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Seismic Performance of Adaptive Building Systems: Advances and Challenges

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Abstract— The seismic performance of adaptive buildings represents a significant advancement in structural engineering, aiming to enhance resilience and safety during earthquakes. Adaptive buildings utilize innovative technologies such as base isolation, energy dissipation systems, and real-time control mechanisms to dynamically respond to seismic forces. These structures are designed to adjust their stiffness, damping, and mass properties in real-time, optimizing their performance under varying seismic loads. This adaptability reduces structural damage, minimizes energy dissipation, and ensures occupant safety. Recent studies and experimental results demonstrate that adaptive buildings outperform conventional structures in terms of displacement control, acceleration reduction, and overall seismic energy management. However, challenges such as high initial costs, complex design requirements, and maintenance of adaptive systems remain. In this research work the principles, technologies, and performance metrics of adaptive buildings, highlighting their potential earthquake-resistant design and contribute to sustainable urban development for high seismic zone.

The seismic performance of adaptive building systems represents a significant advancement in earthquake engineering, aiming to mitigate structural damage and enhance the safety of occupants. Adaptive systems differ from conventional static structures by incorporating real-time monitoring, feedback loops, and dynamic response mechanisms that adjust to external forces during seismic events. These systems include technologies such as base isolation, tuned mass dampers (TMDs), active and semi-active control systems, and smart materials (e.g., shape-memory alloys and magnetorheological dampers).

Advantages of adaptive building systems include improved energy dissipation, reduced inter-story drift, and greater flexibility in structural design. These systems are designed to respond autonomously to seismic loads, adapting their stiffness, damping, or mass distribution to counteract ground motions. Additionally, the integration of sensors and control algorithms allows real-time structural assessment, enabling rapid post-earthquake evaluations and minimizing downtime. Future advancements aim to develop more cost-effective, scalable adaptive solutions suitable for both new constructions and retrofitting existing buildings. This research underscores the transformative potential of adaptive building systems in modern seismic design, contributing to safer, more sustainable, and resilient built environments.

Key Words: *ETABS, Earthquake Loading, High-Rise, Response Spectrum Method, Story Drift.*

1. INTRODUCTION

1.1 General Introduction

As we all know, the increasing frequency and intensity of earthquakes around the world have raised urgent concerns about the structural safety of buildings and infrastructure. Traditional fixed support systems, while stable under static loads, often fall short when subjected to dynamic seismic forces. This has led engineers and researchers to explore innovative and adaptive support systems that can respond intelligently to such unpredictable events.

Today, we delve into the comparative performance of rubber isolators, friction dampers, and fixed base supports — each offering unique advantages in seismic energy absorption and structural protection. This discussion not only aims to deepen our technical understanding but also to inspire the future development of safer, more resilient structures in earthquake-prone regions.

1.2 RESEARCH OBJECTIVE

1. **To analyze** the seismic performance of an RCC G+9 multi-storey building in Earthquake Zones II and IV with medium soil conditions, and to compare base shear values across different support systems—fixed, rubber, and frictional—highlighting the amplification of base shear in higher seismic zones.
2. **To study** the variation of base shear with increasing building height, from G+9 to G+25, and establish the trend of increasing base shear with taller structures.
3. **To evaluate** the impact of building stiffness on seismic force attraction by comparing base shear values in shorter (G+9) and taller buildings, demonstrating higher base shear in stiffer, shorter buildings.
4. **To compare** the displacement response of the RCC structure under Zone II and Zone IV conditions across fixed, rubber, and friction supports, and quantify the increase in displacement in higher seismic zones.
5. **To assess** the story drift behavior as building height increases, and establish the trend of increasing lateral displacement with height for all types of support systems.
6. **To determine** the most effective support system for minimizing seismic response, with a focus on identifying optimum control of base shear, displacement, and drift using rubber and friction dampers

