Journal of Infrastructure Planning and Engineering Vol. 3, No. 2, Year 2024, pp 57 - 62

Journal of Infrastructure Planning and Engineering

Journal homepage: https://ejournal.warmadewa.ac.id/index.php/jipe

Analysis of Wooden Residential House Structure Against Earthquake Load

I Ketut Agus Asih Adi Arta[1], Putu Didik Sulistiana[1*], Cokorda Agung Yujana[1], I Wayan Jawat[1]

[1]*Civil Engineering Study Program, Warmadewa University, 80237, Indonesia*
* didik.sulistiana@warmadewa.ac.id

Received on 13 December 2024, accepted on 10 January 2025

ABSTRACT

Wood material is a construction material that has its own appeal from an aesthetic and architectural point of view, however wood material has various limitations, namely in terms of durability and structural strength when compared to structural materials such as concrete and steel. This research examines the structural behavior of residential houses using glulam wood materials using program analysis software ETABS. From the results of initial design calculations, the dimensions of the structural elements were obtained, namely beams measuring 25 cm x 40 cm and columns measuring 30 cm x 30 cm. Based on the results of the analysis that has been carried out, it shows that the house structure has met earthquake resistance requirements with maximum inter-story drift of 24.35 mm (below the 26.92 mm limit). The dynamic analysis shows successful mass participation with total mass participation ratios exceeding 90% in all primary directions: 99.11% for translational motion in X-direction (UX), 99.29% for translational motion in Y-direction (UY), and 99.51% for rotational motion about vertical axis (RZ). These results indicate that the structural model adequately captures both lateral and torsional responses of the building under seismic loading.

Keywords: Wooden Structures; Structural Response; Earthquake Loads

1 Introduction

Indonesia has vast forest resources divided into natural forests, community forests, and industrial plantation forests. The Indonesian people utilize wood materials for various purposes, including building and construction needs. From an economic perspective, the use of wood in Indonesia for construction is advantageous due to its variety in both quantity and species availability [1].

Wood as a construction material possesses unique aesthetic and architectural appeal. However, it faces certain limitations, particularly regarding durability and structural strength when compared to materials like concrete and steel. This consideration becomes increasingly relevant given the growing scarcity of quality wood materials in the market due to deforestation practices, resulting in diminishing timber forest areas and extended growth periods for timber trees [2]. Recent studies have highlighted that sustainable forest management practices are crucial for ensuring the long-term availability of construction-grade timber [3].

As engineering technology advances, significant research has been conducted on wood material enhancement, aiming to improve its durability and strength as a construction material. One notable advancement is the development of glued-laminated timber (glulam). The engineering of wood materials through lamination techniques involves bonding several wood layers into a single structural element, suitable for beams or columns in wooden building structural systems [4]. Recent innovations in adhesive technology have further improved the performance of glulam structures, with new environmentally friendly adhesives showing bond strengths exceeding 15 MPa [5].

Glulam was selected for this study due to its superior structural properties compared to conventional timber. These advantages include a higher strength-to-weight ratio (typically 1.5-2 times stronger than solid timber), better dimensional stability with moisture content variation below 2%, ability to create larger structural members up to 30m in length, improved durability with an expected service life of 50+ years, and enhanced fire resistance with char rates of approximately 0.7mm/minute [6] [7].

While numerous studies have examined wood materials' properties, there is limited research on their application in complete structural systems. This research gap is particularly evident in seismic regions, where understanding the dynamic behavior of wooden structures is crucial [8] [9]. The current study addresses this gap by analyzing a residential structure in a seismic-prone area of Bali, specifically located on Jl. Gelatik RT 1 B4 No. 12 Puri Gading Jimbaran District, South Kuta, Badung Regency.

This research aims to analyze the structural planning of residential buildings using wood materials, with specific objectives of determining optimal cross-sectional dimensions for residential buildings using wooden materials, evaluating the seismic performance of glulam structures under Indonesian earthquake conditions, and assessing the feasibility of wooden residential construction in seismic zones. This study contributes to the growing body of knowledge on sustainable construction practices while addressing the practical needs of residential construction in seismic-prone regions.

