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Comparative Study Of Base Isolated & Fixed Base RC Frame Structure

Radhika[#1], Rajesh Kumar Misra[*2], A.K. jha[#3]
[1]M. tech scholar, LNCT, BHOPAL
[2,3]Professor, LNCT, BHOPAL

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.

1. 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 be powerful enough to 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 loss of life worldwide. They pose a major political and social challenge and are a significant concern for structural engineers.

The energy released during an earthquake generates waves, known as primary and secondary waves, which cause ground motion that is transmitted to structures through their foundations. Depending on the intensity of the vibrations, these movements can lead to cracks and settlement in the structure. The earthquake-induced movement generates inertia forces in the structure, which increase the damage as ground motion intensifies. Engineers can use ductility to allow structures to undergo greater deformation than the elastic limit permits, by increasing the applied forces slightly. The elastic limit is the maximum point at which a structure can deform and return to its original shape. If the building exceeds this limit, cracks may develop. While ductility allows for some acceptable damage, introducing more elasticity to the structure can increase costs and reduce damage by strengthening the building, though this may negatively impact weaker components.

A recent advancement in earthquake-resistant design is base isolation, which is commonly used as an anti-seismic strategy. **Base isolation reduces the impact of ground motion on a structure, effectively neutralizing the effects of an earthquake.** 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. A flexible structure will have a longer lifespan. In this type of design, when the ground moves, no acceleration is transferred to the structure. The displacement between the structure and the ground matches the ground's displacement.

Figure 1 Base Isolated Building

- Base: The part that supports or serves as the foundation for an object or structure.
- Isolation: The state of being separated, referring to decoupling a structure from its foundation, separating the superstructure from columns or piers.

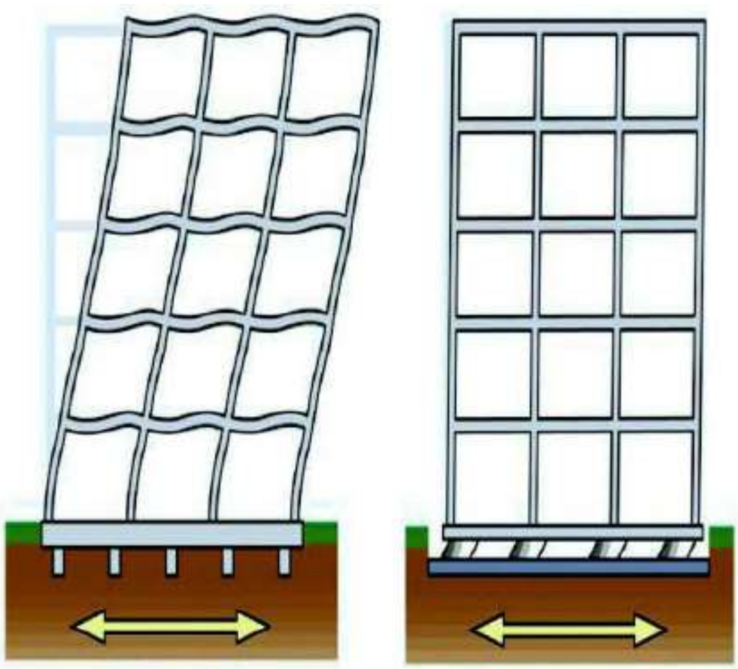

Figure 2 Performance of building with or without base isolation

2. BASE ISOLATION CONSIDERATIONS:

- To enhance the safety of the structure.
- To reduce lateral seismic forces.
- To address the inability of existing buildings to withstand earthquakes.
- To allow the structure to withstand small earthquakes without damage.
- In high-level earthquakes, the structure may experience some structural and non-structural damage but will not collapse.

To help achieve the performance of base isolation system, passive devices, including dampers and isolators, can be incorporated into buildings. The isolation system provides the lateral flexibility and the damping necessary for efficient isolation and develops the appropriate stiffness that is required for service load. Options include elastomeric systems, sliding systems and hybrid systems which will be detailed in this chapter.

In the category of structural control, base isolation system is classified as passive control. Isolators are the major devices that are implemented in a structural system for the purpose of isolation. In addition, dampers can be used in cooperation with an isolation system for energy dissipation within the system. The typical isolators and dampers are classified in Figure 3 and 4.

