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The Assessment of Tall Building Structure Performance Due to Seismic Effect in Malaysia

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ABSTRACT

Recent natural disasters have brought attention to the vulnerability of buildings in Malaysia, resulting in severe damage, loss of life, and economic setbacks. Many existing reinforced concrete structures in the country were not adequately designed to withstand seismic forces, as they primarily focused on vertical loads. Therefore, it is crucial to evaluate the seismic performance of buildings to ensure their safety during earthquakes. This research aims to develop fragility curves specific to tall concrete buildings in Malaysia. The study analyzes two building models, differing in the number of stories: a 30-story type I building and a 25-story type II building. The analysis involves pushover analysis and incremental dynamic analysis, considering gravity and wind loads as per the Malaysian standard practice (BS8110). Lateral design loads are utilized for the pushover analysis, while five records of far-field ground motion are employed for the incremental dynamic analysis. Furthermore, different soil types are taken into consideration to assess their impact on the structural response. Fragility curves are produced through the examination of inter-story drift ratios recorded during the evaluation of five distinct ground motions for each soil classification, along with incremental variations in peak ground acceleration. The structural performance is evaluated using five distinct performance levels: operational phase (OP), immediate occupancy (IO), damage control (DC), life safety (LS), and collapse prevention (CP). Fragility curves are developed for both building models, considering the four soil types. The findings reveal that the inter-story drift ratio or damage measure values increase with higher peak ground accelerations. Additionally, the pushover analysis indicates that the 30-story model (type I building) exhibits higher base shear compared to the 25-story model (type II building), suggesting a correlation between base shear and building height. A total of eight fragility curves are constructed, representing the probability of exceeding IO and CP limit states. Notably, under soil type A bedrock with a peak ground acceleration of 0.1 g, the 30-story building demonstrates better performance compared to the 25-story building, with maximum probabilities of exceeding CP damage states of 4% and 8% respectively. The fragility curves highlight the significant influence of soil conditions on structural vulnerability.

Keywords:
Seismic; tall building; IDA; fragility curve; soil effect

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1. Introduction

Earthquakes, as inevitable natural phenomena, entail the sudden movement of the Earth's crust, resulting from the release of accumulated energy. Although Malaysia is not situated in an active and critical earthquake zone like Japan, Indonesia, or the Philippines, it is not entirely immune to seismic activity. Geographically located on the Eurasian plate, in proximity to the Western Australian Plates and the Eastern Philippines, Malaysia experiences the effects of both distant and local earthquakes [1,2]. The impact of seismic events varies across different regions of Malaysia. While seismic tremors in Peninsular Malaysia primarily stem from the Indian-Australian Plate subduction zone and the Eurasian Plate, Sabah and Sarawak are subjected to seismic activity related to the Philippine Plate subduction zone and the Eurasian Plate, situated within the Pacific Ring of Fire [3].

According to data from United States Geographical Survey (USGS) and the European-Mediterranean Seismological Centre (EMSC), a total of 215 earthquakes with a magnitude of four or above have occurred within a 300 km radius of Malaysia over the past decade, as illustrated in figure 1. These seismic events translate to an annual average of approximately 21 earthquakes, equivalent to one per month. On average, Malaysia experiences an earthquake approximately every 16 days. Notably, 2015 witnessed an unusually high seismic activity with 37 earthquakes of magnitude 4 or higher detected within the 300 km radius, with the strongest registering a magnitude of 6.1. The most powerful earthquake in the vicinity of Malaysia within the last decade occurred on December 21, 2015, at 02:47 local time in the Asia/Kuching time zone. This seismic event recorded a magnitude of 6.1 and originated 72 kilometers (approximately 45 miles) to the south-southwest of Tawau, at a depth of 14 kilometers.

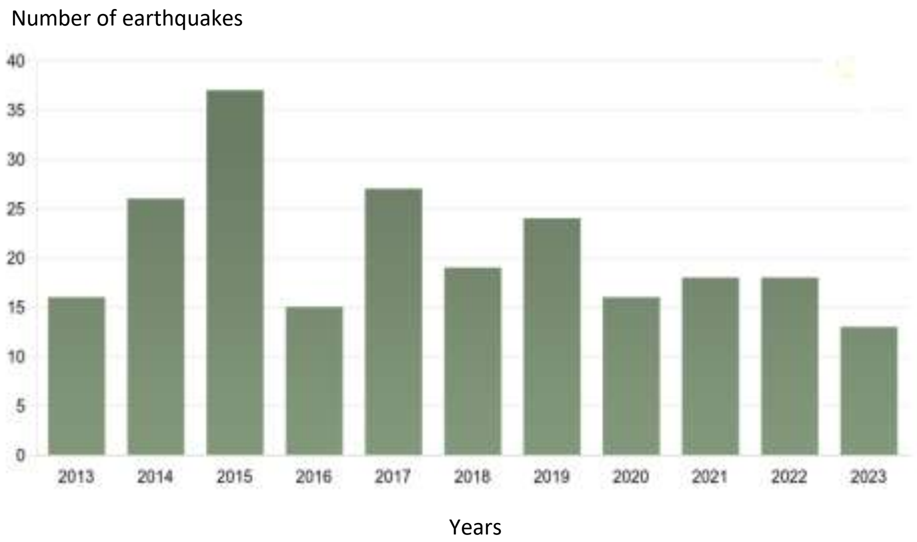


Fig. 1. Yearly earthquakes within 300 kilometres of Malaysia with a magnitude of four and above

While Malaysia has grappled with seismic activity for decades, the construction of tall buildings has become a defining feature of its evolving urban landscape [4]. The construction of tall buildings has emerged as a prominent feature within Malaysia's evolving urban landscape. The proliferation of such structures is not unique to Malaysia but is observed globally. Major cities in Malaysia now boast skyscrapers with varying heights, ranging from 14 to 88 stories, serving both commercial and residential purposes [5]. Reinforced concrete and steel structures are the predominant construction materials in Malaysia, owing to their strength and cost-effectiveness [6,7]. However, the vulnerability of tall buildings to seismic activity poses significant economic and human risks.

Given the increasing occurrence of earthquakes in neighboring regions, questions arise regarding the ability of existing structures in Malaysia to withstand seismic loads [3,8,9]. Most buildings in Malaysia were not originally designed with earthquakes in mind, making it challenging to accurately predict the extent of potential damages during seismic events [10,11]. Therefore, comprehensively understanding the structural performance and seismic efficiency of high-rise buildings becomes crucial in ensuring their safety. Accurate prediction of potential damage is essential for the development of optimal retrofitting strategies and risk mitigation plans for existing buildings [12,13]. Moreover, the utilization of fragility curves enables the assessment of seismic risks and estimation of physical damages resulting from the strongest mainshocks.

