

Seismic Performance Assessment of a Medium-Rise Concrete Building under Multiple Earthquake Scenarios Using STAAD Pro

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Abstract

This study examines the seismic performance of a medium-rise reinforced concrete building in Malaysia using STAAD Pro software, a widely adopted analytical tool in structural engineering practice. The building is modelled and subjected to seismic simulations based on ground motion data from four significant earthquake events: Cheutsu-Oki, Trinidad, Northridge, and Chi-Chi. The assessment focuses on key structural response parameters, namely shear force, bending moment, and deflection, to evaluate the building's behaviour under varying seismic intensities. The results demonstrate clear differences in structural response among the earthquake scenarios, with the Northridge event producing the highest stress demands and displacement levels, indicating its governing severity. These findings highlight the critical importance of resilient structural design and continuous improvement of seismic mitigation strategies, even in regions of low-to-moderate seismicity. The novelty of this study lies in its comparative evaluation of multiple real earthquake ground motions applied to a Malaysian medium-rise concrete building using a consistent analytical framework, providing new insight into seismic demand sensitivity and performance trends in low-to-moderate seismic regions. Overall, the study provides meaningful insights for enhancing the seismic resilience of medium-rise concrete structures, contributing to safer and more robust urban built environments.

Keywords: seismic analysis, medium-rise concrete building, structural performance, earthquake simulation, STAAD Pro

1. Introduction

In recent years, the increasing occurrence of earthquakes worldwide has heightened the demand for resilient and earthquake-resistant infrastructure. Although Malaysia is categorised as a low-to-moderate seismicity region, seismic events remain a significant concern due to its proximity to active tectonic boundaries, particularly the Sumatra Fault system. The 2015 Ranau earthquake (Mw 6.0) near Mount Kinabalu marked a critical turning point in national seismic awareness, resulting in landslides, casualties, and infrastructure damage that affected both the local economy and tourism sector. Since then, efforts to enhance seismic preparedness have intensified through improved disaster management strategies, structural evaluation initiatives, and increased awareness of seismic risk. Nevertheless, rapid urbanisation and the prevalence of non-seismically designed buildings where less than one percent of existing structures are reported to be seismic resistant continue to pose substantial challenges to structural safety during earthquake events. In this context, mid-rise buildings, typically ranging from five to ten storeys, represent a dominant building typology in Malaysian urban areas due to land constraints and zoning regulations. These structures commonly serve residential, commercial, and institutional functions and are predominantly constructed using reinforced concrete systems. Given their

widespread use and potential vulnerability, seismic performance assessment of mid-rise concrete buildings is essential to ensure adequate safety and serviceability under earthquake loading.

Globally, seismic research has progressively shifted towards performance-based seismic design (PBSD), which enables engineers to evaluate structural behaviour against predefined performance objectives rather than relying solely on prescriptive code limits. Performance-based seismic design allows designers to set performance objectives and design buildings to meet the targeted performance criteria (Padalu & Surana, 2024), thereby offering a more rational framework for assessing damage levels and post-earthquake functionality. In parallel, recent studies have highlighted the importance of ground motion characteristics in governing seismic demand. Kumar and Ghosh (2025) demonstrated that near-field ground motions can induce significantly higher displacement demands compared to far-field motions, underscoring the need for comparative assessment using multiple earthquake records. Furthermore, advances in data-driven and artificial intelligence-based seismic assessment have gained traction in recent years. Xie (2025) reported that deep learning techniques are increasingly being adopted to address complex challenges in earthquake engineering, including damage prediction and rapid performance evaluation. Despite these global advancements, many seismic assessments in low-to-moderate seismic regions, including Malaysia, continue to rely on conventional linear and quasi-static approaches. STAAD Pro remains widely employed due to its robustness and practicality in simulating seismic loading and evaluating key response parameters such as shear force, bending moment, deflection, and base shear. Previous studies using STAAD Pro have demonstrated its effectiveness in capturing regional seismic effects and comparative demand trends (Ramakrishna et al., 2022; Salam & Kumar, 2022). Within the Malaysian context, earlier investigations have focused on local ground motion characteristics, finite element-based damage assessment, and seismic performance of buildings and infrastructure. However, limited studies have integrated comparative multi-event seismic assessment within a globally aligned performance-based perspective. This research addresses this gap by comparatively evaluating the seismic response of a Malaysian mid-rise concrete hospital building under multiple international earthquake scenarios, thereby strengthening the linkage between local practice and current global seismic design trends.

In the Malaysian context, Sooria, Sawada, and Goto (2012) investigated potential ground motion characteristics in Peninsular Malaysia and proposed a seismic design framework based on ground motion prediction models. Their work laid essential groundwork for understanding regional seismicity, which is particularly relevant for seismic simulation and performance assessment of Malaysian buildings. To improve site-specific seismic evaluation, Ismail, Ibrahim, and Adnan (2022) employed Multi-Channel Analysis of Surface Waves (MASW) to determine shear wave velocity profiles, which serve as critical input parameters for estimating ground response and seismic demand. This contribution highlights the importance of subsurface characterisation in accurately predicting structural behaviour during earthquake events. Beyond building structures, advanced applications of STAAD Pro have been demonstrated in dam and infrastructure studies. Ismail et al. (2021a) evaluated the seismic performance of roller compacted concrete dams, while Ismail et al. (2021b) applied two-dimensional finite element analysis to reinforced concrete buildings under seismic loading. Collectively, these studies confirm the versatility of STAAD Pro for both linear and nonlinear seismic analysis across different structural typologies, including dams and mid-rise buildings.

In parallel, research on material behaviour under seismic and vibrational loading has provided valuable insights into energy dissipation and damping enhancement mechanisms. Experimental investigations by Ismail, Rajhan, Hamid, and Ibrahim (2019) examined the mechanical properties of magnetic rubber composites, while subsequent studies by Ismail et al. (2019a, 2019b) explored the dynamic mechanical and magnetic properties of carbon nanotube-reinforced rubber systems. These findings demonstrate the potential of advanced composite materials to improve vibration control and seismic resilience. Earlier experimental work by Ismail et al. (2018) further contributed to understanding the mechanical performance of elastomeric materials containing carbon nanotubes. Together, these studies emphasise the importance of integrating material innovation with structural analysis to enhance seismic performance.