3. TYPES OF BASE ISOLATION:

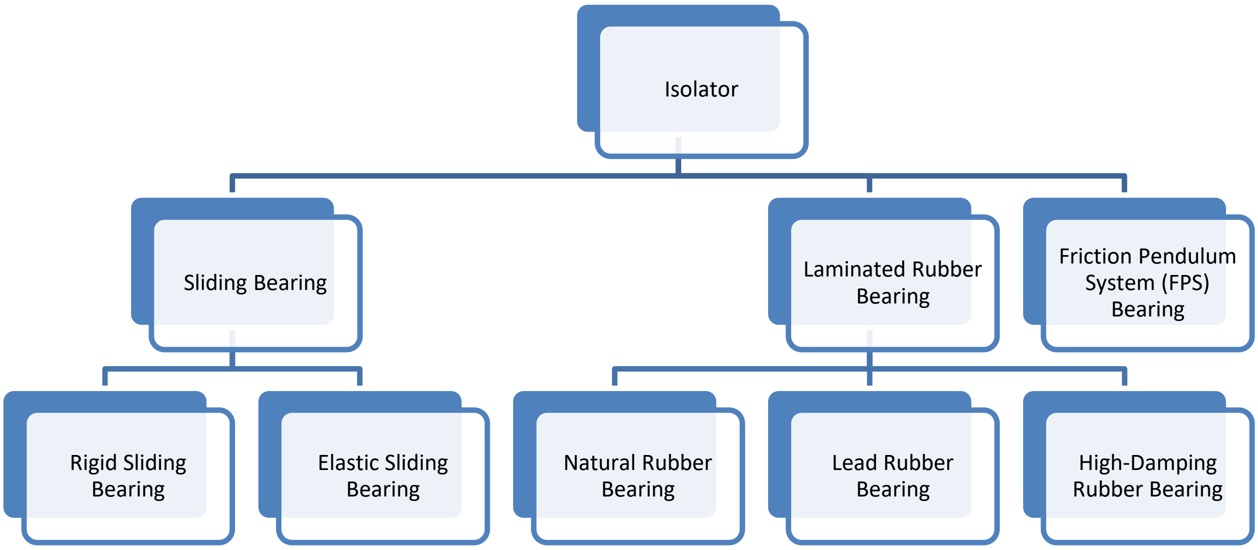

Figure 3 The Classification of Isolators

- **Types of damper:**

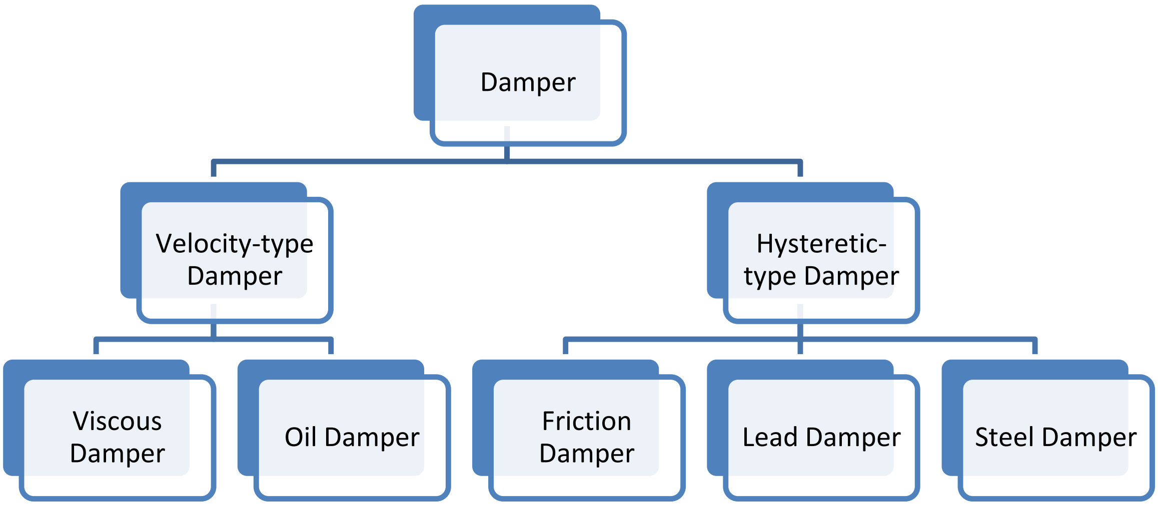

Figure 4 The Classification of dampers

Now a day there are different types of base isolators are available some of them are mentioned below;

i. Sliding Bearing
   a) Rigid Sliding Bearing
   b) Elastic Sliding Bearing

ii. Laminated Rubber (Elastomeric) Bearing
   a) Natural and synthetic rubber bearing (Low Damping Rubber Bearing)
   b) Natural rubber bearing (High Damping Rubber Bearing)
   c) Lead Rubber Bearing (LRB)

iii. Friction Pendulum System (FPS) Bearing

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.

3.1 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. Available with excellent flexibility and high restoring ability, high damping rubber bearing can absorb some input energy of the earthquake before the energy is transmitted to the substructure and can be restored after the earthquake.

By enhancing the rubber formula, the damping capacity of the rubber material is increased, allowing the damping ratio of high damping rubber bearings to reach between 15% and 18%. During an earthquake, these bearings exhibit excellent seismic performance by achieving large deformations with reduced stiffness

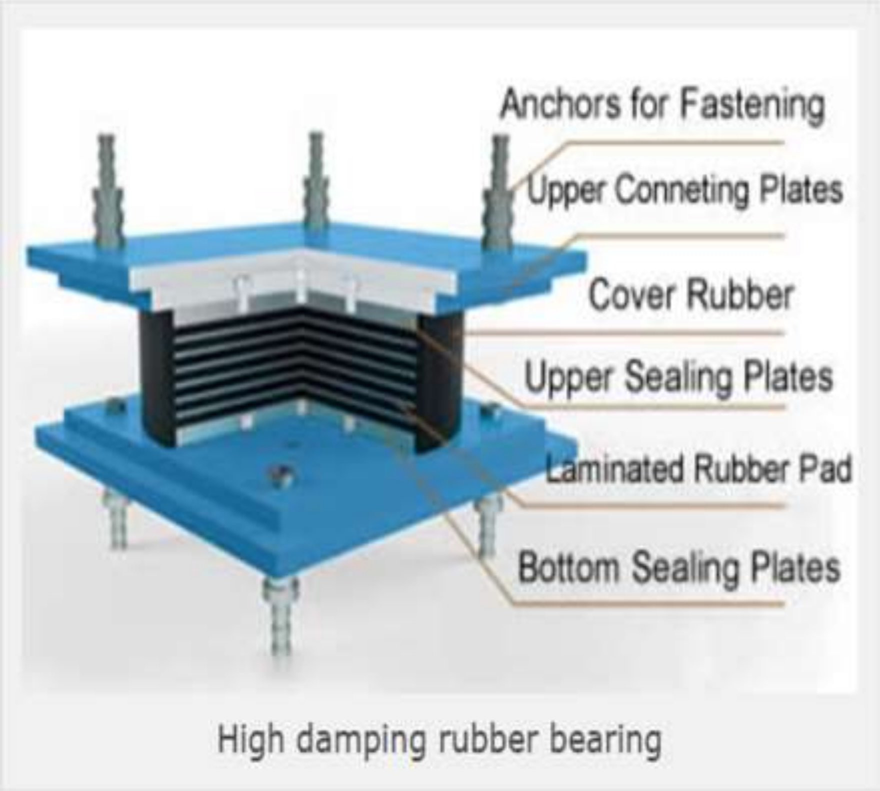

Figure 5 High damping rubber isolators (HDR)

