Structural Performance Analysis of the Techno BRI IT Ragunan Building Under Dynamic Earthquake Loads

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Abstract

Indonesia is highly vulnerable to earthquakes due to its location at the convergence of three major tectonic plates. This study aims to analyze and compare the structural performance of the Techno BRI IT Ragunan Building in Jakarta under dynamic earthquake loads using two analytical approaches: the response spectrum method and the time history method. The structural model was developed in three dimensions using ETABS v18.1.0, referring to SNI 1726:2019 and SNI 1727:2020. Time history analysis was conducted using three representative earthquake records: Shallow Crustal (Niigata), Benioff (Ibaraki-Off), and Megathrust (Tohoku). Spectral matching was applied to align the time history data with the design response spectrum, with ETABS chosen due to its lower error values compared to SeismoMatch. The maximum interstory drift values obtained from the response spectrum analysis are 33.875 mm in the X-direction and 35.277 mm in the Y-direction. For the time history analysis, the maximum drift values are as follows: 29.271 mm (X) and 38.572 mm (Y) for the Shallow Crustal earthquake; 32.604 mm (X) and 31.576 mm (Y) for the Benioff earthquake; and 35.470 mm (X) and 38.566 mm (Y) for the Megathrust earthquake. All values remain within the allowable limits and meet the Immediate Occupancy (IO) performance level according to ATC-40 criteria. These results indicate that the structure maintains adequate lateral stiffness and is capable of sustaining functionality with minimal risk to occupants after a seismic event.

Keywords: Structural Analysis, Interstory Drift, Dynamic Earthquake Load, Response Spectrum, Time History, Spectral Matching, ETABS, ATC-40, Performance Level.

1. INTRODUCTION

Indonesia is located within the Pacific Ring of Fire, where the Eurasian, Indo-Australian, and Pacific tectonic plates converge, making it one of the most earthquake-prone countries in the world. This seismic vulnerability presents significant risks to the built environment, especially high-rise buildings in densely populated urban areas (Pusat Studi Gempa Nasional, 2022). Inadequate structural design or failure to comply with seismic codes can result in severe damage, economic loss, and threats to human safety.

The increasing development of mid- to high-rise buildings necessitates reliable structural performance assessments under dynamic earthquake loads. In this context, modern seismic design approaches, such as response spectrum and time history analyses, have become essential tools for evaluating building behavior during earthquakes. These methods provide a realistic simulation of structural response, especially for irregular structures in seismically active zones.

This study focuses on evaluating the seismic performance of the Techno BRI IT Ragunan Building in Jakarta using both response spectrum and time history analyses. The assessment aims to determine interstory drift responses and classify structural performance levels based on ATC-40 guidelines, contributing to safer and more resilient structural design practices in Indonesia.

1.1. Seismicity and Tectonic Setting in Indonesia

Indonesia's location on the Pacific Ring of Fire results in high seismic activity, primarily due to the convergence of the Eurasian, Indo-Australian, and Pacific tectonic plates. This condition produces three dominant earthquake types; Shallow Crustal Earthquakes: Occur near the Earth's surface (<70 km depth), typically along active faults;

Benioff Zone Earthquakes: Intermediate-depth seismic events (70–300 km), often related to subduction zones; Megathrust Earthquakes: High-magnitude quakes at shallow depths along subduction interfaces (<70 km) (Bulo, 2020). Each earthquake type has distinct frequency content and energy release characteristics, necessitating customized structural response evaluations in design and analysis.

1.2. Seismic Structural Analysis Methods

Structural response to earthquake loading can be evaluated using either static or dynamic methods, depending on the complexity, height, and irregularity of the building, as well as the seismicity of the site (Elnashai & Sarno, 2008). To clarify the classification and interrelation between these analysis techniques, Figure 1 presents a flowchart outlining the various structural analysis methods used in earthquake engineering, distinguishing between elastic and inelastic procedures.

