AN INTEGRATED ANALYSIS OF LEAD RUBBER BEARINGS AND FLUID VISCOUS DAMPERS FOR ENHANCING SEISMIC RESILIENCE OF BUILDING

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Abstract — **This study evaluates the seismic performance of a G+13 reinforced concrete building in Seismic Zone IV using a hybrid system of Lead Rubber Bearings (LRBs) and Fluid Viscous Dampers (FVDs). The structure, modeled in ETABS with Soil Type 2 parameters, incorporates LRBs designed for a total seismic weight of 344,208 kN and a design displacement of 8.26 mm. FVDs were placed at the 4th and 6th floors in both directions to achieve ~30% damping.**

Linear static and dynamic analyses show that the integrated LRB+FVD system reduces peak displacement, inter-story drift, and base shear by approximately 68%, 65%, and 60%, respectively, compared to the fixed-base model. These reductions outperform LRB-only (50%, 47%, 43%) and FVD-only (58%, 53%, 49%) systems. Model-5, employing the hybrid approach, demonstrated the best overall performance.

The results highlight the effectiveness of combining base isolation and supplemental damping for enhancing seismic resilience in high-rise buildings, offering a robust strategy for earthquake-resistant design.

Keywords— **Seismic Performance, Fluid Viscous Dampers, Lead Rubber Bearing, ETABS, RC Buildings, Storey Drift, Base Shear, Earthquake-Resistant Design, Modal Mass participation Ratio**

I. INTRODUCTION

1.1 General

The increasing frequency and intensity of seismic events have necessitated innovative approaches to building design and retrofitting. Seismic events pose significant threats to building safety, structural integrity, and human life. Innovative strategies are necessary to improve building resilience as the risk of seismic damage increases due to urbanization and population growth. Dampers and Base Isolation are two widely used effective seismic mitigation strategies. Nevertheless, additional research is necessary given their unique shortcomings and possible advantages.
The growing need to develop earthquake-resilient infrastructure, particularly high-rise buildings in seismic-prone zones, has led to the adoption of specialized engineering systems. Buildings in such zones are not only susceptible to ground shaking but also face risks of resonance, collapse, and operational failure. On the other hand, it is also well understood that, while building structures including passive energy dissipating systems are effective for long-duration, long-period ground motions (Takewaki, et.al.), they are not necessarily effective for near-fault (rather high-frequency) ground motions (Xu et.al.). This is because the passive damper systems (friction dampers, viscoelastic dampers, and hysteretic dampers), cannot respond effectively to impulsive loadings. Smart resolution of these two issues may be one of the most controversial issues in the field of seismic resistant and control design (Koo et.al.)

Therefore, engineers have turned to advanced techniques that decouple structural behavior from ground vibrations.

1.2 Need for Seismic Resilience in High-Rise Structures

The increasing prevalence of high-rise buildings in urban landscapes, especially within seismically active regions, underscores the imperative for enhanced seismic resilience. Traditional seismic design approaches, which primarily focus on augmenting structural strength and stiffness, have demonstrated limitations (Gang Xu, et.al.)
Tall structures experience lateral forces from wind. Without tuned mass dampers, these buildings can sway excessively, leading to discomfort for occupants and potential structural fatigue over time. The inherent stiffness of the structure may not be sufficient to mitigate these effects. Most of the hilly areas come under seismic zones, in such cases building built on sloping grounds are highly vulnerable to earthquake. This is due to the fact that columns in the ground floor differ in their heights according to the slope of the ground. For tall buildings and high towers, wind load may also be taken as critical loading. (Sumana C V, et.al.)
The absence of base isolation limits the architectural flexibility that can be achieved in high-rise design. Architects may need to adhere to more conservative designs that prioritize structural integrity over aesthetic or functional considerations. Base isolation device reduces the stiffness and increases the flexibility in the structure. The basic concept of base isolation technique is “to increase time period and reduce acceleration of fixed base structure” from this, reduction of the seismic effect on structure is seen. (Sumana C V, et.al.)
Hybrid control strategies, combining the strengths of both passive and active systems, have emerged as promising solutions. These systems aim to mitigate seismic energy more effectively, enhancing the overall resilience of high-rise structures. The

implementation of such technologies not only safeguards structural integrity but also ensures the rapid restoration of functionality post-earthquake, aligning with the broader objectives of sustainable urban development. (Shrikant M. Harle)
In emergencies such as earthquakes or strong winds, the lack of effective isolation or damping can pose serious risks to occupant safety. Evacuation procedures may be complicated by structural instability or damage.
In summary, while high-rise buildings are an essential component of urban development, their performance during seismic events and under wind loads can be significantly compromised without base isolation and tuned mass dampers. These limitations highlight the importance of incorporating advanced engineering solutions in the design of tall structures to ensure safety, comfort, and longevity.

1.3 Seismic Mitigation Techniques

Two major strategies have emerged in seismic design, base isolation and energy dissipation using dampers. Base isolation works by introducing flexible elements at the foundation level, which absorb seismic energy and prevent its direct transmission to the structure. Common isolation devices include elastomeric bearings, lead rubber bearings (LRBs), and friction pendulum systems. In contrast, damping systems like fluid viscous dampers (FVDs), friction dampers, and tuned mass dampers (TMDs) work by dissipating vibrational energy within the superstructure, reducing acceleration and inter-storey drift.
Introducing base isolation systems can significantly reduce the seismic forces transmitted to the building during an earthquake. This decouples the structure from ground motion, minimizing damage and enhancing occupant safety. Utilizing adaptive dampers or semi-active control devices can enhance the effectiveness of base isolation by adjusting damping properties in real-time based on structural response to seismic activity. Base isolation is the recent development for seismic resistant designs, this may not totally control the ground movement but helps in minimizing the impact of ground movement. (Abhilash Naik, et.al.)
Installing dampers at strategic locations within the building can help reduce wind-induced vibrations, improving occupant comfort and structural performance. TMDs can stabilize the building against lateral forces, particularly in tall structures where sway is a concern.
Using high-strength concrete can reduce the size of structural elements, allowing for more usable space while maintaining structural integrity. Incorporating pre-engineered steel systems can optimize design efficiency and flexibility, allowing for larger column-free spaces that are better able to withstand dynamic loads.

1.3.1 Base Isolation

Base isolation is a passive seismic control technique that decouples the structure from ground motion by introducing flexible elements between the building and its foundation. The key principle involves increasing the natural period of the structure, thereby shifting the building's response away from the predominant frequencies of the earthquake. This results in reduced acceleration, displacement, and force transmission to the superstructure.

1.3.1.1 Types of base isolators

Elastomeric Bearings: The most commonly used base isolators, elastomeric bearings consist of layers of natural or synthetic rubber sandwiched between steel plates.

Natural Rubber Bearings (NRB): Made from natural rubber, these provide flexibility but limited damping.

Synthetic Rubber Bearings: Similar to NRB but made from synthetic materials for enhanced performance.

Lead Rubber Bearings (LRB): Incorporate a lead core within the rubber to improve damping capacity, making them effective in high-seismic areas. Time period of building can be adequately increased by using LRB as compared to fixed base which will result in reducing natural frequency of the building. (Abhilash Naik, et.al.)

Elastomeric bearings are typically composed of alternating layers of rubber and steel plates. The rubber layers provide flexibility and energy dissipation, while the steel plates offer stiffness and strength.

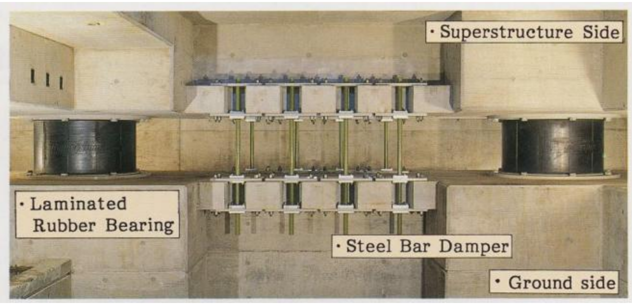

Fig.1: Elastomeric Bearings

The Fig-1 illustrates a seismic base isolation system combining Laminated Rubber Bearings (LRBs) and Steel Bar Dampers. The LRBs, located on both sides, serve as the primary isolation units designed to accommodate lateral displacements during seismic events while supporting vertical loads from the superstructure. The Steel Bar Dampers installed between the LRBs provide additional energy dissipation, enhancing the overall damping capability of the system.

Friction Pendulum Bearings: These bearings utilize a pendulum mechanism, allowing the structure to move laterally during seismic events while dissipating energy through friction.

Flat Slider Bearings: Use a flat sliding surface for movement.

Curved Slider Bearings: Employ a curved surface that enhances the pendulum effect and provides better energy dissipation.

Friction pendulum bearings are a type of seismic isolation device that combine the flexibility of rubber with a sliding friction element. This unique design allows for significant horizontal displacement during an earthquake while providing a controlled restoring force.

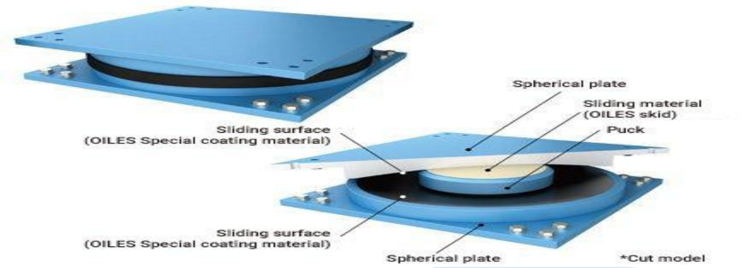

Fig.2: Friction pendulum bearings

The Fig.2 shows the construction and working principle of a Friction Pendulum Bearing (FPB), which is a type of seismic isolation device that combines sliding and pendulum action to dissipate seismic energy and limit structural displacements.

