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"A Comparative Study of Seismic Performance of the Reinforced Concrete Buildings with and Without Rubber Base Isolation Under Zone III and IV Conditions"

1 Shubham Anandrao Sutar, 2 Mrudula Dilip Bhoi, 3 Sandesh Ganesh Lokhande, 4 Sanket Pravin Karave, 5 Omkar Babasaheb Patil, 6 Rohit Shivaji Mohite, 7 Prof. D. G. Patil.

1-6 Students of B.Tech, Civil Engineering, Ashokrao Mane Group of Institutions Vathar, Tarf Vadgaon, Dist. - Kolhapur, Maharashtra, India.

7 Assistant Professor, Department of Civil Engineering, Ashokrao Mane Group of Institutions Vathar,Tarf Vadgaon, Dist.- Kolhapur, Maharashtra, India.

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Abstract- The paper aims at discussing the comparative seismic analysis of reinforced concrete (RC) buildings with and without rubber base isolation system in terms of their performance under earthquake loading in Zone III and IV Seismic Zones. By means of ETABS software, the building models (G+15, G+25 and G+35) of different heights were simulated to achieve the seismic behavior being measured by parameters which include base shear, negative value of maximum story displacement and inter-story drift. Lateral seismic force analyses were conducted by adhering to IS 1893:2002 as laid out using response spectrum to provide the responses of the structure as well under fixed-base as under rubber-isolated system. The findings show that base-isolated buildings have the significant decrease of seismic forces: base shear, maximum displacement, and story drift were reduced by 40 45 percent, up to 48 percent and to about 35 40 percent, respectively, over the corresponding values of fixed-base buildings. More of these improvements were felt in buildings that were taller and those that were at higher seismic zones. The results support the effectiveness of rubber base isolators in improving structural stability, occupant protection, and the maintenance of operation within earthquakes. In support of this study, this paper helps establish base isolation as a potential seismic retrofitting tool applicable to mid- to high-rise RC building structures, and in providing the worth of base isolation through its application in earthquake-resistant design and structural engineering activities.

Keywords: Base Isolation, Earthquake Engineering, ETABS Simulation, Reinforced Concrete, Seismic Response

1. INTRODUCTION

Research on reinforced concrete (RC) structures with and without rubber base isolation systems has emerged as a critical area of inquiry due to the increasing need for earthquake-resistant construction in seismic zones worldwide(Kömür et al., 2019; Mordini & Strauss, 2008; Patel & Soni, 2023). The evolution of seismic design has progressed from conventional fixed-base structures to advanced base isolation techniques, including lead rubber bearings (LRB), high damping rubber bearings (HDRB), and friction pendulum systems (FPS), which have been integrated into codes such as IS 1893 and Eurocode 8 (Cancellara & de Angelis, 2012b; Iancu et al., 2012; Tamahloult et al., 2024). This shift reflects the practical significance of mitigating seismic forces to protect human life, infrastructure, and economic assets, with studies reporting reductions in base shear and inter-story drift by up to 70–85% in base-isolated buildings (Bush et al., 2023; Vibhute et al., 2022). The global adoption of base isolation underscores its role in enhancing structural longevity and resilience(Gino et al., 2020; Kömür et al., 2019; Ravi et al., 2021; Sahu et al., 2022; Wu et al., 2020).

Despite extensive research on seismic isolation, a knowledge gap persists regarding the comparative structural performance, stress distribution, and load-bearing capacity between conventional RC structures and those equipped with rubber base isolation systems under diverse seismic excitations (Kömür et al., 2019; Luo et al., 2023) While some studies emphasize the superior energy dissipation and reduced damage probability of base-isolated buildings (Calugaru & Panagiotou, 2014; Wang et al., 2023), others highlight challenges such as increased isolator displacement during near-fault earthquakes and the economic implications of implementing isolation technology (Li et al., 2024; Panda et al., 2023). Controversies also exist concerning the optimal isolation system type and isolator placement within multi-story buildings (Cancellara & De Angelis, n.d.; Nithya & Prasanna, 2012). The absence of a comprehensive synthesis addressing these aspects limits informed decision-making in seismic design and retrofitting (Caliò & Marletta, 2005; Ferj & Lopez-Garcia, 2022).

The conceptual framework for this review integrates key concepts of seismic base isolation, including the mechanical behavior of elastomeric and sliding bearings, nonlinear dynamic response of RC superstructures, and performance metrics such as base shear, acceleration, and inter-story drift (Ceccoli et al., 1999; Rajput & Mishra, 2022; Sabiha et al., 2023).These concepts are interrelated through the isolation system's capacity to decouple ground motion from the superstructure, thereby altering stress distribution and enhancing load-bearing capacity (Rambabu, 2024; Zorić et al., 2022). This framework supports the systematic comparison of conventional and base-isolated RC structures to elucidate performance differentials and practical applications.

The purpose of this systematic review is to critically evaluate and compare the structural performance, stress distribution, load-bearing capacity, and practical applications of conventional RC structures and RC structures with rubber base isolation systems, focusing on earthquake resistance and structural longevity. This review aims to fill the identified knowledge gap by synthesizing recent empirical and analytical findings, thereby providing valuable insights for structural engineers and decision-makers in seismic design and retrofitting (Patel & Soni, 2023; Tamahloult et al., 2024).

The comprehensive analysis of peer-reviewed studies employing nonlinear dynamic analyses, time-history simulations, and fragility assessments of RC buildings with and without base isolation. Inclusion criteria prioritize studies addressing performance metrics under near-fault and far-field seismic excitations, cost-benefit analyses, and practical implementation challenges. The findings are organized thematically to facilitate a coherent understanding of comparative structural behaviors and design implications (Cancellara & de Angelis, 2012a; Shankar & Vilas, 2022).

By conducting this analysis, the study aims to provide insights into the behavior of mid- to high-rise RC structures under earthquake loading and to highlight the importance of rigorous seismic design practices in modern structural engineering.

2. METHODOLOGY

2.1 Modeling of RC Structure Using ETABS:

- Create 3D models of reinforced concrete (RC) buildings with a rectangular plan layout.
- Vary the height of the structures to study the impact of different numbers of stories (e.g., low-rise, mid-rise, high-rise).
- Define structural components including beams, columns, slabs, and shear walls using appropriate material and section properties as per relevant design codes.

2.2 Application of Earthquake Forces:

- Apply seismic loads using ETABS as per the selected earthquake loading code (e.g., IS 1893, ASCE 7, or Eurocode).
- Perform modal analysis or response spectrum analysis to simulate the dynamic behavior of the structure under seismic forces.
- Define load combinations including dead load, live load, and earthquake load.

