Malaysian Journal
Of Civil
Engineering

Full Paper

IDENTIFYING KEY COST DRIVERS IN SEISMIC DESIGN OF REINFORCED CONCRETE STRUCTURES IN MALAYSIA

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Article history
Received
15 July 2025
Received in revised form
30 September 2025
Accepted
02 October 2025
Published online
01 December 2025

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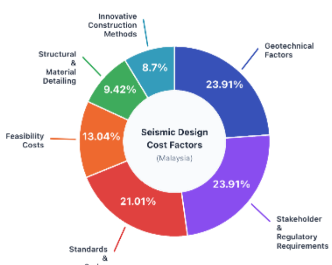
Graphical abstract



Abstract

The increasing awareness of seismic hazards in Malaysia has highlighted the urgent need for earthquake-resistant design in reinforced concrete (RC) buildings. While seismic provisions enhance structural resilience, they also raise construction costs, creating challenges for stakeholders. This study investigates the key cost factors influencing the adoption of seismic design in Malaysia using a qualitative approach. Semi-structured interviews with experts were analysed through thematic and content analysis, providing new insights into cost drivers from professional practice. Six main themes emerged: geotechnical factors and stakeholder/regulatory requirements were the most significant (23.91% each), followed by standards and codes (21.01%), feasibility costs (13.04%), structural and material detailing (9.42%), and innovative construction methods (8.70%). Results show that while innovative techniques were acknowledged, their adoption remained limited. This study provides practical insights in linking professional perspectives with coded frequency analysis, enabling a structured prioritization of seismic cost drivers. The findings highlight the need for early-stage geotechnical assessments, streamlined regulatory processes, and strategic integration of technology to balance safety and cost-efficiency. These insights provide practical guidance for policymakers, engineers, and contractors seeking sustainable approaches to seismic design in Malaysia.

Keywords: seismic design, reinforced concrete, construction economics, cost analysis

1.0 INTRODUCTION

Natural disasters, particularly earthquakes, pose significant threats to the safety and integrity of built environments, especially in seismically active regions. The growing awareness of seismic hazards in Malaysia, particularly after the 2015 Ranau earthquake in Sabah, has underscored the urgent need for reinforced concrete (RC) buildings to be designed with adequate seismic resistance. While seismic provisions such as Eurocode 8 (EC8) and the Malaysian National Annex offer technical guidance to improve structural resilience, their implementation often results in significant cost implications (Faisal et al., 2020; Ramli & Alel, 2017). These increased costs, driven by stricter design requirements, additional geotechnical investigations, and regulatory compliance, present a major challenge for engineers, contractors, and policymakers. Despite the importance of this issue, limited studies have systematically examined the specific factors contributing to seismic design cost escalation in the Malaysian context.

In Malaysia, the adoption of EC8 through the Malaysian National Annex reflects growing recognition of the need for earthquake-resistant design, particularly following recorded tremors in Sabah and other parts of the region (Table 1). However, implementing seismic design in reinforced concrete (RC) buildings introduces cost implications that are not typically encountered in conventional construction designed under Eurocode 2 (EC2). These costs arise due to enhanced material requirements, higher ductility demands, and more rigorous detailing specifications.

Despite the growing application of seismic design, limited research has been conducted to assess the specific factors contributing to increased construction costs from a professional perspective. Previous research has explored the economic implications of implementing seismic design, particularly in reinforced concrete structures. For example, Ramli et al. (2017) found that buildings designed according to EC8 exhibited 7% to 32.4% higher construction costs for beams compared to those designed under EC2, primarily due to increased ductility and reinforcement detailing requirements. Similarly, Adiyanto et al. (2021) reported that material complexity, especially the consideration of design in Eurocode 8, such as Strong Column – Weak Beam, significantly increased seismic design costs.

