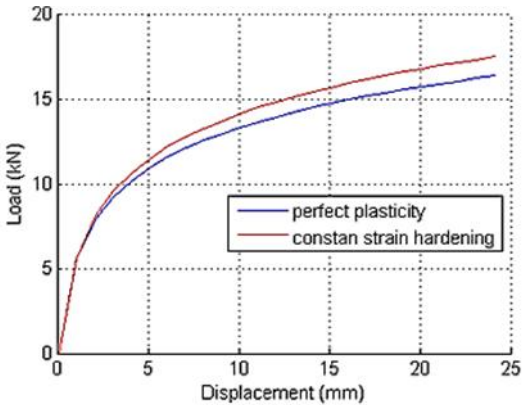

Figure 10. Load-Slip curves with the displacement of steel-wood-steel joints with the assumption of elastoplastic bolts.

Fig. 10 shows the curve between the two assumptions of elasto-plastic, using an 8 cm thickness of LVL wood and a 10 mm diameter of bolts, and a wood density of 0.34. It can be seen that the assumption of constant strain hardening bolts has greater joint strength, this is due to an increase in the yield strength of the bolt after yield. Determination of the value of lateral resistance in FEM uses the 5% offset method, which is a method for determining the yield load of joints based on ASTM D5652.

Comparison of strength Experimental, SNI 7973-2013, EYM, and FEM

Fig. 11 shows that based on SNI analysis of ± 42.63%, EYM analysis of the lateral joint resistance value of ± 59.11%, and numerical analysis of FEM obtained ± 51.50% of the experimental lateral resistance value

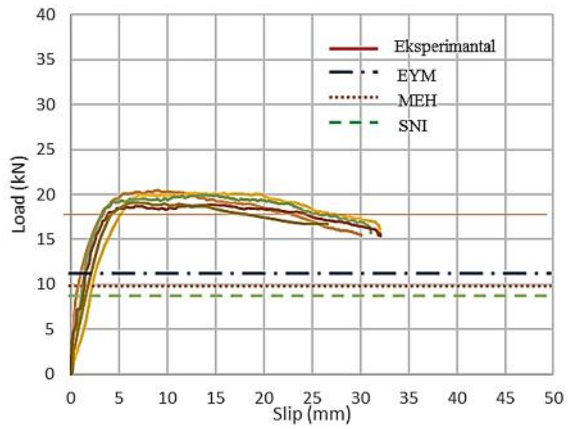

Figure 11. Comparison of the Load Carying Capacity Eksperimental, SNI, EYM and FEM

Stiffness and Ductility

Ductility value obtained from the comparison value δ $0,8P_{maks}$ with δ_y using 5% offset diameter of the obtained melting point of strength or load carrying capacity, from the melting point of the straight line drawn lengthwise so that would be obtained melt deflection (δ_y). a value of $0.8P_{max,}$ a straight line is drawn to cut the load reduction curve, at the intersection the line is drawn downward to obtain 0.8 Pmax. According to (Kiwelu et al., 2014) that the value of the ductility ratio D_i of wooden structures is divided into four classifications, brittle $D_i \leq 2$, Low-ductility $2 < D_i \leq 4$, Moderate ductility $4 < D_i \leq 6$, and High ductility $D_i > 6$. Initial Stiffness was obtained from the slope of the graph between $0,1P_{max}$ with $0,4P_{max}$ as follows Fig. 12

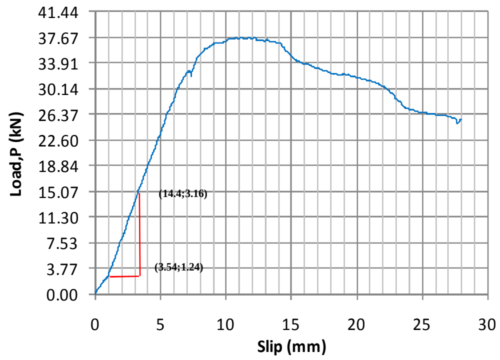

Figure 12. Determination of connection thickness

The results of the calculation of the stiffness and ductility of the single bolt and multi bolt connection can be seen in the following Table 5.

Table 5. Stiffness (S) and ductility (D) index

Object	Connection			
	Single bolt		Multi bolt	
	(S)	(D)	(S)	(D)
1	7.93	6.53	9.00	3.46
2	3.89	7.63	8.79	3.84
3	7.89	10.19	9.67	3.18
4	7.78	6.44	8.35	3.27
5	7.21	7.11	9.12	4.61
Average	**6.94**	**7.58**	**8.99**	**3.68**

The joint stiffness is affected by the bolt joint fastening system and will increase the slip resistance, but will reduce the bending angle of the bolt. Decreasing the bending angle of the bolt results in low stiffness, which is caused by the axial force of the bolt associated with the bolt embedment against the LVL Sengon. In a single bolt connection, the stiffness of the joint is lower than that of the multi bolts, this is due to an increase in the carrying capacity of the connection by increasing the number of bolts. The theoretical value of joint ductility as the number of bolts increases, the strength of the joint will increase twice, however, this does not apply to joints with two or more bolts. In NDS 2005 and SNI 7973-2013 it has been explained that the effect of group action factors. the group action

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factor of the connection is caused by the embedment of the outer bolt pressing on the wood, so that it will affect the value of the joint slip.

E. Conclusions

The joint stiffness is affected by the bolt joint fastener force system which will increase the slip resistance but will reduce the bending angle of the bolt. In a single bolt connection obtained by 6.94, in the multi bolt connection stiffnes is a 8.99, decreasing bolt bending angle results in low stiffness but high ductility value. The stiffness value of the joint increases with the increasing number of bolts, this is due to an increase in the carrying capacity of the LVL Sengon wood due to the axial force of the bolt. The average value of the ductility of the connection of one bolt was 7.58 and for the connection of multi bolts an average of 3.68 was obtained. The increasing the number of bolts, the lower the ductility value of the joint. The ductility value of the joint decreases due to the increase in the number of bolts. This is due to the group action factor of the joint, the connection of the outer bolt will compress the wood which will affect the value of the joint slip and reduce the bending angle of the bolt.

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