

SEISMIC PERFORMANCE OF STEEL INSTANT HOUSES FOR DISASTER RECONSTRUCTION

Widarto Sutrisno^{1,2}, *Iman Satyarno¹, Ali Awaludin¹, Ashar Saputra¹ and Angga Fajar Setiawan¹

¹Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Indonesia

²Civil Engineering Study Program, Universitas Sarjanawiyata Tamansiswa, Indonesia

*Corresponding Author, Received: 21 Jan. 2025, Revised: 29 April 2025, Accepted: 30 April 2025

ABSTRACT: The 2018 Palu and Lombok earthquakes contributed to the challenges of providing both rapid and resilient housing during disaster emergency responses, considering the frequent aftershocks. An alternative proposition is Steel Instant House (SIH), which uses readily available steel column beams and can be quickly assembled through welded connections. Therefore, this study aimed to assess house performance using laboratory experiments and computer modeling methodologies using sheathing-to-frame connections, natural frequency, and lateral tension. The results showed that there was a significant correlation with the load displacement curves obtained from the modeling. The sheathing connection generated a maximum load of 0.75 kN for board pull-through and 0.9 kN for plank pull-out. Both methods provided a natural frequency of 3-4 Hz for the open frame (OF) and approximately 16 Hz for the full sheathing (FS), making the house less susceptible to resonance with seismic vibrations. The OF could resist loads of four times the structure's weight, deformations of 200 mm, or drifts exceeding 6% without sustaining damage. However, the FS could support loads to 1.5 times the structure's weight and deformations of approximately 125 mm or drifts surpassing 3.25% without having damage. This method solved the problem of reconstruction, ensuring that low- and moderate-income communities could have access to safe housing after natural disasters for more resilient and sustainable.

Keywords: Pushover, Seismic performance, Natural frequency, Steel instant house

1. INTRODUCTION

The Indonesian government is providing household assistance to rebuild collapsed houses after the 2018 Palu and Lombok earthquakes. To ensure recovery, houses must be designed and built safer or better [1], using simple structural modifications and hazard-resistant construction [2]. In this context, reconstruction is essential to provide shelter, reduce the risk of damage and collapse during future earthquakes, thereby ensuring community safety and stability [3].

The challenges faced during reconstruction include inappropriate implementation [4], insufficient availability of conventional materials [5], and a relatively slow house development process [6]. Therefore, studies regarding rapid construction with widely available materials and sheathing that accommodates local wisdom are essential to address further disasters.

Preventing dangerous design requires accurate structural fundamental frequency estimation [7]. This is particularly crucial in seismic regions, where ground motion can trigger resonance in the structure, showing the relevance of the initial free vibration mode. Additionally, the frequency content of ground acceleration is important since certain constructions are more susceptible to specific frequencies [8]. When structure height is important, factors such as mass, stiffness, structural system, design, and materials influence frequency [9].

In previous studies, Selvaraj et al. (2019, 2021)

investigated the fastener connection strength and failure of CFS stud and material composition of sheathing board [10, 11]. Liu et al. (2024) showed lateral resistance of assembled cold-formed steel (CFS) walls sheathed with an integrated board [12].

Zhou et al. (2019) stated that the initial natural frequency would cause damage to the structure [13]. Therefore, in order to control the structural behavior, the natural frequency of vibrations of the structure should be kept depending on the house function [14].

Dubina (2008) used Finite Element Method (FEM), monotonic, and cyclic experiments to evaluate CFS-framed houses under seismic activity [15]. Pan et al. (2018) examined classic light-frame wood houses with various sheathing [16]. Meanwhile, Zhou et al. (2019) used a shaking table to evaluate a light steel building with a timber wall-roof measuring 4000 mm × 3000 mm × 2450 mm (length × width × height) [17].

In 2020, Zang et al. showed an assembled-type light steel (ATLS) modular system with bottom and top frames that were 6055 mm long, 2500 mm wide, and 2800 mm high. Vertical bearing capacity and horizontal stiffness were measured using wallboard and high-strength bolt-join connectors [18]. Light steel frame houses were cheaper, faster, and had fewer global warming potential emissions than traditional ones, according to Bianchi et al. (2021).

Currently, several earthquake-resistant house systems are available to aid in reconstruction in rural areas [22-26]. Widayanti et al. (2020) assessed community satisfaction through the Customer

Satisfaction Index, showing that the CSI values for temporary houses during rehabilitation and reconstruction fall within the satisfied category [27]. However, cultural backgrounds often reject the concept of temporary housing [28]. Sun et al. (2023) developed an innovative design idea for a light steel frame structure for rural areas that could reduce the structural design time by over 80% [29]. In Lombok, local wisdom and traditional construction methods have shown durability against natural disasters, compared to new concrete structures, which were disapproved of by village elders [30].

An earthquake-resistant house is proposed to solve the problem of reconstruction that occurs, namely, Steel Instant House (SIH), which is designed to have adequate seismic performance. This innovative solution aims to reduce the time and cost of rebuilding a house after a natural disaster, providing a safer and more sustainable option for communities in high-risk areas with a social culture. SIH with a light roof and sheathing combination is designed using welded joints that are rigid, which can increase the rigidity of the structural joints [31].

When the strength and elasticity of steel are combined with appropriate engineering and design, it makes SIH a safe option in earthquake areas for better structural performance [32]. Sutrisno et al. (2022) have modelled SIH and demonstrated that it remains in a linear state when attempted in a high seismic zone [33]. However, the steel structure with the sheathing combination house's performance in the pull-lateral test has not been investigated. This shows the need for further studies with laboratory tests to identify any deficiencies and their actual performance.

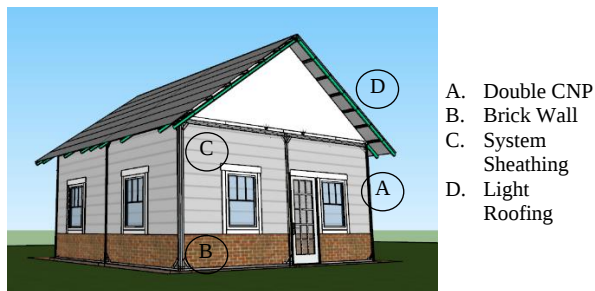


Fig.1 Illustration of RISBA

This study conducted a connection strength and failure of CFS stud and sheathing board, natural frequency, as well as seismic performance investigation of the SIH, namely RISBA, in Indonesia. The RISBA had dimensions of 6000 mm × 6000 mm × 3000 mm (length × width × height), as shown in Fig.1. The wall used a composite structure, with 300 cm height, a 60 cm brick wall at the base, including a mix of GRC boards inside and plank boards outside at 240 cm. The results were expected to provide valuable insights into the structural behavior of RISBA under seismic loading, which could be used to improve design

and construction.

