Multidisciplinary | Peer-Reviewed
Open Access | Research Journal
ISSN : 3139-2954

Article ID: IRJIST-2026-075
Volume 1 | Issue 2 | 2026
https://doi.org/10.67308/irjist.75

International Research Journal of Innovation in Science and Technology

Seismic Performance of Multi-Storey Composite Column Framed Buildings (G+3, G+5 and G+8) with Lead Rubber Bearing Base Isolation Using SAP2000

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Abstract

In earthquake-sensitive areas, especially for multi-storey buildings, structural damage can be severe due to earthquake-induced forces. Base isolation systems, particularly Lead Rubber Bearings (LRBs), have proven effective in enhancing seismic performance by minimizing the transmission of ground motion to the superstructure. In this study, the seismic behaviour of composite column framed buildings with G+3, G+5, and G+8 configurations was analysed using SAP2000 under fixed-base and LRB base-isolated conditions. Three-dimensional numerical models were developed in accordance with IS 1893:2016 and IS 456:2000 and analysed using the Nonlinear Time History Analysis (NLTH) method. Structural response was evaluated in terms of natural time period, storey displacement, inter-storey drift, and base shear. The results showed that the fundamental time period increased significantly with the introduction of LRB isolation, leading to a reduction in seismic force demand. The base-isolated structures reduced base shear by 50.70%, 44.42%, and 29.42% for G+3, G+5, and G+8 buildings, respectively, while maintaining inter-storey drift values within the permissible code limits. Although the flexibility of the isolation system resulted in increased storey displacements, these remained within acceptable performance limits and contributed to enhanced energy dissipation during seismic events. The findings demonstrate that LRB base isolation effectively reduces seismic demand and enhances the seismic performance of composite column buildings, making it a suitable and reliable solution for the design of resilient multi-storey structures in earthquake-prone regions.

Keywords: Base Isolation; Lead Rubber Bearing (LRB); Composite Column Structure; Nonlinear Time History Analysis; SAP2000; Base Shear, Storey Drift.

1. Introduction

Earthquakes rank among the most catastrophic natural disasters, frequently causing extensive damage to structures, resulting in possible collapse, considerable loss of life, and enormous economic repercussions (Zhang & Lu 2024). An entire structure or a disproportionately significant chunk of it collapses as a result of an initial local failure spreading from element to element (Athira & Kolakkattil 2025). This has prompted engineers and scientists to develop innovative techniques and methods to protect buildings and structures from the destructive forces of earthquakes. (Subramani et. al. 2014).

As a source of food for thought for engineers and scientists, the earthquakes that have occurred in recent times have offered sufficient proof of the performance of various types of structures under a variety of earthquake situations and at a variety of foundation conditions. (Subramani et. al. 2014).

Many researchers worked to improve the base isolation method so that it would work better and have fewer problems because it is so useful (Alberto Di Matteo et. al. 2019). Seismic isolation systems are at the forefront of these technologies, and they are often positioned between a building's structure and its foundation (Zhang & Lu 2024). High-level seismic design strategies, such as seismic isolation and shaking control (dampers) design, have been used to make this happen (Javier Lopez Gimenez 2022).

A technique for improving structural performance that is based on the demand reduction plan is seismic isolation of structures. In order to lessen the seismic response of that segment during earthquake stimulation, it is used to remove all or a portion of the structure from the ground or other structural components (Ghasemi & Talaeitaba 2020). In real life, this approach is put into action by putting low lateral stiffness devices between the building and its foundations. This separates the movement of the structure being supported from the movement of the ground during earthquakes (Domenico et. al. 2019). Numerous buildings have been built on different kinds of seismic bearings, and these structures have proven to perform better during earthquakes (Santhosh et. al. 2013).

Buildings equipped with seismic isolation offer numerous important benefits. Even after powerful earthquakes, the remote buildings will remain secure. (Subramani et. al. 2014) FPB has a historical damping mechanism that uses frictional forces and a restoring mechanism that is based on pendulum motion. (Akazawa et. al. 2024)

Seismic isolation works for both new and existing buildings of any shape. Meanwhile, researchers are developing advanced shape-memory and adjustable mass dampers (Subramani et. al. 2014). Types of base isolators:

- Laminated Rubber (Elastomeric) Bearing.
- High Damping Rubber (HDR) Bearing.
- Lead Rubber Bearing (LRB).
- Sliding bearings.
- Friction Pendulum (FPS) System Bearing.
- Rubber Base System.

