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Seismic Performance of Mid-Rise and High-Rise RC Buildings Using Elastomeric Bearings

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Abstract - Earthquakes impose large lateral forces on conventional fixed-base buildings, resulting in high base shear, inter-storey drifts and floor accelerations that frequently cause extensive structural and non-structural damage. Base isolation using elastomeric bearings, particularly lead rubber bearings (LRBs), offers an effective passive strategy to mitigate these demands by elongating the fundamental period and dissipating seismic energy at the isolation interface. This study evaluates the seismic performance of mid-rise (10-storey) and high-rise (18-storey) reinforced concrete special moment-resisting frame buildings under both fixed-base and LRB-isolated conditions. Three-dimensional models were developed in ETABS and subjected to linear static, response-spectrum and nonlinear time-history analyses using seven spectrum-compatible ground-motion records selected from the PEER NGA-West2 database, encompassing both near-fault and far-field characteristics. Results demonstrate that the incorporation of LRBs produced a consistent reduction in base shear of 75–92% and a reduction in top-storey acceleration of 78–91% across all records for both building heights. Inter-storey drift ratios were generally reduced under far-field motions, promoting near-rigid-body behaviour of the superstructure; however, limited increases in drift were observed under certain near-fault pulse-type records. The isolation system also significantly lengthened the fundamental periods, confirming effective decoupling of the superstructure from ground motion. Overall, the findings establish that pure elastomeric isolation using LRBs remains highly effective for both mid-rise and high-rise RC frame buildings, substantially lowering force and acceleration demands while highlighting the need for careful bearing design when near-fault ground motions are anticipated.

Keywords: Base isolation, Lead rubber bearings, Seismic performance, Mid-rise buildings, High-rise buildings, Near-fault earthquakes

1. INTRODUCTION

Earthquakes generate intense ground motions that impose large lateral forces on structures, producing elevated base shear, inter-storey drifts and floor accelerations. Conventional fixed-base design relies on strength and ductility; while this can prevent collapse, it often permits significant structural and non-structural damage, prolonged downtime and high repair costs [1], [2]. In regions of moderate to high seismicity governed by IS 1893 (Part 1): 2016, the limitations of purely strength-based design have stimulated interest in passive protection strategies that reduce seismic demands rather than merely resisting them.

Base isolation inserts a flexible interface between the superstructure and foundation, elongating the fundamental period beyond the predominant periods of typical ground motions and dissipating energy at the isolation level [3]. Among isolation devices, lead rubber bearings (LRBs) have achieved the widest practical acceptance. An LRB consists of alternating layers of rubber vulcanized to steel shims with a central lead core that provides hysteretic damping. Extensive studies report reductions in base shear of 50–80%, inter-storey drifts of 40–70% and floor accelerations of 50–75% under far-field motions [1], [2], [4].

Despite these advantages, several challenges remain. Tall buildings can develop tensile forces in perimeter bearings under large overturning moments. Near-fault ground motions containing long-period velocity pulses can impose large displacement demands that may exceed design limits [5]. Systematic side-by-side comparisons of linear and nonlinear responses for the same moment-resisting frame under identical modelling assumptions and mixed near-fault/far-field records are still limited, particularly for pure LRB systems applied to both mid-rise and high-rise RC frames in the Indian context. This study evaluates the seismic performance of 10-storey (mid-rise) and 18-storey (high-rise) RC special moment-resisting frame buildings under fixed-base and LRB-isolated conditions. Three-dimensional models are analysed using modal, response-spectrum and nonlinear time-history methods with a suite of seven spectrum-compatible records. Key response parameters—base shear, inter-storey drift ratio and top-storey acceleration—are compared quantitatively to assess isolation effectiveness across the two height regimes. Finally, the practical implications of

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isolator tension, thermal effects, and large-strain behaviour for mid-rise and high-rise RC moment-resisting frames have received insufficient attention in a unified analytical framework. Regions of moderate to high seismicity. The remainder of the paper is organised as follows. Section 2 presents a detailed literature review and the identified research gaps. Section 3 describes the building configurations, modelling assumptions, LRB properties, and ground-motion selection. Section 4 outlines the analysis methodology. Section 5 reports and discusses the comparative results. Section 6 summarises the principal conclusions and recommendations for future work.