Extending to broader structural systems, Ismail and Ismail (2017a) applied finite element modelling to investigate the dynamic response of concrete-faced rockfill dams, while Ismail and Abdul Karim (2017b) assessed the seismic behaviour of concrete bridge piers. These investigations reinforce the applicability of finite element-based seismic assessment techniques to a wide range of structural systems. In addition, vulnerability studies by Ismail, Ibrahim, and Razali (2017c) identified common weaknesses in public and mid-rise buildings subjected to seismic events, while Ismail, Kamsani, and Nadzri (2017d) demonstrated the effectiveness of seismic analysis in concrete dam structures. Studies on high-rise and medium-rise reinforced concrete buildings subjected to low-intensity earthquakes (Ismail & Zamahidi, 2015; Ismail, Ibrahim, & Adnan, 2018b) further confirmed that even regions of low seismicity may experience moderate structural damage, particularly at critical beam-column joints.

More recent research has focused on advanced seismic isolation systems and innovative materials to enhance structural resilience. Comparative studies by Cao et al. (2024, 2025) evaluated base isolation and interlayer isolation strategies in complex twin-tower configurations, revealing the significant influence of tower geometry, mass distribution, and isolation layout on seismic response. Their work also introduced incremental analysis frameworks that consider multiple intensity measures and failure modes. Complementing these system-level approaches, Ismail et al. (2023) investigated the magnetic properties of vulcanised natural rubber nanocomposites, demonstrating their potential for energy dissipation in seismic applications. Collectively, these studies highlight the growing emphasis on combining advanced analysis techniques, isolation strategies, and damping materials to achieve more resilient seismic design solutions.

The novelty of this study lies in its comparative evaluation of multiple real earthquake ground motions applied to a Malaysian medium-rise hospital building using a consistent peak ground acceleration framework. Unlike conventional STAAD Pro-based seismic assessments that focus on a single seismic input or generic design spectra, this study highlights the relative sensitivity of structural response to different ground motion characteristics, offering practical insights for seismic risk awareness and preliminary seismic assessment in low-to-moderate seismic regions.

2. Description of structure and methods

This study evaluates the structural performance of a mid-rise reinforced concrete hospital building in Malaysia using STAAD Pro software, a widely recognised analytical tool in structural engineering practice. The research framework encompasses comprehensive building modelling, seismic simulation, quasi-static seismic analysis, comparative performance assessment, and the formulation of design-oriented recommendations. A detailed architectural blueprint of the KPJ Selangor Hospital, provided by KPJ Healthcare Berhad, is used as the basis for developing an accurate three-dimensional digital model of the structure. The building is modelled in accordance with the requirements of the Uniform Building By-Laws (UBBL), incorporating standardised beam and column dimensions representative of common construction practice in Malaysia. The primary objective of the study is to simulate and analyse the structural response of the building under four significant earthquake events—Cheutsu-Oki, Trinidad, Northridge, and Chi-Chi—in order to evaluate seismic demand and propose strategies to enhance the seismic resilience of similar medium-rise buildings nationwide. The selection of the four earthquake records—Cheutsu-Oki, Trinidad, Northridge, and Chi-Chi—was made to represent a broad spectrum of seismic demand scenarios relevant for comparative assessment. These earthquakes differ in terms of magnitude, peak ground acceleration (PGA), and ground motion characteristics, allowing evaluation of structural response under varying intensity levels and excitation features. Such variation is essential for understanding the sensitivity of mid-rise reinforced concrete buildings to different seismic inputs rather than relying on a single representative event.

The STAAD Pro modelling process includes all primary structural components, namely beams, columns, and slabs, with material properties, geometric dimensions, and modelling assumptions defined in accordance with UBBL provisions. This modelling approach ensures consistency with local design practice and provides a reliable platform for assessing the comparative seismic behaviour of the structure under different earthquake

scenarios, as summarised in **Table 1** and illustrated in **Figure 1**. In addition, key modelling assumptions adopted in the analysis are explicitly defined to enhance transparency and reproducibility. These include the assumed damping ratio, boundary conditions at the foundation level, and mass participation considerations used in the seismic analysis. Clearly stating these assumptions ensures consistency with standard seismic modelling practice and provides a reliable basis for interpreting the comparative results obtained from the STAAD Pro simulations.

Table 1. Input Data for Structural Modelling

No	Parameter of Building	Data
1	Number of stories	G + 5
2	Grade of Concrete	M25
3	Storey Height	4.0m
4	Beam Size	0.6m x 0.32m
5	Column Size	0.7m x 0.7m

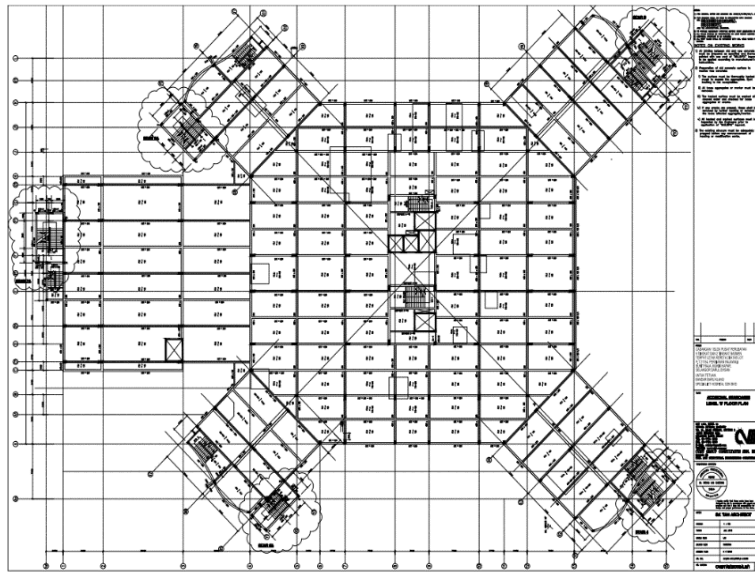


Figure 1. Structural Drawing of Ground Floor 5 of Storey Mid-Rise Building

Earthquake loading refers to the forces and ground motions induced by seismic events that act on the ground and are transmitted to structures resting upon it. During an earthquake, seismic waves propagate through the Earth's crust, releasing energy that results in ground shaking and dynamic excitation of structural systems. The evaluation of earthquake loading begins with the determination of the total seismic mass of the structure and its distribution across individual storeys. This process involves identifying the dimensions and material properties of all structural components and calculating their respective contributions to the overall building mass. In seismic analysis, live loads are commonly excluded or partially considered, as earthquake occurrence is independent of building occupancy and conservative assumptions are typically adopted to represent realistic loading conditions.

