

Seismic Evaluation of High-Rise Building Performance During Earthquakes by Employing Shear Wall Framing Systems

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Abstract

It is vital to consider earthquakes in high-rise building design due to the potential seismic hazards that can pose substantial dangers to the structural integrity and safety of these structures. These buildings are more prone to lateral forces and vibrations during an earthquake, given their height and mass. Incorporating seismic design measures, such as the use of shear walls, helps mitigate the effect of earthquakes on tall buildings, ensuring their resilience and the protection of human life and buildings. Designing structures exclusively for seismic protection may be economically impractical, given the rare occurrence of earthquakes during a structure's lifespan. Despite the infrequency of earthquakes in Malaysia, concerns among Malaysians have arisen due to seismic activities in neighbouring countries, prompting a need for considerations in constructing structures that address both economic feasibility and potential seismic threats. This research focuses on evaluating the seismic performance of a 50-story tall building during earthquakes, utilizing shear wall framing systems. Response spectrum analysis is applied to assess various parameters such as displacement, drift, and stiffness at different levels. The results of these parameters in a building with shear walls positioned at both the centre and corners are compared to those of a structure lacking shear walls. The study reveals that the placement of shear walls and the symmetry of the frame impact the building's performance during earthquakes. According to the findings, structures with shear walls demonstrate better resistance to deformation caused by seismic loads compared to buildings without shear walls. Therefore, integrating shear walls into tall buildings proves to be an advantageous strategy for mitigating seismic damage in high-rise structures. Therefore, incorporating shear walls into tall buildings proves to be a beneficial approach to mitigate seismic damage in high-rise structures.

1. Introduction

Structural damage poses major dangers to building stability, compromising safety and functionality and impacts community resilience [1], [2]. Effective assessment and repair strategies are vital for restoring structural

integrity and minimizing risks, informing emergency responses and policy decisions for long-term sustainability [3]-[5]. Earthquakes generate ground motion that, if not properly addressed in the design, can lead to structural damage, collapse, or compromise the safety of occupants. Seismic waves, generated by a fault rupture, propagate in all directions. Many structures in Malaysia were not designed to resist seismic activity. Consequently, when an earthquake happens, the impact on buildings can be severe. Earthquakes can expose high-rise buildings to severe shaking, leading to structural damage such as cracks, fractures, or even collapse. The size of damage depends on factors like the building's design, construction materials, and the intensity of the earthquake [6]-[10].

The design of high-rise buildings is principally influenced by wind and seismic loads, necessitating accuracy and adherence to the MS EN 1998-1 code for seismic design. Despite Malaysia not being in the Pacific Ring of Fire, which is more disposed to earthquakes, the country is encompassed by regions prone to seismic activity, exhibiting natural threats that require to be considered in building design. Malaysia has witnessed several notable tremors resulting from earthquakes in neighbouring countries such as Indonesia. Unlike decades ago, when earthquakes seemed improbable in our region, a growing trend since 1984 has revealed increased tremors, with the strongest registering at a magnitude of 5 on the Richter scale in the Kenyir Dam area. Notable instances include tremors in Bukit Tinggi, Pahang on Nov 30, 2007, Jerantut, Pahang on March 27, 2009 (magnitude 2.6 Richter scale), and a significant event in Manjung, Perak on April 29, 2009, reaching a magnitude as high as 3.2 on the Richter Scale [11]-[14]. In 2015, Sabah experienced its most serious earthquake, measuring 5.9 on the Richter scale, resulting in damage to structures and infrastructure. This damage was attributed to Malaysia's prior adherence to British Standards, which required seismic protections.

In recent years, tall buildings in Kuala Lumpur have experienced shakes, attributed to the 1500 km-long Sumatra Fault system, located just 350 km away at its closest point from Peninsular Malaysia [15]-[17]. Malaysians were shocked on Nov 26, 2004, by the Sumatra-Andaman earthquake, which, with a severity of 9 on the Richter scale, had a profound and direct effect on the country. The resulting tsunami led to numerous casualties, recording 50 deaths in Malaysia alone, and caused significant disruption, particularly for residents in high-rise buildings in the western states of the Peninsula [18]. Consequently, it has been confirmed that Malaysia is not as resistant to earthquake catastrophes as previously believed. Civil structures in Malaysia were usually designed considering only vertical dead load and living load, without consideration for the lateral load imposed by earthquakes. Due to the potential for severe earthquakes to compromise structural integrity, further study and assessments are essential, especially for densely occupied structures like hospitals, schools, and offices, to implement practical measures to address this concern.

