IJVAST | Vol. 2, Issue 2 | June 2026 | Open Access — Peer Reviewed Research Paper

Earthquake Response of Base-Isolated RC Buildings in Zone IV

Harshal Bhatt[1], Pravin Pawade[2]

Department of Civil Engineering

Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat, Gujarat, India

Abstract—Base isolation is a well-established seismic protection strategy that decouples a building's superstructure from damaging ground motion by introducing a flexible interface, typically comprising elastomeric or friction-based bearings, at the foundation level. This study investigates the seismic response of a representative multi-storey reinforced concrete (RC) building located in Seismic Zone IV of the Indian seismic code, comparing a conventional fixed-base configuration against base-isolated configurations using Lead Rubber Bearings (LRB) and Friction Pendulum Bearings (FPS). Nonlinear time-history analysis was performed using a set of scaled natural and spectrum-compatible ground-motion records, and results were evaluated in terms of storey drift, floor acceleration, base shear, and isolator displacement demand. The base-isolated models exhibited substantial reductions in peak storey drift (up to 62%) and floor acceleration (up to 58%) relative to the fixed-base model, at the cost of increased isolator-level displacement that must be accommodated in the isolation gap and utility connections. The Lead Rubber Bearing system showed slightly higher energy dissipation and reduced residual displacement compared to the Friction Pendulum system for the ground motions considered, while both isolation systems significantly outperformed the fixed-base configuration across all response parameters. These findings reinforce the effectiveness of base isolation as a seismic protection strategy for RC buildings in high-seismicity zones and provide comparative guidance for isolator system selection in regions such as Zone IV.

Index Terms—*Base Isolation, Seismic Zone IV, Lead Rubber Bearing, Friction Pendulum System, Nonlinear Time-History Analysis, Storey Drift, Reinforced Concrete Buildings, Earthquake Engineering.*

I. INTRODUCTION

India's seismic hazard map classifies a substantial portion of the country, including much of Gujarat, into Seismic Zone IV, characterized by high expected ground-motion intensity. Conventional seismic design of reinforced concrete (RC) buildings relies on ductile detailing to allow controlled inelastic deformation and energy dissipation during strong ground shaking, which, while preventing collapse, can still result in significant structural and non-structural damage.

Base isolation offers an alternative seismic protection philosophy: rather than absorbing earthquake energy through structural damage, a flexible isolation interface at the foundation level lengthens the fundamental period of the structure and dissipates energy through the isolators themselves, substantially reducing the seismic forces and deformations transmitted to the superstructure. This approach has been increasingly adopted for critical and essential facilities such as hospitals, data centers, and government buildings in high-seismicity regions.

This study evaluates the comparative seismic performance of a representative multi-storey RC building modeled with a fixed base, Lead Rubber Bearings (LRB), and Friction Pendulum Bearings while Friction Pendulum Systems achieve isolation and re-centering through a curved sliding surface, with the pendulum geometry governing the effective isolation period independent of the supported mass.

C. Performance Studies in Indian Seismic Context

Prior studies on base-isolated buildings under Indian seismic code provisions have generally reported substantial reductions in storey drift and floor acceleration relative to fixed-base designs, though most such studies have been conducted for Zone V; comparatively fewer studies have specifically examined Zone IV conditions representative of cities such as Surat and Ahmedabad.

III. BUILDING DESCRIPTION AND MODELING

A. Building Configuration

A representative eight-storey RC office building with a plan configuration of five bays at 6 m spacing in each direction was selected for analysis, designed as per Indian standard RC design codes for a location in Seismic Zone IV with medium soil conditions.

B. Structural Modeling

A three-dimensional finite-element model of the

(FPS), under a set of ground motions representative of Seismic Zone IV, to quantify the benefits and trade-offs of base isolation for this seismic environment.

II. LITERATURE REVIEW

A. Base Isolation Fundamentals

Base isolation systems function primarily by period elongation, shifting the structure's fundamental period away from the dominant energy content of typical earthquake ground motions, thereby reducing the spectral acceleration demand transmitted to the superstructure while introducing supplemental damping through the isolator hysteresis.

B. Elastomeric and Friction-Based Isolators

Lead Rubber Bearings combine laminated elastomeric layers with a central lead core to provide both flexibility and hysteretic energy dissipation,

building was developed, with beams and columns modeled as nonlinear frame elements incorporating concentrated plastic hinges at member ends, calibrated to standard moment-curvature relationships for the designed reinforcement detailing.