More recent studies have expanded this understanding within the Southeast Asian context. (Zulkhibri et al., 2024) investigated a six-storey RC apartment block in Sabah, Malaysia, and reported that seismic design increased reinforcement quantities by 7–31%, with overall structural costs rising by 3.3–12.7%. Another study by the same group assessed a 12-storey building on soft soil (Type D) and found seismic design increased structural costs by 3.4–19.1%, depending on ground motion parameters and ductility class (Zulkhibri et al., 2023). Faisal et al. (2020) analysed low- to mid-rise RC buildings (1–12 storeys) and found that EC8-based seismic design led to a 4–191% increase in concrete volume and up to 318% in reinforcement steel usage compared to conventional design, indicating that material specifications were a major contributor to cost escalation.

In Indonesia, Rahman Arifin & Jonrinaldi (2024) compared simple houses with and without earthquake-resistant features, reporting only a 3.63% cost increase, suggesting that early-stage design integration could mitigate cost burdens. On a broader scale, Flores-Mendoza et al. (2022) examined the role of structural innovation, such as dampers and ductile detailing, in reducing seismic damage-related costs. Their findings showed that while upfront costs may increase slightly, long-term cost savings and damage mitigation potential often justify the investment. These studies collectively suggest that geotechnical investigations, regulatory compliance, and structural detailing remain dominant cost factors, while innovative technologies may offer cost-effective alternatives without compromising seismic performance. However, there remains a gap in qualitative assessments based on direct industry insights, particularly in the Malaysian context.

While several studies have addressed the technical aspects and general cost impacts of seismic design, limited research has been conducted from a qualitative perspective that incorporates the views of industry professionals, particularly in the Malaysian context, where the application of Eurocode 8 is still relatively new. The absence of localised data on cost-driving factors and the lack of strategic guidance for managing these costs present a significant research gap. Therefore, this study addresses this gap by employing a qualitative approach to investigate cost drivers associated with seismic design implementation. Through expert interviews and thematic analysis using NVivo software, this research aims to identify and quantify the most influential factors contributing to cost escalation. In addition, this research aims to propose practical mitigation strategies based on expert insights to support more cost-effective and resilient seismic design practices.

Table 1 Table of the latest earthquakes near Malaysia from 2018 until 2025 (Malaysia Earthquake Report, 2025)

Date	Location	Magnitude	Max. Mercalli Intensity	Distance tremors	Number of Deaths
18 March 2025	Sibolga, North Sumatra, Indonesia	5.4	V. Moderate	316 km from Kuala Lumpur	1 death
3 April 2023	Kota Kinabalu, Sabah	5.5	III. Slight	57 km from Kota Kinabalu	-
1 October 2022	Sibolga, North Sumatra, Indonesia	5.9	VII. Very Strong	329 km from Kuala Lumpur, Malaysia	1 death
25 February 2022	Bukit Tinggi, West Sumatra, Indonesia	6.1	VII. Very Strong	370 km from Kuala Lumpur, Malaysia	11 deaths
8 March 2018	North Ranau, Sabah	5.2	VI. Strong	58 km from Kota Kinabalu	18 deaths

2.0 SEISMIC HAZARD IN MALAYSIA

Malaysia has long been considered a region of low to moderate seismicity due to its location outside the Pacific Ring of Fire. However, in recent decades, both distant large-magnitude earthquakes and local intraplate events have raised concerns about the seismic vulnerability of the built environment, particularly in parts of East Malaysia such as Sabah. Notably, the 2015 Ranau earthquake (magnitude 6.0) caused significant structural damage and casualties, prompting a reevaluation of the country's seismic risk profile (Ida Sharmiza et al., 2022; Tongkul, 2017).

Based on recent geological and seismotectonic studies, Malaysia can be broadly divided into several seismic zones. Table 2 shows the divided seismic zones and the ductility class in Malaysia according to NA to MS EN 1998-1:2017 (Department Standards Malaysia, 2017). Sabah has been identified as the region with the highest seismic risk in the country due to its proximity to the Sulu and Celebes seas subduction zones and the presence of active local faults such as the Lahad Datu-Semporna Fault Zone (Harith et al., 2023; Cheng, 2016). In contrast, Peninsular Malaysia is generally subjected to tremors originating from distant earthquakes in Sumatra, particularly along the Sunda Arc subduction zone, which can still affect high-rise buildings and critical infrastructure due to long-period ground motions (Hakim et al., 2024).