The aim of this study is to analyse the seismic susceptibility of high-rise structures in Malaysia and suggest strategies for improving their capacity to withstand seismic events. By integrating seismic parameters into the design process and utilizing fragility curves, the study seeks to assess potential damage and develop effective strategies to mitigate risks. The findings of this research will contribute to the advancement of seismic-resistant structures in Malaysia, ultimately safeguarding lives and minimizing financial losses. Based on the developed fragility curve, the damage indicators derived from these curve can be utilized to evaluate structural damage [14].

2. Methodology

2.1 Research Flow Chart

The methodology encompassed a well-planed work plan that guided the research from initiation to completion as shown in Figure 2. Through this methodology, profound insights into the behavior of tall buildings in different soil conditions were gained, allowing informed conclusions and recommendations to be drawn. The combination of a thorough literature review, rigorous modelling techniques, and powerful analysis tools ensured the reliability and accuracy of the research outcomes.

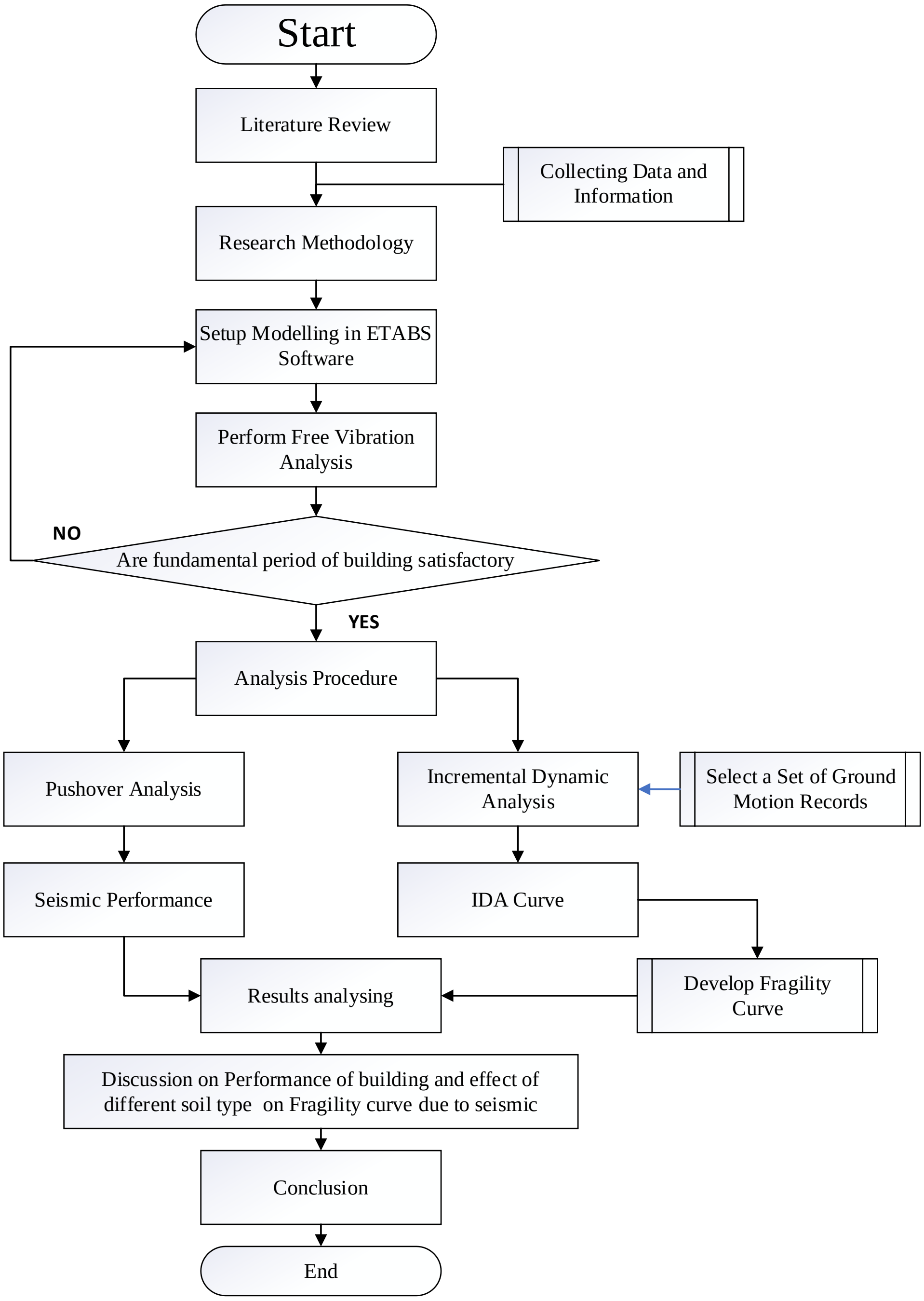


Fig. 2. Research flow chart

2.2 High Rise Building

Building height played a significant role in seismic analysis as it directly affected the amplification of seismic forces, dynamic response characteristic, lateral load resistance, differential deformations, and human safety considerations. By considering the height of a building in seismic analysis, response of structures were observed either can be resilient and capable of withstanding the anticipated ground motions, and ensuring the safety of the building and its occupants [9]. This study aimed to examine the seismic evaluation of tall buildings with varying heights. The two buildings exhibit contrasting characteristics in terms of their architectural classification. Building A is classified as Type I, boasting a total of 30-story. On the other hand, Building B falls under the classification of Type II, encompassing a total of 25-story. The first building has 11 parking areas, while the second tall building has seven parking areas. Both buildings are designed with different plans for the parking levels and residential story.

Selecting 25-story to 30-story buildings as a case study for seismic analysis in Malaysia offers several advantages. It aligns with local building practices, addresses the seismic hazard considerations specific to the region, focuses on design challenges and structural considerations relevant to tall buildings, assesses the impact on urban infrastructure, and provides practicality in terms of modelling and analysis. Together, these factors contribute to the suitability of such buildings as a case study for seismic analysis in Malaysia.

In modelling, material properties were assigned to accurately represent the behavior of materials under various loading conditions. These properties were crucial for capturing the response of the materials within the simulated or analysed structure. However, in this research, the material properties was not set as manipulated variable that might produce different result of analysis. The types of material present in the structure or system being analysed were identified. Design codes, standards, and specifications were consulted for guidelines on material properties, taking into account the material type and grade. The chosen properties aligned with the intended use, complied with relevant codes and standards, and reflected the specific characteristics of the materials used in the structure or system.