In 2017, Malaysia established the implementation of the MS EN 1998-1 national code of practice for designing structures to withstand seismic forces, granting for the integration of criteria in building design to improve earthquake resilience [19]. This code is vital for all design processes in Malaysia to ensure the prevention of disastrous occurrences, such as building collapses. While Malaysia has not experienced earthquakes directly, the seismic activity in neighbouring countries can potentially impact the buildings through transmitted waves. To improve the stability of buildings in the appearance of earthquakes, Malaysia should start an assessment of all structural aspects that could contribute to the earthquake. Several strategies exist to avoid structural collapse, and one effective approach usually employed involves installing shear walls within a building. This practical method has gained extensive function as a reliable means of ensuring structural stability and preventing potential failures [20]-[25]. Shear walls play a crucial role in tall buildings, remarkably in seismic regions and exhibit notable stiffness, providing substantial resistance.

Employing shear walls strategically within a structure can establish an effective system for resisting lateral forces [26]-[28]. Ozkul et al. [29] investigated the impact of shear walls on the seismic performance of reinforced concrete frame buildings, examining two existing structures with strategically placed shear walls. The study proven the successful and cost-efficient use of shear walls to improve building stiffness. Kamarudin et al. [30] observed that employing proper materials and shear walls can avoid severe damages, even in cases where the seismic response of beams and columns is inadequate. The research by Lou et al. [31] showed that shear walls notably contribute to the building's strength and stiffness along their orientation, efficiently reducing lateral sway and thereby extending the structure's lifespan. Moving on, the research conducted by Khademi et al. [32] investigated the seismic resistance of high-rise buildings with RC shear walls and steel concentrically braced systems. The findings indicated that, in comparison to buildings with RC shear walls, structures with steel dual concentric bracing showed a reduced resistance index. In another study, Simon et al. [33] conducted research on the position and orientation of shear walls in RC buildings to achieve deflection and drifts. According to the results, it has been determined that locating shear walls at the boundary is the optimal selection for managing the deflection and drifts of RC buildings.

This study investigates how tall buildings perform under seismic conditions when constructed with reinforced concrete shear wall framing systems. The focus is on evaluating how shear walls influence a building's capacity to resist lateral forces. To conduct the analysis, ETABS Software and the response spectrum method are employed. The search comprehensively evaluates parameters such as storey displacement, storey

drift, and storey stiffness, aiming to provide a thorough understanding of the seismic behavior demonstrated by the structures.

2. Material and Methods

In this research, seismic performance analysis is conducted on a structure located in the city of Penang, Malaysia. The selection of Penang as the study area is motivated by its island surroundings, characterized by numerous tall buildings, with the expectation of additional high-rise constructions in the future. Therefore, ensuring structural resilience against earthquakes is crucial. Given Penang's heightened susceptibility to potential natural disasters, the examination of structures in this area holds greater significance compared to other parts of Peninsular Malaysia. In this investigation, the study initially focuses on rigid frames, recognizing that various frame systems exhibit distinct stiffness and flexibility characteristics. This occurs before incorporating concrete shear walls into the design of high-rise buildings.

Rigid frames are deemed suitable for locations with minimal seismic activity, making them a viable choice for application in Malaysia. Nevertheless, given Malaysia's shifting proximity to the Pacific Ring of Fire, the anticipation of earthquakes with magnitudes ranging from 6.0 to 7.0 soon raises concerns. Considering this prediction, it becomes imperative to guarantee the structural resilience of buildings in Malaysia against the impending earthquake. Consequently, the research will incorporate the use of reinforced concrete shear wall systems in the building under examination. In this study, the column dimensions vary according to the building height, as outlined in Table 1. The beam sizes are uniformly assumed to be 250 mm in thickness and 600 mm in depth, while the slab thickness is consistently assumed to be 175 mm. In this investigation, vertical loads consist of the structure's own weight, along with dead and live loads. Lateral loads encompass earthquake forces operating laterally.

Table 1 Dimensions of columns in a model of a tall building

Floor	Column Size (mm)
43 – 50	200 x 300
36 – 42	250 x 300
29 – 35	300 x 400
22 – 28	300 x 500
15 – 21	350 x 600
8 – 14	400 x 700
GB – 7	450 x 800

The examination of the tall structure in this research is conducted utilizing the engineering software ETABS. The building is represented in the model with individual floors, accounting for the changes in column size based on height. This study investigates the effectiveness of shear walls in various positions within high-rise buildings.

