| No | Tanggal | Keterangan |
|---|---|---|
| 1 | 9 Februari 2018 | Penulis korespondensi mengirimkan **naskah publikasi** ke organizing committee via e-mail. |
| 2 | 22 Februari 2018 | Penulis korespondensi menanyakan proses registrasi online. |
| | | Organizing Committee memberikan informasi prosedur registrasi online. |
| 3 | 26 Februari 2018 | Organizing Committee menerima naskah publikasi via sistem online. |
| 4 | 4 Maret 2018 | Organizing Committee memberikan informasi naskah diterima di sistem dan penulis diminta melanjutkan proses registrasi. |
| 5 | 7 Maret 2018 | Penulis pengirimkan dokumen kelengkapan registrasi. |
| | | Organizing Committee memberikan informasi proses regitrasi sudah lengkap dan memberikan informasi bahwa naskah dinyatakan **Accepted** untuk dipresentasikan. |
| 6 | 12 Maret 2018 | Organizing Committee memberikan informasi mengenai Conference Program. |
| 7 | 10 Oktober 2018 | Naskah **terbit** pada prosiding terindeks SCOPUS. |

**yosafat ap** <yosafat.ap@gmail.com> Fri, Feb 9, 2018, 12:03 PM
to Roi, Jean, Sarah, razka, Core

Dear Prof. Dr. A. Senthilkumar
Dear Organizing Commitee of ICACE 2018

Attached is fullpaper, according to my previous email, about the request for submit fullpaper that has passed the deadline. I have also done registration and submit fullpaper via online through the website http://mysubmissions.online/icace-2018/.

Thank you very much Prof., I hope my paper can be accepted to be presented at ICACE 2018, March 8-9.

Regards,

Dr. Yosafat Aji Pranata
Assistant Professor
Department of Civil Engineering, Universitas Kristen Maranatha
Indonesia

...

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ICACE_2018_YAPe...

## about register on http://www.ic-ace.org/

**yosafat ap** <yosafat.ap@gmail.com> Feb 22, 2018, 11:52 AM
to info

Dear Organizing Commitee of 2nd International Conference on Architecture and Civil Engineering (http://www.ic-ace.org).

My name Yosafat Aji Pranata, i want to register for Conference, but have something problem, which is i cannot register via online.

Can i register my papers manually via email ?

Thank you in advance.

Regards.

Yosafat Aji Pranata
Assistant Professor
Department of Civil Engineering, Universitas Kristen Maranatha
Bandung, Indonesia

**info@ic-ace.org**
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Feb 22, 2018, 6:09 PM

Dear Yosafat,

Thank you for your email.

Indeed, all registration online is due to generate an automatic ID. We suggest you to submit your paper online and reply your paper to this email. Please follow the easy steps below:

1- Register to our website through http://ic-ace.org/user/register
2- Activate your account by click on a link forwarded to your email.
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Looking forward t seeing you at ICACE 2018.

Best Regards,
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# Paper Submission Form

**ICACE 2018** <info@ic-ace.org>
to me, icace.org

Mon, Feb 26, 2018, 5:23 PM

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| Paper Title: | **Behavior of Laminated-Timber Slab Using Mechanical Connector** |
|---|---|

**View Paper**

Thanks a lot. | Thank you for your mail. | Noted with thanks.

**Core Conferences** <coreconferencesmail@gmail.com>
to me, Roi, Jean, Sarah, razka

Sun, Mar 4, 2018, 12:12 PM

Hi,

The paper is accepted, but we haven't received the registration. Can you let me when you have done the registration?

...

Yes, I will. | Will do. | I haven't received it yet.

Reply | Reply all | Forward

## Paper Submission Form

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Wed, Mar 7, 2018, 8:56 AM

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| Paper Title: | **Behavior of Laminated-Timber Slab Using Mechanical Connector** |
|---|---|

**View Paper**

## Notification of Acceptance - 189857

**submission@ic-ace.org**
to me, yosafat.ap

Wed, Mar 7, 2018, 3:58 PM

Dear Dr. Yosafat Aji Pranata,

The review process of the International Conference on Architecture and Civil Engineering (ICACE 2018) has been completed. Based on the recommendations by Technical Committee, we are pleased to inform you that your paper has been accepted for publication and oral presentation. The notification of acceptance and the review form is attached herewith. Your paper has been assigned with an ID of 189857. Please refer to this ID whenever you communicate with our office in the future.