2. BUILDING DESCRIPTION AND MODELLING

2.1 Structural Configurations

Table No.1 Geometric and structural characteristics of the building models

Description	**10 Story**	**18 Story**
Building dimensions (m)	16 X16	16 X 16
Building System	MRF	MRF
Ground floor story height	3.0	3.0
Typical story height	3.0	3.0
Building total height (m)	30	54
Building use	Residential	Residential
Dead load	Program calculated	Program calculated
Floor finish (kN/m2)	1.5	1.5
Live-load (kN/m2)	2.0	2.0
Wall load (kN/m)	13.8	13.8
Slab thickness (mm)	150	150
Concrete strength (MPa)	M30	M30
Steel grade (MPa)	Fe500	Fe500

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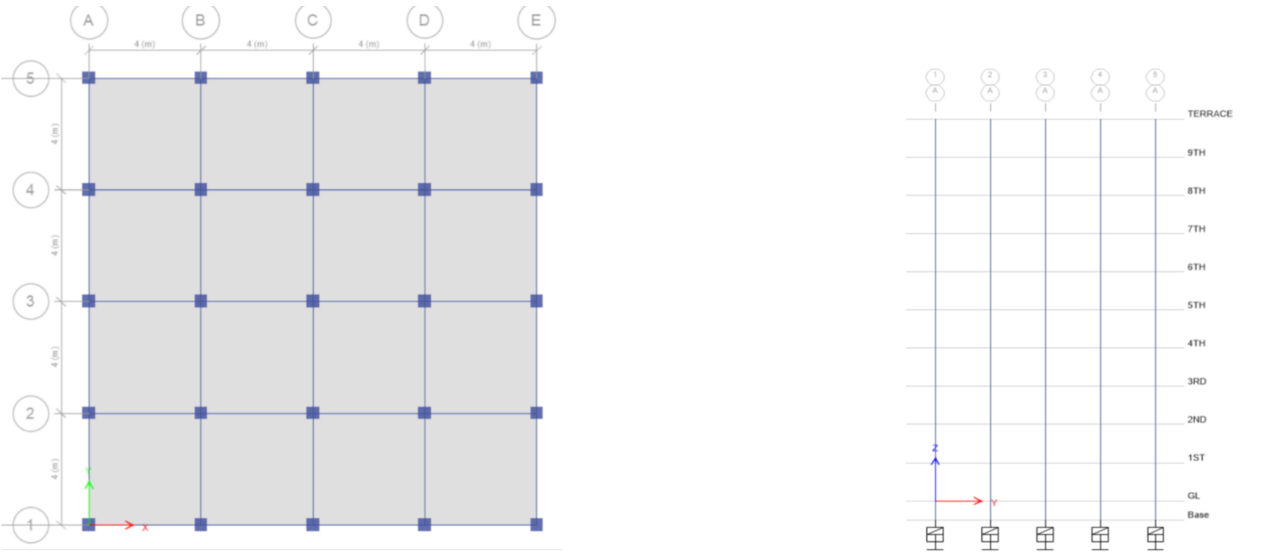
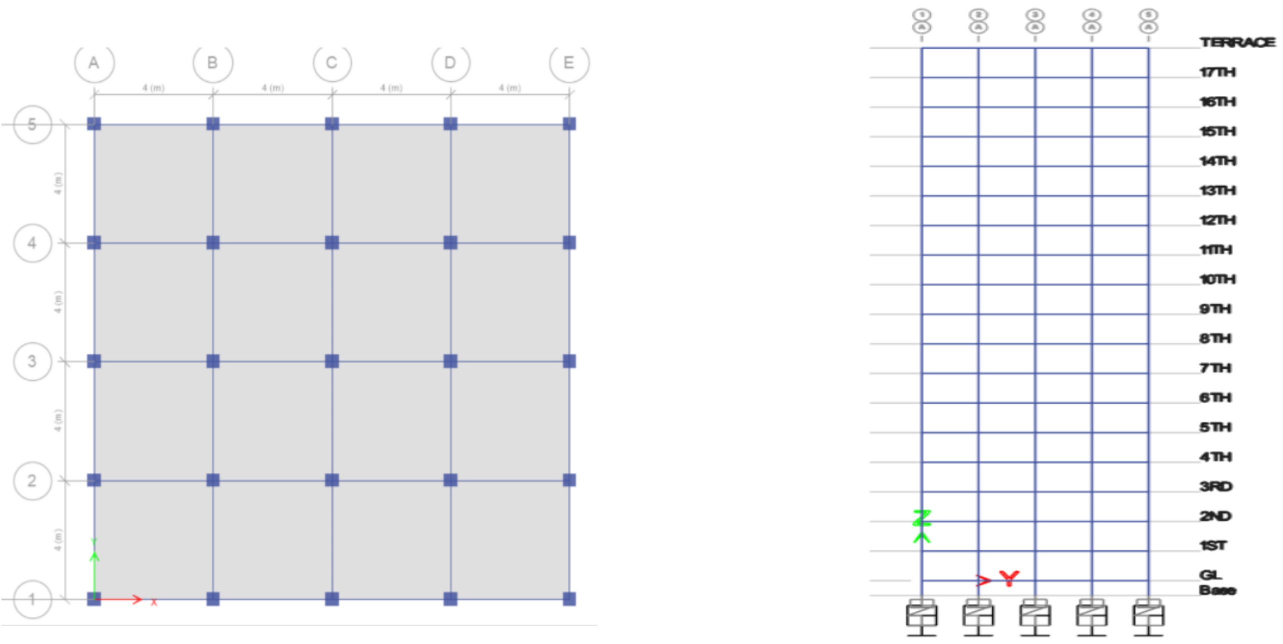
Base model photo