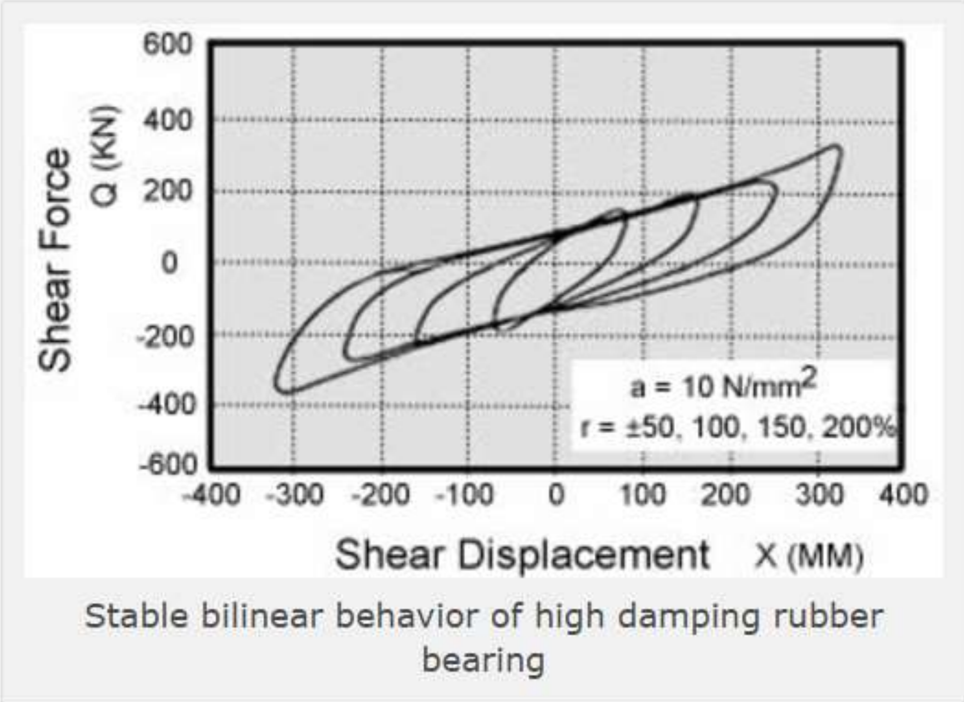

Figure 6 HDR with stable bilinear behaviour

Features of HDR

- High damping rubber bearings offer excellent vertical load capacity, recovery ability, and damping properties.
- Due to their hysteretic behavior, they provide seismic isolation for small, medium, and large earthquakes.
- These bearings inherently provide seismic isolation without requiring additional devices, reducing maintenance and repair costs.
- Their flexibility and damping performance are minimally affected by temperature changes, making them suitable for a wide range of applications.
- Made from newly developed natural rubber, they exhibit excellent creep resistance.
- The internal rubber is protected by EPDM, making the bearings resistant to ozone and ultraviolet rays, which enhances their aging resistance.

3.2 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.

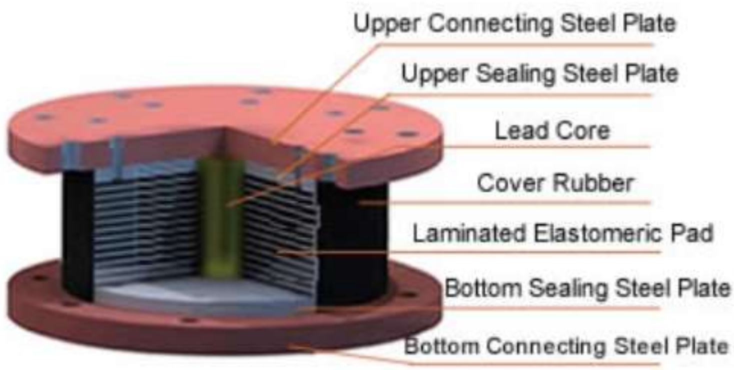

Figure 7 Lead-Rubber Bearing Isolators (LRB)

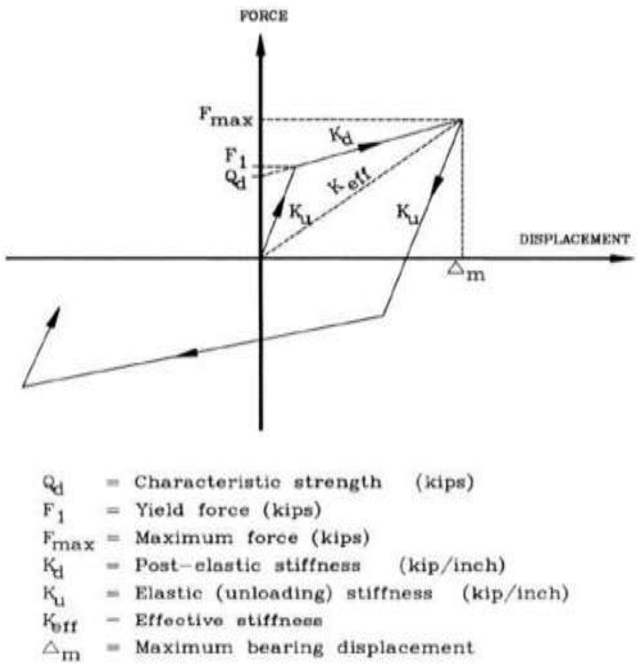

Figure 8 Graph of hysteresis loop

Features of LRB

- Stiff and strong in the vertical direction, yet flexible in the horizontal direction.
- Absorbs earthquake forces by deforming the bearing's shape.

- Allows buildings to maintain their original shape and position due to the high elasticity of the rubber.
- Damping capacity can be adjusted by varying the number of lead plugs.
- Offers excellent vertical load capacity, ranging from 50 kN to 20000 kN.
- Reduces ground acceleration by lengthening the structure's vibration period.
- The rubber component is highly durable and elastic, withstanding damage during and after an earthquake.
- Easy to install without the need for a separate damper.
- Requires minimal maintenance.
- Exhibits stable bilinear behavior, as shown in the image below.

4. OBJECTIVE 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

5. LITERATURE SURVEY

- **Lin et al. [1992]** presented the seismic performance of rigid base and base-isolated concentrically braced and special moment-resisting steel frames. They referenced various codes for designing both the base isolation and fixed base frames. The fixed base frames were designed according to the 1990 Structural Engineering Association of California (SEAOC) guidelines for recommended design base shear, while the base-isolated buildings were designed for lateral forces of 100%, 50%, and 25% of the SEAOC recommendations. The study utilized 54 different ground motion records. A nonlinear time hiStorey analysis was conducted to evaluate various outcomes, including roof displacement and frame collapse, as well as the yielding of frames and elements, and total relative roof displacement. The results indicated that using 50% of the SEAOC-recommended lateral force provided superior performance compared to other combinations. Additionally, a comparative study was conducted on the peak responses between the fixed and isolated moment-resisting braced steel frames.

- Erickson [2010] examined the response of an industrial structure subjected to seismic forces, with the building designed in accordance with the IBC code. The study evaluated the superstructure's elastic response under dynamic loading. The work highlights three industrial buildings resting on a single isolation slab, discussing various design, analysis, and isolator placement challenges in a comparative manner.

- **Luco [2014]** investigated the effects of soil-structure interaction (SSI) on base-isolated buildings. The findings revealed that the deformation of an inelastic structure increases when the soil effects are considered. In contrast, when SSI is neglected, the structure undergoes undamped vibrations, leading to critical harmonic excitation, after which the behavior of both the structure and the isolator becomes unbounded. The results were influenced by the damping characteristics of the isolator. The resonant response of both the isolator and the superstructure was found to increase when SSI was taken into account.
- **Swetha and Rao [2015]** performed a dynamic analysis on a G+4 Storey building using the Newmark-beta method. Ground motion acceleration data from the El Centro earthquake were used for the analysis. A static analysis was also conducted, comparing peak lateral forces, shear forces, and displacements. The design adhered to IS1893 (Part 1):2002, and the study drew conclusions on the vulnerability of ground-Storey and weak buildings during earthquakes.