C. Isolator Modeling

Lead Rubber Bearings were modeled using a bilinear hysteretic force-deformation relationship, and Friction Pendulum Bearings were modeled using a friction-pendulum element with velocity-dependent friction coefficient, both calibrated to manufacturer-representative properties for the building's seismic weight.

D. Ground Motion Selection and Scaling

Seven ground-motion records were selected and spectrally matched to the Indian code design spectrum for Zone IV, medium soil, to perform nonlinear time-history analysis in accordance with standard code provisions for base-isolated building analysis.

Key structural and isolator design parameters for the fixed-base and isolated models are summarized in Table I.

TABLE I — Structural and Isolator Design Parameters

Parameter	Fixed-Base Model	LRB-Isolated Model	FPS-Isolated Model
Number of storeys	8	8	8
Fundamental period (s)	0.94	2.35	2.42
Isolator effective stiffness (kN/m)	—	1450	1380
Isolator damping ratio (%)	—	18-20	15-18
Design seismic zone	IV	IV	IV

IV. ANALYSIS METHODOLOGY

Nonlinear time-history analysis was performed for three building configurations: (1) fixed-base, (2) LRB-isolated, and (3) FPS-isolated, each subjected to the same set of seven scaled ground-motion records applied independently in the two principal horizontal directions. Response parameters extracted from each analysis included peak storey drift ratio, peak floor absolute acceleration, base shear, and, for the isolated models, peak isolator displacement and residual displacement after each ground motion.

Results for each response parameter were averaged across the seven ground motions in accordance with standard code provisions for nonlinear time-history analysis of base-isolated structures, and are presented as the design-basis response envelope for each configuration.

V. RESULTS AND DISCUSSION

A. Storey Drift Response

Peak storey drift ratio in the fixed-base model reached 1.42% at the fourth storey, exceeding typical code-recommended limits for life-safety performance under design-basis shaking. The LRB-isolated model reduced peak storey drift to 0.54% (approximately 62% reduction), and the FPS-isolated model to 0.58% (approximately 59% reduction), both comfortably within acceptable limits.

B. Floor Acceleration Response

Peak floor acceleration in the fixed-base model reached 0.86g at the roof level, reduced to 0.36g in the LRB model and 0.39g in the FPS model, representing reductions of approximately 58% and 55% respectively, indicating substantially improved protection for non-structural components and building contents.

C. Base Shear

Base shear in both isolated models was reduced by approximately 45-50% relative to the fixed-base model, consistent with the intended function of the isolation system in limiting force transmission to the superstructure, despite the additional mass and stiffness contribution of the isolators themselves.

D. Isolator Displacement Demand

Peak isolator displacement was 312 mm for the LRB system and 298 mm for the FPS system under the design-basis ground-motion set, both requiring adequate seismic gap provision around the building perimeter and flexible utility connections across the isolation interface. A comparative summary of peak response parameters across all three configurations is presented in Table II.

VI. COMPARATIVE PERFORMANCE OF ISOLATION SYSTEMS

While both isolation systems performed similarly in reducing storey drift and floor acceleration, the LRB system exhibited marginally lower residual displacement after ground-motion cessation, attributed to the re-centering behavior provided by the elastomeric rubber layers, whereas the FPS system's re-centering depends primarily on the curvature of the sliding surface and gravity restoring force.

VII. DESIGN IMPLICATIONS FOR ZONE IV

The results indicate that base isolation provides substantial seismic performance benefits for RC buildings even in Zone IV, a moderately high but not the highest seismic zone in the Indian code, suggesting that base isolation may be a viable and beneficial strategy beyond its traditional application to Zone V critical facilities, particularly for buildings requiring enhanced post-earthquake functionality such as hospitals and data centers located in Zone IV cities.

VIII. CHALLENGES AND LIMITATIONS

Practical challenges to wider adoption of base isolation in Zone IV construction include the additional capital cost of isolator hardware and specialized detailing, the need for adequate seismic gap and flexible utility connections around the isolation interface, and limited local availability of qualified isolator suppliers and installation expertise in some regions. This study is also limited to a single building configuration and ground-motion set, and further parametric studies across building heights and soil conditions would strengthen the generality of the findings.

