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EXPLORING THE EFFICACY OF BASE ISOLATION SYSTEM IN MITIGATING SEISMIC FORCES FOR IRREGULAR STRUCTURES

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ABSTRACT

Irregular reinforced concrete (RC) structures present unique challenges in seismic design, often requiring innovative solutions to ensure adequate protection against earthquake forces. This study examines base isolators, focusing on their critical role in reducing seismic forces by decoupling structures from ground movement during earthquakes. The project aims to assess the application of base isolation systems (BIS) in irregular structures and their impact on seismic performance. The literature review covers the evolution of structural engineering in RC buildings. The modelling phase utilises ETABS to create three models for base-isolated and fixed-base structures. Seismic analysis through the response spectrum method in ETABS provides insights into the dynamic behaviour of these structures. The comparative analysis reveals a significant increase in time periods for base-isolated structures across all models, indicating enhanced seismic performance. The circular frequencies further support the effectiveness of base isolation in reducing stiffness and improving overall seismic resilience. Furthermore, the study focuses on maximum storey displacement in both X and Y directions, highlighting the superior performance of base-isolated structures in restricting lateral movement during seismic events. The reduction in maximum storey drift values reinforces the effectiveness of the base isolation system in mitigating seismic forces, offering improved structural stability and reduced deformations. Hence, the consistently superior performance of base-isolated structures compared to fixed-base counterparts, as evidenced by increased time periods, lower circular frequencies, and reduced maximum storey drift values, supports the viability of base isolation as a seismic retrofitting solution for irregular structures.

Keywords: *Base-isolators, irregularities, RC structures, response spectrum, seismic analysis, analysis, vertical setback irregularities*

INTRODUCTION

In recent decades, structural engineering has seen significant advancements in designing and analyzing reinforced concrete (RC) buildings, driven by the need to improve safety, performance, and resilience, particularly against seismic events. A critical development in this evolution has been incorporating shear walls, which mitigate the effects of lateral forces induced by earthquakes, wind, and other dynamic loads. As urbanization continues, the demand for efficient and resilient building designs has grown, prompting researchers and practitioners to refine methods for assessing structural performance, especially in buildings with shear walls. Using shear walls adds complexity to the design and analysis of RC structures due to their interaction with the overall building system, introducing challenges such as structural irregularities.

Structural irregularities, including geometry, stiffness, and mass distribution variations, can significantly affect how a building behaves under lateral loads. These irregularities often arise from deviations in design, causing uneven stress distribution and localized weaknesses. Therefore, understanding and accurately quantifying these irregularities is crucial for ensuring structural safety. The response spectrum methodology, a tool for analyzing how structures respond to seismic activity, has emerged as a valuable approach for

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assessing buildings with such irregularities. This method provides insight into the building's dynamic behavior, allowing engineers to predict how different vibration modes affect the structure. When combined with advanced computational techniques, this methodology offers a comprehensive framework for evaluating the impact of irregularities on building performance.

The literature reveals that irregularity in RC buildings, such as vertical setbacks, mass concentrations, and stiffness variations, can increase vulnerability during seismic events. Shear walls have been shown to mitigate some of these effects, improving the building's lateral stiffness and resistance. However, irregularities still pose a significant challenge, particularly in urban environments with common vertical irregularities. Base isolation systems (BIS) have emerged as an additional method to reduce seismic forces in irregular structures. Research has demonstrated the effectiveness of these systems, particularly in reducing inter-story drifts and floor accelerations, thereby enhancing seismic performance. For instance, studies by Sarno et al. [1] evaluated the reliability of linear and nonlinear dynamic analyses for irregular buildings with BIS, highlighting the need for stricter regulations due to observed significant reductions in inter-story drifts. This issue was further supported by research demonstrating a 70% reduction in floor accelerations, showcasing the benefits of base isolation in improving structural resilience.

Additionally, a comparative study on two types of BIS, high-damping rubber bearings (HDRB) and lead rubber bearings (LRB), in buildings with plan irregularities showed that base-isolated structures performed significantly better under seismic loads compared to traditional fixed-base structures [2]. Similar findings were echoed in research using school buildings as case studies, where BIS dramatically reduced base shear forces and story drifts [3].