In response to these hazards, the Department of Standards Malaysia has published the Malaysia National Annex to

Eurocode 8 (MS EN 1998-1:2015), which outlines design ground acceleration values (agR) and site classifications for various seismic zones. For example, Sabah is designated with agR values ranging from 0.07g to 0.16g, depending on local fault proximity and soil type (Department Standard Malaysia, 2017). These values are critical for structural engineers in designing buildings with sufficient seismic resistance.

More recently, an updated and comprehensive Seismic Hazard Zones Map for Malaysia was developed by Kassem et al. (2023) (Figure 1). This map was produced using probabilistic seismic hazard assessment (PSHA) techniques and considers regional seismotectonic data, historical earthquake records, and fault activity models. The map categorises Malaysia into five seismic hazard zones (Zones 0 to IV) based on peak ground acceleration (PGA) values with a 10% probability of exceedance in 50 years. The key findings show:

- **Zone IV** (highest hazard) covers Ranau, Lahad Datu, Tawau, and surrounding areas in Sabah, with PGA values exceeding 0.25g.
- **Zone III** includes parts of Kota Kinabalu, Sandakan, and areas near known faults.
- **Zone II and I** cover moderate-risk areas, including portions of central Sabah and some eastern states of Peninsular Malaysia.
- **Zone 0**, which includes much of Peninsular Malaysia, remains a low-hazard zone with PGA values <0.04g.

This map presents a more refined and localised seismic risk classification for Malaysia and underscores the importance of integrating seismic hazard zoning into building codes and land-use planning. It supports the growing consensus that Sabah, particularly its eastern and central regions, is exposed to significant seismic hazard and must be treated with site-specific design approaches. Despite these advancements, many existing structures in Malaysia, especially those built before 2017, were not designed for seismic resistance. This is compounded by challenges such as limited technical expertise, cost concerns, and inconsistent enforcement of updated codes. As seismic risk awareness grows, integrating updated hazard maps into design guidelines is essential for achieving resilient and safe built environments.

Table 2 Seismicity Hazard Zone

Zones	ag OR	agS	Ductility Class
Very Low Seismicity	ag ≤ 0.04g	agS ≤ 0.05 g	-
Low Seismicity	0.04g < ag ≤ 0.08g	0.05g < agS ≤ 0.10g	Ductility Class Low (DCL)
Low to Moderate Seismicity	ag > 0.08g	agS > 0.10g	Ductility Class Medium (DCM)

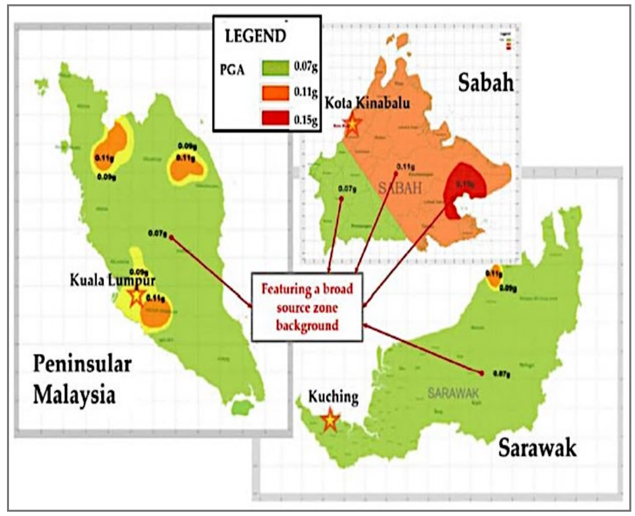


Figure 1 Proposed Seismic Hazard Zones Map (Kassem et al., 2023)

3.0 METHODOLOGY

This study employed a qualitative research approach, involving semi-structured interviews with professional engineers in Malaysia. Additionally, case insights from previous studies on advanced seismic technologies were incorporated into the analysis. A case study was used to capture the lived experiences of engineers and quantity surveyors working on reinforced concrete projects that included seismic design (Bekele & Ago, 2022). This paper aims to identify key factors contributing to the cost of seismic design in reinforced concrete buildings in Malaysia, as well as to explore the implications and practical strategies related to seismic-resistant design practices.

