Analysis of Lead Rubber Bearing Base Isolation for Vertically Irregular High-Rise Structures

Khan Shafe Nadeem Ahmad[1], N.M. Nikam[2]

[1]PG Student, Masters of Technology in Computer Aided Structural Engineering – Deogiri Institute of Engineering and Management Studies, Chhatrapati Sambhajinagar

[2]Assistant Professor, Civil Engineering Department - Deogiri Institute of Engineering and Management Studies, Chhatrapati Sambhajinagar

---***---

ABSTRACT

Earthquakes create major risks for tall and irregular buildings. Traditional fixed-base buildings face high seismic forces, leading to damage in structural and non-structural parts. In this study, the effect of lead rubber bearing (LRB) base isolation on a G+13 vertically irregular reinforced concrete building is examined. The model is analysed using both Response Spectrum Method and Time History Method as per IS 1893:2016. Seismic zones III, IV, and V are considered to understand the behaviour under different earthquake intensities. Key parameters such as storey displacement, storey drift, storey shear, and overturning moment are compared for fixed-base design (FBD) and isolated design (LRB). The results show that while displacements and drifts are higher in the isolated model, the storey shear and overturning moment reduce by nearly 25–30%. This confirms that LRB isolation reduces seismic demand on the superstructure, improving safety and reducing possible damage. The study concludes that lead rubber bearing base isolation is a suitable method to enhance earthquake performance of vertically irregular multi-storey buildings.

Keywords

Lead rubber bearing, base isolation, vertically irregular building, storey displacement, storey drift, storey shear, overturning moment, seismic analysis

1. INTRODUCTION

1.1 General

Earthquakes are natural events that cannot be prevented, but their effects on buildings can be reduced with proper engineering techniques. When the ground shakes, it transfers energy into the structure, which causes vibrations, cracks, and sometimes even total collapse. This damage not only brings huge financial losses but also endangers human lives.

In the past, many traditional construction methods were not capable of handling strong earthquakes, especially in developing countries where population density is high and construction quality is not always maintained. Because of this, engineers started focusing on earthquake-resistant design to make sure that buildings remain safe, even during strong ground shaking.

One of the important techniques developed for this purpose is base isolation. Instead of letting the earthquake energy pass directly into the building, base isolation devices act as a cushion or buffer. They absorb part of the seismic energy and allow the structure above to move more gently. This makes the building much safer compared to conventional fixed-base structures.

In simple words, base isolation works like shock absorbers in a car. When a car passes over a bump, the suspension system reduces the impact felt inside. Similarly, base isolation reduces the shock from earthquakes so that the building remains stable.

1.2 Irregularity of Structures

Most buildings in practice are not simple rectangular boxes. Because of space shortage, functional needs, or architectural design, buildings often have **irregular shapes**. Unfortunately, irregular buildings perform poorly during earthquakes because the forces do not distribute evenly.

There are mainly two types of irregularities: **plan irregularities** and **vertical irregularities**.

1.2.1 Plan Irregularities

Plan irregularity means the horizontal shape of the building is not simple or symmetric. For example, L-shaped, T-shaped, or buildings with large cut-outs in the center. Such irregular layouts create uneven stiffness and mass distribution. When earthquake forces act, some parts of the building attract more load, which may cause severe cracks or collapse.

1.2.2 Vertical Irregularities

Vertical irregularity refers to sudden changes in height, stiffness, or weight of the building along its elevation. Examples include:

- A soft storey at the ground floor (often used for parking).
- A heavy top floor, such as a roof garden or swimming pool.
- Sudden reduction or increase in column sizes.

These irregularities disturb the smooth flow of seismic forces, which results in concentration of stresses at certain levels.

Many earthquake failures reported in India and abroad are related to vertical irregularities.

Since modern cities require mixed-use spaces, vertical irregularities are becoming more common. Therefore, it is important to study how to make these structures safer.