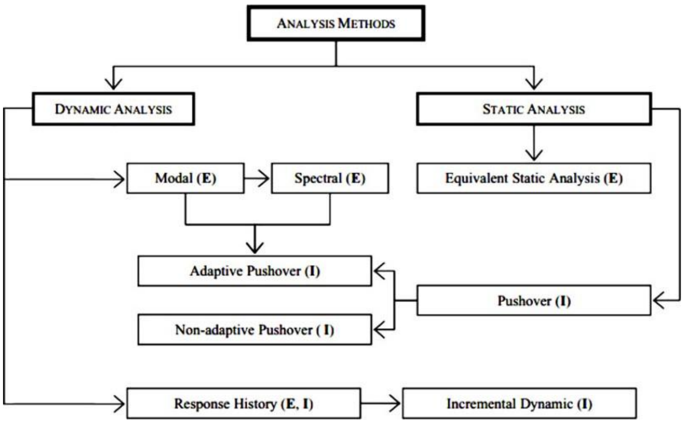


Fig. 1 Structural Analysis Methods Under Seismic Loads

1.2.1. Static Analysis

This simplified method assumes that the dynamic effects of an earthquake can be represented by an equivalent lateral force distributed along the height of the structure. It is widely used for low-rise, regular structures in regions of low to moderate seismicity. Although straightforward, this method cannot accurately capture higher-mode effects or complex structural behavior under real seismic excitation (Amajida, 2023).

1.2.2. Dynamic Analysis

Dynamic Analysis is more accurate and suitable for irregular or high-rise buildings. This includes: Response Spectrum Analysis (RSA): Calculates peak structural responses based on design spectra; Time History Analysis (THA): Uses real or synthetic ground motion records to simulate structure response over time (Cindy, 2024). Dynamic analysis is especially recommended for structures in Seismic Design Categories D, E, or F as defined in SNI 1726:2019, where the response is highly sensitive to structural irregularities and site conditions (SNI 1726:2019).

1.3. Ground Motion Processing and Spectral Matching

In time history analysis, the selected ground motions must be compatible with the design response spectrum. To achieve this, spectral matching is performed. According to SNI 1726:2019 Clause 7.11.4, the average spectrum of selected ground motions should not deviate more than ±10% from the target spectrum over the period range of interest (SNI 1726:2019). The matching is mathematically evaluated using the percentage error (ε) between the design spectrum Sa(T) and the matched spectrum Sa'(T), In this study, ETABS was used for both time history and spectral matching due to its superior accuracy, where error values remained within code-defined limits (maximum <10%) (Wibowo et al., 2023).

1.4. Structural Performance Based on Drift

Interstory drift is a critical indicator of seismic performance, defined as:

$$\text{Drift Ratio} = \frac{\Delta}{h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where (Δ) is lateral displacement between stories and (h) is story height. According to ATC-40, performance levels are: Immediate Occupancy (IO): Drift ≤ 0.7%; Life Safety (LS): Drift ≤ 1.5%; Collapse Prevention (CP): Drift ≤ 2.5%. This study classifies structural performance based on maximum drift under both RSA and THA (SNI 1726:2019).

2. METHOD

This research aims to evaluate the seismic performance of the Techno BRI IT Ragunan Building, a mid-rise reinforced concrete structure located in Jakarta, Indonesia, which lies in a high seismic risk zone. The building's behavior under dynamic earthquake loading is assessed using two widely accepted structural analysis approaches: the Response Spectrum Analysis (RSA) and the Time History Analysis (THA). These methods are implemented using ETABS v18.1.0, a structural analysis software widely used in professional engineering practice and academic research.

The analysis framework follows the provisions of the Indonesian Seismic Design Standard (SNI 1726:2019) and the Load Combination Code (SNI 1727:2020), with modeling assumptions and material definitions based on SNI 2847:2019. The selected dynamic loads represent three major tectonic sources relevant to Indonesia's seismicity: Shallow Crustal, Benioff, and Megathrust earthquakes. Real ground motion records from these earthquake types are obtained and modified using spectral matching techniques to align with the target design spectrum for the project site.

2.1. Research Object

The object of this study is the Techno BRI IT Ragunan Building, located in Ragunan, South Jakarta, Indonesia. The building serves as a technology and information center for Bank Rakyat Indonesia (BRI), with functions including office spaces, IT infrastructure, and support facilities.This structure is a mid-rise reinforced concrete building consisting of 13 stories with 52.75 meters total height. The location of the study is illustrated in the following figure.