Thematic analysis was used to identify patterns of meaning in interview transcripts, using Braun and Clarke's (2006) six-step methodology. Respondents were specifically chosen for their competence and experience in structural design and seismic-related projects, including engineers from the Public Works Department (JKR) and academics from Universiti Teknologi Malaysia (Bernard, 2002; Lewis & Sheppard, 2006; Dolores et al., 2007). Next, five people took part, which is within the recommended range of 5-25 for phenomenological investigations (Creswell, 1998; Prance, 2004). NVivo was used to transcribe and analyse data through thematic analysis, which systematically produces codes and themes (Jennifer, 2001; Lochmiller, 2021). Figure 2 illustrates the methodology through a flowchart, detailing the steps involved in collecting data until the final conclusion.

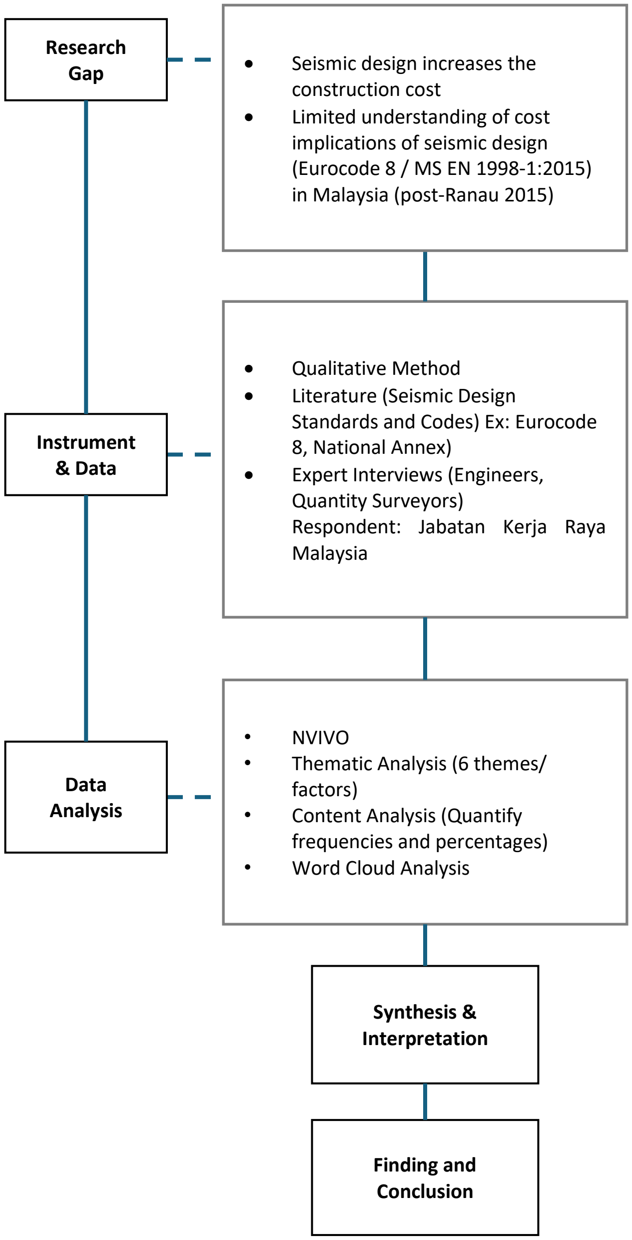


Figure 2 Flow Chart of Methodology

4.0 RESULTS

This section presents the findings from a qualitative inquiry into the key factors contributing to cost increases in the seismic design of reinforced concrete (RC) buildings in Malaysia. The analysis employed a combination of thematic analysis and content analysis to systematically extract recurring patterns, perspectives, and issues raised by professional stakeholders during the interview sessions. This approach enabled a deep understanding of participants' experiences and interpretations, offering a rich, context-sensitive exploration of the complexities involved in seismic design.