3. Results and Discussion

A shear wall is a vertical structural element that spans from the foundation to the top of a building, and its dimensions are determined by design specifications. These walls are constructed to maintain the stability of structural systems when subjected to lateral forces. By enhancing the lateral stiffness of a building, shear walls play a crucial role in minimizing the lateral deflection of the structure [34]-[36]. Shear walls effectively resist and transfer lateral loads to the foundation and thereby enhance the overall structural integrity. They help prevent buildings from swaying by giving strength and stiffness sideways, which keeps the structure stable and safe.

The specific placement, thickness, and reinforcement of shear walls depend on various factors, including building height, location, building codes, and the expected magnitude of lateral forces. Therefore, careful consideration of these variables is essential in determining the appropriate design for shear walls in a structure. As shown in Fig. 1(a), the initial analysis involves examining the building without a shear wall. Following this, the analysis is repeated with shear walls placed in two different locations, as depicted in Fig. 1(b) at the corner and in Fig. 1(c) at the centre of the building.

Seismic analysis evaluates how structures respond to earthquakes, assessing their dynamic behavior and ability to withstand seismic forces without excessive deformations. This study utilizes response spectrum analysis, a dynamic method used to evaluate how structures respond to earthquakes. This analysis shows the maximum structural response based on natural periods of vibration. Derived from recorded ground motion, this approach provides insights into seismic forces' distribution across frequencies to ensure structural safety during earthquakes.

To maintain the structural integrity, it is essential to analyze the storey displacement ensuring that the building can withstand expected forces and that the displacement remains within acceptable limits. Fig. 2

illustrates the findings of storey displacement in terms of relationship of storey and storey displacement between the three models. The graph reveals that model 1 exhibits the highest storey displacements in comparison to models 2 and 3. Model 2, with the most optimal frame system positioning, shows the lowest storey displacements, demonstrating superior earthquake resistance, a vital factor for valuable seismic performance. As depicted in this figure, for model A, which lacks a shear wall, the highest displacement at level 50 is approximately 0.009mm. In the case of model B, a building with a shear wall at the corner, the storey displacement is observed to be 0.0077mm at level 50. For model C, a high-rise structure with a shear wall located at the centre, the storey displacement is measured at 0.0080mm at level 50.

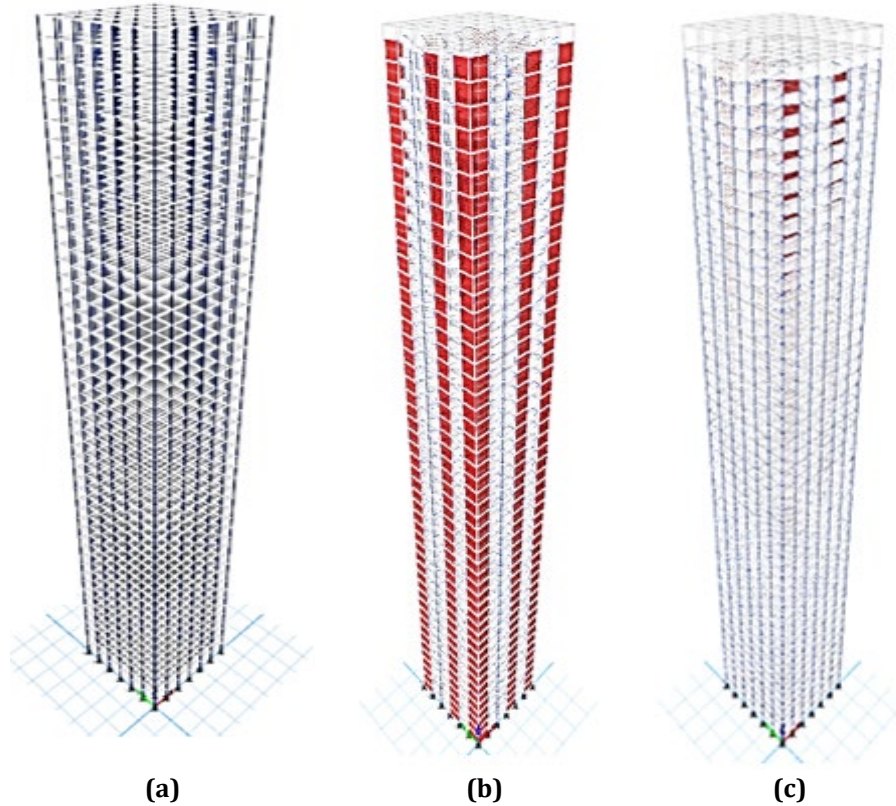


Fig. 1 High-rise building without shear wall (a); shear wall at the corner (b); and at the center (c)