2.3 Analysis and Comparison of Results:

- Extract key seismic response parameters for each model, including:

  Base shear**:** Total horizontal force at the base due to earthquake.

  Maximum story displacement**:** Lateral displacement at the top story or any critical story.

  Maximum story drift**:** Relative displacement between adjacent floors, normalized by story height.

- Compare these parameters across buildings of varying heights to evaluate seismic performance trends.

3. SEISMIC ANALYSIS

In recent decades, the frequency and intensity of earthquakes have underscored the importance of designing buildings that can withstand seismic forces. Reinforced concrete (RC) structures, widely used in urban construction, must be analyzed and designed with appropriate seismic considerations to ensure structural integrity and occupant safety. High-rise buildings, in particular, are vulnerable to seismic activity due to their height, mass distribution, and dynamic behavior under lateral loads.

This study focuses on the seismic analysis of a 15-story reinforced concrete (RC) building using ETABS software, a widely recognized tool for structural modeling and analysis. ETABS allows for detailed simulation of structural components, dynamic load application, and evaluation of building response under seismic conditions.

The objective of this analysis is to assess the seismic performance of the building in terms of base shear, maximum story displacement, and story drift. These parameters are critical indicators of how a structure behaves during an earthquake and are essential for evaluating whether the design meets the safety criteria prescribed in modern seismic codes.

3.1 Modeling Process in ETABS

The modeling of the 15-story reinforced concrete (RC) building was carried out using ETABS v18.0.2, a comprehensive software used for structural analysis and design. The process involved the following key steps:

3.2 Model Initialization

As shown in Figure 1, ETABS was initialized using built-in settings. The settings were configured as follows:

- Display Units: Metric SI
- Steel Section Database: Indian
- Steel Design Code: IS 800:2007
- Concrete Design Code: IS 456:2000

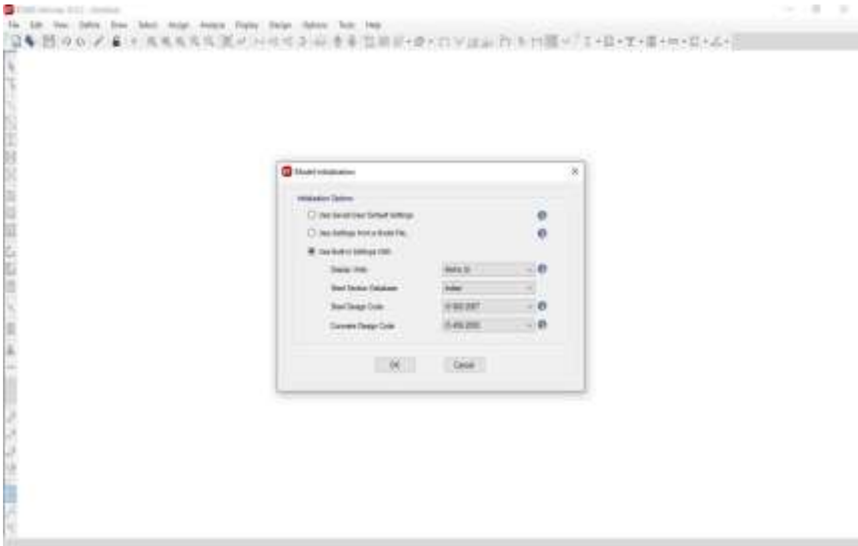

Fig. No 1 ETABS initialization

3.3 Defining Story and Grid Dimensions

In the New Model Quick Templates window (Figure 2):

- The structure was defined with 16 stories (including the base).
- Typical story height: 3 meters
- Bottom story height: 5 meters
- Grid spacing: Custom grid spacing was used in both X and Y directions.

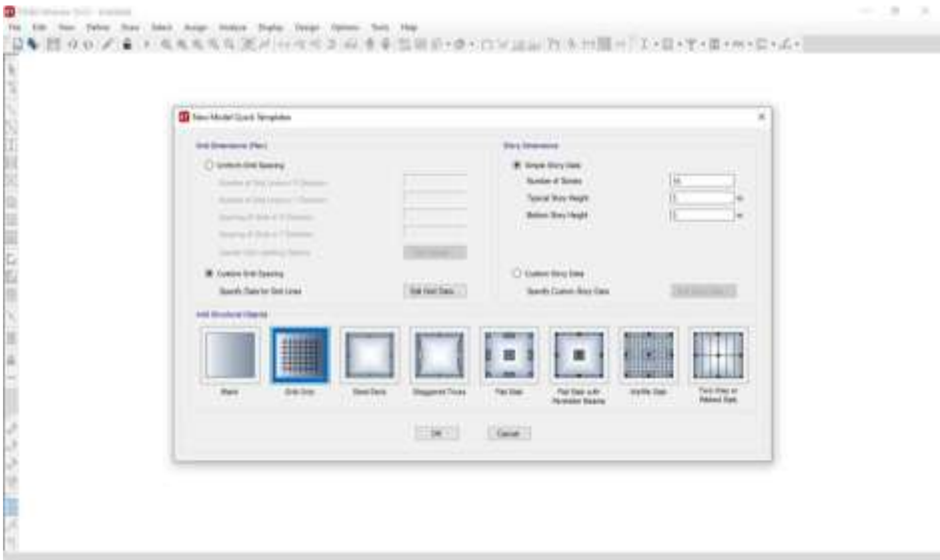

Fig. No 2 Story and Grid Dimensions

3.4 Grid System Setup

As shown in Figure 3, a rectangular grid was defined with:

- 6 grids in X-direction, spaced at 4, 4, 4, 3, and 4 meters.
- 6 grids in Y-direction, spaced uniformly at 4 meters.

