

The Performance Assessment of Lead Rubber Bearing-Isolated High-Rise Reinforced Concrete Buildings in Indian Seismic Zones

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Seismic isolation can modify the dynamic response of reinforced-concrete (RC) buildings by partially decoupling the superstructure from ground motion. However, comparative evidence for tall RC buildings integrating direct structural response measures with probabilistic fragility assessment across all Indian seismic zones remains limited. This study investigates a 20-storey RC Special Moment Resisting Frame (SMRF) in two configurations: a conventional fixed-base model and an otherwise identical model supported on Lead Rubber Bearings (LRBs). The models were developed in ETABS in accordance with IS 1893 (Part 1):2016, IS 456:2000, and IS 875. Modal, response-spectrum, and dynamic analyses were combined with a fragility framework to evaluate changes in fundamental period, base shear, roof displacement, inter-storey drift, and damage-state exceedance. The LRB configuration substantially reduced superstructure demands. Base shear decreased by about 66.7%, while roof displacement decreased by about 37–43% across the investigated seismic zones. Maximum inter-storey drift decreased by more than 92%. The first-mode period increased from 2.681 s for the fixed-base model to 3.421 s for the isolated model, representing a 27.6% increase. Fragility analysis indicated a shift toward higher PGA levels for complete damage, with median PGA increasing from approximately 0.80 g to 1.60 g. Overall, the results demonstrate the potential of LRB isolation to enhance seismic performance while acknowledging numerical and modelling limitations.

Keywords: Lead Rubber Bearing; Base Isolation; response-history analysis; Seismic Fragility; Seismic Performance.

1. Introduction

Earthquake loading can impose substantial inertia on a fixed-base reinforced-concrete structure because ground movement is transmitted directly into the building mass and lateral-force-resisting system. The resulting demand is reflected in quantities such as base shear, floor displacement, and inter-story deformation, with consequences for both structural and non-structural components (Kelly, 1997; Naeim & Kelly, 1999; Skinner et al., 1993). The problem is particularly relevant for tall buildings, where dynamic characteristics and higher-mode contributions can influence the distribution of earthquake demand. Base isolation addresses this problem by inserting a mechanically characterized interface between the foundation and the superstructure. The interface provides lateral flexibility and energy dissipation, altering the building's effective dynamic properties. LRBs are attractive for this purpose because laminated rubber and steel layers provide vertical load support and horizontal flexibility, while the lead core contributes hysteretic energy dissipation (Kelly, 1997; Skinner et al., 1993; Naeim & Kelly, 1999). The resulting increase in effective period can reduce the acceleration demand transmitted to the superstructure when the isolation period is appropriately selected. The performance of an LRB system depends on the bearing properties, as well as the characteristics of the superstructure and excitation. Previous experimental and analytical investigations have shown that effective stiffness, post-yield stiffness, characteristic strength, damping, and displacement capacity influence the response of isolated structures (Constantinou et al., 2007; Fenz & Constantinou, 2008; Ryan et al., 2010). Consequently, the benefit of isolation should not be expressed solely as a reduction in a single response quantity; displacement demand at the isolation level and the isolator's compatibility with the structural system must also be assessed.

Response quantities such as base shear and roof displacement describe structural demand, but they do not by themselves express the likelihood of reaching a specified damage state. A fragility formulation complements these deterministic

measures by relating an engineering demand or damage state to an intensity measure such as PGA. Such curves provide a probabilistic means of comparing the fixed-base and isolated configurations and of quantifying how the estimated damage-state capacity changes when the isolation system is introduced. The present comparison follows the four-zone framework adopted in IS 1893 (Part 1):2016: Zones II, III, IV and V. The zone factor increases from 0.10 in Zone II to 0.36 in Zone V, representing progressively greater design seismic demand within the code framework. The zone-wise comparison helps assess whether the relative benefit of isolation varies with increasing seismic demand. Particular attention is given to Zones IV and V because they represent the higher-hazard categories in the adopted zonation scheme.

Existing studies have established the usefulness of isolation in reducing earthquake response, but the published evidence is not uniform across building height, structural configuration, isolation parameters, ground-motion characteristics, and performance measures. Many investigations focus on a single hazard setting or a single class of structure, whereas fewer studies combine a common high-rise RC model, the four Indian seismic zones, and a probabilistic damage assessment. This study addresses that specific comparison rather than generalizing the results to all isolated buildings. The investigation considers a 20-storey RC SMRF in fixed-base and LRB-isolated forms. The models use the same geometry, material properties, mass distribution, and gravity loading, so the main modeling difference is the presence of the isolation system. ETABS is used for modal and response-spectrum analyses and for the dynamic simulations. Structural response is evaluated through period, base shear, roof displacement and inter-storey drift, while a lognormal fragility formulation is used to compare the adopted damage states. The principal contribution is a consistent zone-wise comparison of the two configurations using a common structural model and a combination of deterministic and probabilistic indicators. In addition to reporting changes in superstructure response, the study explicitly considers the

isolation layer's displacement demand and distinguishes code-zone screening from the formal fragility analysis based on the selected ground-motion set.

1.1 Principle of Base Isolation

In a fixed-base model, the foundation provides a direct kinematic connection between the ground and the structural system. Earthquake-induced inertia therefore develops throughout the building's height. Base isolation changes this interaction by introducing a flexible interface that concentrates a larger share of the relative horizontal deformation at the isolation level. Researchers have developed this concept extensively in seismic-isolation research (Skinner, Robinson and McVerry, 1993; Kelly, 1997; Naeim & Kelly, 1999).

An LRB consists of alternating elastomeric and steel layers surrounding a lead core. Its vertical stiffness is selected to carry gravity loads, while its lateral characteristics are governed by the rubber layers and the hysteretic behaviour of the lead core. In a structural model, these properties are represented through an appropriate nonlinear link formulation. The intended effect is to lengthen the effective structural period and dissipate earthquake energy before the

superstructure undergoes large deformation (Kelly, 1997; Constantinou et al., 2007).

Two mechanisms are therefore central to LRB action: lateral flexibility and hysteretic energy dissipation. During cyclic loading, the rubber layers accommodate horizontal deformation, and the lead core yields, dissipating energy. Earlier studies have reported reductions in quantities such as base shear, acceleration, and drift when isolation is properly designed (Fenz & Constantinou, 2008; Jangid, 2007; Providakis, 2008). The magnitude of the benefit nevertheless depends on the isolator properties, building period, mass, site conditions, and earthquake-record characteristics. Figure 1 illustrates the fundamental difference between fixed-base and base-isolated configurations. In the fixed-base configuration, lateral deformation is distributed through the superstructure, whereas the isolated model allows a large component of relative movement to occur across the bearings. This generally reduces inter-storey deformation above the isolation plane, but it does not eliminate displacement demand; instead, the bearing displacement becomes a critical design quantity. Adequate clearance, stable bearing behaviour and sufficient displacement capacity are therefore necessary for an isolated building.

