© MAY 2026 | IRE Journals | Volume 9 Issue 11 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I11-1717435

Seismic Performance Evaluation of Vertically Regular and Irregular High-Rise Structures with Base Isolation Using Response Spectrum Analysis

FARDIN JAMADAR[1], SURENDRANATH JADHAV[2], SANDEEP SAWANT[3]
[1] PG Student, Department of Civil Engineering, KIT's College of Engineering (Empowered Autonomous), Kolhapur, India.
[2, 3] Assistant Professor, Department of Civil Engineering, KIT's College of Engineering (Empowered Autonomous), Kolhapur, India.

Abstract- This study investigates the seismic performance of vertically regular and irregular high-rise structures using response spectrum analysis. Four structural configurations are considered: regular fixed-base, regular base-isolated, irregular fixed-base, and irregular base-isolated models using Lead Rubber Bearings (LRB). The buildings are modeled in ETABS with identical geometry, material properties, and loading conditions, and seismic analysis is carried out in accordance with IS 1893 (Part 1): 2016. Vertical irregularity is introduced in the form of setback geometry along the height of the structure. Key response parameters such as base shear, storey displacement, storey drift, and overturning moment are evaluated. The results indicate that vertically irregular structures exhibit different seismic behavior compared to regular structures due to uneven distribution of stiffness and mass, leading to localized effects such as drift concentration. The introduction of base isolation significantly reduces seismic forces and improves overall structural performance. Composite structures demonstrate better response compared to RCC structures due to reduced mass and enhanced ductility. Among all configurations, the base-isolated composite structure shows the most efficient seismic performance, achieving significant reduction in base shear and overturning moment while maintaining acceptable deformation limits.

Index Terms- Response Spectrum Analysis, Vertical Irregularity, Lead Rubber Bearing (LRB), Base Isolation, RCC Structure, Composite Structure, High-Rise Building, Seismic Performance, ETABS, Storey Drift

I. INTRODUCTION

Rapid urbanization and increasing population have led to the construction of high-rise buildings, especially in seismic-prone regions. These structures are highly susceptible to earthquake-induced forces due to their considerable height, mass, and flexibility. Accurate evaluation of seismic response is therefore essential to ensure structural safety and serviceability. Conventional analysis methods such as equivalent static and response spectrum analysis are widely used in design practice; however, the response spectrum method provides a more reliable estimation of dynamic behavior under seismic loading as per IS 1893 (Part 1): 2016 [2].

Vertical irregularities in buildings, such as setbacks along the height, significantly influence seismic performance by causing discontinuities in mass, stiffness, and strength distribution. These irregularities lead to concentration of stresses and increased deformation at specific levels, making structures more vulnerable during earthquakes. Previous studies have shown that composite structures perform better than conventional RCC structures due to reduced self-weight and improved ductility [7], [8]. However, the presence of vertical irregularity can alter structural response and requires detailed investigation using appropriate analysis methods.

To enhance seismic performance, base isolation systems such as Lead Rubber Bearings (LRB) are widely adopted, as they reduce the transmission of seismic forces by increasing structural flexibility and dissipating energy [5], [6]. In this study, the seismic behavior of vertically regular and irregular high-rise structures is evaluated using response spectrum analysis. Four models—regular fixed-base, regular base-isolated, irregular fixed-base, and irregular base-isolated—are analyzed to understand the combined effects of vertical irregularity and base isolation on structural response parameters such as base shear, displacement, drift, and overturning moment.

II. LITERATURE REVIEW

Seismic analysis of high-rise structures has been widely studied using dynamic methods to accurately capture structural response under earthquake loading. Chopra [1] emphasized that response spectrum and time history analyses provide more reliable results compared to static methods, particularly for multi-storey buildings. The provisions of IS 1893 (Part 1): 2016 [2] also recommend response spectrum analysis for evaluating seismic forces in high-rise structures. Several studies have investigated the performance of different structural systems, where Patil and Pujari [7] and Patidar and Maru [8] reported that composite structures exhibit improved seismic performance compared to RCC structures due to reduced mass and enhanced ductility. Chowdhury et al. [9] further confirmed that composite systems contribute to better structural efficiency and resilience under seismic loading.

Base isolation has emerged as an effective technique for improving seismic performance by reducing the transfer of ground motion to the superstructure. Kelly [5] demonstrated that Lead Rubber Bearings (LRB) increase the fundamental time period and dissipate energy through hysteretic behavior, resulting in reduced base shear and structural forces. Naeim and Kelly [6] further developed design methodologies for base-isolated structures and highlighted their effectiveness in minimizing seismic damage. However, limited research has focused on the combined influence of vertical irregularity and base isolation in high-rise buildings. Vertical irregularities, such as setbacks, introduce discontinuities in stiffness and mass distribution, leading to concentration of forces and increased vulnerability. Therefore, this study aims to evaluate the seismic performance of vertically regular and irregular high-rise structures with and without base isolation using response spectrum analysis.