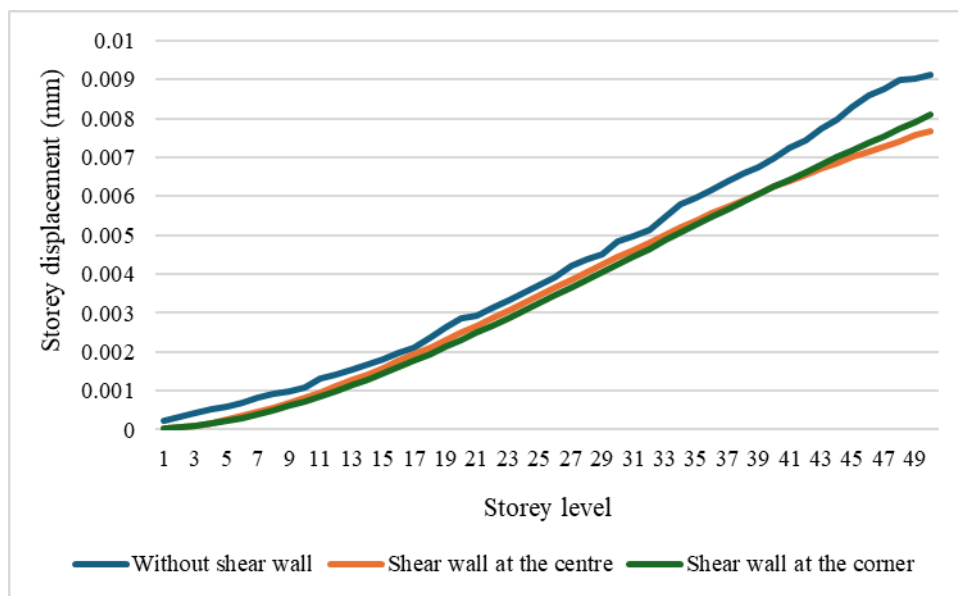


Fig. 2 Storey displacement for different levels of the building

Based on the findings of this study, model 2, which incorporated shear walls at the building's corners, demonstrated superior results in maximum displacement. Consequently, it can be stated that structures with uniform stiffness yielded better outcomes. On the other hand, model 3 with an internal shear wall, placed opposite the building, displayed a minimal displacement value.

As per this study's outcomes, the placement of shear walls at both ends produced better results in terms of maximum displacement. This led to the conclusion that structures with consistent stiffness showed better performance in reducing the impact of earthquakes. Based on the study, the placing of shear walls at both ends yielded better results in terms of maximum displacement. This led to the conclusion that structures with consistent stiffness performed more effectively in reducing the effect of earthquakes.

In high-rise buildings, the concept of storey stiffness acts a vital role in ensuring structural reliability and resilience against external forces, such as wind or seismic loads. The distribution and alignment of stiffness throughout various storeys contribute significantly to the building's overall capability to tolerate deformations and uphold stability. Achieving a balanced and uniform storey stiffness is needed to minimize sway and vibrations in tall structures, improving their performance and safety in varying conditions. Fig. 3 illustrates that the introduction of a shear wall to the high-rise building structures results in an increase in storey stiffness.

The difference in storey stiffness between the first and fiftieth levels of a 50-storey building can vary based on the building's design, construction materials, and structural considerations. As can be seen in the results of this study in Fig. 3, the lower levels may have higher stiffness due to the need to support the weight of the whole structure above. For the upper levels, the stiffness may diminish as the mass of the building is already supported by the lower storeys. The findings of this study indicate that model 1, which lacks a shear wall, exhibits the lowest storey stiffness, while the inclusion of an internal shear wall in the structures results in the highest storey stiffness for earthquake resilience.

The storey stiffness in high-rise structures with shear walls is higher than in buildings lacking shear walls. This indicates that structures incorporating shear walls tend to demonstrate increased stiffness when subjected to seismic loads. The arrangement, size, and design of shear walls are significant factors influencing the building's storey stiffness. The arrangement and characteristics of the shear walls play a substantial role in determining the total stiffness of the building's stories.

