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Behavior of Laminated-Timber Slab Using Mechanical Connector

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Abstract. The behavior of the floor slab supports the function of the slab. In high-rise residential buildings, the behavior that needs to be known is due to the presence of static load and vibration load. Behavior due to static load is the flexural behavior of the floor slab due to the loads that work on it is the gravitational load. This study discussed the bending behavior of laminated timber floor slab due to static load. The scope of the research is the wood used is Mersawa wood (*Anisoptera* spp.), The test used three point loading test in accordance with ASTM D143, the behavior discussed is flexural strength, the laminate floor slab is arranged horizontally with the mechanical connector that is bolt with 10 mm diameter. The test shows that the average bending capacity (proportional limit load) is 25.65 kN. The failure mode occur is simple tension. The result of the test indicated that, in general the proportional limit load is higher than service load, so the floor slab can be used for residential building, such as multistory buildings. The deflection of wooden floor slabs due to static and vibration loads is smaller than the permit deflection limit. These results indicate that the slab has sufficient stiffness and has adequate comfort to the vibration.

Keywords: Slab · Timber · Laminated · Bolt · Flexural

1 Introduction

Indonesia is a tropical country which is rich in natural resources, such as timber. Timber is one of the building materials that are widely used as supporting the structure of the building. In Indonesia timber as a construction material is still widely used, among others, used for midrise buildings, houses, bridges, train bearings, and others. Especially in building buildings, timber construction is widely used to make trusses, beams, columns, and slabs. In Indonesia, traditional wooden houses such as stage houses mostly use wooden construction [8]. Along with the development of time, timber construction is still widely used in modern buildings both regular houses and multi-story buildings. One of the many wooden structure components is the floor slab. The floor slab is the structure that first receives the load, both dead and live loads which then channel to another frame structure system (Fig. 1).

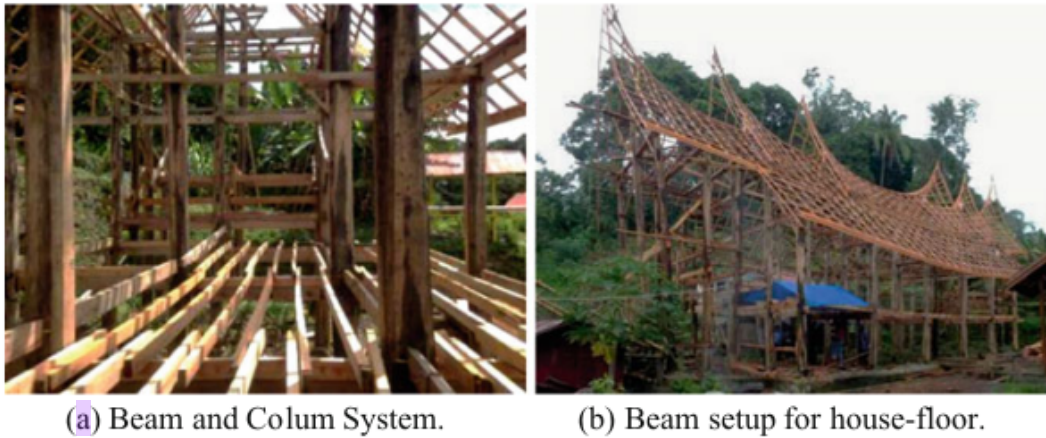(a) Beam and Colum System.   (b) Beam setup for house-floor.

Fig. 1. Minangkabau traditional wooden house [8]

Timber is increasingly difficult to find especially solid wood with large dimensions and long spans due to illegal logging that occurs more and more, especially in Indonesia. The average available timber has a small diameter and short span whereas in the construction of buildings used timber that has a large diameter and long span. This scarcity of solid timber has resulted in consultants seeking solutions to this problem. One solution is the method of timber engineering. One example of the method of timber engineering is laminated timber. Laminated timber is processed wood consisting of several layers of wood arranged in such a way as to form a unity of lamina. The use of laminated timber is more advantageous from several sides. The advantages include: stronger power three times or equivalent solid sawn timber, expanding very small wood shrinkage, and varying wood dimensions. The use of laminated timber is highly recommended for earthquake prone buildings. So laminated timber is preferred by consumers.