(a) (b)

Figure. 1 (a). Plan view and (b) Elevation view of 10 storey building



(a) (b)

Figure. 2 (a). Plan view and (b) Elevation view of 18 storey building

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2.2 Numerical Modelling

Three-dimensional finite-element models were developed in ETABS. Frame elements represented beams and columns; shell elements represented slabs. Geometric nonlinearity (P-delta) was activated. Material nonlinearity was introduced through plastic hinges assigned at member ends in accordance with ASCE 41. Fixed-base models were supported on rigid supports. For isolated models the supports were replaced by LRBs modelled as bilinear hysteretic link elements. Identical isolator properties were assigned beneath every column to preserve plan regularity.

The LRB bilinear model is defined by initial stiffness K_1, characteristic strength Qd, post-yield stiffness K_2 and yield displacement. Properties were proportioned so that the effective isolation periods of both buildings fell in the range 2.0–3.0 s, a range widely recognised as effective for shifting structural response away from the high-energy portion of the IS 1893 design spectrum. Vertical stiffness was kept sufficiently high to limit vertical deformations and prevent rocking under design-level overturning moments. No tensile capacity beyond the nominal cavitation stress of the rubber was assumed.

2.3 Ground-Motion Suite

Seven recorded accelerograms were selected from the PEER NGA-West2 database (Table 1). The suite spans moment magnitudes 6.0–7.6 and includes both near-fault pulse-type records (Imperial Valley, Kobe) and far-field records. All records were scaled to be spectrum-compatible at the fundamental periods of the respective buildings.

Table 2: Ground-motion records used in the study

No.	Event	Mw	Rrup (km)	PGA (g)	Mechanism	Type
1	Chi-Chi	7.6	15.7	0.45	Reverse	Far-field
2	Gazli	7.0	10.7	0.40	Reverse	Near-fault
3	Imperial Valley	6.5	8.9	0.46	Strike-slip	Near-fault
4	Italy	6.9	12.5	0.27	Normal	Far-field
5	Palmser	6.0	12.7	0.37	Reverse	Far-field
6	Whittier	6.0	14.8	0.12	Reverse	Far-field
7	Kobe	6.9	6.9	0.33	Strike-slip	Near-fault

3. RESULTS AND DISCUSSION

3.1 Base Shear

Base shear is the most fundamental indicator of global seismic demand. Table 2 summarises the peak base shear obtained from nonlinear time-history analyses. For the 10-storey building, fixed-base base shear ranged from 4147 kN to 11193 kN; after isolation the values fell to 759–1538 kN, corresponding to reductions of 80–92%. For the 18-storey building the reductions ranged from 77% to 93%. Absolute isolated base shears remained well below 1600 kN in all cases. The slightly lower percentage reduction observed for the taller building is attributable to greater higher-mode contributions and larger overturning moments resisted by the isolation layer.