The fundamental principle of base isolation system is to rectify the response of the structure in order that the bottom will move below the structure while not transferring these motions into the construction. In a perfect system for the supple this separation would be total. However, within the existing world there's a desire to own some contact between the construction and sub structure (Sahu & Sahu 2019),

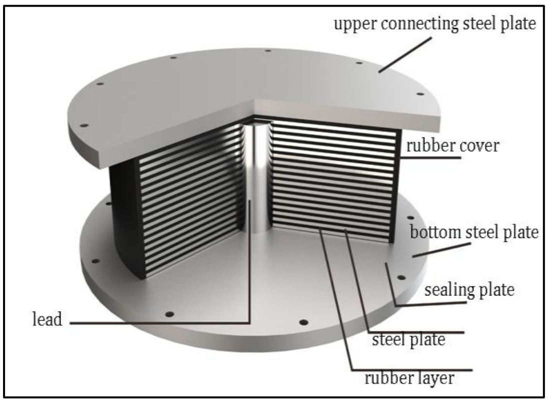


Figure 1: *Rubber Isolator*

2. Literature Review

Zhang and Lu (2024) demonstrated that high damping rubber bearings (HDRBs) with enhanced stiffness properties successfully limit extreme deformations, as their equivalent stiffness coefficient increases alongside deformation amplitude-a behaviour validated through numerical and experimental testing. Akazawa et al. (2024) conducted full-scale shaking table tests on a three-story base-isolated hospital specimen. Their findings revealed that while the sliding coefficient increases under low-contact pressure and low-velocity conditions, a low friction coefficient crucially protects internal medical equipment during near-fault and long-period ground motions. Santhosh et al. (2013) showed that a seismically isolated six-story building experiences substantial reductions in maximum floor acceleration, inter-story drifts, and story shear forces compared to its fixed-base counterpart. Extending this comparison to taller structures, Ghasemi and Talaeitaba (2020) analyzed 12 buildings ranging from 8 to 24 stories using MATLAB-generated cross-sectional curves. They concluded that isolated structures form far fewer plastic hinges at or beyond the Immediate Occupancy (IO) level, and unlike fixed-base buildings, their response modification factor remains unaffected by the seismic design level of the beams and columns. Furthermore, Subramani et al. (2014) provided a global overview of base isolation techniques, emphasizing that incorporating additional damping effectively minimizes seismic responses across diverse ground motions. Supporting these findings, Reddy and Ramesh (2015) utilized ETABS software to model G+5 and G+13 structures, confirming that base-isolated buildings exhibit increased mode periods and significantly reduced base shear, ultimately delivering a superior seismic response compared to traditional fixed-base designs.

Thus, in the current work literature review is executed on the topic of Seismic Performance of multi-storey buildings Composite Column framed Structure with Base Isolation Technique in SAP. Also, the literature review contains a research paper that identified ultimately delivering a superior seismic response compared to traditional fixed-base designs. Various researchers have carried out studies on the aforesaid topic (Sarno et. al. 2011, Lipte et. al. 2018, Sahu & Sahu 2019, Domenico et al 2020, Patil & John 2021, Vaiana et. al. 2021, Shakouri et. al. 2021, Tanwer et. al. 2022, Forcellini & Kalfas 2023, Gambiro et. al. 2023).

The literature review identified the following research gaps: 1) From the reviewed literature, it is evident that most prior studies have concentrated on the seismic performance of low- and medium-rise reinforced concrete or steel buildings equipped with base isolation systems. There is a lack of research on high-rise multi-storey buildings of composite column structures that incorporate base isolation techniques. 2) While researchers have noted that base isolation systems like HDRBs and friction pendulum bearings are effective in reducing base shear, story drift, floor acceleration, and structural damage, the combined seismic behaviour of composite columns and base isolation systems has not been extensively studied using SAP software. 3) Furthermore, earlier studies primarily assessed conventional reinforced concrete buildings under general earthquake loading conditions. However, there is still a need for a detailed comparison between fixed-base and base-isolated multi-story buildings of composite structures under near-fault and long-period ground motions.

3. Objectives

1) To investigate the seismic performance of composite column structure in different seismic zones.
2) To evaluate and compare the performance of G+3, G+5 and G+8 structures under various performance parameters such as base shear, storey displacement, storey drift, natural time period etc. between fixed base and base isolation systems.
3) To investigate various basis isolation methods, particularly the rubber base isolation method, and assess how well they work under seismic loads in comparison to traditional fixed base constructions.

4. Modeling of Structure

In the present study, the seismic response of multi-storey buildings (G + 3, G + 5 and G + 8) using Lead Rubber Bearings (LRB) as base isolation systems designed in SAP 2000 software is investigated. This paper's goal is to use SAP2000 software to analyze the composite column building structure of a multi-storey building (G + 3, G + 5, and G + 8). It uses SAP2000 to do a software seismic study of the entire structure using the time history technique. SAP2000 is the most complete, effective, and most useful general purpose structural program on the market.

The study was carried out using SAP2000, which was used to compare the seismic performance of fixed-base and base-isolated models of G + 3, G + 5, and G + 8 composite column buildings. 3D models consisted of rigid diaphragms at each floor and frame and shell elements for beams, columns and slabs. The material qualities have been designed based on the design codes and loads (Dead load, Live load and Seismic load) have been applied as per standards (IS 456: 2000). The nonlinear link components allow for horizontal flexibility while preventing vertical and rotational motion in a lead rubber bearing (LRB) isolation system. Response spectrum and nonlinear time-history techniques were used in the analyses, which evaluated floor accelerations, interstory drift, and base shear reduction. Six models were used as part of the study, and are presented below. Elevations are shown in figures 2, 3 and 4 and a plan view is shown in figure 5. The adopted methodology enabled a systematic assessment of base isolated structures seismic resilience.