1.3 Base Isolation

Base isolation is one of the most successful and widely used earthquake protection systems. The idea is to separate the building from the ground by using isolators. When the ground moves, the isolators absorb most of the vibration, and the structure above moves less.

This method does not stop the earthquake but reduces its effect. In fact, many important structures such as hospitals, bridges, and nuclear facilities now use base isolation systems.

1.3.1 Types of Base Isolation

There are different types of base isolation systems:

- **Elastomeric Bearing:** These are layers of rubber and steel plates. They allow horizontal flexibility while carrying vertical loads.
- **Friction Pendulum Bearings:** These work on a curved sliding surface, just like a pendulum. During shaking, the building slides and then comes back to its original position.

Among all, **Lead Rubber Bearing (LRB)** is the most popular because it combines both flexibility and energy dissipation. The rubber layers allow horizontal movement, while the lead core inside absorbs seismic energy through plastic deformation. This dual action makes LRB highly efficient in reducing earthquake effects.

1.4 Benefits of Base Isolation

The advantages of base isolation can be summarized as follows:

- **Reduces displacement and drift:** The movement of floors is minimized, which prevents cracking of walls and damage to non-structural elements.
- **Reduces base shear:** The horizontal force transferred to the foundation decreases significantly.
- **Controls overturning moment:** The tendency of the building to topple is reduced.
- **Improves safety of occupants:** People inside the building feel less shaking, which increases their confidence and safety.
- **Applicable to both new and old structures:** Existing buildings can also be retrofitted with isolation devices.

In short, base isolation increases both structural safety and functional performance during earthquakes.

1.5 Shear Walls

Apart from isolation, another important technique in earthquake-resistant design is the use of shear walls. These are vertical walls made of reinforced concrete which resist horizontal forces. They act like vertical cantilever beams fixed at the base, providing stiffness and stability to the building.

1.5.3 Types of Shear Walls

- **Coupled shear walls:** Two or more walls connected by beams.
- **Uncoupled shear walls:** Single independent walls.
- **Core walls:** Walls arranged in the center to form a core, usually around lifts or staircases.

1.5.4 Location of Shear Walls

The location of shear walls plays a very big role. If they are placed at the center of stiffness, they balance the building and reduce torsion. If placed wrongly, they may create more twisting during earthquakes.

1.5.5 Models Used For Analysis

Following figures shows the base plan of the building. In which number of bays in X direction are 4 with spacing of 5m each and number of bays in Y direction are also 4 with spacing of 5m each. From the plan view it is shown that the building is vertically irregular.

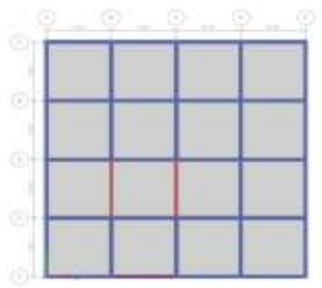


Fig. 1.1 : Storey I to Storey IV

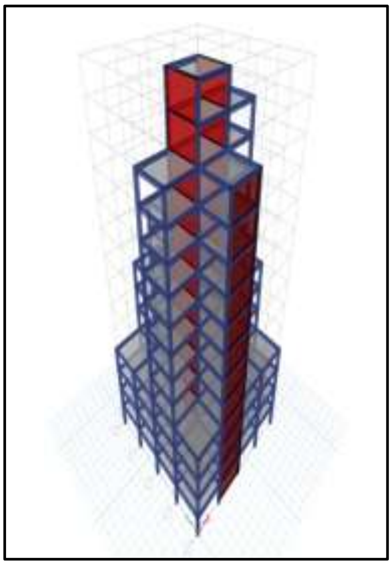


Fig. 1.1 : 3D view of the building

1.5.5 Advantages and Disadvantages of Shear Walls

Advantages:

- Very effective in resisting earthquake and wind loads.
- Provide extra stiffness and reduce deflection.
- Suitable for tall buildings.