1.3 PROJECT STATEMENT

In earthquake-prone regions, conventional fixed support systems in buildings often fail to adequately dissipate seismic energy, leading to structural damage, high inter-story drift, and potential collapse. While alternative adaptive systems such as rubber bearings and friction dampers have shown promise in improving seismic performance, there remains a lack of comprehensive comparative analysis among these support mechanisms under various seismic conditions. Without such analysis, structural designers face challenges in selecting the most effective support system for specific site conditions and performance objectives. This study aims to address this gap by evaluating and comparing the seismic behavior of buildings supported on rubber isolators, friction dampers, and fixed supports in terms of energy dissipation, displacement control, and overall structural stability.

2. LITERATURE SURVEY

Study existing research on adaptive building systems and seismic performance.
Analyse codes, standards (e.g., IS 1893 and case studies).
Identify advancements & challenges in adaptive systems for seismic resilience.

- Study of Provision & Guidelines of Various Earthquake Codes

Earthquake-resistant design codes provide critical guidelines to ensure structural safety during seismic events. Different countries and regions have developed their own codes based on local seismicity, construction practices, and technological advancements. Below is a comparative study of key earthquake codes, their provisions, and design philosophies.

Indian Standard (IS 1893 & IS 13920) – India
Applicability: Mandatory for seismic zones IV in India.

Key Features:

- Seismic Zonation: India divided into Zones II (low) to V (very high).
- Response Reduction Factor (R): Reduces design forces based on ductility.
- Ductile Detailing (IS 13920): Special confining reinforcement in beams and columns.
- Soil Classification: Site-specific amplification factors (Type I to IV).

Challenges:

- Limited provisions for high-rise and base-isolated structures.
- Needs updates for performance-based design.

Case Study of Adaptive Building for Various Location

Case Study: Adaptive Building for Pune Region

Introduction

Location: Pune, Maharashtra, India

Seismic Zone: Zone III (Moderate Seismicity, as per IS 1893:2016)

Objective: Design an adaptive building to enhance earthquake resilience while optimizing cost and performance.

Why Adaptive Building for Pune:

- Moderate Seismic Risk: Pune is in Zone III, meaning potential for MMI VI-VII shaking.
- Urban Growth: High-rise constructions demand innovative seismic solutions.
- Soil Conditions: Mixed soil types (soft to medium) necessitate dynamic response control.

Proposed Adaptive Building Features

A. Structural System

- Hybrid Frame with Base Isolation
  - Lead Rubber Bearings (LRBs) at the base to decouple the building from ground motion.
  - Semi-Active Dampers (Magnetorheological or Tuned Mass Dampers) for mid- and high-rise floors'

B. Energy-Efficient Adaptive Components

- Shape Memory Alloys (SMAs) in beam-column joints for self-centering capability.
- Variable Stiffness Walls to redistribute loads dynamically.

Challenges & Solutions for Pune Implementation

Challenge	Solution
Higher Initial Cost	Use hybrid (passive + adaptive) systems for cost efficiency.
Power Dependency	Backup batteries + energy-harvesting dampers.
Skilled Labor Shortage	Training programs with local engineering colleges.
Code Compliance	Follow IS 1893 + IS 13920 with additional adaptive tech guidelines.

An adaptive building in Pune (Zone III) can significantly improve seismic resilience while remaining cost-effective. By integrating base isolation, smart damping, and AI monitoring, such structures can withstand moderate earthquakes with minimal disruption. Future steps include code updates to formalize adaptive design standards in India.

Case Study: Adaptive Building for Nagpur (Seismic Zone III), Maharashtra

Introduction

- Location: Nagpur, Maharashtra (Seismic Zone II, IS 1893:2016)
- Building Type: 25-Story mixed-use (Residential + Commercial)
- Objective: Implement adaptive seismic technologies to enhance resilience while optimizing cost.