Sliding Bearings: These systems use predefined coefficients of friction to allow horizontal movement while limiting the forces transferred to the structure. They can be shaped or spherical sliders for improved performance. They are typically composed of a sliding surface, a friction element, and a restoring force mechanism. A low-friction surface, such as Teflon or stainless steel, is placed between the structure and the foundation. This surface allows for smooth horizontal movement. A friction element, often made of lead or a lead-alloy, is incorporated into the bearing. This element provides a controlled level of resistance to sliding, preventing excessive displacement. A restoring force mechanism, such as a spring or a pendulum, is used to bring the structure back to its original position after an earthquake.

Fig.3: Sliding Bearings

Fig.3 shows the installation of sliding bearings beneath a structure, which serve as a seismic base isolation system. These bearings are placed between the superstructure and the concrete foundation blocks to allow controlled horizontal movement during seismic events.

Roller and Ball Bearings: Primarily used in machinery isolation, these bearings consist of cylindrical rollers or balls that facilitate movement and can provide some level of damping. In ball bearings, a set of steel balls are placed between a concave inner race and a convex outer race. As the bearing rotates, the balls roll between the races, reducing friction and allowing smooth movement. Ball bearings are suitable for a wide range of applications, including bicycles, automobiles, and industrial machinery. They are particularly effective in applications where high rotational speeds and precision are required. Both ball and roller bearings are essential components in many mechanical systems. The choice between the two depends on factors such as the load to be supported, the required rotational speed, and the desired level of friction reduction.

Fig.4: Roller and Ball Bearings

Fig.4 shows the installation of roller and ball bearings, which are types of seismic isolation devices designed to permit smooth horizontal movement of a structure during an earthquake. These bearings are placed between the building's superstructure and its foundation to reduce the transmission of ground motion.

High Damping Bearings: These are similar to elastomeric bearings but are designed specifically to provide higher energy dissipation, making them suitable for structures in high seismic zones. High damping bearings revolves around their ability to absorb and dissipate seismic energy through a combination of flexible rubber layers and rigid steel plates. This innovative design allows them to provide effective seismic isolation, ensuring structural integrity and safety during earthquakes. Their adaptable nature and low maintenance requirements make them a vital component in modern civil engineering for earthquake-resistant design.

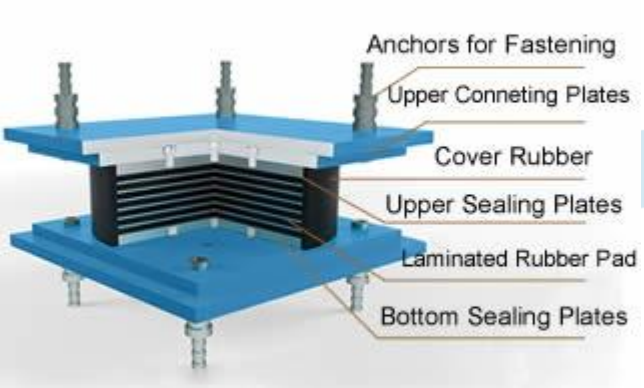

Fig.5: High Damping Bearings

Fig.5 illustrates the construction of a High Damping Rubber Bearing (HDRB), a type of seismic isolation device used to absorb and dissipate earthquake energy while supporting the vertical loads of a structure. The bearing is composed of multiple layers of laminated rubber pads and steel plates, which provide vertical stiffness to carry the structural weight, while the rubber layers allow horizontal flexibility. The high damping property of the rubber material enables the bearing to dissipate seismic energy through hysteresis, thereby reducing structural vibrations.

Spring Systems: Though not commonly used in structural applications due to their flexibility in both vertical and horizontal directions, springs can be part of isolation systems in specific contexts. Spring systems play a crucial role in base isolators by providing flexibility and damping that protect structures from seismic forces. Through effective decoupling and energy absorption, these systems enhance building resilience during earthquakes, making them an essential component in modern seismic design strategies.

Fig.6: Spring Systems

Fig.6 shows a spring-based isolation system, which is used in seismic protection to provide flexible support and energy dissipation for structures during earthquake events.

This system consists of helical coil springs placed between a structure and its foundation. The springs offer vertical and horizontal flexibility, allowing the structure to move independently of ground motion. Above and below the springs, metal plates and bearing components are used to properly transmit loads and maintain alignment.

Table.1: Comparison of different types of Base isolators

Feature	LRBs	Elastomeric Bearings (NRB/Synthetic)	Friction Pendulum Bearings	Sliding Bearings	High Damping Bearings
Flexibility	☑	☑	☑	☑	☑
High Damping	☑ (built-in)	✖ (needs extra damping)	☑ (friction)	☑ (friction)	☑
Restoring Force	☑ (automatic)	☑ (rubber elasticity)	☑ (pendulum effect)	✖ (needs design)	☑
Displacement Control	Good	Good	Larger	Larger	Good
Complexity	Simple	Simple	Complex	Complex	Moderate
Proven in Real Earthquakes	☑	☑	☑	☑	☑
Maintenance	Low	Low	Moderate	Moderate	Low

Table.1 Values displays, Lead Rubber Bearings (LRBs) are often considered more suitable, especially for critical or high-risk structures, because they offer an ideal balance of flexibility, strength, energy dissipation, and restoring capability. LRBs, NRBs, Friction Pendulum Bearings, Sliding Bearings, and High Damping Bearings based on key features. LRBs and High Damping Bearings offer built-in damping and restoring force, with simple design and low maintenance. NRBs are flexible but need extra damping. Friction and Sliding Bearings allow larger displacements, but are more complex and require designed restoring mechanisms. LRBs and NRBs are the most widely proven in real earthquakes.

1.3.2 Lead Rubber Bearings (LRBs):

Lead Rubber Bearings (LRBs) are highly suitable for seismic isolation because they combine several crucial functions within a single unit. They effectively isolate seismic forces by increasing the building's flexibility and shifting its natural frequency away from the damaging range of ground motions. The integrated lead core within the LRB dissipates a significant amount of seismic energy through controlled yielding, reducing the forces transmitted to the structure. LRBs also control lateral displacements to manageable levels, ensuring the building remains stable and functional after an earthquake. Additionally, the inherent elasticity of the rubber layers and the plastic deformation of the lead core provide a strong restoring force that automatically brings the building back to its original position after seismic events. Proven successful in real-world earthquakes across various countries, LRBs offer a reliable, efficient, and cost-effective solution, making them ideal for critical infrastructure like hospitals, bridges, and emergency facilities.

These consist of alternating layers of rubber and steel shims with a lead core. The rubber provides flexibility, the steel ensures vertical load capacity, and the lead core yields under seismic loading to dissipate energy.

1.3.2.1 Advantages of Lead Rubber Bearings (LRBs):

Significantly reduces seismic forces acting on the superstructure.

Protects structural and non-structural components.

Allows for continued functionality of critical facilities (e.g., hospitals) after seismic events.

1.3.2.2 Limitations:

Less effective in handling vertical seismic accelerations.

Performance may vary with high-frequency or near-fault ground motions.

Requires adequate space and specific foundation conditions for installation.

1.3.3 Damping Systems

Damping systems work by absorbing and dissipating the kinetic energy imparted by seismic forces, reducing the amplitude of structural vibrations. They are typically installed in locations of high strain, such as braces or beam-column joints, and are designed to activate during excessive motion.

1.3.3.1 Types of Damping Systems

Viscous damper: viscous damping is a way to add energy dissipation to the lateral system of a building structure. A viscous damper dissipates energy by pushing fluid through an orifice, producing a damping pressure which provides a force or seismic energy. In this damper, by using viscous fluid inside a cylinder, energy is dissipated. Due to ease of installation, adaptability and coordination with other members also diversity in their sizes, viscous dampers have many applications in designing and retrofitting. (Lalit Arya, et.al.)

Fig.7: Viscous Dampers

Fig.7 displays the installation of viscous dampers in structural systems, commonly used for seismic and wind vibration control in buildings and bridges. The left part of the image shows viscous dampers integrated into a braced frame of a building under construction, while the right part shows viscous dampers applied to a bridge structure. These dampers are cylindrical devices filled with a viscous fluid (usually silicone-based), and they work by dissipating kinetic energy from structural motion through fluid resistance.

Friction damper: Friction Dampers are normally modeled directly in structural design software either directly or more commonly, as a fictitious yielding element The two main outputs of the structural design being the required response force and travel. With these two parameters, Quaketek can provide Dampers ranging from 0.5kip (2kN) to 350kips (1500kN) of tested response force per damper with travels commonly between 0.5inches (12mm) and 12inches (300mm). Larger response forces can be generated by connecting the dampers in parallel, generating in excess of 1,400kips (6,000kN) Dampers can be designed for indoor or outdoor applications as the finishes can be adapted for different environments. (Prof. Lalit Arya, et.al.) Friction dampers, showed that the robust design of passive device can be done in a safe and economic process. (Sergio Pastor Ontiveros-Perez, et.al.)

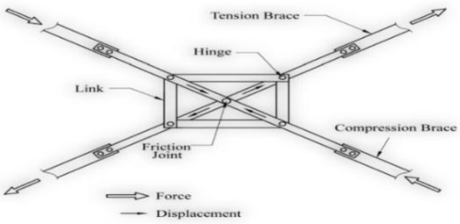

Fig.8: Friction damper

Fig.8 illustrates the working principle of a friction damper system, which is used to dissipate seismic energy through frictional resistance developed at preloaded interfaces.

Tuned mass damper: A tuned mass damper (TMD), also known as a harmonic absorber or seismic damper, is a device mounted in structures to reduce mechanical vibrations, consisting of a mass mounted on one or more damped springs. Its oscillation frequency is tuned to be similar to the resonant frequency of the object it is mounted to, and reduces the object's maximum amplitude while weighing much less than it. TMDs can prevent discomfort, damage, or outright structural failure. They are frequently used in power transmission, automobiles and buildings. (Prof. Lalit Arya, et.al.)