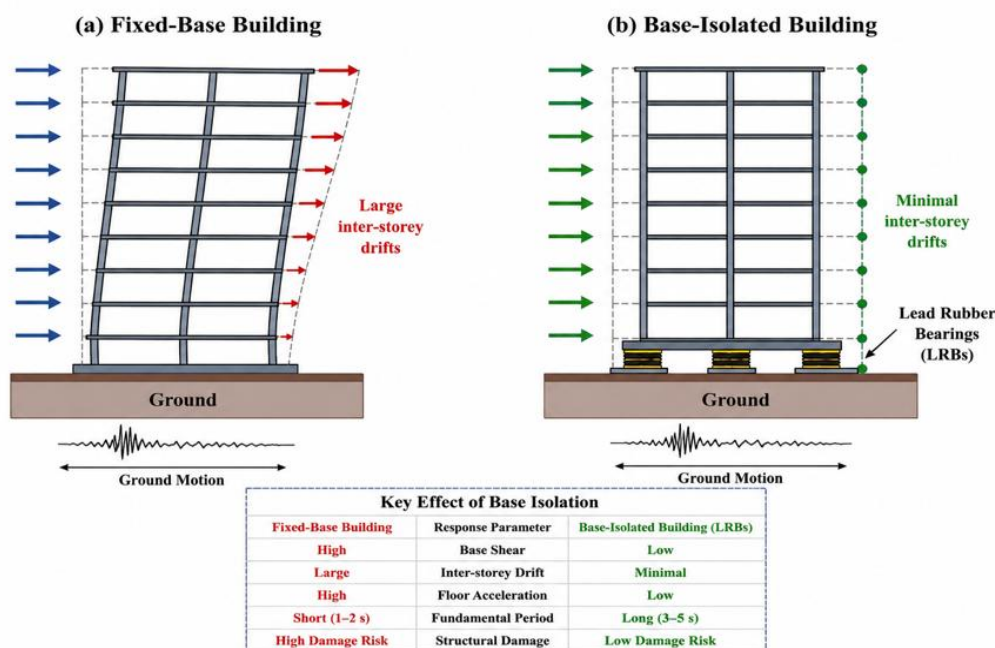


Figure 1 Schematic illustration of the seismic behavior of fixed-base and LRB-isolated reinforced concrete buildings under earthquake loading.

The effectiveness of isolation depends on the relationship between the building's dynamic properties and the isolation system's characteristics. Earlier investigations have identified the importance of mass distribution, stiffness and damping, isolator displacement capacity, ground-motion characteristics and possible impact or uplift effects (Nagarajaiah & Sun, 2001; Mazza & Vulcano, 2012; Cardone et al., 2019). These considerations are especially relevant when an LRB system is introduced into a tall structure.

For high-rise RC buildings, the isolation period may interact with higher structural modes and long-period components of earthquake motion. A credible assessment must therefore examine both the superstructure's response and the isolation layer's deformation. This study follows this approach by reporting conventional structural response quantities along with the displacement demand of the LRBs.

1.2 Seismic Zonation of India According to IS 1893 (Part 1):2016

IS 1893 (Part 1):2016 governs seismic design provisions in India and classifies the country into four seismic zones based on expected earthquake intensity and seismic hazard levels. According to the Bureau of Indian Standards (BIS, 2016), each seismic zone is characterized by a seismic zone

factor (Z), representing the effective peak ground acceleration corresponding to the Maximum Considered Earthquake.

The prescribed seismic zone factors are:

- Zone II: $Z = 0.10$ (Low Seismic Risk)
- Zone III: $Z = 0.16$ (Moderate Seismic Risk)
- Zone IV: $Z = 0.24$ (Severe Seismic Risk)
- Zone V: $Z = 0.36$ (Very Severe Seismic Risk)

A higher seismic zone factor corresponds to a higher level of seismic hazard and greater design seismic forces. Chopra (2020), Jain (2016), and Agarwal and Shrikhande (2006) emphasized that structures in Zones IV and V require enhanced seismic-resistant design measures due to the higher likelihood of severe ground motion from earthquakes. Zone V represents the highest seismic hazard category and includes regions such as the northeastern states, parts of Uttarakhand, Jammu and Kashmir, Himachal Pradesh, the Rann of Kachchh, and the Andaman and Nicobar Islands. Conversely, Zone II comprises areas of relatively low seismicity. Murty (2012) highlighted that despite lower hazard levels in Zones II and III, proper seismic design remains essential because moderate earthquakes can still cause substantial structural damage when buildings are inadequately designed

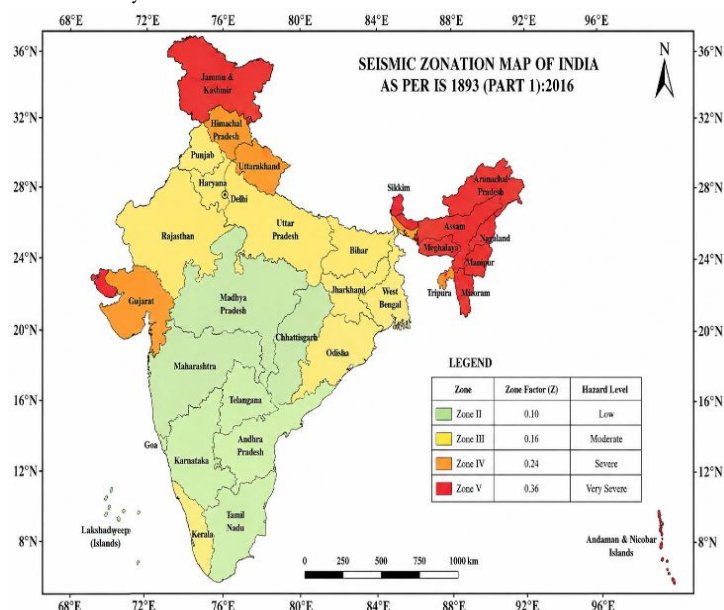


Figure 2 Seismic zonation map of India according to IS 1893 (Part 1):2016, showing the classification of regions into Zones II, III, IV, and V based on seismic hazard levels.

Figure 2 presents India's seismic zonation map according to IS 1893 (Part 1):2016. The map provides the basis for evaluating the influence of increasing seismic hazard intensity on structural performance. In the present study, seismic analyses are performed for all four seismic zones to investigate the effectiveness of Lead Rubber Bearing isolation systems under varying earthquake intensities and to establish their suitability for performance-based seismic design applications.

2. Literature Review

Recent research on seismic isolation has increasingly focused on the effectiveness, reliability, and performance of Lead Rubber Bearing systems for reducing earthquake-induced demands in buildings and other critical structures. Yurdakul and Yıldız (2020) investigated the design of LRB isolation systems for reinforced concrete buildings and demonstrated that appropriate selection of isolator properties can substantially improve seismic response while satisfying design requirements. Their work highlighted the importance of accurately determining the effective stiffness, damping, and displacement characteristics of LRBs for achieving the desired isolation performance. Similarly, Rong et al. (2020) examined the optimum parameters of LRB-supported buildings under near-fault ground motions and showed that isolator properties strongly influence both structural acceleration and bearing displacement. These findings established the importance of selecting isolation parameters according to the characteristics of the expected ground motion.

Suzzan and Tavio (2020) compared fixed-base, LRB-isolated, and friction-pendulum-isolated building configurations using ETABS. Their results showed that the LRB system substantially increased the structural period and reduced roof drift, improving structural performance compared with the fixed-base configuration. The study demonstrated the practical applicability of LRB isolation for buildings located in earthquake-prone regions.

Fakih et al. (2021) evaluated the application of LRB isolators to a high-rise reinforced concrete building and compared the isolated structure with a conventional fixed-base structural system. The isolated configuration exhibited a significant increase in fundamental period together with reductions in base shear, roof acceleration, and inter-storey drift. The study particularly demonstrated the potential of LRB systems for high-rise RC buildings, although the analysis was based on a limited set of earthquake records.

Phadtare and Patil (2021) extended the assessment of LRB systems by considering an asymmetric reinforced concrete building and combining deterministic and probabilistic approaches. Fragility curves were developed using near-field and far-field earthquake records, with maximum inter-storey drift ratio adopted as the engineering demand parameter. The results indicated that base isolation improved seismic performance across different damage states and demonstrated the usefulness of fragility-based assessment for quantifying the reliability of isolated RC buildings.