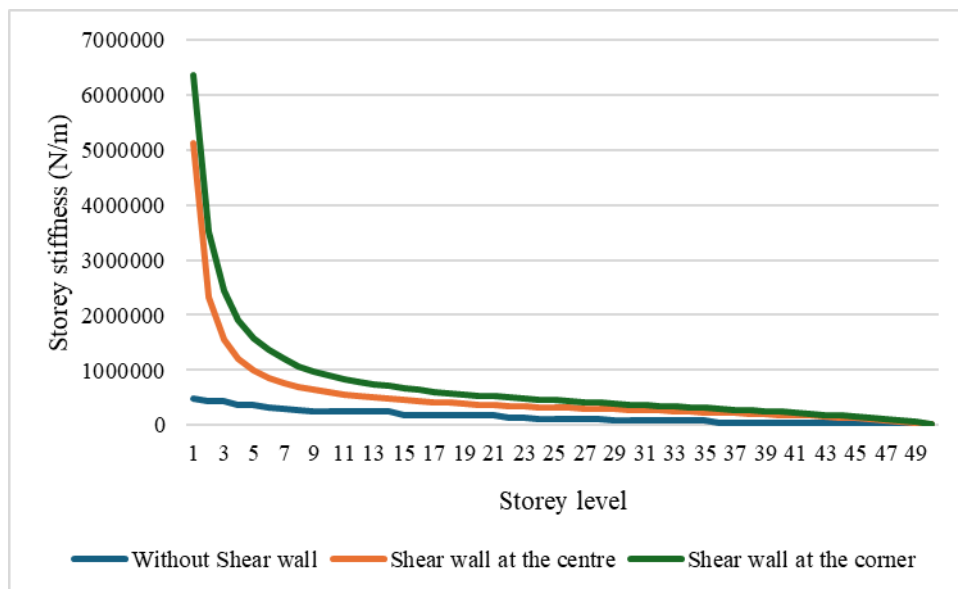


Fig. 3 Storey stiffness for different levels of the building

One vital consideration in seismic design involves drift, referring to the lateral displacement of the building at each level during an earthquake. When a building encounters lateral forces, storey drift refers to the relative displacement between adjacent levels. It is determined as the distance between two successive stories divided by the height of that specific level. Drift considers significance as extreme lateral displacement can result in damage. Building codes usually specify the allowable drift for a structure, considering factors like occupancy, structural system, and regional seismic activity. In general, drift is expressed as a ratio of lateral displacement to building height and is expected to be higher at upper levels due to factors such as flexibility, dynamic response, and the distribution of lateral forces. As indicated by Fig. 4, the storey drift of the building decreases at each level when a shear wall is incorporated. In contrast to the models 2 and 3, model 1, lacking a shear wall, exhibits larger data for storey drift. Models 2 and 3, featuring shear walls, show notably smaller story drifts compared to

the first model. According to this study, one of the factors influencing storey drift is the location and layout of the shear wall. This suggests that the distribution of lateral loads and resulting storey drift can be significantly influenced by the placement and arrangement of shear walls within buildings. The study's results indicate that positioning a shear wall in the centre is highly effective in resisting earthquake stresses.

