Comparative Study of Base Isolated & Fixed Base RC Frame Structure

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ABSTRACT

Earthquakes can inflict significant or severe structural damage. To safeguard buildings from such damage, various structural design techniques are employed, including the installation of shear walls, bracing systems, base isolation devices, and dampers. In this study, we will utilize the base isolation technique. This method decreases seismic forces by offering high lateral flexibility, which extends the structure's vibration period and reduces base shear. Ongoing research and development are actively advancing various types of base isolation techniques. This study provides an overview of isolation techniques and the preliminary design of high-damping rubber bearings and lead rubber bearings, following the guidelines outlined in the Uniform Building Code (UBC - 1997).It involves modelling and analyzing both fixed-base and base-isolated G+6 story structures using E-TABS software to assess floor response, displacement, drift, and the structural time period during an earthquake. The aim is to illustrate the effectiveness of isolation systems in earthquake-resistant building design.

Keywords—Base Isolation Technique, High-damping rubber bearings, Lead rubber bearings, Floor response, Storey Displacement, Story drift, Structural time period.

INTRODUCTION

An earthquake is the noticeable shaking of the Earth's surface caused by the sudden release of energy in the Earth's crust, which generates seismic waves that result in ground shaking. Earthquakes can cause injuries and fatalities, as well as severe damage to man-made structures such as buildings, dams, bridges, and roads. Every year, earthquakes displace thousands of people, render them homeless, and cause significant injury and lives losses worldwide. They pose a major political and social challenge and are a significant concern for structural engineers.

Recent advancements in technology guide systems to mitigate earthquake forces on structures, including shear walls, bracing, base isolation, and seismic dampers. This study will focus on base isolation, a concept designed to decouple the superstructure from the ground.

This technique aims to prevent or significantly reduce the transmission of seismic forces to the building by increasing its lateral flexibility, which in turn lengthens the structure's vibration period. An increased vibration period reduces Storey acceleration and base shear, enhancing the building's ability to resist earthquake impacts.Base isolation reduces the impact of ground motion on a structure, effectively neutralizing the effects of an earthquake. By separating the structure from the ground through a flexible isolation system placed between the foundation and the building, it prevents damage to the superstructure. This flexible system absorbs the shock impact of the earthquake, significantly reducing the seismic energy transmitted to the structure and helping maintain its stability over time. Base isolation also increases the natural period of the structure, minimizing displacement during seismic events. The idea is to separate the building from its foundation so that during seismic activity, the building remains unaffected by ground motion.

Figure 1: Isolation in Bhuj Hospital, Gujarat

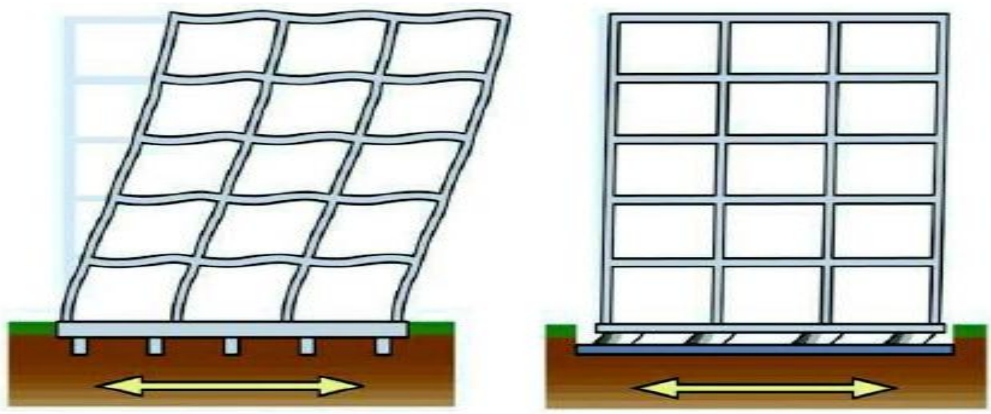


Figure 1: building with or without base isolation

a) PRINCIPLE OF BASE ISOLATION:

- To make the building horizontally flexible while maintaining vertical stiffness.
- To increase the natural period of the building.
- To reduce displacement through damping in the isolation system.
- To decrease the acceleration experienced by the building's stories.

b) BASE ISOLATION SYSTEM SHOULD INCLUDE:

- Elastic mounts to increase the vibration period of the structure, reducing the forces acting on it.
- Energy dissipaters or dampers to manage the deflection occurring between the structure and the ground.
- Stiffness to resist seismic forces and wind loads.

The typical isolators and dampers are classified in Figure 3 and 4.

a) TYPES OF BASE ISOLATION:

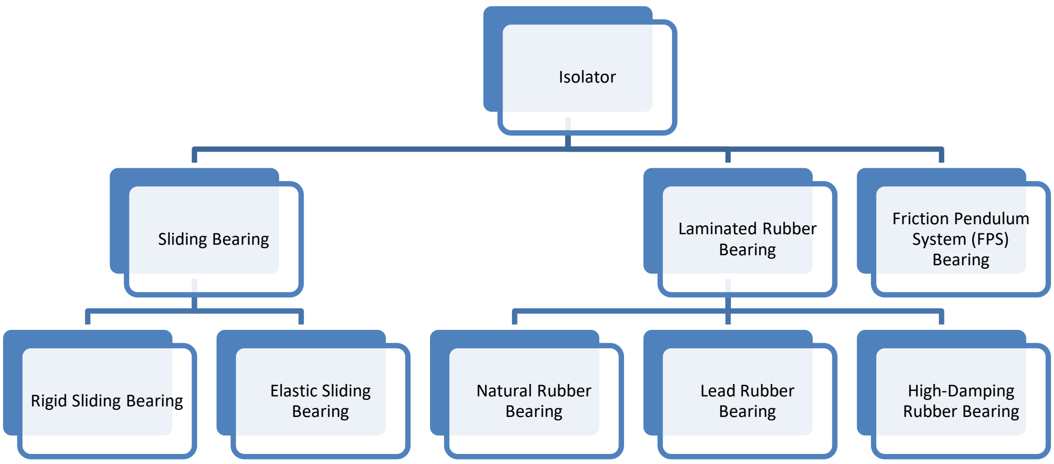


Figure 2: The Classification of Isolators

b) Types of damper:

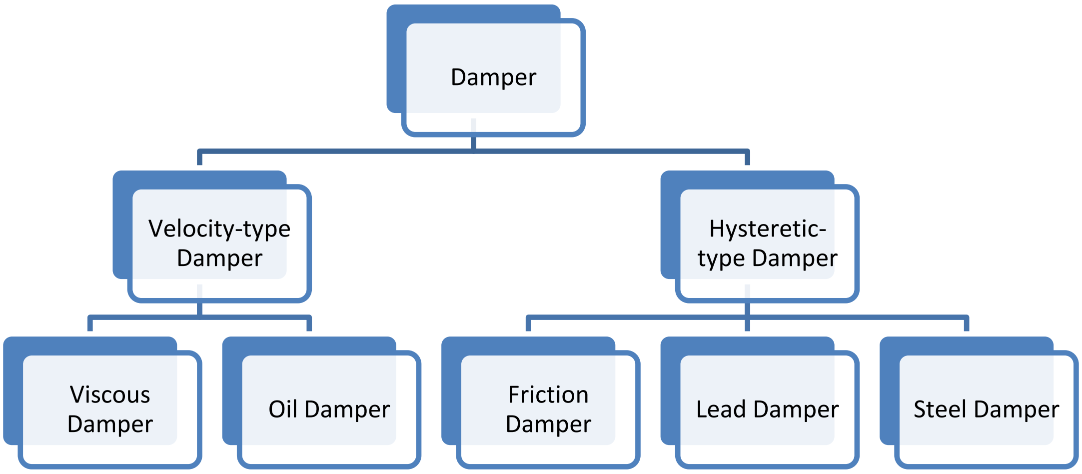


Figure 3: The Classification of dampers

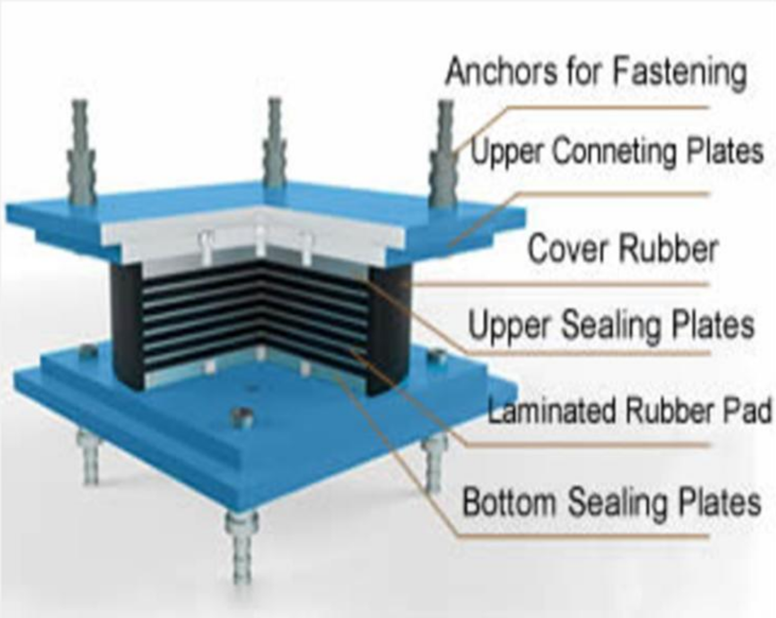
Basic design procedures for high damping rubber isolators (HDR) and lead-rubber bearing (LRB) isolators are given in this chapter.

Base isolation device are made by the alternate layer of rubber and steel plates in circular or rectangular shapes. For lead rubber bearing a led plug is inserted in high damping rubber isolator.

High damping rubber isolators (HDR)

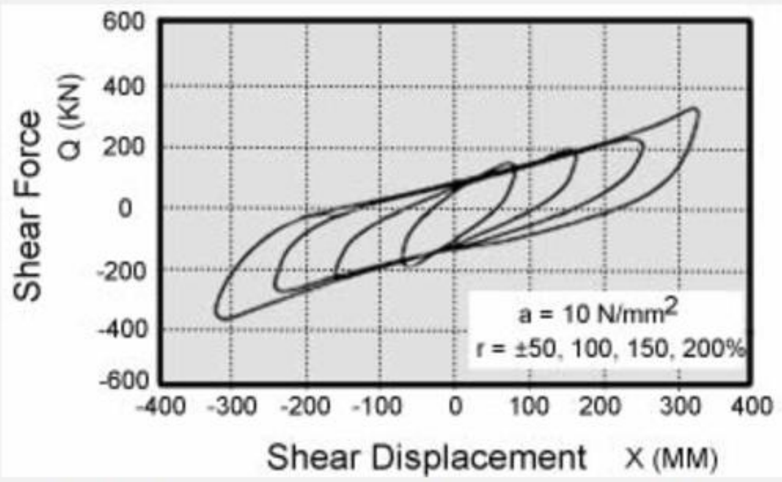
It is made of specialized rubber with excellent damping properties, layered with steel. Damping is a factor within or applied to an oscillatory system that reduces, limits, or prevents its oscillations.

The elastic stiffness of the bearing depends on the degree of deformation: when deformation is small, stiffness is high, and when deformation is large, stiffness decreases. This principle enables the high damping rubber bearing to provide an effective seismic isolation function.



High damping rubber bearing

Figure 4 High damping rubber isolators (HDR)



Stable bilinear behavior of high damping rubber bearing

Figure 5: HDR with stable bilinear behaviour

Lead-rubber bearing isolators (LRB)

A lead rubber bearing, commonly used in building and bridge constructions, offers a practical and cost-effective solution for seismic isolation. It consists of a laminated elastomeric bearing pad, top and bottom sealing and connecting plates, with a lead plug inserted in the centre of the bearing, as depicted in the fig 7.

During an earthquake, a non-isolated building will shake in multiple directions due to inertial forces, leading to deformation and damage. In contrast, a base-isolated building will experience displacement but retain its original shape, avoiding damage. This is because the lead rubber bearing effectively dissipates the inertial forces acting on the building, prolongs its vibration period, and reduces its acceleration.