Table 3: Peak base shear (kN) and percentage reduction

Ground Motion	10-St Fixed	10-St LRB	% Red.	18-St Fixed	18-St LRB	% Red.
Chi-Chi	8609	1070	88%	8648	1418	84%
Gazli	11193	1538	87%	8186	1166	86%
Imperial Valley	4147	837	80%	6520	1266	81%
Italy	4810	840	83%	5482	1308	77%
Palmser	4760	943	81%	3951	615	85%
Whittier	8855	759	92%	4158	278	93%
Kobe	8610	1079	88%	8648	1418	87%

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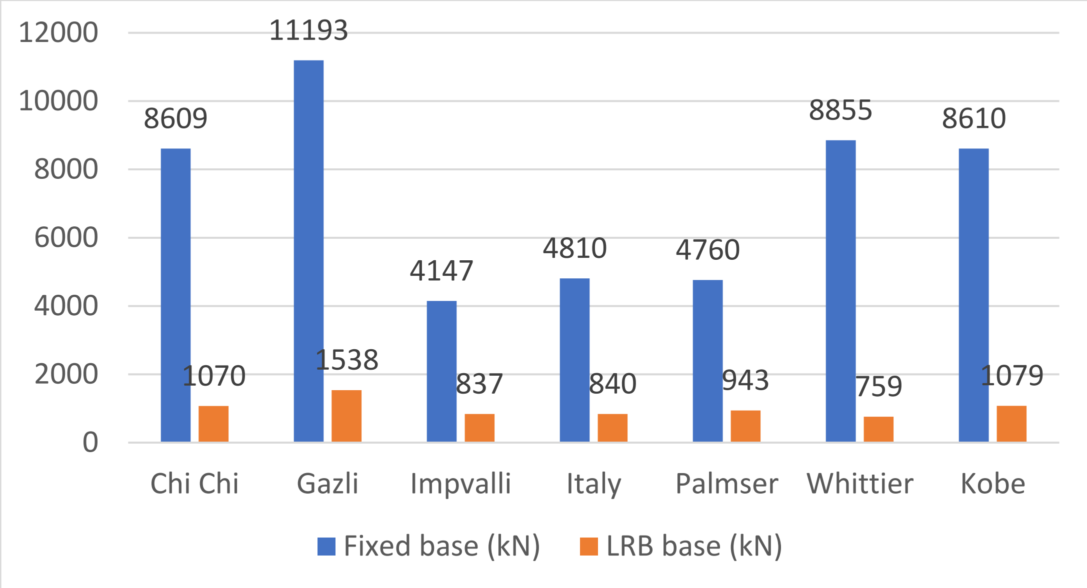

Figure 3 Comparison of base shear for 10 storey building under selected earthquake records