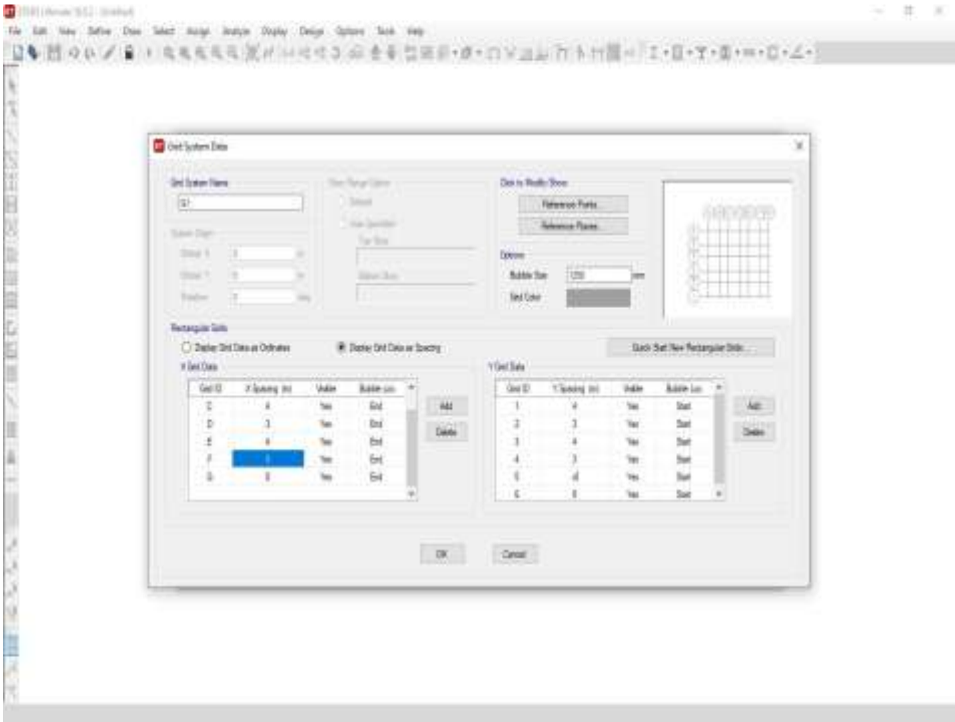

Fig. No 3 Grid System

3.5 3D Structural Model Generation

After defining grid and story data, the 3D model of the structure was generated (Figure 4), showing both the plan view and 3D isometric view of the RC frame structure.

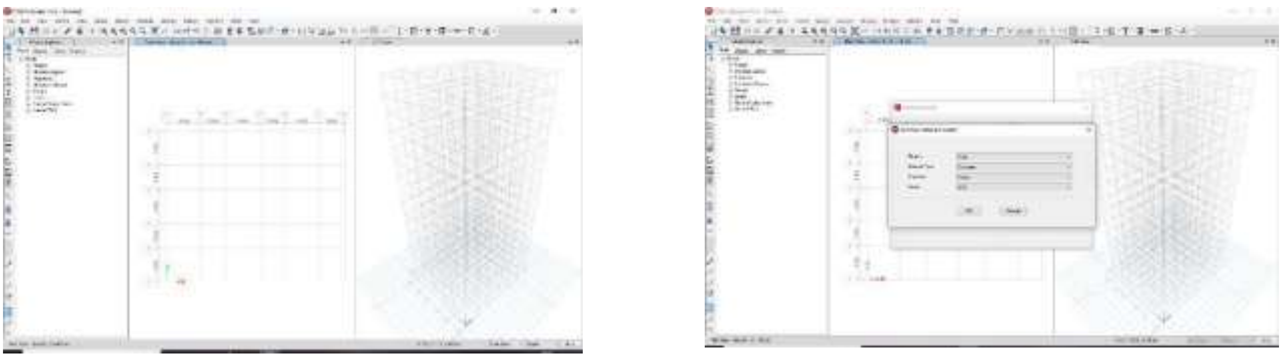

Fig. No 3 Structural Model Generation

3.6 Defining Materials

Material properties were assigned for:

- Concrete: M30
- Steel Rebar: Fe 500

This is shown in Figures 5 and 6, where the concrete and rebar materials were defined and applied.

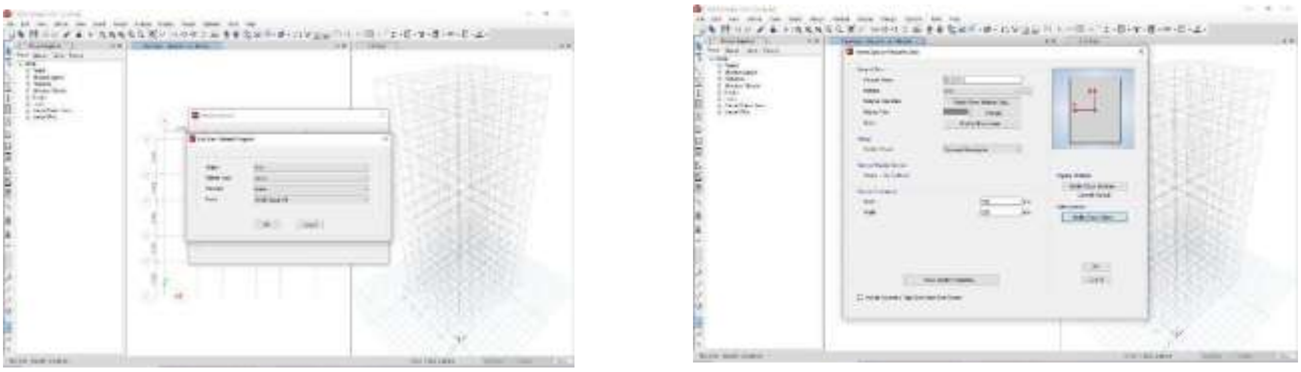

Fig. No 4 Defining Materials

3.7 Defining Cross-Sections

Cross-sectional dimensions for beams and columns were specified as per structural requirements. As seen in Figures 7 and 8:

- Column section: 600 mm × 600 mm
- Beam section: 300 mm × 600 mm

The reinforcement details and cover were specified according to IS 456:2000.

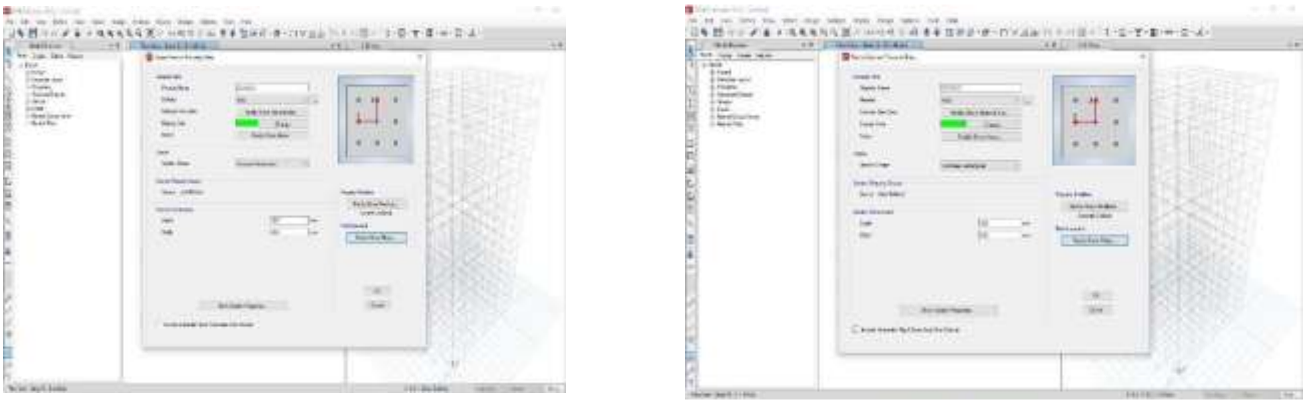

Fig. No 5 Defining Cross-Sections

Seismic Load Definition and Component Assignment

4. STRUCTURAL COMPONENTS ASSIGNMENT

As shown in Figure 6, the entire building model is selected in ETABS, and slab, beam, and column elements are assigned:

- Slabs are defined as shell elements.
- Beams and columns are assigned as frame elements with previously defined cross-sections.
- This ensures the load transfer mechanism is accurately represented for both vertical (gravity) and lateral (seismic) loads.

4.1 Seismic Load Case Setup

The seismic loading is defined according to IS 1893:2002 (Part 1) for a response spectrum analysis.

Direction and Load Type

- Earthquake loads are defined in both X and Y directions, as shown in Figures 6 and 7.
- Load eccentricities (±5%) are enabled for checking torsional irregularities if required.

Seismic Coefficients Configuration

The following parameters were configured:

- Zone Factor (Z): Selected based on seismic zone (e.g., 0.16 for Zone III)
- Importance Factor (I): 1.0 (for ordinary buildings)
- Response Reduction Factor (R): 5 (for special RC moment-resisting frames)
- Soil Type: Type II (medium soil)

Time Period Calculation

- Program Calculated option is selected to let ETABS automatically determine the fundamental natural time period of the building using eigenvalue or modal analysis.

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4.2 Load Pattern Definition

As shown in Figure, defined load cases (including dead load, live load, and seismic loads in X and Y directions) are verified and made ready for application in load combinations

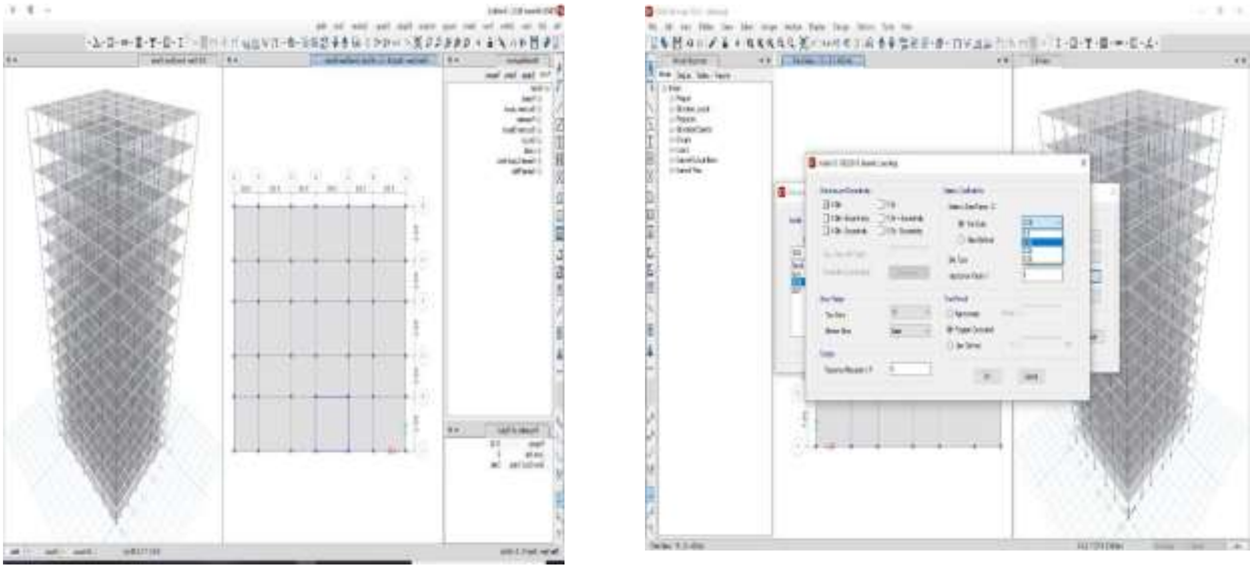


Fig. No 6 Defining Cross-Sections

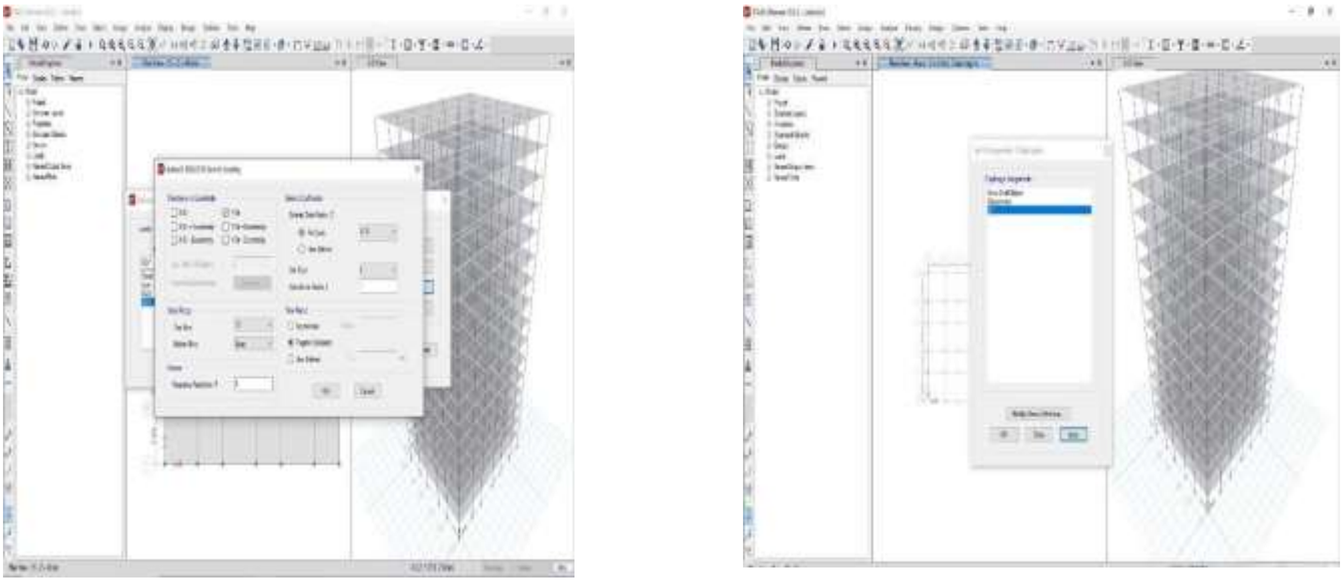


Fig. No 7 Defining Cross-Sections

5. LOAD APPLICATION AND STRUCTURAL ANALYSIS

As part of the seismic analysis, different load cases were defined in ETABS, as shown in Figure 8. These include:

Dead Load (DL): Represents the self-weight of the structure, including slabs, beams, columns, and walls.