In this study, four significant earthquake events—Cheutsu-Oki, Trinidad, Northridge, and Chi-Chi—were selected to represent a range of seismic characteristics and intensity levels. These earthquake records were chosen based on their distinct magnitudes, peak ground accelerations, and ground motion characteristics, thereby providing a broad spectrum of seismic loading scenarios for comparative assessment. The selected

ground motion data enable evaluation of the building’s structural response under varying seismic demands, as summarised in **Table 2**.

Table 2. Ground Motion Data for Analysis

No	Earthquake Event	Earthquake Magnitude	Peak Ground Acceleration (PGA)
1	Cheutsu-Oki (Japan)	6.8	0.175
2	Trinidad (USA)	5.7	0.194
3	Northridge (USA)	6.69	0.564
4	Chichi (Taiwan)	6.2	0.361

To ensure a consistent and meaningful comparison across different seismic events, each selected earthquake record was normalised to a Peak Ground Acceleration (PGA) of 0.1g. This standardisation enables a direct evaluation of the building’s structural response to varying ground motion characteristics while maintaining a uniform intensity level. Peak Ground Acceleration (PGA), defined as the maximum horizontal acceleration experienced at the ground surface during an earthquake, is a key parameter governing seismic demand, as it directly influences base shear and the overall inertial forces acting on a structure. Although acceleration–time histories are utilised to derive seismic demand parameters, the analysis conducted in this study represents a quasi-static seismic evaluation rather than a fully nonlinear dynamic time-history analysis. This approach is appropriate for comparative assessment and preliminary performance evaluation; however, it does not explicitly account for inelastic structural behaviour, higher-mode effects, or cumulative damage, which should be considered in future studies employing advanced dynamic analysis techniques.

Figure 2 illustrates the acceleration–time histories of the selected earthquake events following PGA normalisation. The ground motion records are sourced from internationally recognised seismic databases and reflect a range of earthquake characteristics observed in different seismic regions. **Figure 3** presents the application of the corresponding seismic forces to the building model, illustrating the imposed lateral loading conditions adopted in the analysis.

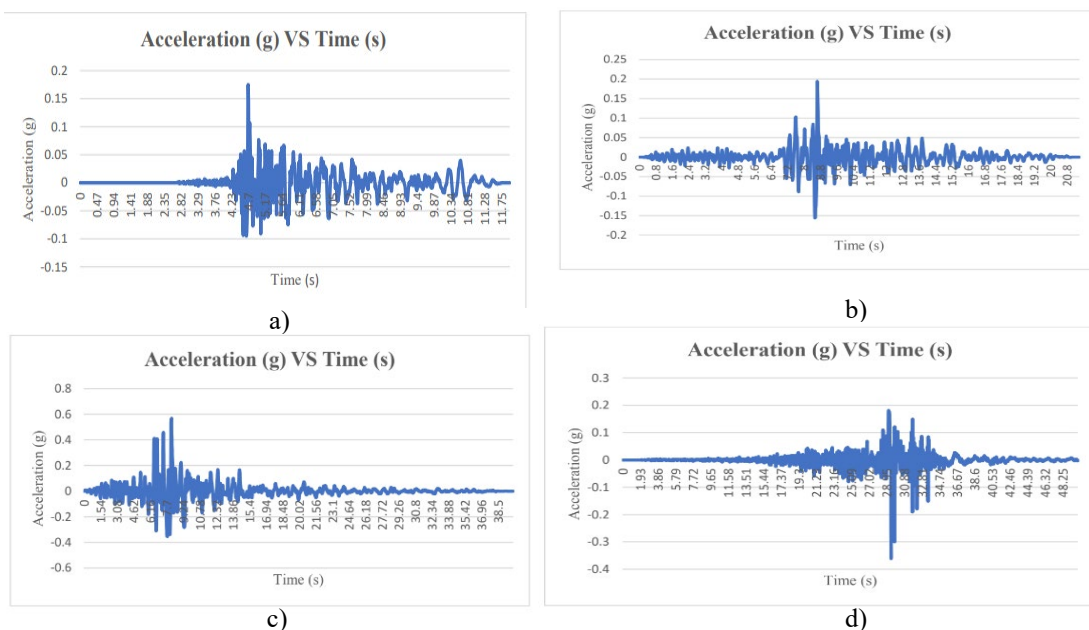


Figure 2. Acceleration-Time Histories for Selected Earthquake Events: a) Cheutsu-Oki (Japan) Earthquake, b) Trinidad (USA) Earthquake, c) Northridge (USA) Earthquake and d) Chi Chi (Taiwan) Earthquake.

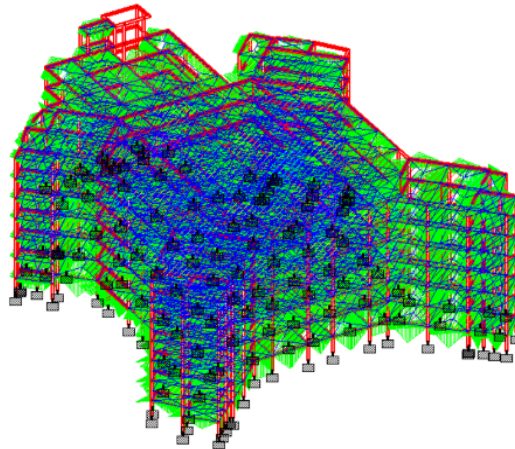


Figure 3. Seismic Load acting on structure

3. Results and Discussion

The analysis focused on key structural response parameters, including storey displacements, bending moments, and shear forces developed within the building elements under seismic loading. Through the conducted seismic simulations, the structural performance of the building was systematically evaluated to identify critical regions exhibiting higher seismic demand and increased susceptibility to potential damage, which may require additional reinforcement or design enhancement. Detailed numerical outputs and graphical visualisations were extracted using the Post-Processing mode in STAAD Pro, enabling comprehensive interpretation of structural behaviour under different earthquake scenarios, as illustrated in **Figure 4**.