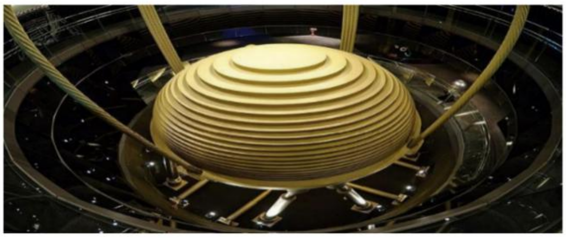

Fig.9: Tuned mass damper

Fig.9 depicts a Tuned Mass Damper (TMD), an advanced vibration control device used to reduce structural motion caused by wind, earthquakes, or other dynamic forces. The image shows a large spherical mass, suspended by steel cables and supported by shock absorbers, a setup commonly seen in high-rise buildings like the Taipei 101.

Yielding dampers: Yielding damper or metallic yielding energy dissipation device or passive energy dissipation device is manufactured from easily yielded metal or alloy material. It dissipates energy through its plastic deformation (yielding of the metallic device) which converts vibratory energy and consequently declines the damage to the primary structural elements. yielding dampers are economical, effective, and proved to be a good energy dissipater. (Prof. Lalit Arya, et.al.)

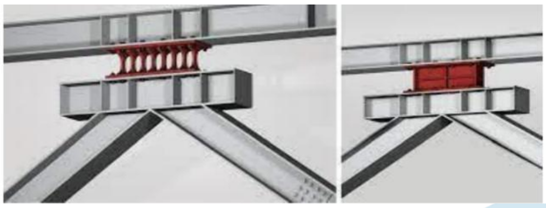

Fig.10: Yielding dampers

Fig.10: Yielding Dampers (YDs), also known as metallic yielding devices, are passive energy dissipation systems designed to enhance the seismic performance of structures. The image illustrates two common configurations of YDs used in braced frames. On the left, a corrugated or flexural-type yielding damper is placed between the beam and brace connection, allowing controlled inelastic deformation through flexure under seismic loading. On the right, a shear panel damper uses flat steel plates designed to yield in shear, dissipating seismic energy efficiently. Both configurations focus seismic energy into replaceable, ductile components, thereby protecting the main structural elements from damage and improving the building's overall resilience.

Magnetorheological damper: Magnetic Damper consists of two racks, two pinions, a copper disk and rare-earth magnets. This type of damper is neither expensive nor dependent on temperature. Magnetic damping is not strength that is why it is effective in dynamic vibration absorbers which require less damping. (Prof. Lalit Arya, et.al.)

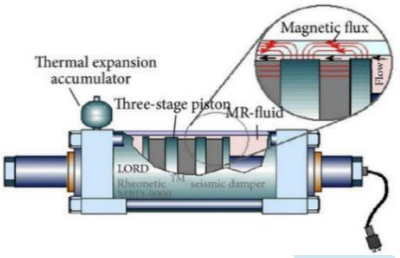

Fig.11: Magnetorheological damper (Magnetic Damper)

Fig.11: Magnetorheological (MR) Damper, a type of semi-active control device, utilizes MR fluid whose viscosity can be altered in real time by applying a magnetic field. The diagram shows the internal components of the damper, including a three-stage piston and thermal expansion accumulator. When activated, the magnetic field causes the MR fluid to thicken, increasing resistance to piston motion and thereby dissipating seismic or vibrational energy. The inset magnifies the interaction between the magnetic field and the MR fluid, illustrating how magnetic flux lines influence particle alignment within the fluid to modulate damping force. These devices are widely used in seismic and vibration control systems for buildings, bridges, and vehicles due to their fast response and adjustable performance.

In summary, Magnetorheological dampers, which have a semi-active system, are being developed as damping devices for building structures. Passive control systems, such as energy-dissipating devices, are also used as dampers in buildings to increase their energy dissipation capacity and prevent damage during earthquakes. Linear and nonlinear fluid viscous dampers are used to mitigate seismic-induced pounding between adjacent buildings.

1.3.4 Fluid Viscous Dampers (FVDs):

These contain a piston-cylinder arrangement filled with viscous fluid. As the building moves, the piston forces the fluid through small orifices, dissipating energy through viscous shear. They are effective across a wide frequency range and particularly useful in retrofitting applications.

1.3.4.1 Advantages of Fluid viscous dampers (FVDs):

Reduces inter-storey drift, improving structural and occupant safety.

Enhances performance without significant alteration of building geometry.

Can be easily incorporated into new and existing structures.

1.3.4.2 Limitations:

Require precise tuning and calibration.

Some types may degrade over time or under repeated loading.

Performance can be limited under extreme seismic conditions.

1.3.5 Combined Use

Recent trends in seismic engineering emphasize integrated systems that combine base isolation with damping devices. This hybrid approach leverages the strengths of each technique—base isolation reduces seismic demand at the base, while dampers address residual motions throughout the structure. Such systems have shown superior performance across a broader range of seismic inputs and structural configurations.

The addition of dampers can reduce dynamic displacement by as much as 50%. This reduction not only enhances safety but also decreases the forces acting on the structure. By minimizing displacement, the required size of base isolation systems can be reduced, leading to cost savings in materials and construction. The overall system may become less expensive compared to using base isolators alone.

Reduced displacement requirements allow for more usable space within the building since the perimeter can be closer to property lines. By reducing forces transmitted to the structure, these systems significantly lower the risk of damage during earthquakes.

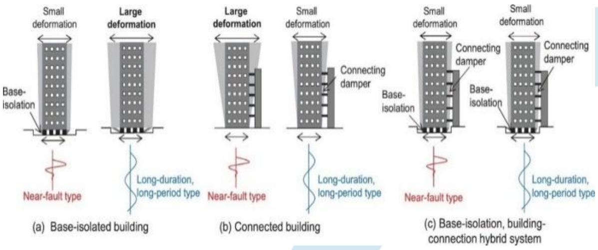

Fig.12: Earthquake response properties under near-fault and long-duration, long-period ground motions: (a) Base-isolated building, (b) Connected building, (c) Base-isolation, building-connection hybrid system.

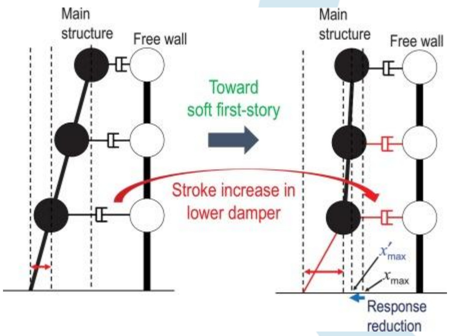

Fig.13: Advantageous feature of base-isolation for the energy consumption at the connecting dampers

A base-isolated building and a building with connecting dampers are two representatives of passive controlled buildings, Fig.12 (a), (b)). A new hybrid passive control system consists of a multi-story base-isolated main building (apartment house), a free wall (car parking tower) and a group of interconnecting oil dampers as shown in Fig.12(c). Oil dampers are usually installed as connecting dampers because of its sufficient stroke and damping performance. The general earthquake response properties of these buildings under near-fault and long-duration, long-period ground motions are explained in Fig.12. While the base-isolated building is vulnerable to the long-period ground motion and the connected building is vulnerable to the near-fault ground motion, the building with the proposed hybrid system is effective for both types of ground motions. The hybrid passive control system can resist for the near-fault ground motion via the base-isolation mechanism and respond effectively to the long-duration, long-period ground motion via the building connection mechanism. Furthermore, the base-isolation mechanism is quite advantageous for the energy consumption at the connecting dampers in all stories as shown in Fig.13. (M. Kasagi, et.al.)

1.4 Performance Gaps in Existing Systems

While both base isolation and damping systems have independently demonstrated effectiveness, they exhibit limitations under specific conditions. For example, LRBs may not effectively respond to high-frequency, near-fault ground motions, as observed during the 2011 Tohoku Earthquake in Japan. Conversely, passive dampers may underperform during long-period ground shaking due to limited response time and damping range. This creates a critical need for hybrid systems that combine the strengths of both technologies.

1.5 Benefits of Integrated Systems
The integration of Lead Rubber Bearings (LRBs) and Fluid Viscous Dampers (FVDs) aims to create a hybrid seismic protection strategy that enhances the overall resilience of buildings subjected to diverse seismic events. This approach leverages the distinct strengths of both systems—LRBs effectively reduce base shear and increase the natural period of the structure, thereby lowering its response to long-period ground motions, while FVDs provide efficient energy dissipation during high-frequency, near-fault excitations. By combining these technologies, the integrated system seeks to minimize structural and non-structural damage, reduce inter-storey drifts, and lower floor accelerations, ensuring enhanced life safety and improved post-earthquake functionality. Furthermore, the hybrid system contributes to cost-effective design, facilitates retrofitting of existing structures, and supports sustainability by reducing cumulative damage and extending the life cycle of buildings. This dual mechanism approach aligns with modern performance-based seismic design philosophies and presents a comprehensive solution to the limitations posed by using either system in isolation.

II. PROBLEM STATEMENT

2.1 Overview of Seismic Vulnerability in Urban Areas

Urban centres are increasingly located in moderate to high seismic zones. With limited land availability, cities are expanding vertically, increasing reliance on high-rise buildings. These structures, although optimized for space, present unique challenges in seismic resilience. Earthquakes in dense cities can lead to disproportionate damage due to ground shaking, building interactions, and cascading failures.

2.2 Structural Deficiencies in Tall Buildings

Without sufficient energy dissipation mechanisms, tall buildings tend to undergo severe lateral movement. Rigid connections and conventional materials struggle to accommodate cyclic displacements, leading to material degradation, loss of stiffness, and potential collapse. Structures without isolators or dampers often transfer seismic loads directly to load-bearing members, which may not be designed for such dynamic stress.