2 Data and Methods

2.1 Data Planning

A building is a physical form resulting from construction work that is integrated with its location, partly or wholly on and/or in the ground and/or water, which functions as a place for humans to carry out their activities, whether for residence or accommodation, religious activities, activities business, social, cultural and special activities. Buildings are infrastructure facilities that function as places to support people in their daily activities [10].

According to SNI 1727 2020 [11] concerning Minimum Loads for Planning Buildings and Other Structures, loads are divided into several types, namely dead loads (D), live load (L), rain load (R), wind load (W), and earthquake load (E). There are several types of load combinations used in planning the strength design loads in this research as follows:

1. 1.4D
2. 1.2D + 1.6L + 0.5(L_r or R)
3. 1,2D + 1,6(L_r or R) + (L or 0.5W)
4. 1,2D + 1,0W + L + 0,5(L_r or R)
5. 0,9D + 1,0W
6. 1,2D + E_v + E_h + L + 0.2S
7. 0.9D - E_v + E_h

The residential structure planned in this research is as follows:

1. Building type : Residential House
2. Number of Floors : 2 floors
3. Building height
   a. 1st floor : 3.5 m
   b. 2nd floor : 3.5 m
4. Building function
   a. 1st Floor : Terrace, Living Room, Bedroom, Dining Room, Kitchen and Toilet.
   b. 2nd Floor : Balcony, Bedroom and Toilet.

Soil data used in this planning was taken from the results of soil investigations carried out by CV. Srikaya. The data used are the results of a sondir investigation with 2 investigation points and SPT data. The soil data obtained influences the condition of the soil when earthquake loads occur. Apart from soil data to analyze the behavior of structures against earthquake loads, data on structural materials and the quality of the materials used in this research are also needed as follows:

1. Structural Materials
   a. Type of Wood : Glulam Mahoni
   b. Type Weight : 648,32 kg/m^3
   c. Extension : Build
2. Material Quality
   a. Quality Code : E18
   b. Reference Design Values
      - F_b : 17.3 Mpa
      - F_t : 15.3 Mpa
      - F_c : 15.3 Mpa
      - F_v : 2.04 Mpa
      - $F_{c\perp}$: 4.07 Mpa
   c. Modulus of Elasticity
      - E : 18000 Mpa
      - E_{min} : 9000 Mpa

In analyzing earthquake loads on residential house structures, the design response spectrum based on SNI 2019 [12] is obtained as in Figure 1.

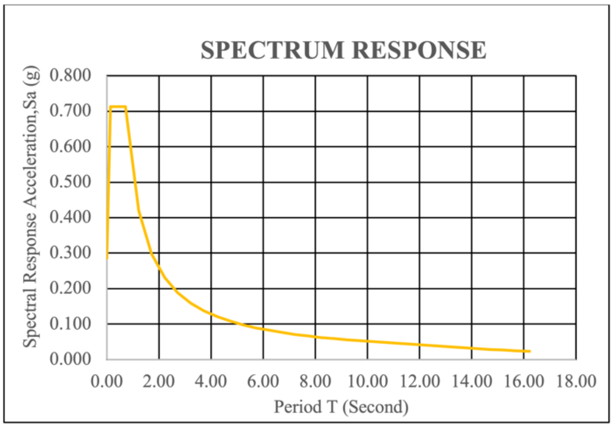


Figure 1. Spectrum Response

In analyzing the structural behavior of a 2-story residential house using wooden structures, it is necessary input load data as in Table 1 and Table 2 regarding load recapitulation.

