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Advancing Structural Resilience in Malaysia through Seismic Design of Reinforced Concrete Buildings

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Abstract

Malaysia is classified as a low to moderate seismic region, but in some cases and places, it will experience tremor risks from the tectonic plates' activity. For example, in the year 2015, Ranau earthquakes happened with a magnitude of 6.0 and occurred crack on some buildings. The introduction of seismic design in reinforced concrete buildings will enhance and increase the safety of the building. This paper aims to explore the technologies and structural strategies that can support cost-effectiveness in seismic design in Malaysia. Method used in this study is by doing interviews with experts and based on the content analysis from the previous paper and case study. The findings will highlight the structural system optimisation and technology integration. Besides, this study will also look into the cost effectiveness of the technologies and structural efficiency.

1. Introduction

Despite not being located directly on a major seismic fault, Malaysia is becoming more vulnerable to tremors from regional earthquakes, especially those that originate in Sumatra. Sumatra and Andaman Island earthquakes are the primary causes of earthquake activity in Peninsular Malaysia (Felix Tongkul, 2021; Abdollah Vaez Shoushtari *et al.* 2018). As a neighbor of Indonesia and a country close to the Ring of Fire, Malaysia needs to be aware of infrastructure and building practices in order to prepare for future disasters. Due to its proximity to Sumatra and past earthquakes, Malaysia was situated in an area with low to moderate seismicity, but the risk was rising. For instance, the 1976 Sabah earthquake at Lahad Datu had a magnitude of 6point 2. The most recent earthquake, which had a magnitude of 6point 0, occurred in Ranau in 2015 (AK Matusin *et al*, 2020). This study looks at how seismic design can improve the structural resilience of Malaysian reinforced concrete buildings. It focuses on the viability, financial effects, and usefulness of implementing mitigation technologies like base isolators, dampers, and hybrid systems.

Despite being classified as having low to moderate seismic activity, Malaysia is located near active plates such as Indonesia, which is defined as having a high seismic zone (Sulaiman, 2019). The Pacific Ring of Fire is a massive dangerous circle that surrounds the Pacific Ocean and contains the majority of the world's earthquakes and volcanoes. Figure 1 shows that this fearful zone is marked on the map in red and orange (Harith *et al.,* 2023). It begins in western North and South America, then continues across the ocean to Japan, the Philippines, and Indonesia before arriving in New Zealand. The map also depicts other deep ocean trenches with names such as Japan Trench and Mariana Trench. These trenches are where massive portions of the Earth's surface collide, resulting in the earthquakes and volcanic eruptions that make this area so deadly.

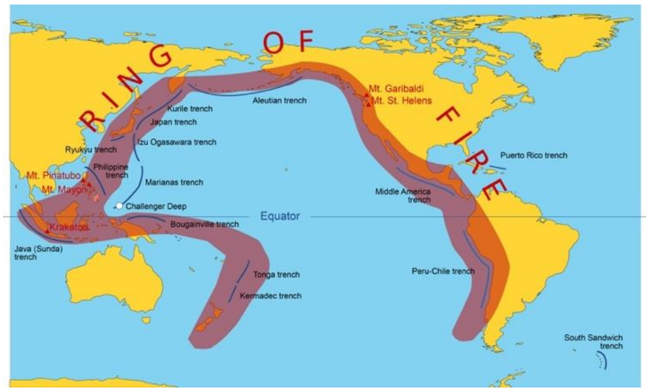

Fig. 1 *Pacific Ring of fire (Harith et al., 2023)*

Table 1 illustrates that not all earthquakes in this area result in the same level of damage (Harith *et al.,* 2023). For instance, the 2023 earthquake that struck Turkey and Syria was quite catastrophic. It was the worst earthquake on the list, with a magnitude of 7.8, and it caused damage to almost 100,000 buildings. Last but not least is the 2023 earthquake in Morocco. Despite being somewhat weaker (magnitude 6.8), it nevertheless seriously damaged roughly 59,000 buildings. Surprisingly, despite being much smaller with a magnitude of only 5.6, the 2022 Indonesian earthquake nonetheless caused damage to almost 60,000 structures. The 2015 Malaysian earthquake, however, is the most interesting example. Even though it had a powerful magnitude of 6.0, just 61 buildings were damaged. This demonstrates that damage from earthquakes is not entirely determined by their magnitude. Instead, other factors are also significant, like the depth of the earthquake, the population of the area, and above all the strength of the buildings to withstand these disasters.