2.3 Limitations of Independent Seismic Control Systems

While base isolation is effective in minimizing base shear and lengthening the natural period, it cannot adequately handle high-frequency ground motions. On the other hand, dampers reduce structural vibrations but are not sufficient to isolate seismic energy input. Using either system in isolation exposes the building to specific types of seismic risk, limiting overall resilience.

2.4 Justification for an Integrated Approach

A hybrid system that combines LRBs and FVDs presents a comprehensive solution. It addresses both long-period and high-frequency ground motions and provides redundancy in seismic protection. This study proposes a detailed investigation into the performance of such systems in a high-rise building model, contributing to the advancement of seismic design practices.

stiffness and displacement control, particularly in high-rise structures. They offer superior performance in limiting storey displacement and base shear, making them the more efficient option for enhancing seismic resilience in adjacent buildings.

III. LITERATURE REVIEW

3.1. Literature review on Base isolation system

1.Modeling Lead-Rubber Seismic Isolation Bearings Using the Unified Mechanics Theory- Hernan Martin Hernandez Morales- Accepted March 12, 2020
This study introduces a novel approach using Unified Mechanics Theory to model the force-displacement response of LRBs. The method integrates thermodynamics and Newtonian mechanics to account for material degradation without relying on empirical curve fitting. Lead-rubber seismic isolation bearings (LRB) have been installed in a number of essential and critical structures, like hospitals, universities and bridges, located in earthquake-prone areas. The purpose of using LRB is providing the structure with period lengthening and the capacity of dissipating a considerable amount of earthquake energy to mitigate the effects of strong ground motions.
2. Seismic isolation in buildings to be a practical reality: Behavior of structure and installation technique- A. B. M. Saiful Islam, Mohammed Jameel and Mohd Zamin Jumaat- Accepted 17 February, 2011
Incorporating practical isolation systems into building structures requires flexibility, damping, and service load resistance. Additional requirements such as durability, cost, ease of installation, and project-specific requirements influence device selection, but all practical systems must include these essential elements. The entire superstructure will be supported by discrete isolators with dynamic characteristics chosen to uncouple the ground motion. Displacement and yielding are concentrated at the isolation devices, while the superstructure behaves similarly to a rigid body. The research included a thorough revision of the sequential development of seismic isolation systems.
3. Effectiveness of Base Isolation Technique and Influence of Isolator Characteristics on Response of a Base Isolated Building - Sunita Tolani, Dr. Ajay Sharma- 2016

Top floor absolute acceleration, inter-storey drift and base shear are very less in base isolated building in comparison to corresponding response of fixed base building which indicates reduction of earthquake induced forces in structure and ensures safety of structural and non-structural components of the building. In Base isolated building having LRB system, increase in the period of isolation increases the bearing displacement but decreases the superstructure acceleration. Increase in isolator damping decreases both the bearing displacement and the superstructure acceleration.

Increase in the period of isolation increases the bearing displacement but decreases the superstructure acceleration. However, the response is not much influenced by isolation period. Increase in isolator damping decreases both the bearing displacement and the superstructure acceleration. Increase in the Normalized Yield Strength (F0) decreases the bearing displacement but increases the superstructure acceleration.
4. Base Isolation System- prof. Ravi Gupta, Khan Aftab, Ansari Rehmat Ali, Ifran Shaikh, Wasim Shaikh- 2021

Seismic isolation retrofit in base or mid-story has advantages over the conventional strengthening method as follows. It is effective for reform buildings while they are in use as usual, because the work area can be limited or outside of the building.

Construction cost is cheaper than the conventional strengthening method in the case of middle-rise buildings; e.g. around 10 storied or more. Taking temporary move to other place during construction work inside the building into consideration, and also from the view point of life cycle cost reflecting the seismic performance, cost benefit increases. Seismic performance is excellent not only to secure structural safety but also for the preservation of function and properties.

5. Seismic isolation in buildings to be a practical reality: Behavior of structure and installation technique- A. B. M. Saiful Islam, Mohammed Jameel and Mohd Zamin Jumaat- Accepted 17 February, 2011

Incorporating practical isolation systems into building structures requires flexibility, damping, and service load resistance. Additional requirements such as durability, cost, ease of installation, and project-specific requirements influence device selection, but all practical systems must include these essential elements. The entire superstructure will be supported by discrete isolators with dynamic characteristics chosen to uncouple the ground motion. Displacement and yielding are concentrated at the isolation devices, while the superstructure behaves similarly to a rigid body. The research included a thorough revision of the sequential development of seismic isolation systems.

The research covers the isolation system, properties, device categories, recognition, and its impact on building structures.

6. Effectiveness of Base Isolation Technique and Influence of Isolator Characteristics on Response of a Base Isolated Building - Sunita Tolani, Dr. Ajay Sharma- 2016

Top floor absolute acceleration, inter-storey drift and base shear are very less in base isolated building in comparison to corresponding response of fixed base building which indicates reduction of earthquake induced forces in structure and ensures safety of structural and non-structural components of the building. In Base isolated building having LRB system, increase in the period of isolation increases the bearing displacement but decreases the superstructure acceleration. Increase in isolator damping decreases both the bearing displacement and the superstructure acceleration.

Increase in the period of isolation increases the bearing displacement but decreases the superstructure acceleration. However, the response is not much influenced by isolation period. Increase in isolator damping decreases both the bearing displacement and the superstructure acceleration. Increase in the Normalized Yield Strength (F0) decreases the bearing displacement but increases the superstructure acceleration.

7. Base Isolation System- prof. Ravi Gupta, Khan Aftab, Ansari Rehmat Ali, Ifran Shaikh, Wasim Shaikh- 2021

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In the case of mid-story isolation, repair and space are necessary for piping, staircase, elevator and escalator to follow the large displacement of the isolation story. The retrofit work herein described was done safely and reliably almost without jacks and temporary support. Noise was also measured at various points during construction work to choose suitable method and device. These experiences can be reflected on the future project of this type.

8. A practical optimisation method for friction tuned mass dampers in multi-storey buildings subjected to earthquake excitations-Boshra Besharatian, et.al. – 2024

This article proposes a new particle swarm optimisation (PSO) algorithm to optimise simultaneously the parameters (frequency ratio and friction ratio) of FTMDs fitted on multi-degree of freedom (MDOF) systems and frames subjected to real earthquake ground motions. To reduce lateral drifts, the parameters of friction tuned mass dampers (FTMDs) need to be “tuned up” during the design process, which can be a challenging task for multi storey buildings subjected to real ground motions. To address this issue, this article proposes a practical particle swarm optimisation (PSO) algorithm to optimise simultaneously the parameters (frequency ratio and friction ratio) of FTMDs fitted on multi-degree of freedom (MDOF) systems and frames subjected to real seismic records.

3.2. Literature review on Dampers

1. Passive, semi-active, active and hybrid mass dampers: A literature review with associated applications on building-like structures-Lefteris Koutsoloukas, et.al.– 2022

In this paper, an up-to-date literature review of studies considering mass damper technology was carried out. Studies that investigated passive, semi-active, active and hybrid control using mass dampers were included and their findings were discussed. New innovative control approaches proposed by the structural control community even up to this day were presented. Moreover, the limitations of each type of control system were reported in order to highlight the research gaps that have to be tackled. The studies considering the control of real building-like structures were also gathered and presented in a tabulated form. In addition to that, a novel list of control algorithms utilised on real-building like structures was devised.

2. Improving Total-Building Seismic Performance Using Linear Fluid Viscous Dampers-Giuseppe Marcantonio Del Gobbo, et.al. -2018

This study demonstrates the effectiveness of linear FVDs in enhancing seismic performance of buildings. The authors propose a modified energy method for sizing dampers, showing significant reductions in interstory drifts and floor accelerations. This study on the damping-repair cost relationship provides insight when selecting levels of damping for structural designs and retrofits. It also highlights that retrofit methods may be enhanced by using repair costs, rather than structural parameters. The FVD buildings significantly reduce both drift-sensitive and acceleration-sensitive damage.

3. A Novel Displacement-Based Seismic Design Procedure Considering Non-Linear Fluid Viscous Dampers and Damage Control-Gustavo Ayala, et.al. -2025

The authors propose a new seismic design methodology that incorporates nonlinear FVDs, focusing on displacement-based approaches and damage control strategies. An innovative, displacement-based, seismic design procedure for new and existing planar framed structures considering non-linear fluid viscous dampers, is presented. In this procedure, the damping matrix is approximated by the sum of a classical and a complementary damping matrix, which is representative of a non-classical damping matrix, to apply the conventional modal spectral analysis.

4. Nonlinear Dynamic Characteristics of a Micro-Vibration Fluid Viscous Damper- Xiaolei Jiao, et.al. -2018

This study investigates the nonlinear dynamic behavior of micro-vibration FVDs, analyzing their damping and elastic forces under various conditions.The results reveal that if the entrance effect is not considered, the elastic force and damping force are linear forces. When the entrance effect is considered, the damper has a nonlinear elastic force and a nonlinear damping force. These nonlinear forces are related to the orifice length, diameter, fluid viscosity, excitation amplitude and frequency.

3.3. Combined Literature Review

1. Automatic generation of smart earthquake-resistant building system: Hybrid system of base-isolation and building-connection- M. Kasagi, et.al. - 2021

An automatic generation algorithm of the proposed smart base-isolation and building-connection hybrid system has been proposed. It has been demonstrated that, once an objective function in terms of top displacement and top acceleration under a design ground motion is introduced and a sensitivity-based algorithm is devised, a smart hybrid system consisting of a base-isolation system and a building connection system can be generated automatically. While the proposed algorithm does not work well in a building without the connecting-damper system, it works well in the proposed smart hybrid system with the connecting damper system. The smart hybrid system has a soft first-story mechanism and the mechanism indicates that the automatic introduction of the base-isolation system is possible and desired in the main structure from the viewpoint of performance upgrade. It has been made clear from the energy analysis that the proposed smart hybrid system makes the connecting damper at every floor level effective.