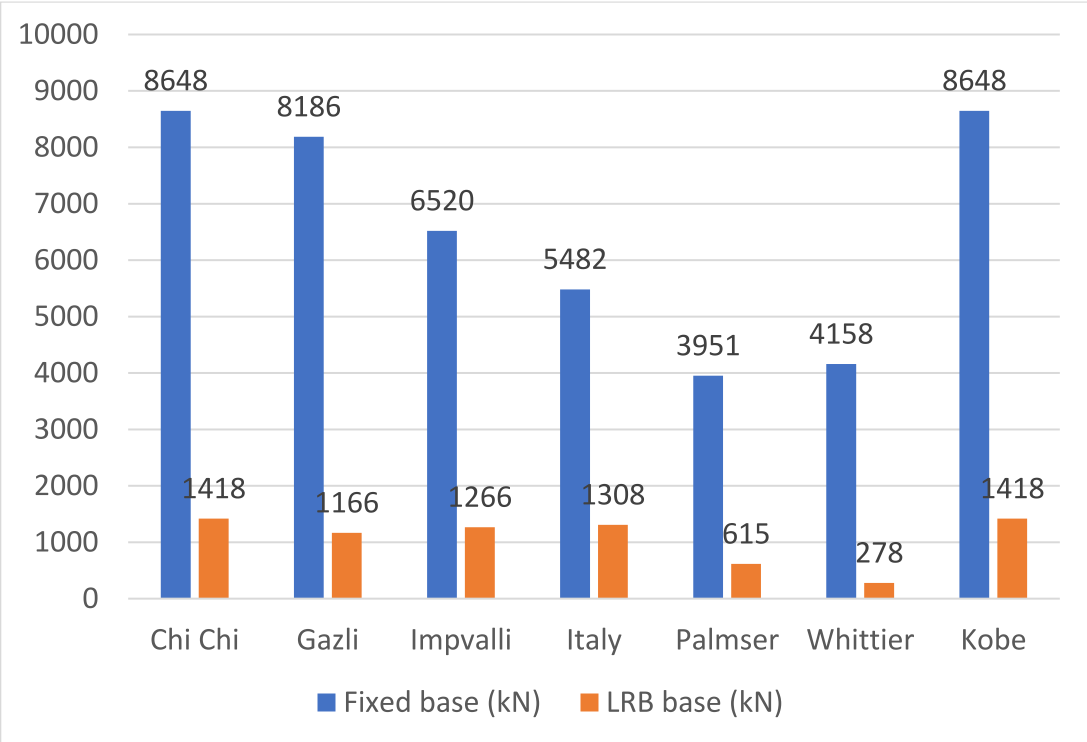

Figure 4 Comparison of base shear for 18 storey building under selected earthquake records

3.2 Inter-Storey Drift Ratio

Under the majority of far-field and moderately near-fault records, maximum inter-storey drift ratios of both buildings were reduced by 25–50%. This reduction results from near-rigid-body translation of the superstructure once the isolators yield. However, under certain strong near-fault pulse-type motions (Italy, Kobe and Gazli) localised increases in inter-storey drift of up to 20–25% were observed. These increases arise from the large rigid-body displacement imposed at the base together with residual higher-mode contributions. Even in these cases the absolute drift values remained within acceptable performance limits, yet the finding underscores the necessity of careful isolator proportioning when pulse-type ground motions are expected.

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Table 4 Comparison of Critical Storey Drift for 10 storey building (Fixed Base vs Isolated Base)

Earthquake	Fixed Base Critical Drift	Isolated Base Critical Drift	% Reduction
Chi Chi	0.009529	0.00491	52.65%
Gazli	0.01324	0.015679	18.97%
Imperial	0.006027	0.004856	46.02%
Italy	0.004995	0.012068	40.68%
Palmser	0.005113	0.003336	58.06%
Whittier	0.010227	0.005103	50.10%
Kobe	0.012827	0.003211	74.97%