Fig. 2 Research Object

2.2. Research Stage

The research followed sequential stages to evaluate the seismic performance of the Techno BRI IT Ragunan Building under dynamic loading. It began with a review of relevant standards (SNI 1726:2019, SNI 1727:2020, SNI 2847:2019) and ATC-40 performance criteria. A 3D model of the 12-story reinforced concrete building was created in ETABS v18.1.0, including gravity and seismic loads. Modal analysis was used to obtain natural periods and mode shapes.

Three ground motions—Niigata (Shallow Crustal), Ibaraki-Off (Benioff), and Tohoku (Megathrust)—were spectrally matched to the design spectrum with a maximum error of 10%. Two dynamic analyses were performed: Response Spectrum Analysis (RSA) for peak modal responses, and Time History Analysis (THA) to simulate real-time structural behavior. Interstory drift results were compared to ATC-40 limits, and both analysis methods were evaluated to determine the structure's compliance with performance-based seismic design.

2.3. Data Collection

The data used in this study were derived from both primary and secondary sources. Primary data included architectural and structural drawings of the Techno BRI IT Ragunan Building, which informed the development of an accurate 3D model in ETABS. Secondary data comprised seismic design parameters from SNI 1726:2019, load definitions from SNI 1727:2020, and material properties based on SNI 2847:2019.

Ground motion data were sourced from the NGA-West2 database for Shallow Crustal events and from the PEER subduction database for Benioff and Megathrust earthquakes. Selection was based on seismic compatibility, including magnitude, source distance, and Vs30 values. The study site at the Techno BRI IT Ragunan Building, Jakarta, is classified as Site Class SE (soft soil) according to SNI 1726:2019, with a Vs30 range of 0–175 m/s, which significantly affects seismic amplification and structural response. Ground motion records—Niigata (Shallow Crustal), Ibaraki-Off (Benioff), and Tohoku (Megathrust)—were selected from validated databases and adjusted using spectral matching to align with the site-specific design spectrum. All data were verified prior to analysis to ensure compliance with relevant codes and realistic modeling of structural behavior.

3. RESEARCH AND DISCUSSION

3.1. Structural Period and Mode Shapes

In this study, the Techno BRI IT Ragunan Building was modeled as a three-dimensional (3D) structure using ETABS v18.1.0. The structural configuration and material properties were defined based on the original structural drawings, ensuring an accurate representation of the building's geometry and construction details. The figure below illustrates the 3D structural model developed in ETABS.