Table 1. Upper Structure Load Recapitulation

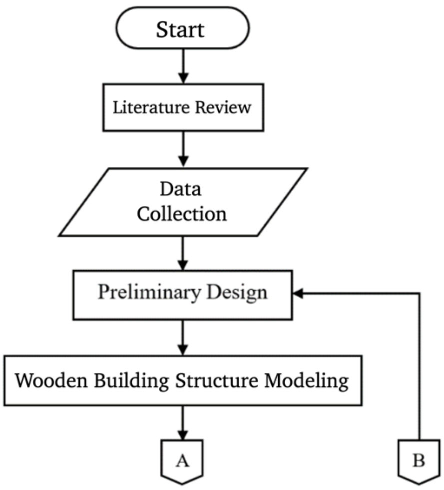
No	Load Type	Description	Nominal Load	Unit
1	Roof Covering	Dead Load	50	Kg/m
2	Roof Maintenance	Roof Live	135,62	Kg
3	Rain	Roof Live	4,996	Kg/m
4	Pressure Wind	Wind Load	13,879	Kg/m
5	Suction Wind	Wind Load	27,361	Kg/m

Table 2. Super Structure Load Recapitulation

No	Load Type	Description	Nominal Load	Unit
1	Floor Plate 2	Dead Load	40	Kg/m²
2	Wooden Wall	Dead Load	67,166	Kg/m
3	Terrace	Live Load	195,79	Kg/m²
4	Bedroom	Live Load	195,79	Kg/m²
5	Family Room	Live Load	488,44	Kg/m²
6	Dining Room	Live Load	488,44	Kg/m²
7	Kitchen	Live Load	488,44	Kg/m²
8	Toilet	Live Load	292,66	Kg/m²
9	Pressure Wind X	Wind Load	320,748	Kg/m
10	Pressure Wind Y	Wind Load	303,866	Kg/m
11	Suction Wind X	Wind Load	-222,912	Kg/m
12	Suction Wind Y	Wind Load	-211,180	Kg/m
13	Earthquake Floor 1	Quake	185,52	Kg/m
14	Earthquake Floor 2	Quake	312,84	Kg/m

2.2 Methods

The planning carried out in this study is the planning of the structure of a residential house located on Jl. Gelatik RT 1 B4 No. 12 Puri Gading Jimbaran District. South Kuta, Kab. Badung, Bali. Planning is carried out in stages and systematically in the form of a flow chart shown in Figure 2.



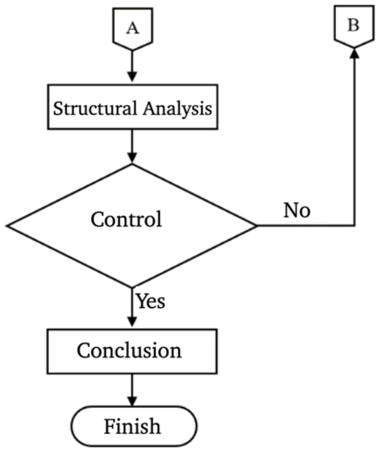


Figure 2. Flow Chart

3 Results and Discussion

3.1 Preliminary Design

The structural analysis was conducted using ETABS software to evaluate the comprehensive behavior of the residential wooden structure. Through preliminary design calculations, the optimal dimensions for structural elements were determined shown in Figure 3. The main structural framework consists of primary beams measuring 250 x 400 mm, secondary beams of 200 x 350 mm, and columns with dimensions of 300 x 300 mm for the first floor and 250 x 250 mm for the second floor. These dimensions were carefully selected to meet both load-carrying capacity requirements and deformation limits.