Why Nagpur Needs Adaptive Buildings:

✓ Moderate Seismic Risk: Potential for MMI VI-VII shaking (e.g., 1993 Killari earthquake impact).

✓ Urban Expansion: Rapid high-rise construction demands innovative seismic solutions.

✓ Soil Variability: Hard basalt rock in some areas vs. soft alluvial soils near rivers.

- **Adaptive Technologies Proposed**

A. Hybrid Base Isolation + Damping System

- Friction Pendulum Bearings (FPB) – Low-cost isolation for Nagpur's rock-dominated soil.
- Semi-Active Magnetorheological (MR) Dampers – Adjust stiffness in real-time.

B. Self-Repairing Materials

- Shape Memory Alloys (SMAs) in critical joints to minimize residual deformations.

Seismic Performance Analysis

A. Expected Ground Motion (Nagpur, Zone II)

PGA: 0.16g (IS 1893)

Soil Type: Type II (Medium Soil) near Nag River, Type I (Rock) in core areas.

II. PROBLEM FORMULATION

In this title of parametric investigation, a detailed study of analysis of RCC structure using IS codes and British code has been presented. Analysis of all the above-mentioned structures has been carried out by using different Earthquake with response spectrum Method. In the present study, analysis of G+9, G+25 multi-storied building located India has been done. Analysis has been carried out by assuming the buildings in all seismic zones. Three-dimensional model of the building is prepared in ETABS Software. Basic parameters considered for the analysis are,

1. Occupancy of the building: Residential building
2. Number of stories: G+9 (10 storied)
3. Number of bays along X axis :5no's
4. Number of bays along Y axis :2no's
5. Total Height of building: 27 m
6. Shape of building: Rectangular
7. Geometric details a) Ground floor height: 3 m b) Floor to floor height: 3 m
8. Material details a) Concrete Grade: M35 (COLUMNS AND BEAMS) b) Steel: HYSD reinforcement of Grade Fe500 Bearing Capacity of Soil: 200 kN/m2
9. Type of Construction: Reinforced Cement Concrete Framed Structure
10. Column: 0.750 m × 0.450 m
11. Beams: 0.230 m × 0.530m
12. Slab thickness: 0.150 m
13. Grade of concrete: M35
14. Grade of Reinforcing steel: HYSD Fe500
15. Live load: 3.0 kn/m2(IS: 875:1987)
16. Density of Reinforced concrete: 25 kn/m3
17. Seismic Zones: Zone II, Zone IV.
18. Site type: Medium (II) of IS Code 1893-2016
19. Importance factor: 1.0
20. Response reduction factor: 5
21. Damping Ratio: 5%
22. Structural class: C
23. Wind design code: IS 875: 1987 (Part 3)
24. RCC design code: IS 456:2000
25. Steel design code: IS 800: 2007
26. Earthquake design code: IS 1893: 2016 Building models in ETABS Software Fixed supports and rubber base isolator supports used for comparison will look like Figures 4.21 and 4.22 in ETABS software.