During an earthquake, the lead plug moves along with the laminated rubber, converting the energy from this movement into heat, which efficiently reduces the inertial forces acting on the building, thereby slowing its vibrations. At the same time, the rubber component retains its original shape due to its high elasticity.

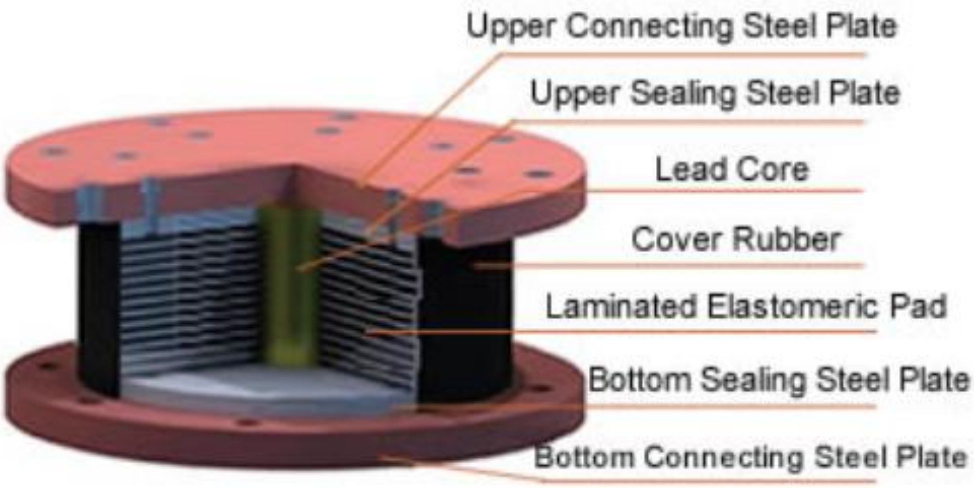


Figure 6: Lead-Rubber Bearing Isolators (LRB)

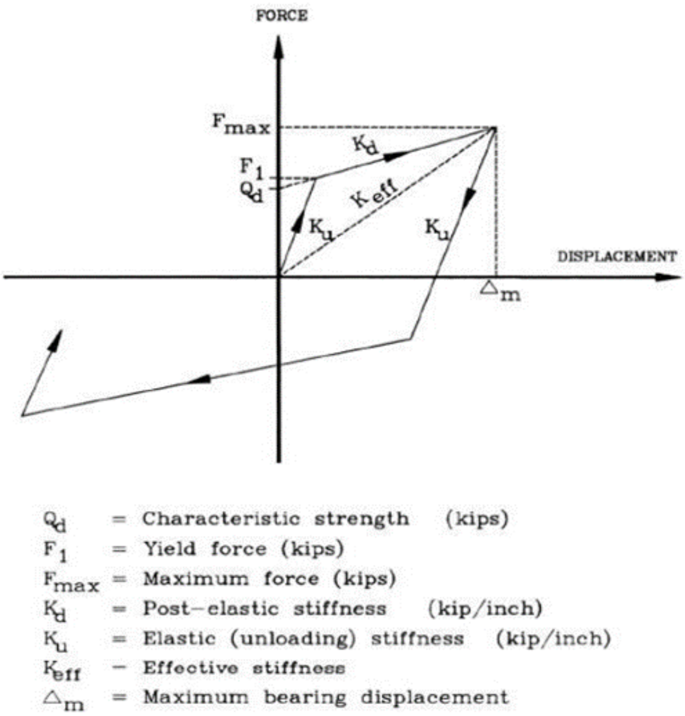


Figure 7: Graph of hysteresis loop

OBJECTIVES OF THE STUDY

This study involves the design of a G+6 Storey building with both fixed base and base isolation configurations, following the guidelines of IS 1893:2016 using ETABS 18.1.1.Initially, analyze the fixed base building to determine the maximum reaction at each column. Based on these reactions, we manually design the base isolation device. Subsequently, analyze the base-isolated building and compare the results, including base shear, Storey drift, Storey displacement, and time period, to those of the fixed base structure. Based on results obtained the following objectives of the present study are drawn;

- Examination of different types of base isolators
- Modeling and analysis of the building with a fixed base
- Modeling and analysis of the building with a base isolation device
- Comparison of the results obtained

LITERATURE SURVEY

Lin Su et al. [1991] analyzed a new base isolator developed by combining the properties of the Electricity de France (EDF) base isolator and the resilient base isolator (R-FB1) device, resulting in the creation of the sliding resilient base isolation system (SR-F). They generated response spectra curves for this isolator and compared them with those from the EDF and R-FB1 systems, as well as with a fixed base system. The findings from these different earthquake scenarios were then compared to the new SR-F isolator. The peak responses for the EDF and R-FB1 systems were recorded and analyzed in relation to the SR-F system, showing that maximum responses were reduced without significant base displacement.

Shenton III [1993] compared and analyzed the relative performance of fixed base and base-isolated structures. The responses of the base-isolated structure were compared to those of the fixed base structure, with base shear varying according to SEAOC recommendations. Three different post-earthquake time hiStorey records were selected to conduct a nonlinear dynamic analysis for both the fixed base and base-isolated structures. The results were then compared for 25% and 50% of the specified lateral forces according to SEAOC, and the building's performance was evaluated under different lateral force conditions.

Concellara et al. [2013] conducted a comparison between lead rubber isolators and friction sliders. The isolator studied consisted of a lead rubber bearing combined with a friction slider (FS), referred to as a high damping hybrid seismic isolator. The seismic performance of this high damping hybrid isolator was compared to that of a lead rubber isolator. The same structure was analyzed under varying seismic conditions, differing in both frequency and intensity. The paper primarily focuses on a high damping hybrid seismic isolator (HDHSI) and its comparison with a lead rubber isolator. Both types of isolators were installed in a building, and a nonlinear time hiStorey analysis was conducted under different seismic conditions. The results were compared in terms of base shear, shear force, and displacement at the base of the superstructure. The findings indicate that HDHSI offers better protection during severe seismic activity than the lead rubber isolator.

