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Eric Strauss *Editor*

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Preface

The 2024 8th International Conference on Civil Engineering (ICOCE 2024) was successfully and physically held in Singapore during March 22–24, 2024. This event has provided a unique opportunity for international scholars, researchers and practitioners working in a wide variety of scientific areas with a common interest in civil engineering to interact and share knowledge.

This year, there were more than 40 participants in total. They were from China, Singapore, USA, Philippines, India, Thailand, Kuwait, UK, Japan, Korea, Indonesia, etc. The conference has included discussions on topics such as wastewater treatment and water quality analysis, renewable energy and electric motor technology, infrastructure engineering and hydraulic engineering, properties of building materials and structures, environmental pollution control and resource management, seismic response of engineering structures and construction management, building materials, building environment, and construction management, engineering vibration and mechanical properties of building structures. In addition, two excellent keynote speeches were delivered by Prof. Joseph Kim from California State University Long Beach, USA, and Assoc. Prof. Ong Ghim Ping Raymond from the National University of Singapore, Singapore. After that, Assoc. Prof. Kwun Nam Hui from University of Macau, China, Assoc. Prof. Chian Siau Chen, Darren from the National University of Singapore, Singapore, and Dr. Kim Yongmin from the University of Glasgow, Singapore, gave outstanding invited speeches. All the speeches and presentations focused on the latest information and most innovative developments in their respective expertise areas of civil engineering.

ICOCE 2024 has received more than 70 papers. Thirty-six papers were accepted for publication in the Conference Proceedings. All the submissions were peer reviewed by Conference Committees. The papers selected depended on their originality, language, quality, and their relevancy to the conference. The proceeding is divided into six chapters, including engineering vibration and mechanical properties of building structures, mechanical properties of concrete structures, hydraulic engineering and flood control, urban planning and infrastructure engineering, properties of building materials and structures, building environment and environmental impact assessment of buildings, engineering project management and optimization. We are sure that the proceedings will serve as an important research tool to become a source of references and knowledge, which will lead to not only scientific and engineering findings but also to new products and technologies.

Finally, we would like to deeply express our heartfelt appreciation to all our delegates, keynote speakers, invited speakers, session chairs, and international reviewers as well as all the committee members involved in the technical evaluation of conference papers and in the conference organization for your enthusiasm, effort, and great contributions. Apart from that, we would like to extend our thanks to all the authors and external reviewers for your willingness to make the conference a worthwhile experience. It is your recognized competence, enthusiasm, valuable time, and expertise that have enabled us to prepare and hold the conference and make it a great success.

Dimondale, USA Prof. Eric Strauss

Contents

Flexural Behavior of Indonesian Berua Timber: Experimental Test and Numerical Analysis

Yosafat Aji Pranata, Anang Kristianto, and Novi

Abstract The bending behavior of timber beams in a frame systems of modular timber house or permanent timber house needs to be known, specifically for the mechanical properties of bending forces, modulus of rupture, and modulus of elasticity. These three parameters are important parameters for the purposes of timber beam design in timber buildings both for non-multistorey and multistorey. One of the experimental testing methods in the laboratory for flexural or bending tests is based on the ASTM D143-21 Standard. The purpose of this study is to do the nonlinear finite element modeling of timber beam and experimental testing in the laboratory that is a flexural test to determine the behavior of beams. The scopes of the research, namely the bending behaviors, reviewed are as follows: the parameters of bending strength, modulus of rupture, and modulus of elasticity, the timber studied is Indonesian Berua timber, and bending testing is based on the ASTM standard reference which is D143-21. The method that used in this study is based on experimental tests and numerical analyses to obtain the empirical parameter of the bending strength. The results showed that the average flexural strength of timber with experimental test results obtained by 31.52 MPa, modulus of rupture 46.68 MPa, and modulus of elasticity 4143.51 MPa, while the results of the nonlinear finite element modeling showed the bending strength of 29.33 MPa (% difference with experimental results is − 6.96%), modulus of rupture 49.63 MPa (% difference with experimental results is 6.34%), and modulus of elasticity 3477.19 MPa (% difference with experimental results is − 16.09%). These results show that in general the nonlinear finite element modeling produces values that are close to the results of experimental testing. One of the important benefits of numerical modeling is to study the behavior of buildings due to working loads so that predictions of strength, rigidity, and stability behavior can be known. This is important as a reference to the feasibility requirements of the design of a building.