In this study, the correlation between FEM simulations and laboratory experiments was observed, concentrating on force, displacement, and natural frequency. However, sheathing crack propagation was not estimated. The collapse time or phase was also observed to identify structural performance limits. Each effort to verify FEM accuracy and ensure that the numerical model accurately represents the structure's behavior helps design earthquake-resistant housing sustainably.

By understanding the relationship between lateral load resistance and displacement, engineers could better assess the performance of this structure during earthquakes. Additionally, identifying the failure modes would help identify potential weak points in the design that require strengthening to enhance overall structural performance and safety.

2. RESEARCH SIGNIFICANCE

The study on the seismic performance of steel instant houses for disaster reconstruction provides insights into their structural integrity and ductility, which improves resilience in high-risk earthquake zones. It also helps policymakers develop sustainable housing solutions. Additionally, the study introduces innovative lightweight steel configurations to enhance construction efficiency while maintaining safety and durability. Overall, this research contributes to creating more resilient and sustainable housing options for vulnerable populations in earthquake-prone areas.

3. METHODS

3.1 Experimental Methods

3.1.1 Sheathing to frame connection test

The specimens used are shown in Fig. 2. The adjustment procedure was developed using one self-drilling screw on one flange of one side of the CFS.

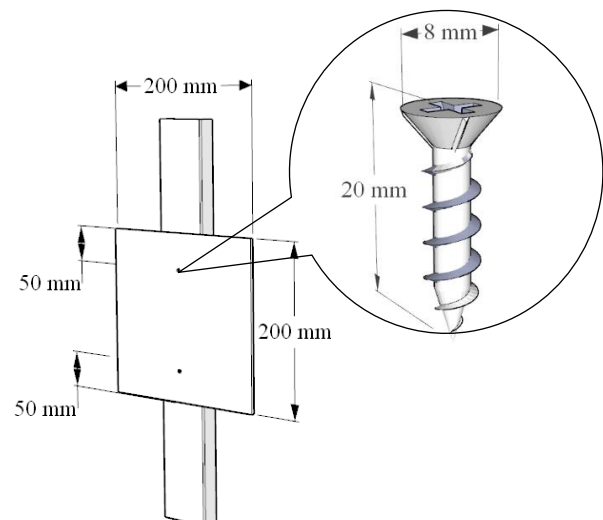


Fig.2 Sheathing to frame connection

Considering that the shear behavior of the joint may depend on the screw-sheath CFS profile system, a total of 8 specimens were designed and tested with UTM, aiming to investigate the influence of different materials. Configuration specimens were prepared by varying the thickness of the glass fiber reinforced concrete (GRC) board panel (4 mm) and the plank (8 mm) with a screw diameter of 4.2 mm and a CFS 75 strip thickness of 0.75 mm.

3.1.2 Vibration test

Natural frequency recording was measured using a 10.000 mV/g sensitivity accelerometer placed on the specimen near the beam-column connection, as shown in Fig.3. The test was conducted at ambient frequency and using vibrator. Subsequently, the responses were recorded in the data logger and could be analyzed later with Dewesoft software. This data would be crucial in understanding the dynamic behavior of the beam-column connection under different sheathing systems and conditions, with the procedures shown in Fig.4.

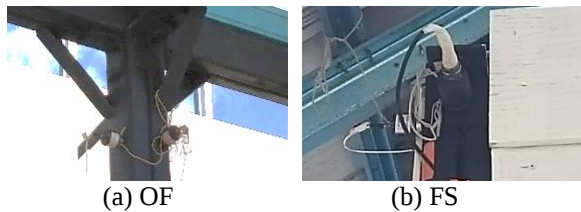


Fig.3 Accelerometer of X-Y direction

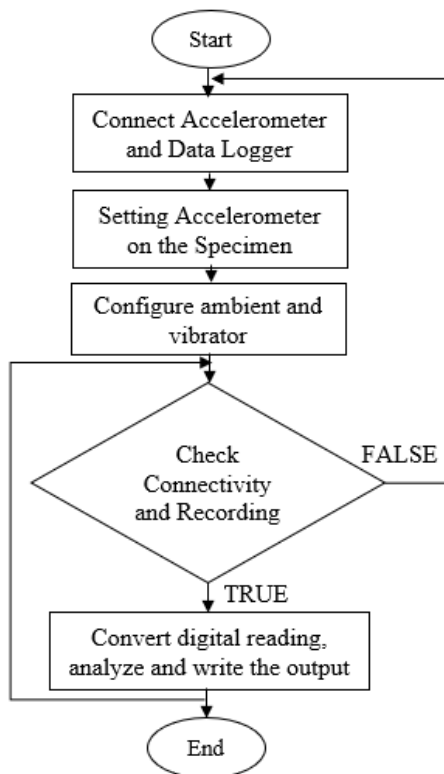


Fig.4 Flowchart of vibration test

3.1.3 Lateral test

The half of prototype SSIH Open Frame (OF) and Full Sheathing (FS) were tested under lateral load in Structural and Building Material Laboratory of Gadjah Mada University. The experimental setup for the lateral test is shown in Fig.5.

In the lateral load assignment, the hydraulic jack (10 tons capacity) was installed on static frame. To monitor the load magnitude, the loadcell was also installed on hydraulic jack and wire ends. To measure the displacement, LVDT (Linear Variable Differential Transducer) with a readability of 100 mm and an accuracy of 1/100 mm were installed at the top end of the column. The data recording tool used during the test was assisted with Dewesoft software.

The loading protocol used in the lateral test is shown in Fig.6. The two loadings protocol initiated with incremental loading and unloading, starting with a small load of approximately 2 kN, 4 kN, and 6 kN for OF as well as 5 kN, followed by 10 kN, and 15 kN for FS. Subsequently, the loading progressively increased until structure reached the point of failure, with the procedures shown in Fig.7.

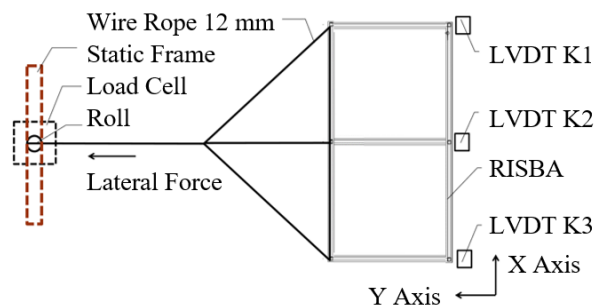


Fig.5 Lateral test plan

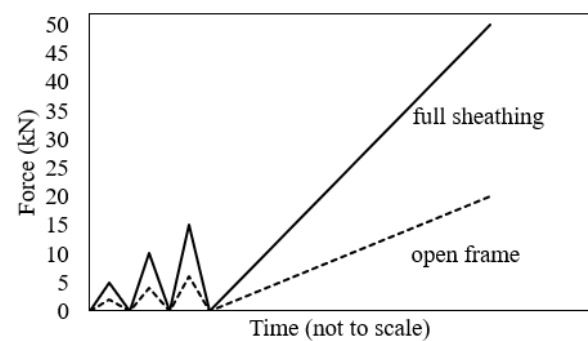


Fig.6 Loading protocol

One specimen of FS was constructed using a common CFS sheathing system [34], consisting of a 240 cm board wall system at the top, combined with a 60 cm brick wall at the bottom. The lateral test was carried out by applying a pull load to the half full-scale RISBA. The pull load was assigned to the elevation of the top beam, generating the deviation and the ability of structure to resist lateral forces.