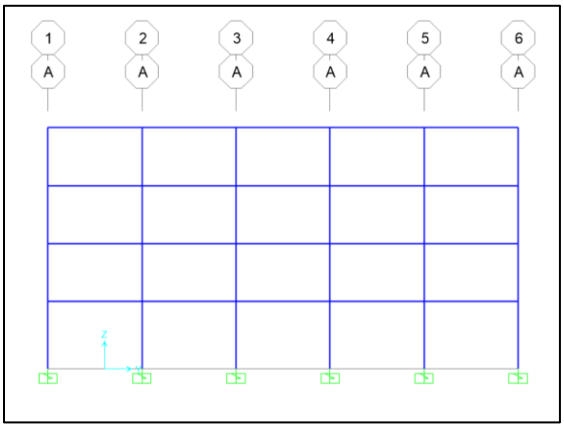


Figure 2: *Elevation of G + 3 model*

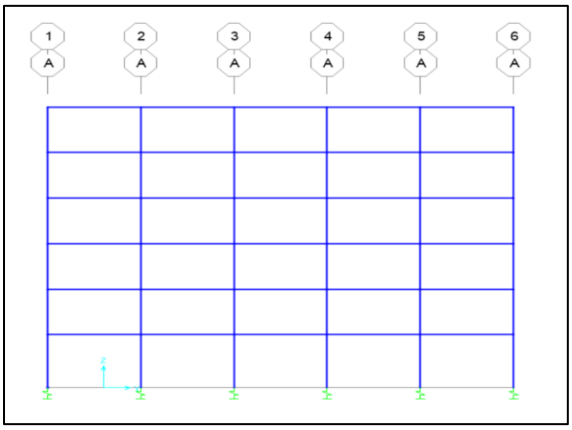


Figure 3: *Elevation of G + 5 model*

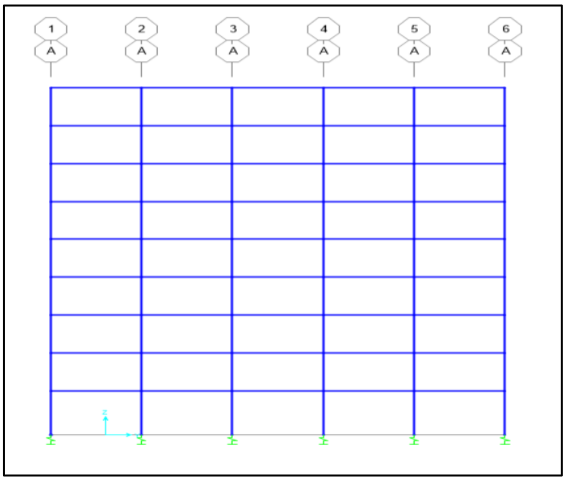


Figure 4: *Elevation of G + 8 model*

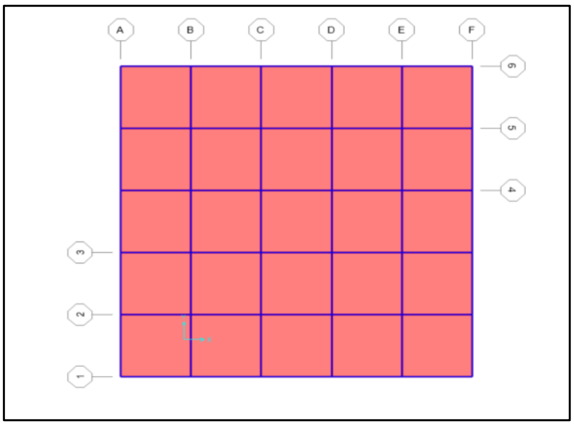


Figure 5: *Plan view of the models*

The cross-sectional properties of the components listed in Table 2 are used in the modelling with SAP2000 software, while the geometric parameter of the building frames are listed in Table 1.

Table 1: *Structural geometric parameters*

Model parameters	**Values**		
	G+3	**G+5**	**G+8**
Structure type	Composite Column Framed Structure ISMB 300		
Total number of stories	4	6	9
Height of ground storey	3.5 m	3.5 m	3.5 m
Height of upper stories	3.0 m	3.0 m	3.0 m
Total height of the building	12.5 m	18.5 m	27.5 m
Number of bays in x direction	5	5	5
Number of bays in y direction	5	5	5
Width of bay in x direction	5 m	5 m	5 m
Width of bay in y direction	5 m	5 m	5 m

Table 2: *Cross-sectional properties*

Elements	Cross-sectional area		
	G+3	G+5	G+8
Column	450 × 450	500 × 500	500 × 500
Beam	350 × 400	350 × 400	400 × 400
Slab thickness	150 mm	150 mm	150 mm

After finding out the configuration of the building, the next step was to assign material properties as specified in Table 3 to the structural models. The structural models (G + 3, G + 5 and G + 8) were subjected to various load combinations, as per the applicable codes of practices like IS 875 (1987) & IS 1893 (2016).