Keywords Flexural strength · Modulus of elasticity · Berua timber · Nonlinear finite element modeling

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1 Introduction

Timber beams are one of the main components of frame structure, with the function to withstand the internal forces that work on the builds which are shear forces and flexural moments. The three main parameters in the design of a bending structure component are the bending strength (F_b), the modulus of elasticity (MoE), and the modulus of rupture (MoR). Bending strength is used as a parameter in the calculation of corrected bending capacity, modulus of elasticity is used as a parameter in the calculation of beam deflection, while modulus of rupture is also used as a parameter in the calculation of bending capacity. One empirical method of testing bending wood is to use the ASTM D143-21 [1] reference.

Research history or publication of timber bending strength research has been done previously, namely Pranata and Suryoatmono [2], which is the nonlinear finite element analysis/modeling for compression of one Indonesian timber species. In this research, the compressive strength and modulus of elasticity of the red Meranti timber was studied numerically based on nonlinear finite element modeling and empirically through experimental testing in the laboratory. Subsequent research on the bending strength, MoE, and MoR for Ulin timber (Eusideroxylon zwageri) has also been conducted by Pranata and Palapessy [3] with results that are the flexural strength, MoE, and MoR Ulin timber parameters. Research related to modulus of elasticity has also been conducted on existing buildings, which is a traditional Minangkabau house located in North Sumatra Indonesia by Pranata and Tobing [4] and nondestructive testing to obtain the dynamic elastic modulus of the existing Minangkabau wooden house; the results obtained from this research are as follows: The column modulus of elasticity (average) is 12670.08 MPa, the floor beam modulus of elasticity (average) is 13119.00 MPa, the roof beam modulus of elasticity (average) is 12997.37 MPa, the floor board modulus of elasticity (average) is 11151.11 MPa, and the timber wall modulus of elasticity (average) is 12976.00 MPa. Numerical modeling of timber and timber joints research including the failure mode could be identified using this FEA approach [5]. Semi-destructive of timber mechanical properties also can be done using both experimental and numerical analyses [6]. Numerical simulation can be used for studying about the acoustic wave propagation in standing trees [7]. Orthotropic material, especially the three-dimensional nonlinear simulation for timber research, also studied before [8].

The purposes of this research are to do the nonlinear finite element modeling of timber beam and experimental testing in the laboratory that is a flexural test to find out the behavior of timber bending. The scopes of the research of the flexural behavior reviewed are the parameters of bending strength, modulus of rupture, and modulus of elasticity. The timber that studied is Berua timber originating from the Nias Island in Indonesia, and bending testing is based on the reference regulation's ASTM D143-21 [1]. Numerical analysis based on the nonlinear finite element modeling is done using ADINA software [9], and the cross-section size of the test object is 140 $\times$ 140 mm with 760 clear span length.

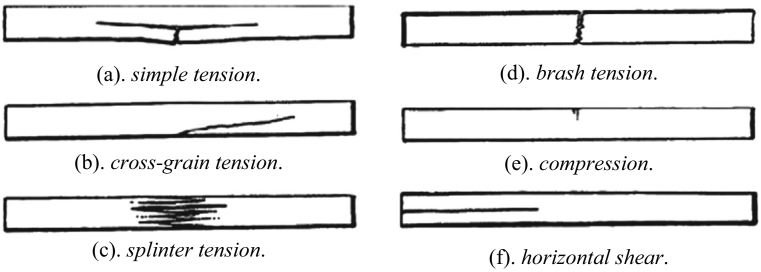

Fig. 1 Classification of beam bending failures in accordance with ASTM [1]

2 Basic Theory

2.1 Timber Flexural Behavior

The bending strength is the limit strength that timber can achieve when the timber component fails due to bending [10]. Based on ASTM D143-21 [1], the criterion for static bending flexural failures with the center-point loading test object model consists of several classifications depending on the condition of the surface crack. Classifications of beam failure are simple tension, cross-grain tension, splinter tension, brash tension, compression, and horizontal shear. Schematic beam failure due to full a bending load is shown in Fig. 1. The type of simple tension failure (Fig. 1a) is a crack in the outermost fiber of the pull and then cracks spread in the parallel direction of the fiber.

The type of cross-grain tension failure (Fig. 1b) is a crack in the outermost fiber of the pull section with the direction of crossing cracking or crossing the direction of the fiber. Splinter tension failure type (Fig. 1c) is in the outermost fiber of the pull; there is a shale-shaped crack so that the wood splits. The type of brash tension failure (Fig. 1d) is a crack that is brittle or brittle in the outermost fiber of the pull. The compression failure type (Fig. 1e) is a crack occurring in the outermost fiber of the compressed part. The horizontal shear failure type (Fig. 1f) is a creeping crack following the direction of the fiber or called shear failure.