Table 1 *Magnitude of recently earthquake (Harith et al., 2023)*

Place	**Marrakech, Morocco**	**Turkiye, Syria**	**Cuanjur, Indonesia**	**Sabah, Malaysia**
Year	2023	2023	2022	2015
Magnitude	6.8	7.8	5.6	6.0
Depth (km)	20	18	11	10
Total Building Damage	Around 59,000	100,000	60,000	61

2 Literature Review

2.1 Seismic Design In Malaysia

To be safe and resilient, structures in Malaysia, which has low to moderate seismic activity, must incorporate technical concerns and Malaysian criteria into the seismic design process. There are several challenges and concerns with Malaysia's implementation of Eurocode 8 (EC8). This study's framework identifies five critical factors for adopting seismic design for the country and stakeholders. The first is the implementation of Eurocode 8 and the National Annex (N. Lam *et al*, 2016), followed by ductile design and structural detailing (J. Chiang, 2016), cost implications (M. I. Adiyanto *et al,* 2013), seismic vulnerability assessment (K. Tan *et al,* 2018), and technical professional training (D. Looi *et al*, 2021). Because of this hazard effect, structures must be designed to withstand earthquakes' dynamic forces. A structure designed to withstand earthquakes suffers less damage than a conventionally structure.

There are several laws and rules governing seismic design. Although these events are frequently minor, their potential influence on reinforced concrete (RC) buildings designed for gravity and wind loads presents structural concerns. To meet the nation's seismic design criteria, various standard codes were employed as design references. In accordance with the Malaysian National Annex, Malaysia will follow Eurocode 8, which is specific to seismic design. The incorporation of seismic design concepts has evolved from a technical consideration to a critical component of developing resilient infrastructure capable of enduring probable seismic disasters while staying economically viable.

Figure 2 shows the Malaysian seismic zones in three different colours. There are no red zones in the peninsular area, and they are scattered around Sabah, which has records from the Ranau earthquake in 2015.

The nation utilised the map below to determine the seismic vulnerability in Malaysia. Malaysia's various geological features create distinct obstacles for seismic design implementation. Architects can improve seismic resistance in buildings while ensuring occupant safety by combining seismic hazard assessment, design standards, structural systems, and modern technology (S. Shareef, 2023). Engineers must conduct thorough site investigations and soil studies to better understand local ground conditions and their possible impact on seismic response.

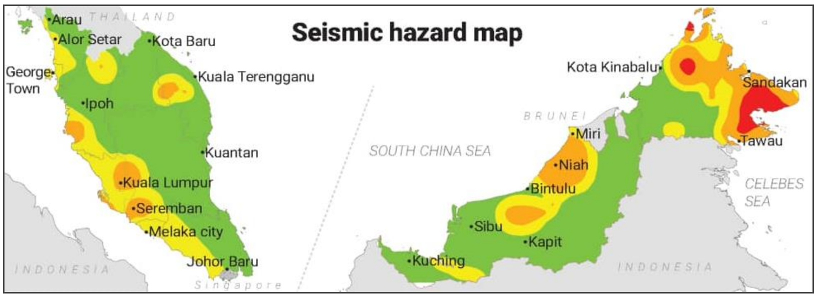

Fig. 2 *Seismic Hazard Map (Mineral and Geoscience Department, 2025)*

Three seismic zones are displayed in Table 2, with the first ductility class having very little seismicity. The impact of seismic design on the cost of structural material in Sabah was mentioned by H A Roslan *et al.* (2021), who validated the design requirements explicitly by zones. The seismicity is typically not needed in this area. Next is low seismicity, which is moderate seismic and requires ductility class low (DCL), which is based on the fundamental ductility requirements for seismic resistance as stated in Eurocode 8. In order to improve the building's structural performance, the low to moderate seismic analysis requirements will be fully covered based on the ductility class Medium (DCM).

