

# Comparative Seismic Performance Analysis of Rubber Bearing and Friction Pendulum Base Isolation Systems for G+10 R.C.C. Building

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**Abstract** - Base isolation is a critical seismic protection strategy designed to decouple structures from hazardous ground motions by introducing flexible components at the foundation level. This study presents a comprehensive comparative assessment of the seismic performance of a G+10 storey reinforced concrete building. The investigation evaluates two distinct base isolation technologies. Rubber Base Isolation and the Friction Pendulum System (FPS) benchmarking their performance against a conventional Fixed Base configuration.

The building model, characterized by a total height of 33 metres and situated in Seismic Zone V, was developed and analysed using the structural analysis software SAP2000. The research employs three rigorous analytical approaches to ensure a robust evaluation: Equivalent Static Method (ESM), Response Spectrum Analysis (RSA), and Time History Analysis (THA). For the dynamic time history simulations, two significant historical ground motion records the El Centro (1940) and Bhuj (2001) earthquakes are utilized to test the superstructure under varying frequency contents. Key structural response parameters evaluated throughout the study include base shear, lateral load distribution, storey shear, storey displacement, storey drift, fundamental time period, and natural frequency

**Key Words:** Base Isolation, Rubber Base Isolation, Friction Pendulum System, SAP2000, Seismic Response, G+10 Building, Time History Analysis.

## 1. INTRODUCTION

### 1.1 General Overview of Seismic Protection

The primary objective of earthquake engineering is to ensure structural reliability and human comfort by maintaining internal forces and displacements within manageable limits. Traditional seismic protection methodologies have historically relied on the inherent capacity of structural components to dissipate seismic energy through inelastic deformation, thereby providing earthquake resistance. While this approach offers a degree of safety, it often results in severe structural damage during significant seismic events. An alternative, more

advanced approach involves decoupling the structure from the ground or integrating energy-dissipating components at strategic locations within the framework. This method of seismic isolation provides greater protection and significantly reduces the potential for catastrophic structural loss.

The necessity for such advanced mitigation strategies is underscored by the devastating impacts of historical earthquakes in India, including the 1950 Assam, 1991 Uttarkashi, 1993 Maharashtra, and 2001 Gujarat events. These disasters demonstrate that seismic forces remain a substantial threat to a nation's socio-economic stability. Consequently, there is an urgent demand for design solutions, such as seismic isolators and energy-dissipating devices, that can effectively dampen seismic energy and reduce the transmission of lateral loads to the upper storeys of a building.



Figure 1 Damage caused by an earthquake

### 1.2 Fundamentals of Earthquake

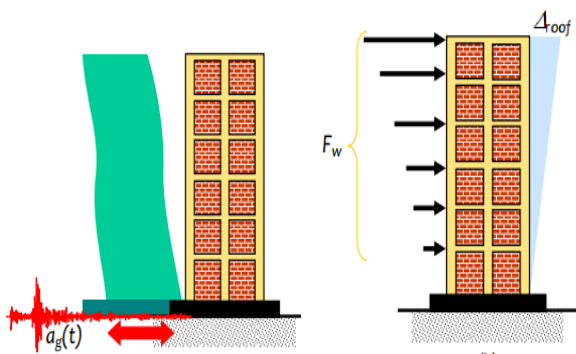
Earthquakes occur when the movement of tectonic plates releases accumulated energy in the form of seismic waves, causing ground shaking. This slip happens along a fault plane, originating at the hypocenter beneath the surface, while the point directly above on the surface is termed the epicenter. These vibrations travel away from the origin point with an amplitude that gradually decreases with distance.

Seismic energy manifests as two primary types of waves: body waves (P and S waves) and surface waves. While shorter structures like brick and stone houses are particularly vulnerable to body waves, tall buildings are more susceptible to the damage caused by surface waves, especially when situated on soft soil conditions. The magnitude and intensity of these forces are recorded using seismographs, which produce a seismogram for analytical study.