2.2 Orthotropic Material

Within the range of a particular promotional boundary, material behavior is modeled as orthotropic elastic linear behavior. The constitutive behavior of orthotropic elastic linear material can be described under Hooke's law [11, 12].

$$\begin{Bmatrix} \varepsilon_{\mathrm{L}} \\ \varepsilon_{\mathrm{R}} \\ \varepsilon_{\mathrm{T}} \\ \gamma_{\mathrm{RT}} \\ \gamma_{\mathrm{LT}} \\ \gamma_{\mathrm{LR}} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E_{\mathrm{L}}} & \frac{-\nu_{\mathrm{RL}}}{E_{\mathrm{R}}} & \frac{-\nu_{\mathrm{TL}}}{E_{\mathrm{T}}} & 0 & 0 & 0 \\ \frac{-\nu_{\mathrm{LR}}}{E_{\mathrm{L}}} & \frac{1}{E_{R}} & \frac{-\nu_{\mathrm{TR}}}{E_{\mathrm{T}}} & 0 & 0 & 0 \\ \frac{-\nu_{\mathrm{LT}}}{E_{\mathrm{L}}} & \frac{-\nu_{\mathrm{RT}}}{E_{\mathrm{R}}} & \frac{1}{E_{\mathrm{T}}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{\mathrm{RT}}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{\mathrm{LT}}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{\mathrm{LR}}} \end{bmatrix} \begin{Bmatrix} \sigma_{\mathrm{L}} \\ \sigma_{\mathrm{R}} \\ \sigma_{\mathrm{T}} \\ \tau_{\mathrm{RT}} \\ \tau_{\mathrm{LT}} \\ \tau_{\mathrm{LR}} \end{Bmatrix} \tag{1}$$

Shear modulus [13] for all tree directions in this research are calculated using equations,

$$G_{\mathrm{LR}} = \frac{E_{\mathrm{L}} \cdot E_{\mathrm{R}}}{E_{\mathrm{L}} \cdot (1 + \nu_{\mathrm{LR}}) + E_{\mathrm{R}} \cdot (1 + \nu_{\mathrm{RL}})} \tag{2}$$

$$G_{\mathrm{LT}} = \frac{E_{\mathrm{L}} \cdot E_{\mathrm{T}}}{E_{\mathrm{L}} \cdot (1 + \nu_{\mathrm{LT}}) + E_{\mathrm{T}} \cdot (1 + \nu_{\mathrm{TL}})} \tag{3}$$

$$G_{\mathrm{RT}} = \frac{E_{\mathrm{R}} \cdot E_{\mathrm{T}}}{E_{\mathrm{R}} \cdot (1 + \nu_{\mathrm{RT}}) + E_{\mathrm{T}} \cdot (1 + \nu_{\mathrm{RT}})} \tag{4}$$

The orthotropic plastic material model based on Hill's yield criteria [12] is an extension of von Mises' yield criteria:

$$f\left(\sigma_{ij}\right) = F(\sigma_{bb} - \sigma_{cc})^2 + G(\sigma_{cc} - \sigma_{aa})^2 + H(\sigma_{aa} - \sigma_{bb})^2$$

$$+2L\sigma_{ab}^2 + 2M\sigma_{ac}^2 + 2N\sigma_{bc}^2 - 1 = 0 \tag{5}$$

$$F = \frac{1}{2}\left(\frac{1}{Y^2} + \frac{1}{Z^2} - \frac{1}{X^2}\right) \tag{6}$$

$$G = \frac{1}{2}\left(\frac{1}{Z^2} + \frac{1}{X^2} - \frac{1}{Y^2}\right) \tag{7}$$

$$H = \frac{1}{2}\left(\frac{1}{X^2} + \frac{1}{Y^2} - \frac{1}{Z^2}\right) \tag{8}$$

$$L = \frac{1}{2Y_{ab}^2} \tag{9}$$

$$M = \frac{1}{2Y_{ac}^2} \tag{10}$$

$$N = \frac{1}{2Y_{bc}^2} \tag{11}$$

Here, a, b, c are the three principal directions, while X, Y, Z are yield stresses at the direction a, b, c and Y_{ab}, Y_{ac}, Y_{bc} are yield stresses for pure shear for all the three planes (a, b), (a, c), and (b, c).