2.3 Applied Loads

In this study, the building model was specifically designed to accommodate gravity and wind loads, adhering to standard practices commonly followed in Malaysia. The live load for the residential floor area, intended for domestic and residential activities, was determined to be 2 kN/m². For the parking levels falling under category C, where gatherings may occur, a live load of 5 kN/m² was assigned. In addition, a superimposed load of 1.5 kN/m² and 1.3 kN/m² was applied to the residential and parking areas, respectively. These loadings were chosen in accordance with established guidelines and design codes to ensure the structural integrity and overall safety of the building [9]. The wind load calculation for this study in Malaysia was conducted with specific consideration for the local conditions and requirements. The essential wind speed of 33 m/sec was selected based on regional wind climate data and historical records specific to the study location. By incorporating the exposure category B, which accounts for the terrain, topography, and surrounding structures, the wind load analysis accurately reflects the site conditions in Malaysia. The choice of [14] as the reference standard for wind load calculation provides a well-established and widely accepted methodology for structural design in many parts of the world, including Malaysia. This standard takes into account various factors such as wind speeds, terrain characteristics, and building height to determine the appropriate wind loads.

2.4 Selecting Ground Motion Records

Incremental dynamic analysis (IDA) was performed by utilizing a series of natural earthquakes, requiring the availability of suitable ground motion record series. Selecting the appropriate ground motions for time-history analysis proved to be a challenge due to the diverse effects they had on structural response, stemming from variations in their characteristics. Considering the seismic hazard scenario in Malaysia, which is influenced by both distant earthquakes in Peninsular Malaysia and local earthquakes in East Malaysia, a selection of 20 earthquakes was made for the purpose of conducting incremental dynamic analysis. These earthquakes encompassed different soil types and peak ground acceleration (PGA) values, comprising both distant and local tremors to ensure comprehensive coverage. The selection of ground motion records for IDA was crucial, and data from the Pacific Earthquake Engineering Research Center (PEER) ground motion database were used.

Determining the appropriate number of ground motion recordings was a significant consideration. Existing codes and previous research recommended a minimum of three or seven sets of ground motion records [15-17]. However, the specific requirements and objectives of this study guided the selection process. In this study, each soil type was associated with five sets of ground motion records, as outlined in Table 1. The selection was based on their relevance to the research objectives and their ability to provide comprehensive insights into the structural response under various seismic conditions.

Table 1
Selected ground motion record

Earthquake occurred	Date occurred	Magnitude recorded (Mw)
Soil Type A		
Chi-Chi, Taiwan	1999	7.62
Chi-Chi, Taiwan	1999	6.3
El Monte Country Park	2004	5.03
Santa Margarita Ranch	2008	5.39
El Mayor-Cucapah, Mexico	2010	7.2
Soil Type B		
Kern Country	1952	7.36
Southern Calif	1952	6
Lytle Creek	1970	5.33
Friuli, Italy-02	1976	5.91
Irpinia, Italy-01	1980	6.9
Soil Type C		
Kern Country	1952	7.36
Imperial Valley-05	1955	5.4
Lytle Creek	1970	5.33
San Fernado	1971	6.61
Tabas, Iran	1978	7.35
Soil Type D		
Kern Country	1952	7.36
Imperial Valley-05	1955	5.4
Lytle Creek	1970	5.33
San Fernado	1971	6.61
Tabas, Iran	1978	7.35

3. Results
3.1 Modal Analysis

The analysis of vibration characteristics, including natural frequencies and corresponding mode shapes, is performed through modal or free vibration analysis [18]. To determine these characteristics, an Eigen procedure was employed. The entire building structure underwent modal analysis, considering 12 modes to accurately assess the mass participation ratio of the building. During an earthquake, buildings undergo oscillations, resulting in the generation of inertia forces

[19]. The magnitude, duration, and impact of these oscillations on a building are influenced by various factors, such as the building's properties, dynamic characteristics, and the earthquake itself.

3.1.1 Natural period of building

The natural period of a building, denoted as the time required for one complete cycle of oscillation, is a critical parameter in structural dynamics. When a structure is exposed to an earthquake, it eventually responds to vibration. The summary of the analysis result for both buildings has been tabulated in Table 2. As the vertical dimension of a building increases, there is a corresponding increase in its mass, while concurrently experiencing a decrease in its overall stiffness. The direct proportionality between the height of a building and its natural period is evident. Taller structures, due to their increased mass and reduced overall stiffness, exhibit longer fundamental natural periods. Specifically, the 25-story and 30-story buildings possess fundamental translational natural periods of 2.895s and 3.487s, respectively. In essence, the temporal oscillations exhibited by buildings are contingent upon their respective heights. Buildings with greater height exhibit longer fundamental natural translational periods. The vertical distribution of mass and stiffness throughout the height of a building significantly influences its dynamic response. In tall structures, mass is incrementally added with each floor, and stiffness is distributed unevenly, with lower floors exhibiting greater rigidity. This distribution results in the development of multiple vibration modes, each associated with a specific natural period.

Table 2
Mode shape and building period

Mode shape	Natural building period, T (Second)	
	Type I – 25 Storey	Type I – 25 Storey
1	2.895	3.487
2	1.610	2.200
3	1.483	1.873
4	0.82	1.128
5	0.542	0.845
6	0.466	0.733
7	0.400	0.623
8	0.250	0.329
9	0.241	0.302
10	0.120	0.263
11	0.169	0.224
12	0.145	0.191

3.1 Pushover Analysis

Following the allocation of all model properties, a displacement-controlled pushover analysis is conducted on the models. The application of incremental loads follows the application of gravity loads. The models are subjected to triangular and uniform load distributions until the desired displacement is attained. The outcome was utilised for the purpose of contrasting the capacity curves and structural distortion at the point of performance.

3.1.1 Capacity curve

Figure 3 displays the pushover curve for both structures. The aforementioned curves depict the overall performance of the frame in terms of its stiffness and ductility on a global scale. The reduction in the slope of pushover curves is observed to be proportional to the increase in the lateral displacement of the building. The aforementioned phenomenon can be attributed to the gradual development of plastic hinges in both the beam and column components across the entirety of the edifice. From Figure 3, it was observed that the capacity curve of a building is significantly influenced by the number of stories it possesses. In light of the result obtained, an intriguing observation emerges: 25-story buildings exhibit a higher resistance to base shear compared to their 30-story counterparts. This finding prompts further discussion to understand the underlying factors that contribute to this difference and explore its implications for structural performance and safety. Possible explanation for this observation lies in the building stiffness, structural configuration, damping and redundancy.