Shrimali et al. [2015] discussed the increasing use of control devices to reduce seismic vulnerability, focusing on the pounding effect between nearby buildings. The study compared damper systems and isolated systems, finding that hybrid seismic hazard control systems perform better than semi-active control systems. The paper also examined the varying parameters of control devices to optimize seismic performance.

Raikar et al. [2020]in their analysis found that Improvement of base isolation system under extreme excitations, such as Reduction in Storey Drift in both X and Y direction, Reduction in Base Force in both X and Y direction Reduction in Moment along Z direction.

Domadzra [2024] This paper explores how the properties of Lead Rubber Bearings (LRB) and Friction Pendulum Systems (FPS) affect the seismic performance of base-isolated buildings. A thorough analysis was conducted to assess various factors influencing these base isolation systems. The study compares the seismic effects of LRBs and FPSs on structural responses to earthquakes, focusing on key elements such as the friction coefficient, radius of curvature, lead core diameter, and hysteretic behavior. A review of existing literature highlights that different factors are critical for the seismic performance of buildings with LRB and FPS systems. For LRB-isolated buildings, key parameters include damping efficiency, lead core diameter, and stiffness ratios. For FPS-isolated buildings, important factors include the friction coefficient, radius of curvature, and effective damping. The paper concludes that the most influential factors in the seismic performance of base-isolated buildings are the friction coefficient, radius of curvature in FPS, and the stiffness characteristics of LRBs. This work provides valuable insights for researchers and engineers involved in seismic design and retrofitting of base-isolated structures.

Jain et al. [2024] The results of the research work showed that the base-isolated RC frames designed with DDBD outperformed those designed with FBD, exhibiting 35.68% less response and a lower probability of collapse.

Ali et al. [2024] A sliding-based isolation system is an effective method to improve the seismic performance of low-rise brick masonry buildings, which are commonly found worldwide.

METHDOLOGY AND MODELING

Earlier versions of UBC code preferred a statically lateral response method of design which is based on a single mode of vibration. In this method, design forces were computed from the forces in the isolator at design displacement which makes the whole analysis process simple.

The static lateral response procedure may be used for the design of a seismic-isolated structure if they fulfill the criteria given below:

a) The structure should be located at least 10 kilometers from all active faults.

b) The height of the structure above the base isolation is equal to or less than or 19.8 m.

c) The effective period of the isolated structure, is greater than three times the fixed base period of the structure.

d) The structure should be of regular configuration above the base isolation.

Design of High-Damping Rubber Isolators

The final output for the design of the LRB isolators in the ETAB software are mention below;

a) Finally input values of internal column for E-TAB Software:

Rotational Inertia, I 0.011139 kN/m

For U1 Effective Stiffness, Kv 1288858.525 kN/m

For U2 & U3 Effective Stiffness, KH2792.53 kN/m

For U2 & U3 Effective Damping 0.15

For U2 & U3 Distance from End-J, DY 0.00851 m

For U2 & U3 Stiffness, K1 18273.453 kN/m

For U2 & U3 Yield Strength, Fy 160.485 kN

b) Finally input values of external column for E-TAB Software:

Rotational Inertia, I 0.004010 kN/m

For U1 Effective Stiffness, Kv 724982.920 kN/m

For U2 & U3 Effective Stiffness, KH1570.80 kN/m

For U2 & U3 Effective Damping 0.15

For U2 & U3 Distance from End-J, DY 0.00851 m

For U2 & U3 Stiffness, K1 11399.527 kN/m

For U2 & U3 Yield Strength, Fy 100.115 Kn

Design of Lead Rubber Bearing Isolators

The final output for the design of the LRB isolators in the ETAB software is mention below;

a) Finally input values of internal column for ETABS:

Rotational Inertia, I 0.020865 kN/m

For U1 Effective Stiffness, Kv 2390622.51 kN/m

For U2 & U3 Effective Stiffness, KH2390.62 kN/m

For U2 & U3 Effective Damping 0.15

For U2 & U3 Distance from End-J, DY 0.01149 m

For U2 & U3 Stiffness, K1 18273.453 kN/m

For U2 & U3 Yield Strength, Fy 216.655 kN

b) Finally input values of external column for ETABS:

Rotational Inertia, I 0.008094 kN/m

For U1 Effective Stiffness, Kv 1491341.855 kN/m

For U2 & U3 Effective Stiffness, KH1491.34 kN/m

For U2 & U3 Effective Damping 0.15

For U2 & U3 Distance from End-J, DY 0.01149 m

For U2 & U3 Stiffness, K1 11399.527 kN/m

For U2 & U3 Yield Strength, Fy 135.156 kN

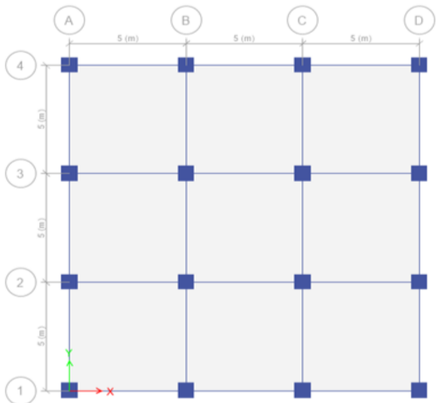


Figure 8: Plan view of the Model

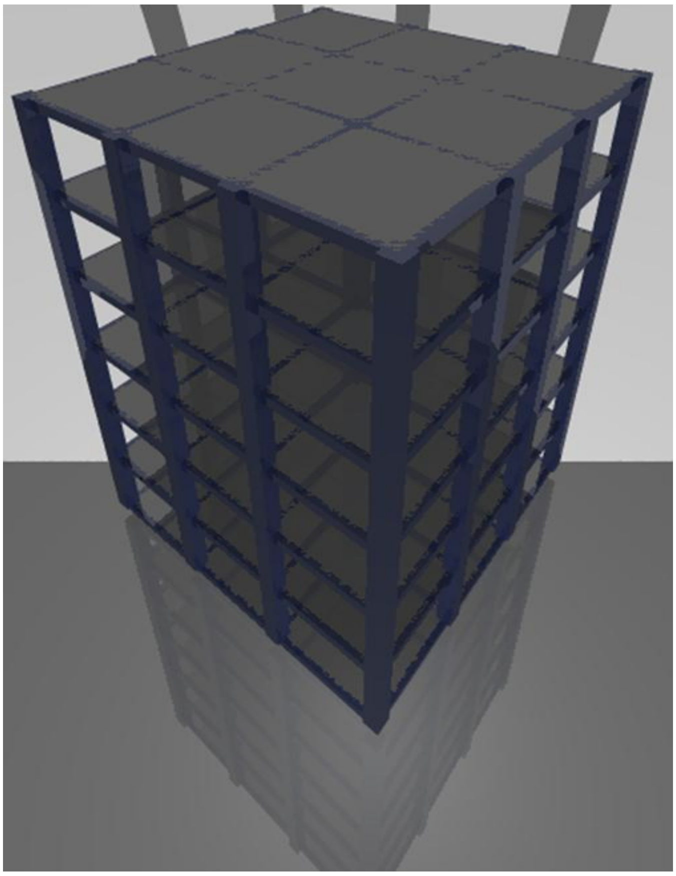


Figure 9: 3D view of the Model

RESULT

a) Base shear and Storey forces

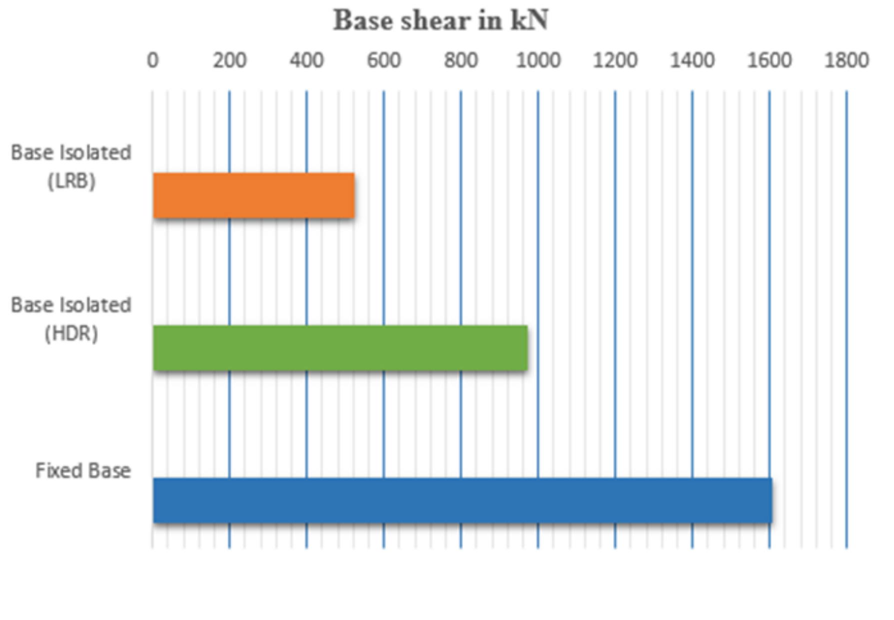


Figure 11: Graphical representation of Base shear bar chart

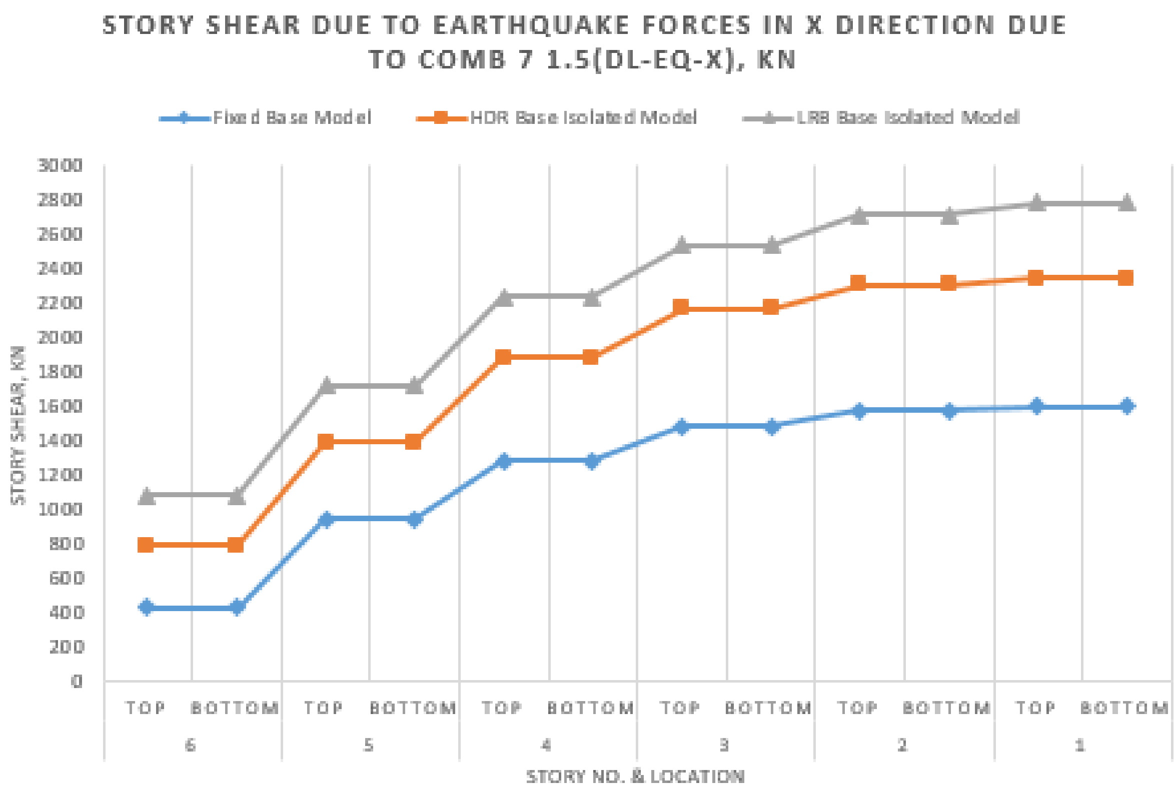


Figure 12: Graphical representation of Storey shear due to Earthquake forces in X direction