2.3 Determining Yield Point

Proportional limit load determination using the Yasumura and Kawai [14] method is a method that has been applied to research with timber structure element test objects and timber frame structures. In the Yasumura and Kawai methods, initial stiffness (in the form of a straight line) is calculated between the range of a 10 and 40% maximum load. It further defined a straight line between two points where the values are 40 and 90% the maximum load. The yield point is determined from the meeting of the two lines (see Fig. 2). P_y can be used to obtain F_{b}, which is $M_y.y/I_x$ (mechanics of material equation) while Pu can be used to obtain MoR, which is also $M_u.y/I_x$.

$$F_y = M_y.y/I_x \quad \text{where} \quad M_y = P_y \cdot L/4 \tag{12}$$

$$\text{MoR} = M_u \cdot y/I_x \quad \text{where} \quad M_u = P_u/L/4 \tag{13}$$

$$D_y = P \cdot L^3/(48 \cdot \text{MoE} \cdot I_x) \tag{14}$$

$$\text{MoE} = P \cdot L^3/\left(48 \cdot D_y \cdot I_x\right) \tag{15}$$

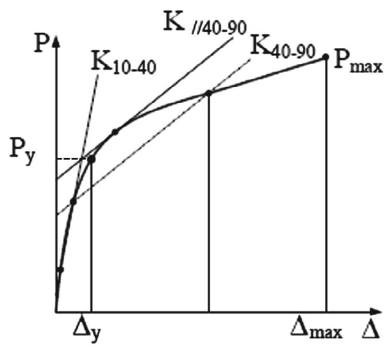

Fig. 2 Determining yield point in accordance with Yasumura and Kawai method [14]

2.4 Finite Element Analysis

A 3-D solid element is a three-dimensional solid model that is not limited to shape, loading, material properties, and boundary conditions [9, 15]. Consequently, there are likely to be six voltage values (three normal stresses and three shear stresses) and the transition that occurs in three directions, namely *u*, *v*, and *w*. Material stress and strain measurement method [9] for small strain models is defined for strains with a value of less than 2%. The assumption of the small displacement/small strain model uses the assumption that input data are a curve model of engineering stress and engineering strain relationship, and then, output data are a model of Cauchy stress relationship curve and engineering strain while the large displacement/large strain model uses the assumption of output data which is a model of the relationship curve Kirchhoff stress and left Hencky strains or Jaumann strains.

Nonlinear finite element analysis to predict the flexural behavior of timber beam can be done using a FEA software named ADINA [9]. The stress–strain curves for all three principal axes of the orthotropic material are modeled using the Hill's yield equations. The relationship between the yield stress and the plastic strain can be used to determining the hardening rule in terms of t. The 3-D element of solid is a 20-node isoparametric element applicable to 3-D analysis. A numerical model of the specimen is modeled using the 3-D quadric element with 20 nodes as shown in Fig. 3.

The equilibrium equations [9] to be solved are as follows:

$$ {}^{t+\Delta t}R - {}^{t+\Delta t}F = 0 \tag{16} $$

Here, ${}^{t+\Delta t}R$ is the vector of applied nodal loads, and ${}^{t+\Delta t}F$ is the equivalent force vector to the element stresses. The arc length method or the load–displacement control (LDC) method can be used to solve the nonlinear equilibrium of a model until collapse. The arc length method can be used in a nonlinear static analysis for incremental loads. The arc length method can also be used in contact problems [9]. The equations are as follows:

$$ {}^{t+\Delta t}K^{(i-1)}\Delta U^{(i)} = \left({}^{t+\Delta t}\lambda^{(i-1)} + \Delta\lambda^{(i)}\right)R + R_P - {}^{t+\Delta t}F^{(i-1)} \tag{17} $$

$$ {}^{t+\Delta t}U^{(i)} = {}^{t+\Delta t}U^{(i-1)} + \Delta U^{(i)} \tag{18} $$

$$ f\left(\Delta\lambda^{(i)}, \Delta U^{(i)}\right) = 0 \tag{19} $$

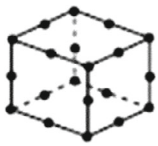

Fig. 3 Quadric element with 20 nodes [9]

Here, the tangent stiffness matrix ${}^{t+\Delta t}K^{(i-1)}$ is used at the end of iteration $(i-1)$ at time $t+\Delta t$, R is vector in terms of constant load, R_P is the load vector that obtained from previous run, and the load scaling factor ${}^{t+\Delta t}\lambda^{(i-1)}$ is used at the iteration of $i-1$ at time $t+\Delta t \cdot \Delta\lambda^{(i)}$ is the increment in the load scaling factor.