III. METHODOLOGY

TABLE 1. Methodology Adopted in the Study

Step No.	Description of Methodology
1	Selection of G+ high-rise building geometry for both regular and vertically irregular configurations
2	Modelling of regular and irregular structures in ETABS software
3	Assignment of material properties as per IS 456 and relevant steel design codes (IS 800)
4	Application of dead load, live load, and floor finish loads as per IS 875
5	Definition of response spectrum function as per IS 1893 (Part 1): 2016
6	Response Spectrum Analysis of fixed-base regular and irregular models
7	Modelling of Lead Rubber Bearings (LRB) at foundation level with appropriate stiffness and damping properties
8	Response Spectrum Analysis of base-isolated regular and irregular models
9	Extraction of key response parameters such as base shear, storey displacement, storey drift, and overturning moment
10	Comparative evaluation of seismic performance between regular and irregular structures with and without base isolation

IV. MODELING AND DESIGN

A G+ high-rise building is modeled in ETABS to evaluate the seismic performance of vertically regular and irregular structures under fixed-base and base-isolated conditions. Vertical irregularity is introduced through setback geometry along the height. Material properties are assigned as per IS 456: 2000 [3] and IS 800: 2007 [4], and loads are applied according to IS 875. Seismic analysis is performed using the response spectrum method as per IS 1893 (Part 1): 2016 [2]. Base isolation is incorporated using Lead Rubber Bearings (LRB) with appropriate stiffness and damping properties [5], [6]. The structural response is evaluated in terms of base shear, storey displacement, storey drift, and overturning moment.

TABLE 2. Parameters of the developed RCC and Composite models

Parameter	Remarks	
	RCC	Composite
Structure type	G+23	G+23
Total No. of stories	23	23
Total height of building from ground floor to terrace	69m	69m
Size of column	700X300mm	600X500mm (ISHB 400)
	750X300mm	600X500mm (ISHB 450)
Size of beam	600X230mm	ISWB 550
	650X230mm	ISWB 450
Thickness of slab/deck slab	150mm	150mm
Wall thickness	230mm	230mm
Typical storey height	3m	3m
Height of parapet wall	1.5m	1.5m
Grade of concrete	M40	M40
Grade of steel (rebar)	Fe 500	Fe 500
Density of RCC	25 kN/m3	25 kN/m3
Density of steel	7850 kg/m3	7850 kg/m3
Live load on each floors except terrace	2 kN/m2	2 kN/m2
Floor finish on each floors	1.5 kN/m2	1.5 kN/m2
Soil type	Soft	Soft
Importance factor (EQ)	1.2	1.2
Response factor value	5 (SMRF)	5 (SMRF)
Damping ratios	0.05	0.05
Composite Stee	-	(Fe 345 grade)
Density of brick	20 kn/m3	20 kn/m3
Wind speed	47 m/sec²	47 m/sec²
Scale Factor	1176.12	1176.12