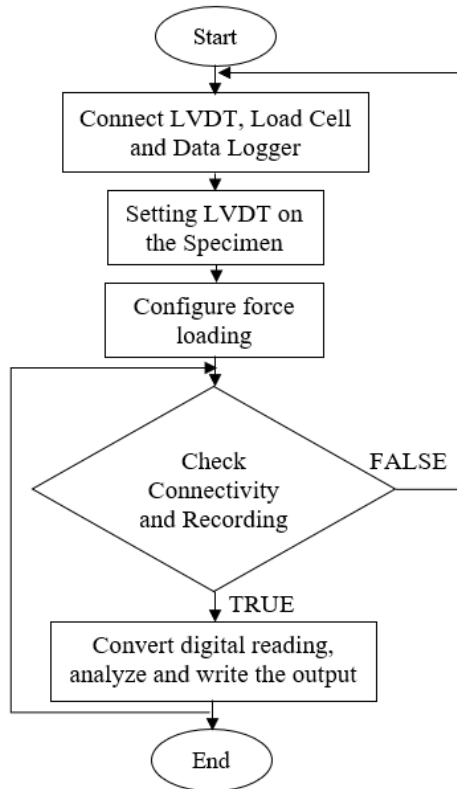


Fig.7 Flowchart of lateral test

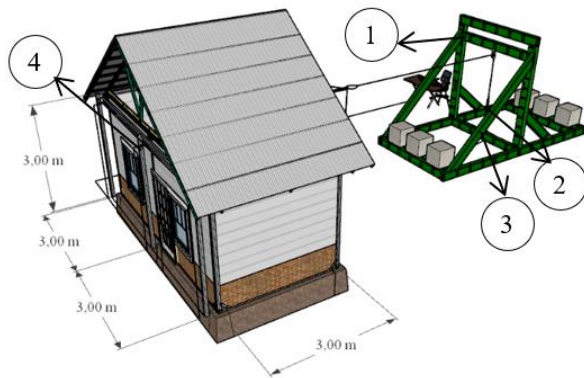


Fig.8 Lateral loading OF test setup

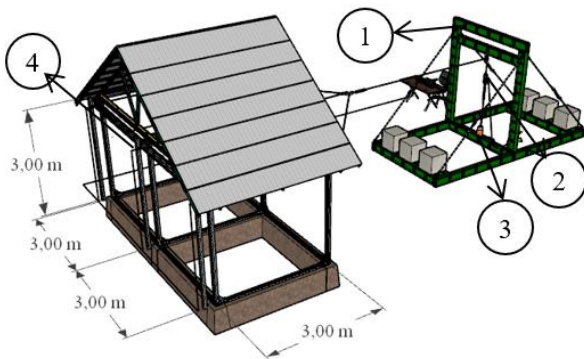


Fig.9 Lateral loading FS test setup

Table 1 Experimental devices

No.	Component
1	Static frame
2	Load Cell 10 Ton
3	Hydraulic Jack 10 Ton
4	Linear Variable Differential Transducer 100 mm

In the experimental test, there are two specimens of the half prototype of OF and one SF with a beam-column welded connection. OF-A and OF-B were the same prototype using a closed double channel section profile of CNP 95x33x10x1.8 for the entire column, beam, and single channel for tie beam sections. Regarding the beam-column connection, there are stiffeners with L40 and L70 angled steel profiles.

Details of the test setup and its specifications in the connection assembly work are shown in Figs. 8-9. The components used in the test setup are listed in Table 1.

3.2 Numerical Modeling

3.2.1 Sheathing to Frame Connection

The CFS frame, composed of thin-walled, CFS sections, is represented as beam elements. Meanwhile, the cement board material, made of membrane elements, shows rigidity and load-transferring capacity. Screws holding the board to the CFS frame played a significant role, while link elements were used to represent their behavior when loads slide and break under stress as well as shear. Link type used multilinear relationship, which defined the force-deformation relationship from the sheathing to frame connection test result, as shown in Fig.10.

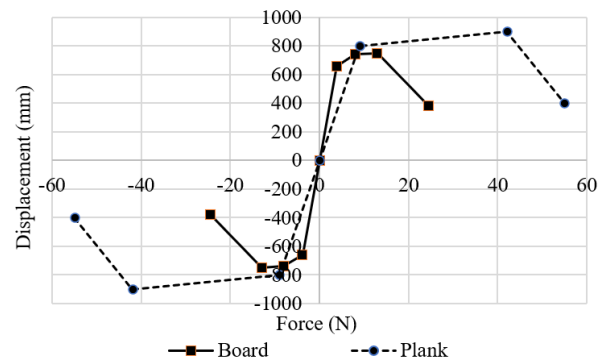


Fig.10 Multi-linear Force-Deformation Definition

3.2.2 Vibration

In this study, the numerical model of the half-prototype SSIH was developed with finite element method using SAP2000 commercial program, as shown in Fig.11. Model started by creating a computer model of structure. This included defining the geometry, material properties, and section properties of the RISBA elements. The modal analysis was conducted to verify natural frequency compared to the experimental result.

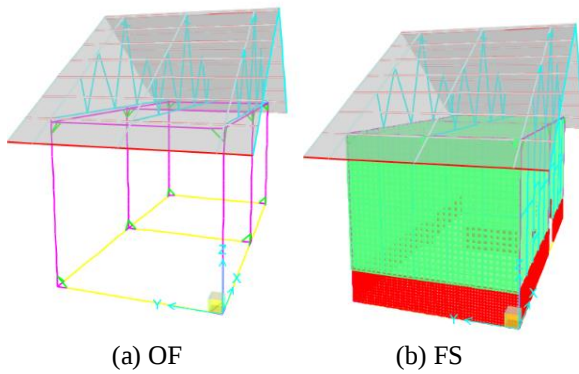


Fig.11 Numerical model

3.2.3 Lateral load

Lateral load uses pushover as a simplified nonlinear method to estimate seismic structural behavior and deformations. During this process, there is a need to define hinge properties, which are crucial for simulating nonlinear behavior during the pushover analysis and assign to the appropriate frame elements once the basic model is established. This is followed by setting up the load patterns and defining a nonlinear static load case specifically for the pushover analysis using displacement-controlled.

After the load case is configured, analysis is run and results are reviewed by plotting the static pushover curve, which shows the relationship between base shear and displacement. The static pushover curve can provide valuable insights into the structural behavior under lateral loads. The evaluation method for finding performance points follows the ATC-40 capacity spectrum, which is showed by the intersection of the demand spectrum as well as capacity curves.