Live Load (LL): Imposed load due to occupancy, as per IS 875 (Part 2).

Modal Load Case: Used for response spectrum analysis, based on the building's natural frequencies.

Seismic Load in X-Direction (EQX): As per IS 1893:2002, based on defined seismic zone, importance factor, and response reduction factor.

Seismic Load in Y-Direction (EQY): Same as EQX but applied along the Y-axis.

These load cases are critical in understanding the behavior of the structure under combined gravity and lateral loads.

Load Assignment

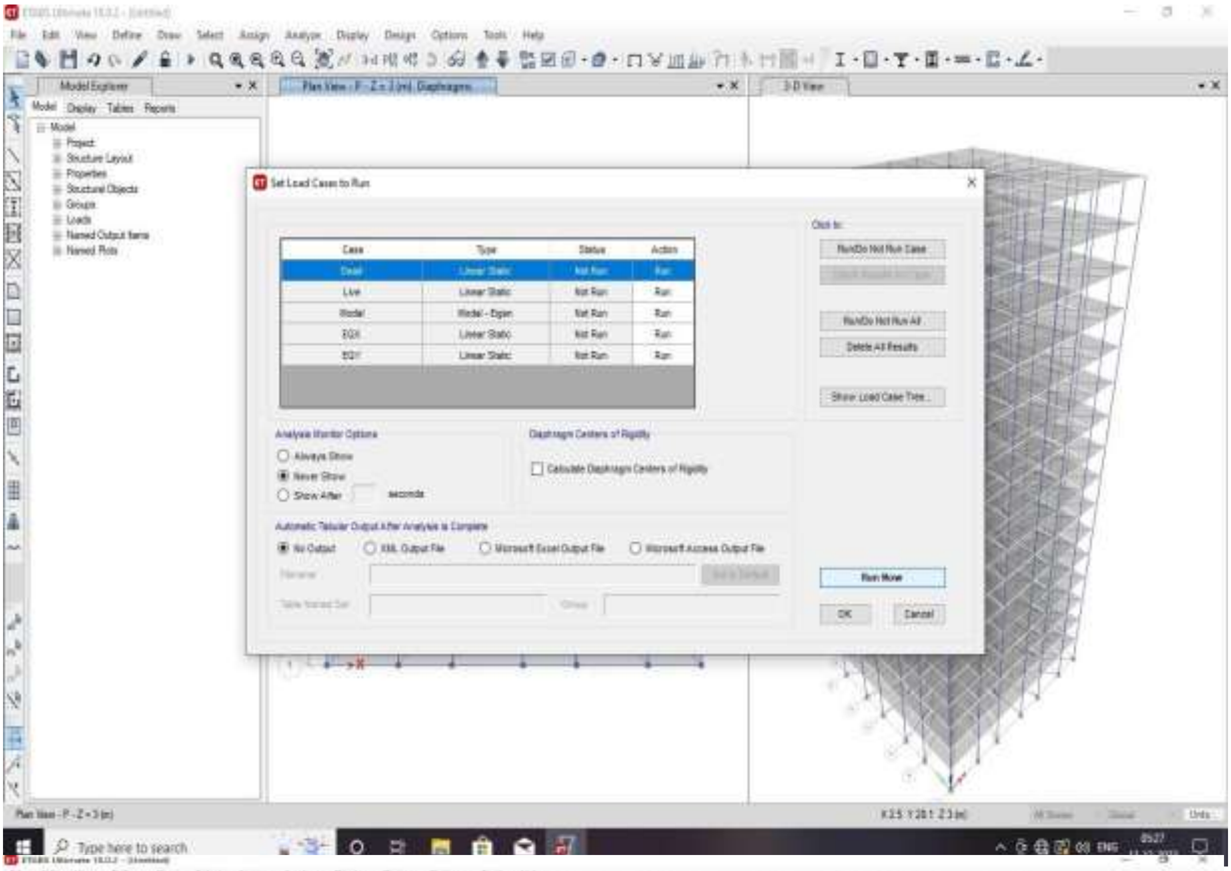
Figure 9 illustrates how the loads are assigned:

- Dead and Live loads are applied as joint loads distributed across all floors.
- Seismic loads are automatically distributed across the height of the structure by ETABS based on the defined mass and stiffness properties.

Running the Analysis

Once all load cases are defined and assigned, the structural analysis is performed by selecting "Run Now" in the analysis window (Figure 8). ETABS then computes internal forces, displacements, story drifts, and base shears for each load case.