In order to register the conference and have your paper included in the publication successfully, you shall finish following three (3) steps.

1. Download and complete the registration form. ( http://ic-ace.org/registration)
2. Complete the payment of registration fee. (The detailed information can be found in the Registration form)
3. Upload your registration form, proof of payment, and scanned of student identification (if any) via http://ic-ace.org/registration-form
.

If you have any problem in preparing the documents, please feel free to contact us via info@ic-ace.org

we are looking forward to meeting you in Penang, Malaysia.

Best Regards,
Organizing Committee
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**yosafat ap** <yosafat.ap@gmail.com>
to submission, Yosafat

Mon, Mar 12, 2018, 11:45 AM

Dear Organizing Commitee of IC-ACE 2018

Thank you for the Notification of Acceptance of my paper (ID 189857). Currenty i still on process for completing the Registration Form and Bank Transfer (Author, International).

Can i get list of event program Sir/Madam ? I need the information about event program, for planning about my hotel and flight schedule.

Thank you.

Regards,

Dr. Yosafat Aji Pranata.

•••

**submission@ic-ace.org**
to me

Mon, Mar 12, 2018, 3:33 PM

Dear Dr Yosafat Aji Pranata,

Thank you for your email.

We will email schedule of the ICACE 2018 to all registered participants
10 days before the event. For your information 9th May at 4pm to 6pm we
have the registration that is not compulsory. The opening ceremony,
presentations and closing ceremony will be on 10th May from 8am to 7pm.

Please do not hesitate to contact us if you need more information.

Looking forward to seeing you in ICACE 2018.

Best Regards,
Organizing Committee of ICACE 2018
[www.ic-ace.org](http://www.ic-ace.org)
[info@ic-ace.org](mailto:info@ic-ace.org)

# Notification of Acceptance of the ICACE 2018

9th – 10th May 2018, Batu Ferringhi, Penang, Malaysia
www.ic-ace.org

Dear Yosafat A.P., Roi M., Jean H.S., Sarah I.Y., Chris T.L

**Paper ID:** 189857
(*) Please use this ID code for any further communication with us!

**Paper Title:** Behavior of Laminated-Timber Slab Using Mechanical Connector

Congratulations! The organizing committee is pleased to inform you that your paper has been accepted for oral presentation which will be taken place at Parkroyal Hotel, Batu Ferringhi, Penang, Malaysia on 10th May 2018. Meanwhile, your paper will be published in one of the Scopus indexed journal listed in our website.

Our ultimate goal is to bring together and create a unique opportunity for collaboration between industry and academic researchers. Therefore we believe this conference will be a platform for researchers to discuss the current problems faced by the industry.

For the latest update information of the conference, please check the conference website at **http://www.ic-ace.org** . Feel free to email us at **info@ic-ace.org** if you have any inquiries.

ICACE 2018 promises to be an exciting meeting, both scientifically and culturally, and we look forward to meeting you in Penang for truly rewarding days!

Yours sincerely,

Dr. Nordin Abd Rahman, Chairman of ICACE 2018

# Review Form

2nd International Conference on Architecture and Civil Engineering (ICACE 2018)

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**Paper ID:** 189857
**Paper Title:** Behavior of Laminated-Timber Slab Using Mechanical Connector
**Date Sent to Reviewer:** 27/02/2018

Please rate the paper according to the criteria below. Indicate your rating by placing '×'.