Gravity loads such as dead loads and live loads were calculated based on the functional requirements of the building, and the zone factor and soil condition were considered in calculating seismic loads. The amount and distribution of vertical loads (dead and live loads) applied on each level of the structure, including structural self-weight and floor finishes, is summarized in Table 4.

The lateral load distributions for seismic analysis provided in Table 5 along with the response spectrum parameters used in the dynamic analysis and equivalent static load as per IS 1893 (2016) are shown.

Table 3: *Material properties*

Properties (Concrete)	Values	Properties (Rebar)	Values
Grade	M30	Grade	HYSD 500
Unit weight	25 kN/m³	Mass per unit volume	7810 kg/m³
Poisson ratio	0.2	Modulus of Elasticity	2.5 × 10⁵ MPa
Coefficient of thermal expansion	5.5 × 10⁻⁶ /°C	Coefficient of Thermal Expansion	11.7 × 10⁻⁶ /°C
Shear modulus	11,410 MPa	Minimum Yield Strength (fy)	500 MPa
Modulus of elasticity	27,386 MPa	Minimum Tensile Strength (fu)	545 MPa
Damping ratio	5%	–	–
Compressive strength (fck)	30 MPa	–	–

Table 4: *Loads considered in the study*

Loads	Values		
	G+3	G+5	G+8
Dead load	Self-weight of beams, columns and slabs		
Live load	3.0 kN/m²	3.0 kN/m²	3.0 kN/m²

Table 5: *Seismic loading parameter*

Parameters	G+3	G+5	G+8
Earthquake load	Response spectrum		
Seismic zone	V	V	V
Zone factor	0.36	0.36	0.36
Importance factor	1.0	1.0	1.0
Site type	II	II	II
Response reduction factor	3	3	3
Damping	5%	5%	5%

The base-isolated models (G + 3, G + 5 and G + 8 with LRB) were treated in particular, as they used lower seismic forces above the isolation point to demonstrate the energy dissipation characteristics of the lead rubber bearings. LRBs are constructed of steel shims (Fe 450/500) for vertical stiffness, vulcanized rubber layers (IHRD 60 hardness) and a lead core for energy dissipation. To achieve a proper compromise between flexibility and stability, important parameters such as shape factor, diameter to height ratio and mechanical characteristics of LRBs are optimized in the design. If the height is too great, the structure may buckle and if too low, it may not allow displacement as this is required to ensure the seismic performance. The material properties assigned to the LRB of the base-isolated models 4, 5 and 6 are shown in Table 6.

Table 6: *Material properties of LRB*

LRB elements	LRB properties	Values
Rubber	Young's modulus [E]	4.45 MPa
	Rubber hardness	60
	Shear modulus [G]	1.06 MPa
	Elongation upon rubber breakage [ξb]	400% (4.0)
	Material constant/modification factor [k]	0.57
	Design shear strain [γmax]	50% (0.5)
	Effective damping [ξeff]	5% (0.05)
Lead core	Yield strength of lead core [fpy]	8820 kN/m2
	Allowable normal stress [σc]	7840 kN/m2
Steel plate	Yield strength of steel plate [fy]	2.74×105 kN/m2
	Shear yield strength of steel [fs]	1.65× 105 kN/m2

The models to be built in the SAP2000 Software for Fixed supports and rubber base isolator support will appear as in Figures.

- Model 01: G + 3 with fixed base.
- Model 02: G + 5 with fixed base.

- Model 03: G + 8 with fixed base.
- Model 04: G + 3 with LRB (base isolated).
- Model 05: G + 5 with LRB (base isolated).
- Model 06: G + 8 with LRB (base isolated).