2. Comparing Seismic Performance of Steel Structures Equipped with Viscous Dampers and Lead Rubber Bearing Base Isolation under Near-Field Earthquake- Mohammad Ganji, et.al. – 2017

This study evaluates the seismic behavior of steel frames equipped with either viscous dampers or LRB isolators under near-fault earthquake records. The analysis indicates that both systems enhance seismic performance, with LRBs showing superior performance in reducing lateral displacements. Seismic isolator-equipped structures were also associated with seismic performance level enhancement from life safety to uninterrupted usability at both earthquake hazard levels. Relative lateral displacement at floor levels in damper-equipped structures and seismic isolator-installed buildings were found to be about 29% and 68% improved over that of the structure with no energy dissipation system. Results of distribution of shear forces within structures equipped with viscous damper and seismic isolator, as compared against that of the structures with no energy dissipation system, indicted increased and decreased shear forces, respectively.

3. Application of Viscous Damper and Laminated Rubber Bearing Pads for Bridges in Seismic Regions-Armin Mehrabi, et.al. - 2021

This research investigates the combined use of viscous dampers and laminated rubber bearing pads (LRBPs) in highway bridges. The study demonstrates that the hybrid system effectively reduces relative displacements and residual deformations under various earthquake scenarios. Lead Rubber Bearing Pads (LRBPs) are directly placed between girders and piers and their role is to provide the bridge span with horizontal movement, and to transmit the gravity loads from the deck to the piers. Although not designed for seismic loads, they can act as a fuse, partially isolating the substructure from the superstructure and keeping the piers intact during earthquakes.

3.4. OBJECTIVES

1. To design a G+13 building, incorporating Lead Rubber Bearings (LRBs) and Fluid Viscous Dampers (FVDs) for seismic performance.

2. To evaluate the model accuracy and resilience under seismic zone-4.

3. To analyze and compare the effectiveness of hybrid configurations of Lead Rubber Bearings (LRBs) and Fluid Viscous Dampers (FVDs).

IV. METHODOLOGY

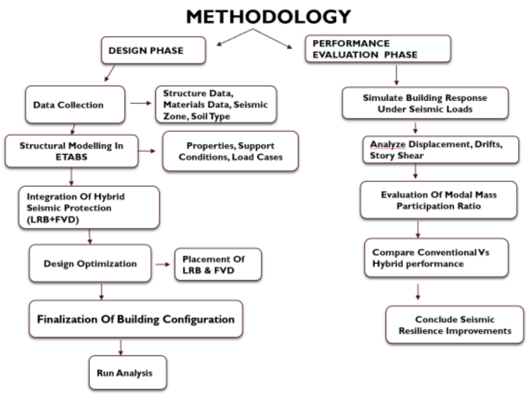


Fig.14: Flowchart of step by step process

The flowchart in Fig.14 outlines the step-by-step methodology followed for evaluating seismic performance of buildings with and without hybrid seismic protection (LRB + FVD). It is divided into two major phases: Design Phase and Performance Evaluation Phase.

4.1 Design Description

a) Building specifications: G+13 RC frame structure

b) Site seismic data (Zone, Soil type): Zone – 4

c) Soil type – 2

a) Structure Type: The building considered is a G+13 reinforced concrete (RC) frame structure, representing a high-rise urban building commonly found in seismic-prone regions. The structure is designed to resist both gravity and lateral loads, incorporating moment-resisting frames as the primary lateral load-resisting system.

b) Seismic Zone: The site is located in Seismic Zone 4, as per the Indian seismic zoning classification (IS 1893), which represents a high seismic risk area. This zone is expected to experience intense ground shaking during a major earthquake, necessitating advanced seismic control measures.

c) Soil Type: The subsoil condition at the site corresponds to Soil Type 2, which typically refers to medium-stiff soil or medium-dense sand and gravel. This soil type has moderate stiffness and damping characteristics, affecting the building's natural frequency and its response to seismic waves.

Table.2: Frame Section Property Definitions - Concrete Beam Reinforcing

Name	Longitudinal Bar Material	Tie Bar Material	Top Cover mm	Bottom Cover mm
B 200*600	HYSD550	HYSD550	60	60
B 300*600	HYSD550	HYSD550	60	60

This table presents the reinforcement detailing specifications for two types of beam sections, labeled as B 200×600 and B 300×600, indicating their respective cross-sectional dimensions in millimeters.

Table.3: Frame Section Property Definitions - Concrete Column Reinforcing

Name	Longitudinal Bar Material	Tie Bar Material	Reinforcement Configuration	Is Designed?	Clear Cover to Ties mm	Number Bars 3-Dir	Number Bars 2-Dir	Longitudinal Bar Size	Corner Bar Size	Tie Bar Size	Tie Bar Spacing cm²	Number Ties 3-Dir	Number Ties 2-Dir
C 200X1000	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3
C 200X1200	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3
C 200X760	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3
C 200X900	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3
C 230X1000	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3
C 230X1200	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3
C 230X900	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3
C 300X1000	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3
C 300X1200	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3
C 300X600X6...	HYSD550	HYSD550	Rectangular	Yes	22.5	4	4	20	20	10	1.5	3	3
C 300X760	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3
C 300X900	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3
C450X1200	HYSD550	HYSD550	Rectangular	Yes	40	3	5	20	20	10	1.5	3	3

This table outlines the column reinforcement details for various column types with specified cross-sectional dimensions and reinforcement configurations.

Table.4: Load Cases Definitions

Name	Exclude Group	Mass Source	Stiffness Type	Load Type	Load Name
Dead	None	MsSrc1	P-Delta	Load	Dead
EQ X	None	MsSrc1	P-Delta	Load	EQ X
EQ Y	None	MsSrc1	P-Delta	Load	EQ Y
Filling	None	MsSrc1	P-Delta	Load	Filling
Live	None	MsSrc1	P-Delta	Load	Live
LL>3	None	MsSrc1	P-Delta	Load	LL>3
NLL	None	MsSrc1	P-Delta	Load	NLL
RLL	None	MsSrc1	P-Delta	Load	RLL
SDL	None	MsSrc1	P-Delta	Load	SDL
WIND X	None	MsSrc1	P-Delta	Load	WIND X
WIND Y	None	MsSrc1	P-Delta	Load	WIND Y

The table represents the load case configuration typically used in structural analysis software like ETABS or SAP2000. It defines various loads acting on a structure and their characteristics essential for seismic and structural evaluation.

The stiffness type applied across all load cases is "P-Delta", indicating that second-order effects (geometric nonlinearity due to deformation) are considered in the analysis, which is crucial for high-rise or flexible structures.

The load type for each case is defined as "Load", and the load name in the final column reiterates the specific load applied. The load cases include:

Dead: Permanent structural and non-structural weight.

EQ X & EQ Y: Earthquake loads in the X and Y directions.

Filling: Load due to infill materials like brickwork.

Live and LL>3: Standard and additional live loads.

NLL and RLL: Likely represent different categories of live loads, such as non-reducible and reducible.

SDL: Superimposed dead load.

WIND X & WIND Y: Wind loads in horizontal directions.

4.1.1 Storey definitions
Base to plinth = 1.5 m
Plinth to stilt = 3.78 m
Stilt to ground floor = 3.47 m
Ground floor to terrace = 3.17 m (floor to floor)
Terrace to headroom = 1.5 m (floor to floor)

Table.5: Storey Definitions

Name	Height m	Master Story	Similar To	Splice Story	Color
HEADROOM	1.524	Yes	None	No	Blue
LIFT BOTTOM...	1.524	Yes	None	No	Blue
TERRACE	3.175	Yes	None	No	Blue
12TH	3.175	Yes	None	No	Blue
11TH	3.175	Yes	None	No	Blue
10TH	3.175	Yes	None	No	Blue
9TH	3.175	Yes	None	No	Blue
8TH	3.175	Yes	None	No	Blue
7TH	3.175	Yes	None	No	Blue
6TH	3.175	Yes	None	No	Blue
5TH	3.175	Yes	None	No	Blue
4TH	3.175	Yes	None	No	Blue
3RD	3.175	Yes	None	No	Blue
2ND	3.175	Yes	None	No	Blue
1ST	3.175	Yes	None	No	Blue
GR	3.47	No	1ST	No	Green
STILT	3.7846	No	1ST	No	Cyan
PLINTH	1.5	No	1ST	No	Red

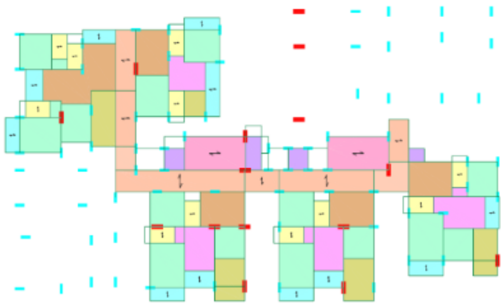


Fig.15: Building Plan.1: 1st,4th,7th,10th Floor, and TERRACE

Fig.16: Building Plan.2: GF,2nd,5th,8th and 11th Floor

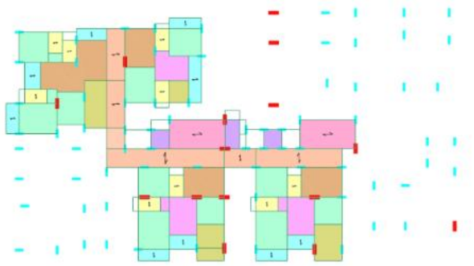


Fig.17: Building Plan.3: 3rd,6th,9th and 12th Floor

4.1.2 Model-1(Conventional) – No seismic isolation or damping

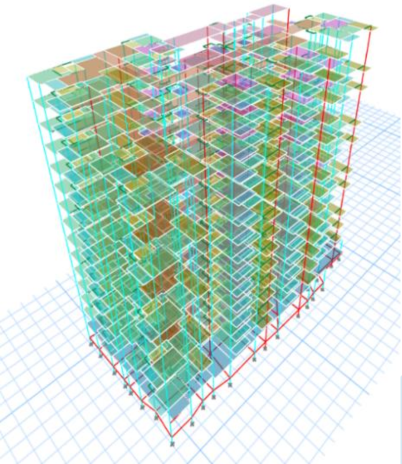


Fig.18: Isometric View of Model-1
Fig.18 Shows the isometric view showcases a 3D model of a multi-story reinforced concrete (RC) building created in ETABS. The structure includes multiple bays in both X and Y directions, with clearly defined slabs, beams, columns, and core wall elements. The building is modeled without any base isolation or energy dissipation devices, indicating it is designed following conventional seismic design practices.