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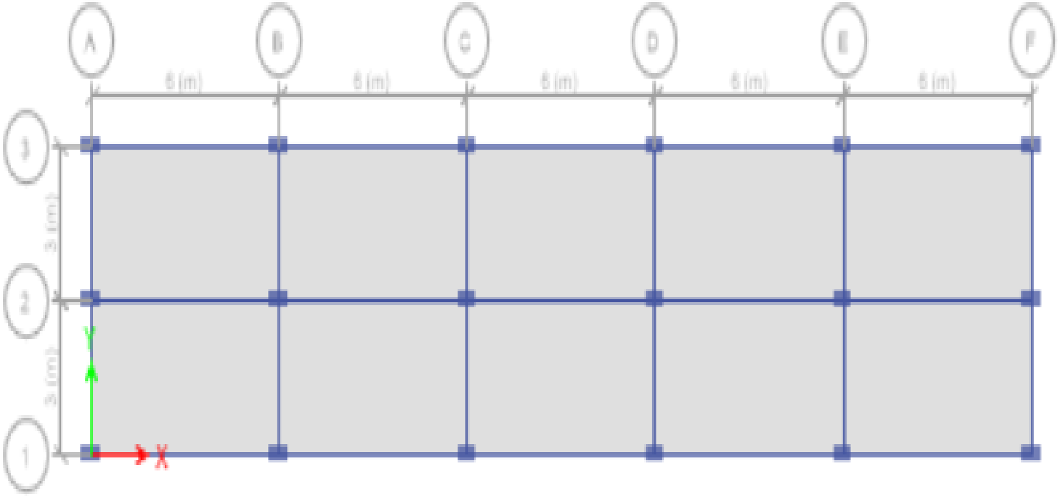
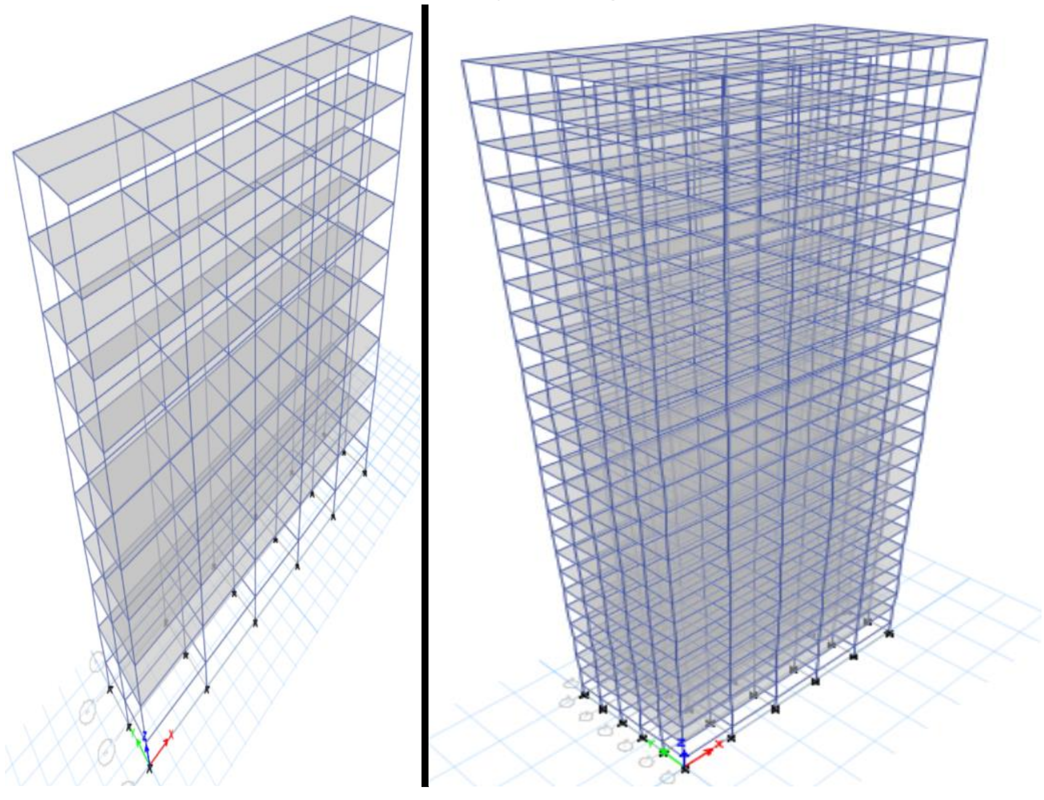
A. Software Plan



B. 3d Line Model G+9 & G+25 Story Building



III. RESULTS AND DISCUSSIONS

A. Base Shear Results

Table 1.1 Base Shear Results for G+9 story building in Fixed Support, Rubber Support and Frictional Support in Earthquake Zone II and Zone – IV with Medium Soil.