Khoshnoudian et al. (2021) investigated the probabilistic damage behaviour of base-isolated reinforced concrete structures subjected to near-fault pulse-like bidirectional ground motions. The study considered LRB and friction-based isolation systems and used incremental dynamic assessment to investigate damage probabilities over different intensity levels. The findings emphasized that near-fault pulse characteristics can significantly affect the displacement demand of isolation systems and therefore should be explicitly considered when evaluating the seismic reliability of isolated structures.

Aghaeidoost and Billah (2022) examined the sensitivity of seismic fragility predictions of base-isolated bridges to different LRB modelling approaches. Their results demonstrated that the representation of the isolation device can influence the estimated seismic fragility and structural response. This study is particularly relevant to performance-based assessment because it highlights the need for appropriate representation of isolator properties when

developing fragility functions and estimating damage probabilities.

Deringöl and Güneyisi (2023) investigated the seismic performance of high-rise structures equipped with LRB isolation systems by varying the isolation period. The study showed that changes in the isolation period significantly influence structural response under earthquake excitation. The results confirmed that the appropriate selection of the isolation period is essential for achieving an effective balance among reductions in structural acceleration, drift, and isolation displacement, particularly for tall structures.

Haseli and Mozafarpour Taromi (2024) evaluated mid-rise reinforced concrete moment-resisting buildings equipped with LRBs using fragility curves. Eight- and twelve-story buildings with and without isolation were assessed, and inter-storey drift was used to establish different damage-state probabilities. Their results indicated that LRB systems increased the structural period, reduced inter-storey drift, and decreased the probability of earthquake-induced damage. The study also indicated that the benefits of isolation become particularly important as building height increases

Recent research has also addressed the behaviour of LRBs under severe deformation and complex loading conditions. Aghaeidoost and Billah (2024) developed an advanced rate-dependent analytical model for LRBs, recognizing that conventional simplified representations may not adequately capture the response of bearings under varying loading rates. Experimental investigations by other researchers have further demonstrated that LRBs can exhibit stiffness changes and degradation under large shear strains, emphasizing the importance of realistic isolator characterization in seismic assessment.

More recent studies have moved toward examining LRB performance under near-fault excitation and increased seismic demand. Haveri et al. (2026) investigated a multistorey reinforced concrete building designed in accordance with Indian standards and evaluated the effectiveness of LRB isolation under increased seismic demand

associated with higher seismic hazard conditions. The study is particularly relevant to the Indian context because the building was designed in accordance with IS 456:2000 and IS 1893:2016, providing a direct basis for assessing the applicability of LRB isolation in Indian seismic design practice. Kayı et al. (2026) further investigated how reinforced concrete superstructure characteristics influence the seismic response of an RC building retrofitted with LRBs. Their findings showed that changes in beam and column dimensions and other structural characteristics can significantly influence inter-storey drift demands, indicating that isolation effectiveness cannot be evaluated independently of the characteristics of the superstructure.

Overall, the literature from 2020–2026 demonstrates that LRB isolation can substantially improve seismic performance by reducing base shear, inter-storey drift, acceleration response, and earthquake-induced damage probability. Recent studies have also established that isolation effectiveness is influenced by building height, structural irregularity, isolation period, damping, ground-motion characteristics, near-fault effects, and the modelling assumptions adopted for the LRB system. Importantly, the literature has increasingly incorporated probabilistic and fragility-based approaches, moving beyond conventional response parameters to quantitatively evaluate damage-state exceedance and seismic reliability.

Despite these advances, a research gap remains in systematically evaluating high-rise reinforced concrete buildings equipped with LRB systems across the full range of Indian seismic hazard zones. In particular, few studies have simultaneously compared fixed-base and LRB-isolated high-rise RC buildings with common structural configurations and consistent performance indicators across Seismic Zones II, III, IV, and V of IS 1893 (Part 1):2016. Furthermore, the combined interpretation of conventional response parameters—such as base shear, roof displacement, inter-storey drift, fundamental period, and frequency—with probabilistic damage-state exceedance remains

comparatively limited for Indian high-rise buildings. Therefore, this study addresses this gap by comparatively evaluating fixed-base and LRB-isolated high-rise RC buildings under seismic conditions specified for India. The assessment

considers key structural response parameters and fragility-based damage probabilities to provide a comprehensive evaluation of the effectiveness of LRB isolation for earthquake-resistant high-rise construction.

3. Methodology

The methodology integrates advanced structural modelling and nonlinear dynamic analysis to comprehensively evaluate the seismic performance and effectiveness of Lead Rubber Bearing isolation systems.

Table 1 Structural Details of 20-Storey Building

Parameter	Value
Number of Stories	20
Plan Dimension	20m x 20m (5 bays x 5 bays @ 4m each)
Typical Floor Height	3.0 m
Total Building Height	60.0 m
Beam Size (All Floors)	300mm x 600mm
Column Size (GF to 10F)	600mm x 600mm
Column Size (11F to 20F)	500mm x 500mm
Slab Thickness	150 mm
Concrete Grade	M30 (fck = 30 MPa)
Steel Grade	Fe500 (fy = 500 MPa)
Dead Load (Floor Finish + SDL)	2.0 kN/m ²
Live Load (All Floors)	3.0 kN/m ²
Live Load (Roof)	1.5 kN/m ²
Wall Load (External Walls)	12 kN/m
Wall Load (Internal Walls)	8 kN/m
Soil Type (IS 1893:2016)	Type II – Medium Soil
Building Importance Factor (I)	1.0
Response Reduction Factor (R)	5.0 (SMRF)

A 20-storey reinforced concrete. Special Moment Resisting Frame (SMRF) building with a regular plan dimension of 20 m × 20 m (5 × 5 bays at 4 m spacing) and a total height of 60 m was modelled in ETABS in accordance with IS 456:2000, IS 875 (Parts 1–3), and IS 1893 (Part 1):2016. Table 1 summarizes the structural configuration and design parameters adopted in

the study. Two structural configurations were considered: (i) a conventional fixed-base building and (ii) a base-isolated building incorporating Lead Rubber Bearings at the foundation level. We assigned gravity, wind, and seismic loads corresponding to Indian Seismic Zones II, III, IV, and V to both models. Table 2 summarizes the seismic design parameters adopted according

to IS 1893 (Part 1):2016. The methodology was developed to evaluate the seismic response and effectiveness of Lead Rubber Bearing isolation for a high-rise reinforced concrete building under different levels of seismic hazard in India. The numerical investigation was conducted using ETABS, with the structural models developed in accordance with the relevant provisions of IS 456:2000, IS 875 (Parts 1–3), and IS 1893 (Part 1):2016. The assessment considers two structural configurations: (i) a conventional fixed-base RC building and (ii) an otherwise identical RC building isolated at the foundation level using Lead Rubber Bearings. The two configurations were subjected to identical gravity and seismic loading conditions to enable a consistent comparison of their seismic response.

3.1 Structural Model

A regular 20-storey RC Special Moment Resisting Frame (SMRF) building was selected for the

numerical investigation. The building has a square plan of 20 m $\times$ 20 m, with five bays in each principal direction and a uniform bay spacing of 4.0 m. Each storey has a height of 3.0 m, resulting in an overall structural height of 60 m above the foundation level. The regular configuration was selected to minimize the influence of plan and vertical irregularities and to evaluate the effect of the isolation system independently. The structural members were modelled using three-dimensional frame elements, while the floor slabs were represented using shell elements with appropriate diaphragm constraints. The floor system was assumed to act as a rigid diaphragm in its own plane. The columns were varied in size along the height to account for the higher gravity and lateral demands in the lower storeys. Table 1 summarizes the structural and material properties adopted in the numerical model, and Figure 3 presents the typical plan configuration.