4.1 Thematic Analysis

Thematic analysis was particularly suited for this study as it provided a flexible yet rigorous framework to identify and analyse themes within the dataset (Braun & Clarke, 2006). In this research, themes were derived inductively from the data collected through semi-structured interviews with structural engineers, quantity surveyors, and consultants with experience in seismic construction projects. The analysis focused on exploring not only what factors influence cost, but also how and why these factors manifest in practice.

Table 3 summarises the six dominant themes that emerged from expert interviews on seismic design cost factors. These include: (1) Standards and Codes, (2) Geotechnical Considerations, (3) Material Requirements, (4) Structural Detailing, (5) Stakeholder and Regulatory Compliance, and (6) Innovation and Design Complexity. Among the identified themes, the dominant concern across all respondents was the influence of standards and codes, particularly the Malaysia National Annex to Eurocode 8 (EC8). Respondents consistently noted that the implementation of EC8-based seismic design standards significantly impacts structural detailing and material usage, thereby increasing costs. One respondent (R2) emphasised, "Malaysian National Annex requires reinforced concrete buildings to be designed for lateral seismic forces besides wind loads," indicating that new design requirements expand both the structural scope and complexity of projects. This observation aligns with the findings of Vafaei et al. (2022), who highlighted that Malaysia's recent adoption of EC8 has substantially reshaped structural design practices, particularly for high-importance and multi-storey buildings.

Another highly recurring theme was geotechnical investigation and site-specific analysis, which were frequently cited as critical cost drivers due to the requirement for detailed soil studies, especially in high-risk zones such as Sabah. These investigations often necessitate advanced laboratory testing and specialist consultancy, which directly contribute to elevated project costs. The interviews also revealed that these factors are not always considered in early project budgeting, leading to unforeseen cost escalations during design development.

Structural detailing and material specification were also emphasised as significant factors. Respondents noted that seismic detailing, such as enhanced confinement at beam-column joints, lap length adjustments, and the use of higher-grade reinforcement, demands additional material volume and labour time, contributing further to the overall cost. Additionally, compliance with stakeholder and regulatory requirements was found to introduce complexity, as project approvals often require thorough documentation and justifications under seismic codes, which prolongs timelines and increases overhead costs.

Table 3 Key themes identified from expert interviews on seismic design cost factors