The 25-story building may have a stiffer structural system compared to the 30-story building. Stiffness plays a crucial role in distributing and resisting lateral forces. The 25-story building has a more rigid and robust structural design, it can effectively transfer and distribute the applied base shear throughout the structure, resulting in higher resistance. The structural configuration and geometry of the building will have a more favourable configuration, such as a wider footprint or a more efficient distribution of lateral load-resisting elements, which can enhance its resistance to base shear. The 30-story building despite being taller, will have a less optimal configuration that affect its overall resistance.

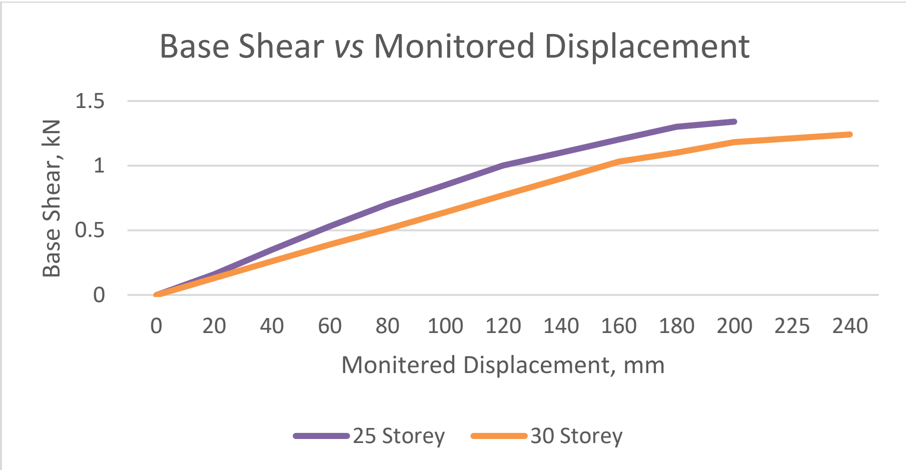


Fig. 3. Capacity curve for both type

3.1.2 Roof lateral displacement

Roof lateral displacement refer to the horizontal movement or deflection of a building's roof under the influence of lateral loads. The dynamic response of the roof to lateral loads involves the study of how the roof deflects and oscillates in response to external forces. The lateral displacement of both models is compared in the same amount of lateral load that collapses in the 30-story building (1248.020 kN). The result presented in Table 3. The lateral displacement of 25 story building is lower than 30 story building. It is observed that the lateral displacement is reduced when the height of the building decrease. The height of a building can have significant impact on roof lateral displacement when the structure is subjected to lateral loads.

As the height of a building increases, its mass and inertia also increase. Inertia is the resistance of an object to changes in its state of motion, and in the context of lateral displacement, it influences how the building responds to lateral forces. A taller building tends to have greater mass distributed over a larger height, which can result in larger lateral displacements. Besides, the distribution of flexibility and stiffness along the height of a building influences how lateral loads are distributed. In tall buildings, the distribution of lateral stiffness is often uneven, with lower floors being stiffer than upper floors. This uneven distribution can contribute to a more complex dynamic response and potentially larger lateral displacements. In summary, the height of a building is a crucial factor influencing roof lateral displacement. Tall buildings pose unique challenges in terms of dynamic response and lateral stability, requiring careful engineering considerations to mitigate the effects of lateral forces and ensure the safety and performance of the structure.

Table 3
Lateral roof displacement

Case	25-story	30-story
Displacement (mm)	165	240

3.2 Incremental Dynamic Analysis

The IDA curve was generated using five distinct ground motion records associated with various earthquakes for each soil type. This allowed for the illustration of structural response variability to increasing earthquake ground records. Peak ground acceleration, recognized as a preferred intensity measure intensity [20], was employed. The IDA curve depicted the maximum drift ratio and peak ground acceleration for the analyzed frames. Scale factors were incrementally increased until collapse occurred, leading to the conclusion of the analysis. This marked the critical point at which the structural limits under intensifying seismic conditions were discerned. The termination at collapse allowed the understanding of vulnerability thresholds for the structures under scrutiny, forming the basis for further insights into fragility and vulnerability, crucial aspects in comprehending the seismic performance of the analyzed frames.

As depicted in the Figure 4, the building exhibited an operational performance (OP) limit state with a drift ratio of 0.5% for soil types A, B, and D, when peak ground acceleration reached 0.1, 0.13, and 0.28g, respectively. Soil type C was not capture because the value of inter story drift ratio is below 0.005 (0.5%). Additionally, the building experienced an immediate occupancy (IO) limit state with a drift ratio of 1% at PGA levels of 0.19g for soil type B and 0.27g for soil type D. Furthermore, a life safety (LS) limit state was observed at a drift ratio of 1.5% with PGA levels of 0.29g for soil type B and 0.41g for soil type D. Finally, a collapse prevention (CP) limit state occurred at a drift ratio of 2.5% when subjected to soil type B and PGA of 0.5g.