Table 2 *Description of the condition of each zone (Mineral and Geoscience Department, 2025)*

Zones	Description
	Tremors in certain locations No danger to structure and human lives
	Tremors felt by all Minor structural cracks
	Tremors felt by all Evacuation Necessary
	Strong tremors, loss of balance. Major structural damage. Broken beams. Wall collapse.

The use of seismic design in reinforced concrete (RC) structures is essential because Malaysia is so close to tectonically active regions like Sumatra, Indonesia. Seismic resistant design components have not been widely incorporated into building methods, despite the growing risk. RC buildings, where the NA was used to determine the seismic zones, which were then classified using the ground acceleration parameters. AgS stands for site-specific ground acceleration, while Ag is the design ground acceleration.

2.2 Economic Impact and Design Considerations

The structural requirements and any other requirements to survive tremors for reinforced concrete buildings will be the focus of the research. A comparison between the seismic and conventional designs will be done. Conventional refers to non-seismic buildings, and Eurocode 2's "Design of Concrete Structures - Part 1-1: General Rules and Rules for Buildings" (EN 1992-1-1:2004) contains the design requirements for conventional buildings. Bond and Harris (2006) claim that this code is a foundation for structural design, concentrating on environmental conditions and static loads while accounting for vertical loads and horizontal elements such as wind (Mosley, 2012).

Economic consequences are one of the seismic design elements that must be carefully considered in order to maximize the safety and cost-effectiveness of structures in earthquake-prone locations. Conventional code-based designs often priorities reducing the initial costs of construction, even if seismic damage during a building's lifetime can result in significant financial losses, according to M. Sarcheshmehpour *et al.* (2021). Cost based strategies that consider life cycle costs, like maintenance and repair, may result in more economical designs. Based on the materials used, the seismic design method is claimed to have a greater building cost than conventional design. This is because majority of studies on seismic design focus on economic and technological approaches for reinforced concrete structures. In this study, structural system optimisation and technology integration are examined as economical approaches to seismic design in Malaysia. Adoption is constrained by the perception that seismic design is expensive.

2.3 Technology and Structural Innovation in Seismic Design

The field of seismic engineering has made huge advances in recent years. These days, engineers are merging various structural systems and employing improved design techniques to make buildings safer during earthquakes. This part will cover three primary topics, advanced seismic technologies, structural system combinations, and innovative design techniques. Engineers have discovered that shear walls and Special Moment Resisting Frames (SMRF) work together to provide a far stronger system than SMRF alone. This combination, known as a dual system, functions well because each component has unique advantages. The moment frame offers flexibility, and the shear walls offer strength and stiffness. Comparing dual shear wall-frame systems to SMRF systems, research shows that both systems can reduce wind-induced story displacement by 25% to 38% (Değer & Wallace, 2015). According to recent research, the seismic performance of RC frame-shear wall dual structural systems has significantly improved (Xu *et al.,* 2023). Compared to using either method alone, this balanced strategy performs significantly better during earthquakes.

In seismic engineering, innovative technologies such as dampers and base isolators are the most interesting developments. During earthquakes, base isolation keeps the building from moving with the ground. According to Leblouba (2022), seismically, separated structures function better than those that are not, showing less slips and floor accelerations. Furthermore, by distancing structures from ground motion, seismic isolation provides an improved option that considerably lowers the forces of gravity (Ghafar *et al.,* 2025). In order to further improve seismic resilience, the 1981 guidelines promoted the use of seismic isolation and dampening devices. These technologies help absorb and distribute seismic energy, significantly reducing the impact of seismic pressures by allowing structures to move independently of ground motion (Kawashima *et al*., 2012). Strict rules for structural details and reinforcement were also set by the law, particularly for important components like joints, beams, and columns. The goal was to increase ductility and energy dissipation capability to prevent cracking failures under seismic loading (Matsushima *et al*., 2017).