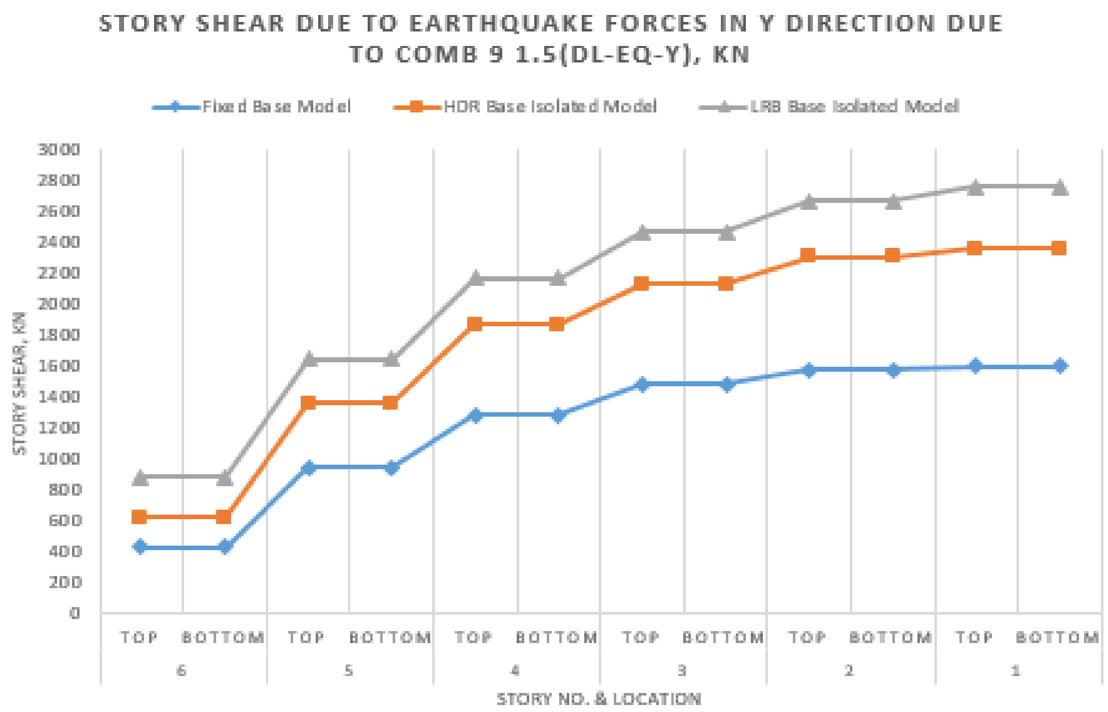


Figure 13: Graphical representation of Storey shear due to Earthquake forces in Y direction

b) Storey displacement

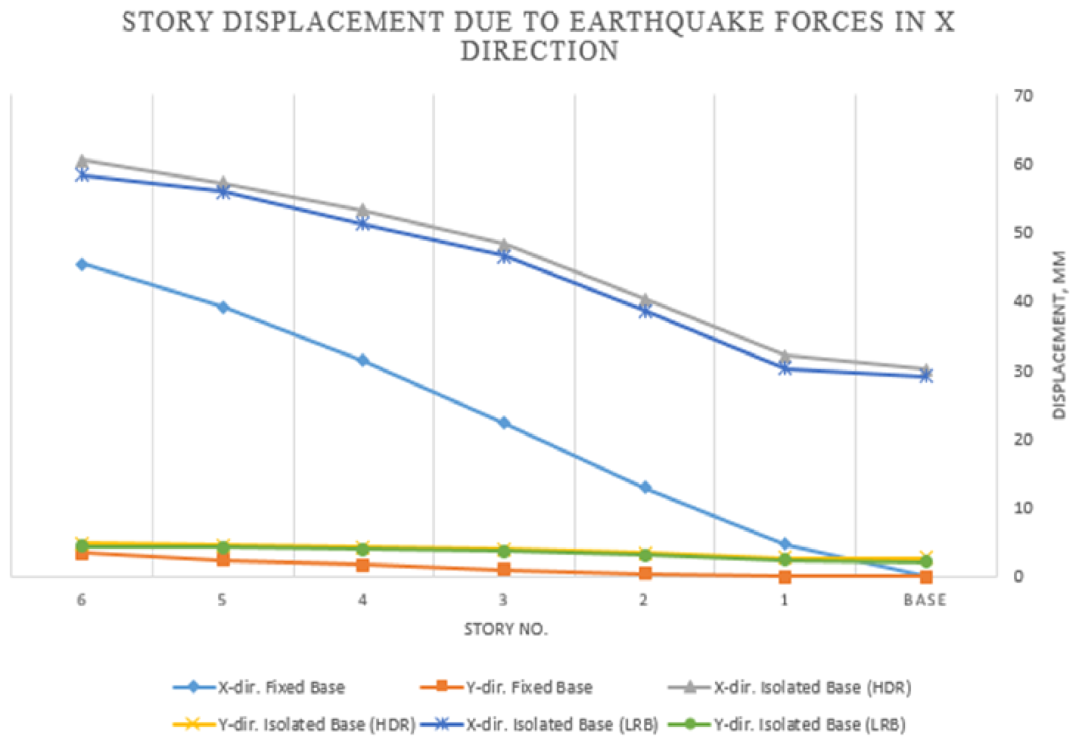


Figure 14: Graphical representation of Storey Displacement due to Earthquake forces in X direction.