Incorporating base isolation in irregular buildings is also essential for improving seismic performance. Research on friction pendulum isolators and LRB has demonstrated their effectiveness in reducing base shear and inter-story drifts, particularly in buildings with plan irregularities [4]. Additionally, buildings with torsional irregularities benefit significantly from BIS, with studies showing that lead-core rubber elastomeric bearings are more sensitive to torsional effects than friction pendulum systems [5]. Similarly, advanced seismic design methodologies, such as the modal displacement-based design (MDBD), have proven capable of accurately predicting seismic demands in base-isolated buildings with vertical irregularities, improving the accuracy of building performance evaluations [6]. BIS, such as the rubber bearing with steel rings (RRB), has significantly reduced seismic impacts on multi-story buildings. Research demonstrated that these systems reduced acceleration by up to 57.16%, shear by 56.83%, and drift by 59.66%, proving highly effective in enhancing seismic resilience [7].

Furthermore, research on irregular structures indicates that specific configurations, such as those with plan or vertical irregularities, experience greater seismic demands. For example, tall RC buildings with tunnel-type corridor spaces exhibited increased torsion under seismic loading, leading to more significant damage in structures with horizontal irregularities [8]. Using coupling beams between shear walls has improved stiffness and strength, preventing collapse by absorbing seismic energy [9]. Studies have also shown that irregular shapes in building plans result in higher lateral displacements and drifts, highlighting the need for careful design considerations when dealing with irregular geometries [10].

Another study highlighted the impact of vertical setbacks on seismic resilience, noting that as setbacks increase, structural fragility decreases, making these irregularities less susceptible to damage during seismic events [10]. Furthermore, incorporating shear walls and BIS has proven to enhance the seismic performance of RC buildings, particularly those with structural irregularities. However, the complexity of irregularity requires ongoing research to refine design methodologies. Future studies should continue to explore the interaction between various structural elements and isolation systems to optimize the resilience of buildings in earthquake-prone regions. Hence, the objectives for this study are as follows;

1. To analyse the impact of identified irregularities on the seismic performance of the buildings.
2. To evaluate the performance of irregular RC structures with BIS.
3. To compare the performance of irregular RC structures with BIS to those with traditional fixed-base structures.

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METHODOLOGY

The methodology employed in this study encompasses a comprehensive approach integrating various stages of research. Beginning with a thorough literature review, existing studies, and methods related to seismic analysis through response spectrum methodology (RSM) were critically examined. Subsequently, clear objectives were defined to guide this study. Figure 1 represents the methodology followed using ETABS software modelling techniques, particularly seismic analysis. A detailed model was developed to simulate seismic responses effectively. Through comparative analysis, the performance of different models was evaluated. Finally, the results obtained were rigorously analysed and discussed.

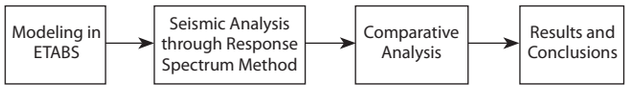


Figure 1 Flow diagram representing methodology

Modelling

Both cases were modelled in ETABS software, which created three models with a base isolation system and three with a traditional fixed base, along with all the properties, loads, conditions, and supports. Figures 2, 3, and 4 present all three different models with irregular vertical setbacks.