### 1.3 Dynamic Actions on Building (Wind and Earthquake Loading)

Designing for wind forces and earthquake effects involves fundamentally different engineering principles. Wind design is based on power-type loading, where a structure is subjected to pressure on its exposed surface area. In contrast, earthquake development involves displacement-type loading, where the structure is subjected to spontaneous ground movement at its base, inducing inertia forces within the building.

A critical difference lies in the nature of the demand: wind power exerts a force with a non-zero mean factor and minimal oscillation, whereas ground motion during an earthquake is cyclic around the framework's neutral axis. Consequently, the stresses induced by seismic events experience several full inversions within a very short duration, placing immense demand on the building's structural integrity. While wind engineering requires only elastic behaviour across the displacement range, earthquake design allows for a choice between designing for versatility (elasticity) or undergoing inelastic behaviour to survive extreme events.



**Figure 2** Difference in the design effect on a building during natural actions of earthquake ground movement at base and Wind pressure on exposed area

### 1.4 Seismic Design Philosophy and Ductility

Modern seismic design acknowledges that buildings designed to remain perfectly elastic during major earthquakes would be economically unviable. Therefore, the traditional philosophy of earthquake-resistant design (as opposed to earthquake-proof) accepts that a structure

may sustain damage to dissipate energy, provided it does not collapse. The criteria for safety generally include:

- Minor shaking: No damage to structural or non-structural components.
- Moderate shaking: Minor structural damage and some non-structural component damage.
- Severe shaking: Significant structural damage but no collapse to save lives.

A building's ability to withstand massive displacement requests through damage without collapsing is defined as ductility. Achieving proper ductility is a complex process that requires rigorous testing of materials and specific detailing of structural members to ensure they can sustain inelastic behaviour under cyclic loading.

### 1.5 The Concept and Process of Base Isolation

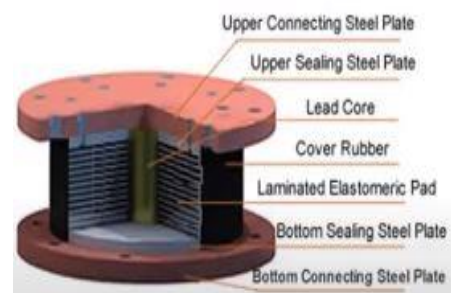
Base isolation often referred to as external isolation is a technique that separates a structure from its foundation, allowing for lateral movement. These systems typically consist of bearings that permit horizontal rotation, dampers to control displacements, and components that provide rigidity under service-level lateral loads.

By increasing the flexibility of the structural system at the base, the fundamental time period is shifted away from the dominant frequencies of ground motion. This shift reduces the inertia forces transmitted to the superstructure. To prevent excessive displacements that could lead to serviceability issues, mechanical devices like elastomeric bearings or friction sliders are used to provide hysteretic or friction-based energy damping.

### 1.6 Isolation Technologies: Rubber and Friction Pendulum Systems

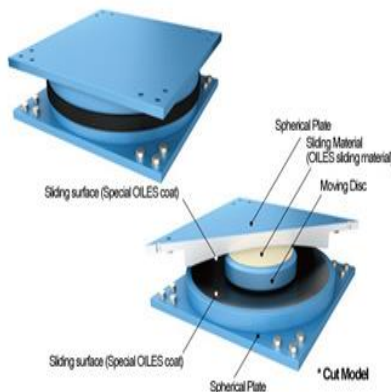
Two of the most prominent isolation technologies are Rubber Bearings and Friction Pendulum Systems.

1. Rubber Bearings: These include Natural Rubber Bearings (NRB) and Lead Rubber Bearings (LRB). LRBs utilize a lead core to enhance energy dissipation and provide damping. These bearings are vertically stiff to support the building's weight but horizontally flexible to decouple it from ground motions.



**Figure 3** Lead bearing elastomeric isolator

- Friction Pendulum Systems (FPS): These kinematic systems utilize a steel globe or slider placed on a concave curved surface. During lateral motion, the building is slightly elevated as the slider moves along the concave surface, utilizing gravity as a restoring force and friction to dampen energy. FPS is highly effective across various climates and offers superior self-centering capabilities.