In addition, another problem faced is the application of laminated timber to the structural system in an innovative and easy to implement in the field. Laminated timber with a mechanical system (bolts) can be a solution to the problem. One example of applying laminated timber to the structural system is the floor slab. Material selection for floor slabs is an important thing to consider considering the floor slab is the structure that first receives the load which then channeled to another truss system. The aim of this research is to study behavior of the bending behavior of laminated timber floor slab due to static load, which are strength both at proportional load and ultimate limit load, stiffness or ductility of floor slab. The scope of the research is the wood used, which is Mersawa wood (*Anisoptera* spp.), The test used is three point loading test in accordance with ASTM D143 [2], the behavior discussed is flexural strength, the laminate floor slab is arranged horizontally with the mechanical connector that is bolt with 10 mm diameter and 200 mm spaces between bolts. Specimens used for the study amounted to 3 (three) specimens.

2 Basic Theory

2.1 Bending Strength, Shear Strength, and Deformation

Basic theory used for design are bending strength, shear strength, and deformation in accordance with SNI 7973:2013 [3]. The normal stress analysis of bending section beams due to bending is used to calculate the flexural stress distribution at the cross section in the middle of the span. From the calculation result that is the bending stress on the tensile part, it can be known the magnitude of tensile force [5]. Flexural nominal strength (for beam with rectangular cross section) in accordance with SNI 7973:2013 [3] which is the design method of LRFD (Load Resistance Factor Design),

$$f_b \leq F_b' \tag{1}$$

where f_b and F_b' are,

$$f_b = \frac{M.y}{I_x} \tag{2}$$

$$F_b' = F_b.C_M.C_t.C_L.C_F.C_{fu}.C_r.C_i.K_F.\phi_b.\lambda \tag{3}$$

where f_b is normal stress due to flexural, M is flexural moment, y is distance from centroid axis to edge of beam, F_b' is adjusted bending design, F_b is reference bending design (flexural strength parallel to the grain), C_M is wet service factor, C_t is temperature factor, C_L is stability correction factor, C_F is size factor for sawn lumber, C_{fu} is flat use factor, C_r is repetitive member factor for dimension lumber, C_i is incising factor for dimension lumber, K_F is format conversion factor, ϕ_b is resistance factor for bending, λ is time effect factor.

The design rules of shear strength used by the design method of LRFD (Load Resistance Factor Design) are reviewed from SNI 7973: 2013 [3]. The following equations of parallel shear strength requirements of parallel fiber on solid wood are,

$$f_v \leq F_v' \tag{4}$$

where f_v and F_v' are,

$$f_v = \frac{V.Q}{(I_x.b)} \tag{5}$$

$$F_v' = F_v.C_M.C_t.C_i.K_F.\phi_v.\lambda \tag{6}$$

where f_v is actual shear stress parallel to the grain, F_v' is adjusted shear stress parallel to the grain, V is shear force, F_v is reference shear stress parallel to the grain, Q is static moment of cross section, I_x is inertia moment of cross section, b and d are width and height of beam, and ϕ_v is resistance factor for shear.

The design of the bending moment force used in the LRFD design method is reviewed from SNI 7973: 2013. In addition, there are several provisions concerning the

beam stability factor. The slenderness ratio (R_B) for the bending structure component, shall meet the requirements,

$$R_B = \left(\frac{l_e . d}{b^2}\right)^{0.5} \leq 50 \tag{7}$$

where l_e is effective length of beam and l_u is actual length of beam. To review the requirements analysis of structural deflection requirements,

$$\Delta' \leq \Delta_{allowed} \tag{8}$$

where Δ' is deflection of beam due to loads.

2.2   Methods for Determine Proportional and Ultimate Loads

Knowledge of the method of determining the proportional point and the ultimate limit loads is very important. There are several methods that can be used to determine this point, especially for wood materials [6] i.e. EEEP and Yasumura and Kawai methods.

The EEEP (Equivalent Energy Elastic-Plastic Curve) method is a commonly used method of steel material and often wood material, i.e. curve modeling into a perfect elastic-plastic behavior model (Fig. 2a). The extent of the empirical test result curve is assumed to be equal to the area of the bilinier curve. In the Yasumura and Kawai methods, initial rigidity (straight line) is calculated between the range of 10–40% of the maximum load. Next is defined a straight line between two points where the value of 40 and 90% of the maximum load. The melting point is determined from the meeting of the two lines (Fig. 2b). Figure 3 shows an example of load determination under proportional load (P_y) load conditions and loads on ultimate boundary conditions (P_u). Thus it can also be determined by the deformation in term of proportional (d_y) and ultimate (d_u) limits.