TABLE: Auto Seismic - IS 1893:2002							
Load Pattern	Z	Soil Type	I	R	Base Shear(kN)	Base Shear (kN)	Base Shear(kN)
					Fixed support	Rubber Base Support	Frictional Base Support
Zone-2	0.1	II	1	5	107.6622	57.7735	57.7735
Zone - 4	0.24	II	1	5	258.3892	138.6563	138.6563

Graph 1.1 Base Shear Vs. Fixed Support, Rubber Support and Frictional Support in Earthquake Zone II and Zone – IV.

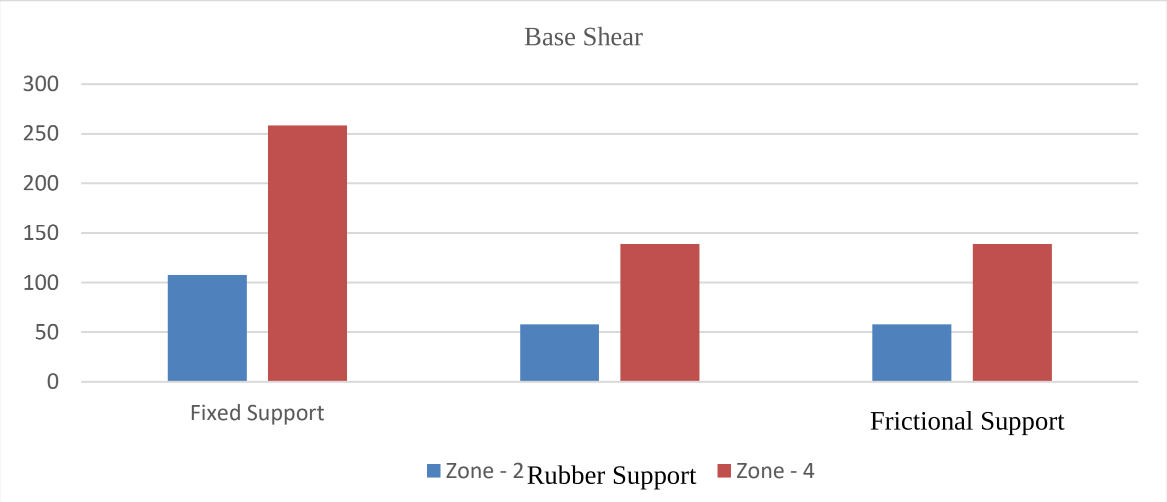


Table 1.2 Earthquake Displacement Results for G+9 story building in Fixed Support, Rubber Support and Frictional Support in Earthquake Zone II and Zone – IV with Medium Soil

TABLE: Diaphragm Centre of Mass Displacements							
Story	Load Case/Combo	UX	UX	UX	UX	UX	UX
		mm	mm	mm	mm	mm	mm
		fixed Support zone -2	Rubber Support zone-2	frictional support zone -2	fixed Support	Rubber Support zone-4	frictional support zone -4
9th slab	EQ+X	9.086	54.6	70.659	21.806	131.039	169.582
8th slab	EQ+X	8.764	49.283	65.343	21.034	118.28	156.823
7th slab	EQ+X	8.259	43.869	59.928	19.822	105.287	143.828
6th slab	EQ+X	7.571	38.357	54.416	18.171	92.057	130.598
5th slab	EQ+X	6.731	32.763	48.821	16.154	78.631	117.171
4th slab	EQ+X	5.774	27.106	43.164	13.858	65.055	103.594
3rd slab	EQ+X	4.732	21.403	37.46	11.357	51.367	89.905
2nd slab	EQ+X	3.621	15.662	31.719	8.69	37.589	76.126
1st slab	EQ+X	2.426	9.877	25.932	5.823	23.704	62.237

Graph: 1.2 Earthquake Displacement Results Vs. Fixed Support, Rubber Support and Frictional Support in Earthquake Zone II and Zone – IV.