| Criterion | Excellent | Above average | Average | Below Average | Poor | Not Applicable |
|---|---|---|---|---|---|---|
| Conceptual foundation/ Building on relevant literature | | | × | | | |
| Development of research question/ aims & objectives | | | × | | | |
| Method (not relevant for conceptual paper) | | | × | | | |
| Quality of analysis/ Coherence of argument | | × | | | | |
| Relevance of finding for theory/ practice/ policy | | × | | | | |
| Clarity and readability | | | × | | | |
| Contribution | | | × | | | |
| English | | | × | | | |
| | Strong Accept | Accept | Marginally Accept | Reject | Strongly Reject | |
| Overall Evaluation | | × | | | | |

Comment to Author'(s):

- "Aim and scope of research" could be at the end of introduction. No need as a new section.
- Please improve quality of Figure 2.
- Reference 9 is not correct. Please follow the instruction for citing the websites.

# Behavior of Laminated-Timber Slab Using Mechanical Connector

**Yosafat A.P.[1], Roi M.[2], Jean H.S. [2], Sarah I.Y. [2], Chris T.L[2].**

[1,2] Department of Civil Engineering, Maranatha Christian University, Indonesia
[1] E-mail yosafat.ap@gmail.com, yosafat.ap@eng.maranatha.edu

**ABSTRACT**: Floor slab that made from two or more timber lamina, generally connected together with mechanical connectors (bolt or nail-laminated) or chemical such as glue (glue-laminated). 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. In 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 is 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 3 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 multistorey 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.

**Key words:** slab, timber, laminated, bolt, flexural.

## 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 mid rise 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. Along with the development of time, timber construction is still widely used in modern buildings both regular houses and multistorey 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. The selection of materials for floor slabs should be considered well, the selection of this floor slab should be sturdy, rigid, has the same height and comfortably to be grounded. And the selection of floor slabs should also be lightweight but sturdy so as to save the size of other structures such as foundation, due to its light weight.

Figure 1. Minangkabau Traditional Wooden House [8].

### Laminated Timber System

Today, 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, varying wood dimensions, hard and anti termites and fungi, and the price is cheaper. The use of laminated timber is highly recommended for earthquake prone buildings. So laminated timber is preferred by consumers.

Figure 2. Timber floor slabs [9].

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. Thus, the selection of laminated timber with a mechanical system as a structural system material is the right choice, because it is easy to apply in the field and the timber has a light weight that can save the size of other structural systems and of course has a strong and earthquake resistant strength.

Timber is chosen as a construction material because it has a light weight so that the weight of the structure itself becomes light and in the implementation of its work easier. Besides it is reviewed in terms of architecture, the timber building has a high aesthetic value and distinctive. In addition, buildings with wooden structural materials have many other advantages such as wooden structures are more secure against earthquake hazards, more resistant to pressure and flexure, and one of the structural materials that are environmentally friendly because the timber can be recycled perfectly and decomposed in nature. In its development the use of timber as a structural material can be utilized maximally and economically although other structural materials such as steel and concrete are also often used.

**Aim and Scope of Research**

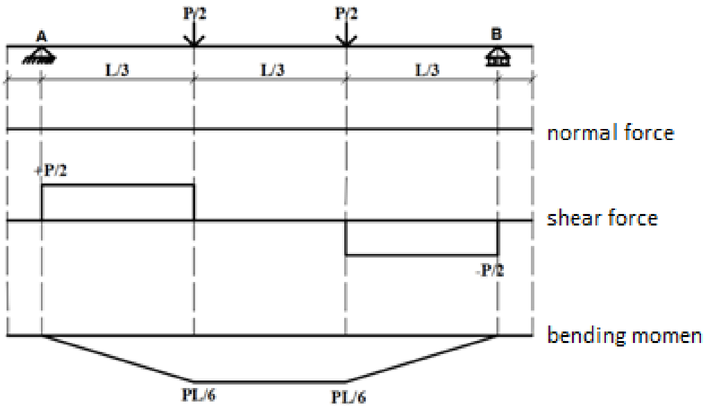
The aim of this research is to study behavior of the bending behavior of laminated timber floor slab due to static load, which are strength both at proportional load and ultimate limit load, stiffness or ductility of floor slab.