3 Experimental Test, Results, and Discussion

3.1 Experimental Test

The results of an experimental study of Berua timber beam test objects are shown in Fig. 4. Testing is done using the universal testing machine. The testing method is the third point bending test in accordance with ASTM D143-21 [1] or also called the center-point loading test method. The speed of a crosshead is 2.5 mm/min. The model of bending test objects used in this study uses references based on the specifications of primary test objects (primary method with a net span length of 760 mm beams). The test object is made with a cross-sectional size of 140 × 140 mm with a total length of wood beams is 920 mm. Furthermore, the beam mounted on the bending test mount with a clear distance is 760 mm according to ASTM 143–21 [1].

Figure 4 shows the testing process of the B-N-01 test object which is the stage of the test object setup and continued with the bending testing process. Figure 5 shows the results of the destructive test that is the beam bending test. In general, the beam failure pattern is simple tension failure for all test objects which are B-N-01, B-N-02, and B-N-03.

Furthermore, Fig. 6 shows beam modeling using the nonlinear finite element method. Beam element modeling uses a solid 3-D element type, while mesh modeling uses quadric element type with 20 nodes. The test results are that the relationship curve between a load and beam deformation is more displayed in Fig. 7 and Table 1. Calculation of the load at proportional limit conditions (yield points) and the ultimate load is done on the basis of the theory of the Yasumura and Kawai methods [10].

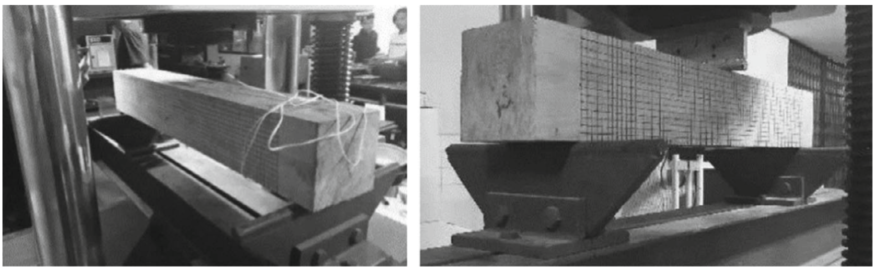

Fig. 4 Setup of the beam specimen in universal testing machine

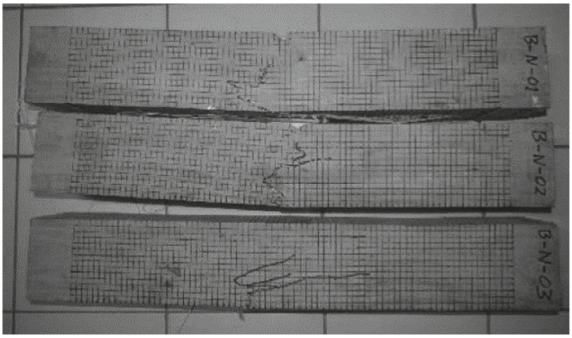

Fig. 5 Failure of the beam specimens due to destructive tests

The result of numerical analysis is displayed in Fig. 7, and the results of calculation of the proportional limit load and the ultimate loads are displayed in Table 1.