- **Wang et al. [2015]** addressed the issue of vibration in isolators by introducing a new type of metal rubber isolator. The paper provides a historical overview of metal rubber research and highlights its potential as a material for seismic isolators. The study includes experimental work on the dynamic modeling and parameters of metal rubber isolators, focusing on their effectiveness in vibration control. The future scope and usability of metal rubber isolators are also discussed.

- **Cancellara et al. [2016]** conducted an experimental study on two base isolation systems for a multiStorey RCC building, designed according to European codes. The study, focusing on plan irregularity, compared high-damping rubber bearings (HDRB) with friction bearings, and lead rubber isolators with friction sliders. Time hiStorey analysis was performed, and the results were compared based on the building's response to ground motion.

- **Darshale et al. [2016]** investigated the response of base-isolated structures, emphasizing that base isolation is a passive energy dissipation system. They examined the use of lead rubber isolators, finding that while base isolation increases the fundamental natural time period and reduces horizontal stiffness, it also decreases inter-Storey drift. A G+14 RCC building was analyzed, comparing rigid base and base-isolated structures. The study found that base isolation significantly increased the natural time period (from 1.7 seconds to 4.3 seconds), enhancing energy dissipation and reducing response forces like base shear and acceleration.

- **Kerileng and Dundu [2017]** in their paper discusses the concept of base isolation and reviews existing base isolation systems. Most of the base isolation systems reviewed can absorb earthquake energy in 2 dimensions. In conclusion, the friction pendulum is observed to be the only base isolation that is capable is absorbing earthquake energy in both three principal directions. The observed research results, it shows that the structural deformations going into the inelastic/plastic range and the consequent is likely to be completely eliminated in FPS, and the structure needed to designed for much smaller acceleration.

- **Tanwer et al. [2019]** in their study found that the base isolation system substantially increases the time period of the structure. It reduces correspondingly the base shear up to 75% as compared to fixed one. Fundamental period of the structure is approximately twice for the isolated structure. Fundamental modes prove more effective in seismic analysis. Performance of the structure with base isolation systems proves more effective than a fixed base. In base-isolated structure frequency has reduced as compared to the fixed base structure. Storey drift has considerably reduced by provision of a base isolator. The reduction in storey drift at 9.0m height are 13%, 13%, and 15%, respectively, for HDRB, LDRB, and LRB structures as compared to the non-isolated structure.

- **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. maximum shear force, bending moment, storey acceleration, base shear decreases; whereas increase in lateral displacements were observed for bottom storey of base isolated building as compared with fixed base building model.

- **Ozeret al. [2023]** in this study they compare the seismic response of fixed-base and various base isolation models, including Lead Rubber Bearings (LRB), Curved Surface Friction Bearings (FPS), and Flat Sliders (FS), for regular low- and mid-rise reinforced concrete (RC) framed buildings. A total of 352 nonlinear time hiStorey analyses were performed on three-dimensional building models, using 11 different ground motion pairs. Key parameters related to seismic behavior, such as displacement and acceleration demands, interStorey drift ratios, base shear demands, and isolator capacity usage ratios, were examined. As expected, fixed-base models experienced the highest seismic demands, with many cases exceeding the controlled damage state. In contrast, base-isolated models only reached the limited damage state in a few instances. While base-isolated models exhibited higher total lateral displacements, most seismic demands were dissipated at the isolator interface, with transmitted demands being minimal. The results also showed that combining LRB and FS isolators increased seismic demands compared to using only LRB isolators, as FS isolators lack recall force. LRB isolators proved to be a better option for regular buildings without re-centering issues. Additionally, significant variation in seismic responses was observed across different ground motion records, highlighting the importance of using a sufficient number of records for accurate seismic performance evaluation.

- **Thakur and Tiwary [2024]** Steel-concrete composite construction has gained significant popularity worldwide as an alternative to traditional steel or concrete buildings. While India uses less steel in the construction sector compared to many other emerging economies, composite buildings are expected to play a major role in the construction of tall buildings due to their lower dead load and cost-effectiveness. Although earthquakes can cause severe and often irreparable damage, their impacts can be mitigated through careful design. While natural disasters cannot be prevented, their effects can be minimized with effective design strategies. One promising approach to enhance the seismic performance of buildings is the combination of base isolation and fluid viscous dampers, which help dissipate energy and reduce the impact of earthquakes.

- **Patil and Patil (2024)** This manuscript reviews the design of steel buildings and analyzes the effectiveness of various damper and base isolation systems across different seismic zones for multi-Storey steel-framed buildings. Steel buildings are favored for their strength, ease of construction, and economic value, as scrap material can be reused after demolition. Base isolation enhances structural safety and provides protection for both occupants and property, and it is also used to retrofit historic buildings. The study focuses on the seismic analysis of a G+10 multi-Storey steel building, both with and without dampers (viscous and friction dampers) and base isolation systems (friction isolation and lead plug bearings). While these seismic provisions are commonly used, this review aims to determine which combination is most suitable for stabilizing steel buildings in different seismic zones. The analysis will consider seismic zones II, III, IV, and V using ETABS software, examining the effects of various damper and base isolation combinations. The results, including storey drift, storey displacement, and base shear, will be analyzed to identify the optimal system for seismic stability.

6. 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.

6.1 Design of High-Damping Rubber Isolators

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

1. 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, KH	2792.53	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

2. 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, KH	1570.80	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

6.2 Design of Lead Rubber Bearing Isolators

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

1. 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, KH	2390.62	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

2. 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, KH	1491.34	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