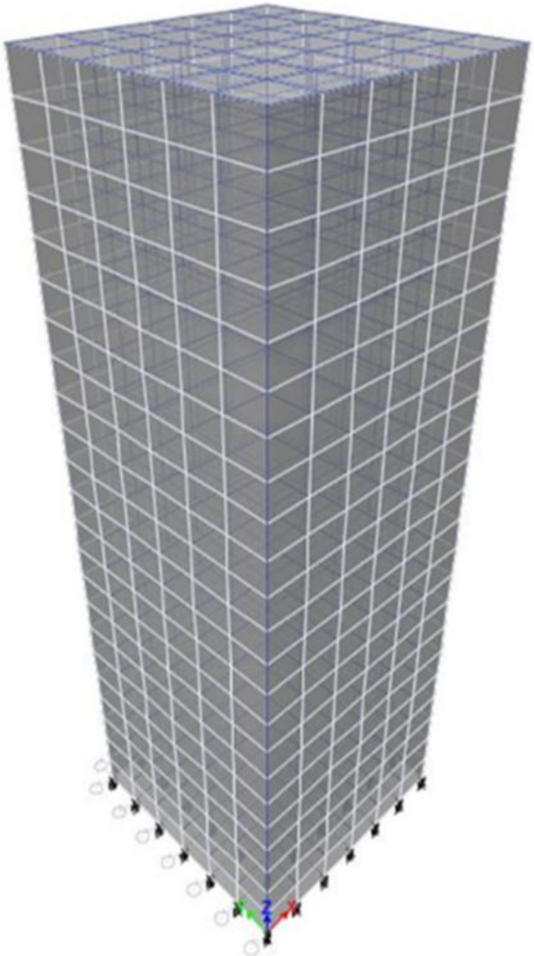

Fig. 1, Uniform Building Model

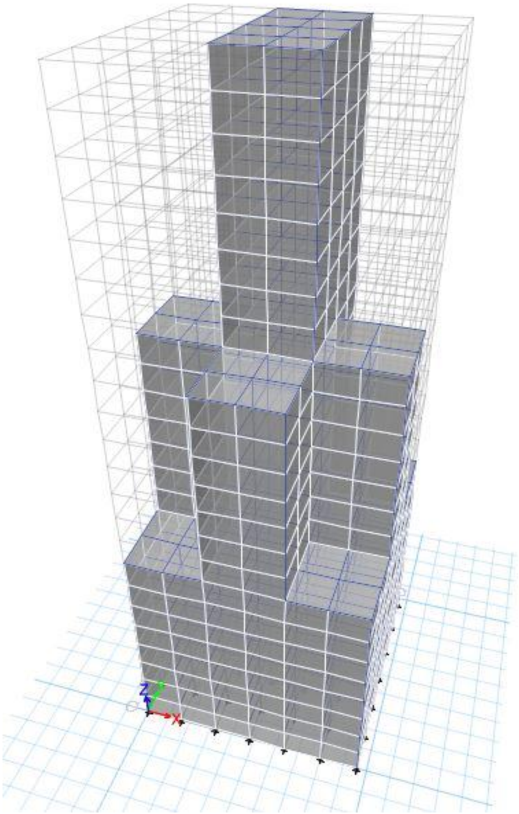

Fig. 2, Non-uniform Building Model

V. RESULTS AND DISCUSSION

1. Base Shear

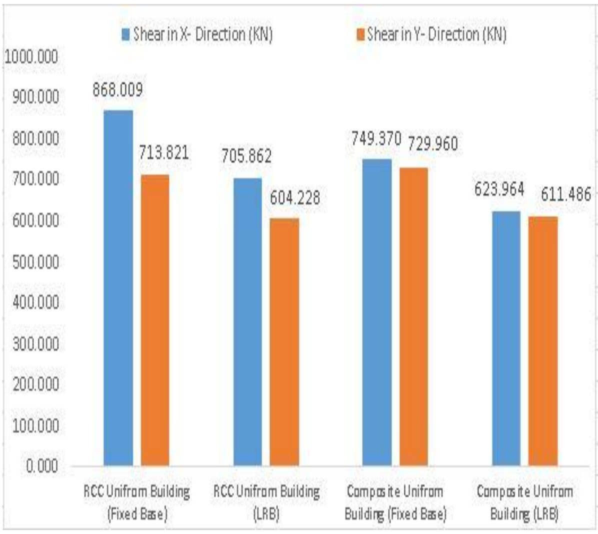

Fig. 3, Base Shear of Uniform Building

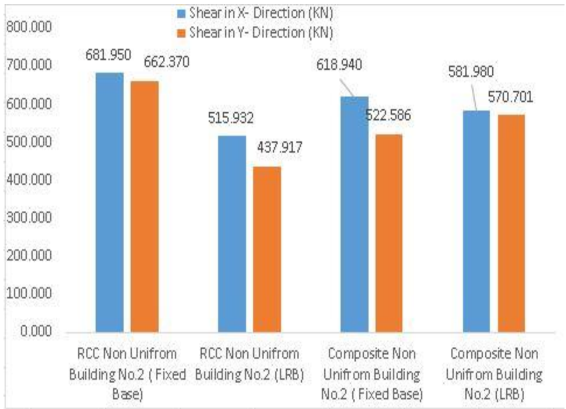

Fig.4, Base Shear of Non-uniform Model

The base shear values for the vertically regular (uniform) building show that the RCC fixed-base model has the highest value of 868.01 kN, which reduces to 705.86 kN with the introduction of LRB. Composite structures show lower values, with 749.37 kN (fixed-base) reducing to 623.96 kN (LRB).

For the vertically irregular building, the base shear values are comparatively lower, with 681.95 kN for RCC fixed-base and 581.98 kN for composite LRB. This indicates that vertical irregularity alters stiffness distribution and reduces overall base shear. The use of LRB results in an approximate reduction of 25–30% in both configurations, demonstrating its effectiveness in minimizing seismic forces.