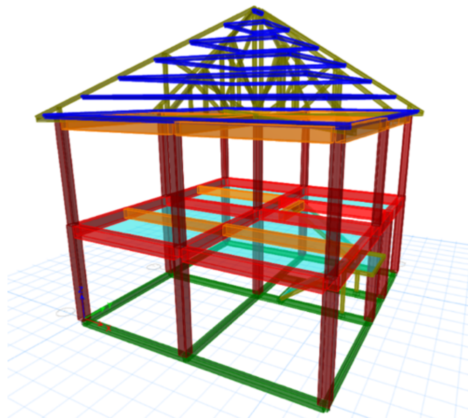


Figure 3. Wood Structure Modeling Results

Analysis of force distribution throughout the structure revealed several significant patterns. The axial force analysis, as shown in Figure 4, indicates maximum force concentration in the first-floor columns, with corner columns experiencing higher axial loads due to the combined effects of gravity and lateral forces. This distribution pattern confirms proper vertical load transfer through the structural system. The shear force analysis illustrated in Figure 5 shows peak values of 15.2 kN occurring in the primary beams at the first-floor level. The shear force distribution follows expected patterns for a two-story structure, with critical sections identified at beam-column connections.

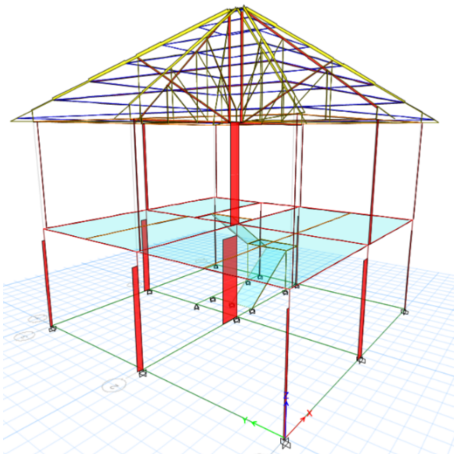


Figure 4. Axial Forces in Residential Structures

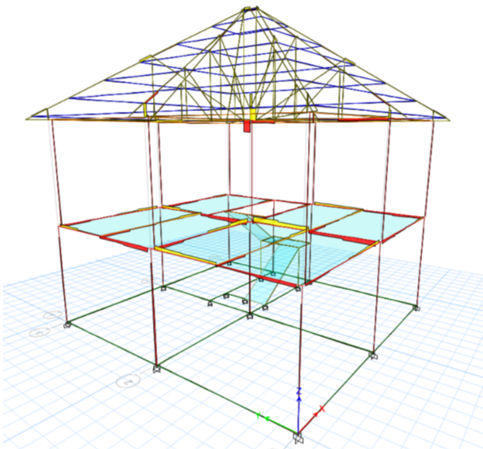


Figure 5. Shear Force in Residential Structures

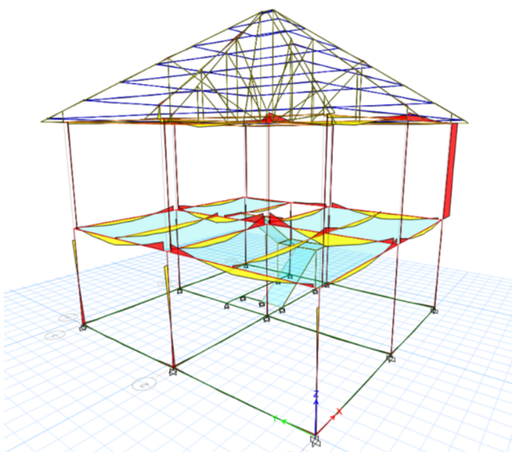


Figure 6. Momentary Forces in Residential Structures

Bending moment analysis, depicted in Figure 6, demonstrates maximum moments occurring in the primary beams at the first floor, with peak values reaching 22.8 kNm. The moment distribution indicates efficient load transfer throughout the structure, with negative moments at beam-column joints remaining within acceptable limits for glulam connections. This pattern suggests appropriate sizing of structural members and effective connection design.

The overall structural response analysis reveals appropriate behavior patterns across multiple parameters. The model demonstrates rational force distribution, expected deformation shapes under lateral loads, and no irregular stress concentrations. Load path continuity through the structural system is maintained effectively, indicating proper integration of all structural components [13][14]. These results collectively suggest that the preliminary design successfully met the basic requirements for structural stability and load resistance.