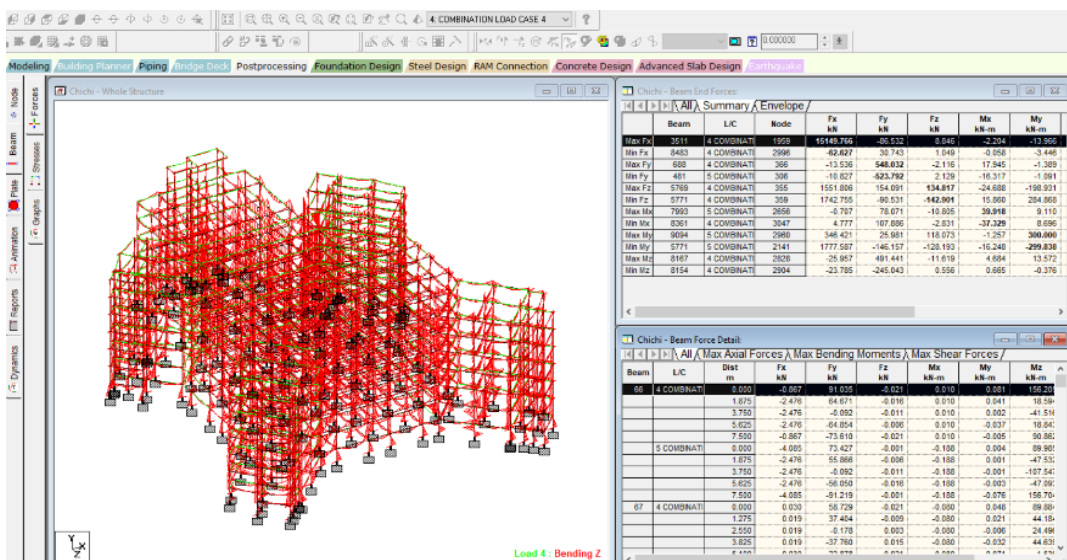


Figure 4. Bending Moment Distribution Visualized in Post-Processing Mode

Figure 5 presents a summary of beam end forces, providing a comprehensive overview of the internal forces and bending moments acting at both ends of the beam elements within the structural model. These results are essential for understanding load transfer mechanisms throughout the structure and for verifying the adequacy of beam design under seismic loading. The table highlights the maximum force and moment demands experienced by individual beams, enabling evaluation of critical members subjected to higher seismic actions and supporting informed decisions on reinforcement detailing and potential design modifications.

Figure 5(a) illustrates an isometric view of the structural model, offering a three-dimensional representation of the building geometry, load distribution, and deformation patterns under seismic excitation. This global perspective integrates the X-, Y-, and Z-axis responses, allowing visualisation of overall structural behaviour, including lateral sway and potential torsional effects, as well as the transmission of seismic forces from the superstructure to the foundation. **Figure 5(b)** presents the +X view (Y–Z plane), which captures the longitudinal response of the building and facilitates assessment of storey-wise force distribution, inter-storey drift behaviour, and the vertical propagation of shear forces and bending moments. **Figure 5(c)** shows the +Y view (X–Z plane), providing insight into lateral behaviour across the building width and enabling identification of asymmetric deformations that may indicate stiffness or mass irregularities. **Figure 5(d)** depicts the +Z view, representing a plan view of the structure, which is particularly useful for examining horizontal displacements, diaphragm action, and torsional response under seismic loading, ensuring efficient lateral force transfer to vertical resisting elements. Meanwhile, **Figure 6** presents an isometric view of the structural model, offering a three-dimensional representation that captures the overall geometry, load distribution, and deformation characteristics of the building under seismic loading. By integrating responses along the X-, Y-, and Z-axes, this visualisation provides a comprehensive depiction of the building’s global seismic behaviour, including lateral sway and potential torsional response. The isometric view also illustrates the transmission path of seismic forces from the superstructure to the foundation, enabling identification of critical regions experiencing higher stress concentration or significant deformation. Such visual insight supports targeted evaluation of structural elements that may require enhanced detailing or reinforcement to improve seismic performance.

Cheutsu-Oki.std - Beam End Forces:

	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kN-m	My kN-m	Mz kN-m
Max Fx	3511	4 COMBINATI	1959	15087.583	-44.153	1.066	-0.133	4.725	45.246
Min Fx	8483	5 COMBINATI	2996	-62.166	23.472	0.043	-0.009	-1.052	25.556
Max Fy	688	4 COMBINATI	366	-11.844	522.653	-0.204	19.363	0.006	272.931
Min Fy	481	5 COMBINATI	306	-11.828	-498.519	0.435	-17.822	0.248	282.639
Max Fz	5789	5 COMBINATI	421	1491.025	-124.481	125.034	-1.615	-240.384	-235.399
Min Fz	5771	5 COMBINATI	359	1780.659	-116.366	-136.108	0.793	258.816	-220.146
Max Mx	7993	5 COMBINATI	2656	1.234	94.134	-10.021	39.758	11.411	101.320
Min Mx	8361	5 COMBINATI	3047	1.686	107.509	-1.758	-36.754	5.934	244.244
Max My	9094	4 COMBINATI	2960	346.186	19.357	118.437	-0.632	298.964	-47.854
Min My	5771	5 COMBINATI	2141	1734.478	-116.366	-136.108	0.793	-286.228	245.314
Max Mz	8167	4 COMBINATI	2828	-31.390	475.341	-3.558	4.224	6.770	672.739
Min Mz	8236	5 COMBINATI	2964	-36.628	-381.326	5.261	-3.658	-4.352	-445.983

(a)

Northridge.std - Beam End Forces:

	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kN-m	My kN-m	Mz kN-m
Max Fx	3511	5 COMBINATI	1959	15266.484	-170.373	22.286	5.474	45.394	385.716
Min Fx	2823	4 COMBINATI	583	-538.344	-75.471	-2.529	3.551	13.692	-25.042
Max Fy	688	5 COMBINATI	366	-8.444	597.447	-5.904	15.260	-4.267	413.238
Min Fy	7208	5 COMBINATI	2208	21.347	-577.671	-15.072	3.842	-1.763	179.325
Max Fz	8105	5 COMBINATI	2857	-19.592	-218.790	176.408	-11.081	-92.066	-453.441
Min Fz	8155	4 COMBINATI	2886	58.709	264.617	-206.759	11.460	127.735	-193.378
Max Mx	8744	5 COMBINATI	2369	1029.288	68.503	-14.425	86.183	-38.696	-62.553
Min Mx	8744	4 COMBINATI	2369	764.467	-45.032	24.198	-86.312	53.534	73.510
Max My	3708	5 COMBINATI	421	1606.189	-19.690	-84.834	50.508	339.087	-383.413
Min My	5769	4 COMBINATI	355	1288.891	41.346	97.443	-62.024	-349.894	-37.168
Max Mz	7218	5 COMBINATI	2137	74.871	-247.675	0.097	-0.470	2.611	777.897
Min Mz	7664	5 COMBINATI	2564	12.933	-307.526	1.906	1.275	-3.070	-580.634

(b)

Trinidad.std - Beam End Forces:

	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kN-m	My kN-m	Mz kN-m
Max Fx	3511	4 COMBINATI	1959	15092.201	-47.309	1.656	0.314	1.020	53.797
Min Fx	8483	5 COMBINATI	2996	-62.201	23.017	0.001	-0.007	-0.948	24.395
Max Fy	688	4 COMBINATI	366	-12.160	524.546	-0.091	19.634	-0.097	276.471
Min Fy	481	5 COMBINATI	306	-12.023	-500.403	0.335	-17.574	0.150	286.147
Max Fz	5789	4 COMBINATI	421	1486.802	-130.077	125.597	-2.853	-233.369	-252.899
Min Fz	5771	4 COMBINATI	359	1777.478	-122.101	-136.404	-1.981	260.277	-237.978
Max Mx	7993	4 COMBINATI	2656	1.699	97.984	-9.847	39.767	11.517	111.029
Min Mx	8361	4 COMBINATI	3047	2.316	107.541	-1.681	-36.802	5.349	244.371
Max My	9094	4 COMBINATI	2960	346.205	17.763	118.456	-0.516	299.028	-42.100
Min My	5771	5 COMBINATI	2141	1742.864	-114.588	-134.689	1.592	-287.216	243.733
Max Mz	8167	4 COMBINATI	2828	-30.417	476.526	-4.150	4.302	7.265	675.039
Min Mz	8236	5 COMBINATI	2964	-35.532	-382.505	5.711	-3.735	-5.165	-446.837

(c)

Chichi.std - Beam End Forces:

	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kN-m	My kN-m	Mz kN-m
Max Fx	3511	4 COMBINATI	1959	15149.766	-86.532	8.846	-2.204	-13.966	160.100
Min Fx	8483	4 COMBINATI	2996	-62.627	30.743	1.049	-0.058	-3.446	44.095
Max Fy	688	4 COMBINATI	366	-13.536	548.032	-2.116	17.945	-1.389	320.517
Min Fy	481	5 COMBINATI	306	-10.827	-523.792	2.129	-16.317	-1.091	329.791
Max Fz	5789	4 COMBINATI	355	1551.806	154.091	134.817	-24.688	-198.931	329.795
Min Fz	5771	4 COMBINATI	359	1742.755	-90.531	-142.901	15.860	284.868	-138.708
Max Mx	7993	5 COMBINATI	2656	-0.707	78.071	-10.805	39.918	9.110	60.799
Min Mx	8361	4 COMBINATI	3047	4.777	107.886	-2.831	-37.329	8.696	244.945
Max My	9094	5 COMBINATI	2960	346.421	25.981	118.073	-1.257	300.000	-71.748
Min My	5771	5 COMBINATI	2141	1777.587	-146.157	-128.193	-16.248	-299.838	270.878
Max Mz	8167	4 COMBINATI	2828	-25.957	491.441	-11.619	4.684	13.572	704.021
Min Mz	8154	4 COMBINATI	2904	-23.785	-245.043	0.556	0.665	-0.376	-467.848

(d)

Figure 5. Summary Beam End Force for a) Cheutsu-Oki (Japan) Earthquake, b) Trinidad (USA) Earthquake, c) Northridge (USA) Earthquake and d) Chi Chi (Taiwan) Earthquake.