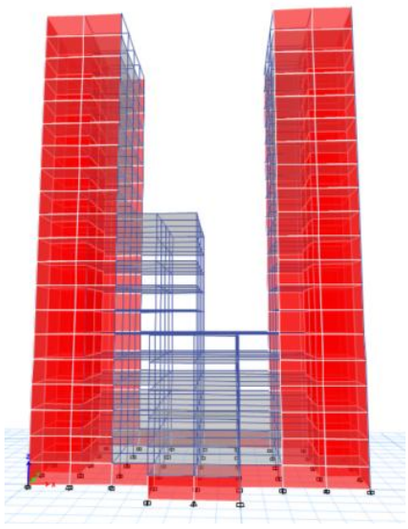


Figure 2 Irregular model 1

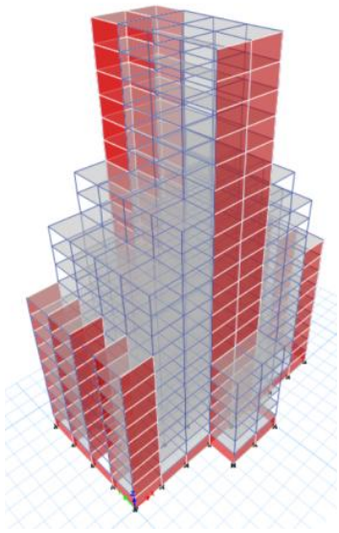


Figure 3 Irregular model 2

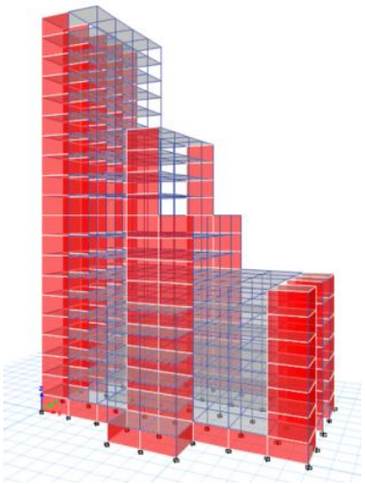


Figure 4 Irregular model 3

Table 1 Live Load (IS: 875 Part-2)

Occupancy Type (Business & Office buildings)	Load kN/m^2
Rooms for general use with separate storage	2.5
Rooms without separate	4
Kitchen	3
Toilets & Bathrooms	2
Corridors, passages, lobbies and staircases including fire escapes - as per the floor serviced (excluding stores) but not less than	4
Cafeterias and dining rooms	3
Vaults and strong room - to be calculated but not less than	5

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Table 2 Seismic parameters

Parameter	Value
Z i.e. Zone Factor (Clause 6.4.2)	0.24 (For zone IV)
I i.e. Importance Factor	1
R i.e. Response Reduction Factor (Clause 7.2.6)	5
Soil Type (Clause 6.4.2.1)	Type-2
Analysis type	Dynamic analysis

Base Isolation System

An elastomeric rubber base isolation system is a type of seismic protection system designed to mitigate the impact of earthquake forces on a structure. These systems are widely used in earthquake-prone areas to reduce the risk of structural damage and ensure the safety of occupants by isolating the building from ground motion.

An elastomeric rubber base isolation system is used in this project.

Stiffness = 250 kN/m
Yield Strength = 80 N/mm^2
Post Yield Stiffness Ratio = 0.1
Effective Stiffness = 800 kN/m

Material Properties

Compressive strength of concrete, f_{ck} = 30 N/mm^2
Concrete density = 25 kN/m^3
Design gross density for Common Burnt clay bricks = 19.2 kN/m^3
Reinforced steel yield strength, fy = 500 N/mm^2
Modulus of elasticity of steel, Es = 2.0×105 N/mm^2

ANALYSIS

The analysis section of this study delves into the seismic assessment conducted utilising the RSM across six distinct structures: three irregular RC structures with base-isolated and three RC structures with traditional fixed bases. This pivotal section provides a comprehensive overview of the methodology and findings, elucidating the intricacies of seismic behaviour within each structure. Through rigorous data collection and analysis, the dynamic response of these structures was scrutinised to seismic excitation, elucidating the disparities between irregular and regular configurations.

Comparative Analysis

The seismic analysis was conducted using the RSM for six RC irregular structures, comprising three irregular structures with base-isolated and three irregular structures with traditional fixed bases. Through meticulous examination and comparison of key parameters such as maximum storey displacement, maximum storey drift, maximum storey overturning moment, storey shears, and modal properties in each structure type have been explored.