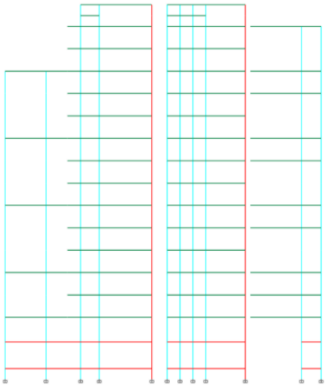


Fig.19: Elevation View of Model-1
Fig.19 Shows the elevation view provides a side projection of the same building, highlighting the vertical alignment and distribution of floors, columns, and beams. The symmetry and regularity in the layout reflect a typical conventional RC frame structure. The absence of isolators or dampers confirms this is the baseline model for comparison against hybrid seismic protection systems.
4.1.3 Model-2(Partial LRB) – LRBs at base only under columns with higher axial loads

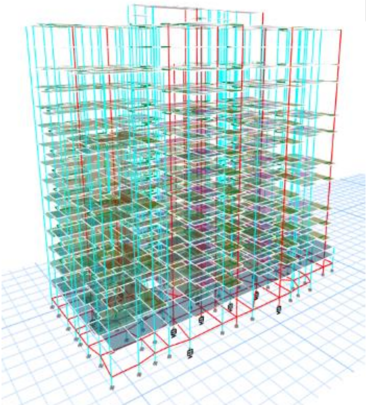


Fig.20: Isometric View of Model-2
Fig.20 This 3D representation shows the structural configuration of Model-2 with Lead Rubber Bearings (LRBs) selectively placed only at the base of specific columns—those subjected to higher axial loads. The visual highlights a hybrid base where some columns remain traditionally fixed while others are supported on isolators.

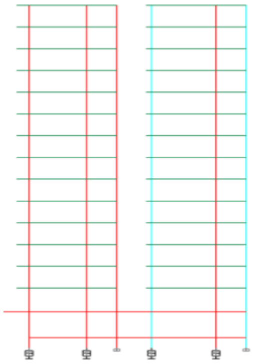
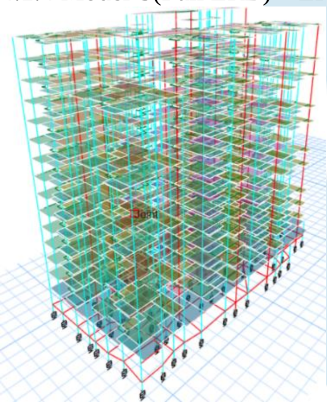


Fig.21: Elevation View of Model-2

Fig.21 The elevation diagram further confirms that LRBs are not uniformly distributed; only select columns (likely with higher load demands) are equipped with isolators at their base level. This creates a semi-isolated base condition.

Model-2 features Lead Rubber Bearings (LRBs) installed only under columns with higher axial loads, offering targeted seismic isolation. Unlike Model-1, which is a fixed-base system with no isolation, Model-2 partially decouples the structure from ground motion, reducing seismic forces at key points. This selective approach improves resilience at critical supports while maintaining cost-efficiency.

4.1.4 Model-3(Full LRB) – LRBs at base under all columns



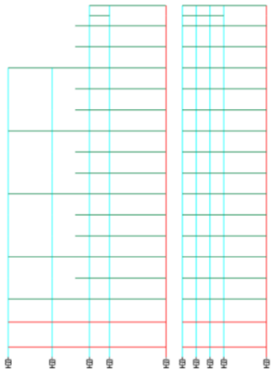


Fig.22: Isometric View of Model-3

Fig.23: Elevation View of Model-3

Fig.22 and Fig.23 represents a building structure where Lead Rubber Bearings (LRBs) are installed under all columns at the base, offering comprehensive seismic isolation. The isometric and elevation views illustrate full coverage of base isolators, providing uniform energy dissipation and minimizing the transfer of seismic forces into the superstructure.

Compared to Model-1 (Conventional): Model-1 lacks any isolation system, leading to full seismic energy transfer and higher structural demands. Model-3 significantly reduces base shear, lateral displacements, and enhances safety.

Compared to Model-2 (Partial LRB): While Model-2 uses LRBs selectively under high-load columns, it may lead to uneven seismic response. Model-3, with full isolation, ensures more balanced and effective performance during earthquakes.

4.1.5 Storey definitions – Model-4 (Partial FVD) –FVDs at 4th–6th and 12th–13th floors

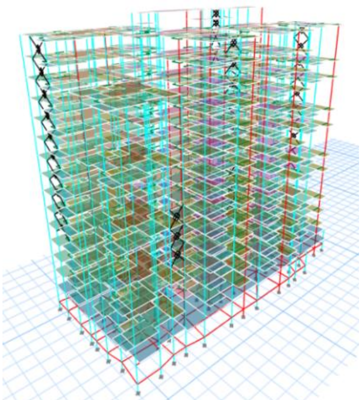


Fig.24: Isometric View of Model-4

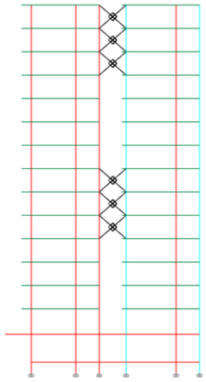


Fig.25: Elevation View of Model-4

Fig.24 and Fig.25 shows where model incorporates fluid viscous dampers (FVDs) placed selectively at intermediate and upper floors (specifically 4th–6th and 12th–13th), rather than throughout the full height of the building. The purpose is to provide targeted energy dissipation where inter-story drifts are expected to be more critical during seismic activity.

Vs. Model-1 (Conventional): Unlike the conventional model, Model-4 introduces energy dissipation devices that actively reduce vibrations. Model-1 lacks any form of seismic control, resulting in higher drifts and longer natural periods.

Vs. Model-2 (Partial LRB): Model-2 isolates the base partially using Lead Rubber Bearings (LRBs), reducing base shear but not addressing upper story movements. Model-4 complements this by tackling higher-floor dynamic responses, where base isolation alone might be less effective.

Vs. Model-3 (Full LRB): While Model-3 isolates the entire base uniformly, it may result in larger superstructure displacements. Model-4 instead absorbs energy within the structure, reducing inter-story drift without lifting the entire structure on isolators. It offers a different control mechanism compared to full base isolation.

Model-4 is focused on strategic damping through floor-level dampers, improving control over localized drift and accelerations. It represents a hybrid approach distinct from base isolation strategies, offering enhanced resilience especially in tall, irregular, or asymmetrical buildings where floor-level tuning is beneficial.

4.1.6 Model-5(Full LRB + Partial FVD) – LRBs under all columns + FVDs at 4th–6th and 12th–13th floors

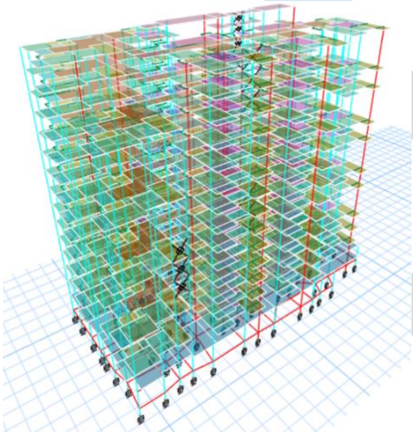


Fig.26: Isometric View of Model-5

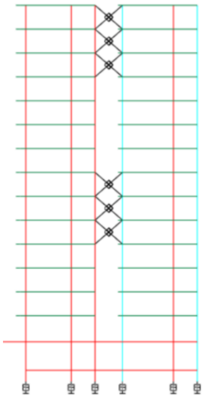


Fig.27: Elevation View

Fig.26 and Fig.27 represent Model-5, which integrates Lead Rubber Bearings (LRBs) under all column bases and includes Fluid Viscous Dampers (FVDs) at specific intermediate floors (4th–6th and 12th–13th floors). This hybrid approach combines seismic base isolation with targeted energy dissipation to enhance the structural performance under dynamic loads, such as earthquakes.

Compared to Model-1: Unlike Model-1, which has no seismic isolation or damping, Model-5 significantly improves earthquake resistance by incorporating both base isolation and energy dissipation systems.

Compared to Model-2: While Model-2 applies LRBs only under high axial load columns, Model-5 provides a uniform isolation system under all columns, ensuring more consistent seismic response and less torsional irregularity.

Compared to Model-3: Model-3 also has LRBs under all columns, but lacks additional damping. Model-5 enhances energy dissipation further through FVDs, particularly targeting floor levels prone to higher drift or acceleration.

Compared to Model-4: Model-4 only uses FVDs without any base isolation. Model-5 builds upon that by also incorporating full base isolation, offering both flexibility and damping — making it the most robust and resilient among all five models.

4.2 Base Isolation System

LRBs are a type of seismic isolation device that combines vertical load support, horizontal flexibility, and energy dissipation. They consist of alternating layers of rubber and steel shims with a lead core at the center.