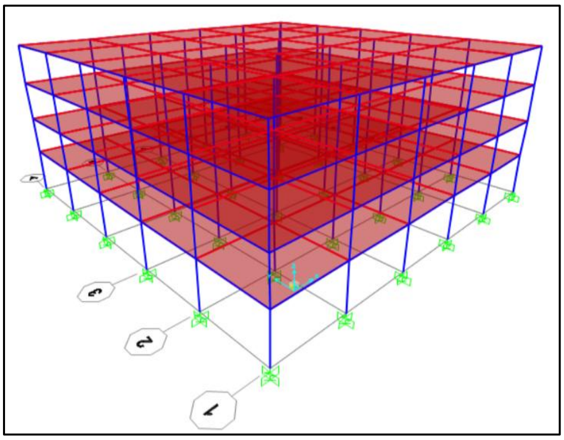


***Figure 6:** Model 01: G + 3 with fixed base*

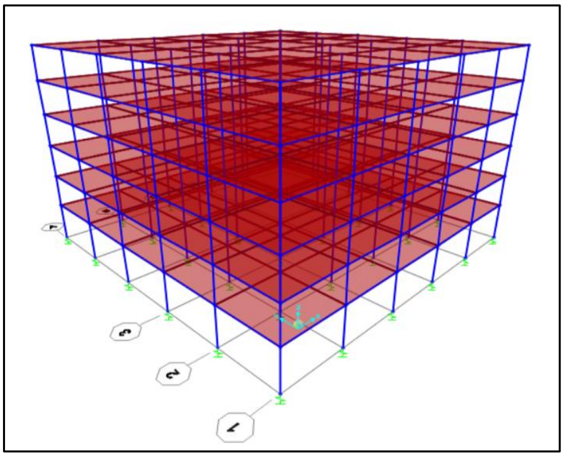


***Figure 7:** Model 02: G + 5 with fixed base*

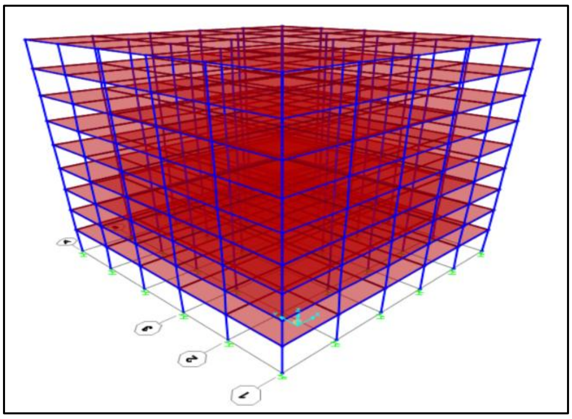


***Figure 8:** Model 03: G + 8 with fixed base*

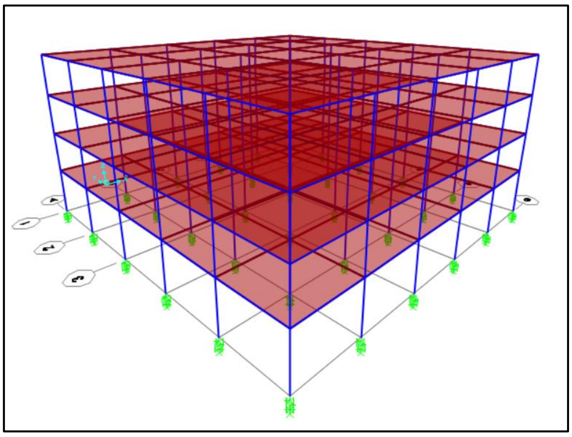


***Figure 9:** Model 04: G + 3 with LRB (base isolated)*

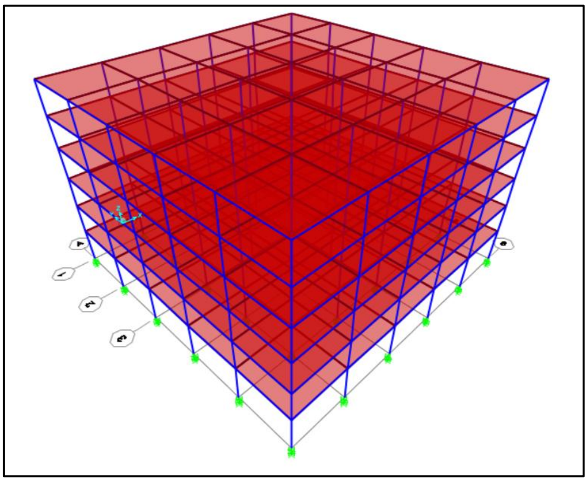


Figure 10: Model 05: G + 5 with LRB (base isolated)

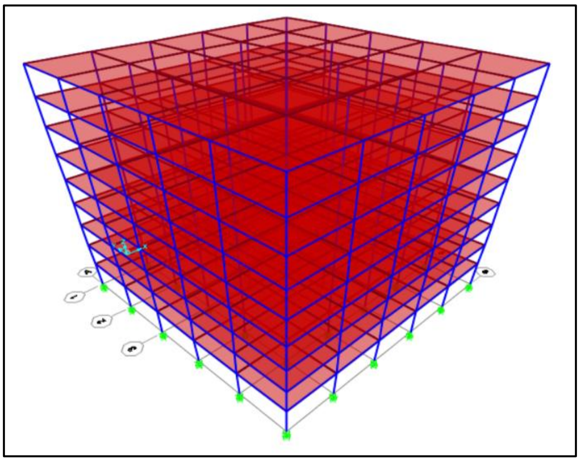
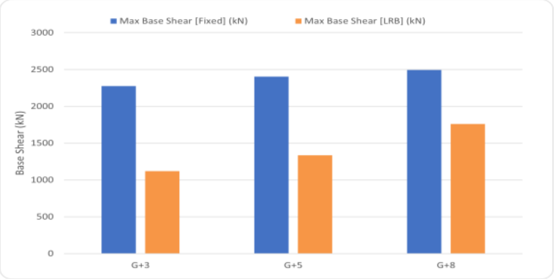


***Figure 11:** Model 06: G + 8 with LRB (base isolated)*

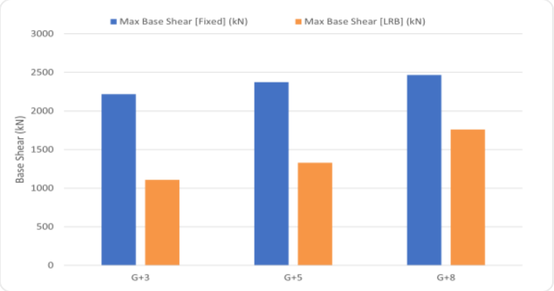
5. Results And Discussion

In this work the performance and effectiveness are studied for composite column building structure under seismic loading by carrying out time history analysis. The analytical work carried out with reference to this objective. The results obtained with respect to the following parameters.