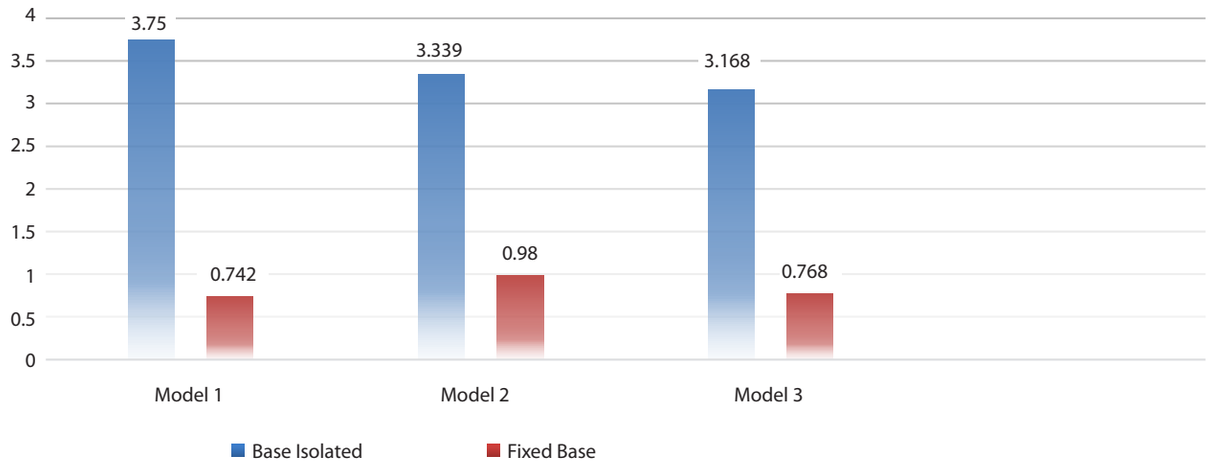


Figure 5 Time period of fixed and base-isolated models

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The time periods of the base-isolated structures (Model 1, Model 2, and Model 3) are considerably higher than their fixed-base counterparts. This indicates a significant enhancement in the dynamic characteristics of the structures when BIS is employed. This suggests the robustness and effectiveness of the base isolation system in mitigating seismic forces across various structural configurations. The increase in time periods for the base-isolated structures implies a reduction in the dynamic response and accelerations experienced by the structures during seismic events. This reduction is crucial for minimising potential damage and enhancing the overall seismic performance of the structures.

The circular frequencies provide insights into the dynamic behaviour of structures subjected to seismic forces. A lower circular frequency indicates a softer and more flexible structure, while a higher circular frequency suggests a stiffer structure.

For all three models, the circular frequencies of the base-isolated structures are consistently lower than those of the fixed base structures. This condition implies that the base-isolated structures exhibit a softer and more flexible response to seismic forces than their fixed-base counterparts. Mentioning the overall comparison across all models, the circular frequencies of the base-isolated structures are significantly lower than those of the fixed base structures. This overall trend reinforces the effectiveness of the base isolation system in reducing stiffness and enhancing the seismic performance of irregular RC structures.

For the fixed base structures, the maximum storey displacement in the X direction is notably higher compared to the base-isolated structures. The fixed base structure experiences substantial lateral movement during seismic events, ranging from several hundred to over six hundred units. In contrast, the base-isolated structures exhibit significantly lower maximum storey displacements, typically ranging from 1 to 2 units. This stark difference indicates that the base isolation system effectively mitigates the lateral movement induced by seismic forces in the X direction. The base-isolated structures demonstrate superior performance in restricting lateral displacement, thereby enhancing the overall seismic resilience of the structures. The comparative analysis indicates that implementing a base isolation system substantially reduces maximum storey displacement during seismic events. The base-isolated structures exhibit better seismic performance, effectively minimising the impact of seismic forces on lateral movement compared to traditional fixed base structures. This study supports evaluating and comparing the performance of irregular RC structures with BIS to those with traditional fixed-base structures. The results underscore the importance and effectiveness of base isolation in enhancing the seismic resilience of