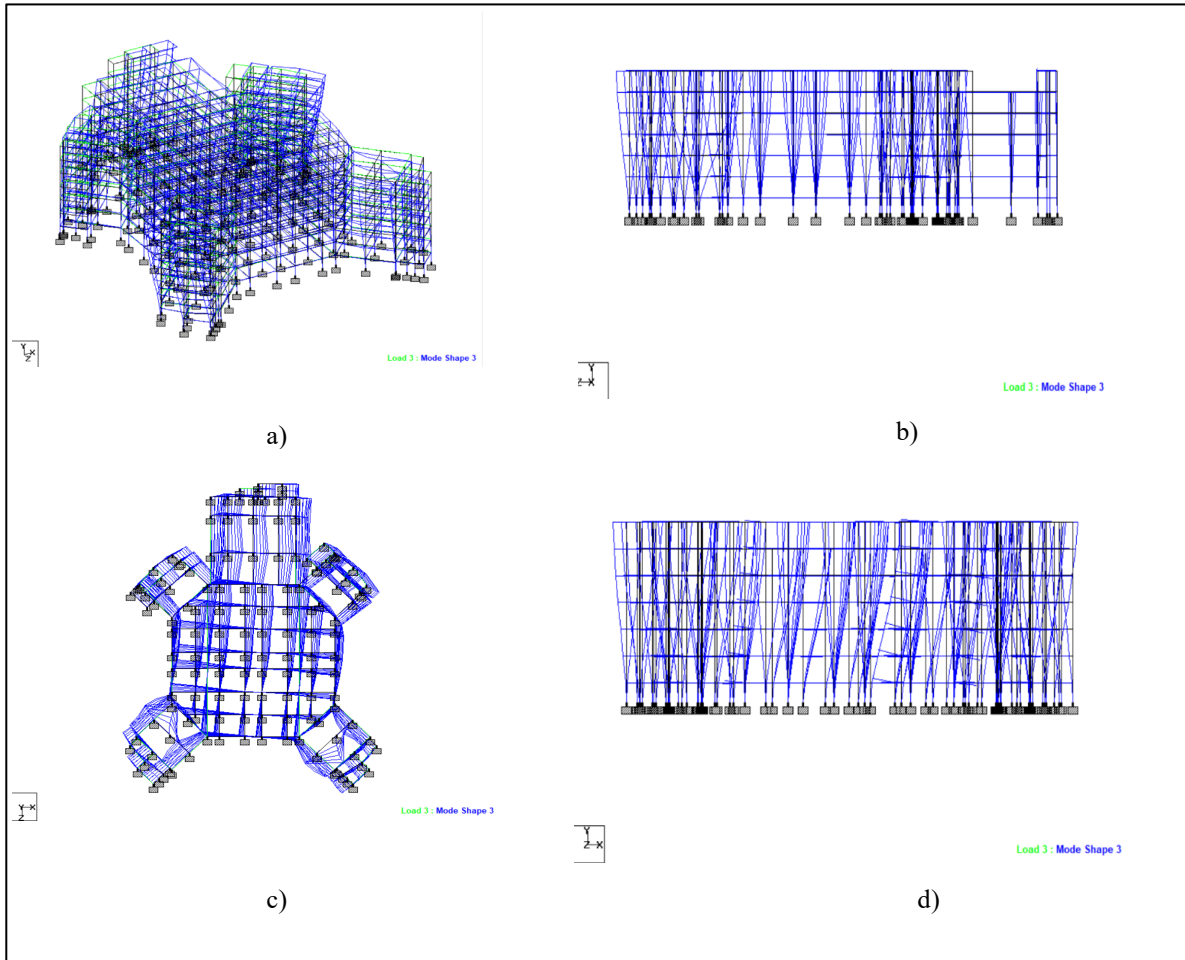


Figure 6. Visualisation of Structural Behaviour in STAAD Pro: a) Isometric, b) X-Axis, c) Y-Axis, d) Z-Axis

The Northridge earthquake generated the highest shear force demands along both the Y- and Z-axes, with peak values of 597.48 kN and 206.76 kN, respectively, as shown in **Figure 7**. These results indicate that the Northridge event imposed the most severe lateral loading on the structure, primarily due to its higher peak ground acceleration and distinct ground motion characteristics. Further examination of bending moment responses, presented in **Figure 8**, confirms the dominant influence of the Northridge earthquake. Along the Y-axis, the maximum bending moment reached 339.09 kN/m, exceeding the values recorded for the Chi-Chi (299.84 kN/m), Cheutsu-Oki (286.23 kN/m), and Trinidad (287.22 kN/m) events. This disparity reflects the significantly higher seismic demand imposed on the structural members during the Northridge excitation. A similar trend is observed along the Z-axis, where the Northridge event produced the highest bending moment of 777.90 kN/m. Although the Chi-Chi earthquake also resulted in substantial bending demand (704.02 kN/m), the Trinidad and Cheutsu-Oki events exhibited comparatively lower but closely aligned values of 675.04 kN/m and 672.74 kN/m, respectively. Collectively, these results demonstrate that the Northridge earthquake represents the governing seismic scenario for the analysed structure, underscoring the importance of designing structural systems capable of accommodating elevated shear and bending demands associated with high-intensity ground motions. Peak Ground Acceleration (PGA) and spectral displacement serve as intensity measures, while inter-storey drift ratio is adopted as the primary damage parameter (Sharma et al., 2025).