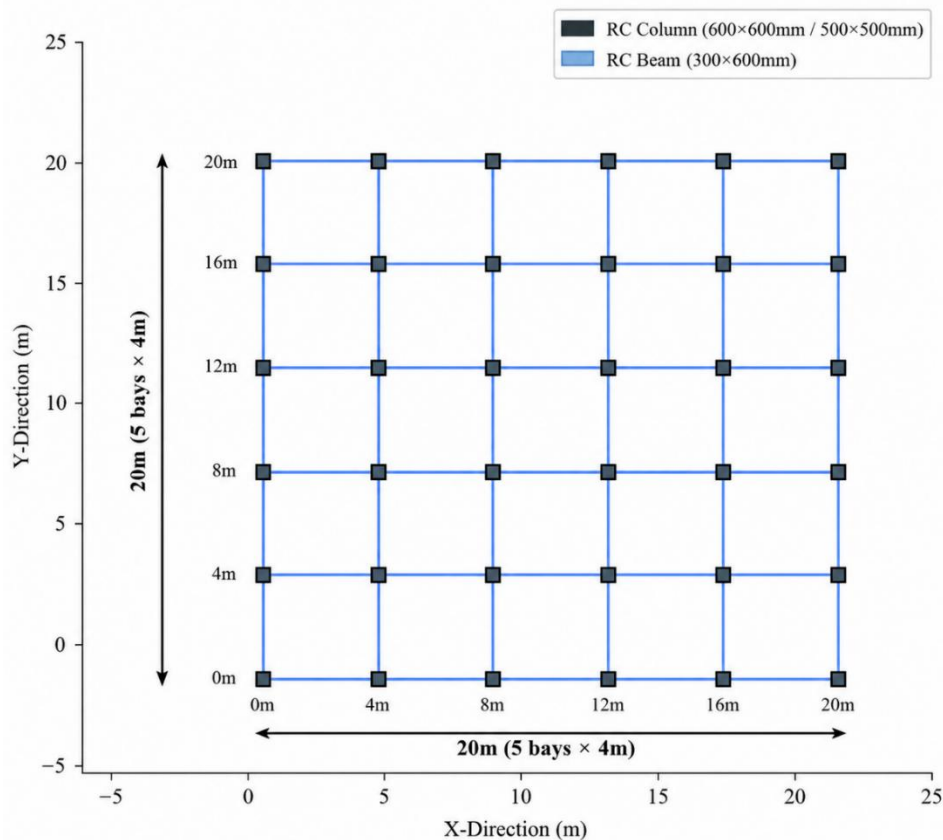


Figure 3 Structural Plan Layout of the 20-Storey Reinforced Concrete Building (20 m $\times$ 20 m, 5 $\times$ 5 Bays @ 4 m Spacing).

The dead loads include the self-weight of structural members, floor finishes, superimposed dead loads, and masonry wall loads, as applicable. The live loads were assigned in accordance with the occupancy assumptions and the relevant provisions of IS 875 (Part 2). Roof live load was assigned separately from the typical floor live load.

3.2 Fixed-Base and Base-Isolated Configurations

Two otherwise identical structural models were developed. In the first configuration, the columns were directly connected to the foundation supports, representing the conventional fixed-base condition. In the second configuration, Lead Rubber Bearings were introduced between the foundation and the superstructure. Thus, the isolation system was located at the base of the building to reduce horizontal seismic transmission from the ground to the superstructure. For a meaningful comparison, the geometry, member properties, material properties, mass distribution, gravity loads, and damping assumptions of the superstructure were held constant across both configurations. The principal difference between the two models was therefore the presence or absence of the LRB isolation system. The LRBs were represented using appropriate nonlinear link elements in ETABS. The isolator properties included the effective horizontal stiffness, characteristic strength, post-yield stiffness, equivalent viscous damping, and allowable displacement. The properties of the bearings were selected based on the required isolation period, supported vertical load, target damping, and maximum design displacement. The vertical stiffness of the bearings was also considered sufficiently large to maintain the superstructure's vertical stability while permitting the required horizontal isolation response.

3.3 Gravity and Environmental Loads

The structural models were subjected to dead load, imposed load, wind load, and earthquake

loading. Dead and imposed loads were defined in accordance with IS 875, while wind loading was evaluated in accordance with IS 875 (Part 3). The self-weight of structural members was automatically accounted for using the ETABS self-weight multiplier. The seismic mass was defined by considering the applicable permanent loads and the appropriate portion of imposed loads in accordance with IS 1893 (Part 1):2016. The same mass definition was maintained for both the fixed-base and isolated configurations to ensure consistency in the comparative assessment.

3.4 Seismic Hazard Consideration

The seismic response of the building was evaluated for Seismic Zones II, III, IV, and V specified in IS 1893 (Part 1):2016. For each seismic zone, the corresponding zone factor (Z) was adopted from the code. The remaining seismic parameters, including the importance factor, response reduction factor where applicable, and soil-dependent spectral characteristics, were selected in accordance with the code provisions. For the RC SMRF building, an importance factor of ($I = 1.0$) was adopted. The response reduction factor ($R = 5.0$) applies to the fixed-base, code-based design model when the RC frame meets the requirements for a Special Moment Resisting Frame. However, the use of ($R = 5.0$) should not be applied directly to nonlinear time-history or fragility analysis as a reduction of the actual earthquake record. For nonlinear dynamic and fragility analyses, the ground-motion records should be applied at their actual or appropriately scaled intensity levels, and the resulting structural response should be evaluated directly. The design response spectrum for each seismic zone was generated in accordance with IS 1893 (Part 1):2016, considering the adopted medium soil condition. The corresponding spectral acceleration was used for modal and response-spectrum analyses, whereas appropriately selected and scaled earthquake ground-motion records were used for dynamic response and fragility assessment.

Table 2 Seismic Design Parameters

Parameter	Adopted value
Seismic code	IS 1893 (Part 1):2016
Seismic zones considered	II, III, IV and V
Zone factor, Z	As specified for each seismic zone
Soil condition	Type II – Medium Soil
Importance factor, I	1.0
Structural system	RC SMRF
Response reduction factor, R	5.0 for code-based SMRF design
Damping ratio – fixed-base superstructure	As specified/adopted for the structural model
Isolation damping	Based on LRB properties
Seismic mass	Dead load + applicable imposed-load fraction
Analysis software	ETABS
Analysis type	Modal, response-spectrum and dynamic/fragility assessment
Seismic input	Code spectrum and selected earthquake ground motions

3.5 Dynamic Analysis and Performance Assessment

The modal properties of both structural configurations were first evaluated to determine the fundamental period, mode shapes, and participating modal mass. The fixed-base and isolated models were subsequently subjected to the same seismic input to quantify the influence of the LRB system. The principal response parameters considered in the comparison were:

1. Fundamental Period and Modal Characteristics;
2. Base Shear;
3. Roof Displacement;
4. Maximum Inter-Storey Drift Ratio;
5. Storey Displacement Profile;
6. Floor Acceleration, Where Applicable;
7. Isolator Displacement and Deformation Demand; And
8. Damage-State Exceedance Probability for Fragility Assessment.

For the isolated structure, particular attention was given to the maximum lateral displacement of the isolation system because excessive bearing displacement may govern the design of the isolation gap and other displacement-dependent components. The responses of the fixed-base and LRB-isolated buildings were compared separately for Seismic Zones II, III, IV, and V. This approach enables the quantification of the influence of increasing seismic hazard on both conventional and isolated structural systems.

3.6 Fragility Assessment

For probabilistic seismic assessment, the structural response obtained from the selected earthquake records was related to appropriate engineering demand parameters, particularly maximum inter-storey drift ratio. Damage-state thresholds were defined to represent increasing levels of structural damage. Fragility functions were then developed by estimating the probability that a specified damage state would be exceeded at a given level of seismic intensity. The comparison between fixed-base and LRB-

isolated buildings was therefore performed not only using deterministic response parameters such as base shear and displacement but also using the probability of exceeding specified damage states. This provides a more comprehensive assessment of the seismic effectiveness and reliability of LRB isolation as earthquake intensity increases. Overall, the methodology provides a consistent framework for comparing fixed-base and LRB-isolated high-rise RC buildings under the seismic hazard levels specified by IS 1893 (Part 1):2016. The approach combines code-based structural modelling, modal and response-spectrum evaluation, dynamic seismic assessment, and fragility-based performance evaluation to quantify the benefits and limitations of LRB isolation for high-rise RC construction in India.