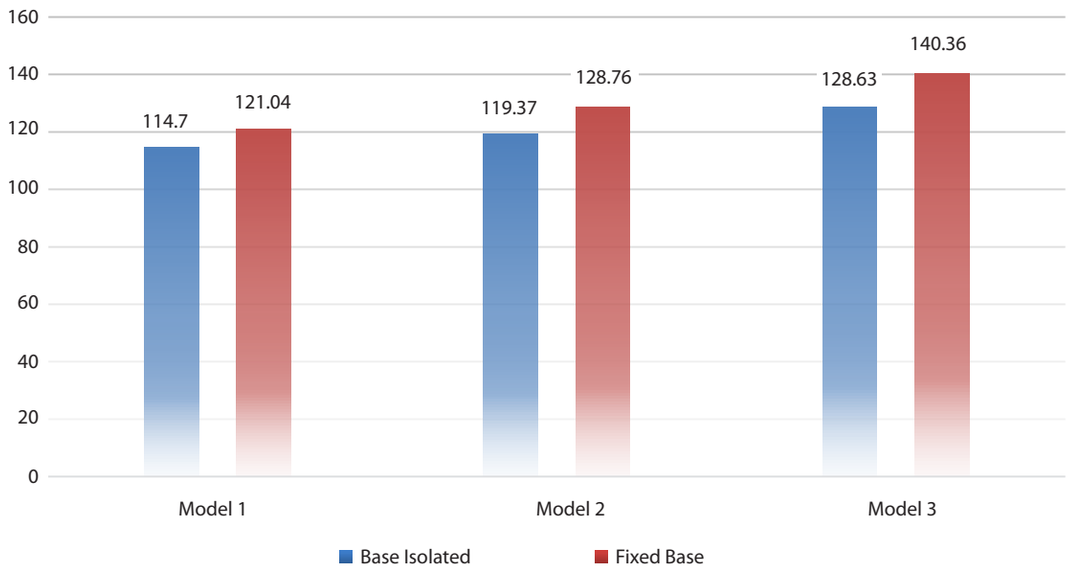


Figure 6 Frequencies of fixed and base-isolated models

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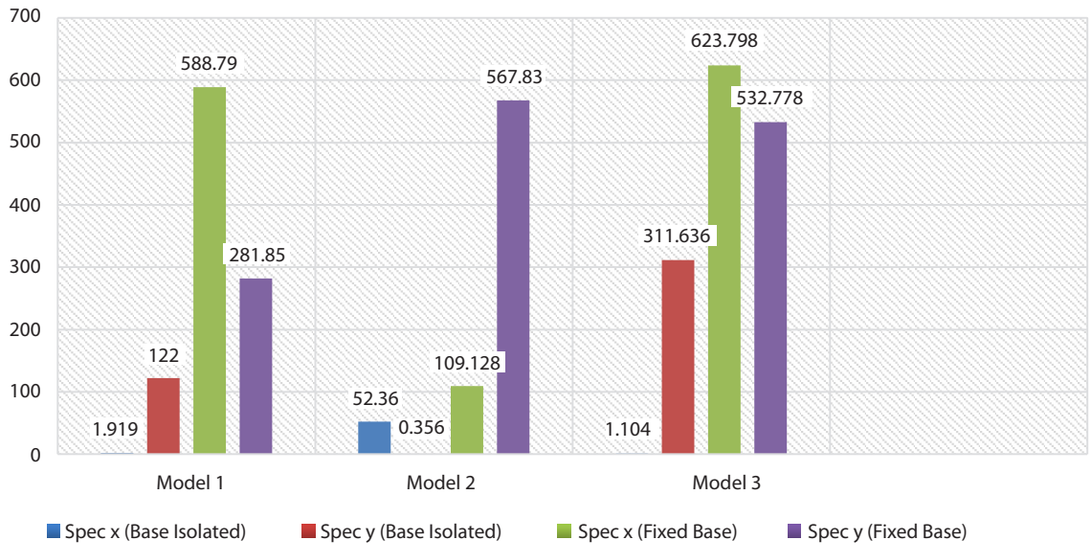


Figure 7 Maximum storey displacement of fixed and base-isolated models

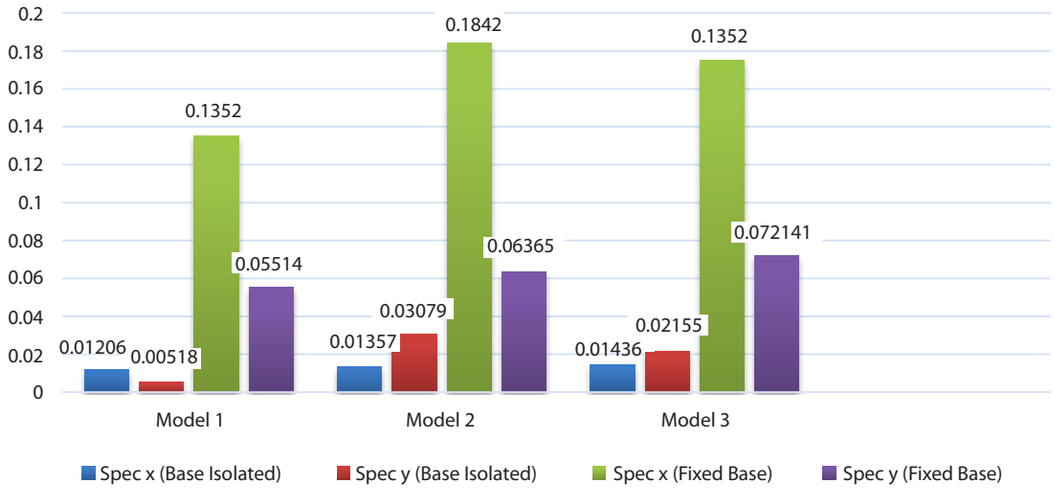


Figure 8 Maximum storey drift of fixed and base-isolated models

structures, especially in irregular configurations. These findings have practical implications for the design and construction of structures in seismically active regions, emphasising the potential benefits of incorporating base isolation strategies to mitigate the destructive effects of seismic forces.