Theme	Sub-Theme		Total Respondent	Summary of Findings	Example Quotes (From Respondents)
A- Codes and Standards	A1	EC8 & NA	3 /5	Different regions require different levels of earthquake design; Eurocode and the Malaysia National Annex are used for seismic design. In Malaysia, the first government project to use ductile design was the Lahat Datu prison.	*"So, when the important factor is high, there are many additional loadings he must make for these buildings, safer than standard buildings" – R5* *"Malaysian National Annex requires reinforced concrete buildings to be designed for lateral seismic forces besides wind loads" - R2*
	A2	Ductile Class			
	A3	ASCE & FEMA			
	A4	Important factor			
	A5	Performance base			
	A6	Seismic Risk			
B-Feasibility Cost	B1	Building cost	3 /5	Costs are raised by 4–10% for minor design changes and by 20-30% for some buildings. These buildings are safer with additional loadings, but it will cost more, which can also be influenced by labour, materials, and time.	*"Seismic design may increase construction costs" – R1* *"Provides significant long-term cost benefit by reducing repair works or reconstruction in the event of earthquakes" – R4*
	B2	Cost Increase			
	B3	Labor cost			
	B4	Long-term Cost Benefit			
C-Geotechnical Factors	C1	Change location	2 /5	To help engineers and seismologists analyse data and forecast earthquakes, a National Annex is necessary to establish parameters for seismic activity. Geotechnical aspects are the focus of Eurocode 8 Part 7.	*"Recommend that you want to reduce the cost, change other locations, or there will be a cost for a retaining wall" - R1* *"If you see in Indonesia, there is a village upside down, so it refers to the underground study. So, it will provide an impact on the cost too if running a soil investigation" - R3*
	C2	Seismologist Parameter			
	C3	Site Specific			
	C4	Soil Investigation			
D-Innovative Construction	D1	Base isolator	3 /5	The application of the IBS system and the use of precast elements in seismic zones are covered in the content, which highlights application technologies such as dampers and base isolators for retrofitting.	*"Use reinforced concrete shear walls (cost-in-situ) to resist the seismic lateral forces" R2* *"Base isolation can provide a cost-effective seismic design in the long run", R5*
	D2	IBS system			
	D3	Shear Wall			
E-Regulations and Stakeholders	E1	Consultants	2 /5	Difficulties are one of the factors to be considered when designing buildings in Malaysia to comply with earthquake regulations. The necessity of consulting with multiple authorities is mentioned, while one must follow Eurocode for sustainable design, other regions have their own rules and authorities.	*"Development and Management Planning Guidelines in risky areas. This is a Malaysian plan of earthquake planning guidelines. He has a special guideline that is also the guideline used by JKR today" - R1* *"But, also in the peninsula, the government has implemented that each design should refer to the seismic design of a particular area." - R3*
	E2	Implementation			
	E3	local authorities			
	E4	seismic in the peninsula			
	E5	Stakeholders			
F-Structural and Material Detailing	F1	Column beam design	3 /5	Specific specifications for joint detailing, reinforcement, column design, and lateral stabilising elements are all part of seismic design. In addition, connection detailing, material strength, and seismic design are crucial components of earthquake-resistant design.	*"Strong column weak beam for larger span, hybrid systems, modular dimensions, value engineering to identify cost-saving opportunities; optimise section sizes" – R4* *"Seismic design requires extra steel reinforcement detailing at critical regions, an increase in reinforced concrete member sizes, overdesigned requirement" - R2*
	F2	Moment Resisting Frames			
	F3	Lateral Force			
	F4	steel reinforcement			

4.2 Content Analysis

In addition to thematic analysis, this study employed content analysis to quantify and interpret the frequency of coding references from interview transcripts. This approach enabled the identification of dominant topics and concepts repeatedly emphasised by respondents, offering a structured way to examine the relative significance of each factor influencing the cost implications of seismic design in reinforced concrete (RC) buildings.

Content analysis, as defined by Berelson (1952), is a systematic, objective, and replicable method for analysing qualitative data, particularly useful in extracting quantifiable insights from verbal content. By applying this technique through NVivo software, key themes were transformed into measurable codes, and their frequencies were analysed to determine their relative importance in the dataset.

4.2.1 Quantified Factors Influencing Seismic Design Costs

Based on Table 4 and Figure 3 (assumed to show coding frequencies), two factors emerged with the highest coding percentages: Geotechnical Factors and Stakeholders & Regulations, both accounting for 23.91% of the total coded references. This indicates that issues related to site-specific ground conditions and regulatory frameworks are perceived by professionals as the most critical cost drivers in seismic design implementation.

Geotechnical Factors were widely mentioned due to the direct relationship between soil conditions and seismic design requirements. Respondents emphasised that softer soils lead to higher seismic forces, thereby necessitating greater material use and more robust structural systems. One participant noted that "changing the location can reduce the need for expensive retaining walls" (R1), highlighting the cost-saving potential of strategic site selection. This is supported by (Ganasan et al., 2020), who found that soil type significantly influences both the base shear demands and construction costs in seismically active zones.

Stakeholders and Regulatory Requirements were tied as the most frequent theme due to the administrative and compliance-related challenges of adhering to multiple regulatory bodies. A respondent commented, "The government has implemented different designs for each region, and the design must refer to the specific seismic zoning" (R3), reflecting the fragmented nature of seismic policy implementation. This supports findings by Hamid and Mohamed (2020), who reported that navigating Malaysia's regulatory system, especially in moderate-risk areas, often results in increased design iterations and costs. The adoption of MS EN 1998 (Eurocode 8) has, in some cases, raised construction costs by 12–18% in affected regions (Awaludin et al., 2021).