Base Shear : Through comparing the maximum base shear obtained from the fixed-base and base-isolated models, it is shown in both Graphs 1 and 2 how the seismic stress is minimized at various building heights using LRB. The G + 3 structure's base shear decreases by 50.70% (from 2274.192 kN to 1120.957 kN), whereas the G + 5 and G + 8 structures see reductions of 44.42% and 29.42%, respectively. LRBs greatly lessen the inertial forces transmitted to the superstructure by lengthening the structure's natural period and moving it away from the prominent frequencies of seismic ground vibrations. This greater percentage reduction for low-rise buildings (G + 3) than mid-rise buildings (G + 5 and G + 8) is to be expected since the shorter, stiffer buildings will gain more from the time shifting effect of base isolation.

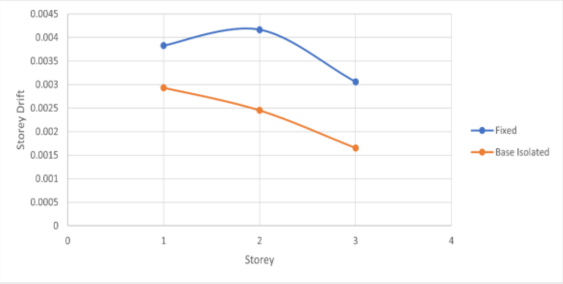


Graph 1: *Base shear in X direction*

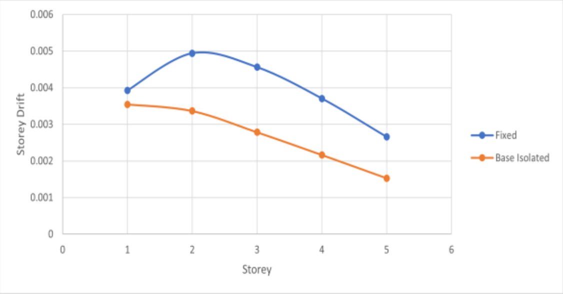


Graph 2: *Base shear in Y direction*

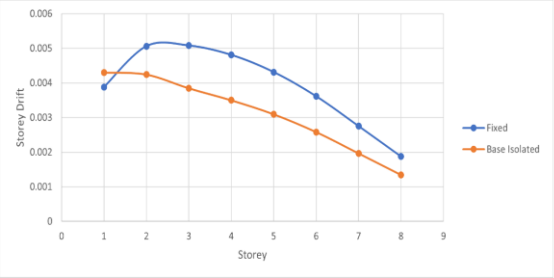
Storey Drift : The results indicate a reduction in storey drift with increasing building height. The storey drift values are highest at the base of the structure, and the storey drift values in fixed base structures are relatively larger than the base isolated structures. In the case of a multistorey model considered, it is obvious that the number of storied is inversely proportional to that of storey drift. Fixed base structures have relatively higher storey drift values than base isolated structures, with the highest storey drift value occurring at the base of the structure.



Graph 3: *Storey Drift of G + 3 model*



Graph 4: *Storey Drift of G + 5 model*



Graph 5: *Storey Drift of G + 8 model*

The inter-storey drift ratio is an important parameter used to evaluate the relative lateral movement between adjacent floors during seismic excitation. Table 7 presents the inter-storey drift ratios in the +X direction for the G+3 building model. Response spectrum analysis shows that the maximum drift values for the fixed-base and base-isolated structures are 0.001389 and 0.000816, respectively. The base-isolated model exhibited a significant reduction in inter-storey drift compared with the fixed-base structure. Furthermore, the obtained drift values are within the permissible limits specified in IS 1893:2016, indicating satisfactory seismic performance.

Table 8 presents the inter-storey drift ratios in the +X direction for the G+5 building model. The maximum drift values obtained from the response spectrum analysis are 0.001647 for the fixed-base structure and 0.00112167 for the base-isolated structure. The results indicate that the implementation of Lead Rubber Bearing (LRB) isolation effectively reduces inter-storey drift and improves the seismic response of the structure. The obtained drift values are within the permissible limits specified in IS 1893:2016.

Table 9 presents the inter-storey drift ratios in the +X direction for the G+8 building model. The maximum drift values obtained from the response spectrum analysis are 0.001687 for the fixed-base structure and 0.00141467 for the base-isolated structure. Similar to the G+3 and G+5 models, the base-isolated structure demonstrated lower inter-storey drift values than the fixed-base structure. All obtained drift values satisfy the requirements of IS 1893:2016, confirming the effectiveness of the LRB isolation system in controlling seismic deformation.