3.7 Modelling In ETABS

The structural modelling and analysis were carried out using the software ETABS, which is widely used for the analysis and design of building structures under gravity, wind, and seismic loading conditions. The modelling procedure adopted in this study is summarized as follows.

Step 1: Grid Definition

A regular plan configuration consisting of five bays of 4 m spacing in both the X- and Y-directions was established. The building comprised 20 storeys, each having a uniform storey height of 3 m. The grid system and storey data served as the reference framework for the placement of all structural members.

Step 2: Structural Member Definition

Reinforced concrete beams measuring 300 mm × 600 mm were provided along all grid lines at each floor level. Columns measuring 600 mm × 600 mm were used from the ground floor to the 10th floor, while columns measuring 500 mm × 500 mm were used from the 11th to the 20th floor. These dimensions were selected based on preliminary design calculations and typical high-rise RC construction practices. A 150 mm thick slab was modelled at each floor level and assigned as a rigid diaphragm.

Step 3: Material and Section Assignment

The software defined material properties for M30-grade concrete and Fe500-grade reinforcing steel. The modulus of elasticity of concrete was calculated in accordance with IS 456:2000 using: $E_c = 5000\sqrt{f_{ck}}$. The calculated material properties and section dimensions were assigned to all structural elements. ETABS automatically evaluated the stiffness and mass characteristics of the structural system.

Step 4: Load Application

The gravity loads were assigned in accordance with IS 875 (Part 1 and Part 2). ETABS automatically calculated the self-weight of all structural components and included it as dead load (DL). An additional superimposed dead load of 2.0 kN/m² was applied at all floor levels to account for floor finishes and non-structural permanent loads. A live load (LL) of 3.0 kN/m² was assigned to all typical floors, while a reduced live load of 1.5 kN/m² was considered for the roof level, as prescribed by IS 875 (Part 2):1987. Masonry wall loads were modelled as uniformly distributed line loads acting on both exterior and interior beams based on the wall dimensions and material density. Seismic loading was defined in accordance with IS 1893 (Part 1):2016. Separate seismic load cases were generated for each seismic zone considered in the study by incorporating the corresponding zone factor (Z). The importance factor was taken as $I = 1.0$, while a response reduction factor of $R = 5.0$ was adopted for the reinforced concrete Special Moment Resisting Frame (SMRF). The design response spectrum for medium soil conditions (Type II soil) was used in the dynamic analysis. Earthquake effects were considered independently along the principal X and Y directions of the structure. Wind loads were assigned in accordance with IS 875 (Part 3):2015. A basic wind speed of 50 m/s was considered, representative of the selected study region. The wind load calculations incorporated Terrain Category 3 and the relevant pressure coefficients recommended by the code. Wind actions were applied separately in the positive and negative directions of both principal axes. The structural

performance was evaluated using the load combinations specified in IS 1893 (Part 1):2016 and IS 456:2000. The following critical load combinations were considered:

- 1.5(DL + LL)
- 1.2(DL + LL ± EQX)
- 1.2(DL + LL ± EQY)
- 1.5(DL ± EQX)
- 1.5(DL ± EQY)
- 0.9DL ± 1.5EQX
- 0.9DL ± 1.5EQY
- 1.2(DL + LL ± WX)
- 1.2(DL + LL ± WY)
- 1.5(DL ± WX)
- 1.5(DL ± WY)
- 0.9DL ± 1.5WX
- 0.9DL ± 1.5WY

where DL denotes dead load, LL denotes live load, EQX and EQY represent earthquake loads in the X and Y directions, respectively, and WX and WY represent wind loads in the corresponding directions. These load combinations were employed to evaluate the structural response in terms of base shear, storey displacement, storey drift, and overall seismic performance.

Step 5: Seismic Analysis Setup

For the Equivalent Static Method, the seismic weight was calculated using the mass source definition comprising dead load and 50% of the imposed load, as specified in IS 1893:2016. The design horizontal seismic coefficient was determined using:

$$A_h = \left(\frac{Z}{2}\right) \left(\frac{I}{R}\right) \left(\frac{S_a}{g}\right) \quad (1)$$

The computed base shear was distributed along the building height using the codal vertical distribution procedure.

Table 3 Seismic Parameters as per IS 1893:2016

Parameter	ZONE II	ZONE III	ZONE IV	ZONE V
Zone Factor (Z)	0.10	0.16	0.24	0.36
Importance Factor (I)	1.0	1.0	1.0	1.0
Response Reduction Factor (R)	5.0	5.0	5.0	5.0
Soil Type	Type II	Type II	Type II	Type II
Damping	5%	5%	5%	5%

For Response Spectrum Analysis (RSA), ETABS defined the design response spectrum for medium soil conditions. Sufficient vibration modes were included to ensure at least 90% mass participation in both principal directions. Modal responses were combined using the Complete Quadratic Combination (CQC) method, which is

suitable for structures having closely spaced modes.

3.8 Base Isolation Modelling

For the base-isolated configuration, Lead Rubber Bearings (LRBs) were installed beneath all ground-level columns, resulting in a total of 36 isolation bearings for the 6 × 6 column grid.

Table 4 LRB Properties Used in ETABS Model

Property	Value
Outer Diameter of Bearing	600 mm
Lead Core Diameter	100 mm
Total Bearing Height	300 mm
Total Rubber Height	200 mm
Initial Stiffness (Ku)	12,500 kN/m
Post-Yield Stiffness (Kd)	1,250 kN/m
Yield Force (Fy)	125 kN
Design Displacement	200 mm
Effective Damping Ratio	15%
Target Isolation Period	3.0 to 3.5 seconds

In ETABS, the LRBs were modelled using nonlinear link elements exhibiting bilinear hysteretic behaviour. The primary parameters defining the bearing behaviour included the initial stiffness (Ku), post-yield stiffness (Kd), yield force (Fy), and effective damping ratio (ξ_{eff}). The LRB properties were selected based on the recommendations of IS 1893 (Part 1):2016 and the design procedures proposed by Naeim and Kelly (1999). The target isolation period was maintained between 3.0 and 3.5 seconds, corresponding to approximately 2.5–3.0 times the fundamental period of the fixed-base structure, thereby achieving significant period elongation and reduction in seismic demand.

3.9 Analysis Procedure

The fixed-base and base-isolated structural models were analysed following the procedure outlined below:

Verification of structural modelling through gravity load analysis.

Modal analysis to determine natural periods and mode shapes.

Equivalent Static Analysis for Seismic Zones II, III, IV, and V.

Response Spectrum Analysis for all seismic zones.

Wind load analysis in accordance with IS 875 (Part 3).

Extraction and comparison of key response parameters, including base shear, story displacement, story drift, story shear, and fundamental time period.

3.10 Seismic Fragility Assessment

A probabilistic seismic fragility assessment was conducted to quantify the likelihood of exceeding different structural damage states under varying earthquake intensities. Four performance levels were considered: Slight Damage (DS1), Moderate Damage (DS2), Extensive Damage (DS3), and Complete Damage (DS4). Incremental Dynamic Analysis (IDA) was performed using scaled ground motions representative of Indian Seismic Zones II, III, IV, and V. The resulting engineering demand parameters were used to establish fragility relationships through

Maximum Likelihood Estimation (MLE). The probability of exceeding a particular damage state was evaluated using the lognormal cumulative distribution function:

$$P[DS|IM] = \Phi \left(\frac{\ln(IM) - \ln(\theta)}{\beta} \right) \quad (1)$$

where:

$P[DS|IM]$ = probability of exceeding a damage state,

IM = intensity measure (Peak Ground Acceleration, PGA),

θ = median PGA capacity corresponding to the damage state,

β = logarithmic standard deviation (dispersion),

Φ = standard normal cumulative distribution function.