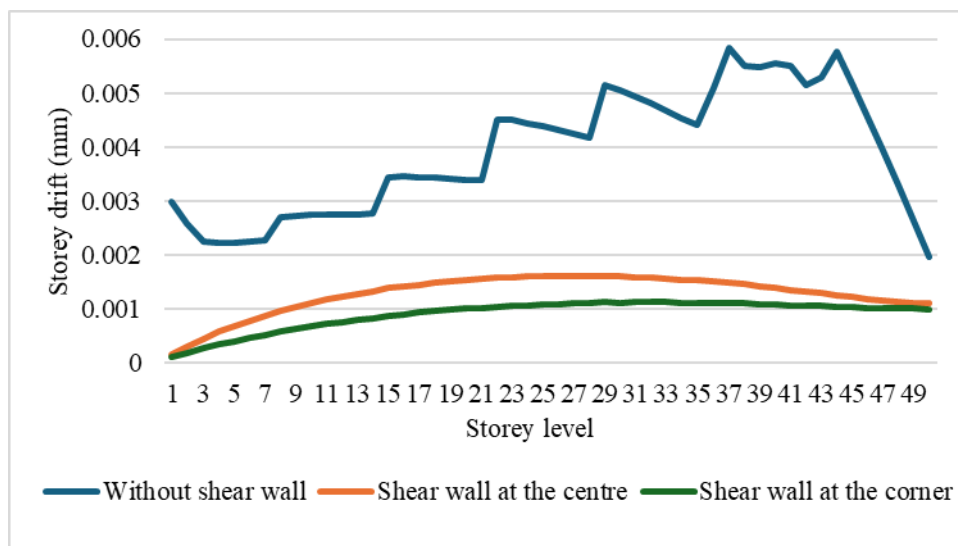


Fig. 4 Storey drift for different levels of the building

4. Conclusions

This study focuses on assessing the seismic performance of a high-rise building with 50 stories during earthquakes using shear wall framing systems. Response spectrum analysis is employed to assess diverse parameters, including displacement, drift, and stiffness across different levels. The outcomes of these parameters in a building featuring shear walls located at both the centre and corners have been compared with those of a structure without shear walls. In this study, storey displacement reveals that buildings lacking shear walls experience more displacement than those with shear walls. Moreover, structures featuring symmetrical shear walls experience lower displacement in contrast to those with asymmetrical shear walls. This research indicates that the arrangement of shear walls and the symmetry of the frame impact its seismic performance. The findings reveal that the shear wall system improves the structure's stiffness, displacement, and drift capacities.

In contrast, the high-rise building incorporating a shear wall exhibits significantly reduced storey drift compared to its counterpart without a shear wall. Additionally, shear walls with symmetrical placement appear less drift than asymmetrical configurations. Furthermore, the building reveals smaller storey drift when the shear wall is located at the corners rather than in the centre. In terms of storey stiffness, a building with a shear wall shows to be stronger than one without, demonstrating that structures incorporating shear walls are better prepared to resist deformation caused by seismic loads than their counterparts lacking shear walls. Therefore, incorporating shear walls into tall buildings proves to be a beneficial approach to mitigate seismic damage in high-rise structures.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** S. J. S. Hakim, N. I. Zahri, and A. M. Mhaya; **data collection:** S. J. S. Hakim, S. N. Mokhtatar and N. Mohamad; **analysis and interpretation of results:** S. J. S. Hakim, N. Jamaluddin and Chia Paknahad; **draft manuscript preparation:** S. J. S. Hakim, N. H. Abd Ghafar, N. I. Zahri. All authors reviewed the results and approved the final version of the manuscript.