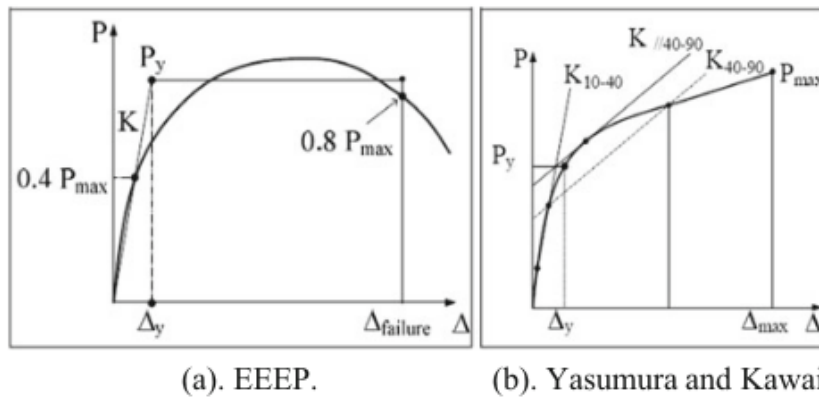(a). EEEP.   (b). Yasumura and Kawai.

Fig. 2. EEEP and Yasumura and Kawai methods for determining the proportional [6]
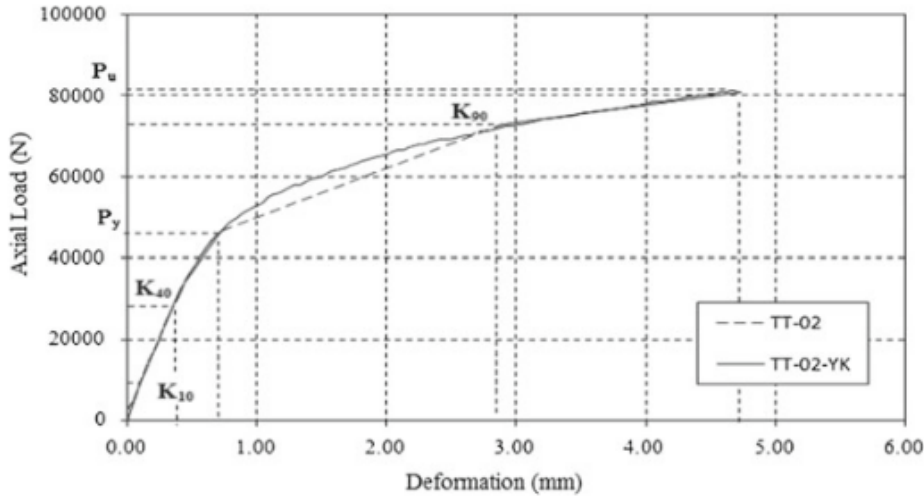
Fig. 3. Example determines the proportional and ultimate limit loads using Yasumura and Kawai method [7]

2.3 Effect of Vibration

Floor structure planning can not be separated from the influence of the vibration, both temporary with short duration and long duration. The vibration serviceability condition of the wood floor slab structure is related to the size of the floor span, the longer the span the impact of the vibration will be greater. Some wood regulations govern the requirements regarding the conditions of comfort limits to vibrations. In Indonesian SNI wood regulations SNI 7973: 2013 [3], specifically has not regulated this matter. From the literary sources of Weckendorf et al. [9], it can be learned that attenuation is an important characteristic of the vibration response of the structural system. Damping can convert kinetic energy into heat, reducing the amplitude of the force or free dynamic movement. In the timber regulation of Eurocode 5 [4] there are design criteria related to vibration in the wood floor slab structure system. Criteria designs include vibrations generated by mechanical or electronic machines placed on floor systems, permissible serviceability requirements, and damping ratio estimation calculations. The Eurocode 5 regulation recommends a 1% damping ratio. This regulation recommends for one segment system structure, the fundamental capital frequency is 11.5 Hz. The existence of vibration frequency resulted in the existence of mass capital, according to the rules of Design Guide for Floor Vibrations [1] then calculation of mass capital can be calculated by equation as follows,

$$f_1 = \frac{18}{\delta} \tag{9}$$

$$M_{mod} = M . \left[\frac{\delta_x^2 + \delta_y^2}{2.\delta^2} + \frac{8}{\pi^2} \frac{\delta_x + \delta_y}{\delta^2} \right] \tag{10}$$

with f_1 being the first eigen frequency and δ is the deflection due to the gravitational load and M_{mod} is the mass capital. M_{mod} is further used as an additional mass due to vibration. In this proposal, the deflection discussed is a deflection in the direction of gravity (y-axis).