4.2.1 Specifications:

Lead Rubber Bearings (LRB) and Fluid Viscous Dampers (FVD), including the relevant units, typical ranges or limits, and the applicable IS code references,

Parameter	Description	Units	Typical Range/ Limit	IS Code Reference
G	Shear modulus of rubber	MPa	0.4 – 1.0 MPa	IS 1893 (Part 1): 2016, Clause 11
Ar	Plan area of rubber bearing	mm²	Depends on diameter (πD²/4), typically 100,000 – 500,000 mm²	IS 1893-2016, Clause 11.2
tr	Total rubber thickness	mm	50 – 300 mm	IS 1893, Table C-1 (Annex C)
hr	Single rubber layer thickness	mm	6 – 20 mm	IS 1893, Clause 11.3
n	Number of rubber layers	—	5 – 20 layers	Derived from tr / hr
dl	Diameter of lead core	mm	40 – 200 mm	Based on energy dissipation needs (IS 1893,
Al	Area of lead core (πdl²/4)	mm²	1250 – 31,400 mm²	Based on lead plug diameter
τy	Yield stress of lead	MPa	8 – 15 MPa	Material-specific, often taken as 10.5 MPa
Kr	Rubber stiffness = GAr / tr	kN/mm	Design-dependent	Derived from geometry
Kl	Lead plug stiffness	kN/mm	Design-specific	Based on material and lead diameter
Keff	Effective horizontal stiffness	kN/mm	Typically 0.5 – 2 times Kr	IS 1893-2016, Clause 11.5
ξ	Equivalent damping ratio	%	10 – 30%	IS 1893:2016, Clause 11.5
D	Design displacement	mm	100 – 300 mm	IS 1893:2016, Clause 11.4

4.2.2 Design for Lead Rubber Bearing System

1. Rubber Stiffness: Kr = (G x Ar) / tr

This provides lateral stiffness due to shear deformation of the rubber.

2. Lead Core Stiffness: Assuming linear behavior before yield: Kl = (Al x El) / tr

Where El approx 1000 MPa (approximate elastic modulus of lead). Post-yield, the energy is dissipated.

3. Effective Stiffness of Bearing: Keff = Kr + Kl

4. Yield Force of Lead Core: Fy = Al x ty

Typically, ty approx 10 MPa for lead.

5. Damping Force per Cycle (Hysteretic Energy): W = 4 x Fy x D

Where D = Design displacement (mm)

6. Equivalent Damping Ratio: ξ = W / (2 x π x Keff x D^2) = (2 x Fy) / (π x Keff x D)

This provides the equivalent viscous damping, typically ranging from 15-30%.

Total weight of the building = 344208.28 kN

(N) Number of Isolators = 15

(D) Displacement = 9.14 mm (taken from ETABS)

Seismic Zone = 4 (Delhi)

Bearing dia = 850 mm (assumed)

(G) Rubber shear modulus = 0.6 MPa

Target damping = 10-30%

Earthquake Time period

X = 0.58 sec

Y = 0.82 sec

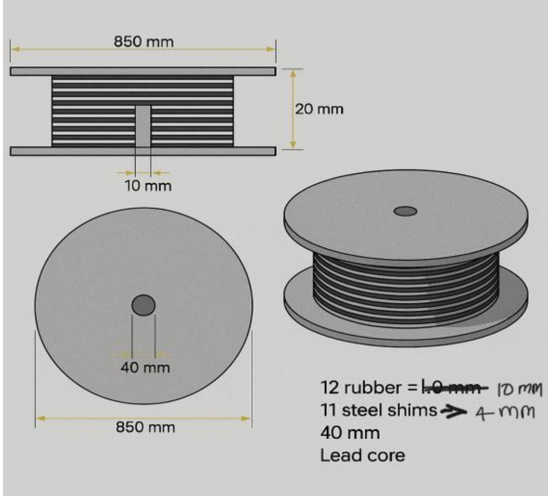


Fig.28: Designed Lead Rubber Bearing

Fig.28 illustrates a detailed design of a Lead Rubber Bearing, a seismic isolation device commonly used at the base of structures. The LRB shown has a circular plan view with an overall diameter of 850 mm and a total height of 200 mm. Internally, it contains a lead core of 40 mm diameter at the center, which provides energy dissipation through plastic deformation during seismic events. Surrounding the lead core are alternating layers of rubber (12 layers, each 10 mm thick) and steel shims (11 layers, each 4 mm thick), contributing to vertical load-carrying capacity and horizontal flexibility. The top and bottom steel plates are used for anchoring the LRB to the foundation and superstructure.

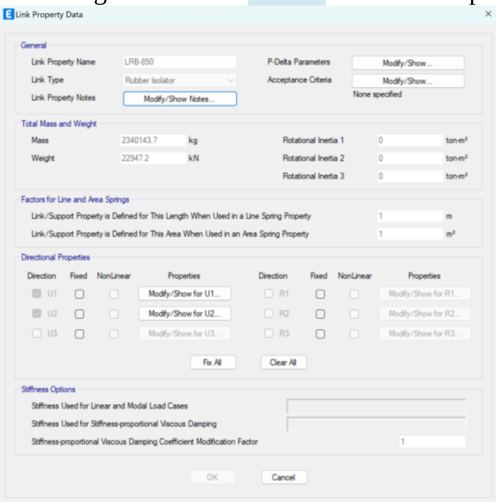


Fig.29: LRB Parameters given in Etabs software

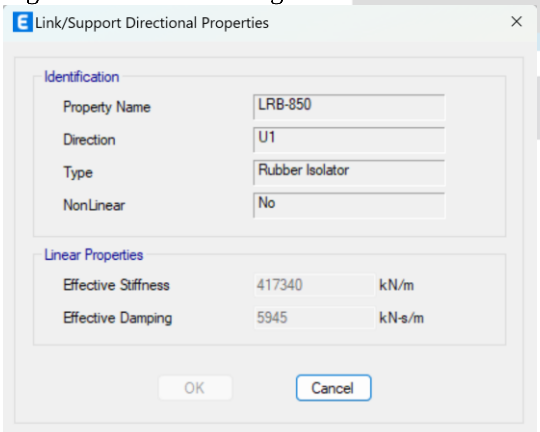


Fig.30: LRB Parameters given in Etabs software

Fig.29 and Fig.30 shows the configuration window for assigning LRB properties in ETABS. The link property is labeled as “LRB-850” under the “Rubber Isolator” type. Key physical attributes such as mass (2340437.1 kg) and weight (229642.7 kN) are defined. Directional properties for translation (U1, U2, U3) and rotation (R1, R2, R3) are available, with nonlinear behavior possibly assigned in specific directions. The window also includes options to modify stiffness settings for linear/nonlinear viscous damping and proportional damping constants. This configuration ensures that the LRB's real-world characteristics are accurately represented in the structural model for seismic analysis.

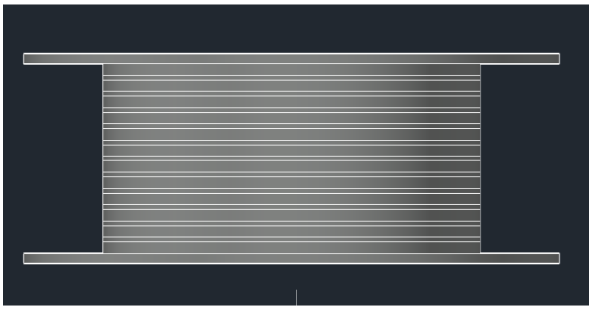


Fig.31: Sketch in Autocad software

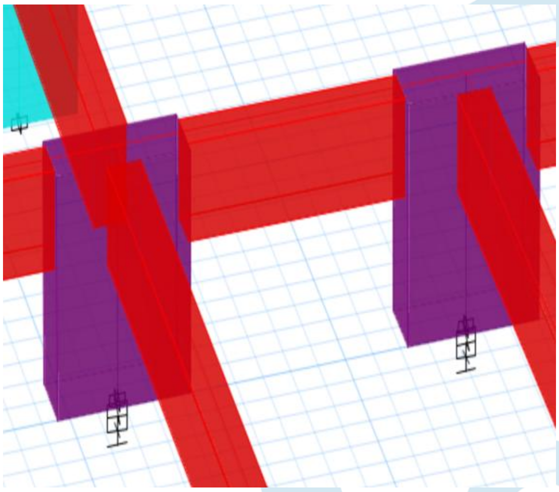


Fig.32: LRB Assigned in Etabs software

Fig.32 is a 3D structural view within ETABS where LRBs are visually integrated at the base of the columns. The red columns and beams represent the primary structural elements, while the violet components at the column bases denote the inserted LRB links. These isolators visibly decouple the structure from the foundation grid below, which allows controlled lateral displacement during seismic events. The modeling accurately reflects the physical placement and function of LRBs as seen in the design drawings and parameters.

4.3 Damping System

FVDs (Fluid Viscous Dampers) are devices that dissipate seismic energy through fluid viscosity, reducing structural vibrations.

4.3.1 Design Components:

Cylinder and Piston Assembly: A piston moves within a cylinder filled with viscous fluid, typically silicone-based.

Orifice Mechanism: Controls the flow of fluid, generating resistance proportional to the velocity of piston movement.