The median fragility parameters were calibrated from the nonlinear dynamic analysis results and are summarized in Table 4.

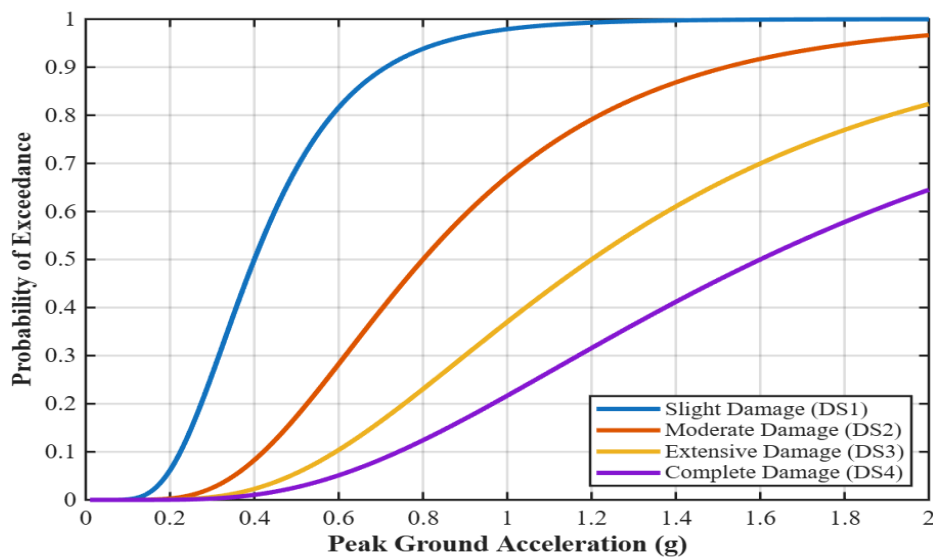


Figure 4 Fragility Curves for Fixed-Base Building

Table 4. Fragility Parameters for Fixed-Base Building

Damage State	Median PGA (g)	Dispersion (β)
Slight	0.18	0.40
Moderate	0.35	0.45
Extensive	0.55	0.50
Complete	0.80	0.55

Table 5. Fragility Parameters for LRB-Isolated Building

Damage State	Median PGA (g)	Dispersion (β)
Slight	0.40	0.45
Moderate	0.80	0.50

Extensive	1.20	0.55
Complete	1.60	0.60

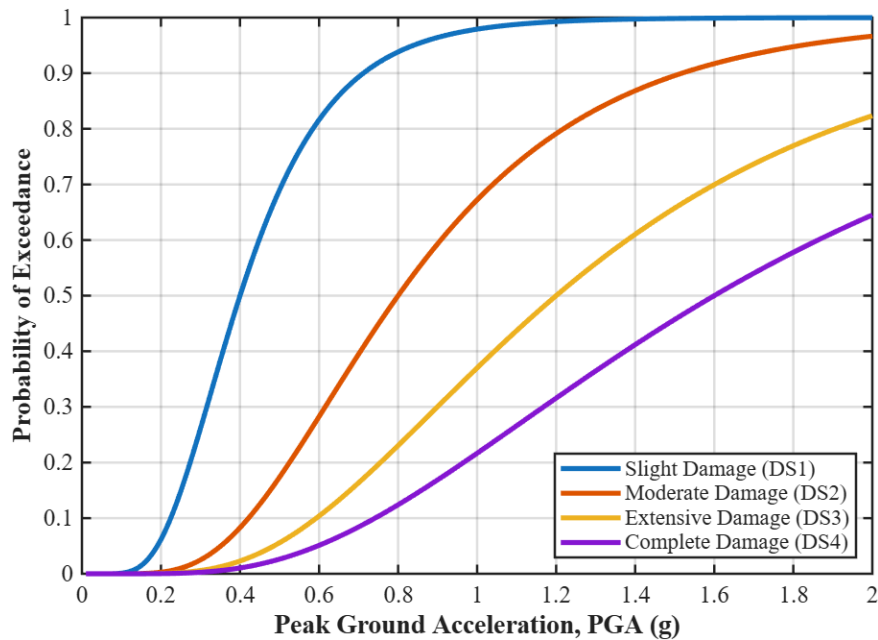


Figure 5 Fragility Curves for LRB-Isolated Building

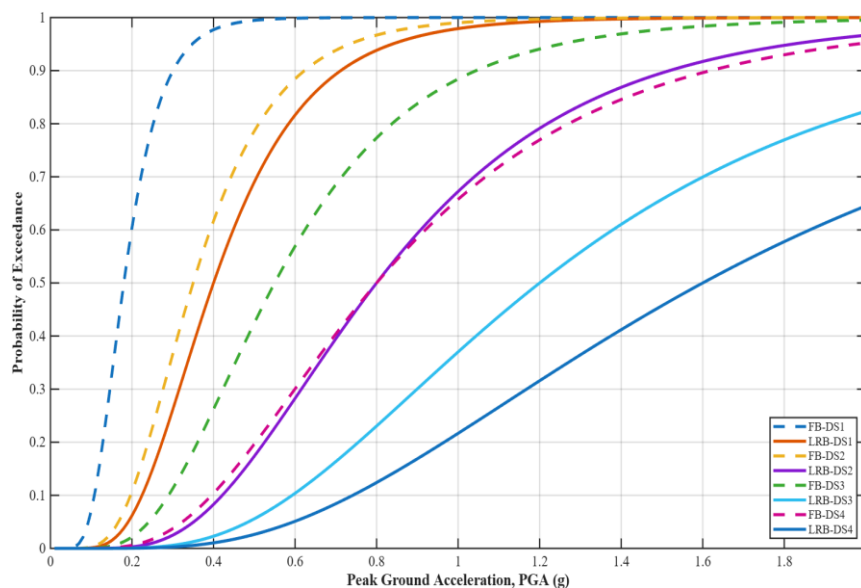


Figure 6 Comparative Fragility Curves of Fixed-Base and LRB-Isolated Buildings

The fragility curves shown in Figures 269-290 demonstrate a significant rightward shift for the LRB-isolated structure compared with the fixed-base building, indicating enhanced seismic resilience. For the fixed-base configuration, the probability of reaching complete damage exceeds

50% at PGA values around 0.80 g, whereas the isolated structure reaches the same probability level only at approximately 1.60 g. This corresponds to approximately twofold increase in the median PGA associated with the adopted complete-damage state due to base isolation.

3.11 Zone-wise Probability of Damage Exceedance

Using the design PGA values corresponding to Indian seismic zones, the probabilities of exceeding each damage state were computed.

Table 6. Seismic Fragility-Based Damage Exceedance Probabilities for Fixed-Base RC Building Across Indian Seismic Zones

Zone	Design PGA (g)	Slight	Moderate	Extensive	Complete
II	0.10	Very Low	Negligible	Negligible	Negligible
III	0.16	Low	Very Low	Negligible	Negligible
IV	0.24	Moderate	Low	Very Low	Negligible
V	0.36	High	Moderate	Low	Very Low

Table 7. Seismic Fragility-Based Damage Exceedance Probabilities for LRB-Isolated RC Building Across Indian Seismic Zones

Zone	Design PGA (g)	Slight	Moderate	Extensive	Complete
II	0.10	Negligible	Negligible	Negligible	Negligible
III	0.16	Very Low	Negligible	Negligible	Negligible
IV	0.24	Low	Negligible	Negligible	Negligible
V	0.36	Moderate	Very Low	Negligible	Negligible

The results confirm that implementing Lead Rubber Bearing (LRB) isolation substantially reduces the probability of structural damage across all seismic zones. The reduction is most pronounced in Zones IV and V, where the isolated structure shows significantly lower probabilities of moderate, extensive, and complete damage than the fixed-base counterpart. These findings highlight the effectiveness of seismic isolation in enhancing structural safety, reducing expected losses, and improving post-earthquake functionality.