2. Storey Displacement

Fig. 5, Displacement of Uniform Building

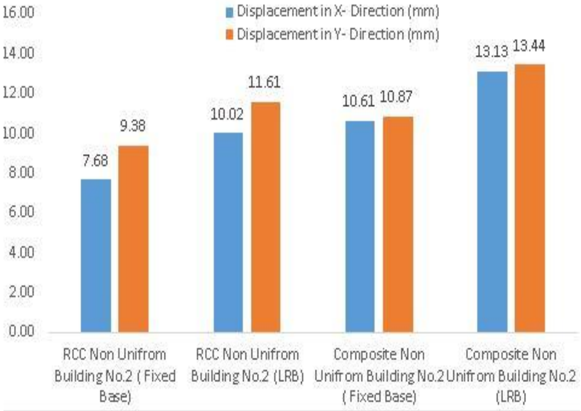

Fig. 6, Displacement of Non-uniform Building

In the regular building, the maximum displacement is observed as 10.20 mm (RCC fixed-base) and increases to 12.95 mm (RCC LRB), while composite structures show values of 11.55 mm (fixed-base) increasing to 13.69 mm with LRB.

For the irregular building, displacement values vary, with 10.02 mm (RCC LRB) and 13.13 mm (Composite LRB). The irregular configuration results in uneven displacement distribution due to geometric discontinuity. The increase in displacement with LRB is expected and indicates enhanced flexibility and energy absorption.

3. Storey Drift

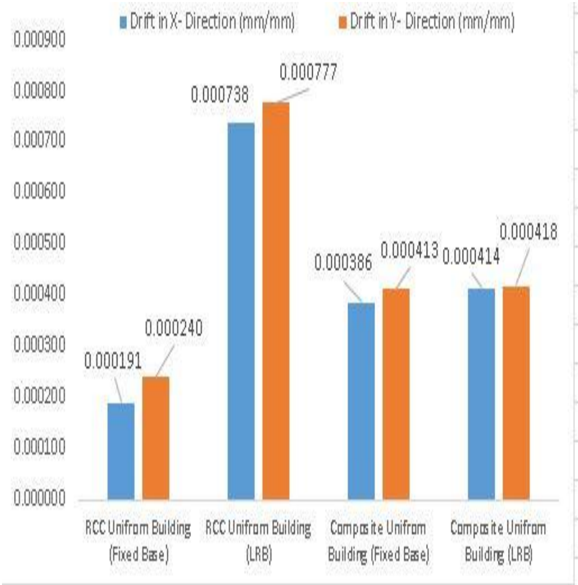

Fig. 7, Storey Drift of Uniform Building

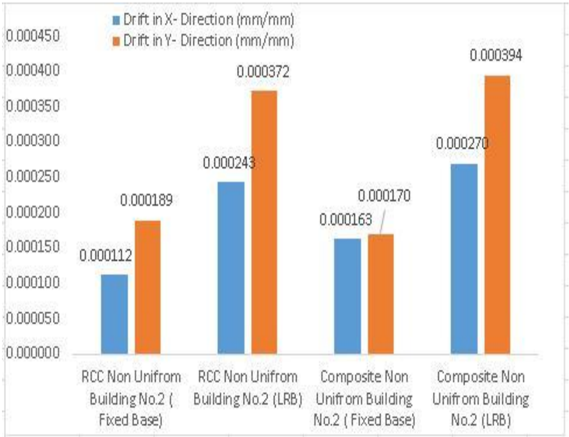

Fig.8, Storey Drift of Non-uniform Building

The storey drift for the regular building shows values of 0.000191 (RCC fixed-base) increasing to 0.000738 (RCC LRB). Composite structures show moderate drift values of 0.000386 (fixed-base) and 0.000414 (LRB).

In the irregular building, drift values are comparatively lower in some regions, with 0.000233 (fixed-base) and 0.000372 (LRB), but show concentration at setback levels. Despite variations, all drift values remain within permissible limits as per IS 1893 (Part 1): 2016, ensuring structural safety.