In pushover analysis, boundary conditions play a critical role in accurately simulating the structural response under lateral loading. The base of structure is pinned to allow rotation but restricts horizontal and vertical movement, which can be useful for analyzing specific structural configurations and essential for simulating realistic seismic conditions under lateral loading scenarios. Properly defining these conditions ensures that the pushover analysis yields reliable data on structure's capacity and performance under lateral loads, thereby aiding in effective seismic design strategies.

4. RESULT AND DISCUSSION

4.1 Sheathing to Frame Connection Test

The test results for GRC force and damages are shown in Figures 12–15. The damaged GRC board connection includes a screw pulled through the GRC. Meanwhile, the affected GRC plank has a screw that was pulled out from the CFS. There are several factors contributing to screw damage. The installation structure plays a role in avoiding damage, with screw

extrusion from the board being the primary element affecting load-deformation curves and shear damage in screw connections [35].

The type of screw head and insertion method can impact the number of damages during installation. Specifically, pan-head screws show better performance than countersunk, when combined with pilot-hole pre-drilling methods [36]. Understanding these factors and implementing appropriate installation methods can help mitigate screw damage in GRC boards effectively.

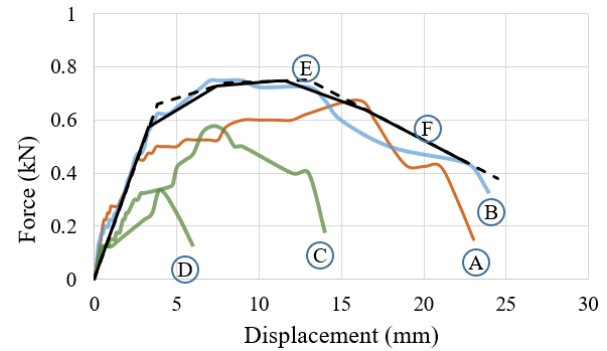


Fig.12 Force vs displacement of GRC-CFS (A, B, C, D), input FEM (E) and output FEM (F)

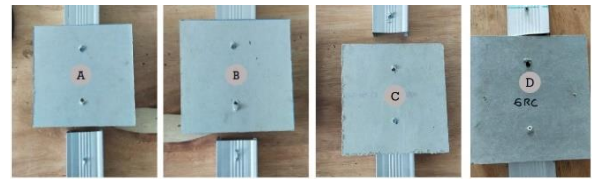


Fig.13 The GRC board damage: screw pulled through the GRC

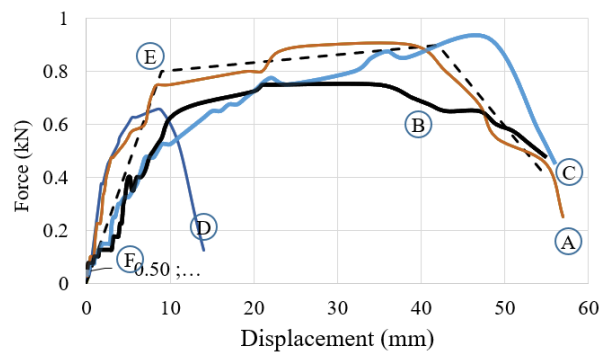


Fig.14 Force vs displacement of GRC plank-CFS (A, B, C, D), input SAP (E), and output SAP (F)

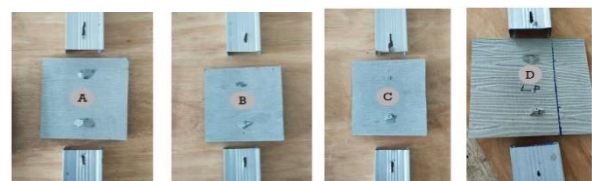


Fig.15 The GRC plank damage: screw pulled out from the CFS.

4.2 Vibration Test

Model analysis shows that the OF's natural frequency on both the X and Y axes are 3.63 Hz and 3.11 Hz, while SF has 16.30 Hz and 16.29 Hz, respectively. The numerical model output frequency is shown in Figs. 18-19. Based on the experiment, the OF natural frequency on both the X and Y axes is 3.17 Hz and 4.24 Hz, while SF has 16.50 Hz and 16.80 Hz, respectively, as shown in Figs. 16-17.

All results obtained on both numerical modeling and experiment analysis are higher than the dominant natural frequency of the ground surface in Palu and Lombok, which are approximately 0.47 Hz and 1.97 Hz [37] and 0.13 Hz [38], respectively, confirming reduced resonance risks compared to seismic ground motion frequencies [39, 40].

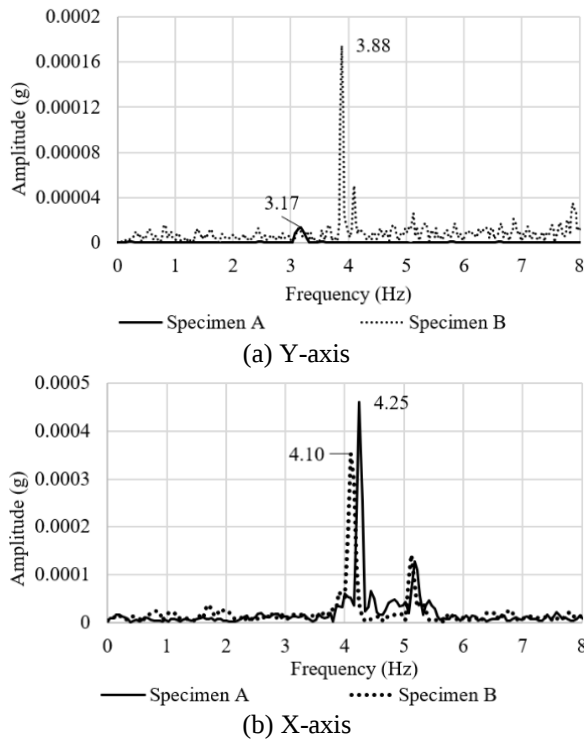


Fig.16 OF natural frequency

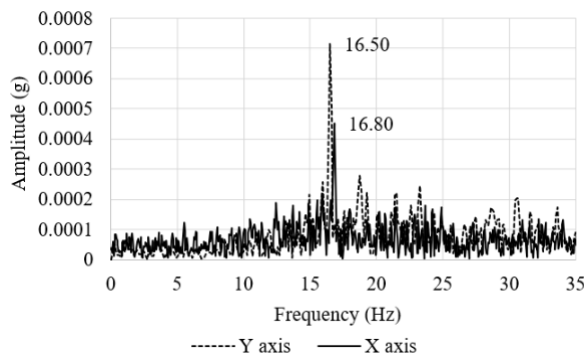


Fig.17 FS natural frequency

The frequency of the X axis, or east-west direction, has a slightly higher value than the Y axis, or north-south direction. This shows that the X-axis has greater rigidity. The X is the 6 m long house direction, and the Y is 3 m wide. The difference in rigidity between the X and Y axes can be attributed to the orientation and dimensions of the house. The longer span of the house in the X axis allows for more stiffness and resistance to lateral forces compared to the shorter span in the Y axis.