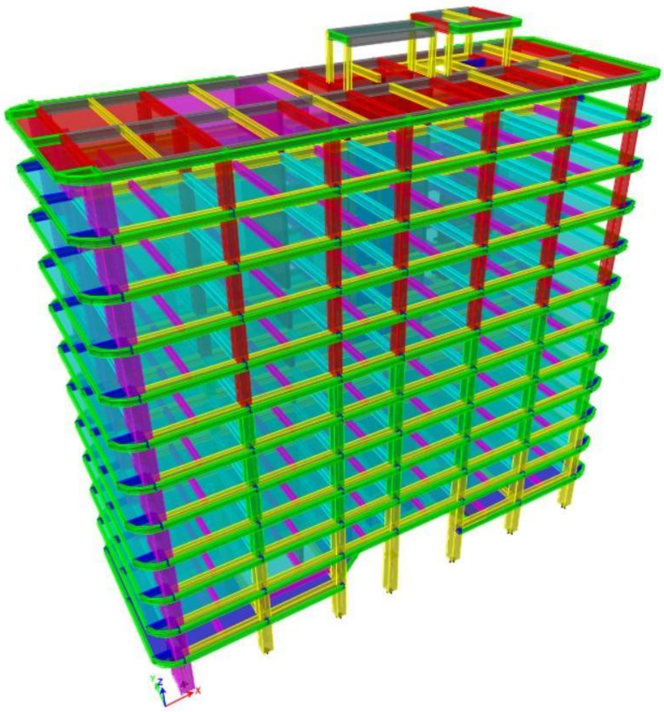


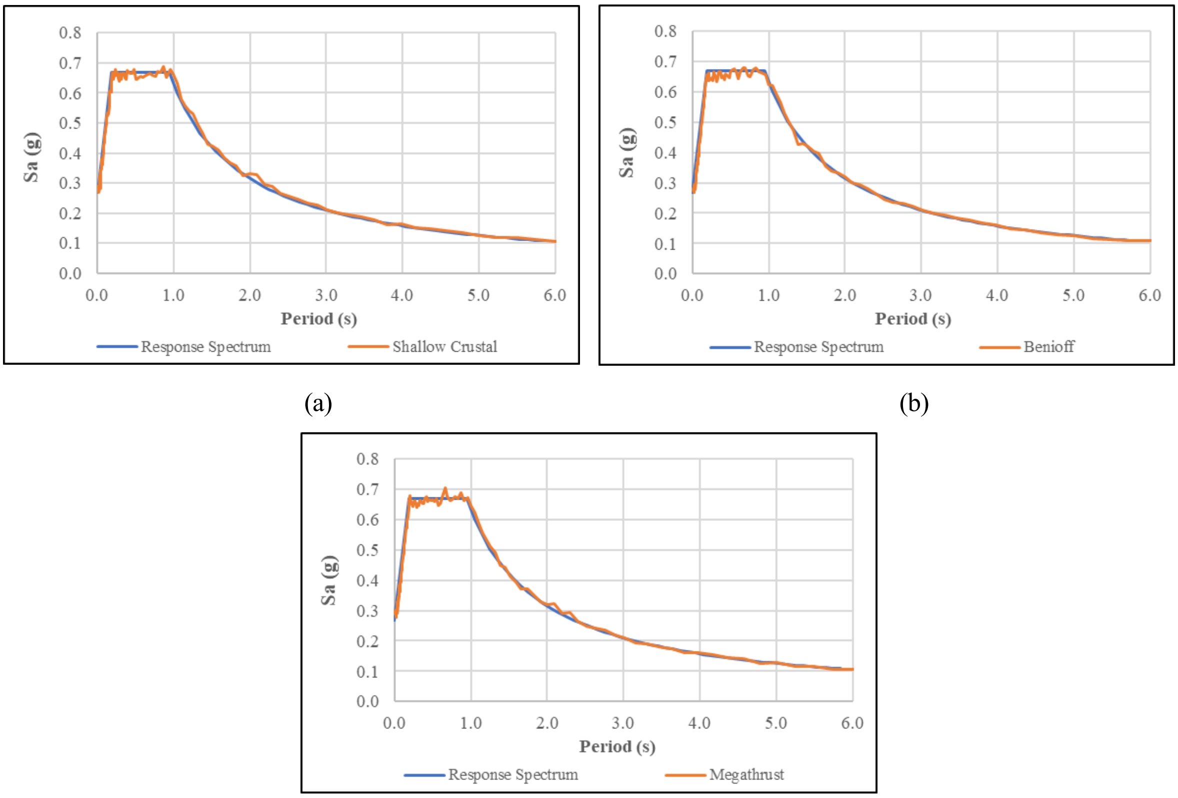
Fig. 3 3D Structural Modeling of the Techno BRI IT Ragunan Building

Modal analysis reveals the fundamental period of the Techno BRI IT Ragunan Building as 1.783 seconds in the X-direction and 1.755 seconds in the Y-direction. These relatively long periods indicate a flexible dynamic behavior, typical of a mid-rise reinforced concrete structure with a moment-resisting frame. The first and second modes show translational motion along the principal axes, while the third mode introduces torsional deformation, which is significant in irregular or asymmetrical mass/stiffness distributions.

3.2. Spectral Matching Accuracy

Spectral matching was performed using ETABS to ensure that the selected ground motion records align with the target design spectrum, as mandated by SNI 1726:2019. The results of the maximum spectral matching errors are: Niigata (Shallow Crustal): 9.2%; Ibaraki-Off (Benioff): 6.5%; Tohoku (Megathrust): 6.9%

All errors fall below the allowable threshold of 10%, indicating that the selected accelerograms are suitable for use in time history analysis and capable of producing reliable dynamic response results. The figure below presents the spectral matching graph between the time history data and the response spectrum.