3 Case Study and Discussion

In this research, the specimens that were used (see Fig. 4), previously had preliminary analysis, and from the results of the analysis that has been done, it can be concluded that the mechanical laminate flooring slabs resulting from this research are mechanized laminated timber flooring slabs (*b*) 450 mm $\times$ (*d*) 60 mm, 5 lamina, 90 mm thick laminate, vertical laminate system. The length of each beam is 1050 mm. Total length of beam span with connection 1200 mm. Mechanical lamination tool is a 10 mm bolt diameter, and space distance per 20 cm. Specification of wood material and connection material used in this research are Mersawa wooden rod (*Anisoptera* spp.) with cross-sectional size (after 4 shades) 90 mm $\times$ 60 mm, used to make wooden floor slabs. The length of the rod is 1200 mm. The number of logs required to make the specimen is 5 (five) laminae. Steel bolt with 10 mm diameter with flexural yield strength Fyb equal to 310 MPa (As per guidance of SNI 7973: 2013). Steel ring with an outer diameter of 26, 13 mm inner diameter, and 0.95 mm ring thickness. Figure 4 show the setup of the specimens on Universal Testing Machine.
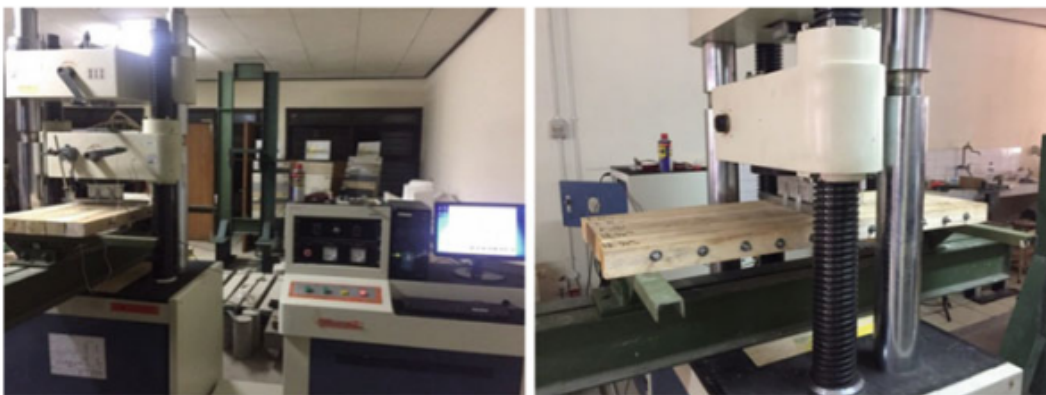
(a). Universal Testing Machine (UTM).   (b). Specimen placed at UTM.

Fig. 4. Setup of the specimens on universal testing machine

Figure 5 shows the results obtained from tests. Failure of the specimens after reach the ultimate loads. The failure mode occur is simple tension. Table 1 show the results of Proportional and Ultimate Limit, both for Loads and Displacements that obtained from tests for all 3 (three) specimens. Methods used are Yasumura and Kawai Methods [6].

(a) Simple tension failure of S20-B01.   (b) Simple tension failure of S20-B02.

Fig. 5. Failure of the specimens after reach the ultimate loads

Table 1. Proportional and ultimate limit load and displacement obtained from tests

Specimen	P_y (N)	D_y (mm)	P_u (N)	D_u (mm)	μ
S20-B01	31.21	6.78	41.11	12.54	1.85
S20-B02	21.34	8.23	26.05	12.40	1.51
S20-B03	24.39	10.73	29.18	23.69	2.21
Average	25.65	8.58	32.11	16.21	1.85

Figure 6 show the results obtained from tests which are load-displacement curves of bending tests. The laminated wood floor slab is designed to withstand maximum load (P) of 31.51 kN. This load is the maximum load limit based on the reference strength of sawn timber E18 according to the reference of SNI 7973: 2013. These results indicate that the beam has sufficient strength according to SNI regulations. The deflection of the wooden floor slab (Δ) is smaller than the permit deflection limit (allowed). These results indicate that the beams have sufficient stiffness according to SNI regulations. Additional mass calculations due to the effect of vibration using Eqs. 9 and 10,

$$f_1 = \frac{18}{0.35} = 51.43 \, \text{Hz}$$

$$M_{mod} = 293.46 \left[\frac{0^2 + 0.35^2}{2 \times 0.35^2} + 0 \right] = 146.73 \, \text{kg}$$