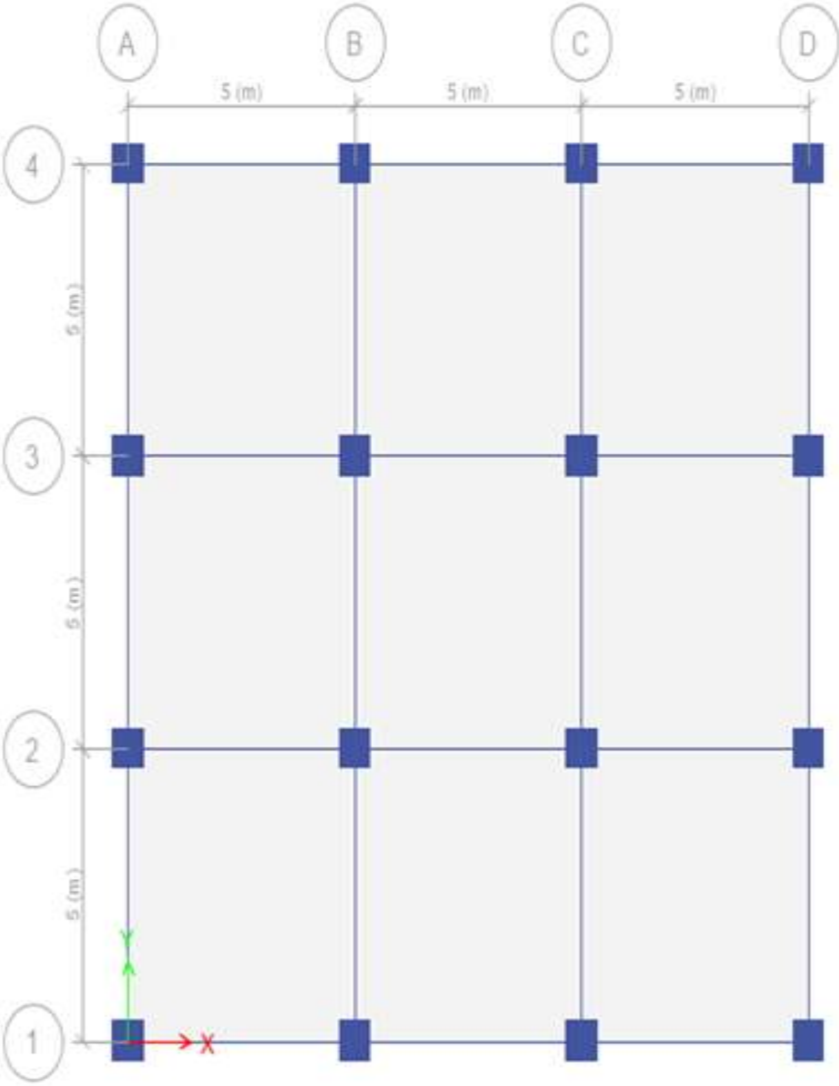

Figure 9 Plan view of the Model

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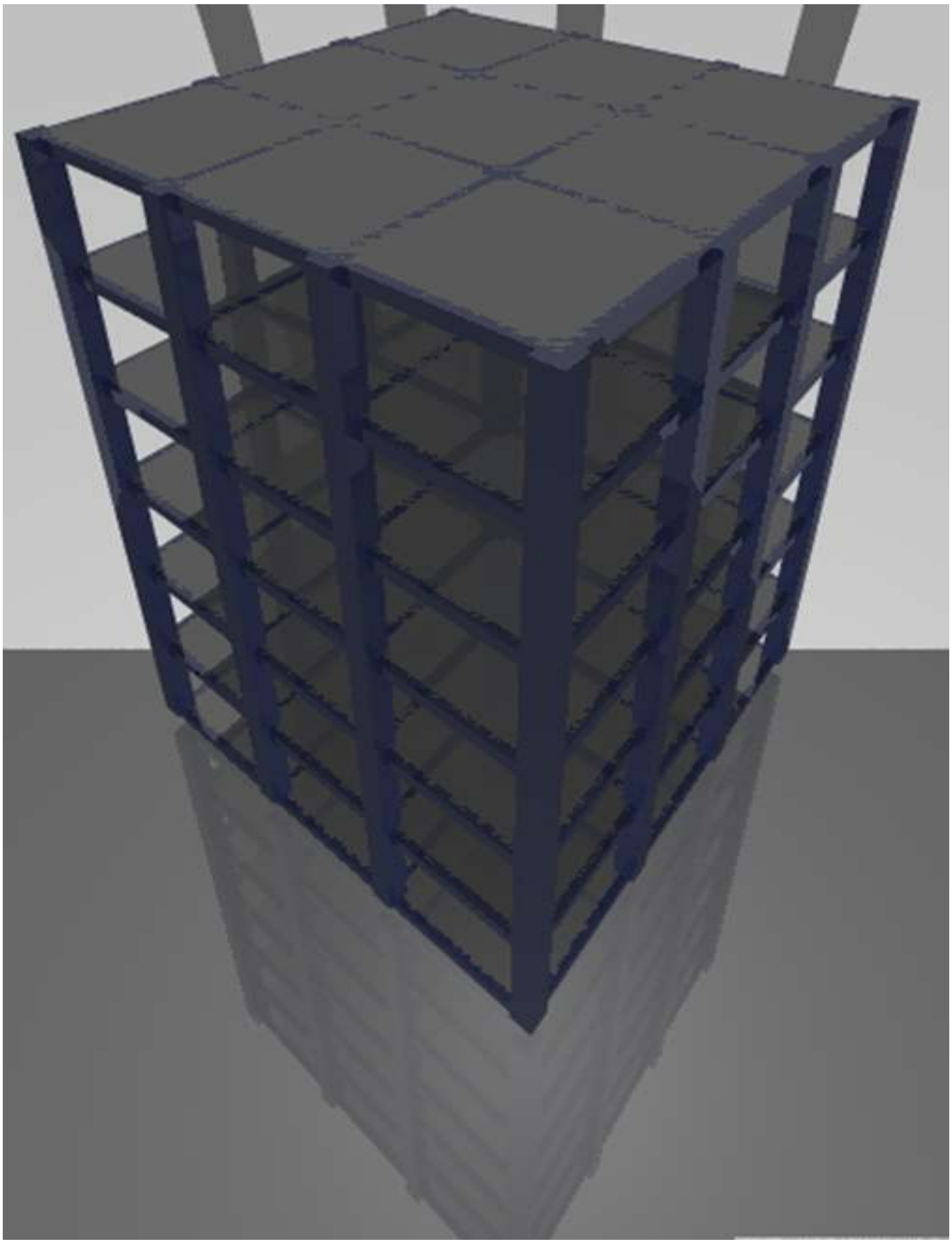