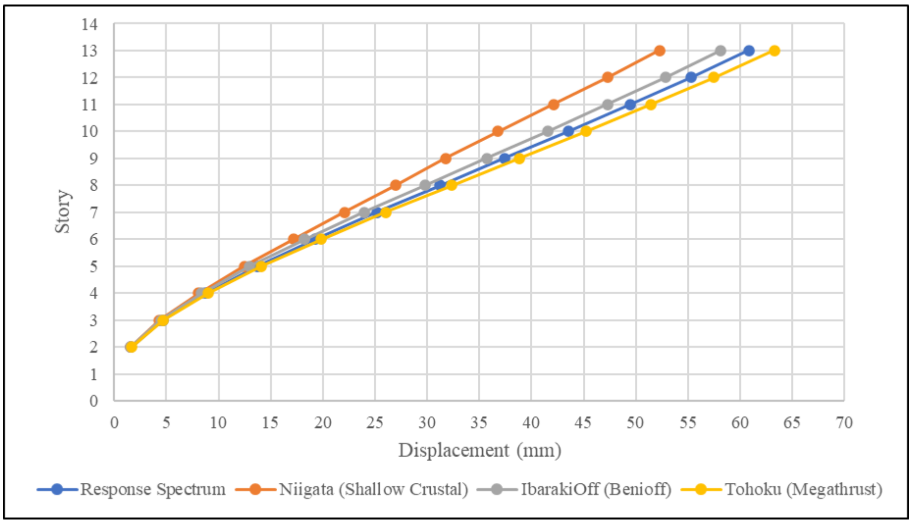
(a) (b)

(c)

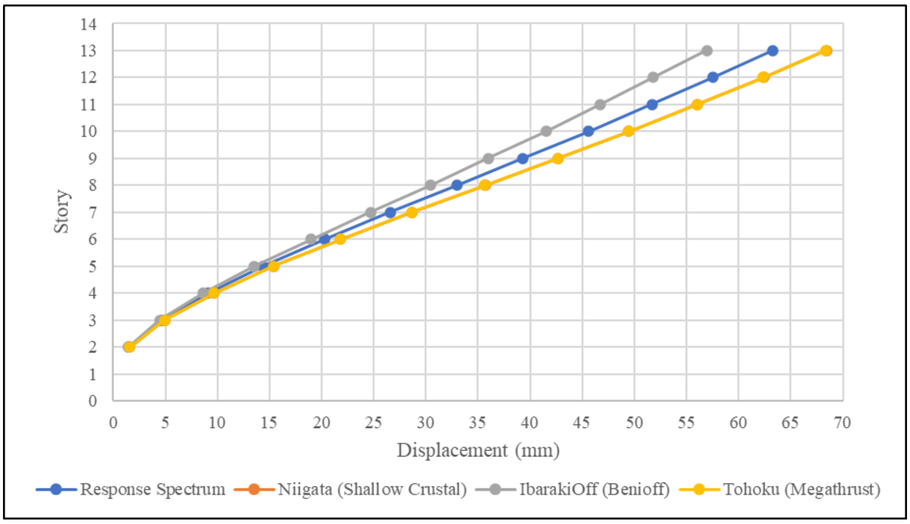
Fig. 4 Spectral Matching Results (a) Shallow Crustal, (b) Benioff, (c) Megathrust

3.3. Structural Displacement

Structural displacement refers to the total lateral movement of the structure, typically measured at the roof level. It reflects the overall flexibility and lateral response of the building under seismic excitation. The following are the horizontal displacement graphics for the entire model under four different earthquake load cases.



(a)



(b)

Fig. 5 Summary of Horizontal Displacement Graph: (a) X-Direction, (b) Y-Direction

From the Response Spectrum Analysis (RSA), the maximum lateral displacements observed are:

- X-direction: 138.773 mm
- Y-direction: 136.008 mm

These values indicate a relatively balanced lateral stiffness between the two principal directions, with slightly higher flexibility in the X-axis. In contrast, the Time History Analysis (THA) produced displacement values that vary depending on the characteristics of each earthquake record. The maximum roof displacements obtained from THA are:

- Niigata (Shallow Crustal): 115.214 mm (X), 133.507 mm (Y)
- Ibaraki-Off (Benioff): 128.543 mm (X), 129.932 mm (Y)
- Tohoku (Megathrust): 132.653 mm (X), 138.211 mm (Y)

Across all cases, the displacement in the Y-direction consistently exceeds that in the X-direction, suggesting lower stiffness or greater modal participation in the Y-axis. Moreover, the displacements fall within the expected range for mid-rise reinforced concrete buildings and show no irregularities that would suggest weak story behavior.