Table 7: *Inter storey drift ratio of G + 3 model*

Storey	Drift ratio [Fixed base]	Drift ratio [Isolated base]	Drift reduction (%)
3	0.001019667	0.000551667	45.89
2	0.001389	0.000818	41.11
1	0.001094	0.000838571	23.35
0	0	0	--

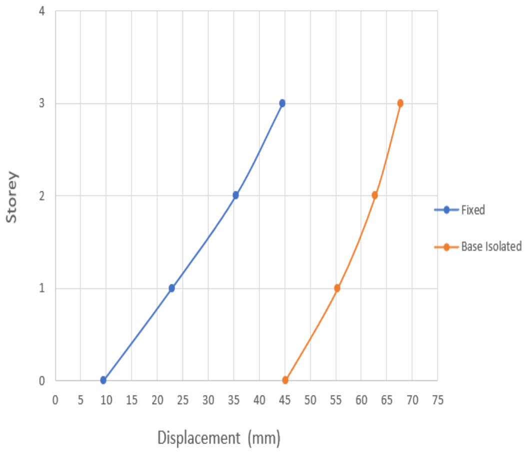
Table 8: *Inter storey drift ratio of G + 5 model*

Storey	Drift ratio [Fixed base]	Drift ratio [Isolated base]	Drift reduction (%)
5	0.000885667	0.000509667	42.45
4	0.001235	0.000721667	41.57
3	0.001520333	0.000928333	38.94
2	0.001647	0.000112167	31.9
1	0.001121429	0.001013143	9.66
0	0	0	--

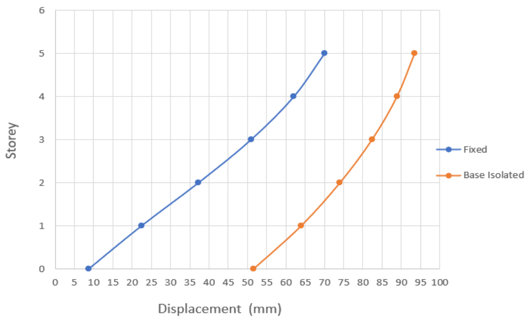
Table 9: *Inter storey drift ratio of G + 8 model*

Storey	Drift ratio [Fixed base]	Drift ratio [Isolated base]	Drift reduction (%)
8	0.000624667	0.000448	28.28
7	0.000917333	0.000655333	28.56
6	0.001204667	0.000860667	28.56
5	0.001437333	0.001031667	28.22
4	0.001602667	0.001166667	27.2
3	0.001693333	0.001282	24.29
2	0.001687333	0.000141467	16.16
1	0.001108571	0.001229143	10.88
0	0	0	--

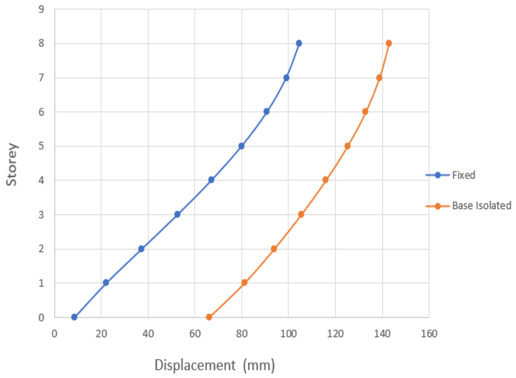
Storey Displacement: Graphs 6, 7, and 8 show that the displacement (X-direction) of multi-storey buildings (G + 3, G + 5, and G + 8) composite column structural systems is different for fixed base and rubber base isolation systems. From the graph it can be inferred that the base isolation system has greater storey displacement than the fix base system.



Graph 6: *Displacement of G + 3 model*



Graph 7: *Displacement of G + 5 model*



Graph 8: *Displacement of G + 8 model*

In order to precisely evaluate a structure's seismic performance under actual earthquake loading conditions, Nonlinear Time History analysis (NLTH) looks at storey displacements. Unlike basic linear analysis techniques, the NLTH analysis takes into account important nonlinear phenomena that can have a significant impact on displacement demands, such as material yielding, geometric nonlinearity (P-Delta effects), and isolation system hysteresis. The NLTH analysis displacements for the models G + 3, G + 5, and G + 8 are shown in Tables 10, 11, and 12, respectively.