Therefore, due to the additional mass due to vibration, the effect on the amount of deflection. From the analysis of the structure of the floor slab to the effect of gravity and vibration loads. From result of modeling SAP2000, get deflection result of floor slab equal to 0.316 mm while the limit is 3.5 mm, so the deflection of the floor slab $\Delta < \Delta_{allowed}$ then the slab meets the comfort requirements of the vibration due to the load.
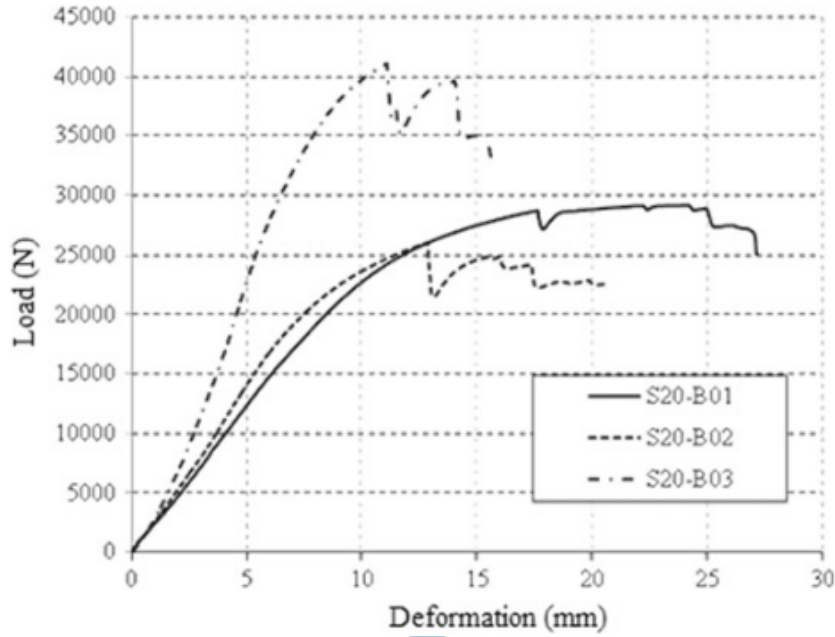
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Fig. 6. Results obtained from tests

4   Conclusion

The test shows that the average bending capacity (proportional limit load) is 25.65 kN. The failure mode occur is simple tension. The result of the test indicated that, in general the proportional limit load is higher than service load, so the floor slab can be used for residential building, such as multi-story building. The deflection of wooden floor slabs (Δ) is smaller than the permit deflection limit and indicate that the slab has sufficient stiffness according to SNI regulations. Deflection due to vibration of wooden floor slabs (Δ) is smaller than the permit deflection limit and indicate that the slab has adequate comfort to the vibration of the load.

References

1. Arcelor Mittal.: Design Guide for Floor Vibrations, Arcelor Mittal Europe—Long products Sections and Merchant Bars. Arcelor Mittal (1996)
2. American Standard Testing and Material.: ASTM D143, American Standard Testing and Material (2008)
3. Badan Standarisasi Nasional.: Spesifikasi Desain Untuk Konstruksi Kayu (SNI 7973:2013). BSN, Jakarta (2013). (in Indonesian)
4. CEN.: Comite′ Europe′en de Normalisation (CEN) Eurocode 5-design of timber structures, part 1–1: general—common rules and rules for buildings. EN 1995-1-1:2004 (E), English version. British Standards Institution, London, UK (2004)
5. Gere, J.: Mechanics of Materials. Brooks/Cole (2009)
6. Munoz, W., Mohammad, M., Salenikovich, A., Quenneville, P.: Determination of yield point and ductility of timber assemblies. In: Search for a Harmonized Approach. Engineered Wood Products Association (2010)

7. Pranata, Y.A., Suryoatmono, B: Kekuatan Tekan Sejajar Serat dan Tegak Lurus Serat Kayu Ulin (Eusideroxylon Zwageri), Civil Eng. J. Bandung Inst. Technol. Indonesia. **21**(1) (2014, April). (in Indonesian)
8. Pranata, Y.A., Tobing, H.L.: Non-destructive testing to obtain the dynamic elastic modulus of the existing Minangkabau wooden house. In: International Conference on Technology, Innovation, Society (ICTIS) 2016, ISBN 978-602-70570-4-3, ITP Press (2016)
9. Weckendorf, J., Toratti, T., Smith, I., Tannert, T.: Vibration serviceability performance of timber floors. Euro. J. Wood Prod. **74**(3), 353–367 (2016)

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