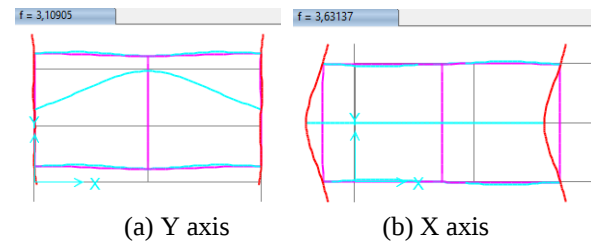


Fig.18 OF mode

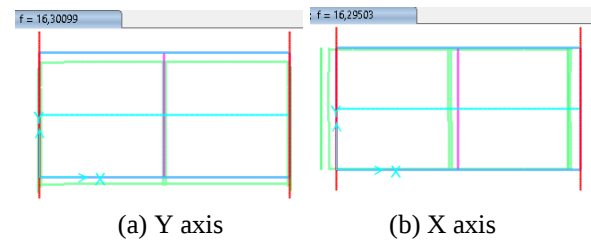


Fig.19 FS mode

These results are essential for assessing the structural stability and seismic performance of buildings in high-risk areas such as Palu and Lombok, where earthquakes are common.

4.3 Lateral Test

RISBA OF and SF modeling is performed by loading on the top of the frame which causes displacement. This correlates with the ability of structure to have an optimal displacement target.

The demand spectra were developed from the 2019 earthquake zone map [41], a recent map in Indonesia. The curve was included in Palu and in Lombok to produce performance point as a meeting point between the pushover analysis output and the demand spectra curve shown in Fig.20. Based on the pushover and demand spectra analysis, performance of RISBA was still in an elastic condition and could be considered safe.

The analysis showed that structure in Palu and Lombok had a sufficient margin of safety against seismic events, with the capacity of house exceeding the calculated demand. This showed that house was well-designed and constructed to withstand potential earthquakes in the area. The results of the analysis provided reassurance to community and stakeholders regarding the safety as well as reliability of structure in these earthquake-prone areas.

FEM analysis for the Lombok and Palu earthquakes showed that performance points were still in a linear condition. Both FEM results of natural frequency of 3-4 Hz and 16 Hz for OF and SF were less susceptible to resonating with earthquake vibrations.

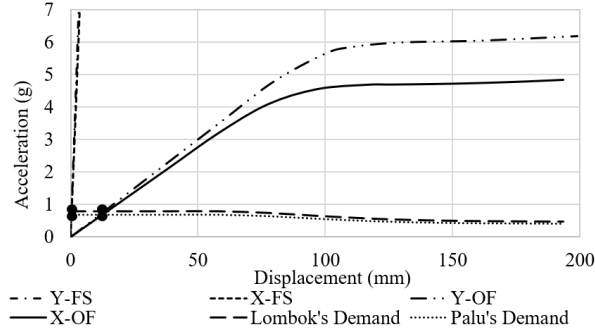


Fig.20 Performance point

The test results show that RISBA can withstand significant drift without experiencing any structural and architectural damage, as presented in Figs.21-22. The lateral test and analysis result of OF welded joints are shown in Figs.23-25.

The tests showed that OF welded joints could deform to approximately 150 mm or drift more than 5% without damage at the O, IO, and LS levels. The results showed that the specimens could cover approximately 18 kN, four times the weight of structure.



Fig.21 Specimen OF after loading: significant drift without experiencing any structural damage

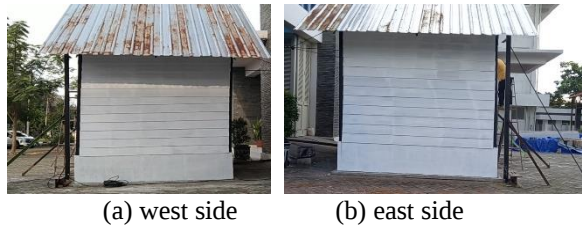


Fig.22 Specimen FS after loading: significant drift without experiencing any architectural damage

The laboratory tests proved that the OF welded joints showed excellent ductility, particularly at the O, IO, and LS levels. At the CP level, yield damage occurred in the bottom beam profile. This suggested that reinforcement or modifications could be necessary to enhance the overall structural integrity of house.

Based on the analysis, OF welded joints were highly resilient and could withstand extensive seismic activity.

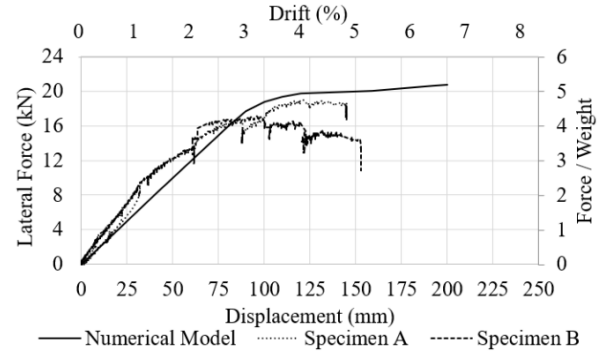


Fig.23 OF lateral force vs Y displacement K1

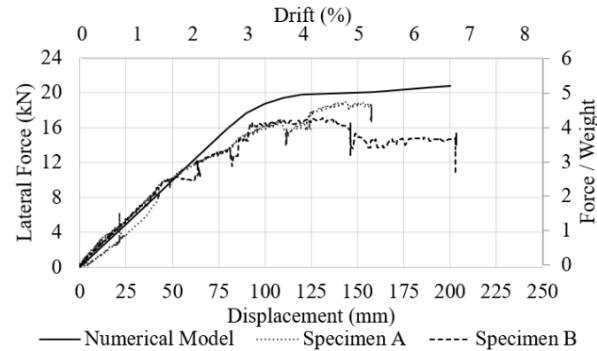


Fig.24 OF lateral force vs Y displacement K2

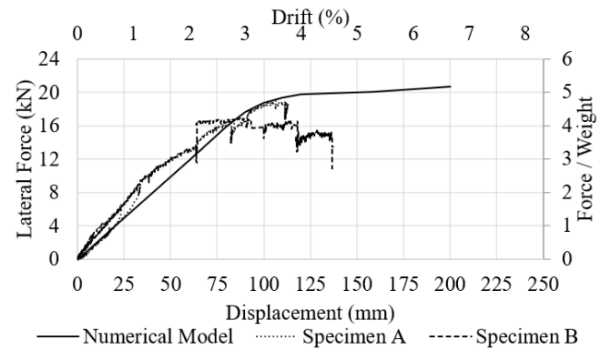


Fig.25 OF lateral force vs Y displacement K3

The result in Fig. 26 showed that RISBA-FS in laboratory tests was able to withstand loads of 45 kN, approximately 1.5 times the weight of structure. RISBA-FS was able to deform approximately 125 mm or drift more than 3.25% without damage to the O, IO, and LS levels. At the CP level, yield damage occurred at the middle column near the top of the 60 cm brick wall. Localized failures near brick walls have the potential to cause masonry crushing and disintegration. Tie-columns, crucial for vertical stability, can fail due to buckling and inadequate ties [42]. Diagonal cracking and spalling of face shells in boundary elements can also indicate failure mechanisms [43], which requires

reinforcement considerations to prevent further damage and collapse of the structure [44].