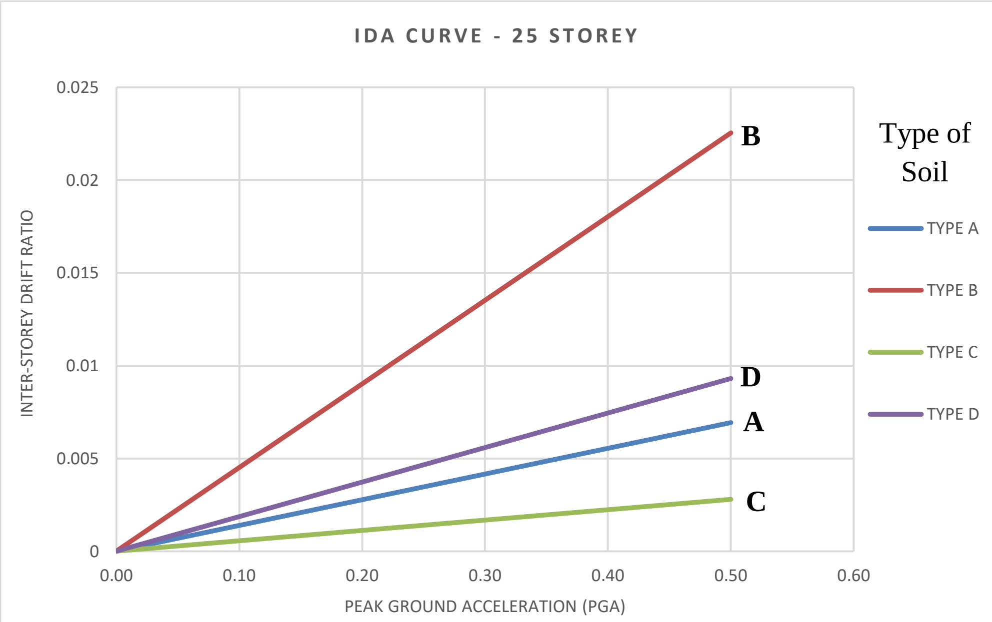


Fig. 4. IDA curve for 25 story building

As depicted in Figure 5, the building encountered OP limit state with a 0.5% drift ratio for soil types B, C, and D at PGA levels of 0.1g, 0.27g, and 0.14g, respectively. Soil type A was not capture because the value of inter story drift ratio is below 0.005 (0.5%). Similarly, the building experienced an IO limit state with a 1% drift ratio at PGA levels of 0.1g for soil type B and 0.13g for soil type D (0.115g) was capture. Furthermore, the LS limit state was observed with a 1.5% drift ratio at PGA levels of 0.31g for soil type B and 0.42g for soil type D. Finally, the CP limit state occurred with a 2.5% drift ratio at PGA levels of 0.5g for soil type B. The analysis results indicate that the CP limit states are significantly influenced by soil type B, suggesting amplified seismic waves compared to other soil types. Each soil type yields distinct limit state values for varying ground accelerations, emphasizing the dependence on site soil characteristics through which seismic waves propagate during an earthquake. In essence, different soil types can either amplify or dissipate seismic motion as the waves travel from the bedrock to the ground level.

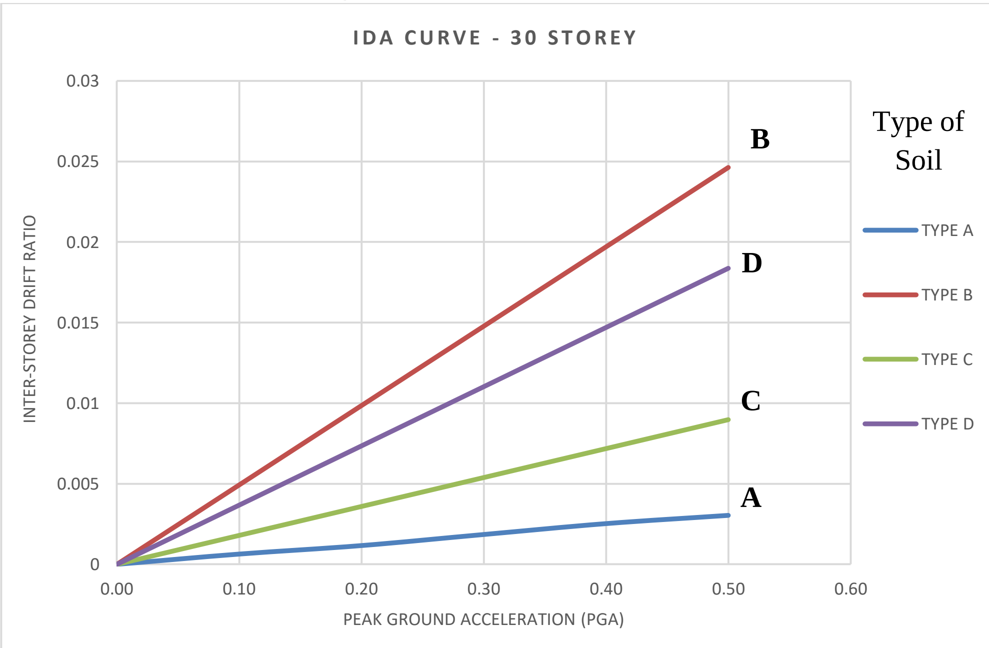


Fig. 5. IDA curve for a 30-story building

3.3 Fragility Curve

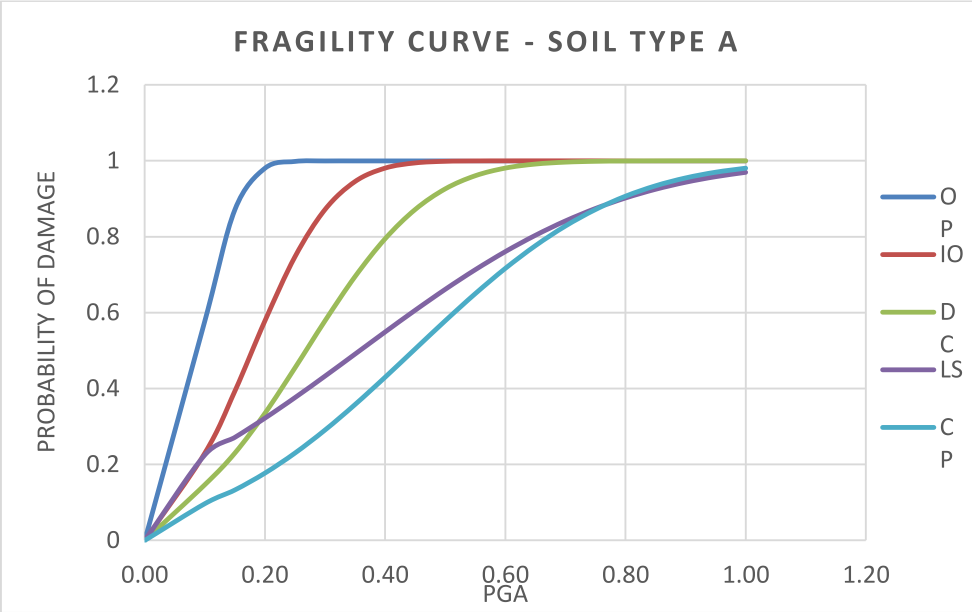
Fragility curves depict the likelihood of a structural response surpassing a specific limit state at a given level of seismic intensity using various methods such as empirical, experimental, computational, and hybrid approaches [21]. The IDA enables the categorization of results based on different intensities, thereby generating a collapse fragility curve. To construct a fragility curve, two parameters, namely the mean and standard deviation, are necessary. In this study, the mean and standard deviation of PGA were computed for each point along the IDA curve, specifically at the vertical gridlines corresponding to drift limit states (Table 4).