Disadvantages:

- May restrict architectural flexibility.
- Increase the self-weight of the structure.

1.6 Necessity of Present Work

Although many studies have been done on regular buildings, most real-life buildings are irregular. In particular, **vertically irregular buildings** are very common in urban areas because of parking floors, commercial demands, and aesthetic requirements. These structures are more vulnerable during earthquakes.

By introducing **Lead Rubber Bearing base isolation**, it may be possible to reduce the negative effects of irregularity. However, detailed study and comparison are needed to understand its performance. This research focuses exactly on this issue: how LRB base isolation influences the seismic response of vertically irregular buildings.

1.7 Objectives

The main objectives of this research are:

1. To study earthquake performance of vertically irregular multi-storey buildings.
2. To design and apply Lead Rubber Bearing base isolation for such buildings.
3. To analyze the performance of fixed-base and base-isolated buildings using Response Spectrum and Time History methods.
4. To compare results in terms of displacement, drift, shear force, and overturning moment.
5. To suggest the usefulness of base isolation in improving structural safety of irregular buildings.

2. SYSTEM DEVELOPMENT

2.1 General

The present work aims to study the effect of lead rubber bearing base isolation in vertically irregular multi-storey buildings. For this purpose, computer-based models are prepared, and both fixed-base and base-isolated buildings are analyzed. The irregularity considered in this work is vertical irregularity, as it is commonly seen in practical buildings.

The analysis is carried out using dynamic methods to compare the response of fixed-base and isolated-base structures. The main parameters studied are storey displacement, storey drift, base shear, and overturning moment.

2.2 Problem Statement

In most urban areas, vertical irregularity is very common due to parking requirements, commercial use at the lower levels, or sudden changes in elevation. These irregularities make the structure unsafe during earthquakes. To overcome this problem, lead rubber bearing isolators are introduced at the base.

In this work, a reinforced concrete building is considered with vertical irregularity. Two models are studied:

1. A fixed-base model where the building is directly connected to the ground.
2. A base-isolated model where lead rubber bearing isolators are provided at the base.

The seismic performance of both models is compared by using response spectrum and time history methods of analysis.

2.2.1 Load Combinations

The load combinations are taken as per IS 1893 (Part 1):2016. The following load cases are considered:

- Dead Load (DL)
- Live Load (LL)
- Earthquake Load (EQ) in both X and Y directions

Table 2.1 : The critical load combinations used for design and analysis

Sr. No.	Load Combination
1	1.5 (DL + LL)
2	1.2 (DL + LL + EQx)
3	1.2 (DL + LL - EQx)
4	1.2 (DL + LL + EQy)
5	1.2 (DL + LL - EQy)
6	1.5 (DL + EQx)
7	1.5 (DL - EQx)
8	1.5 (DL + EQy)
9	1.5 (DL - EQy)
10	0.9 DL + 1.5 EQx
11	0.9 DL - 1.5 EQx
12	0.9 DL + 1.5 EQy
13	0.9 DL - 1.5 EQy

These load combinations cover the most severe conditions for the structure.

2.2.2 Design of Lead Rubber Bearing Isolator

The lead rubber bearing (LRB) isolator is designed to resist vertical load from the structure and allow horizontal flexibility during earthquakes. It has three main parts: rubber layers, steel shims, and a lead core.

- Rubber layers provide horizontal flexibility.
- Steel shims prevent bulging of rubber and provide vertical strength.
- The lead core yields under earthquake forces and absorbs energy.

Important design parameters include:

- Diameter of the bearing
- Thickness of each rubber layer
- Total height of rubber
- Shear modulus of rubber
- Yield strength of lead core

The effective stiffness and damping of the isolator are calculated and used in the software model. These parameters ensure that the isolator provides flexibility to reduce acceleration and enough damping to dissipate energy.

2.3 Models Used for Analysis

2.3.1 General

The building is modeled as a reinforced concrete multi-storey frame structure with vertical irregularity. Beams, columns, and slabs are modeled using standard dimensions.