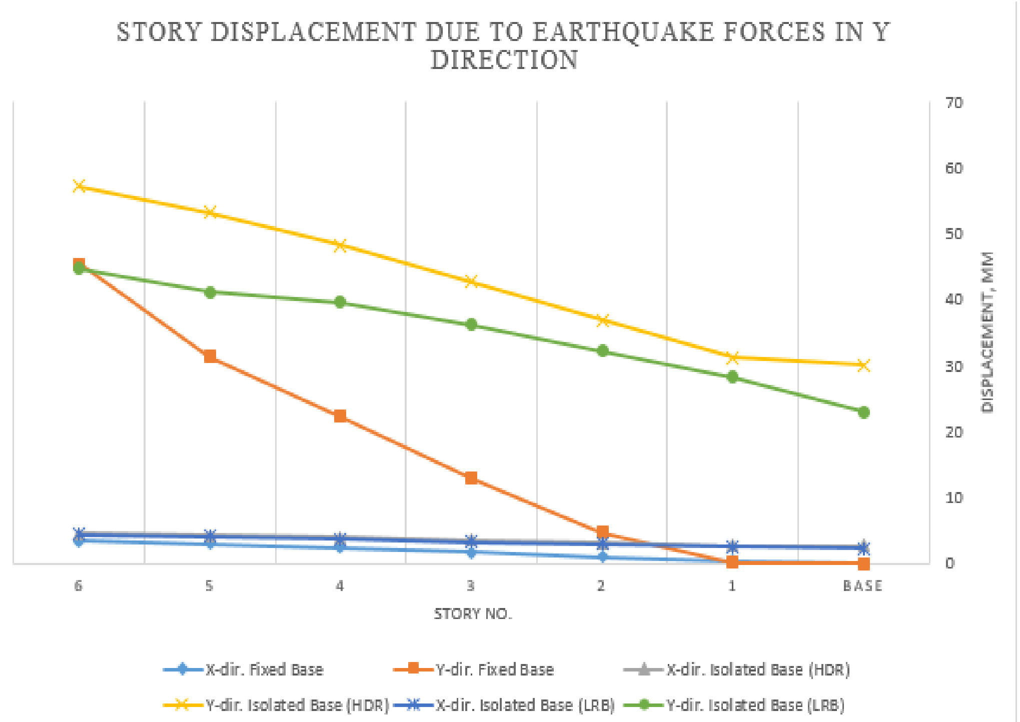


Figure 15: Graphical representation of Storey Displacement due to Earthquake forces in Y direction.

c) Storey drift

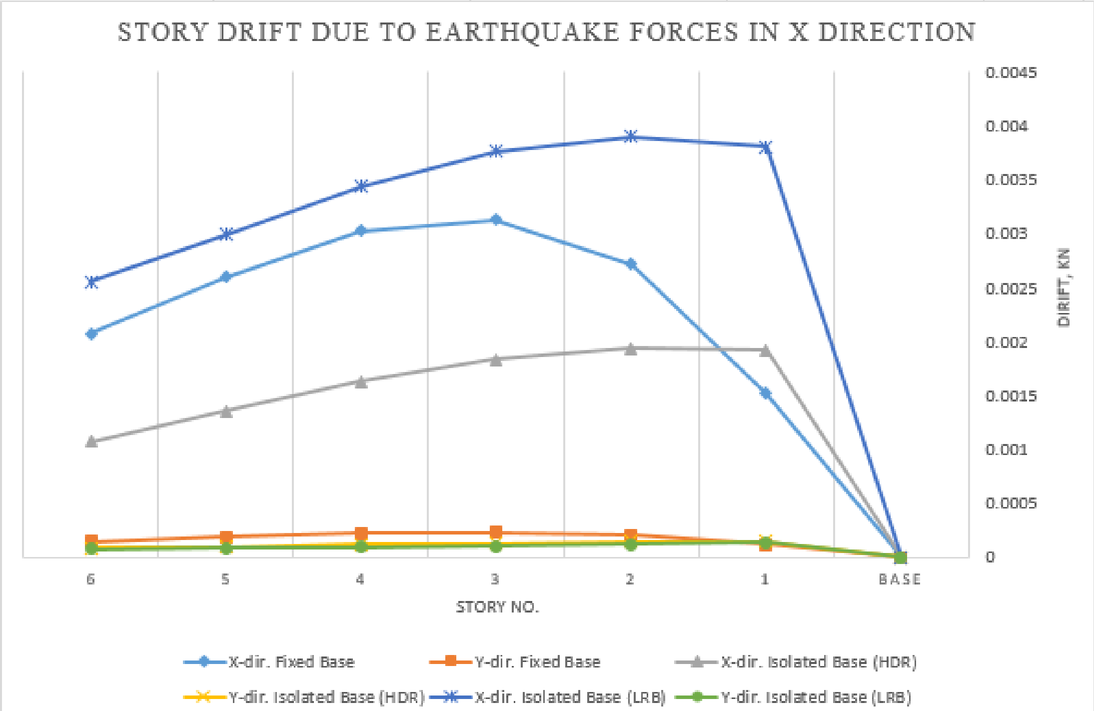


Figure 16: Graphical representation of Storey Drift due to Earthquake forces in X direction.