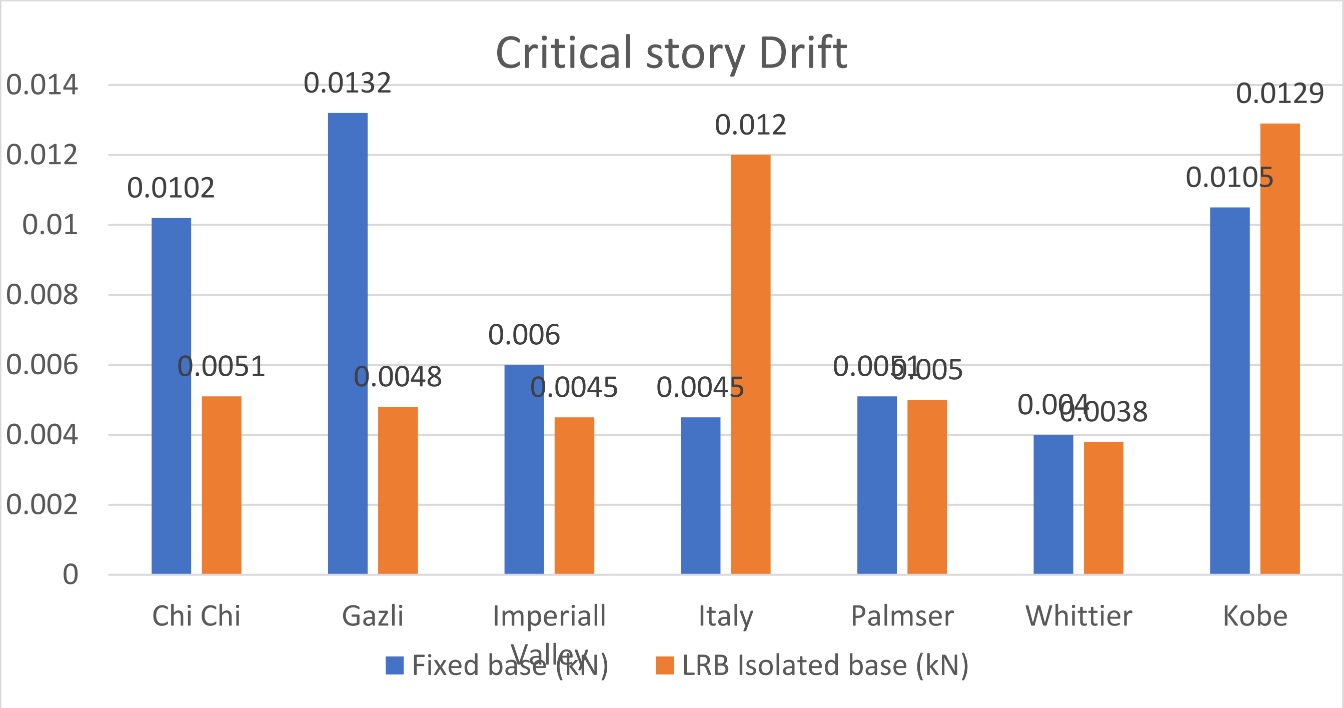

Figure 5: Comparison of critical story drift for 10 storey fixed and base isolated building under selected earthquake records

Table 5 Comparison of Critical Storey Drift for 18 storey building (Fixed Base vs Isolated Base)

Earthquake	Fixed Base Critical Drift	Isolated Base Critical Drift	% Reduction
Chi Chi	0.004204	0.001297	69.15%
Gazli	0.007515	0.002601	65.39%
Imperial Valley	0.008397	0.004533	46.02%

Earthquake	Fixed Base Critical Drift	Isolated Base Critical Drift	% Reduction
Italy	0.010915	0.008800	19.38%
Palmser	0.007955	0.003336	58.06%
Whittier	0.010227	0.005103	50.10%
Kobe	0.012827	0.003211	74.97%

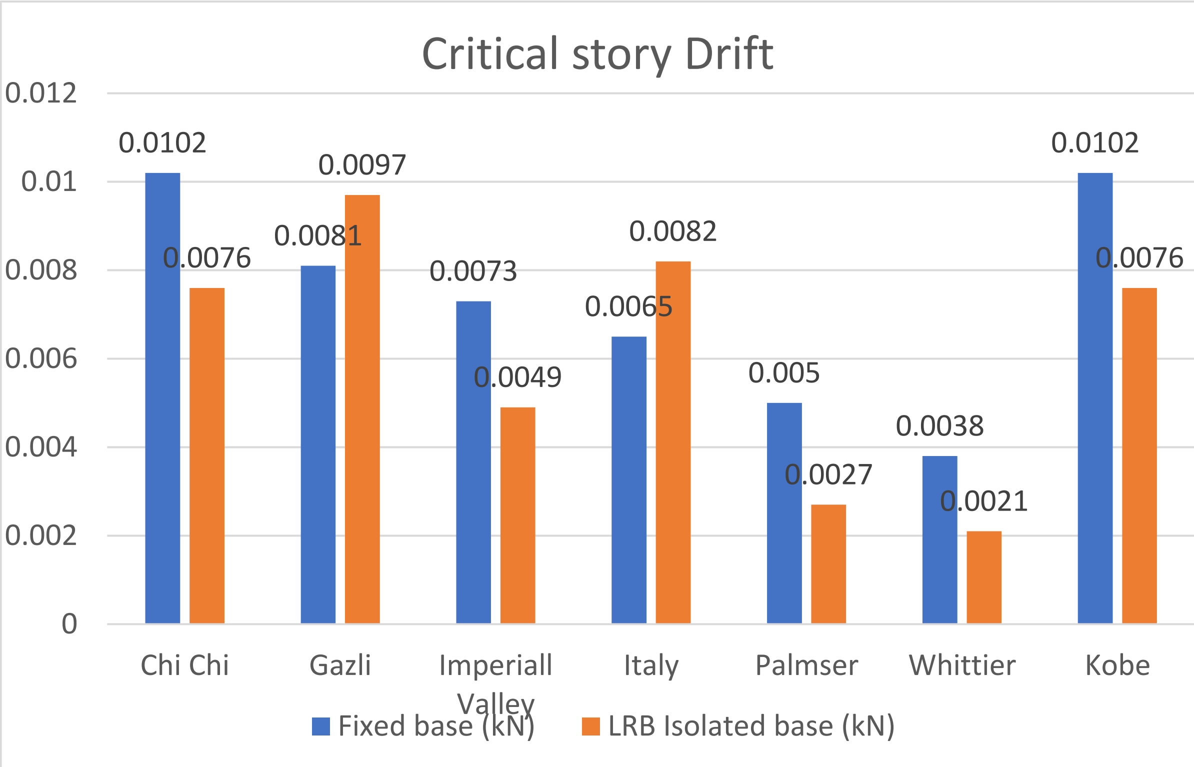

Figure 6: Comparison of critical story drift for 10 storey fixed and base isolated building under selected earthquake records