In previous studies, RISBA design under the 2018 Palu and Lombok earthquake loading showed the capability to respond almost elastically even in very high seismic regions. Based on the laboratory tests, the capacity of steel and joint components used in the Yogyakarta, Lombok, and Palu earthquake loads was still elastic [45], with damage occurring only in the bottom beam [46]. This was critical in absorbing seismic energy and reducing joint system damage [47].

The test results showed good agreement with the FEM analysis in the buckling mode and load-displacement curves. Performance requirement as shown in Table 2 could be covered when specimens were still in a linear condition.

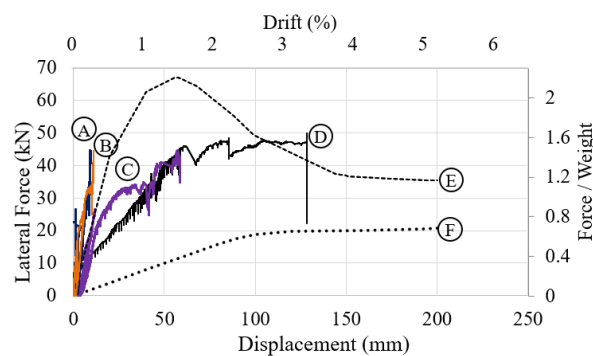


Fig.26 FS lateral force vs Y displacement at (a) K1; (b) K2; (c) K3; (d) K3-collapse; FEM (e)FS and (f) OF

Table 2 Deformation limit ATC's performance

Interstory Drift Limit	Immediate Occupancy	Damage Control	Life Safety	Structural Stability
Maximum Total Drift	0.01	0.01-0.02	0.02	$0.033 \frac{V_i}{P_i} \approx 0.05$
Maximum Inelastic Drift	0.005	0.005-0.015	No Limit	No Limit

Performance level must meet the requirements of Table C2-3, ASCE 41. The requirements for structure in 1% drift (immediate occupancy) and 2% drift (life safety) include the absence of permanent drift at structure components. Furthermore, structure substantially retains original strength and stiffness, negligible damage only occurs at non-structural components, all systems necessary to operate normally are functional, and continued occupancy is likely high. When structure reaches 5% drift (structural stability), the requirement is that there is small residual stiffness and strength to resist lateral loads, gravity load-bearing columns are still in function, large permanent drift and structure will be near collapse, suggesting no occupancy.

The tie beam flange bends at the anchor point of the RISBA OF, as shown in Fig.27. This can lead to reduced load-carrying capacity and potential structural failure. Therefore, immediate reinforcement at the

anchor point is essential to ensure the tie beam flange is properly supported and avoid collapse of the entire structure. It can also prevent any potential structural failures and ensure the safety of house and occupants.



Fig.27 Bending beam: (a) OF-A and (b) OF-B

In FS, a brick wall of 60 cm in height was applied to avoid bending at the bottom beam. As shown in the figures below, damage occurred while the load increased. Cracks started to appear on the sheathing and brick wall as the load on the top beam increased beyond its capacity.

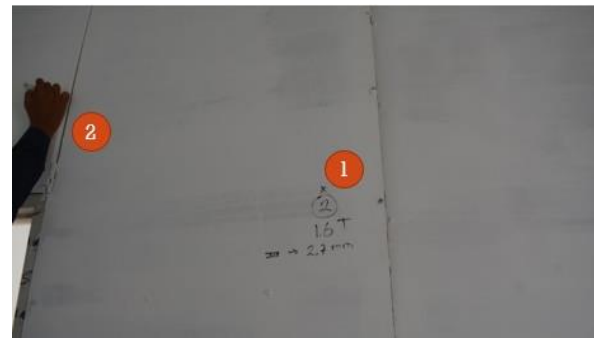


Fig.28 GRC board damage at 10 kN: screws in the vertical direction are pulled through the GRC

At load 10 kN, the screws on the middle wall in the vertical direction are pulled out from the GRC (pull trough) until half the height of the top wall. This started at the wall above the door and cracks began to occur in the GRC (Fig. 28). The cracks in the GRC wall appeared to be spreading, showing that the load was reaching a critical point.

The brick wall efficiently provided support to the bottom beam and prevented bending when exposed to pressure. This design method showed effectiveness in preserving the structural integrity, thereby assuring the ability to endure increasing load without any compromise. The brick wall served as a strong structural element, uniformly distributing the load and preventing any possible deformation or buckling. The adoption of brick wall in FS is essential to ensure durability and stability throughout different magnitudes of seismic activity.

The plaster of the brick wall has hairline cracks at the location of the center column when the load reaches 20 kN (Fig.29). On the corner side, the plaster starts vertical hairline cracks, where pull loads are applied to structure. These cracks show that there may be

excessive movement or deformation in structure, causing stress on the plaster. Therefore, immediate action is essential to prevent further damage to the wall, ensuring the stability and integrity of house.

Under the top 60-cm brick wall, the plaster has wide cracks in the vertical direction at the cover column. The GRC board of the wall in the same load direction begins to break at the bottom and top corners. The implications of the GRC board breaking in terms of safety and stability are critical to the overall safety of house and occupants.



Fig.29 Plaster cracking damage at 20 kN: the plaster starts hairline cracks at the column

Although the load reached 30 kN, more screws on the wall parallel load directions in the vertical and horizontal joints were pulled out from the GRC (Fig. 30). Damage occurred because the load distribution exceeded the GRC resistance limit on the screw. This led to failure of the GRC panel system, causing detachment from the wall and structural instability.

The pictures (Figs. 31–32) show that GRC boards can be used on walls even if screws are taken out on one side of the vertical wall, leaving a gap. This demonstration shows the strength and durability of GRC boards in withstanding an external load of 50 kN. Even though there is a pull-through on one side, the GRC boards are still stable and secure, making them a good choice for building walls. This quality makes GRC boards a popular option for builders and contractors searching for long-lasting and resilient house materials.



Fig.30 Sheathing damage at 30 kN: more screws on the wall were pulled through the GRC

CFS experiences deformation following structure after GRC is removed (Fig.31). The opening of the door causes the middle wall to experience more severe deformation. This causes damage to structure, bending the center column parallel to the top of the 60-cm brick wall.