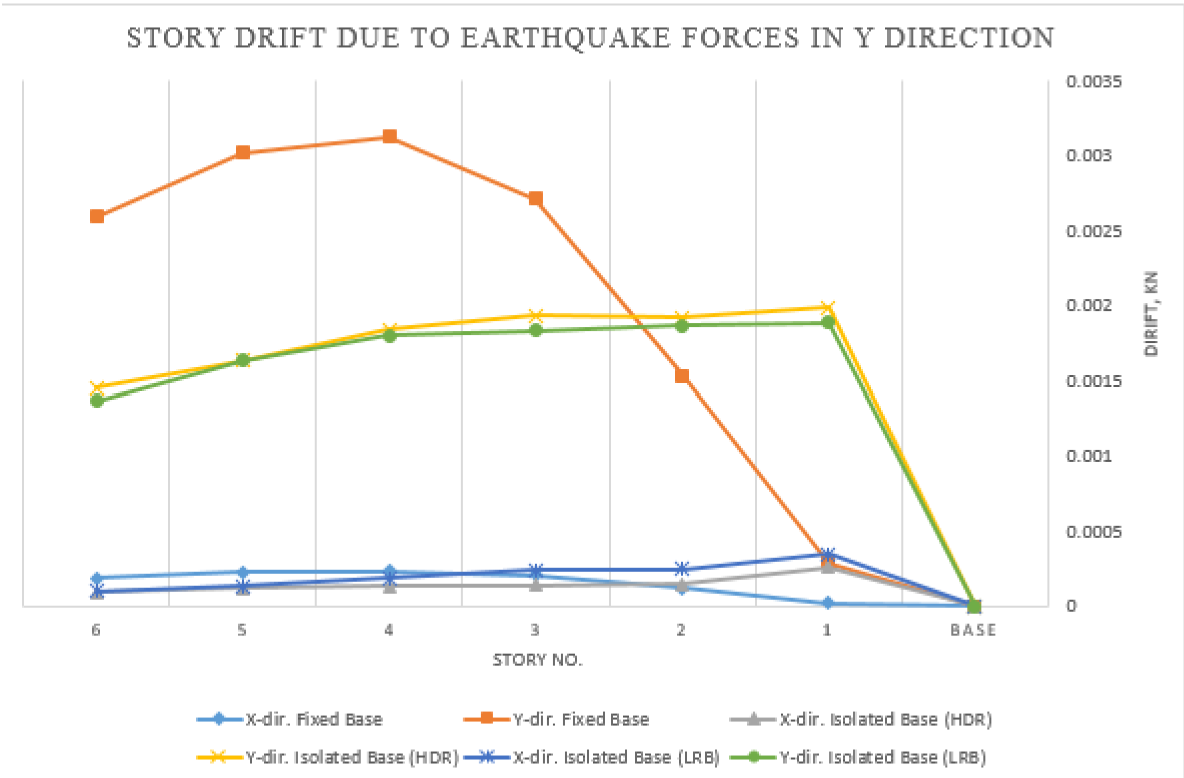


Figure 17: Graphical representation of Storey Drift due to Earthquake forces in Y direction

d) Modal period

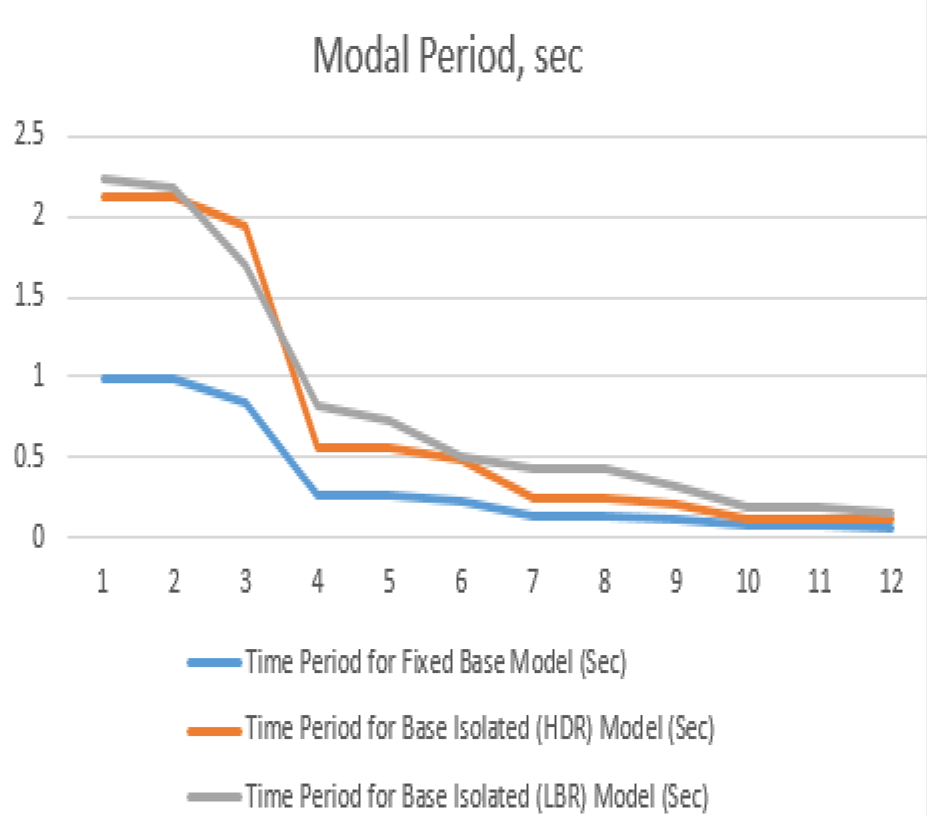


Figure 18: Graphical representation of Time period

CONCLUSION AND FUTURE SCOPE

CONCLUSION

The objective of present study was to analyze a fixed base and base isolated building to assess the seismic behavior of structure in high seismic zone. In this study High Damping Rubber Bearing and Lead Rubber Bearing has been designed. Following observations are made after analyzing G+ 6 Storey building in seismic zone V using ETABS software.

- The base shear gets reduced by 46.5%, when base isolation is provided as compare to fixed based building. The base isolated building is having high efficiency in decreasing the base shear compare to fixed based building.
- Storey drift gets reduced by 50% to 60% in both X & Y directions by using base isolation devices over the fixed based structure.
- The Storey displacement is more in both directions in case of base isolated structure.

- The lateral Storey displacement for base isolated building is always more than the lateral displacement of fixed base building. The increase in the lateral displacement in the ground floor is always be more than the increase in the high floor for base isolated building.
- Time period of the base isolated structure is also increases as compared to fixed base structure due to increase in lateral flexibility of structure by the base isolation system.
- This study shows that ―the building gives better performance by the use of isolators at the base of the building as compared to fixed based building at higher seismic prone area.

FUTURE SCOPE

This study deals with the analysis of fixed base and base isolated structure having G+ 6 Storey in high seismic zone.

The Base isolation system has been considered as a technology to protect and ensure safety of human lives against large-scale earthquakes. However, with higher vision to prevent economic damages and ensure security for the future, authors strongly believe that base isolation is the technology that will realize the seismic protection concept for the next generation‖ (Fumiaki, Toru, Norikatsu ,& Hiroyuki , 2000).

In this study we have only talked about base isolation device for earthquake resistant design. Base isolation is used for only low rise to mid-rise building. The HDR and LBR are the external bearings which requires regular maintenance and its efficiency will depend upon its working life.

Future study can be done in case of use of base isolation device in high rise building and to explore different earthquake resistant system that can be used for high rise building. Any other base isolation system which plays a part to be the integrity of a structure need to be researched.

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