**Figure.4** Flat Friction pendulum section cut

## 1.7 Objectives

Conventional fixed-base buildings in high seismic zones rely heavily on the inelastic deformation of structural members, which inevitably leads to damage. While base isolation offers a solution, there is a need to clarify the comparative effectiveness of different systems specifically Rubber Base Isolation and Friction Pendulum Systems for mid-rise buildings (G+10) under varied analytical methods and real-world earthquake records.

The primary objectives of this study are:

- To perform Equivalent Static Analysis (ESM) in SAP2000 and evaluate the seismic response of fixed and isolated models.
- To conduct Response Spectrum Analysis (RSA) per IS 1893 (Part 1) standards.
- To execute Time History Analysis (THA) using real accelerograms from the El Centro (1940) and Bhuj (2001) earthquakes.
- To quantitatively compare parameters such as base shear, storey displacement, storey drift, time period, and natural frequency across all systems.
- To determine which isolation system provides superior seismic protection for a G+10 reinforced concrete framed structure

## 2. METHODOLOGY

### 2.1 General

The seismic evaluation of structures with inadequate earthquake resistance is essential for ensuring safety in high-risk zones. For this study, a G+10 reinforced concrete (RC) building located in Seismic Zone V is modelled and

analysed using SAP2000 structural analysis software. The methodology focuses on comparing three distinct structural configurations: a conventional Fixed Base, a Rubber Base Isolation system, and a Friction Pendulum System (FPS). To ensure a robust assessment, the building is subjected to Equivalent Static Method (ESM), Response Spectrum Analysis (RSA), and Time History Analysis (THA).

### 2.2 Structural Modeling and Specifications

For this study, a G+10 reinforced concrete (RC) framed building located in Seismic Zone V is modelled and analysed using SAP2000. The building has a total height of 33 metres, comprising 11 storeys with a uniform height of 3 metres each. The architectural layout is rectangular, featuring 5 bays along the X-axis and 4 bays along the Y-axis.

The material and geometric properties are defined as follows:

- Structural Members:** Columns are sized at 0.35 m × 0.35 m, while beams are 0.25 m × 0.35 m. The slabs are modelled with a thickness of 0.125 m.
- Material Grades:** M30 grade concrete is used for all primary members, and Fe415 HYSD reinforcement steel is assigned for design purposes.
- Site Conditions:** The building is situated on Medium (Type II) soil as per IS 1893:2016, with an importance factor of 1.0 and a response reduction factor of 3.

### 2.3 Load Patterns and Design Criteria

The structural integrity is evaluated against vertical and lateral loads in accordance with Indian Standard (IS) codes.

- Dead Loads (DL):** Calculated based on material densities, including 25 kN/m<sup>3</sup> for reinforced concrete. This includes the self-weight of beams, columns, and slabs.
- Imposed Loads (LL):** A live load of 2.5 kN/m<sup>2</sup> is applied to the floor slabs per IS 875 (Part 2).
- Wind Loads (WL):** Assessed according to IS 875:1987 (Part 3) using a pressure coefficient of 0.86.
- Earthquake Loads (EL):** Applied based on IS 1893:2016 parameters for Zone V.

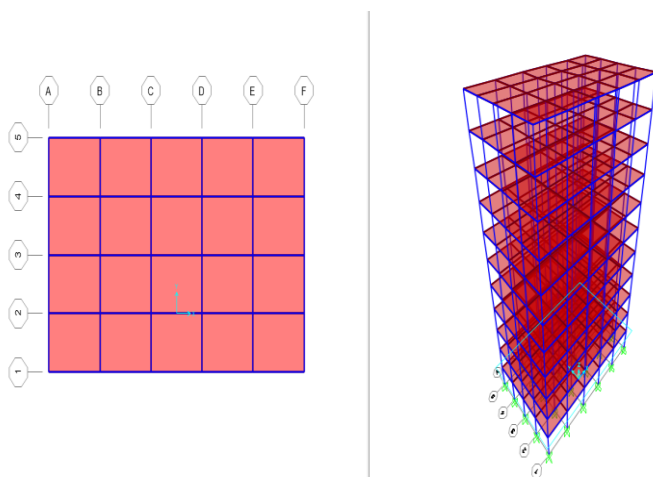
### 2.4 Modeling of Seismic Isolation Systems

The base isolation systems are modelled in SAP2000 using link/support elements to simulate non-linear behaviour.