Table 4
Lateral roof displacement

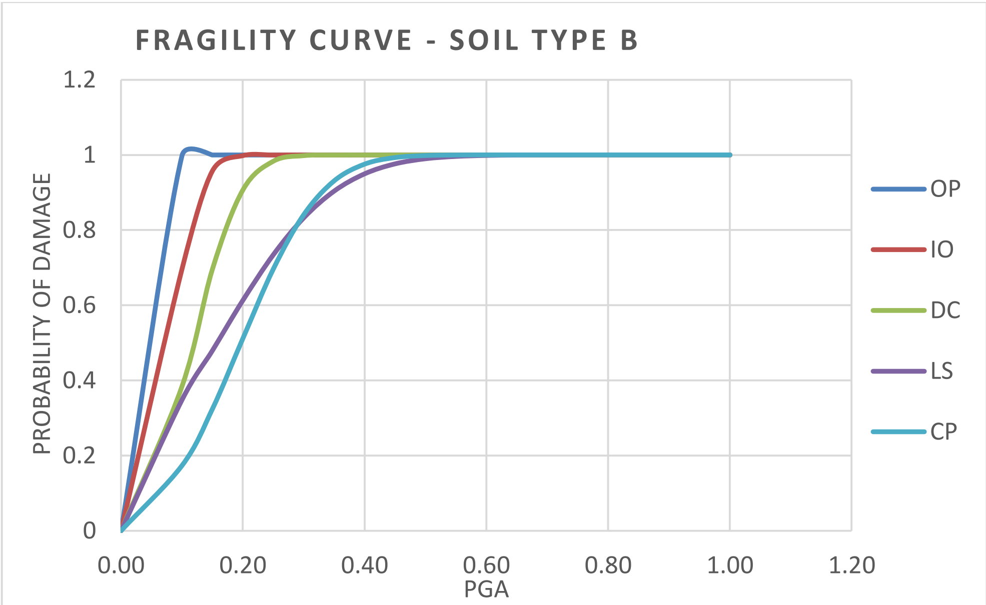
Type of soil	OP μ	OP σ	IO μ	IO σ	DC μ	DC σ	LS μ	LS σ	CP μ	CP σ
Type I – 25 Storey										
A	0.080	0.043	0.161	0.087	0.241	0.130	0.321	0.173	0.402	0.217
B	0.039	0.021	0.079	0.041	0.118	0.062	0.158	0.147	0.197	0.103
C	0.087	0.052	0.173	0.105	0.260	0.157	0.347	0.190	0.433	0.262
D	0.012	0.058	0.023	0.117	0.035	0.175	0.047	0.234	0.058	0.292
Type II – 30 Storey										
A	0.075	0.042	0.156	0.072	0.236	0.103	0.317	0.271	0.398	0.165
B	0.046	0.027	0.093	0.053	0.139	0.080	0.186	0.180	0.232	0.133
C	0.065	0.040	0.130	0.080	0.196	0.120	0.261	0.155	0.326	0.200
D	0.015	0.092	0.029	0.184	0.044	0.275	0.058	0.367	0.073	0.459

The construction of the fragility curve involves a systematic analysis of structural response against a range of ground motion intensities. The IDA curve, discussed previously, is employed to capture the structural behavior under increasing seismic forces. The fragility curve is then derived by correlating the structural response data with the probability of exceeding predefined damage states. At each point on the fragility curve, there is an indication of the probability of a structure surpassing a specific damage threshold at a given level of ground shaking. Damage states categorized based on structural performance levels such as OP, IO, LS, and CP, provide a meaningful framework for understanding the potential severity of damage.

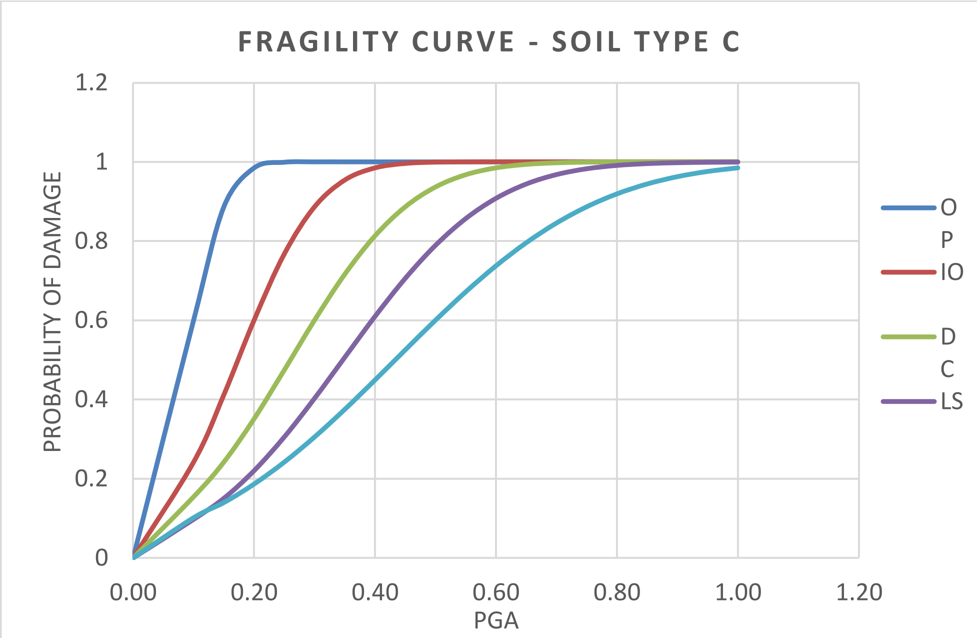
Figure 6 (a-d) demonstrates the probabilities of surpassing the IO for soil types A, B, C, and D at a ground motion of 0.1g. Soil types A and C exhibit similar probabilities of exceeding the IO, as do soil types B and D. However, soil type D stands out with a significantly higher likelihood of surpassing the CP damage state compared to soil types A, B, and C. Considering the CP level, a 25-story building can withstand up to 0.5g under soil type C before collapse, whereas soil types A, B, and D estimate approximately 60, 67, and 93% chances of extensive damage respectively. However, the probability of reaching the IO level is approximately 100% for all soil types. The analysis suggests that 25-story buildings have a high probability of reaching or exceeding the IO and CP performance levels when situated on soil type B.