The base-isolated structures consistently demonstrate lower maximum storey drift values in the X direction compared to the fixed base structures for all models. The reduction in max storey drift indicates the effectiveness of the base isolation system in mitigating seismic forces, offering improved structural stability and reduced deformations. Like the X direction, the base-isolated structures consistently exhibit lower maximum storey drift values in the Y direction than the fixed base structures across all models. The base isolation system reduces deformations and enhances the structure's seismic performance in both principal directions.

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RESULTS AND DISCUSSION

The findings of this study shed light on the critical importance of assessing structural irregularities in RC buildings with BIS and fixed base systems. The comprehensive investigation using the RSM has provided valuable insights into the seismic performance of such structures. The irregularities can lead to amplified seismic vulnerability, uneven distribution of loads, and reduced serviceability, emphasising the need for rigorous evaluation and mitigation strategies. The RSM has proven to be a powerful tool for assessing the dynamic behaviour of RC buildings under seismic loading. Moreover, the research addresses the practical challenges posed by irregularities, such as vertical setbacks. In this comprehensive performance evaluation, we have examined several key aspects of structural behaviour in regular and irregular conditions using different models. The results highlight significant differences between regular and irregular modal data, shedding light on how structural irregularities impact the response of a building to seismic loading. Base-isolated structures consistently exhibited higher time periods across all models, indicating enhanced dynamic characteristics. This increase in time periods suggested a substantial reduction in dynamic response and accelerations during seismic events. The adaptability of the base isolation system was highlighted, showing effectiveness in addressing seismic vulnerabilities in various structural configurations. Base-isolated structures consistently demonstrated lower circular frequencies, implying a softer and more flexible response to seismic forces. The lower circular frequencies suggested the improved ability to absorb and dissipate seismic energy, potentially reducing structural damage and enhancing occupant safety.

Maximum Storey Displacement

Base-isolated structures exhibited significantly lower maximum storey displacements in X and Y directions than fixed-base structures. The base isolation system effectively mitigated lateral movement induced by seismic forces, showcasing superior performance in restricting lateral displacement. Base-isolated structures consistently demonstrated lower maximum storey drift values in all models' X and Y directions. The reduced deformations indicated improved structural stability and enhanced seismic performance.

Maximum Storey Drift

Base-isolated structures consistently demonstrated lower maximum storey drift values in all models' X and Y directions. The reduced deformations indicated improved structural stability and enhanced seismic performance.

CONCLUSION

In conclusion, this study has provided valuable insights into the seismic performance of irregular reinforced concrete (RC) structures, offering a detailed analysis through the response spectrum methodology (RSM). By focusing on structural irregularities and mitigation strategies, the research underscores the critical role of base isolation systems (BIS) in enhancing seismic resilience. The comparison between fixed-base and base-isolated structures revealed significant improvements in seismic performance when BIS are employed, with higher time periods in base-isolated structures indicating reduced dynamic responses and accelerations during earthquakes. The study demonstrated the adaptability of BIS across various structural configurations, highlighting their effectiveness in addressing seismic vulnerabilities. Lower circular frequencies in base-isolated structures suggest a more flexible and softer response to seismic forces, improving the ability to absorb and dissipate energy and thus reducing structural damage. The analyses of maximum storey displacement and drift further emphasized the benefits of BIS, as base-isolated structures consistently exhibited reduced lateral movements, contributing to greater stability and occupant safety. The findings of this research have practical implications for the design and construction of buildings in seismically active regions, offering strong support for the use of BIS in irregular RC structures. This study also opens avenues for further research, reinforcing the importance of base isolation in seismic retrofitting strategies and underscoring its potential to significantly improve seismic performance and resilience in irregular structures.

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