Figure 10 3d view of the Model

7. **RESULT**

a) **Base shear and Storey forces**

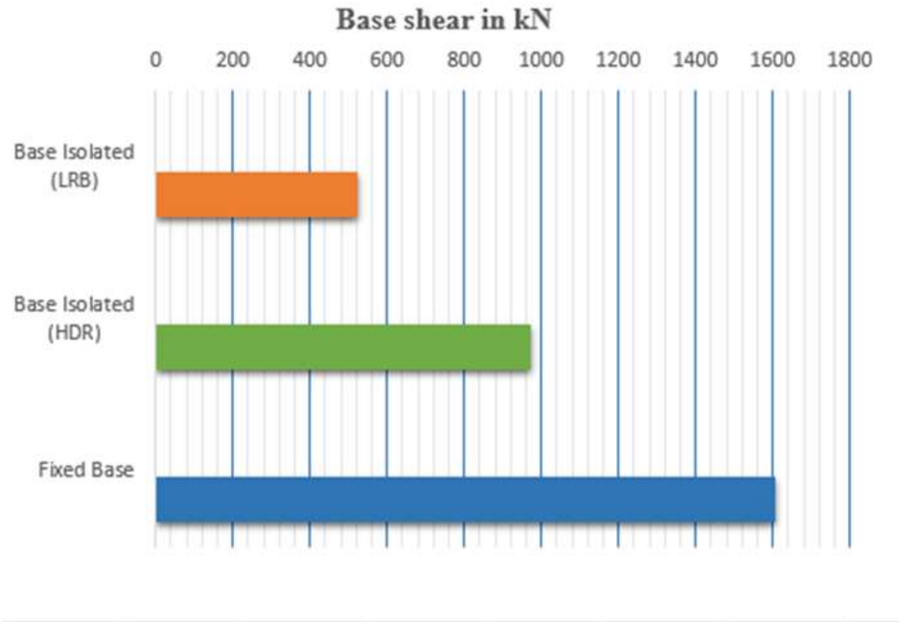

Figure 11 Graphical representation of Base shear bar chart

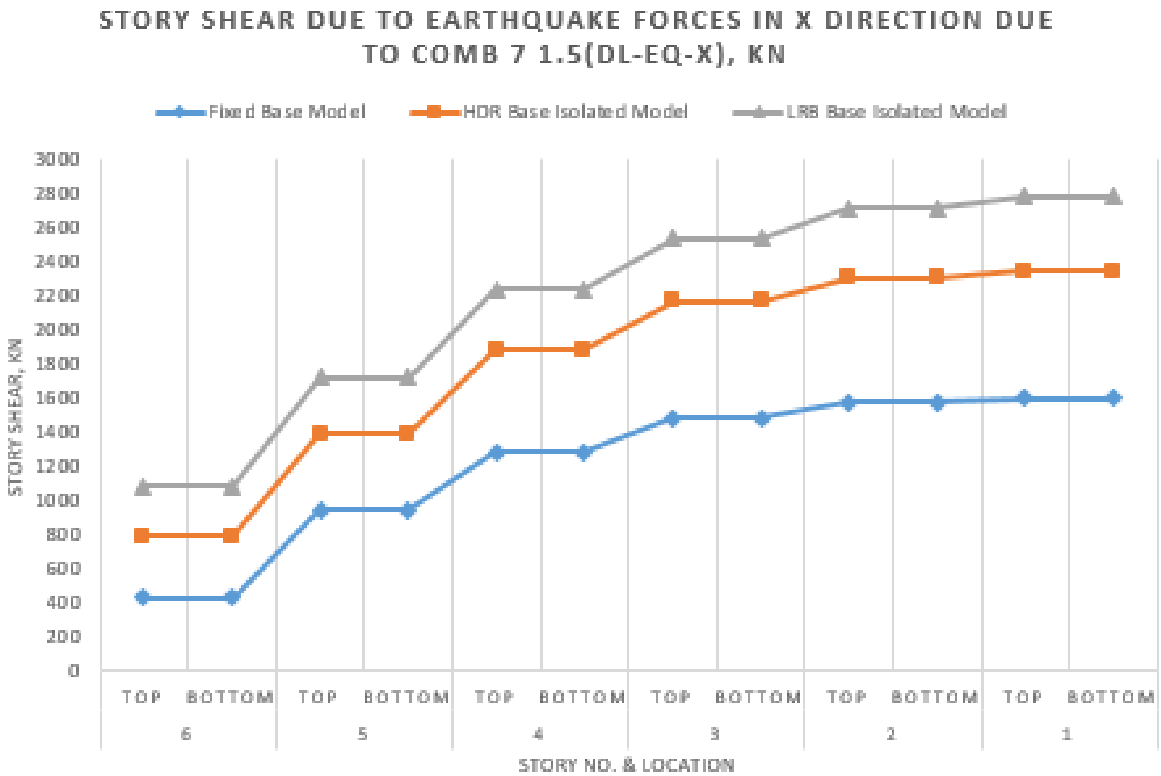

Figure 12 Graphical representation of Storey shear due to Earthquake forces in X direction

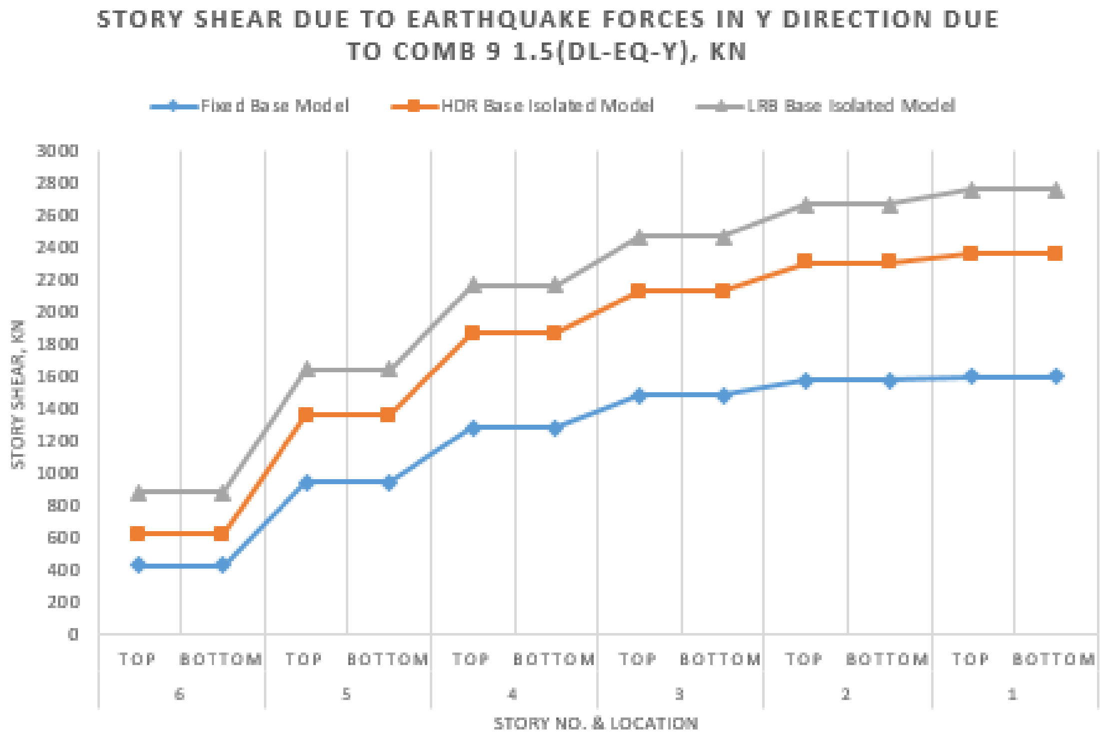

Figure 13 Graphical representation of Storey shear due to Earthquake forces in Y direction