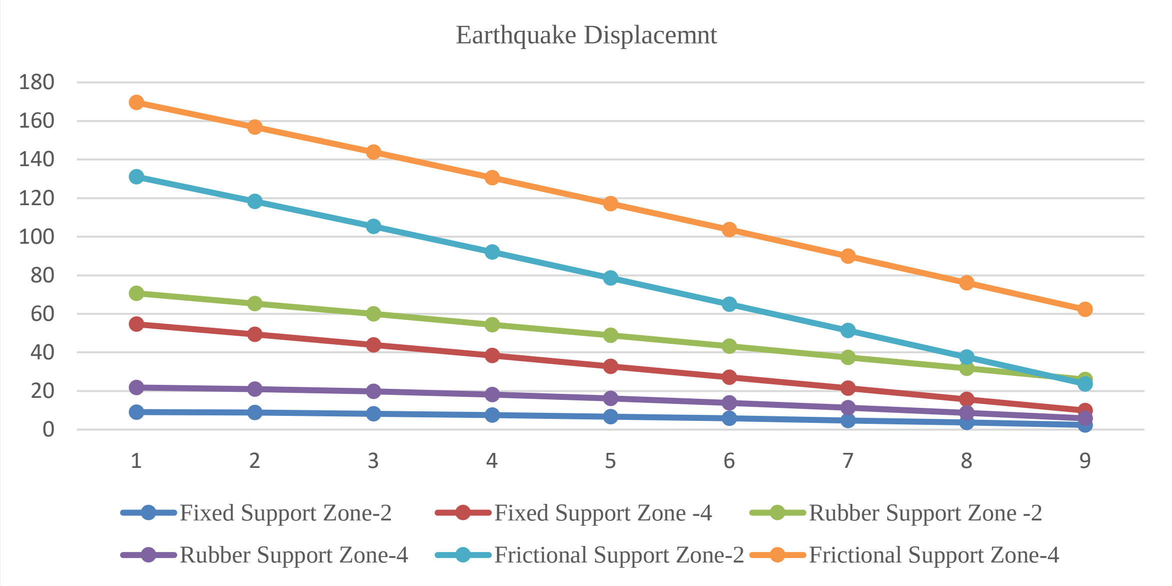
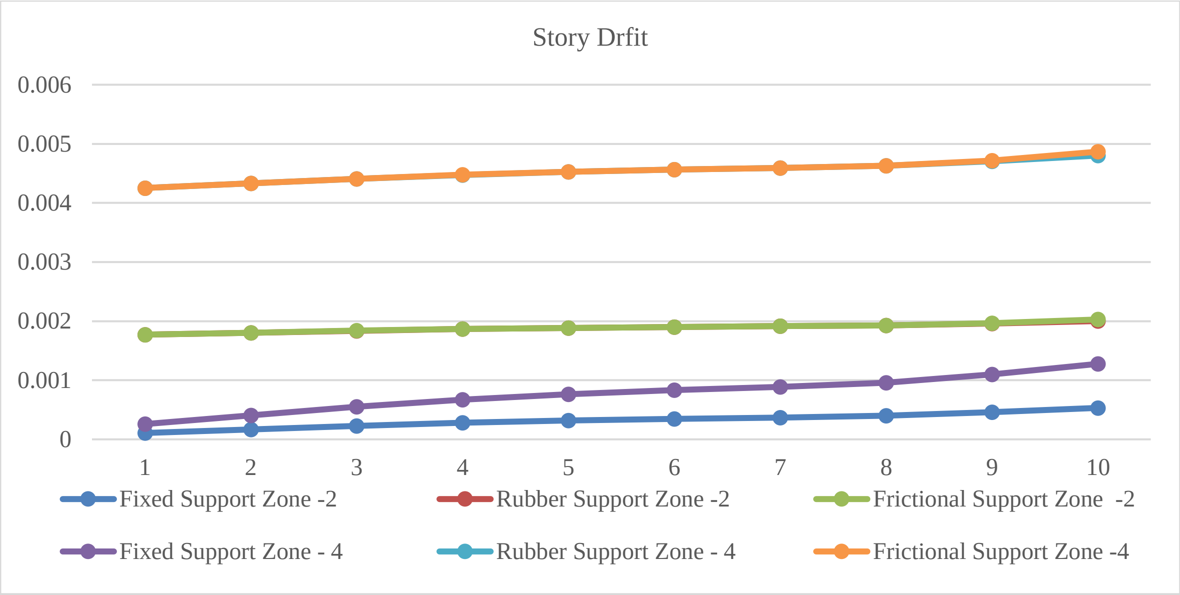