3.3 Top-Storey Acceleration

Top-storey acceleration governs the performance of non-structural components and acceleration-sensitive equipment. For the 10-storey building, peak roof accelerations of 4624–12455 mm/s² under fixed-base conditions were reduced to 728–1786 mm/s² after isolation (80–91% reduction). For the 18-storey building the corresponding reductions were 78–93%. The consistently large attenuation demonstrates that pure elastomeric isolation is highly effective in protecting acceleration-sensitive contents, irrespective of building height or ground-motion type. This benefit is particularly valuable for hospitals, data centres and other facilities that must remain functional after an earthquake.

Table. 6 Variation in Top storey acceleration for 10 storey fixed base & isolated base building.

Earthquake	Fixed Base (mm/s²)	Isolated Base (mm/s²)	% Reduction
Chi Chi	8586	1250	86.2%
Gazli	12455	1786	86.77%
Imperial Valley	4974	1108	77.77%

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Earthquake	Fixed Base (mm/s²)	Isolated Base (mm/s²)	% Reduction
Italy	5357	1418	74.50%
Palmser	7193	1180	86.60%
Whittier	4624	728	85.30%
Kobe	8587	1251	86.46%

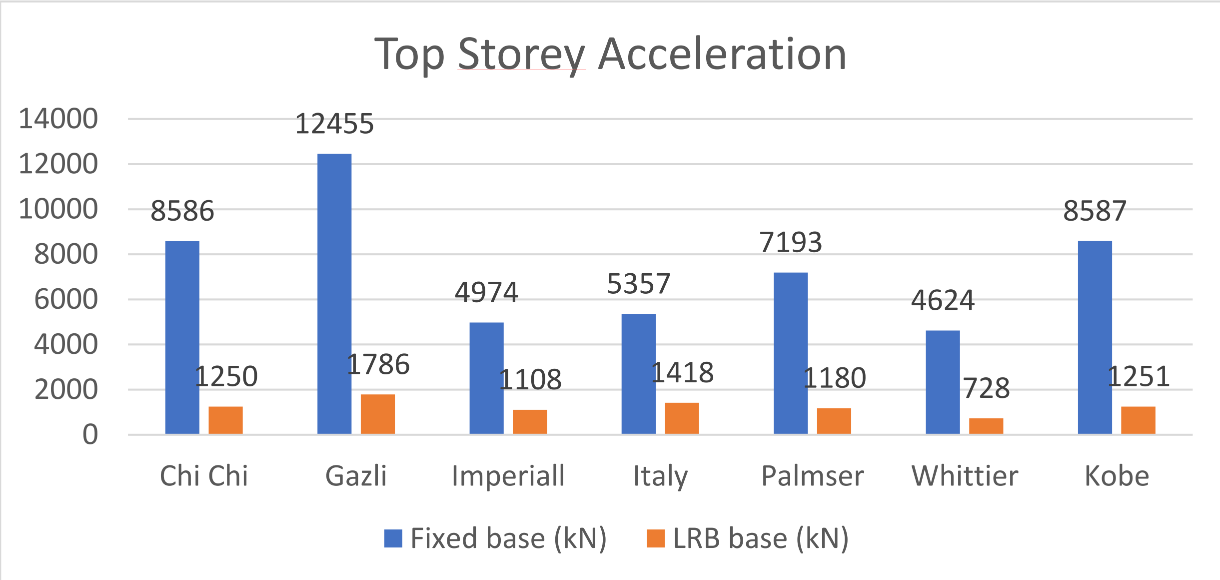

Figure 7: Comparison of Top story acceleration for 10 storey fixed and base isolated building under selected earthquake records

Table. 7 Variation in Top storey acceleration for 18 storey fixed base & isolated base building.