3.4. Interstory Drift

Interstory drift, defined as the relative lateral displacement between consecutive floors, is a critical parameter for evaluating seismic performance, particularly in terms of damage potential to structural and non-structural elements. The drift values provide insight into the distribution of lateral deformation throughout the building height. From the RSA, the maximum interstory drift is recorded as:

- X-direction: 33.875 mm
- Y-direction: 35.277 mm

These values indicate moderate drift response under the design-level earthquake and are well-distributed along the building height.
In the THA, the maximum interstory drifts observed for each ground motion are:

- Niigata (Shallow Crustal): 29.271 mm (X), 38.572 mm (Y)
- Ibaraki-Off (Benioff): 32.604 mm (X), 31.576 mm (Y)
- Tohoku (Megathrust): 35.470 mm (X), 38.566 mm (Y)

Based on the analysis results and the previously presented graphs, all three earthquake load cases using the time history method produced interstory drift values in both the X and Y directions. The results indicate that the maximum drift values remain below the allowable limit of 61.538 mm, corresponding to a 4-meter story height. Therefore, the interstory drifts induced by seismic loading are considered safe and comply with the applicable design standards.

3.5. Performance Evaluation Based on Drift

Structural performance was assessed using ATC-40 criteria, based on the values of Maximum Total Drift and Maximum Inelastic Drift, calculated as the ratio of horizontal displacement to total building height. A structure is classified as Immediate Occupancy (IO) if the Maximum Total Drift is less than 0.01 and the Maximum Inelastic Drift is less than 0.005 (SNI 1726:2019).

Table 1: ATC-40 Structural Performance Levels: (a) X-Direction, (b) Y-Direction

Data	**Dt (m)**	**D1 (m)**	**Max Total Drift (Dt/H)**	**Max Inelastic Drift (Dt-D1)/H**	**Performance Level**
Response Spectrum	0.0608	0.0016	0.0012	0.0011	IO
Niigata (*Shallow Crustal*)	0.0523	0.0015	0.0010	0.0010	IO
IbarakiOff (*Benioff*)	0.0581	0.0016	0.0011	0.0011	IO
Tohoku (*Megathrust*)	0.0633	0.0016	0.0012	0.0012	IO

(a)

Data	**Dt (m)**	**D1 (m)**	**Max Total Drift (Dt/H)**	**Max Inelastic Drift (Dt-D1)/H**	**Performance Level**
Respons Spektrum	0.0633	0.0015	0.0012	0.0012	IO
Niigata (*Shallow Crustal*)	0.0684	0.0016	0.0013	0.0013	IO
IbarakiOff (*Benioff*)	0.0570	0.0015	0.0011	0.0011	IO
Tohoku (*Megathrust*)	0.0684	0.0016	0.0013	0.0013	IO

(b)

For all seismic scenarios analyzed—including response spectrum and time history records (Niigata, Ibaraki-Off, and Tohoku)—the drift values in both X and Y directions fall within the Immediate Occupancy (IO) performance thresholds. This indicates that the building experiences only minor deformation with negligible damage, maintaining full functionality and safety after seismic events without requiring major repairs.

4. CONCLUSSION

This study analyzed the seismic performance of the Techno BRI IT Ragunan Building using both response spectrum and time history analyses. The maximum horizontal displacement due to the response spectrum method was recorded at 60.813 mm in the X-direction and 63.304 mm in the Y-direction, with corresponding maximum interstory drifts of 33.875 mm and 35.277 mm, respectively. For the time history analysis using spectrally matched earthquake records, the highest displacement occurred under the Megathrust (Tohoku) ground motion, reaching 63.275 mm (X) and 68.396 mm (Y), while the highest drift value of 38.572 mm was recorded in the Y-direction under the Shallow Crustal (Niigata) motion. Overall, interstory drift results ranged from 29.271 mm to 38.572 mm, with higher deformation generally observed in the Y-direction across all scenarios. Based on performance evaluation using ATC-40 criteria, the structure meets the Immediate Occupancy (IO) performance level, as the Maximum Total Drift for all cases remains below 0.01, and Maximum Inelastic Drift remains below 0.005, indicating minimal structural and non-structural damage. These results confirm that the building is capable of maintaining full operational functionality and life safety under moderate to strong seismic events.

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