Table 1.3 Story Drift Results for G+9 story building in Fixed Support, Rubber Support and Frictional Support in Earthquake Zone II and Zone – IV with Medium Soil

TABLE: Story Drifts							
Story	Load Case/Combo	Drift	Drift	Drift	Drift	Drift	Drift
		Fixed Support Zone-2	Rubber Support Zone-2	Rubber Support Zone-2	Fixed Support Zone-4	Rubber Support Zone-4	Frictional Support Zon e-4
9th slab	EQ+X	0.000107	0.001772	0.001772	0.000258	0.004253	0.004253
8th slab	EQ+X	0.000168	0.001805	0.001805	0.000404	0.004331	0.004331
7th slab	EQ+X	0.000229	0.001837	0.001838	0.00055	0.00441	0.00441
6th slab	EQ+X	0.00028	0.001865	0.001865	0.000672	0.004475	0.004476
5th slab	EQ+X	0.000319	0.001886	0.001886	0.000765	0.004525	0.004526
4th slab	EQ+X	0.000347	0.001901	0.001901	0.000834	0.004563	0.004563
3rd slab	EQ+X	0.00037	0.001914	0.001914	0.000889	0.004593	0.004593
2nd slab	EQ+X	0.000398	0.001929	0.001929	0.000956	0.004629	0.00463
1st slab	EQ+X	0.000459	0.001961	0.001965	0.001101	0.004707	0.004716
P L	EQ+X	0.000532	0.002001	0.002028	0.001277	0.004802	0.004867

Graph 1.3 Story Drift Results Vs. Fixed Support, Rubber Support and Frictional Support in Earthquake Zone II and Zone – IV.



CONCLUSION

From analysis results it is observed that base isolation technique is very significant in order to reduce seismic response of building models as compared to fixed base building and control damages in building during seismic action.

1. Analysis of RCC G+9 story building in Earthquake Zone II & Zone IV with Medium soil conditions, in zone IV base shear is increase 2.4 times increase as compare to zone II in fixed support conditions similarly in Rubber support and Frictional support base shear is increased 2.39 times, 2.4 times in zone II and zone IV.
2. Base Shear increase with Height – Generally, as building height increases (G+9 to G+25), the base shear values tend to increases. This happens because taller buildings have a higher base shear, which reduces the seismic forces acting at the base.
3. Higher Base Shear for Shorter Buildings – The G+9 structure likely has the highest base shear because shorter buildings tend to be stiffer, leading to greater seismic force attraction. This is a common trend in earthquake engineering.
4. In displacement results in Earthquake Zone II & Zone IV with Medium soil conditions, in zone IV displacement is increase 2.399 times increase as compare to zone II in fixed support conditions similarly in Rubber support and Frictional support displacement is increased 2.39 times, 2.4 times in zone II and zone IV.
5. Story Drift Increases with Height – As the building height increases from G+9 to G+25, the story drift values also increase for all series. This trend is expected since taller buildings tend to experience greater lateral displacement under lateral forces like earthquakes Loads.
6. Optimum control of the parameters considered was observed when the building is damped with Rubber Dampers and friction Damper Model.

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