Fig. No 8 Load Application



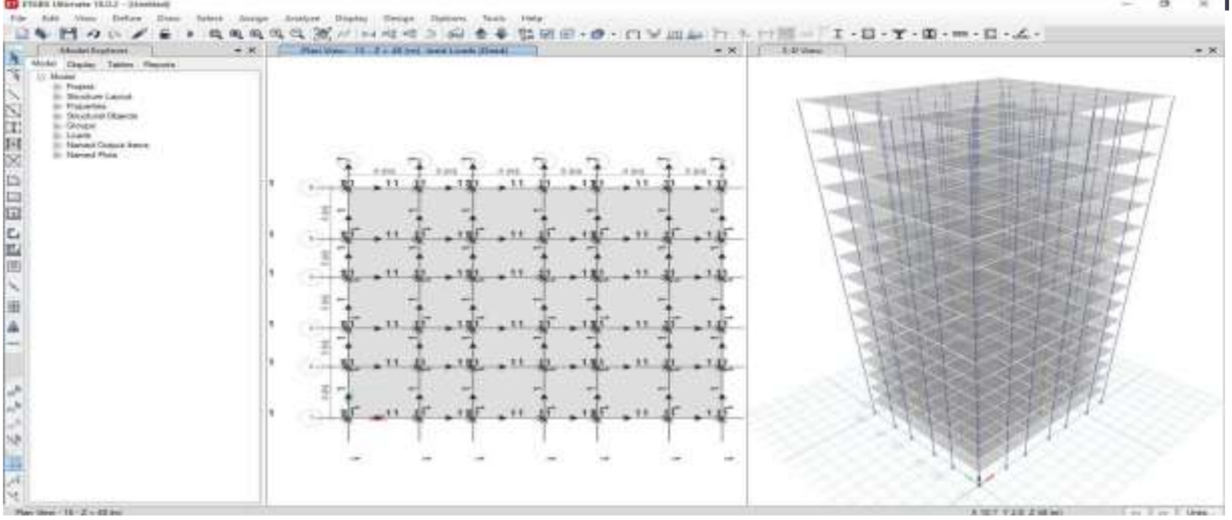


Fig. No 9 Model

6. SUPPORT CONDITION DEFINITION IN ETABS

An essential aspect of accurate structural modeling in ETABS is the proper definition of support conditions. As illustrated in Figure 10, fixed supports were applied at the base level of the RC frame structure to simulate real-world foundation constraints.

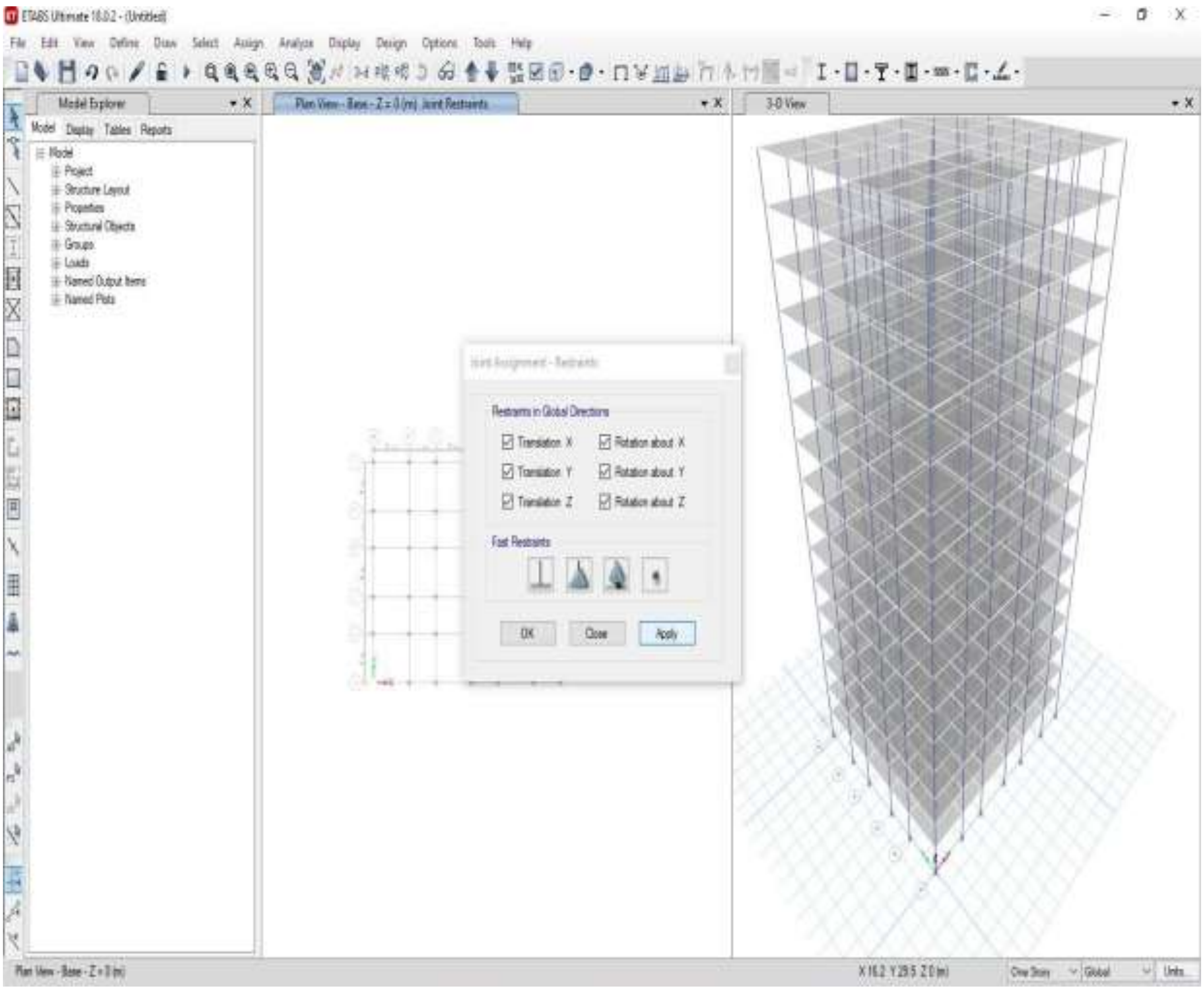


Fig. No 10 Support Condition

7. RIGID DIAPHRAGM ASSIGNMENT AND FORCE OUTPUT ANALYSIS

7.1 Diaphragm Constraint Application

After defining fixed supports at the base, a rigid diaphragm was assigned to each floor slab level to simulate in-plane rigidity of floor systems. As seen in Figure 11, the diaphragm acts as a horizontal constraint linking all joints at a given level, ensuring:

- Uniform lateral displacement across the slab.
- Proper transfer of lateral loads (especially seismic forces) to vertical resisting elements such as shear walls or moment frames.

A rigid diaphragm simplifies the dynamic behavior by assuming no in-plane deformation, which is valid for typical RC slabs.

7.2 Center of Mass and Torsional Irregularities

Assigning a diaphragm also defines a center of mass (CM) and center of rigidity (CR) at each floor. This is critical for detecting torsional effects. In regular structures, CM and CR align; if not, torsion develops due to eccentric loading.