- Rubber Base Isolation:** These isolators are modelled with a high vertical stiffness ( $U1 = 15,000,000$ ) to support gravity loads. The

horizontal directions (U2 and U3) are defined with non-linear properties, including an effective stiffness of 800, a yield strength of 80, and a post-yield stiffness ratio of 0.1.

- Friction Pendulum System (FPS): This kinematic system is defined by its sliding mechanics. The model incorporates a radius of sliding of 2.23 metres, a slow friction coefficient of 0.03, and a fast friction coefficient of 0.05. Similar to the rubber bearings, a high axial stiffness is maintained for U1.



**Figure 5** Building model after assigning beams, columns and slabs fixed rubber base and friction pendulum model

## 2.5 ANALYTIAL METHODS

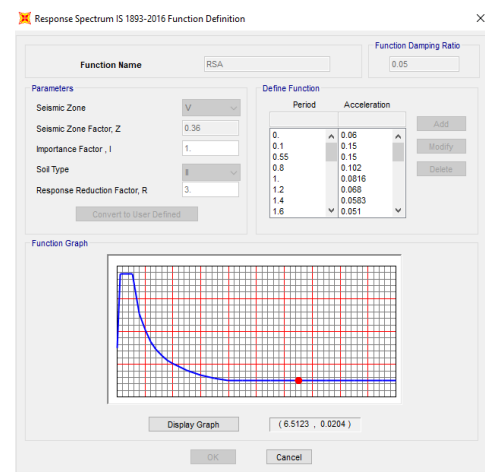
Three distinct analytical methods are employed to ensure a comprehensive evaluation of the building’s seismic response:

- Equivalent Static Method (ESM): A simplified linear static analysis where the total seismic base shear is calculated and distributed across the height of the building based on the fundamental mode of vibration.
- Response Spectrum Analysis (RSA): A modal superposition method that uses the design spectra for Type II soil from IS 1893:2016. This method accounts for the contribution of multiple vibration modes to capture at least 90% of the participating mass.
- Time History Analysis (THA): A dynamic, step-by-step analysis using real earthquake accelerograms to evaluate the non-linear response over time. This study utilizes two strong ground motion records: the El Centro (1940) earthquake for high-frequency characteristics and the Bhuj (2001) earthquake for long-duration, high-amplitude effects.

## 2.6 SAP2000 Model Processing

The step-by-step modelling process in SAP2000 follows this protocol:

- Unit Initialization: Setting the workspace to kN-m.
- Grid Generation: Establishing the 3D frame dimensions and bay spacing.
- Property Definition: Defining M30 concrete and Fe415 steel properties, followed by frame sections for beams/columns and area sections for slabs.
- Load Assignment: Distributing dead, live, and environmental loads according to the calculated attrens.
- Support Assignment: Applying fixed restraints for the baseline model and link/support properties for the isolated configurations.
- Function Setup: Defining the Response Spectrum and Time History functions using the specified earthquake records.



**Figure 6** Defining response spectrum fixed rubber base and friction pendulum model

- Execution: Running the analysis to extract data for base shear, displacement, drift, and time periods