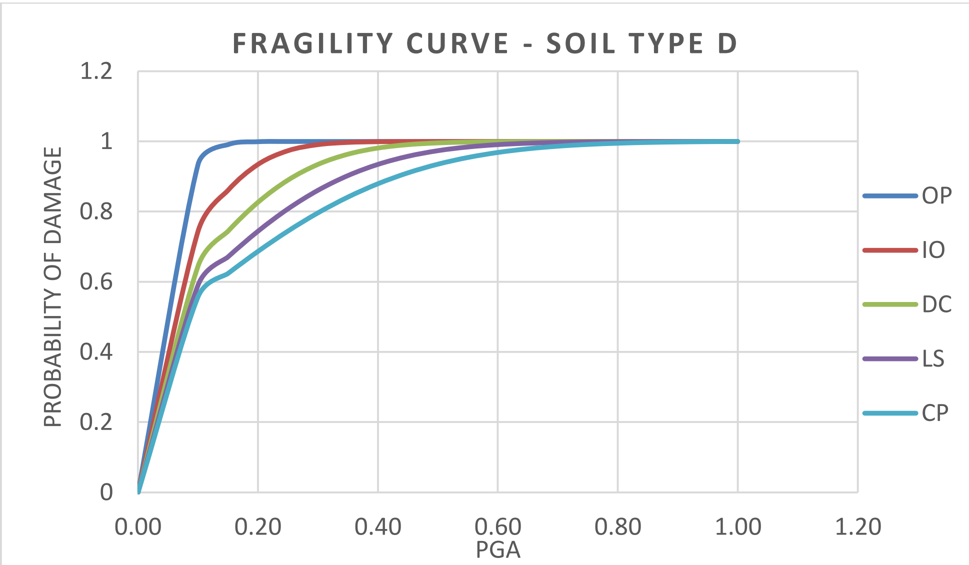
a) Model type I – soil type A



b) Model type I – soil type B



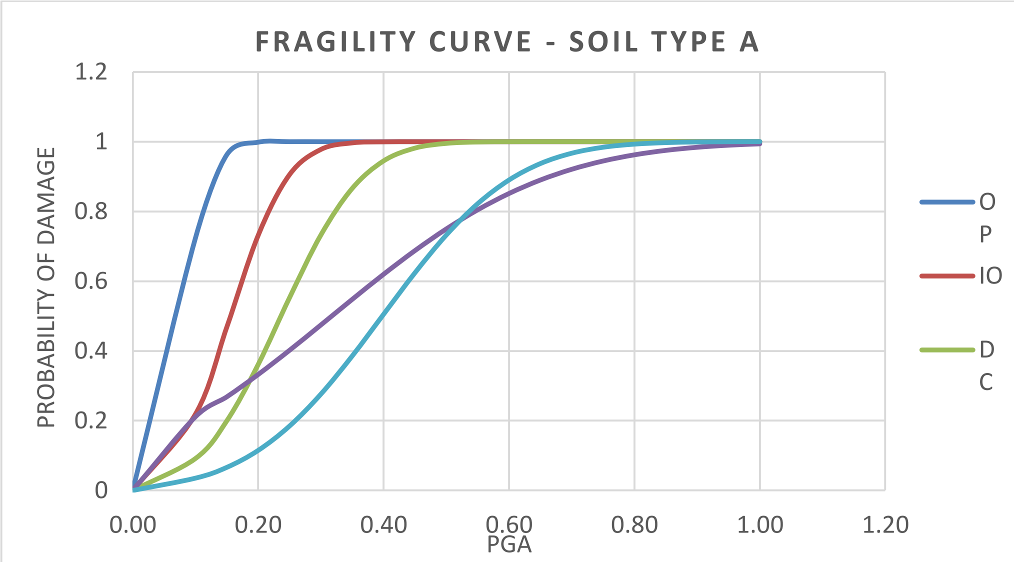
c) Model 25 story – soil type C



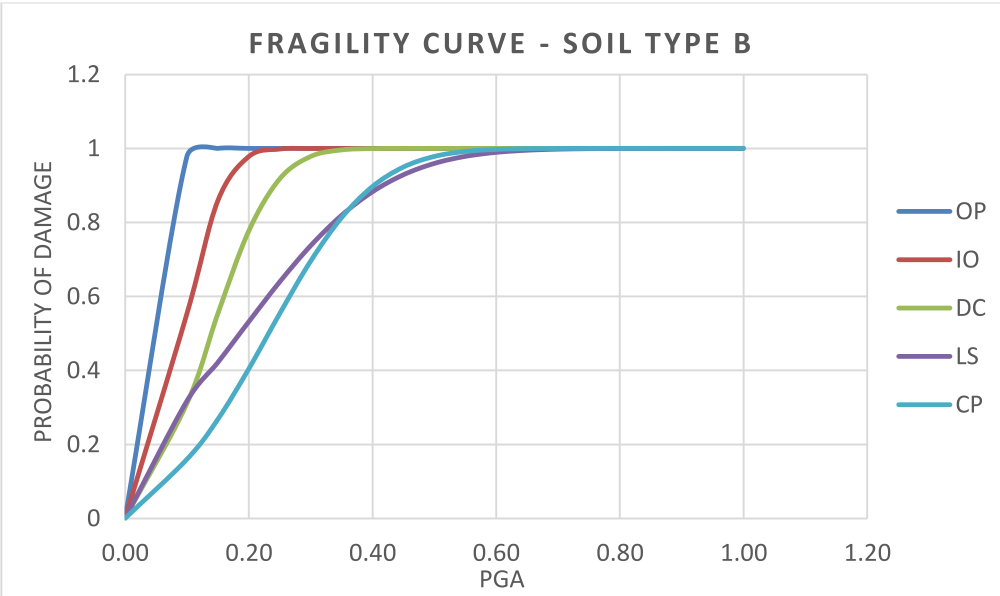
d) Model 25 story – soil type D

Fig. **6**. (a-d) Seismic fragility curve for 25 story building

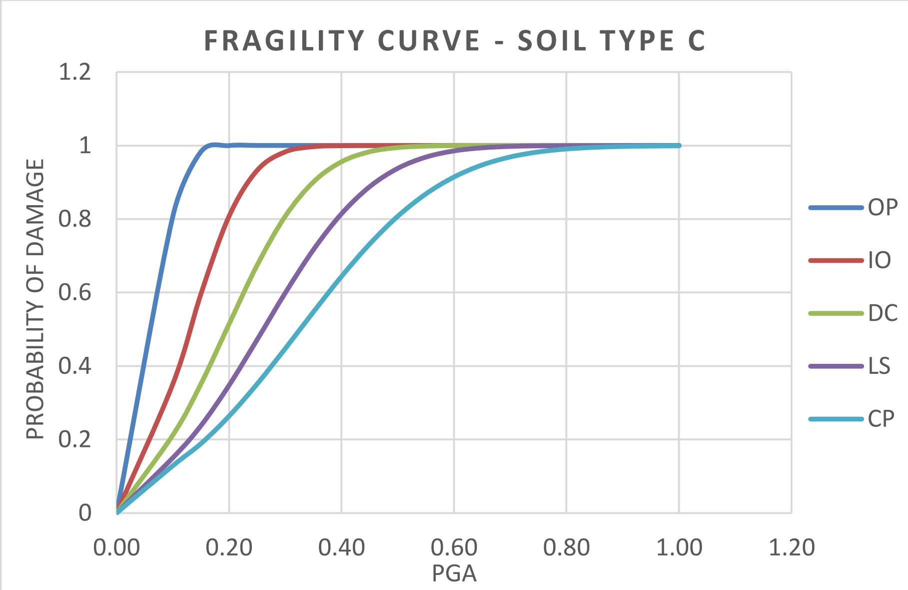
Figure 7 (a-d) showcases fragility curves depicting the performance of a 30-story building across different soil types: A, B, C, and D. The graph reveals that when subjected to weak ground motion of 0.1g, the probability of reaching or surpassing the IO level for soil types A, B, C, and D is approximately 22, 55, 35, and 74% respectively. Similarly, the likelihood of reaching or exceeding the CP level for these soil types is approximately 4, 15, 13, and 52% respectively. For a peak horizontal ground acceleration level of 0.5g, the 30-story building can withstand all soil types, with recorded percentages for soil types A, B, C, and D being 73, 97, 80, and 82% respectively. It is evident that the fragility curves of the building in soil type A exhibit lower probabilities compared to those in soil types B, C, and D. This implies that under soil type A, the chances of extensive damage are comparatively lower than in the other soil types.