Fig.31 Sheathing damage at 40 kN: bigger plaster cracks and screws are taken out



Fig.32 Sheathing damage at 50 kN: a pull-through on one side and the plank are still stable



Fig.33 Frame damage at 50 kN: the central column bends and the structure deforms

When subjected to deformation exceeding 100 mm and a weight of 50kN, the list plank board serving as the outside wall of RISBA FS remained completely undamaged. The plank board shows great structural integrity and strength, capable of enduring severe deformation without any indications of weakness or degradation. This result shows promising short-term performance and attests to the high quality and potential selection of materials used in the construction

of RISBA FS, which is sufficiently ductile and does not collapse suddenly.

Although the results offer valuable insights into the structural performance of the FS systems, real-world scenarios often include unpredictable factors, such as soil variability, construction inconsistencies, environmental exposure, and dynamic loading complexities that are not fully captured in laboratory tests. Fixing these limitations would make the results clearer and more trustworthy, serving as guide future studies, leading to stronger and more dependable uses in post-disaster housing.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, both RISBA OF and FS welded joints showed excellent strength and ductility, particularly under extreme loading conditions. Additionally, the joints showed significant resistance to earthquake-induced forces, indicating their ideal use in structural applications where seismic activity posed a concern. This study showed the potential of welded joints as effective solutions for efforts to mitigate earthquake disasters.

Specimens could record natural frequencies that were less likely to resonate with earthquake vibrations, thereby providing appropriate information for performance levels related to life safety with negligible damage. The information could assist the authorities in promptly responding to earthquakes and preventing the collapse of houses during an emergency. This alternative solution effectively resolved the reconstruction issue and guaranteed that community with low and middle incomes had access to secure housing options in the event of a natural disaster.

The results showed that community used local wisdom to engage in social activities, enhancing the brick wall's functionality and cultural significance. This fostered unity, communication, and strong social bonds, thereby preserving the community unique heritage and identity.

5.2 Recommendation

Future studies should focus on field testing, advanced seismic simulation methods, optimizing steel alloys, modular joints, and hybrid materials to enhance seismic performance, multi-hazard resilience, and socioeconomic studies to support large-scale, sustainable post-disaster reconstruction efforts worldwide.

6. ACKNOWLEDGMENTS

The authors are grateful to Gadjah Mada University for approving this study.

7. REFERENCES

- [1] Clinton W.J., Key Propositions for Building Back Better, UN Secretary-General's Special Envoy for Tsunami Recovery, 2006, pp.1-24
- [2] Venable C., Javernick-Will A. and Liel A.B., Built Back Better? An Analysis of Perceived Performance of Post-Disaster Housing, In Engineering Projects and Organizations Conference (EPOC) - (Re)Organizing in an Uncertain Climate, 2018, pp. 348–366.
- [3] Sarkar R., Post-Earthquake Reconstruction—in Context of Housing, *Advances in Geosciences*, 2006, pp. 91-104
- [4] Zulfiar M.H. and Jayady A., Vulnerability Study in the Construction Sector for Earthquake Disaster Risk Reduction, *Karkasa*, Vol. 4, No. 1, 2018, pp. 21–27.
- [5] Bakti H.K. and Nurmandi A., Post-Disaster Recovery of the Earthquake in North Lombok in 2018, *Geografi*, Vol. 12, No. 02, 2020, pp. 137-151.
- [6] Kamsuta E., Irawanto H.V., Rahmawati and Widayanti B.H., The Effectiveness of Building Risha, Rika, and Riko (3R) Houses for Earthquake-Affected Communities, *Planoeath*, Vol. 5, No. 1, 2020, pp. 20–24.
- [7] Siddika A., Awall Md.R., Al Mamun Md.A. and Humyra T., Study on Natural Frequency of Frame Structures, *Computational Engineering and Physical Modeling 2-2*, 2019, pp. 36-48.
- [8] Jennings P.C., An Introduction to the Earthquake Response of Structures. *International Geophysics Volume 81, Part B*, 2003, pp. 1097-1125.
- [9] Mezzi M., Parducci A. and Verducci P., Architectural and Structural Configurations of Buildings With Innovative Aseismic Systems, *13th World Conference on Earthquake Engineering Vancouver, B.C., Canada*, Paper No. 1318, 2004, pp. 1-12.
- [10] Selvaraj S. and Madhavan M., Investigation on Sheathing-fastener Connection Failures in Cold-formed Steel Wall Panels, *Structures* 20, 2019, pp. 176–188
- [11] Selvaraj S., Madhavan M. and Lau H.H., Sheathing-fastener Connection Strength Based Design Method for Sheathed CFS Point-symmetric Wall Frame Studs, *Structures* 33, 2021, pp. 1473–1494
- [12] Liu Y., Li H., Shi Y., Xiong G., Li H. and Zhe Z., Lateral Resistance of Assembled Cold-formed Steel Walls Sheathed with An Integrated Board, *Journal of Constructional Steel Research* 221, 2024, pp. 1-23.
- [13] Zhou N., Shi W. and Shang J., Seismic Response of A Light Steel Structure Integrated Building with Steel Mortise–tenon Connections, *Advances in Structural Engineering*, Vol. 22 (5), 2019, pp. 1225–1237.
- [14] Mendes P.E.R., Structural Design of a Light Steel