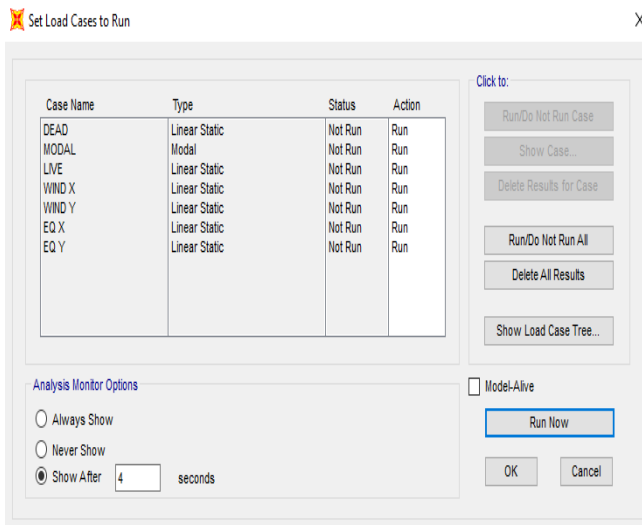


Figure 7 Running the analysis in fixed rubber base and friction pendulum model

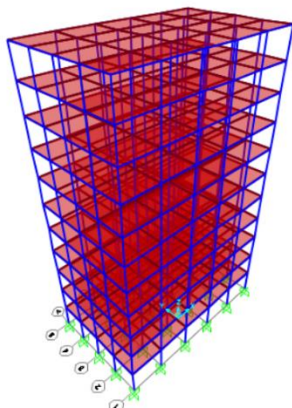


Figure 8 Building Model with rubber isolator at supports

### 3. RESULTS AND DISCUSSION

The analytical results obtained from SAP2000 for the G+10 building across the fixed-base and isolated models indicate that the decoupling provided by base isolation significantly mitigates seismic demand.

#### 3.1 Equivalent Static Method Results

The linear static analysis serves as a baseline for determining base shear and lateral force distribution across the superstructure. The fixed-base model recorded a base shear of 5157.44 kN, while the Rubber Base Isolation reduced this to 2261.61 kN (56.1% reduction) and the Friction Pendulum System (FPS) to 2297.94 kN (55.5% reduction).

Table -1: Comparison of Base Shear

S. No	Load Case	Fixed Base	Rubber Base Isolation	Friction pendulum
1	EQ	5157.441	2261.61	2297.943

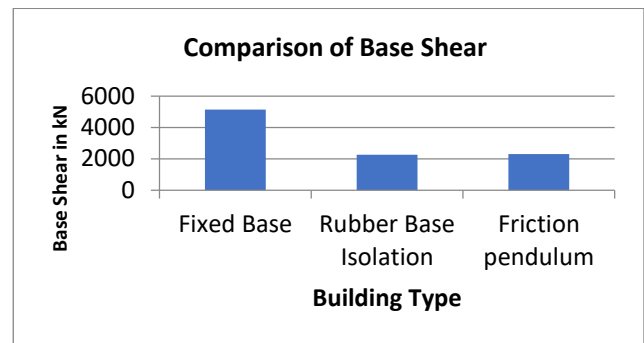


Chart -1: Comparison of Base Shear

The elongation of the fundamental time period is the primary mechanism for this force reduction. The time period increased from 1.743 seconds in the fixed-base model to 1.912 seconds for the Rubber model and 2.092 seconds for the FPS model. This shift moves the structure out of the high-acceleration region (0.1–0.5 seconds) typical of seismic records.

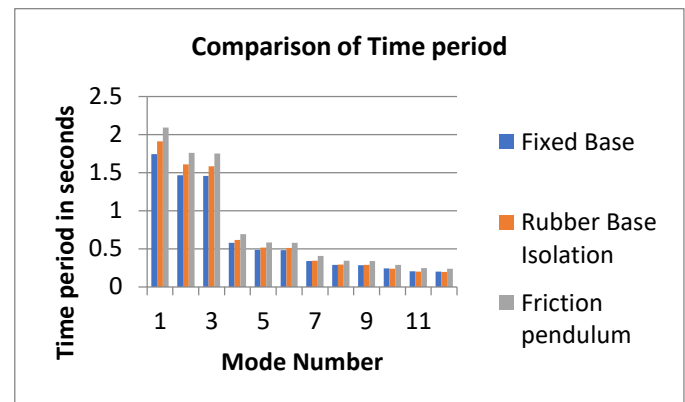


Chart -2: Comparison of Time Period

In terms of superstructure deformation, the roof displacement for the fixed-base model reached 0.2478 m. The isolated models showed lower superstructure displacement, with the Rubber model at 0.1379 m and the FPS at 0.1763 m, as the isolation layer concentrates the deformation at the base level.