References

- [1] Wang, Z., Yang, L., Zhang, S., Hu, W., Hu, C., & Yang, B (2024). Damage detection of FRP structures using the electrical resistance response of MWCNTs networks in a PDMS film substrate. *Sensors and Actuators A: Physical*, 366, 114996. <https://doi.org/10.1016/j.sna.2023.114996>
- [2] Hakim, S. J. S., Mokhtatar, S. N., Shahidan, S., Chik, T. N. T., Jaini, Z. M., Abd Ghafar, N. H., & Kamarudin, A. F. (2021). An ensemble neural network for damage identification in steel girder bridge structure using vibration data. *Civil Engineering and Architecture*, 9(2), 523-532, <https://doi.org/10.13189/cea.2021.090225>
- [3] Zulkifli, F., Mokhtatar, S. N., Chik, T. N. T., Hakim, S. J. S., & Mohammadhassani, M. (2024). A study of building structure resilience to seismic in the Batu Pahat area using rapid visual screening method. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 36 (2), 147-163. <https://doi.org/10.37934/araset.36.2.147163>
- [4] Hassani, S., & Dackermann, U. (2023). Optimization-based damage detection in composite structures using incomplete measurements. *Structures*, 56, 104825, <https://doi.org/10.1016/j.istruc.2023.07.015>
- [5] Hakim, S. J. S., Razak, H. A., Ravanfar, S. A., & Mohammadhassani, M. (2014). Structural damage detection using soft computing method. *Structural Health Monitoring*, 5, 143-151, https://doi.org/10.1007/978-3-319-04570-2_16
- [6] Abu Bakar, M. Z., & Mohamad, Z. F (2023). Local government capacity for earthquake disaster risk reduction in Malaysia: Case studies in Bentong and Selayang areas. *International Journal of Disaster Risk Reduction*, 97, 103987. <https://doi.org/10.1016/j.ijdrr.2023.103987>
- [7] Jaini, Z. M., Sugiura, K., Abdul Kudus, S., Rum, R. H. M., Hakim, S. J. S., & Abd Ghafar, N. H (2023). Natural frequency of lightweight composite slabs based on experimental study and numerical modelling. *International Journal of Integrated Engineering*, 15(9), 87-97, <https://doi.org/10.30880/ijie.2023.15.09.010>
- [8] Sharma, S., & Bhandari, J. (2015). Literature review on the seismic performance of multi-storey building with different locations of shear wall and diagrid. *International Journal of Science and Research*, 6(6), 583-590.
- [9] Ravanfar, S. A., Razak, H. A, Ismail, Z., & Hakim, S. J. S. (2016). A hybrid wavelet based-approach and genetic algorithm to detect damage in beam-like structures without baseline data. *Experimental Mechanics*, 56(8), 1411-1426. <https://doi.org/10.1007/s11340-016-0181-y>
- [10] Hakim, S.J.S., Razak, H.A., & Ravanfar, S.A (2016) Ensemble neural networks for structural damage identification using modal data, *International Journal of Damage Mechanics*, 25(3), 400-430, <https://doi.org/1056789515598639>
- [11] Essam, Y., Kumar, P., Ahmed, A. N., Murti, M. A., & El-Shafie, A. (2021). Exploring the reliability of different artificial intelligence techniques in predicting earthquake for Malaysia. *Soil Dynamics and Earthquake Engineering*, 147, 106826. <https://doi.org/10.1016/j.soildyn.2021.106826>
- [12] Tuken, A., Dahesh, M. A., & As-Siddiqui, M. (2017). Reliability assessment of RC shear wall-frame buildings subjected to seismic loading, *Computers and Concrete*, 20(6), 719-729. <https://doi.org/10.12989/cac.2017.20.6.719>
- [13] Varma, N. N., & Bhalchandra, S. A. (2016). Pushover analysis of RC building with and without floating column. *International Journal of Technical Research and Applications*, 4(5), 44-49.
- [14] Jaini, Z. M., Rum, R. H. M., Hakim, S. J. S., & Mokhtatar, S. N. (2023). Application of foamed concrete and cold-formed steel decking as lightweight composite slabs: Experimental study on structural behaviour. *International Journal of Integrated Engineering*, 15(2), 91-103. <https://doi.org/10.30880/ijie.2023.15.02.009>
- [15] Takagi, J., & Wada, A. (2019). Recent earthquakes and the need for a new philosophy for earthquake-resistant design. *Soil Dynamic and Earthquake Engineering*, 119, 499-507. <https://doi.org/10.1016/j.soildyn.2017.11.024>
- [16] Balendra, T., & Li, Z. (2008). Seismic hazard of Singapore and Malaysia. *Electronic Journal of Structural Engineering*, 8(1), 57-63. <https://10.56748/ejse.8601>
- [17] Brownjohn, J. M. W., & Tso, C. P. (2001). Response of tall buildings to weak long-distance earthquakes. *Earthquake Engineering & Structural Dynamics*, 30(5), 709-729. <https://doi.org/10.1002/eqe.32>
- [18] Sim, K. W., Lee, M. N., Prescott, R. R., & Wong, S. Y. (2023). Perception on landslide risk in Malaysia: A comparison between communities and experts' surveys. *International Journal of Disaster Risk Reduction* 95, 103854. <https://doi.org/10.1016/j.ijdrr.2023>
- [19] Mustafa, K. S., Manap, M. A., Tongkul, F., & Ahmad, Z. (2017). Active faults in peninsular Malaysia with emphasis on active geomorphic features of Bukit Tinggi region. *Malaysia Journal of Geosciences*, 1(1), 13-26.