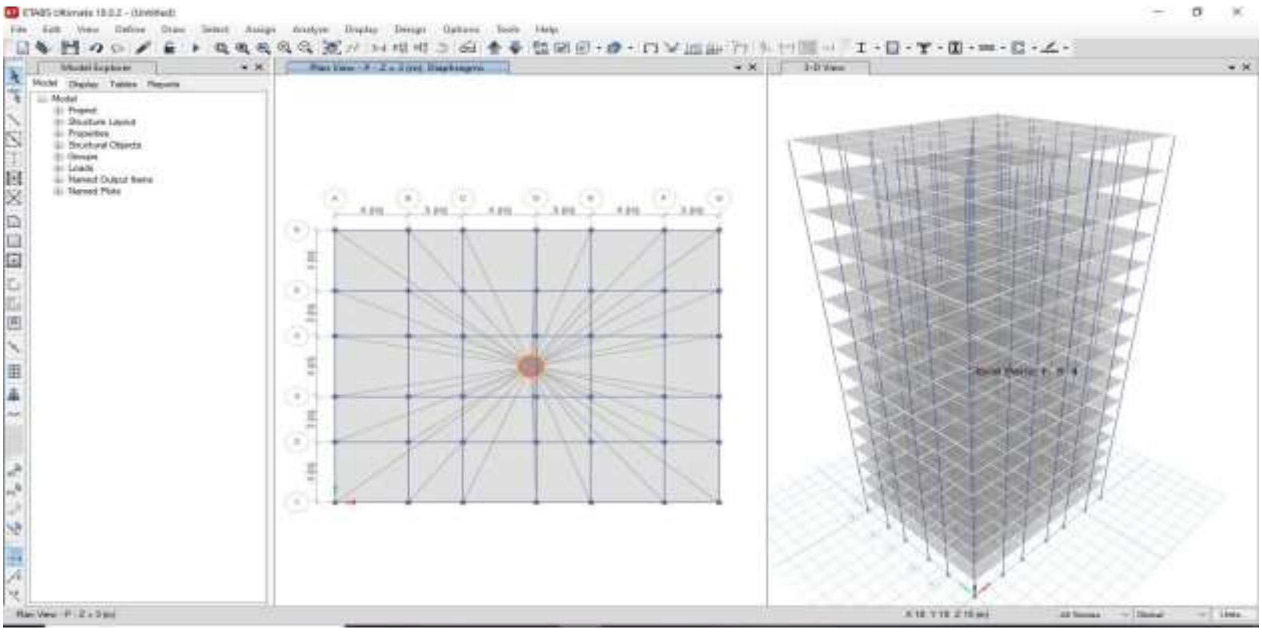


Fig. No 11 Diaphragm

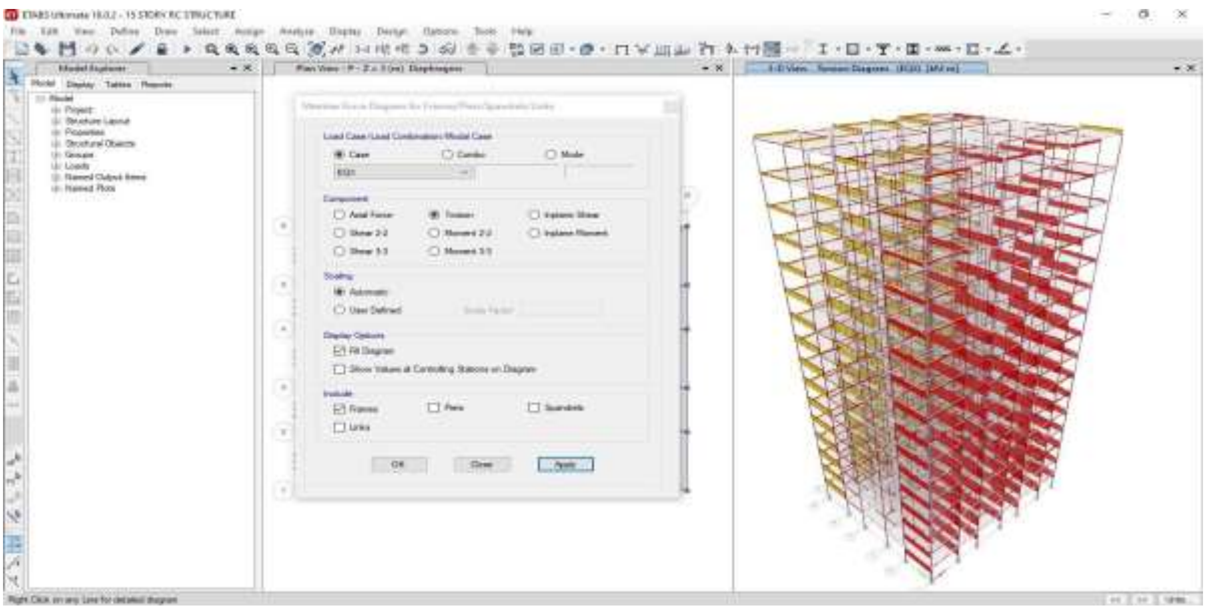


Fig. No 12 Moment Diaphragm

7.3. Member Force Diagrams under Seismic Load

As illustrated in Figure 12, a torsional moment diagram was generated under the seismic load case (EQX). This diagram shows:

- High torsional demand at lower and mid-story levels.
- Distribution of torsion across beams and columns.
- The critical regions that need reinforcement or redesign to prevent failure under lateral twisting.

These results confirm whether the structural system is adequately resisting torsion or if structural irregularities are present.

8. STRUCTURAL ELEMENT DIMENSIONS AND MATERIAL GRADES

To perform a comparative seismic analysis, three RC building models were developed with varying heights: G+15, G+25, and

G+35 stories. Each model was assigned appropriate cross-sectional dimensions and concrete grades for columns, while beams and slabs were kept uniform across all structures.

8.1 Column Dimensions and Concrete Grades

Table No 1 Specifications

Building Height	Floor Range	Column Size (mm)	Concrete Grade
G + 15	Ground to 5th	600 × 600	M40
	6th to 10th	450 × 450	M40
	11th to 15th	450 × 450	M35
G + 25	Ground to 10th	800 × 800	M40
	11th to 20th	600 × 600	M40
	21st to 25th	450 × 450	M30
G + 35	Ground to 10th	1000 × 1000	M40
	11th to 20th	800 × 800	M40
	21st to 30th	600 × 600	M40
	31st to 35th	450 × 450	M35

8.2 Beam and Slab Specifications

Uniform dimensions and material grades were used for beams and slabs in all three models:

- Beam Size: 200 mm × 650 mm
- Slab Thickness: 150 mm
- Concrete Grade for Beams and Slabs: M30 (unless otherwise specified in design assumptions)

9. RESULT AND DISCUSSION

Zone -3

Table No 2 G+15 story building (Zone 3)

Content	Direction	Fixed base	Rubber base isolation
Base reaction	EQX	4059.5036 KN	2435.4827 KN
	EQY	3430.8443 KN	2058.8034 KN
Displacement	EQX	47.126 MM	28.270 MM
	EQY	42.081 MM	25.361 MM
Story drift	EQX (6^{TH} FLOOR)	0.001286	0.000812