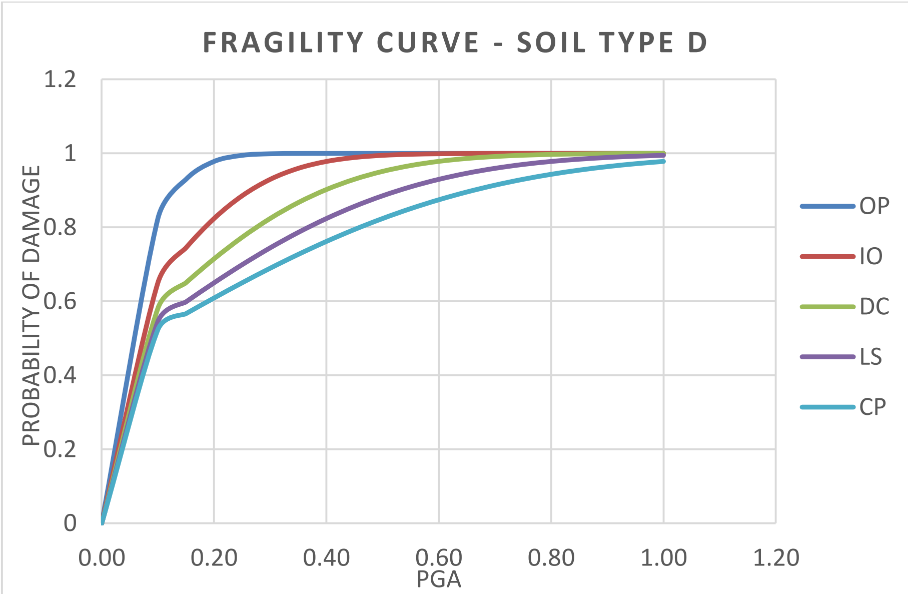
a) Model 30 story – soil type A



b) Model 30 story – soil type B



c) Model 30 story – soil type C



d) Model 30 story – soil type D

Fig. 7. (a-d) Seismic fragility curve for 30 story building

3.1.1 Effect of soil type on the building fragility

The summarized probabilities of building damage under peak ground accelerations of 0.1g and 0.5g are presented in Tables 5 and 6. The analysis reveals that the fragility curves for soil type B indicate a higher susceptibility to damage compared to the other soil types. For instance, when considering a PGA level of 0.5g (Table 6) the fragility curve for soil type B suggests an approximate 100% probability of extensive damage, while the curves for soil types A, C, and D estimate probabilities of around 67, 60, and 93% respectively. This difference becomes more pronounced at higher damage limit states. Thus, it is crucial to appropriately account for local soil conditions in the fragility analysis of reinforced concrete buildings.

The seismic scenarios examined further illustrate the variation in damage levels among different building heights. For the 25-story building, when subjected to soil type B, there is a higher probability of experiencing the CP limit state and associated damage compared to the 30-story building. Specifically, the CP values for the 25-story and 30-story buildings under soil type C are 60 and 80% respectively. This finding suggests that the 30-story building is more susceptible to extensive damage when subjected to soil type C than the 25-story building. Notably, the modification in seismic wave characteristics affects the dynamic behavior of high-rise structures.

Taking into account the specific conditions in Malaysia, where the majority of buildings are tall structures, particularly in Kuala Lumpur city center, the maximum peak ground acceleration is reported to be 0.09g on bedrock soil (MS EN 1991-1-1:2010, 2010). Nevertheless, taking into account the influence of soil conditions, the peak ground acceleration (PGA) has the potential to attain a magnitude of 0.1g. Based on the seismic fragility curves acquired, it has been determined that the 30-story building has maximum probabilities of surpassing the IO and CP damage states at rates of 22 and 4% respectively. This information is presented in Table 5. Therefore, it is anticipated that tall buildings in Kuala Lumpur will only experience repairable damage. Furthermore, it is evident that structures with heights in contrast to the 30-story building demonstrate a decreased likelihood of surpassing IO damage states when situated on bedrock soil, while displaying an increased likelihood when situated on dense sand soil.

Table 5
PGA level of 0.1g

Type of soil	Type A		Type B		Type C		Type D	
Level of performance	IO	CP	IO	CP	IO	CP	IO	CP
Type I	0.23	0.08	0.7	0.17	0.24	0.1	0.74	0.56
Type II	0.22	0.04	0.55	0.15	0.35	0.13	0.65	0.52

Table 6
PGA level of 0.5g

Type of soil	Type A		Type B		Type C		Type D	
Level of performance	IO	CP	IO	CP	IO	CP	IO	CP
Type I	1	0.67	1	1	1	0.6	1	0.93
Type II	1	0.73	1	0.97	1	0.8	1	0.82

4. Conclusions

The conclusions of the studies on tall building structural performance under seismic effects encompass a multifaceted understanding of their dynamic behavior and vulnerability. The examination of dynamic behavior provided insights into seismic response mechanisms, including natural frequency determination and assessment of lateral load resistance systems, enhancing comprehension of structural dynamics crucial for earthquake-resistant design. Furthermore, the development of a comprehensive fragility curve empowers stakeholders with a tool to assess vulnerability and damage likelihood, aiding in decision-making regarding design, retrofitting, and risk assessment. Additionally, the investigation into potential damage under different site conditions highlights the significant influence of local soil characteristics on structural response, emphasizing the critical role of soil conditions in determining seismic performance and potential damage levels. These findings collectively contribute to advancing seismic engineering practices for tall buildings in earthquake-prone regions.

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