Standards and Codes ranked second at 21.01%, underlining the strong influence of Eurocode 8 and the Malaysian National Annex on structural design requirements. These standards necessitate detailed seismic load calculations, ductility classification (DCL, DCM, DCH), and additional reinforcement—all of which contribute to increased construction costs. The significance of this finding is consistent with the work of Vafaei et al. (2022) and Adiyanto and Majid (2014), who found that seismic design using Eurocode 8 can increase material costs by 1.7 to 3.3 times depending on the ductility class selected.

Feasibility Cost (11.04%) was ranked mid-tier in importance. While acknowledged by all respondents, feasibility concerns were often discussed in relation to more fundamental factors such as technical requirements or regulatory frameworks. Respondents cited cost increments of 4–10% for minor seismic provisions and up to 30% for high-risk designs. However, these were often viewed as long-term investments that reduce potential post-earthquake repair and reconstruction costs. This supports the findings of Wei et al. (2019), who emphasised the life-cycle cost benefits of seismic resilience in RC buildings.

Structural and Material Detailing (9.42%) was noted as a contributing factor due to the need for enhanced reinforcement detailing, especially at beam-column joints. According to one respondent, "seismic design requires extra reinforcement at critical regions, increased member sizes, and often leads to overdesign" (R2). This agrees with Fardis et al. (2005), who observed that seismic provisions can lead to significantly higher material quantities, particularly in buildings designed for medium and high ductility. Kassem et al. (2022) also reported that material costs in a 6-storey RC model increased by 0.9% to 8.8%, depending on the applied seismic design category.

Finally, Innovative Construction Methods were the least mentioned theme (8.70%). Although considered beneficial, methods such as precast concrete, shear wall systems, and industrialised building systems (IBS) were not widely adopted in seismic design due to perceptions of complexity or design-specific suitability. One respondent recommended the use of "reinforced concrete shear walls (cast-in-situ) to resist seismic lateral forces" (R2), a view aligned with Mahmood et al. (2019), who emphasised cost-effective innovations in lateral force resistance. Nonetheless, Ganasan et al. (2018) warned of seismic vulnerability at beam-column-wall junctions, underscoring the importance of detailing even in innovative systems.

Table 4 Content Analysis Table for References

Codes	Number of coding references	Aggregate number of coding references	Percentage number of coding references (%)
Codes and Standards	24	29	21.01
Feasibility Cost	10	18	13.04
Geotechnical Factors	17	33	23.91
Innovative Construction	12	12	8.70
Regulation and Stakeholders	17	33	23.91
Structural and Material Detailing	13	13	9.42
TOTAL	**93**	**138**	**100.00**