b) Storey displacement

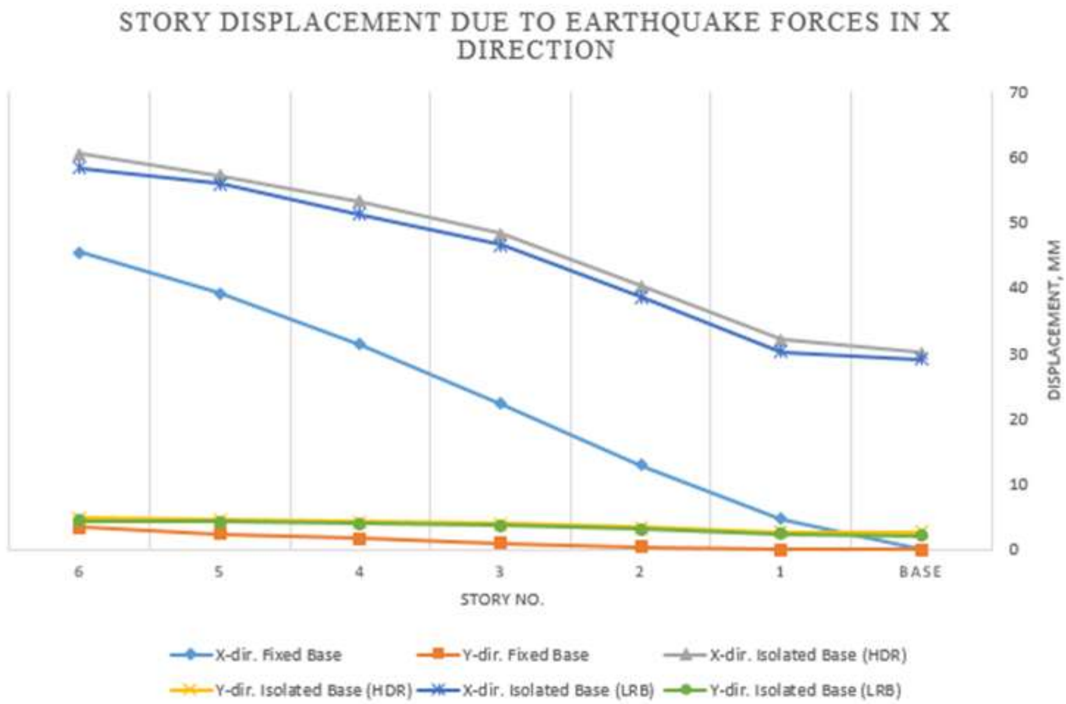

Figure 14 Graphical representation of Storey Displacement due to Earthquake forces in X direction.

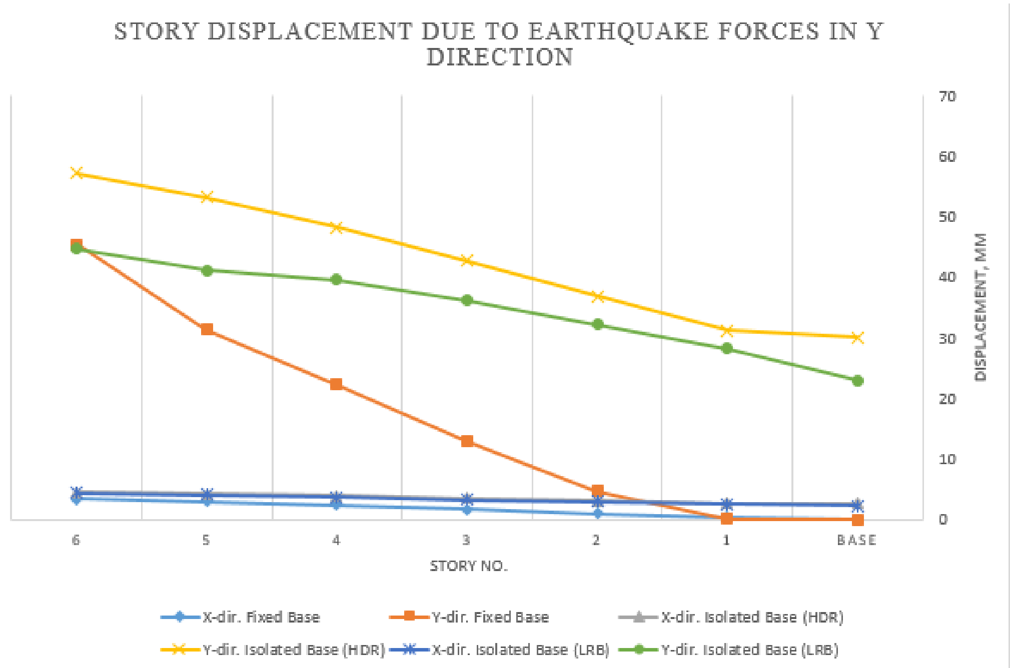

Figure 15 Graphical representation of Storey Displacement due to Earthquake forces in Y direction.

c) Storey drift

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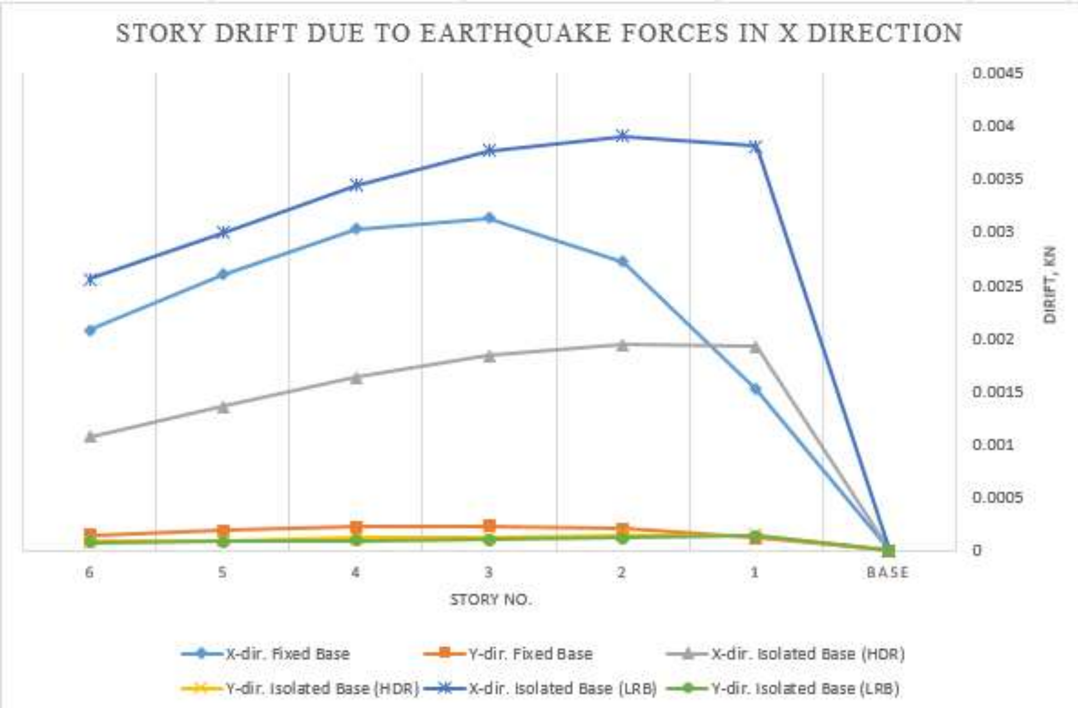

Figure 16 Graphical representation of Storey Drift due to Earthquake forces in X direction.