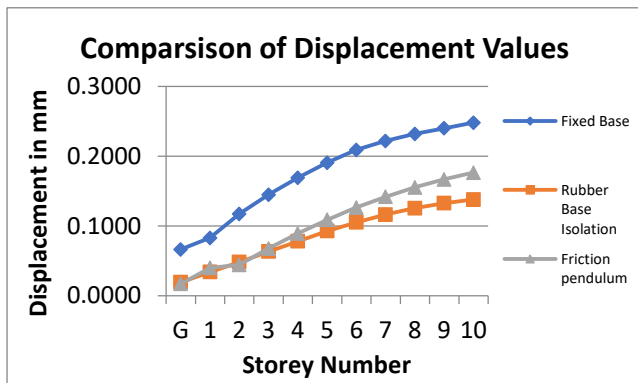


Chart -3: Comparison of Story displacement

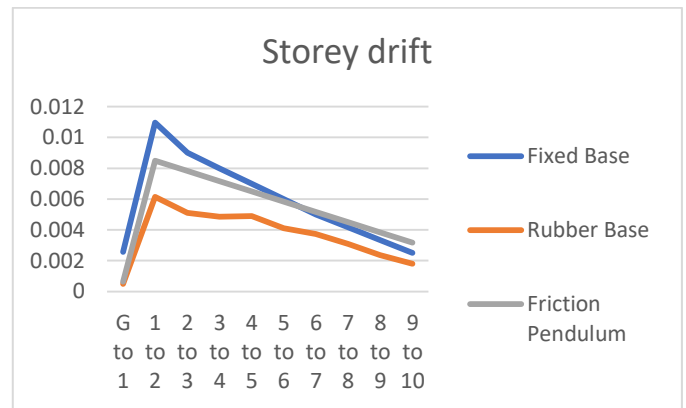


Chart -5: Comparison of Storey drift

### 3.2 Response Spectrum Analysis Results

Dynamic Response Spectrum Analysis confirms that base isolation creates a more uniform shear force distribution. The design base shear for the fixed model was 4790.6 kN, while the Rubber system achieved a reduction of 54.9% (2161.4 kN) and the FPS provided a 50% reduction (2395.6 kN).

Table -1: Comparison of Base Shear

S. No	Load Case	Fixed Base	Rubber Base Isolation	Friction pendulum
1	RSA	4790.6	2161.4	2395.6

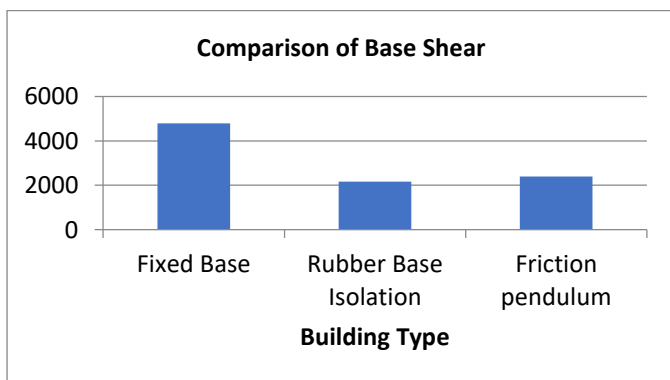


Chart -4: Comparison of Base Shear

Story drift at the lower levels showed the most dramatic improvement. Under RSA, the drift at the lower storeys dropped from 0.00773 in the fixed-base configuration to 0.00189 in the FPS model. This reduction ensures that non-structural components like windows and partitions are protected during seismic events.

### 3.3 Time History Analysis Results

The dynamic step-by-step analysis under real accelerograms validates the performance of the isolators under varying frequency contents. Under the high-frequency El Centro record, the fixed-base shear was 6258.74 kN, which the FPS reduced by 30% to 4381.12 kN. The FPS limited the top displacement to 0.085 m, proving its effectiveness in short-period ground motions.