- [20] Hakim, S. J. S., Jamaluddin, N., Boon, K. H., Mokhtar, S. N., & Jamellodin, Z. (2024). Development of adaptive neuro-fuzzy inference system to predict concrete compressive strength. *Lecture Notes in Civil Engineering*, 385, 327-335. https://doi.org/10.1007/978-981-99-6018-7_24
- [21] Rosli, M. I., Kamal, N. M., & Razak, K. A. (2021). Assessing earthquake-induced debris flow risk in the first UNESCO world heritage in Malaysia. *Remote Sensing Applications: Society and Environment*, 23, 100550. <https://doi.org/10.1016/j.rsase.2021.100550>
- [22] Mohammadhasani, M., Hakim, S. J. S., Jameel, M., Kamarudin, A. F., Mokhtar, S. N., & Budiea, A. M. A. (2023). Effect of infilled walls on the performance of steel frame structures. *International Journal of Integrated Engineering*, 15(2), 79-90. <https://doi.org/10.30880/ijie.2023.15.02.008>
- [23] Alih, S. C., & Vafaei, M. (2019). Performance of reinforced concrete buildings and wooden structures during the 2015 Mw 6.0 Sabah earthquake in Malaysia. *Engineering Failure Analysis*, 102, 351-368, <https://doi.org/10.1016/j.engfailanal.2019.04.056>
- [24] Mhaya, A. M., Shahidan, S., Algaifi, H. A., Zuki, S. S. M., Benjeddou, O., Ibrahim, M. H. W., & Huseien, G. F. (2022). Thermal conductivity of coconut shell-incorporated concrete: A systematic assessment via theory and experiment. *Sustainability*, 14(23), 16167. <https://doi.org/10.3390/su142316167>
- [25] Ravanfar, S. A., Razak, H. A., Ismail, Z., & Hakim, S. J. S. (2015). A hybrid procedure for structural damage identification in beam-like structures using wavelet analysis. *Advances in Structural Engineering*, 18(11), 1901-1913. <https://doi.org/10.1260/1369-4332.18.11.1901>
- [26] Jeon, S. H., & Park, J. H. (2020). Seismic fragility of ordinary reinforced concrete shear walls with coupling beams designed using a performance-based procedure. *Applied Sciences*, 10(12), 4075. <https://doi.org/10.3390/app10124075>
- [27] Huseien, G. F., Kubba, Z., Mhaya, A. M., Malik, N. H., & Mirza, J. (2023). Impact resistance enhancement of sustainable geopolymer composites using high volume tile ceramic wastes. *Journal of Composites Science*, 7(2), 73-92. <https://doi.org/10.3390/jcs7020073>
- [28] Hakim, S. J. S., Irwan, J. M., Ibrahim, M. H. W., Shahidan, S., Ayop, S. S., Anting, N., & Chik, T. N. T. (2024). A hierarchical neural network for identification of multiple damage using modal parameters. *AIP Conference Proceeding*, 2750,0400 67. <https://doi.org/10.1063/5.0149295>
- [29] Ozkul, T. A., Kurtbeyoglu, A., Muzaffer, B., Zengin, B., & Kocak, A. (2019). Effect of shear wall on seismic performance of RC frame buildings. *Engineering Failure Analysis*, 100, 60-75. <https://doi.org/10.1016/j.engfailanal.2019.02.032>
- [30] Kamarudin, M. A. A., Ahmad, S. W., & Wan Ariffin, W. A. R. (2021). The behaviour of high-rise buildings with or without shear wall under different earthquakes. *Construction*, 1(2), 93-101. <https://doi.org/10.15282/construction.v1i2.6957>
- [31] Lou, H. P., Ye, J., Jin, F. L., Gao, B. Q., Wan, Y. Y., & Quan, G. (2021). A practical shear wall layout optimization framework for the design of high-rise buildings. *Structure*, 34(9), 3172-3195. <https://doi.org/10.1016/j.istruc.2021.09.038>
- [32] Khademi, M., Tehranizadeh, M., & Shirkhani, A. (2023). Case studies on the seismic resilience of reinforced concrete shear wall buildings and steel dual concentrically braced buildings. *Structures*, 58, 105596. <https://doi.org/10.1016/j.istruc.2023.105596>
- [33] Simon, A. R., Hridoy, F. K., Siddique, M. F., & Safat, S. A. (2023). Orientation and location of shear walls in RC buildings to control deflection and drifts. *Procedia Structural Integrity*, 46,162-168. <https://doi.org/10.1016/j.prostr.2023.06.028>
- [34] Basavalingappa, M., & Kumar, A. B. (2020). Analysis of high-rise buildings and its behaviour due to shear wall at different locations and in different seismic zones. *International Journal of Engineering Research & Technology*, 9(9), 686-698. <https://doi.org/10.17577/IJERTV9IS090384>
- [35] Nizamani, Z., Luk, W. C., & Haider, S. M. B. (2018). Reinforced concrete buildings with plane frame, shear wall with and without openings. *E3S Web of Conferences*, 65, 02007. <https://doi.org/10.1051/e3sconf/20186502007>
- [36] Hakim, S. J. S., & Razak, H. A. (2012). Damage identification using experimental modal analysis and adaptive neuro-fuzzy interface system (ANFIS). *Conference Proceedings of the Society for Experimental Mechanics Series, IMAC XXX - A Conference and Exposition on Structural Dynamics*, 5, 399-405.