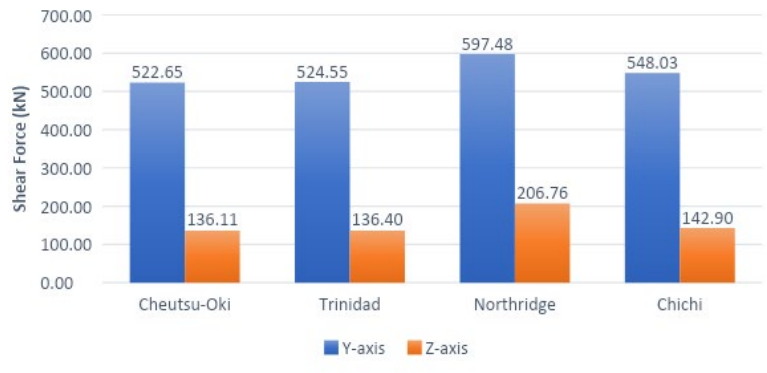


Figure 7. Comparison of Maximum Shear Forces under Various Seismic Events

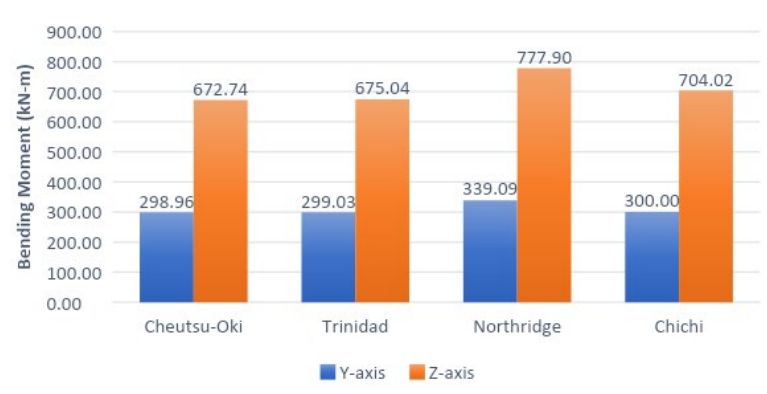


Figure 8. Maximum Bending Moment Values for Different Seismic Events

Understanding the deflection behaviour of a mid-rise reinforced concrete building under different seismic events is essential for evaluating its overall structural performance and serviceability. **Table 3** and **Figure 9** present the storey deflection values recorded at each level, including the ground floor, for the Cheutsu-Oki, Trinidad, Northridge, and Chi-Chi earthquakes. At the ground floor and first storey levels, the Cheutsu-Oki event produced moderate deflections of 0.0557 m and 0.0565 m, respectively. In contrast, the Northridge earthquake resulted in significantly higher deflections of 0.0780 m at the ground floor and 0.0905 m at the first storey, indicating a more severe structural response associated with its higher intensity and frequency content. These observations suggest that lower storey levels are more susceptible to excessive lateral deformation, emphasising the need for careful control of inter-storey drift to ensure structural safety and occupant comfort. At the upper storey levels (Storeys 2 to 5), the Cheutsu-Oki and Trinidad earthquakes exhibited consistently low deflection values ranging between 0.0225 m and 0.0233 m, reflecting stable structural behaviour under moderate seismic excitation. However, the Northridge event again induced noticeably higher deflections, varying from 0.0265 m to 0.0541 m, indicating increased lateral movement under stronger ground shaking. The Chi-Chi earthquake produced deflection values comparable to those of the Cheutsu-Oki and Trinidad events, ranging from 0.0226 m to 0.0235 m, further demonstrating the building’s satisfactory performance under moderate seismic demand. Overall, the Northridge earthquake generated the most pronounced displacements throughout the structure, highlighting the importance of enhanced structural stiffness, effective damping mechanisms, and appropriate detailing at critical storey levels. The relatively low deflection responses observed in the upper storeys under moderate seismic events also confirm the general adequacy of the building’s structural configuration and reinforcement detailing. Understanding the deflection behaviour of a mid-rise reinforced concrete building under various seismic events is essential for assessing its overall structural

performance, particularly in terms of serviceability, lateral stability and potential damage mechanisms. Comparison with previous studies confirms that displacement-based assessment provides a more accurate representation of seismic vulnerability than force-based methods (Sharma et al., 2025). The peak displacement is larger than that of a single Mainshock Impulse (MI) if the first and second MI have the same sign (Fujii, 2025). Mainshock Impulse) refers to a pulse-like strong-motion impulse within an earthquake ground motion, typically associated with near-fault effects. When a structure is subjected to two consecutive pulse-like mainshock impulses, and both impulses act in the same direction (same sign), the resulting peak displacement becomes larger than that caused by a single impulse alone.

Table 3. Maximum Storey Deflections under Different Ground Motions

Deflection (m)	Cheutsu-Oki	Trinidad	Northridge	Chichi
Ground Floor	0.0557	0.0562	0.0780	0.0613
Storey 1	0.0565	0.0572	0.0905	0.0649
Storey 2	0.0225	0.0225	0.0265	0.0227
Storey 3	0.0225	0.0225	0.0332	0.0227
Storey 4	0.0223	0.0223	0.0429	0.0226
Storey 5	0.0233	0.0233	0.0541	0.0235

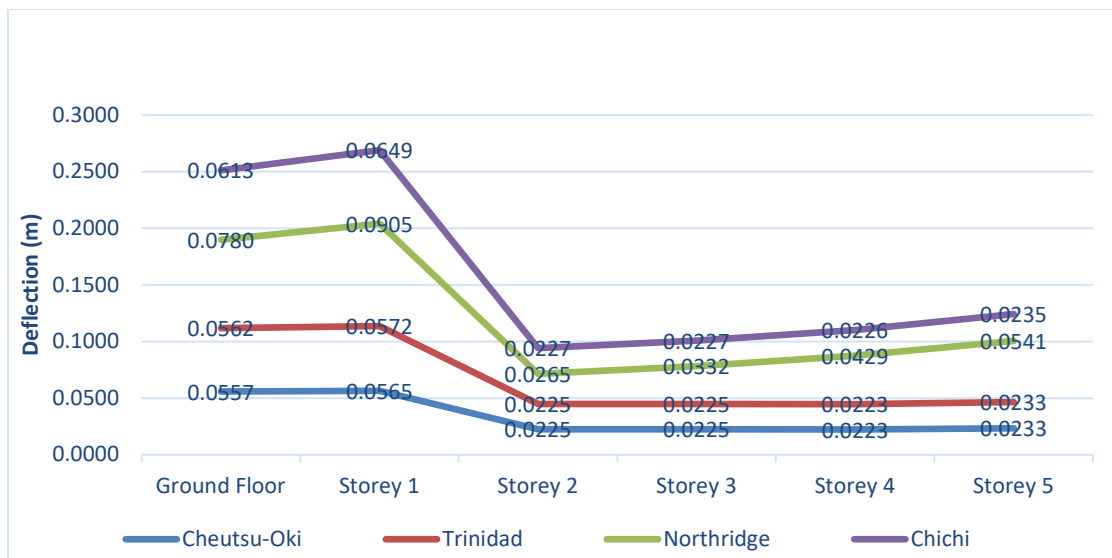


Figure 9. Deflection Values for Storey for Different Seismic Event

Table 4 illustrates the significant variation in base shear demands induced by the different earthquake events applied to the modelled structure. Among the four seismic scenarios, the Northridge earthquake generated the highest base shear, reaching 1.174×10^4 kN, followed by the Chi-Chi event with a value of 4.100×10^3 kN. In contrast, the Cheutsu-Oki and Trinidad earthquakes resulted in substantially lower base shear demands of 5.952×10^2 kN, indicating comparatively milder seismic effects. These variations are primarily attributed to the distinct seismic characteristics of each event, particularly differences in peak ground acceleration (PGA). The Northridge earthquake, characterised by a significantly higher PGA of 0.568g, imposed more severe inertial forces on the structure than the other events, which exhibited lower PGA values. The elevated base shear associated with the Northridge scenario reflects a greater intensity of ground shaking and increased lateral force demand, underscoring the dominant role of PGA in governing seismic loading and overall structural response.