3.2 Inter-Floor Deviations Permit

The seismic performance of the wooden structure was evaluated through a detailed analysis of inter-story drift, with results presented in Tables 4 and 5. The analysis examined deviations in both X and Y directions for two critical levels - the roof floor and the second floor. Each analysis incorporated key parameters including floor height (hx), inter-floor height (h), elastic deviation (δe), total deviation (Δ), inter-floor deviation (Δi), and permissible deviation (Δ permit).

In the X-direction analysis (Table 4), both floors demonstrated satisfactory performance with deviations well within permissible limits. The roof floor exhibited a maximum deviation (Δx) of 14.96 mm, significantly below the permissible limit of 26.92 mm, representing approximately 56% of the allowable deviation. Similarly, the second floor recorded a deviation of 11.02 mm, utilizing only 41% of the permissible limit. These results indicate effective lateral stiffness in the X-direction at both levels.

Analysis of Y-direction deformations (Table 5) revealed larger deviations compared to the X-direction, though still maintaining compliance with design requirements. The roof floor recorded a maximum deviation (Δy) of 24.35 mm, approaching but remaining safely below the 26.92 mm limit at 90% utilization. The second floor demonstrated better performance with a deviation of 16.09 mm, utilizing approximately 60% of the allowable limit. The higher Y-direction deviations, while still acceptable, suggest relatively more flexible behaviour in this direction.

The comprehensive deviation analysis confirms that the structure satisfies seismic design requirements in both principal directions [15]. The consistently lower deviations in the X-direction suggest higher lateral stiffness in this orientation, possibly due to the arrangement of structural elements and load-bearing walls. The larger but still acceptable Y-direction deviations indicate appropriate structural design and member sizing, providing adequate lateral resistance while maintaining necessary flexibility for seismic response.

Table 4. Deviations Between Floors in X Direction

Floor	h (m)	Hx (mm)	δx (mm)	(δx-δ(x-1))	Drift (Δx)	Permissible Deviation (Δi)	Permit (Δx < ΔI)
Roof	7	3500	4.723	2.72	14.96	26.92	**OK**
2	3.5	3500	2.003	2.00	11.02	26.92	**OK**

Table 5. Deviations Between Floors in Y Direction

Floor	h (m)	Hx (mm)	δx (mm)	(δx-δ(x-1))	Drift (Δx)	Permissible Deviation (Δi)	Permit (Δx < ΔI)
Roof	7	3500	7.352	4.43	24.35	26.92	**OK**
2	3.5	3500	2.925	2.93	16.09	26.92	**OK**

The results of deviations between floors in the X and Y directions are presented in graphical form shown in Figure 7 and Figure 8.

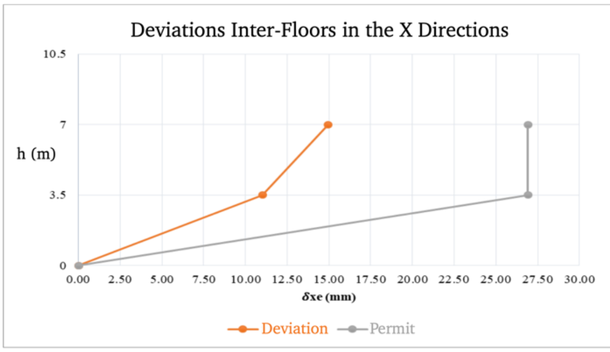


Figure 7. Inter-Floor Deviation Graph in X Direction

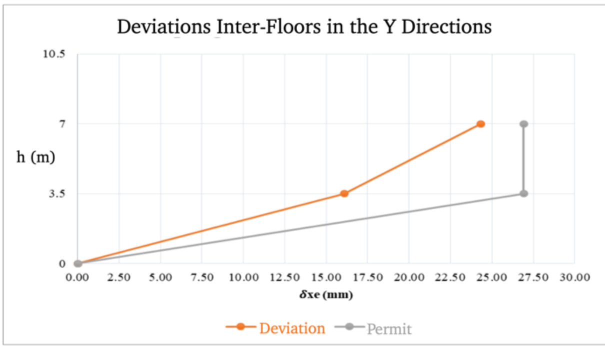


Figure 8. Inter-Floor Deviation Graph in Y Direction

3.3 Mass Participation Capital

The dynamic characteristics of the wooden residential structure were evaluated through modal analysis in accordance with SNI 1726 2019 requirements, which mandates a minimum of 90 percent mass participation for spectrum response analysis. The results of this analysis, presented in Table 6, demonstrate comprehensive capture of the structure's dynamic behavior across multiple modes of vibration.