The scope of the research is the wood used 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 3 mm diameter and 20 mm spaces between bolts. Specimens used for the study amounted to 3 (three) specimens.

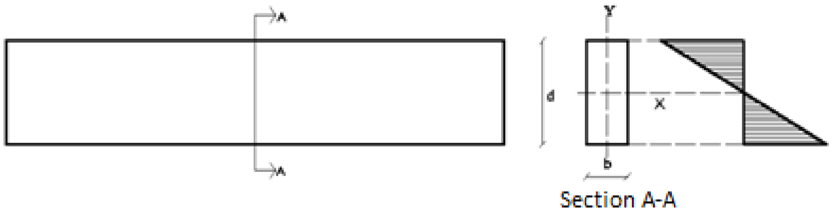
## BASIC THEORY

### 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].




(a). Normal force, Shear force, and Bending momen diagrams.




(b). Normal stress due to flexural load of beam at the mid span.
Figure 3. Bending stress due to flexural loading of beam.

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),

$$f_b \leq F_b' \quad (1.a)$$

where $f_b$ and $F_b'$ are,

$$F_b' = M \cdot y / I_x \ (1) \quad (1.b)$$

$$F_b' = F_b \cdot C_M \cdot C_t \cdot C_L \cdot C_F \cdot C_{fu} \cdot C_r \cdot C_i \cdot K_F \cdot \phi_b \cdot \lambda \quad (1.c)$$

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, $\phi_b$ is ressistance factor for bending, $\lambda$ 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,

$$f_v \leq F_v' \quad (2.a)$$

where $f_v$ and $F_v'$ are,

$$f_v = V \cdot Q / (I_x \cdot b) \quad (2.b)$$

$$F_v' = F_v \cdot C_M \cdot C_t \cdot C_i \cdot K_F \cdot \phi_v \cdot \lambda \quad (2.c)$$

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 is inertia moment of cross section, b and d are width and height of beam, and $\phi_v$ is ressistance 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 (RB) for the bending structure component, shall meet the requirements,

$$R_B = (l_e \cdot d / b^2)^{0.5} \leq 50 \quad (3)$$

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,

$$\Delta' \leq \Delta_{allowed} \quad (4)$$

where Δ' is deflection of beam due to loads.

**Methods for Determine The Proportional and Ultimate Loads**

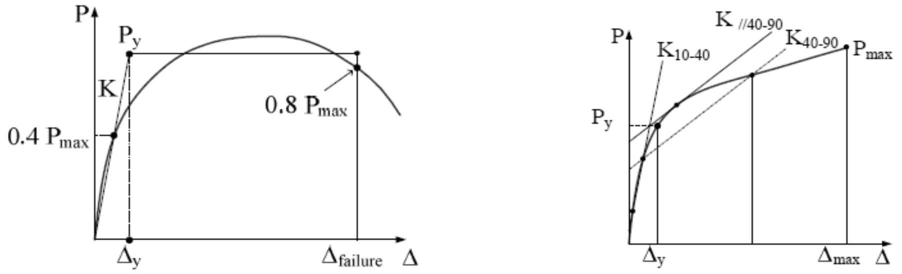
Knowledge of the method of determining the proportional point and the ultimate limit loads is very important. There are several methods that can be used to determine this point, especially for wood materials [6] ie EEEP and Yasumura and Kawai methods.

a. EEEP Method: 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 (Figure 4.a). The extent of the empirical test result curve is assumed to be equal to the area of the bilinier curve. The melting load ($P_y$) is further computed by the following equation,

$$\mathbf{P_y} = \left[\Delta_{\mathbf{failure}} - \sqrt{\Delta^2_{\mathbf{failure}} - \frac{\mathbf{2.w_{failure}}}{\mathbf{K}}}\right].\mathbf{K} \quad (5)$$

where Δfailure is deformation when collapsed and $w_{failure}$ is energy dissipation until collapse.

b. Yasumura and Kawai Methods (YK): 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 (Figure 4.b)




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

Figure 4. EEEP and Yasumura and Kawai Methods for determining the proportional [6].