Another crucial piece of equipment that helps buildings withstand earthquakes is dampers. According to research on viscous dampers, VFDs considerably decreased inter-story drift ratios in retrofitted buildings (Ma & Yuan, 2025). Additionally, studies show that utilizing high-damping rubber bearings with fluid viscous dampers in base-isolated buildings offers superior protection (Belbachir *et al.*, 2023). When it comes to renovating older structures, these technologies are particularly crucial. According to Ghafar *et al.* (2025), a considerable amount of the world's building stock is still vulnerable to earthquakes due to outdated design rules and insufficient seismic considerations. Therefore, it is now essential to retrofit existing structures with recent seismic technology to protect them and bring them up to current safety standards. Base isolators, energy dissipation dampers, and hybrid systems are examples of seismic design advancements that have been created globally to enhance building performance during earthquakes. Figure 3 below shows the examples of systems of technologies for damping and based isolators. In several nations, these solutions have been shown to be successful in lowering seismic demand and minimizing structural damage. However, due to issues with competence, expense, and regulatory limitations, their use in Malaysia is still restricted.

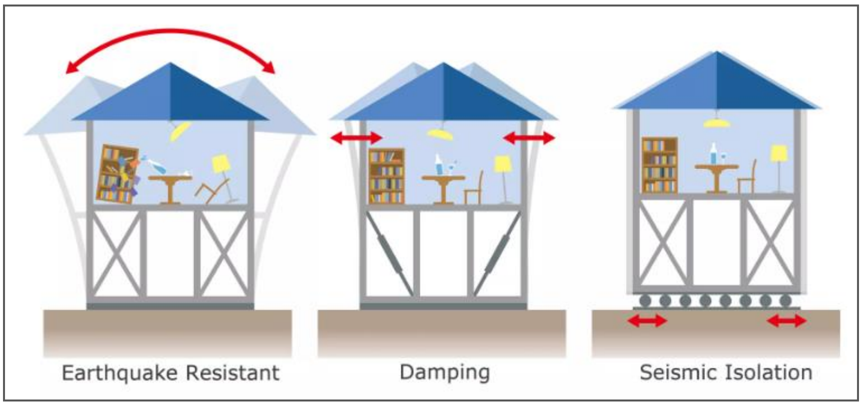

Fig. 3 *System to increase seismic resilience (https://www.realestate-tokyo.com/)*

2.4 Conceptual Framework

This approach provides a straightforward, step-by-step breakdown of the expense of making structures earthquake safe. First, the cost of seismic design is determined by three primary factors, the structure's location (regional considerations), its type (building characteristics and typology), and the safety regulations that need to be adhered to (seismic design code compliance). These elements then result in two primary cost areas that engineers should be concerned about. The first is choosing the right ductile class, which determines how much the building can bend without breaking during an earthquake options include EC2 (no seismic design), DCL (low ductility), DCM (medium ductility), and DCH (high ductility). Surprisingly, the impact of ductility class on building costs is minimal (Akrivi Chatzidaki *et al*., 2024). This is because higher ductility classes require strict design guidelines on the type, quantity, and detailing of reinforcement (Chaudhari & Dhoot, 2016). The second cost area is Elemental Cost Analysis (ECA), which divides the expenses of construction projects into separate categories that correspond to various elements including labour, materials, and overhead (Ruchita Gadave *et al.,* 2019).

All these factors end up contributing to the main goal of structural resilience, which can be achieved by material optimization (effective use of the best materials) and technological innovation (such as base isolators and dampers). By combining various modelling, performance-based design and optimization aim to create structures that are safe, durable, and economical (N. Lopez-Machado *et al.,* 2025). Basically, by understanding the factors that influence costs, carefully analysing them, and concentrating on creative solutions that provide the best protection for the available budget, this framework assists designers in making competent building cost regarding maintain the earthquake safety.