4. Results and Discussion

The seismic performance of the 20-storey reinforced concrete building was evaluated under both fixed-base and Lead Rubber Bearing (LRB) base-isolated configurations across Seismic Zones II, III, IV, and V as per IS 1893:2016. The

results show significant improvements in structural response due to base isolation.

4.1 Base Shear Response

The fixed-base building experienced base shear values ranging from 1324.5 kN in Zone II to 3275.8 kN in Zone V, whereas the isolated building's corresponding values ranged from 441.5 kN to 1091.9 kN. A consistent reduction of approximately 66.7% was observed across all seismic zones. The significant reduction in base shear is attributed to the period elongation introduced by the LRB system, which shifts the structural response to a lower spectral acceleration region of the design spectrum. The reduced seismic forces transmitted to the superstructure improve structural safety and reduce member design requirements.

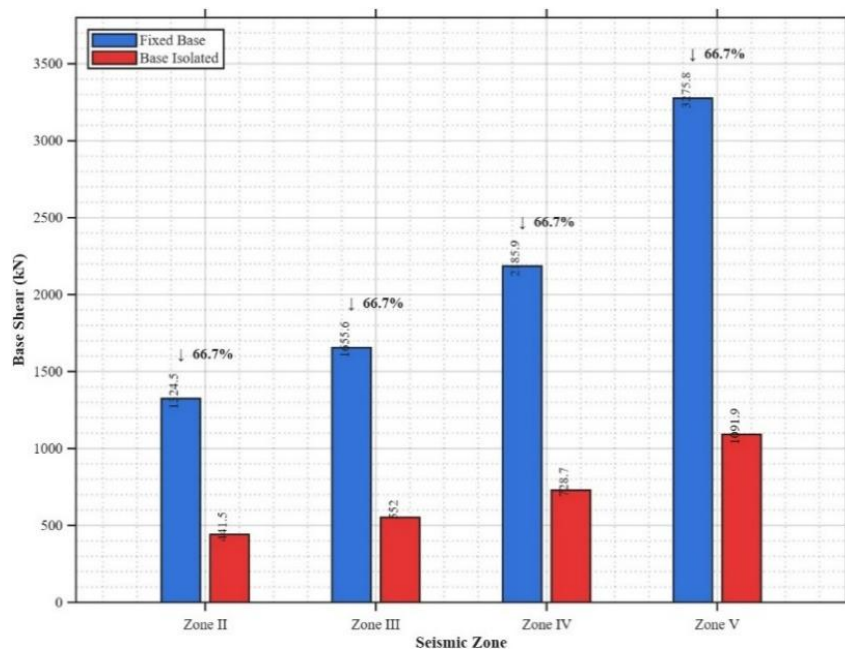


Figure 7 Effect of Base Isolation on Seismic Base Shear across Seismic Zones II–V

4.2 Storey Drift Response

The comparison of maximum storey drift is presented in Figure 8. Maximum storey drift values for the fixed-base building ranged from 0.001069 in Zone II to 0.002389 in Zone V, whereas the corresponding values for the isolated building ranged from only 0.000082 to 0.000173. The drift reduction exceeded 92% in all seismic

zones and reached a maximum of 92.8% in Zone V. This remarkable reduction indicates that the superstructure behaves almost as a rigid body above the isolation layer. Since storey drift is directly associated with structural and non-structural damage, this improvement significantly enhances building resilience and serviceability during earthquakes.

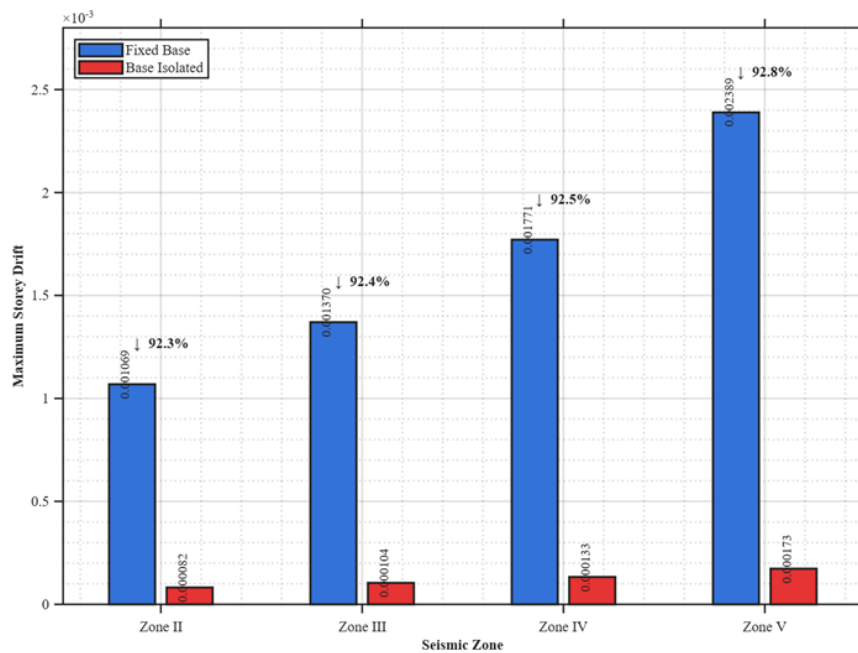


Figure 8 Comparison of Maximum Storey Drift for Fixed-Base and Base-Isolated Buildings in Seismic Zones II–V

4.3 Roof Displacement Response

The maximum roof displacement comparison is shown in Figure 9. The fixed-base building exhibited roof displacements ranging from

0.0454 m in Zone II to 0.1063 m in Zone V, while the base-isolated structure recorded displacements ranging from 0.0286 m to 0.0608 m.

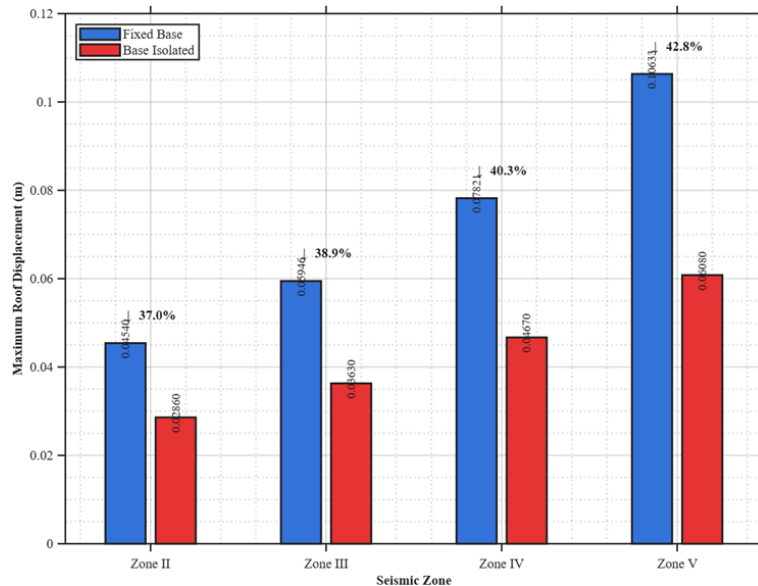


Fig. 9 Comparison of Maximum Roof Displacement for Fixed-Base and Base-Isolated Buildings in Seismic Zones II–V

4.4 Wind Load Performance

Figure 10 illustrates the effect of base isolation under wind loading. Wind responses were evaluated for basic wind speeds of 39 m/s, 44 m/s, 47 m/s, and 50 m/s corresponding to Zones II–V as per IS 875 (Part 3).