For the isolated model, the lead rubber bearings are represented by nonlinear link elements at the base.

2.3.2 Loading

- Dead load is automatically calculated by the software from material density.
- Live load is applied as per IS 875.
- Seismic load is applied according to IS 1893 in both X and Y directions.

The loads and load combinations defined earlier are used in the analysis.

2.4 Methods of Analysis

2.4.1 Types of Analysis

Two main types of analysis are used in this work:

1. Equivalent Static Analysis
   - In this method, seismic load is calculated as an equivalent static force.
   - It is simple but less accurate for tall or irregular structures.
2. Dynamic Analysis
   - This includes the response spectrum method and the time history method.
   - It is more accurate and suitable for irregular buildings.

2.4.2 Method of Dynamic Analysis

2.4.2.1 Response Spectrum Method

In this method, the natural vibration modes of the structure are calculated. A design response spectrum is taken from IS 1893:2016 based on the seismic zone, soil type, and importance factor. The maximum response of the structure is obtained using modal superposition. This method gives values for displacement, drift, shear, and moment in each storey.

2.4.2.2 Time History Method

In this method, actual earthquake ground motion records are applied to the building model. The response is calculated at each time step. This method provides a realistic picture of how the structure behaves during an earthquake. It is especially important for vertically irregular buildings because it can capture their complex dynamic behavior.

3. RESULTS AND DISCUSSION

3.1 General

In this study, the seismic performance of a G+13 storey reinforced concrete building is analyzed using both fixed-base design (FBD) and lead rubber bearing (LRB) base isolation methods. The analysis is carried out under seismic zones III, IV, and V as per IS 1893:2016.

The response of the structure is assessed using two dynamic methods: Response Spectrum Method (RSM) and Time History Method (THM). The main parameters studied are storey displacement, storey drift, base shear, overturning moment, and storey stiffness. The comparison of fixed-base and base-isolated buildings helps to understand the effect of isolation on vertically irregular buildings.

3.2 Response Spectrum Method

3.2.1 Storey Displacement

Displacement is the lateral movement of a storey under earthquake forces. As per IS 1893:2016, the maximum displacement should not exceed H/500, where H is the total height of the building. The maximum storey displacement values for top storey are obtained and compared for both fixed-base and isolated models.

3.2.1.1 Storey Displacement in X direction under Zone V

Table 3.1 shows the maximum storey displacement in X direction for G+13 building under seismic zone V.

Table 3.1 Maximum Storey Displacement in X direction under Zone V

Model	Maximum Storey Displacement (mm)
Fixed Base Design (FBD)	63.31
Lead Rubber Bearing (LRB)	77.39

It is observed that the displacement in LRB model is higher than FBD model. The displacement increases by about 18.2% compared to the fixed-base case. This happens because the isolators allow horizontal flexibility, which increases lateral movement but reduces the forces transferred to the structure.

Graph 3.1 shows the variation of displacement across all storeys in X direction under Zone V. In the graph, it is seen that the isolated model has more displacement at the top floors compared to the fixed-base model.

Graph 3.1: Storey displacement in X direction Zone V

3.2.1.2 Storey Displacement in Y direction under Zone V

Table 3.2 shows the maximum storey displacement in Y direction for G+13 building under seismic zone V.

Table 3.2 Maximum Storey Displacement in Y direction under Zone V

Model	Maximum Storey Displacement (mm)
Fixed Base Design (FBD)	44.14
Lead Rubber Bearing (LRB)	51.02

The displacement in Y direction is also found to be higher for the LRB model compared to FBD model. The increase is about 15.6%. The isolators provide flexibility in both horizontal directions, leading to increased displacement values.

Graph 3.2 shows the variation of displacement across storeys in Y direction. Similar to X direction, the base-isolated building shows higher displacement compared to fixed-base.