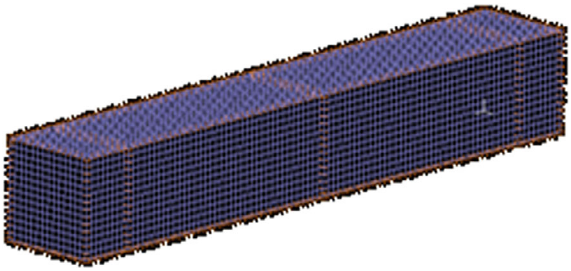

Fig. 6 Schematic 3D finite element modeling of Berua timber beam

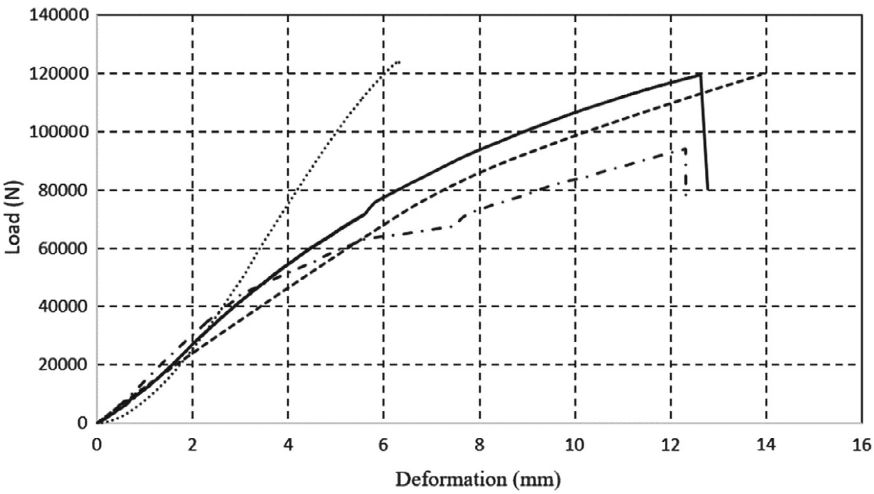

Fig. 7 Results obtained from both experimental and numerical analyses: the load versus beam deformation

Table 1 Bearing load (peak) obtained from experimental tests

Specimen	P_y (N)		D_y (mm)	Pu (N)	Du (mm)	
B-N-01	78,573.00	75,874.33	6.14	119,330.00	112,350.67	12.63
B-N-02	65,167.00		5.70	93,784.00		12.26
B-N-03	83,883.00		4.35	123,938.00		6.34
FEA	70,597.22	70,597.22	5.80	119,472.00	119,472.00	13.90

The % difference of P_y between experimental test results (average value) and FEA is − 6.96% which is indicated that P_y obtained from FEA (70,597.22) is lower than experimental test results (75,874.33 N). The % difference of Pu between experimental test results (average value) and FEA is 6.34% which is indicated that Pu obtained from FEA (119,472.00) is higher than experimental test results (112,350.67 N). These P_y (proportional load) results indicate that modeling with FEA results in lower values than experimental results. The advantage of numerical analysis with FEA in this study is the existence of accurate proportional limit load predictions. This is important for the purposes of predicting the capacity of structural components. With an accurate prediction of the capacity of the components, it can be predicted and also known the capacity of buildings that can be held due to the burdens of both gravity and lateral loads (earthquakes) that hit the building.

Bending or flexural strength (F_b), MoE (modulus of elasticity), and MoR (modulus of rupture) parameters can be calculated using Eqs. 12–15. The results are shown in Tables 2 and 3. These results indicated that the MoE obtained from FEA (3477.19 MPa) is − 16.08% lower than the MoE obtained from experimental tests (4143.51 MPa), the F_b obtained from FEA (29.33 MPa) is − 6.96% lower than the Fb obtained from experimental tests (31.52 MPa), while the MoR obtained from FEA (49.63 MPa) is 6.34% higher than the MoR obtained from experimental tests (46.68 MPa). The MoR parameter obtained from FEA is higher than the experimental tests because B-N-02 has the lowest value both for P_y and P_u.

Table 2 Numerical and experimental results: MoE (MPa)

Specimen	F_b (MPa)		MoR (MPa)	
B-N-01	32.64	31.52	49.58	46.68
B-N-02	27.07		38.96	
B-N-03	34.85		51.49	
FEA	29.33	29.33	49.63	49.63

Table 3 Numerical and experimental results: MoR (MPa)

Specimen	P_y (N)	D_y (mm)	MoE (MPa)	
B-N-01	78,573.00	6.14	3655.73	4143.51
B-N-02	65,167.00	5.70	3266.04	
B-N-03	83,883.00	4.35	5508.75	
FEA	70,597.22	5.80	3477.19	3477.19

4 Conclusion

The results showed the average flexural strength of timber with experimental test results obtained by 31.52 MPa, modulus of rupture 46.68 MPa, and modulus of elasticity 4143.51 MPa, while the results of the nonlinear finite element modeling showed the bending strength of 29.33 MPa (% difference with experimental results is − 6.96%), modulus of rupture 49.63 MPa (% difference with experimental results is 6.34%), and modulus of elasticity 3477.19 MPa (% difference with experimental results is − 16.09%). These results show that in general the nonlinear finite element modeling produces values that are close to the results of experimental testing. One of the important benefits of numerical modeling is to study the behavior of buildings due to working loads so that predictions of strength, rigidity, and stability behavior can be known. This is important as a reference to the feasibility requirements of the design of a building.

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