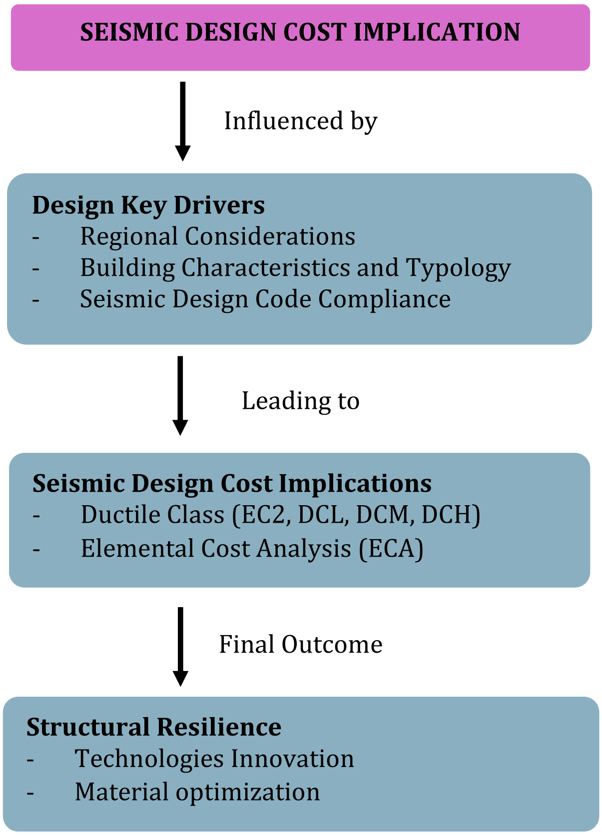

Fig. 4 *Conceptual Framework*

3 Methodology

This study employed a qualitative research design using semi-structured interviews with professional engineers in Malaysia, supported by case insights from prior studies on advanced seismic technologies. Respondents were purposively selected based on their expertise and experience in structural design and seismic-related projects, including engineers from the Public Works Department (JKR) and lecturers from Universiti Teknologi Malaysia (Bernard, 2002; Lewis & Sheppard, 2006; Dolores *et al*., 2007). A case study combined with a phenomenological approach was adopted to capture the lived experiences of engineers and quantity surveyors in reinforced concrete projects integrating seismic design (Bekele & Ago, 2022). Five respondents participated, aligning with the recommended range of 5–25 participants for phenomenological studies (Creswell, 1998; Prance, 2004). Data were transcribed and analyzed using NVivo through thematic analysis, which systematically develops codes and themes (Jennifer, 2001; Lochmiller, 2021). The findings established a comparative framework linking expert perspectives with literature to evaluate adoption strategies and cost implications of dampers, isolators, and hybrid systems in seismic design.

4 Finding And Discussion

The two main concepts of Innovative Construction and Structural and Material Optimisation provide the extensive framework for seismic design techniques shown in this table. Three main strategies that concentrate on boosting building resilience through cutting edge technologies are included in the Innovative Construction category. As the table shows, "Base isolation can provide a cost-effective seismic design in a long run" (R5). This is corroborated by studies that demonstrate that buildings that are seismically isolated from the ground perform better than those that are not, with fewer floor accelerations and drifts (Zhu *et al*., 2023) and potential savings of 5–10% of the building's total structural cost (Leblouba, 2022).

The statement, "In engineering we have created this ductile design, the technology is like a base isolator, a damper technology" (R1), supports research showing that base isolation systems in conjunction with Taylor Devices dampers can save costs while simultaneously improving performance (Patel & Soni, 2023). The IBS system notation "PBT" is used in Malaysia to implement the IBS system in the building industry. Since the Industrialized Building System (IBS) was recently introduced to reduce project construction time and cost, more research is needed on the use of precast components in seismic areas. This is because the integration of precast component connections in IBS structures is crucial for stability under dynamic loads from earthquakes (Park & Yun, 2006).