4. Overturning Moment

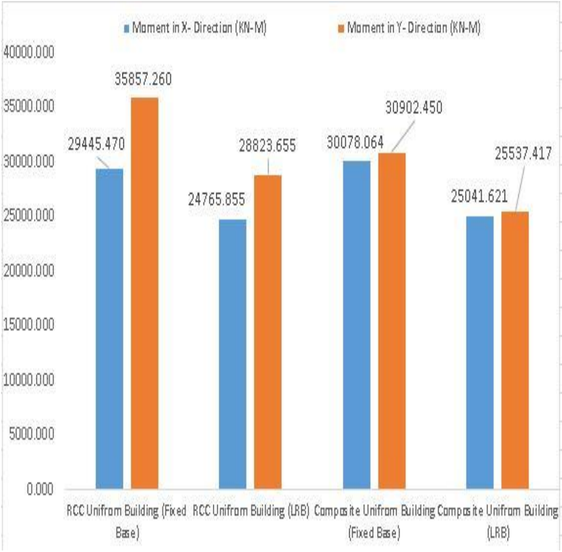

Fig. 9, Overturning Moment of Uniform Building

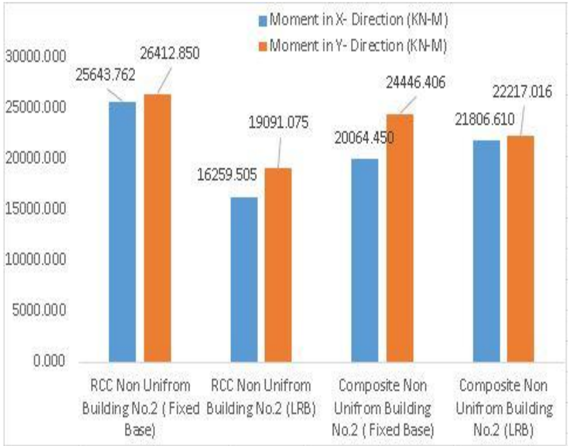

Fig. 10, Overturning Moment of Non-Uniform Building

The overturning moment for the regular building is highest in RCC fixed-base with 29445.47 kN-m, reducing to 24765.86 kN-m with LRB. Composite structures show values of 30078.06 kN-m (fixed-base) reducing to 25041.62 kN-m (LRB).

For the irregular building, overturning moment values reduce to 25643.76 kN-m (RCC fixed-base) and approximately 21806 kN-m (composite LRB). This corresponds to a reduction of nearly 30–40%, indicating improved stability with base isolation.

VI. CONCLUSION

The present study evaluates the seismic performance of vertically regular and irregular high-rise structures under fixed-base and base-isolated conditions using response spectrum analysis as per IS 1893 (Part 1): 2016 [2]. The results indicate that the regular RCC fixed-base model exhibits the highest seismic demand, with base shear of 868.01 kN and overturning moment of 29445.47 kN·m. The introduction of Lead Rubber Bearings (LRB) significantly reduces these values, while composite configurations further improve performance due to reduced mass. Base isolation results in an overall reduction of approximately 25–30% in base shear and 30–40% in overturning moment, demonstrating its effectiveness in minimizing seismic forces.

Vertically irregular structures exhibit different seismic behavior compared to regular structures, with lower global base shear but localized effects such as drift concentration at setback levels. The use of LRB increases displacement due to enhanced flexibility; however, all storey drift values remain within permissible limits as per IS 1893 [2], ensuring structural safety. Overall, base isolation effectively improves seismic performance, and composite structures show superior behavior compared to RCC. Among all configurations, the base-isolated composite model provides the most efficient seismic response, achieving significant force reduction while maintaining acceptable deformation limits.

REFERENCES

[1] A.K.Chopra, ―Dynamics of structures: theory and applications to earthquake engineering,‖ Prentice Hall, 4th ed., pp.1-876, 2012.

[2] IS 1893 (Part 1), ―Criteria for earthquake resistant design of structures,‖ Bureau of Indian Standards, New Delhi, India, 2016.

[3] IS 456, ―Plain and reinforced concrete – code of practice,‖ Bureau of Indian Standards, New Delhi, India, 2000.

[4] IS 800, ―General construction in steel – code of practice,‖ Bureau of Indian Standards, New Delhi, India, 2007.

[5] J.M.Kelly, ―Earthquake-resistant design with rubber,‖ Springer, London, pp.1-240, 1997.

[6] F.Naeim and J.M.Kelly, ―Design of seismic isolated structures: from theory to practice,‖ Wiley, New York, pp.1-350, 1999.

[7] P.Patil and S.Pujari, ―Seismic evaluation of RCC and composite buildings using response spectrum analysis,‖ Int. J. Civil Eng. Res., vol.12, no.3, pp.45-52, 2024.

[8] T.Patidar and S.Maru, ―Comparative study of RCC and composite structures under different soil conditions,‖ Int. J. Res. Appl. Sci. Eng. Technol., vol.12, no.4, pp.112-120, 2024.

[9] M.U.R.Chowdhury, T.Mahamud, M.S.Sarker and M.A.A.Mamun, ―Assessing steel–concrete composite and RCC structures under seismic loading,‖ Discover Civil Eng., vol.1, pp.1-22, 2024.