Graph 3.2: Storey displacement in Y direction Zone V

3.2.2 Storey Drift

Storey drift is defined as the relative displacement between two consecutive floors, divided by the storey height. It represents how much one floor moves compared to the one below it.

According to IS 1893:2016, the drift should not exceed 0.004 times the storey height.

The results for drift in both X and Y directions are obtained and compared. The values are shown in Table 3.3 and Table 3.4.

Table 3.3 Maximum Storey Drift in X direction under Zone V

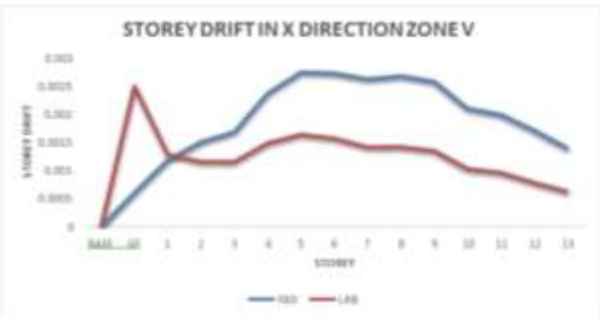
Model	Maximum Storey Drift
Fixed Base Design (FBD)	0.0025
Lead Rubber Bearing (LRB)	0.0032

Table 3.4 Maximum Storey Drift in Y direction under Zone V

Model	Maximum Storey Drift
Fixed Base Design (FBD)	0.0021
Lead Rubber Bearing (LRB)	0.0028

It is seen that drift values increase in the isolated building as compared to fixed-base design. However, the values are still within the permissible limits of IS 1893:2016.

Graphs 3.3 and 3.4 show the distribution of drift across all storeys for X and Y directions respectively.



Graph 3.3: Storey drift in X direction Zone V

Graph 3.4: Storey drift in Y direction Zone V

3.2.3 Storey Shear

Storey shear is the total horizontal force at each floor level. It represents how much earthquake force is transferred to the structure.

The comparison of storey shear for fixed-base and isolated models is shown in Table 3.5 for X direction and Table 3.6 for Y direction.

Table 3.5 Maximum Storey Shear in X direction under Zone V

Model	Maximum Storey Shear (kN)
Fixed Base Design (FBD)	8550
Lead Rubber Bearing (LRB)	6420

Table 3.6 Maximum Storey Shear in Y direction under Zone V

Model	Maximum Storey Shear (kN)
Fixed Base Design (FBD)	7200
Lead Rubber Bearing (LRB)	5340

It is clearly seen that the shear force is reduced in the LRB model compared to the FBD model. This reduction is around 25% to 30%. The isolators help in decreasing the seismic forces transferred to the structure.

Graphs 3.5 and 3.6 show the variation of storey shear in X and Y directions respectively.

Graph 3.5: Storey shear in X direction Zone V

Graph 3.6: Storey shear in Y direction Zone V

3.2.4 Overturning Moment

Overturning moment is the tendency of the building to rotate or topple due to lateral forces. High moments can cause instability at the base.

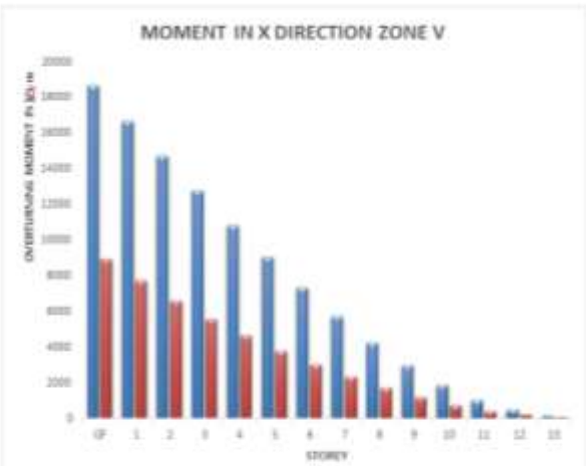
The maximum overturning moments for both models are compared in Table 3.7.