Figure 5 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 the deformation under proportional limit load conditions ($d_y$) and deformation under ultimate load ($d_u$) limit conditions.

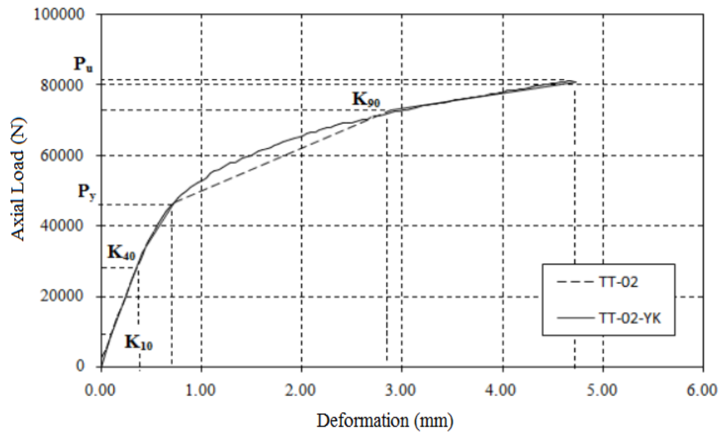



Figure 5. Example determines the proportional and ultimate limit loads using Yasumura and Kawai Method [7].

**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 not yet regulated on this matter. From the literary sources of Weckendorf et.al. [10], 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,

$$f_1 = 18/\delta \quad (6.a)$$

$$\mathbf{M_{mod}} = \mathbf{M}.\left[\frac{\delta_x^2+\delta_y^2}{2.\delta^2} + \frac{8}{\pi^2}\frac{\delta_x\,\delta_y}{\delta^2}\right] \quad (6.b)$$

with $f_1$ being the first eigen frequency and δ is the deflection due to the gravitational load and Mmod is the mass capital. Mmod 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).

**CASE STUDY AND DISCUSSION**

In this research, the specimens that used (see Figure 6), 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 x (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.

Figure 6. Specimens in this research.

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 x 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 srength $F_{yb}$ equal to 310 MPa (As per guidance of SNI 7973: 2013). Steel ring with an outer diameter of 26 mm, 13 mm inner diameter, and 0.95 mm ring thickness. Figure 7 show the setup of the specimens on Universal Testing Machine, an instrument that used for bending tests.

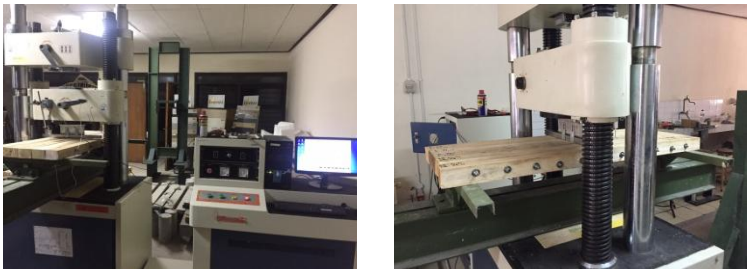


Figure 7. Setup of the specimens on Universal Testing Machine.

Figure 8. Failure of the specimens after reach the ultimate loads.

Figure 8 show 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 that used is Yasumura and Kawai Methods [6]. Figure 9 show the results obtained from tests which are load-displacement curves of bending tests.

Table 1. Proportional and Ultimate Limit Load and Displacement Obtained from Tests.

| Kode Kayu | Py (N) | Dy (mm) | Pu (N) | Du (mm) | Ductility μ |
|---|---|---|---|---|---|
| S20-B01 | 31206.66 | 6.78 | 41110.23 | 12.54 | 1.85 |
| S20-B02 | 21343.62 | 8.23 | 26052.87 | 12.40 | 1.51 |
| S20-B03 | 24386.44 | 10.73 | 29177.65 | 23.69 | 2.21 |
| Average | 25645.57 | 8.58 | 32113.58 | 16.21 | 1.85 |