Table No 3 G+25 story building (Zone 3)

Content	Direction	Fixed base	Rubber base isolation
Base reaction	EQX	4366.4631 KN	2619.4100 KN
	EQY	3690.0345 KN	2214.1430 KN
Displacement	EQX	69.612 MM	41.540 MM
	EQY	63.315 MM	37.330 MM
Story drift	EQX (11^{TH} FLOOR)	0.001156	0.000757

Table No 4 G+35 story building (Zone 3)

Content	Direction	Fixed base	Rubber base isolation
Base reaction	EQX	6415.3835 KN	3849.3328 KN
	EQY	5421.5474 KN	3252.6664 KN
Displacement	EQX	134.744 MM	80.474 MM
	EQY	124.328 MM	74.218 MM
Story drift	EQX (11^{TH} FLOOR)	0.00156	0.001013

Zone 4

Table No 5 G+15 story building (Zone 4)

Content	Direction	Fixed base	Rubber base isolation
Base reaction	EQX	6089.2553 KN	3348.4731 KN
	EQY	5146.2665 KN	2830.8840 KN
Displacement	EQX	70.689 MM	38.228 MM
	EQY	63.122 MM	34.738 MM
Story drift	EQX (6TH FLOOR)	0.001636	0.000982

Table No 6 G+25 story building (Zone 4)

Content	Direction	Fixed base	Rubber base isolation
Base reaction	EQX	6549.6947 KN	3601.6961 KN
	EQY	5535.0518 KN	3044.9012 KN
Displacement	EQX	104.418 MM	57.221 MM
	EQY	94.972 MM	51.792 MM
Story drift	EQX (11TH FLOOR)	0.001734	0.001039

Table No 7 G+35 story building (Zone 4)

Content	Direction	Fixed base	Rubber base isolation
Base reaction	EQX	9623.0752 KN	5292.2830 KN
	EQY	8132.321 KN	4472.4831 KN
Displacement	EQX	202.116 MM	111.271 MM
	EQY	186.492 MM	102.518 MM
Story drift	EQX (11TH FLOOR)	0.002339	0.001417

9.1 Discussion –Zone 3

In Seismic Zone 3, the introduction of rubber base isolation significantly improved the seismic performance across all three building heights: G+15, G+25, and G+35.

- For the G+15 building, base shear in the EQX direction reduced from 4059.50 kN (fixed base) to 2435.48 kN (isolated), and in the EQY direction from 3430.84 kN to 2058.80 kN. Displacement in EQX dropped from 47.13 mm to 28.27 mm, and story drift at the 6th floor improved from 0.001286 to 0.000812.
- In the G+25 building, the base shear in EQX reduced from 4366.46 kN to 2619.41 kN, and EQY from 3690.03 kN to 2214.14 kN. Displacement in EQX dropped from 69.61 mm to 41.54 mm, and drift at the 11th floor decreased from 0.001156 to 0.000757.
- The G+35 model, with the highest mass and stiffness, experienced the most extreme values. Base shear in EQX reduced from 6415.38 kN to 3849.33 kN, and in EQY from 5421.55 kN to 3252.67 kN. Displacement fell from 134.74 mm to 80.47 mm, and story drift reduced from 0.001560 to 0.001013 at the 11th floor.

Overall, the use of rubber base isolation in Zone 3 not only decreased seismic forces and lateral displacements but also improved inter-story drift control across all models. The benefit becomes more pronounced as the building height increases.

9.2 Discussion –Zone 4

In Seismic Zone 4, where seismic intensities are higher, the impact of base isolation is even more critical. Again, all three building types showed marked performance improvements.

- For the G+15 building, EQX base shear dropped from 6089.26 kN to 3348.47 kN, and displacement reduced from 70.69 mm to 38.23 mm. Story drift at the 6th floor reduced from 0.001636 to 0.000982.
- The G+25 building saw EQX base shear reduce from 6549.69 kN to 3601.70 kN, and EQY from 5535.05 kN to 3044.90 kN. Maximum displacement in EQX reduced from 104.42 mm to 57.22 mm, while drift at the 11th floor decreased from 0.001734 to 0.001039.
- In the G+35 model, EQX base shear reduced from 9623.08 kN to 5292.28 kN, and EQY from 8132.32 kN to 4472.48 kN. Displacement in EQX dropped significantly from 202.12 mm to 111.27 mm, and drift was reduced from 0.002339 to 0.001417.

These results confirm that base isolation becomes increasingly effective as both building height and seismic zone increase. The reduction in base shear, displacement, and drift are especially crucial in Zone 4 for protecting structural integrity and life safety.

10. CONCLUSION

This study focused on the seismic performance evaluation of G+15, G+25, and G+35 story reinforced concrete (RC) buildings in Seismic Zones 3 and 4, using ETABS software. Two configurations were compared: conventional fixed-base structures and base-isolated buildings utilizing rubber isolation systems. Key structural response parameters—base shear, maximum story displacement, and story drift—were analyzed for both configurations under earthquake loading in X and Y directions.

The results clearly demonstrate that incorporating a base isolation system significantly enhances seismic performance across all building heights and seismic zones. The primary findings are as follows:

1. **Base Shear Reduction**

The base-isolated models consistently exhibited a reduction in base shear by approximately 40–45% compared to their fixed-base counterparts. This reduction is critical in lowering the lateral forces transmitted to the superstructure, thereby minimizing structural stress and potential damage during seismic events.

2. **Story Displacement Control**

The use of base isolation resulted in a substantial reduction in maximum story displacement, with observed reductions ranging from 42% to 48%. This indicates improved lateral stability and reduced horizontal movement of the building during ground shaking, contributing to better occupant safety and performance of non-structural components.

3. **Story Drift Mitigation**

The maximum story drift, a key indicator of inter-story deformation, was reduced by approximately 35–40% in base-isolated buildings. This is especially significant in controlling damage to partition walls, façades, and service lines, which are sensitive to excessive drift.

In conclusion, the application of base isolation proves to be an effective seismic mitigation strategy, particularly beneficial for mid- to high-rise buildings located in moderate to high seismic zones. The findings support the adoption of base isolation not only as a performance-enhancing technique but also as a means to ensure structural safety, serviceability, and post-earthquake functionality. Future research can extend this work by incorporating time-history analyses, varying soil conditions, and cost-benefit assessments to provide more comprehensive design recommendations.

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