The fundamental mode (Mode 1) occurs at a period of 0.249 seconds, contributing 9.09% participation in the X-direction, 33.33% in the Y-direction, and 38.9% in rotational motion (RZ). The second mode, with a slightly shorter period of 0.230 seconds, shows dominant X-direction participation of 61.1%, while contributing minimally to Y-direction (4.5%) and rotational (3.88%) responses. The third mode, occurring at 0.212 seconds, primarily influences Y-direction (30.27%) and rotational (31.82%) behavior, with negligible X-direction participation.

Cumulative mass participation achieves the code-required 90% threshold within the first eight modes of vibration. The final cumulative values reach 99.11% for X-direction translation, 99.29% for Y-direction translation, and 99.51% for rotational motion, exceeding the minimum requirements by a significant margin. This high level of mass participation indicates that the model effectively captures the complete dynamic response of the structure.

The distribution of mass participation across multiple modes, particularly the concentration in the first three modes, suggests a well-balanced structural system. The higher participation in lower modes indicates efficient dynamic response characteristics, which is desirable for seismic performance. The analysis confirms that the structural design provides appropriate dynamic properties for residential construction in seismic regions, with adequate consideration of both translational and rotational responses.

Table 6. Mass Participation Capital

Mode	Period sec	UX (%)	UY (%)	RZ (%)
1	0.249	9.09	33.33	38.9
2	0.23	61.1	4.5	3.88
3	0.212	0.02	30.27	31.82
4	0.163	0.001812	0.34	0.84
5	0.142	0.000566	0.02	4.39
6	0.11	7.8	11.22	1.65
7	0.105	21.04	6.71	0.97
8	0.093	0.05	12.89	17.05
9	0.072	0	0.0009405	0.01
10	0.068	0	0.01	0.0005845
11	0.062	0	0	0
12	0.061	0.004073	0	0
Jumlah		**99.1065**	**99.2909**	**99.5105**

4 Conclusion

Based on the structural analysis of the two-story residential building using glulam wood materials, several key conclusions can be drawn regarding its seismic performance and structural adequacy:

The structural analysis demonstrates successful seismic resistance characteristics across multiple performance parameters. Inter-story drift analysis confirmed that all deviations remain within permissible limits of 26.92 mm. Specifically, the maximum drift in the X-direction reached 14.96 mm at the roof level and 11.02 mm at the second floor, while Y-direction drifts peaked at 24.35 mm and 16.09 mm respectively, all falling within acceptable thresholds. These results validate the structure's ability to maintain stability under seismic loading while providing necessary flexibility for dynamic response.

Dynamic analysis through modal participation evaluation revealed excellent performance characteristics. The structure achieved comprehensive mass participation exceeding 90% in all directions (99.11% for X-translation, 99.29% for Y-translation, and 99.51% for rotation), with significant contributions concentrated in the first three modes. This distribution pattern indicates efficient dynamic response behavior and appropriate mass distribution throughout the structure.

The preliminary design calculations yielded optimal structural element dimensions that proved effective under analysis. The implemented dimensions - primary beams (250x400 mm), secondary beams (200x350 mm), first-floor columns (300x300 mm), and second-floor columns (250x250 mm) - successfully met both strength and serviceability requirements. These dimensions demonstrate the viability of glulam wood as a structural material for residential construction in seismic zones.