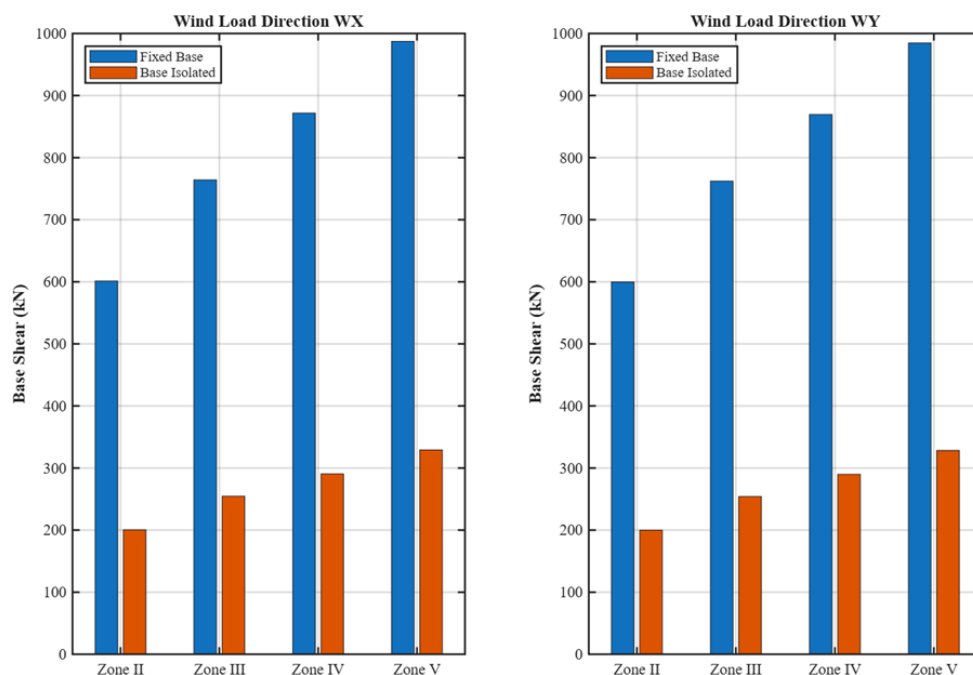


Fig. 10 Wind Base Shear Comparison in WX and WY Directions for Fixed-Base and Base-Isolated Buildings Across All Wind Zones.

For the WX direction, wind base shear increased from 601.3 kN in Zone II to 987.3 kN in Zone V for the fixed-base structure, whereas the isolated building recorded values ranging from 200.4 kN to 329.1 kN. Similar reductions were observed for the WY direction. All wind zones achieved a consistent reduction of approximately 66.7%. The maximum wind-induced storey drift also decreased substantially. In Zone V, drift reduced from 0.000638 in the fixed-base building to 0.000065 in the isolated structure, an approximate reduction of 89.7%.

4.5 Dynamic Characteristics

Incorporating LRBs increased the fundamental period from 2.681 s to 3.421 s, a 27.6% increase. This period elongation shifted the structural response away from the peak spectral acceleration region, thereby reducing seismic demand and enhancing structural resilience.

4.6 Fragility Assessment

The fragility curves revealed a significant improvement in seismic reliability due to base isolation. The median PGA associated with complete damage increased from 0.80 g for the fixed-base building to 1.60 g for the isolated building, indicating approximately a twofold increase in the median PGA associated with the adopted complete-damage state. Furthermore, the isolated structure exhibited substantially lower probabilities of moderate, extensive, and complete damage in Zones IV and V, confirming the effectiveness of LRB isolation in reducing seismic vulnerability under severe earthquake conditions.

4.7 Overall Structural Performance

The collective results obtained from Figures 269-290 clearly demonstrate the effectiveness of Lead Rubber Bearing isolation in reducing structural demand under both seismic and wind loading. For Zone IV, representative of severe seismic conditions, base isolation reduced:

Base shear by 66.7%

Roof displacement by 40.3%

Maximum storey drift by 92.7%

while simultaneously increasing the fundamental period from 2.681 s to 3.421 s, representing a 27.6% increase. The increase in fundamental period confirms the intended period-shift mechanism of the isolation system. By reducing spectral acceleration demand and limiting inter-storey deformation, the LRB system significantly improves structural safety, serviceability, and occupant comfort. Overall, the results presented in Figures 5–8 confirm that Lead Rubber Bearing isolation provides an effective lateral load mitigation strategy for the investigated seismic and wind load cases for high-rise reinforced concrete buildings subjected to both earthquake and wind loading conditions.

5. Conclusion

This study presented a nonlinear dynamic and fragility-based assessment framework for evaluating the seismic performance of fixed-base and Lead Rubber Bearing (LRB)-isolated reinforced concrete buildings across Indian seismic zones. The major conclusions are as follows: Base isolation significantly reduced seismic demand in all seismic zones. The design base shear decreased from 1324.5–3275.8 kN in the fixed-base structure to 441.5–1091.9 kN in the isolated structure, representing an average reduction of approximately 66.7% across all zones. This reduction resulted from the period elongation effect introduced by the LRB system.

Base isolation substantially reduced maximum roof displacement. The reduction ranged from 37.0% in Zone II to 42.8% in Zone V, showing that the isolation system is more effective at higher seismic intensity. Although the isolation layer undergoes larger deformation, the superstructure experiences significantly lower displacement demand. Inter-storey drift reduction was the most significant performance improvement. The maximum storey drift decreased by more than 92% in all seismic zones, with a peak reduction of 92.8% in Zone V. This result confirms that a greater proportion of the lateral deformation is accommodated at the isolation interface rather than through deformation of the superstructure, thereby

minimizing structural and non-structural damage during strong earthquake events.

The fundamental time period increased from 2.681 s to 3.421 s, corresponding to a period elongation of approximately 27.6%. This shift moved the structural response away from the peak spectral acceleration region, thereby reducing force transmission to the superstructure and enhancing overall seismic resilience. Wind-load performance was also significantly improved. Wind-induced base shear decreased by approximately 66.7% in both WX and WY directions across all wind speed zones. Furthermore, maximum wind-induced storey drift reduced by nearly 89.7%, indicating that the benefits of base isolation extend beyond seismic protection and contribute to enhanced serviceability under wind loading.

Fragility assessment demonstrated a substantial improvement in seismic reliability due to base isolation. The median PGA corresponding to complete damage increased from 0.80 g for the fixed-base structure to 1.60 g for the LRB-isolated structure, indicating approximately twofold increase in the median PGA associated with the adopted complete-damage state. The isolated building exhibited significantly lower

probabilities of moderate, extensive, and complete damage, particularly in Seismic Zones IV and V. The comparative assessment confirmed that Lead Rubber Bearing (LRB) isolation provides an effective lateral load mitigation strategy for the investigated seismic and wind load cases, significantly enhancing both seismic and wind performance of high-rise reinforced concrete buildings. The isolation system substantially reduced seismic forces, inter-storey drift, displacement demand, and structural damage potential while improving serviceability, occupant safety, and protection of non-structural components.

Overall, the findings show that LRB isolation is a highly effective seismic protection technology for reinforced concrete buildings in Indian seismic regions, particularly Zones IV and V. The significant reduction in damage probability and increase in seismic capacity highlight the potential of base isolation for performance-based seismic design. The proposed framework can serve as a robust basis for future studies on fragility-based design, resilience assessment, lifecycle performance evaluation, and seismic risk mitigation strategies for earthquake-resistant infrastructure.

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