Table 4. Comparison of Base Shear for Different Earthquake Event

Earthquake Data	Peak Ground Acceleration (PGA)	Manual Calculation (kN)	STAAD.Pro (kN)	Differences (%)
Cheuksu-Oki	0.175	3.12×10^2	3.117×10^2	0.1
Trinidad	0.194	5.96×10^2	5.952×10^2	0.13
Northridge	0.568	1.17×10^4	1.174×10^4	0.3
Chichi	0.361	4.11×10^3	4.100×10^3	0.24

Beyond the numerical comparison of shear forces, bending moments, and deflections, the results provide important insight into the structural behaviour of the mid-rise building under seismic loading. The distribution of lateral demand indicates a clear concentration of seismic forces and deformations at the lower storey levels, particularly under higher peak ground acceleration events such as the Northridge earthquake. This behaviour is consistent with typical mid-rise reinforced concrete structures, where increased stiffness contrast between lower and upper storeys leads to higher shear demand and drift concentration at the base levels. The observed storey deflection patterns suggest that inter-storey drift is governed primarily by ground motion intensity rather than building height alone, highlighting the critical role of PGA in controlling seismic response. From a structural safety perspective, the elevated shear forces and bending moments at critical structural elements under stronger ground motions may increase the risk of damage at beam–column joints and primary load-resisting members. These findings emphasise the need for adequate detailing, stiffness control, and seismic consideration even in regions of low-to-moderate seismicity to ensure acceptable performance and prevent progressive damage during earthquake events. The deflection and displacement patterns further highlight the influence of seismic intensity on structural performance. Higher deflections recorded at the ground and first storey levels under higher PGA events indicate increased inter-storey drift demand, which has direct implications for both serviceability and structural safety. Excessive drift may lead to non-structural damage, reduced occupant comfort, and potential loss of structural integrity if not adequately controlled. In contrast, the relatively lower deflections observed under moderate seismic events demonstrate stable structural behaviour and indicate that the existing structural configuration performs satisfactorily under lower-intensity ground motions. Overall, these findings emphasise the importance of controlling lateral deformation, enhancing stiffness at critical storey levels, and adopting resilient detailing strategies to ensure acceptable performance under stronger seismic events, particularly in regions of low-to-moderate seismicity.

4. Conclusion

This study utilised STAAD Pro software to model a mid-rise reinforced concrete hospital building in Malaysia and evaluate its structural response under four representative seismic events; Cheutsu-Oki, Trinidad, Northridge, and Chi-Chi. The primary objective was to comparatively assess building performance in terms of maximum shear force, bending moment, and deflection. The results reveal a clear correlation between peak ground acceleration (PGA) and structural response, whereby higher PGA values consistently resulted in increased internal force demands and lateral deformations. Among the analysed earthquake scenarios, the Northridge event imposed the most severe structural demands, producing the highest shear forces, bending moments, and deflection levels, and therefore representing the governing seismic case for the structure. These findings emphasise the critical influence of PGA in seismic assessment and highlight the importance of explicitly considering ground motion intensity when evaluating structural resilience, even in regions of low-to-moderate seismicity. Furthermore, the analysis identified specific structural zones exhibiting higher seismic demand under intense ground motion, underscoring the need for strategic reinforcement, adequate detailing, and resilient design practices to mitigate potential damage. Future research should focus on enhancing structural stiffness, integrating effective energy dissipation and damping systems, and adopting advanced nonlinear modelling approaches and innovative construction materials. Such developments have the potential to significantly improve the seismic resilience of buildings and contribute to safer, more robust, and sustainable

built environments. This study provides both theoretical and practical implications for seismic assessment in low-to-moderate seismic regions. Theoretically, it enhances understanding of how different ground motion characteristics and peak ground acceleration levels influence the seismic response of mid-rise reinforced concrete buildings. Practically, the findings offer guidance for engineers in identifying critical structural demand zones and support policymakers in strengthening seismic provisions for building design, particularly for essential facilities, to improve overall structural safety and resilience. It should be noted that this study adopts linear elastic modelling assumptions and simplified seismic representation. Nonlinear material behaviour, soil–structure interaction, and higher-mode effects were not explicitly considered. These limitations suggest that the results should be interpreted as indicative trends rather than absolute performance predictions. Based on the findings of this study, several engineering actions can be considered to enhance the seismic performance of mid-rise reinforced concrete buildings in Malaysia. These include improving lateral stiffness at lower storey levels, strengthening critical beam–column joints, and incorporating supplemental energy dissipation or damping systems to reduce seismic demand under higher peak ground acceleration events. For existing buildings, targeted retrofitting strategies such as column jacketing, shear wall enhancement, or the addition of bracing systems may be effective in mitigating excessive deformation and internal force concentration. It is acknowledged, however, that the present study is subject to certain limitations. The analysis is based on linear elastic and quasi-static seismic assumptions and does not explicitly capture nonlinear material behaviour, cumulative damage effects, or soil–structure interaction. As such, the results should be interpreted as indicative of comparative seismic performance rather than absolute damage prediction. Future studies should incorporate nonlinear dynamic analysis, advanced material modelling, and site-specific effects to provide a more comprehensive assessment of structural seismic resilience.

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Author Contribution

Rozaina Ismail: Conceptualization, supervision, methodology, project administration, and manuscript review and editing.

Hariz Izzuddin Shahabuddin: Data curation, software/model development, formal analysis, and writing the original draft preparation.

Rabiatal Adawiyah Johari: Methodology support, validation, data analysis, and manuscript review.

Nuraliah Athirah Zailani: Data collection, visualization, investigation, and assistance in manuscript preparation. All authors have read and agreed to the published version of the manuscript.

Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

Declaration of Generative Ai in The Writing Process

During the preparation of this work, the authors used ChatGPT to enhance the clarity, readability, and overall language quality of the manuscript. After using this tool, the authors carefully reviewed and edited the content as necessary and take full responsibility for the accuracy, integrity, and final content of the publication.

Data Availability/Supplementary Materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics Statement

The authors declare that this research did not involve human or animal subjects. All experimental procedures were performed following the institutional Safety, Health, and Environmental (HSE) protocols of Universiti Teknologi MARA.

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