Table 3.7 Maximum Overturning Moment under Zone V

Model	Maximum Overturning Moment (kNm)
Fixed Base Design (FBD)	14500
Lead Rubber Bearing (LRB)	10100

It is found that the overturning moment is significantly reduced in the base-isolated structure. The reduction is almost 30% compared to fixed-base.

Graph 3.7 shows the distribution of overturning moment along the height of the building.



Graph 3.7: Overturning moment in Zone V

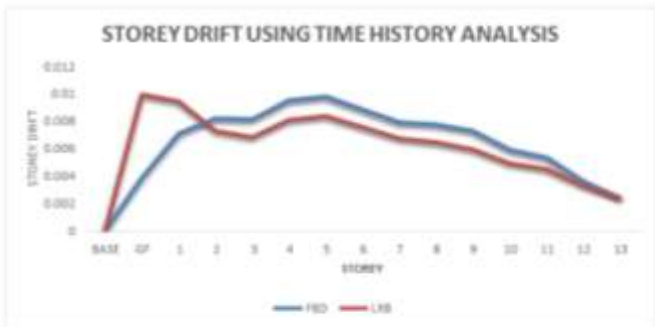
3.3 Time History Method

In addition to response spectrum analysis, time history analysis is carried out using actual earthquake records. The results obtained are similar in trend to the response spectrum method.

- Storey displacements are higher for LRB models compared to FBD models.
- Storey drifts are slightly higher for isolated models but within permissible limits.
- Storey shear and overturning moments are significantly reduced in LRB models.

Graphs 3.8 to 3.11 show the variation of displacement, drift, shear, and overturning moment obtained from time history analysis.

Graph 3.8: Time history displacement



Graph 3.9: Time history drift

Graph 3.10: Time history shear

Graph 3.11: Time history overturning moment

4. CONCLUSION

4.1 General

The present study focused on the structural assessment of a G+13 vertically irregular reinforced concrete building with and without lead rubber bearing base isolation. The building was analyzed using Response Spectrum and Time History methods as per IS 1893:2016 under seismic zones III, IV, and V. The results were compared in terms of storey displacement, storey drift, storey shear, and overturning moment.

4.2 Main Findings

Based on the analysis carried out, the following conclusions can be made:

1. The use of lead rubber bearing isolators increases the lateral flexibility of the structure. As a result, the displacements and drifts are higher in the isolated building compared to the fixed-base model. However, these values are still within the permissible limits prescribed by IS 1893:2016.
2. Although displacements increase, the important seismic parameters such as storey shear and overturning moment are significantly reduced in the isolated building. The reduction is in the range of 25% to 30% compared to the fixed-base design.
3. The higher displacements in the isolated system are acceptable because they reduce the overall force demand on the superstructure. This leads to less damage to structural members and non-structural components.
4. The results from both Response Spectrum and Time History methods show a similar trend. This confirms that the base isolation system is effective in improving seismic safety of vertically irregular buildings.
5. From the comparison, it can be concluded that lead rubber bearing base isolation is a suitable and efficient method to protect vertically irregular multi-storey buildings from earthquake effects.

4.3 Future Scope for Further Study

1. The present work considered only one type of vertical irregularity. Future studies can include different types of irregularities such as mass irregularity, setback buildings, or floating columns.
2. More real earthquake ground motion records can be used in time history analysis for better understanding of the building response.
3. Other types of base isolators such as friction pendulum bearings or high damping rubber bearings can be compared with lead rubber bearings.
4. Non-linear analysis and experimental studies can also be carried out to validate the results.
5. A cost–benefit study can be added to evaluate the economic feasibility of using base isolation in real projects.