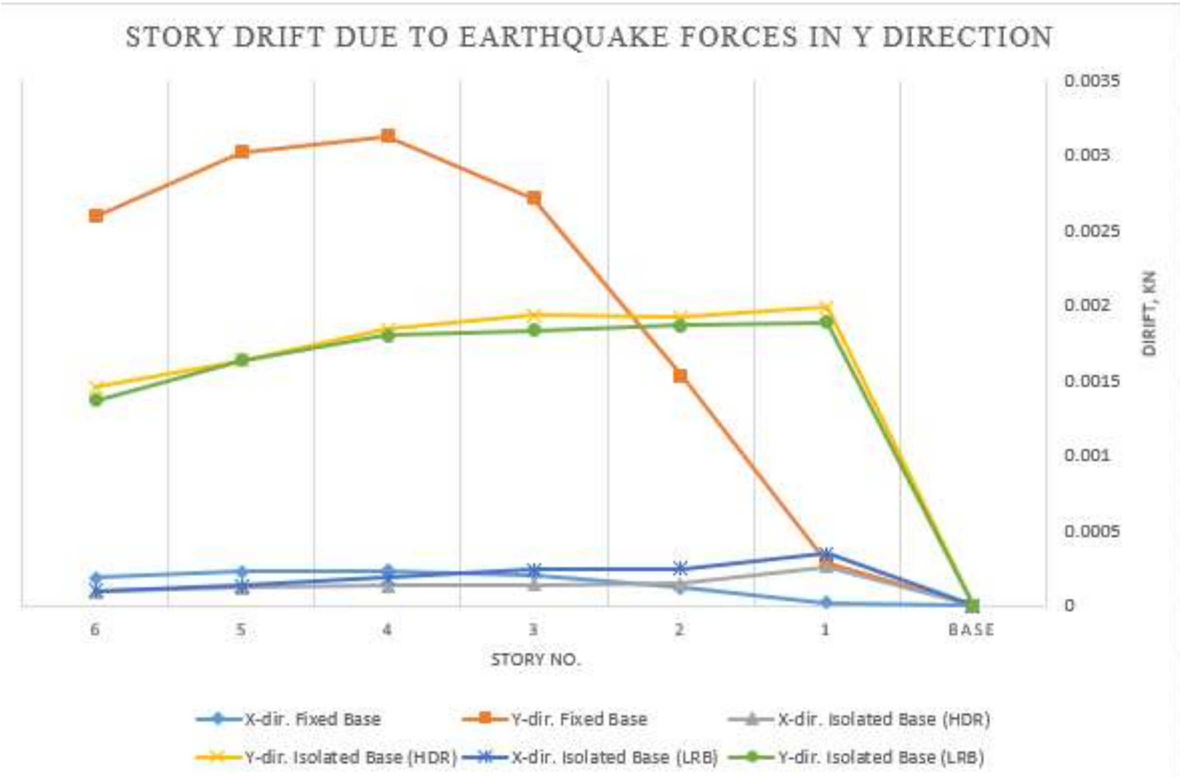

Figure 17 Graphical representation of Storey Drift due to Earthquake forces in Y direction

d) Modal period

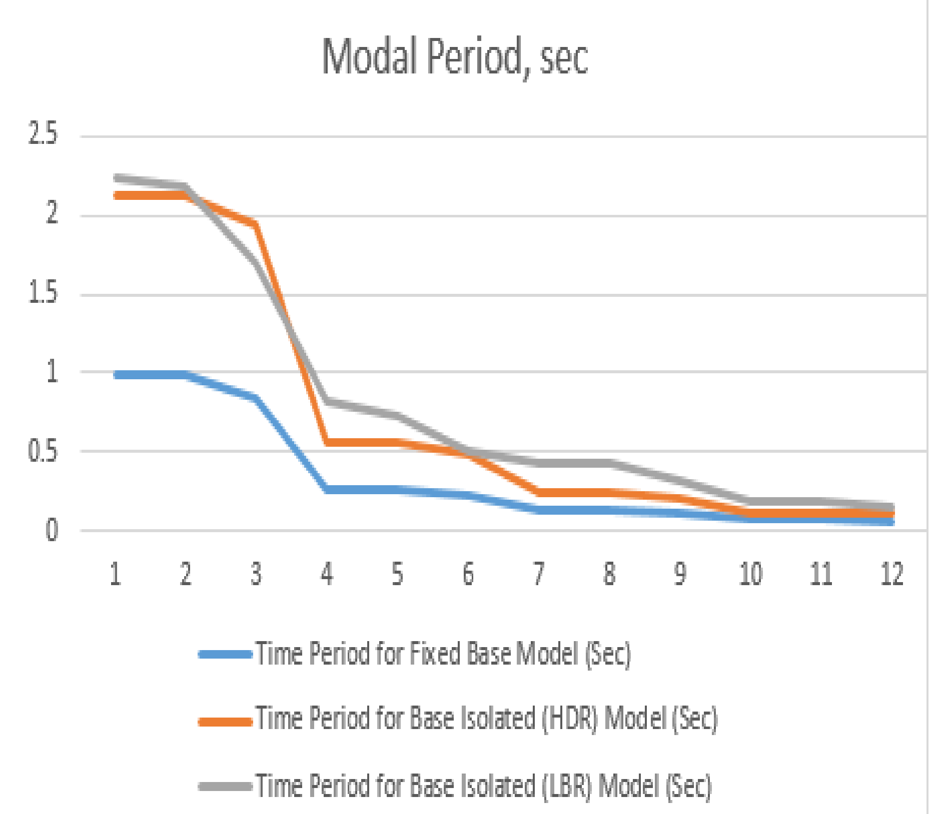

Figure 18 Graphical representation of Time period

8. CONCLUSIONS

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.

9. 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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