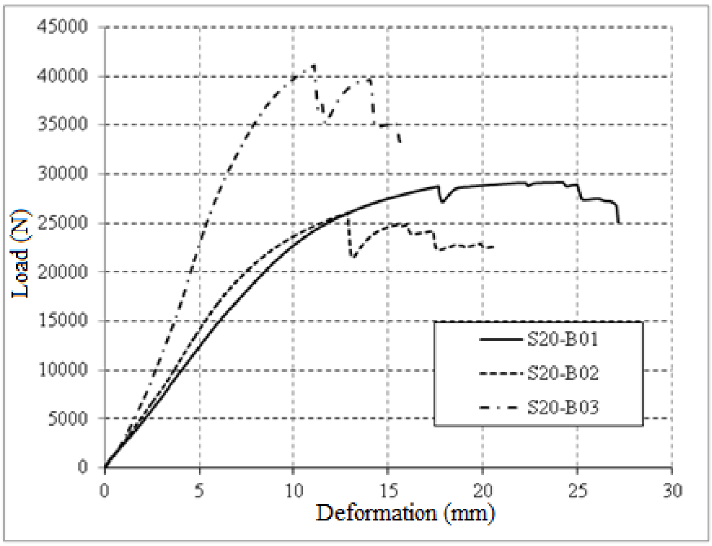



Figure 4. Results obtained from Tests.

The laminated wood floor slab is designed to withstand maximum load (P) of 31504.59 N. 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 Equation 6.a and Equation 6.b are as follows,

$f_1$ = 18/0,35 = 51.43 Hz

$$\mathbf{M_{mod}} = \mathbf{M}.\left[\frac{\delta_x^2+\delta_y^2}{2.\delta^2} + \frac{8}{\pi^2}\frac{\delta_x\ \delta_y}{\delta^2}\right] = \mathbf{293.46}.\left[\frac{0+0.35^2}{2.0.35^2} + \mathbf{0}\right] = \ =146.73 \text{ kg}$$

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, got deflection result of floor slab equal to 0,316 mm. Then,

$$\Delta = 0.316 \text{ mm} \quad < \quad \Delta_{allowed} = L / 300 = 3.5 \text{ mm}$$

deflection of the floor slab $\Delta < \Delta_{allowed}$ then the slab meets the comfort requirements of the vibration due to the load.

## CONCLUSION

The test shows that the average bending capacity (proportional limit load) is 25645.57 N. 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 multistorey 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.

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Lecture Notes in Civil Engineering

Mokhtar Awang
Mohamed Hasnain Isa *Editors*

# The Advances in Civil Engineering Materials

## Selected Papers of the ICACE 2018 held in Batu Ferringhi, Penang Malaysia on 9th–10th May 2018

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# Lecture Notes in Civil Engineering

Volume 19

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Editors

# The Advances in Civil Engineering Materials

## Selected Papers of the ICACE 2018 held in Batu Ferringhi, Penang Malaysia on 9th–10th May 2018

Springer

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ISSN 2366-2557 ISSN 2366-2565 (electronic)
Lecture Notes in Civil Engineering
ISBN 978-981-13-2510-6 ISBN 978-981-13-2511-3 (eBook)
https://doi.org/10.1007/978-981-13-2511-3

Library of Congress Control Number: 2018954020



This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

# Contents

# 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).


M. Awang and M. H. Isa (eds.), *The Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 19, https://doi.org/10.1007/978-981-13-2511-3_6

(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, $\phi_b$ is resistance factor for bending, $\lambda$ 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 $\phi_v$ 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,

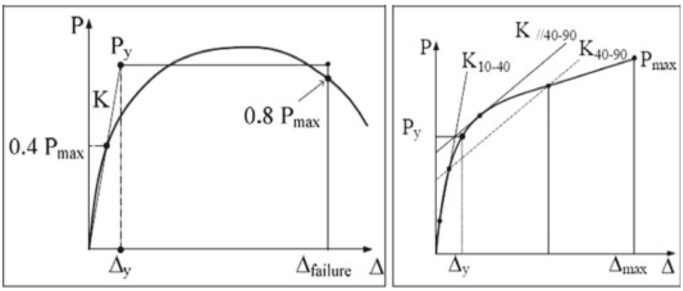
$$\Delta' \leq \Delta_{allowed} \tag{8}$$

where $\Delta'$ 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]