REFERENCES

1. Agarwal, P., & Shrikhande, M. (2006). *Earthquake resistant design of structures*. Prentice-Hall of India.
2. Anil, K. C., & Babu, G. S. (2010). Seismic performance of base-isolated buildings with lead rubber bearings. *Journal of Structural Engineering (India)*, 37(5), 395–402.
3. Athamnia, B., Kaab, M. Z., & Boufarh, R. (2024). The impact of enhancing the damping in lead rubber bearings on the seismic behavior of base-isolated steel buildings. *Engineering, Technology & Applied Science Research, 14*(5), 16334–16339.
4. Avinash, G. C., & Lingeshwaran, N. (2025). Review on base and inter-storey seismic isolation systems for high rise buildings. *Research on Engineering Structures & Materials, 11*(1), 231–271.
5. Baig, M. A., Ansari, I., & Islam, N. (2024). Effect of material characteristics of lead rubber isolators on seismic performance of box girder bridge. *Journal of Engineering and Applied Science, 71*, Article 115.
6. Bai, L., Liang, X., Xin, L., Liu, M., Yu, Z., & Chu, Y. (2023). Investigation on the seismic performance of RC frame buildings with rubber isolation bearing installed in staircases. *Buildings, 13*(3), 616.
7. Chopra, A. K. (2012). *Dynamics of structures: Theory and applications to earthquake engineering* (4th ed.). Prentice Hall.
8. Deringöl, A. H., & Güneyisi, E. M. (2023). Enhancing the seismic performance of high-rise buildings with

lead rubber bearing isolators. *Turkish Journal of Engineering*, 7(2), 99–107.

9. Gaikwad, S., Satarkar, P. R., & Manchalwar, A. (2024). Seismic analysis of five-storied building using U-shaped hybrid isolator and lead rubber bearing isolator. In K. S. Sreekeshava, S. Kolathayar, & N. V. C. Menon (Eds.), *Civil Engineering for Multi-Hazard Risk Reduction* (Lecture Notes in Civil Engineering, Vol. 457, pp. 477–485). Springer.
10. IS 1893 (Part 1):2016. (2016). *Criteria for earthquake resistant design of structures – Part 1: General provisions and buildings*. Bureau of Indian Standards, New Delhi.
11. IS 875 (Part 2):1987. (1987). *Code of practice for design loads (other than earthquake) for buildings and structures – Part 2: Imposed loads*. Bureau of Indian Standards, New Delhi.
12. IJRASET. (2022). Assessment of structural behaviour in lead rubber bearing base-isolated and fixed base building under IS 1893 (Part 6): 2022 guidelines. *International Journal for Research in Applied Science & Engineering Technology*.
13. Kelly, J. M. (1999). Base isolation: A review. *Journal of Seismic Engineering, 3*(1), 49–60.
14. Naeim, F., & Kelly, J. M. (1999). *Design of seismic isolated structures: From theory to practice*. John Wiley & Sons.
15. Robinson, W. H., & Tucker, A. G. (1977). A lead–rubber shear damper. *Bulletin of the New Zealand Society for Earthquake Engineering, 10*(3), 151–153.
16. Seismic response of elevated cylindrical water tank with lead rubber bearing isolation system. (2024). In *Technologies for Sustainable Buildings and Infrastructure* (pp. 269–280). Springer.
17. Skinner, R. I., Robinson, W. H., & McVerry, G. H. (1993). *An introduction to seismic isolation*. Wiley.
18. Somerville, P. (2002). Characterizing near-fault ground motion for the design and evaluation of bridges. In *Proceedings of the 3rd National Seismic Conference and Workshop on Bridges and Highways*, Portland, OR.
19. Subramanian, N. (2013). *Design of reinforced concrete structures*. Oxford University Press.
20. Vibration response reduction of seismic forces using lead rubber bearing isolators in composite buildings. (2022). *Journal of Vibration Engineering & Technologies, 10*, 1309–1324.
21. Warn, G. P., & Ryan, K. L. (2012). A review of seismic isolation for buildings: Historical development and research needs. *Buildings, 2*(3), 300–32