- Frame Dwelling, Dissertação Departamento de Engenharia Civil, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal, 2019, pp. 1-94
- [15] Dubina D., Behavior and Performance of Cold-Formed Steel-framed Houses Under Seismic Action, *Journal of Constructional Steel Research* 64, 2008, pp. 896–913.
- [16] Pan Y., Ventura C.E. and Finn W.D.L., Effects of Ground Motion Duration on the Seismic Performance and Collapse Rate of Light-Frame Wood Houses, *J. Struct. Eng.*, 144(8): 04018112, 2018, pp. 1-11.
- [17] Zhou N., Shi W. and Shang J., Seismic Response of A Light Steel Structure Integrated Building with Mortise–tenon Connections, *Advances in Structural Engineering* Vol. 22(5), 2019, pp. 1225–1237.
- [18] Zhang J.F., Zhao J.J., Yang D.Y., Deng E.F., Wang H., Pang S.Y., Cai L.M. and Gao S.C., Mechanical-property Tests on Assembled-type Light Steel Modular House, *Journal of Constructional Steel Research* 168: 105981, 2020, pp. 1-12.
- [19] Bianchi P.F., Yepes V., Vitorio P.C. and Kripka M., Study of Alternatives for the Design of Sustainable Low-Income Housing in Brazil, *Sustainability* 13: 4757, 2021, pp. 1-15.
- [20] Ramadhan T., Paramita B. and Srinivasan R.S., Study of Cost and Construction Speed of Cladding Wall for Lightweight Steel Frame (LSF), *Buildings* 12: 1958, 2022, pp. 1-14.
- [21] Taylor C., Roy K., Dani A.A., Lim J.B.P., De Silva K. and Jones M., Delivering Sustainable Housing through Material Choice, *Sustainability* 15: 3331, 2023, pp. 1-16.
- [22] Li Q., Wumaier K. and Osamu K., Post-Earthquake Housing Reconstruction Management and Implementation in Rural Areas: Review and Lessons from Dujiangyan, Wenchuan Earthquake, *Buildings* 13(9): 2251, 2023, pp. 1-17.
- [23] Awaludin A., Adiyuano Y. and Mursyid F.A., RISBARI: An alternative house model for the 2018 Lombok earthquake affected people. In *IOP Conference Series: Materials Science and Engineering*, Institute of Physics Publishing, 2020, pp. 1-9.
- [24] Aulady M.F.N. and Fujimi T., Earthquake Loss Estimation of Residential Buildings in Bantul Regency Indonesia, *Jamba: Journal of Disaster Risk Studies*, Vol. 11, No. 1, 2019, pp. 1–10.
- [25] Amalia A.R. and Iranata D., Alternative Design of Post-earthquake Temporary Housing in Indonesia, *Civil Engineering and Architecture*, Vol. 8, No. 3, 2020, pp. 289–296.
- [26] Hijah S.N. and Komarudin M., Rehabilitation and Reconstruction Post-Lombok Earthquake, West Nusa Tenggara Province, 2018, In *Seminar Nasional Teknik Sipil*, 2019, pp. 1–8.
- [27] Widayanti B.H., Yuniarman A., Lestari S.A.P., and Yuniarti S. R., The level of satisfaction in construction of post-earthquake houses in Tanjung Sub-district, North Lombok Regency, *IOP Conf. Series: Earth and Environmental Science* 447: 012028, 2020, pp. 1-8.
- [28] Morganti R. and Tosone A., Building for Housing: Steel Technologies, *Int. Journal for Housing Science*, Vol.34, No.2, 2010, pp. 127-138.
- [29] Sun K., Zhou T., Chen Z., Liu H. and Yang Z., Intelligent Design Concept of Rural Light Steel Frame Structure Based on BIM Technology and Genetic Algorithm, *International Journal of Steel Structures* 23(5), 2023, pp. 1343–1356.
- [30] Paramastri M.A., Community Development, Local Wisdoms, and Ineffective Government Aid: The Case of Lombok Post-Disaster House Reconstruction Project, *Global South Review* Vol.2, 2020, pp. 136-155.
- [31] Komara I., Wahyuni E. and Suprobo P., A study on Cold-formed Steel Frame Connection: A review, *The Journal for Technology and Science*, Vol. 28, No. 3, 2017, pp. 83-89.
- [32] Anujdomale and Kalurkar L.G., Seismic Analysis of RCC and Steel Frame Structure by Using ETABS, *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, Vol. 15, No. 2, 2018, pp. 38–42.
- [33] Sutrisno W., Satyarno I., Awaludin A., Saputra A. and Setiawan A.F., Seismic Performance of Instant Steel Frame House for Post-Earthquake Reconstruction, In *Lecture Notes in Civil Engineering*, Springer Science and Business Media Deutschland GmbH, 2022, pp. 81–97.
- [34] Madsen R.L., Castle T.A. and Schafer B.W., Seismic Design of Cold-Formed Steel Lateral Load-Resisting Systems, *NEHRP Seismic Design Technical Brief* No. 12, 2016, pp. 1-52
- [35] Xingxing W., Wei W., Jihong Y. and Yutian W., Seismic Damage Model for Gypsum Board-to-CFS Stud Screw Connections Considering Ground Motion Duration, *Engineering Structures* 280: 115688, 2023, pp. 1-10
- [36] Abu F. and Ahmad M., Assessment in Screw Fixing Damages of Particleboard Surface: Difference in Screw Head and Self-drilling Features, *Advanced Materials Research* Vol. 748, 2013, pp. 331-335
- [37] Kurniawan M., Brotopuspito K.S. and Setianto A., Study of Soil Seismic Vulnerability Against The Natural Frequency of Buildings in Palu City Based on Microtremor Data, *Proceeding, In Seminar Nasional Kebumihan Ke-9*, 2016, pp. 1-8.
- [38] Azmiyati U., Brotopuspito K.S. and Dibyosaputro S., Building vulnerability to earthquake in Mataram City West Nusa Tenggara, *Riset Kebencanaan Indonesia*, Vol. 2 No. 1, 2016, pp. 77-84.
- [39] Siddika A., Awall M.R., Mamun M.A.Al. and

- Humyra T., Study on Natural Frequency of Frame Structures. Computational Engineering and Physical Modeling 2-2, 2019, pp. 36–48.
- [40] Mase L.Z., Likitlersuang S. and Tobita T., Ground Motion Parameters and Resonance Effect During Strong Earthquake in Northern Thailand, Geotechnical and Geological Engineering 39, 2021, pp. 2207–2219
- [41] National Center for Earthquake Studies, Indonesian Earthquake Hazard De-aggregation Map for Planning and Evaluation of Earthquake-Resistant Infrastructure, Ministry of Public Works and Public Housing, 2022, pp. 1-386.
- [42] Meli R., Brzev S., Astroza M., Boen T., Crisafulli F., Dai J., Farsi M., Hart T., Mebarki A., Moghadam A. S., Quiun D., Tomazevic M. and Yamin L., Seismic Design Guide for Low-Rise Confined Masonry Buildings, Confined Masonry Network, 2011, pp. 1–90.
- [43] Banting B., Seismic Performance Quantification of Concrete Block Masonry Structural Walls with Confined Boundary Elements and Development of the Normal Strain-adjusted Shear Strength Expression (NSSSE), Thesis, McMaster University, 2013, pp. 1–212.
- [44] Sabouni A.R., Advances in Reinforced Concrete Integrity and Failure, Chapter in Advances in Structural Integrity and Failure, IntechOpen, 2023, pp. 1–34.
- [45] Putra S.S.K., Satyarno I. and Saputra A., Study of the Behavior of Sloof Beam Column Double CNP Connections in Instant Steel Structure Houses (RISBA) Under Monotonic Loading, In Civil Engineering, Environmental, Disaster, and Risk Management Symposium (CEEDRiMS), 2021, pp. 184–191.
- [46] Kianjaya H.S., Satyarno, I. and Suhendro B., Experimental Study of Sloof Column Beams in Instant Steel Structure Houses Using Cyclic Loading Method, Jurnal Teknik Sipil. Vol. 16, No. 3, 2021, pp. 159–168.
- [47] Pratama H.Y., Setiawan A.F., Saputra A., Satyarno I. and Putra W.T., Cyclic Loading Test Of Clamped Split Pocket, Mechanism As A Beam-Column Joint System, International Journal of GEOMATE, Vol.27, Issue 119, 2024, pp. 78-91

Copyright © Int. J. of GEOMATE All rights reserved, including making copies, unless permission is obtained from the copyright proprietors.