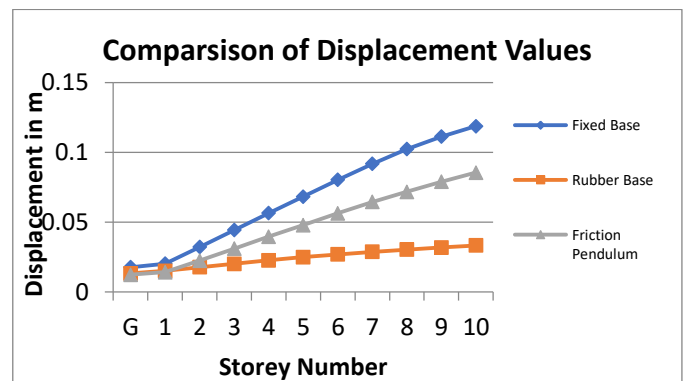


Chart -6: Comparison of Displacement Values

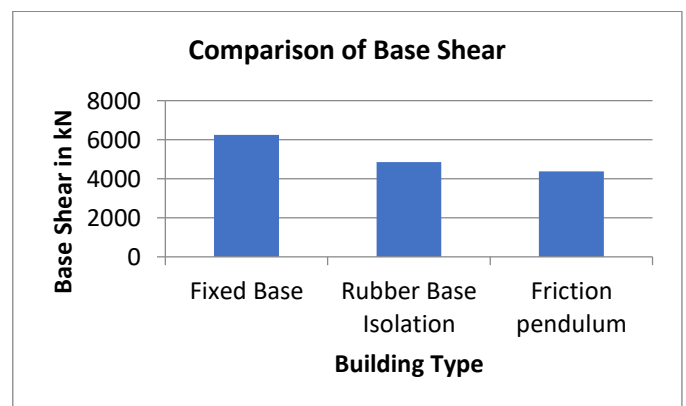


Chart -7: Comparison of Base Shear

For the long-duration, high-amplitude Bhuj earthquake, the FPS still reduced displacement from 0.304 m (fixed base) to 0.210 m. While the displacement demand on the isolators increased during this severe event, the base shear was still mitigated from 6936.13 kN in the fixed model to 5548.90 kN in the FPS model.