Earthquake	Fixed Base (mm/s²)	Isolated Base (mm/s²)	% Reduction
Chi Chi	4532	908	80.31%
Gazli	7760	580	93.54%
Imperiall Valley	3858	850	85.77%
Italy	5247	815	85.60%
Palmser	3757	479	88.60%
Whittier	6017	382	93.58%
Kobe	4532	907	80.74%

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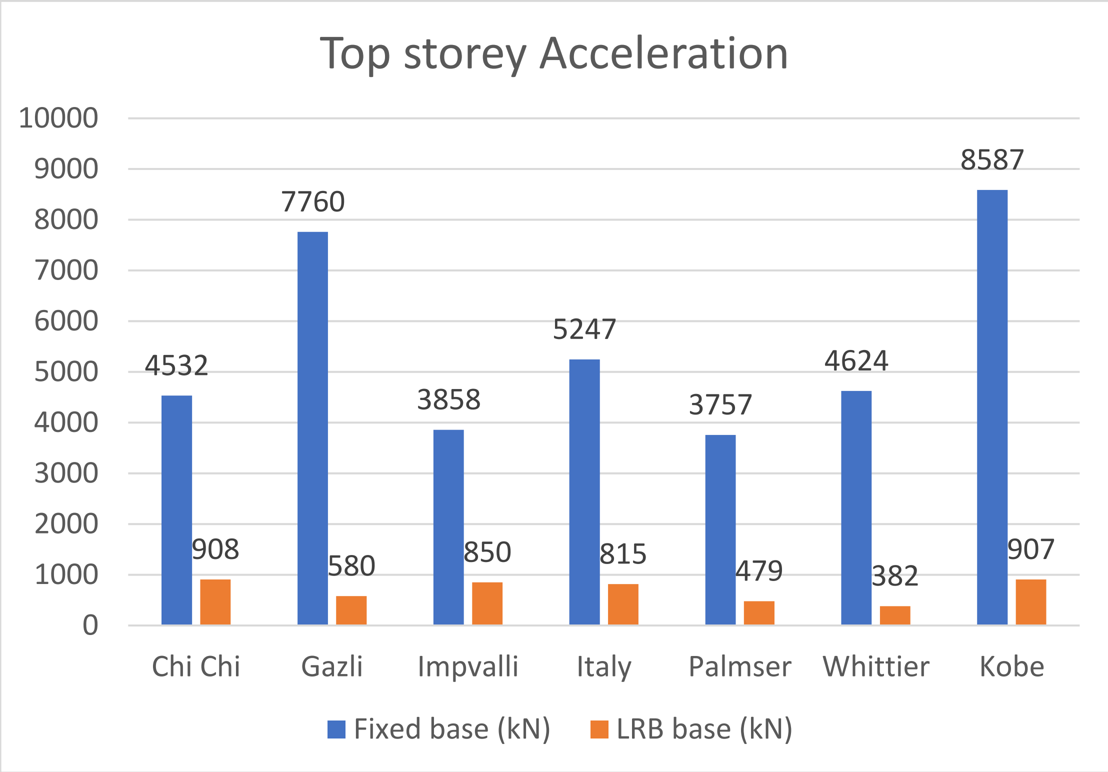

Figure 8: Comparison of Top story acceleration for 18 storey fixed and base isolated building under selected earthquake records

3.4 Discussion

The results confirm that LRB isolation produces reliable and substantial reductions in force and acceleration demands for both mid-rise and high-rise RC frames. The isolation system remains effective under both far-field and near-fault excitations, although control of inter-storey drift under strong velocity pulses requires additional design attention. The slightly lower percentage reductions observed in the taller structure do not diminish the practical value of the system. Pure elastomeric isolation can therefore be confidently employed for mid-rise and high-rise RC moment-resisting frames in regions of moderate to high seismicity, provided isolator properties are selected to achieve an appropriate target period and adequate displacement capacity.

4. CONCLUSIONS

Based on the nonlinear time-history analyses of 10-storey and 18-storey RC SMRF buildings, the following conclusions are drawn:

1. Incorporation of LRBs produced consistent reductions in base shear of 75–92% and in top-storey acceleration of 78–91% for both building heights across all seven ground-motion records.

2. Inter-storey drift ratios were generally reduced under far-field motions, promoting near-rigid-body behaviour of the superstructure. Limited increases (up to 20–25%) occurred under certain strong near-fault pulse-type records, highlighting the need for careful bearing design when such motions are anticipated.

3. Absolute isolated base shears remained below 1600 kN in all cases, indicating that foundation design forces can be substantially reduced.

4. Pure elastomeric isolation using LRBs is highly effective for both mid-rise and high-rise RC frames in regions of moderate to high seismicity. When near-fault ground motions dominate the hazard, supplementary measures such as increased damping or hybrid isolation systems may be warranted.

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Future work should incorporate soil-structure interaction, vertical ground-motion components, thermal degradation of the lead core and irregular plan configurations.

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