TABLE II — Comparative Peak Seismic Response Parameters

Response Parameter	Fixed-Base	LRB-Isolated	FPS-Isolated
Peak storey drift ratio (%)	1.42	0.54	0.58
Peak floor acceleration (g)	0.86	0.36	0.39
Peak base shear (relative, %)	100	52	56
Peak isolator displacement (mm)	—	312	298
Residual displacement (mm)	—	8	14

IX. FUTURE SCOPE

Future work should extend this analysis across a wider range of building heights, plan configurations, and soil conditions representative of Zone IV cities, and should include cost-benefit analysis comparing the life-cycle cost of base-isolated versus conventional fixed-base construction, incorporating post-earthquake downtime and repair cost considerations. Investigation of hybrid isolation-damping systems and isolator performance under near-fault ground motions with strong velocity pulses would also further strengthen design guidance for this seismic zone.

X. CONCLUSION

This study compared the seismic response of a representative RC building in fixed-base, Lead Rubber Bearing-isolated, and Friction Pendulum-isolated configurations under ground motions representative of Seismic Zone IV. Both isolation systems achieved substantial reductions in storey drift (59-62%), floor acceleration (55-58%), and base shear (45-50%) relative to the fixed-base configuration, at the cost of increased isolator displacement demand requiring adequate seismic gap provision. The Lead Rubber Bearing system showed marginally better re-centering behavior than the Friction Pendulum system for the ground motions considered.

 ISSN: Applied For (2026) | DOI: 10.XXXXX/IJVAST.2026.XXXXX |

These findings support the extension of base isolation technology to RC buildings in Zone IV, particularly for facilities where enhanced seismic performance and post-earthquake functionality are priorities.

XI. REFERENCES

[1] Kelly, J.M. (1997). Earthquake-Resistant Design with Rubber (2nd ed.). Springer.

[2] Naeim, F., and Kelly, J.M. (1999). Design of Seismic Isolated Structures: From Theory to Practice. John Wiley & Sons.

[3] Bureau of Indian Standards. (2016). IS 1893 (Part 1): Criteria for earthquake resistant design of structures — General provisions and buildings. BIS, New Delhi.

[4] Bureau of Indian Standards. (2021). IS 16700: Criteria for structural safety of tall concrete buildings. BIS, New Delhi.

[5] Jangid, R.S., and Kelly, J.M. (2001). Base isolation for near-fault motions. Earthquake Engineering and Structural Dynamics, 30(5), 691-707.

[6] Providakis, C.P. (2008). Effect of LRB and FPS isolators on the nonlinear response of base-isolated buildings under near-fault excitations. Engineering Structures, 30(5), 1187-1198.

[7] Constantinou, M.C., Whittaker, A.S., Kalpakidis, Y., Fenz, D.M., and Warn, G.P. (2007). Performance of Seismic Isolation Hardware under Service and Seismic Loading. MCEER Technical Report.

[8] Skinner, R.I., Robinson, W.H., and McVerry, G.H. (1993). An Introduction to Seismic Isolation. John Wiley & Sons.

[9] Matsagar, V.A., and Jangid, R.S. (2004). Influence of isolator characteristics on the response of base-isolated structures. Engineering Structures, 26(12), 1735-1749.

[10] Providakis, C.P. (2009). Pushover analysis of base-isolated steel-concrete composite structures under near-fault excitations. Soil Dynamics and Earthquake Engineering, 29(9), 1249-1258.

[11] Ramallo, J.C., Johnson, E.A., and Spencer, B.F. (2002). Smart base isolation systems. Journal of Engineering Mechanics, 128(10), 1088-1099.

[12] Zayas, V.A., Low, S.S., and Mahin, S.A. (1990). A simple pendulum technique for achieving seismic isolation. Earthquake Spectra, 6(2), 317-333.

[13] Symans, M.D., and Constantinou, M.C. (1998). Passive fluid viscous damping systems for seismic energy dissipation. ISET Journal of Earthquake Technology, 35(4), 185-206.

[14] Kilar, V., and Koren, D. (2010). Seismic behaviour of asymmetric base isolated structures with various distributions of isolators. Engineering Structures, 32(10), 3086-3096.

[15] Providakis, C.P. (2008). Effect of supplemental damping on LRB and FPS seismic isolators under near-fault ground motions. Soil Dynamics and Earthquake Engineering, 29(1), 80-90.

[16] Warn, G.P., and Ryan, K.L. (2012). A review of seismic isolation for buildings: Historical development and research needs. Buildings, 2(3), 300-325.