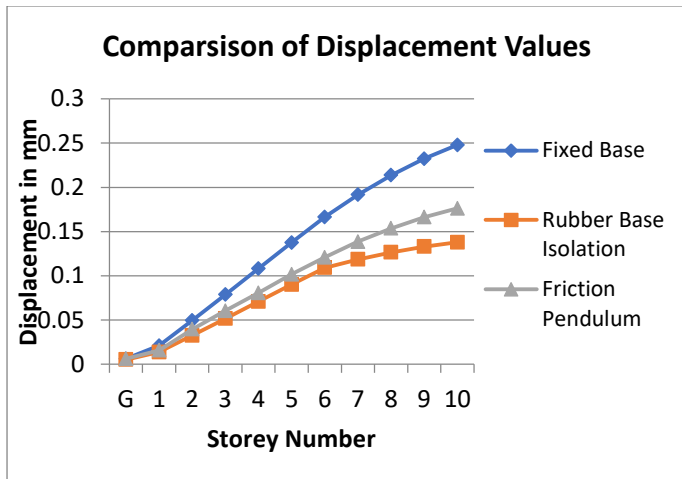


Chart -8: Comparison of Displacement Values

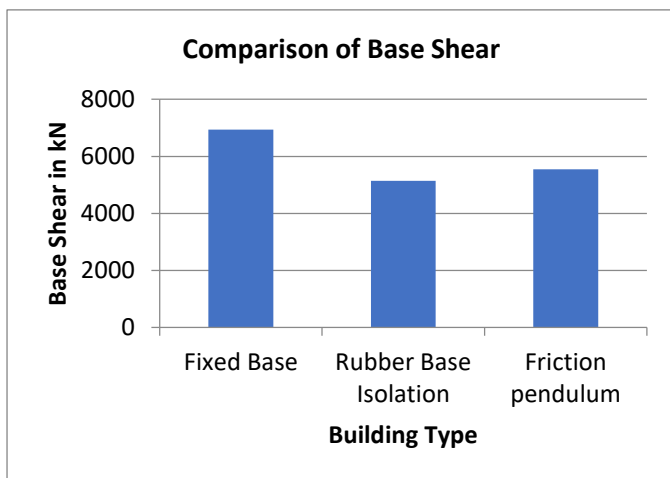


Chart -9: Comparison of Base Shear

### 3.4 Force and Frequency Comparison

The natural frequency of the building decreased across all modes, confirming that the structure became more flexible. The Mode 1 frequency dropped from 0.573 Hz (fixed) to 0.458 Hz (FPS). This corresponds with the reduction in lateral load at the roof level, which decreased by over 50%, dropping from 1019.2 kN in the fixed model to 447.1 kN in the Rubber isolated model.

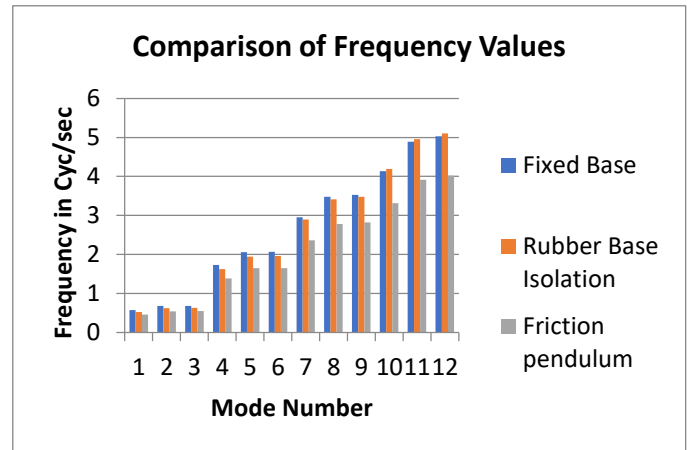


Chart -10: Comparison of Frequency Values

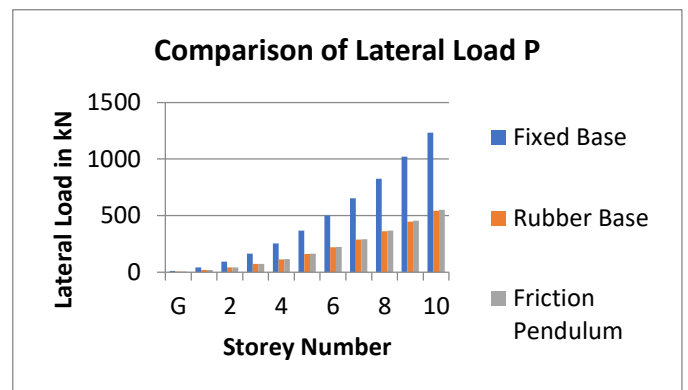


Chart -11: Comparison of Base Shear

## 4. CONCLUSIONS

This study concludes that base isolation is a highly effective strategy for enhancing the seismic performance of G+10 reinforced concrete buildings. By decoupling the superstructure from ground motions, both Rubber Base and Friction Pendulum systems substantially reduce the forces transmitted to the building.

The key findings are summarized below:

1. Significant Force Reduction: Base shear was reduced by 30–50% across all analytical methods, as the isolation systems absorb seismic energy before it reaches the superstructure.
2. Drastic Drift Control: Story drift at lower levels dropped from 0.00773 to 0.00189 with the friction pendulum system, effectively protecting non-structural elements from damage.
3. Period Elongation: The fundamental time period increased from 1.74 seconds to 2.09 seconds, shifting the structure out of the high-acceleration range typical of earthquakes.
4. Superior Performance of FPS: The Friction Pendulum System (FPS) outperformed rubber bearings in every parameter, providing better

displacement control (26% reduction) and stable hysteretic damping.

5. Uniform Shear Distribution: Isolated models showed a more uniform shear force distribution, preventing the dangerous concentrations at lower stories seen in conventional fixed-base buildings.

Overall, base isolation is recommended as a reliable and efficient design strategy for mid-rise buildings in high seismic zones. While simplified methods (ESM and RSA) are suitable for preliminary design, Time History Analysis remains essential for final validation under real-world earthquake records

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