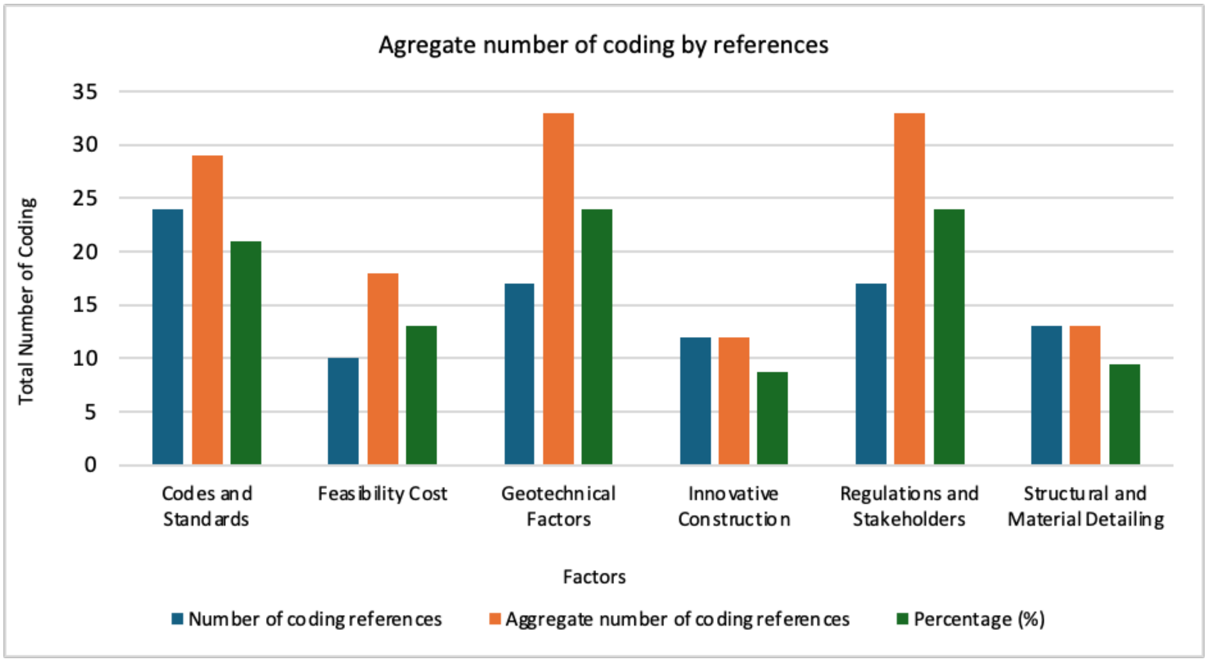


Figure 3 Percentage of Aggregate Number of Coding by References

4.3 Word Cloud Analysis

A word cloud generated via NVivo further reinforced these findings, visually emphasising keywords such as “seismic design,” “earthquake,” “Eurocode,” and “building cost”. These terms reflect the technical, regulatory, and economic themes central to the study. The prominence of terms such as “JKR”, “Malaysia,” and “national” also highlights the institutional and policy-level factors influencing seismic code adoption in Malaysia.

According to Awaludin et al. (2021), the implementation of Eurocode 8 in moderate-to-high seismic zones like Sabah has resulted in considerable project cost increases due to enhanced detailing and compliance requirements. Similarly, Maranhão et al. (2019) highlighted the trade-offs between safety and affordability in adopting seismic-resistant standards in developing countries, where implementation must be balanced with local economic constraints.

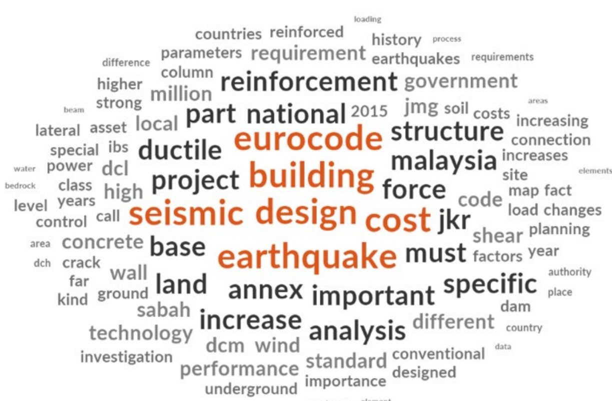


Figure4 Word Cloud

5.0 CONCLUSION

This study examines the primary cost factors for implementing seismic design for reinforced concrete buildings in Malaysia, utilising Eurocode 8 and MS EN 1998-1:2015. The investigation revealed six major themes: geotechnical factors (23.91%), stakeholder and regulatory needs (23.91%), standards and codes (21.01%), feasibility costs (13.04%), structural and material detailing (9.42%), and innovative construction (8.70%). The data show that geotechnical conditions and regulatory requirements have the greatest influence, although standards and codes also play an important role.

These findings offer useful recommendations to stakeholders by emphasising early geotechnical evaluation, simplified regulatory compliance, and selected adoption of new methods as a priority to control seismic design costs in Malaysia. For future studies, it is recommended to conduct detailed investigations into the geotechnical factors that directly affect seismic design costs, including soil classification, site amplification effects, and foundation design adaptations. Quantitative modelling of how different soil types influence seismic base shear, material consumption, and overall construction costs will provide valuable insights for cost planning and site selection in seismic-prone regions.

Acknowledgements

The authors would like to acknowledge Universiti Teknologi Malaysia for supporting this study through the research grant (PY/2023/00911)

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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