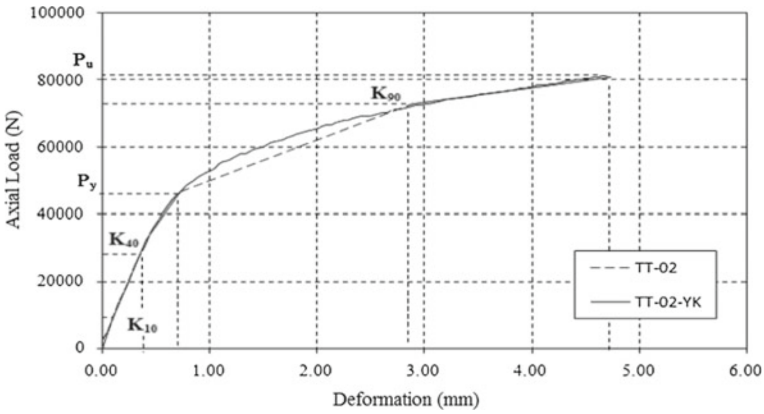



**Fig. 3.** Example determines the proportional and ultimate limit loads using Yasumura and Kawai method [7]

## 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,

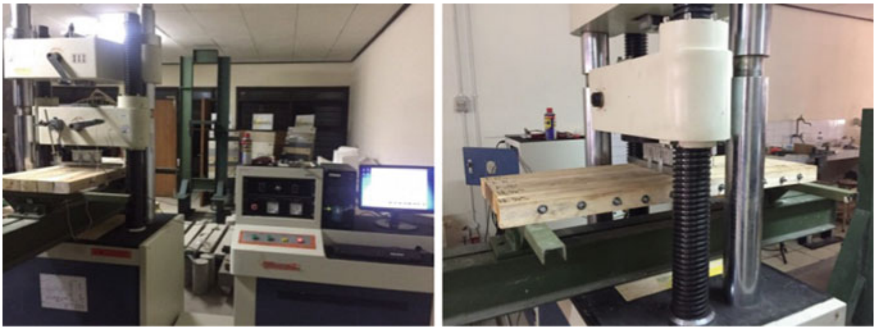
$$f_1 = \frac{18}{\delta} \tag{9}$$

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

with $f_1$ being the first eigen frequency and $\delta$ 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 × (*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 × 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 ($\Delta$) 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, got 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.

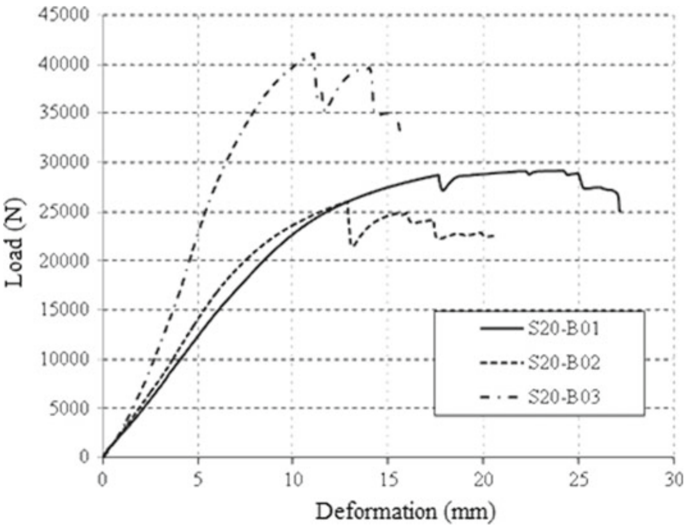



**Fig. 6.** Results obtained from tests

## 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 ($\Delta$) 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 ($\Delta$) is smaller than the permit deflection limit and indicate that the slab has adequate comfort to the vibration of the load.

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