Table 10: Storey Displacement of G + 3 model

Storey	Fixed Base	Base Isolator [LRB]
3	44.5769	67.7499
2	35.3992	62.783
1	22.8962	55.4184
0	9.4919	45.1433
Base	0	0

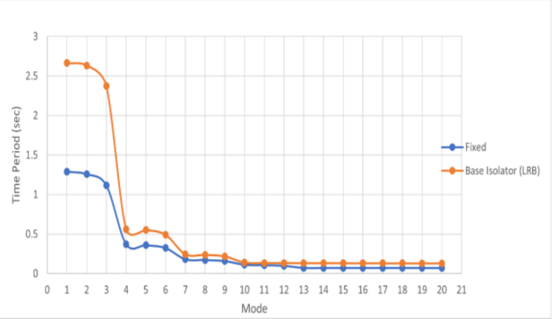
Table 11: *Storey Displacement of G + 5 model*

Storey	Fixed Base	Base Isolator [LRB]
5	70.0222	93.5268
4	62.0504	88.9369
3	50.9345	82.4408
2	37.251	74.0835
1	22.4279	63.9878
0	8.6899	51.5761
Base	0	0

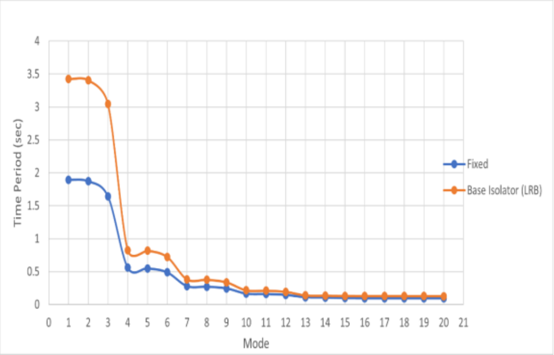
Table 12: *Storey Displacement of G + 8 model*

Storey	Fixed Base	Base Isolator [LRB]
8	104.6967	142.9053
7	99.0728	138.8717
6	90.816	132.9729
5	79.9715	125.2254
4	67.0344	115.9395
3	52.6103	105.4372
2	37.368	93.8974
1	22.1796	81.1644
0	8.5965	66.1046
Base	0	0

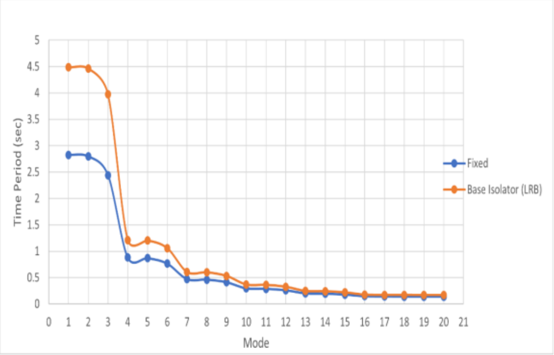
Time Period: Graphs 9, 10, and 11 show the variation in the natural time period of these three structures, for different fixed base and rubber base-isolated systems. The results indicate that the duration period becomes significantly longer when rubber base isolation is employed in preference to fixed base condition. Maximum time duration for the isolated models increases from 2.66 to 4.48 seconds while for the fixed-base models it increases from 1.29 to 2.82 seconds. This longer time period also helps to reduce the seismic load transfer to the superstructure and increase the structural flexibility.



Graph 9: *Time period of G + 3 model*



Graph 10: *Time period of G + 5 model*



Graph 11: *Time period of G + 8 model*

6. Conclusion

In the current research, the seismic behavior of multi-storey composite column structures (G+3, G+5 and G+8) with both fixed-base and Lead Rubber Bearing (LRB) base-isolated systems was studied using Nonlinear Time History Analysis (NLTH). This study focused on important seismic parameters such as natural time period, storey displacement, inter-storey drift, and base shear to evaluate the effectiveness of base isolation under earthquake loading.

The results indicate that the use of LRB base isolation can considerably increase the natural period of the structure compared with the fixed-base system. The increased time period improves structural flexibility and reduces the seismic forces transmitted to the superstructure. The isolated models showed longer time periods for all building heights, demonstrating the influence of the isolation system on the dynamic behaviour of the structures.

The study also observed higher storey displacements in base-isolated buildings compared to fixed-base buildings. This increase in displacement is a result of the isolation system allowing controlled lateral movement at the base level, thereby absorbing and dissipating earthquake energy. Although displacement increases, it remains within acceptable performance limits and helps minimize damage to structural elements.

All base-isolated models exhibited a substantial decrease in inter-storey drift when compared to the fixed-base models. The maximum drift values obtained for both systems were within the permissible limits specified in IS 1893:2016. Furthermore, all obtained inter-storey drift ratios satisfied the code requirements. The reduction in inter-storey drift indicates improved structural integrity and minimizes the risk of structural and non-structural damage during seismic events.

The benefits of the isolation system were further observed through the comparison of base shear values. When LRB isolation was provided, the base shear was reduced by 50.70% for the G+3 building, 44.42% for the G+5 building, and 29.42% for the G+8 building. The results indicate that the period-shifting effect of base isolation is more pronounced in shorter and stiffer buildings, resulting in greater reductions in seismic demand.

In conclusion, the study demonstrates that Lead Rubber Bearing (LRB) base isolation significantly enhances the seismic performance of composite column buildings by reducing base shear and inter-storey drift while increasing structural flexibility. Therefore, LRB base isolation can be considered a practical and reliable solution for multi-storey composite column buildings located in earthquake-prone regions.

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