Specific design approaches that optimize structural efficiency while maintaining seismic resistance are covered within the Structural and Material Optimization subject. As stated in "Strong column weak beam for larger span, hybrid systems, modular dimensions, value engineering to identify cost saving opportunities, optimize section sizes" (R2), the strong column-weak beam idea is a basic seismic design approach. The significance of lateral load resistance systems is emphasized by the shear wall approach "Use reinforced concrete shear walls (cast-in-situ) to resist the seismic lateral forces" (R2). While for the moment resisting frames, the evolution towards integrated approaches is illustrated by the concepts of "Use of reinforced concrete shear walls, modular dimensions, and hybrid systems to resist lateral forces and optimize costs" (R3) and "Suggestions include the use of special moment-resisting frames, closely spaced stirrups in critical regions, confinement reinforcement" (R5).

Table 3 *Thematic Analysis Table*

Theme	Sub-Theme	Code	Example Quotes
Innovative Construction	Base isolators (3/5)	Base isolator as addition technology	*"Base isolation can provide a cost-effective seismic design in a long run" R5*
	Dampers (2/5)	Damper use in seismic design	*"In engineering we have created this ductile design, the technology is like a base isolator, a damper technology"- R1*
	IBS System (2/5)	IBS for efficient construction is seismic zones	*"PBT in Malaysia towards implementation of the IBS system in construction. Further research needs to be done on the use of precast components in seismic areas " – R3*
Structural and Material Optimization	Column Beam Design (2/5)	Strong Column -weak beam concept	*"Strong column weak beam for larger span, hybrid systems, modular dimensions, value engineering to identify cost-saving opportunities; optimize section sizes" - R2*
	Shear Wall (4/5)	Shear wall as lateral load resisting systems	*"Use reinforced concrete shear walls (cost-in-situ) to resist the seismic lateral forces" R2*
	Moment Resisting Frames (1/5)	Special moment-resisting frames allow to control deformation	*"Suggestions include the use of special moment-resisting frames, closely spaced stirrups in critical regions, confinement reinforcement" -R5*
	Hybrid Systems (2/5)	Combining moment-resisting frames with shear walls	*"Use of reinforced concrete shear walls, modular dimensions, and hybrid systems to resist lateral forces and optimize costs"* – R3

5 Conclusion

There are several obstacles and possible study possibilities when examining the financial effects and mitigation techniques of implementing seismic design for reinforced concrete buildings in Malaysia. The lack of local data on seismic risk and construction costs is a significant obstacle that makes it challenging to create precise cost models. Adoption is made even more difficult by industry professionals' opposition, which comes from worries about rising building costs and unclear regulations. Method selected for this study was only focusing on qualitative method because of the limitation expertise in industry seismic design.

These obstacles, however, provide opportunities for study in areas including cost-benefit analysis, cost-effective material selection, and policy recommendations to promote seismic compliance. My research can close the gap between theoretical frameworks and real-world applications by utilizing an exploratory sequential mixed-method study with professional engineers in future. Other than that, this study will be more exciting in future to do the comparison on cost implication with infrastructure in another country. This would ultimately lead to safer and more economical construction practices in Malaysia.

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Conflict of Interest

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

Author Contribution

The authors confirm contribution to the paper as follows: Nurul Masyitah Jamadi ***study conception and design:*** *Nurul Masyitah Jamadi, Nur Hajarul Falahi Abdul Halim, Fara Diva Mustapha;* ***data collection:*** *Nurul Masyitah Jamadi, Nur Hajarul Falahi Abdul Halim, Fara Diva Mustapha;* ***analysis and interpretation of results:*** *Nurul Masyitah Jamadi, Nur Hajarul Falahi Abdul Halim, Fara Diva Mustapha;* ***draft manuscript preparation:*** *Nurul Masyitah Jamadi, Nur Hajarul Falahi Abdul Halim, Fara Diva Mustapha, All authors reviewed the results and approved the final version of the manuscript.*

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