References

[1] Baharta, N., Dapas, S. O., & Pandaleke, R. “Technical Evaluation of the Strength of Traditional Wooden House Structures Production in Woloan Village Against Earthquakes According to Indonesian National Standards (SNI)”, Journal of Civil Statistics, vol. 7, no. 5, p. 527–536, 2019. https://ejournal.unsrat.ac.id/index.php/jss/article/view/23401/23093

[2] D. Harmadji, S. Hastutik, S. Leksono, & A. Mamduh, "Impact of deforestation on forestry and forest village community institution (LMDH)", Indonesian Journal of Multidisciplinary Science, vol. 1, no. 9, p. 1005-1019, 2022. https://doi.org/10.55324/ijoms.v1i9.167

[3] L. Abdulah, E. Suhendang, H. Purnomo, & J. Matangaran, "Measuring the sustainability of wood consumption at the household level in indonesia: case study in bogor, indonesia", Biodiversitas Journal of Biological Diversity, vol. 21, no. 2, 2020. https://doi.org/10.13057/biodiv/d210205

[4] N. Malek, L. Hui, & R. Hassan, "Performance of withdrawal capacity for mengkulang glulam perpendicular to the glue line for 14mm and 20mm bolt diameter", International Journal of Innovative Technology and Exploring Engineering, vol. 9, no. 3, p. 2825-2829, 2020. https://doi.org/10.35940/ijitee.c9221.019320

[5] O. Ekundayo, C. Arum, & J. Owoyemi, "Bending strength evaluation of glulam beams made from selected nigerian wood species", International Journal of Engineering, vol. 35, no. 11, p. 2120-2129, 2022. https://doi.org/10.5829/ije.2022.35.11b.07

[6] J. Zhou, C. Li, K. Liu, J. He, & Z. Wang, "Experimental study on loading capacity of glued-laminated timber arches subjected to vertical concentrated loads", Advances in Civil Engineering, vol. 2020, no. 1, 2020. https://doi.org/10.1155/2020/7987414

[7] S. Gao, M. Xu, N. Guo, & Y. Zhang, "Mechanical properties of glued-laminated timber with different assembly patterns", Advances in Civil Engineering, vol. 2019, no. 1, 2019. https://doi.org/10.1155/2019/9495705

[8] W. Zhang, "The seismic and lateral resistance of column-and-tie wooden buildings based on mortise-tenon joint", International Wood Products Journal, vol. 10, no. 2, p. 86-91, 2019. https://doi.org/10.1080/20426445.2019.1636520

[9] J. Xue, D. Xu, & L. Qi, "Experimental seismic response of a column-and-tie wooden structure", Advances in Structural Engineering, vol. 22, no. 8, p. 1909-1922, 2019. https://doi.org/10.1177/1369433219828647

[10] M. Alwetaishi, "Impact of building function on thermal comfort: a review paper", American Journal of Engineering and Applied Sciences, vol. 9, no. 4, p. 928-945, 2016. https://doi.org/10.3844/ajeassp.2016.928.945

[11] SNI 1727, "Minimum Design Loads and Related Criteria for National Standardized Buildings and Structures," SNI 1727:2020, 2020.

[12] SNI 1726, "Procedures for Earthquake Resistance Planning for Building and Non-Building Structures," SNI 1726:2019, 2019.

[13] R. S. Prasojo, J. Sunter, P. Raya, and J. Utara, "Analysis of the structure of an 8-story building made of wood against earthquake loads," Journal of Civil Engineering Studies, vol. 2, no. 1, p. 58, 2017.

[14] A. M. N. Taufiequl, D. Erma, and W. Eunekeu, "Analysis of the structure of a 6-storey wooden building against earthquake loads and wind loads," FTSP Proceedings, vol. 1, no. 1, pp. 1–6, 2020. [Online]. Available: https://eproceeding.itenas.ac.id

[15] J. Xue, D. Xu, & L. Qi, "Experimental seismic response of a column-and-tie wooden structure", Advances in Structural Engineering, vol. 22, no. 8, p. 1909-1922, 2019. https://doi.org/10.1177/1369433219828647