4.3.2 Design Considerations:

Damping Force: Defined by the equation,

$F = C \cdot V^{\alpha}$

Where,

F: Damping force

C: Damping coefficient

V: Velocity of piston

α (alpha): Velocity exponent (typically between 0.3 and 1.0)

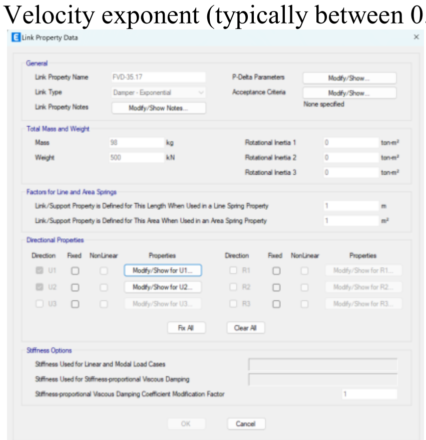


Fig.33: FVD Parameters given in Etabs

Fig.33 shows the Link Property Data dialog box from ETABS for defining a Fluid Viscous Damper (FVD). The link property name is FVD-35.17, and the link type selected is Damper - Exponential. The damper is assigned a mass of 50 kg and a weight of 500 kN. Under Direction Properties, the U1 direction (likely horizontal) is specified with user-defined properties. The FVD acts as a linear damper, meaning it doesn't exhibit nonlinear behavior. The stiffness options are left blank, implying that stiffness proportional damping is not used in this case. These parameters define how the FVD will behave under seismic loads, focusing on energy dissipation without adding stiffness to the structure.

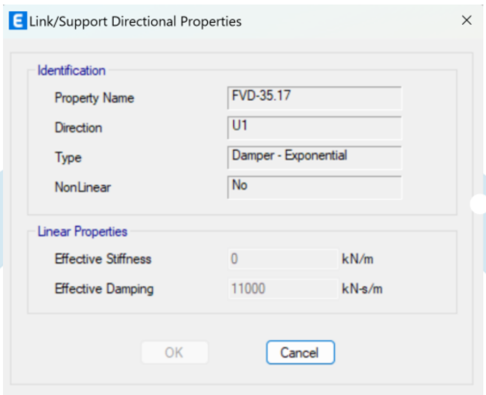
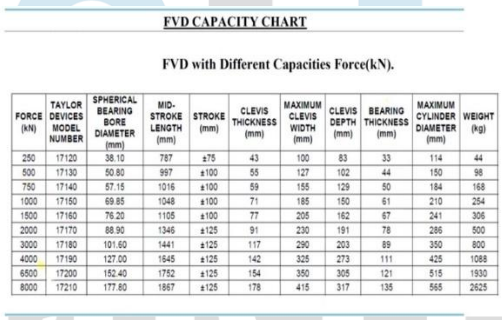


Fig.34: FVD Parameters given in Etabs

Fig.34 Displays the Link/Support Directional Properties window for the FVD in the U1 direction. The damper type is again Exponential, and it is set to linear behavior. The Effective Stiffness is set to 0 kN/m, indicating that the damper doesn't contribute to lateral stiffness. The Effective Damping is set to a high value of 11,000 kN·s/m, showing that the device's primary function is to absorb seismic energy through damping.



FVD CAPACITY CHART

FVD with Different Capacities Force(kN).

FORCE (kN)	TAYLOR DEVICES MODEL NUMBER	SPHERICAL BEARING BORE DIAMETER (mm)	MID-STROKE LENGTH (mm)	STROKE (mm)	CLEVIS THICKNESS (mm)	MAXIMUM CLEVIS WIDTH (mm)	CLEVIS DEPTH (mm)	BEARING THICKNESS (mm)	MAXIMUM CYLINDER DIAMETER (mm)	WEIGHT (kg)
250	17120	38.10	787	±75	43	100	83	33	114	44
500	17130	50.80	997	±100	55	127	102	44	150	98
750	17140	57.15	1016	±100	59	155	129	50	184	168
1000	17150	69.85	1048	±100	71	185	150	61	210	254
1500	17160	76.20	1105	±100	77	205	162	67	241	306
2000	17170	88.90	1346	±125	91	230	191	78	286	500
3000	17180	101.60	1441	±125	117	290	203	89	350	800
4000	17190	127.00	1645	±125	142	325	273	111	425	1088
6500	17200	152.40	1752	±125	154	350	305	121	515	1930
8000	17210	177.80	1867	±125	178	415	317	135	565	2625

Fig.35: FVD Capacity chart

Fig.35 presents the capacity specifications for Fluid Viscous Dampers (FVDs) across a range of force capacities from 250 kN to 8000 kN. Each row corresponds to a specific damper model from Taylor Devices, detailing its mechanical and dimensional parameters.

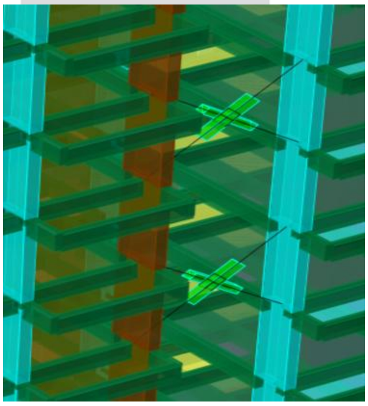


Fig.36: FVD Assigned in Etabs software

Fig.36 shows a 3D rendered view of a building model in ETABS, with Fluid Viscous Dampers (FVDs) visually represented and assigned diagonally between floors. The green-colored diagonal elements symbolize the FVD link assignments, placed between adjacent horizontal framing members, suggesting their role in dissipating seismic or dynamic energy during lateral movement.

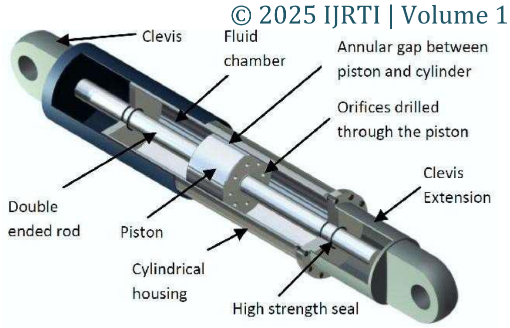


Fig.37: FVD Schematic diagram

The schematic illustrates the internal structure and components of a Fluid Viscous Damper (FVD). It shows a double-ended rod housed within a cylindrical casing, moving back and forth through a piston located centrally. The piston includes orifices drilled through it, allowing fluid movement during motion.

Surrounding the piston is a fluid chamber, where the fluid is forced through the orifices during seismic or dynamic loading, generating damping force through viscous resistance. The annular gap between the piston and cylinder further facilitates energy dissipation.

Clevis ends and clevis extensions at both ends are used for mechanical connection to the structure. High-strength seals ensure no fluid leakage during piston movement. This configuration ensures reliable energy dissipation by converting kinetic energy into heat through fluid shear during relative motion.

V. RESULTS AND DISCUSSION

5.1 Structural Performance Results

Comparison of inter-story drift, and max displacement for both with and without control systems.

Table.6: Comparison of inter-story drift, and max displacement for both with and without control systems.

Model	Roof Disp.Dead Load (mm)	Roof Disp. EQX (mm)	Roof Disp. EQY (mm)	Drift Dead Load	Drift EQX	Drift EQY	Time Period X (s)	Time Period Y (s)
Model 1 (Conventional)	9.14	337.57	255.21	0.00230	0.1050	0.0770	0.58	0.82
Model 2 (Partial LRB)	33.808	355.25	274.55	0.00970	0.1110	0.0806	0.58	0.82
Model 3 (Full LRB)	637.56	2070.17	3966.38	0.19460	0.6160	1.1350	0.58	0.82
Model 4 (Partial FVD)	9.149	506.36	382.81	0.00236	0.1582	0.1160	0.58	0.82
Model 5 (Full LRB + FVD)	638.61	2074.20	3974.08	0.19500	0.6176	1.1380	0.58	0.82

Table.6: Quantitative comparison of roof displacement, inter-story drift, and time period for five structural models under both dead load and seismic load conditions (EQX and EQY directions). The table demonstrates the performance of various control strategies:

Model 1 (Conventional) shows the lowest displacement and drift under dead load but lacks sufficient control under seismic loading.

Model 2 (Partial LRB) offers modest reductions in drift compared to Model 1, with slightly increased roof displacement.

Model 3 (Full LRB) significantly reduces drift but results in the highest roof displacement, particularly under EQY.

Model 4 (Partial FVD) maintains low displacement and drift, indicating effective damping performance without substantial structural modification.

Model 5 (Full LRB + FVD) achieves the highest seismic drift mitigation (similar to Model 3) but also exhibits the largest roof displacements.

Notably, the time periods in both X and Y directions remain constant (0.58 s and 0.82 s, respectively) across all models, suggesting no significant impact of damping and isolation systems on global dynamic characteristics.

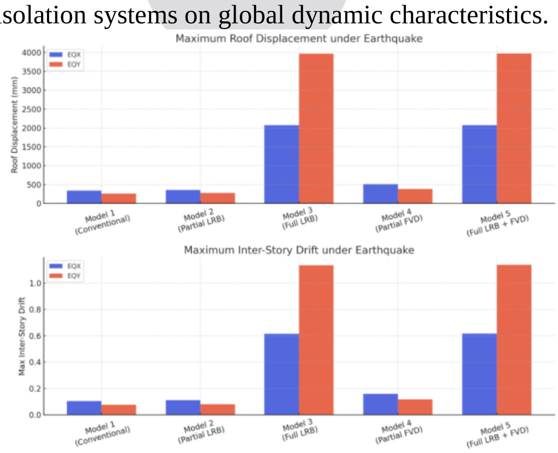


Fig.38: Maximum Roof Displacement and Maximum Inter-Story Drift under seismic loading in both X and Y directions for all five models.

Fig.38 Shows the Comparative analysis of Maximum Roof Displacement (top graph) and Maximum Inter-Story Drift (bottom graph) under seismic loading in the X (EQX) and Y (EQY) directions for five structural models. The results highlight the impact of different seismic protection strategies,

Model 1 (Conventional) serves as a baseline with no damping or isolation systems.

Model 2 (Partial LRB) and Model 3 (Full LRB) incorporate Lead Rubber Bearings (LRBs), with the full implementation significantly reducing inter-story drift but increasing roof displacement.
Model 4 (Partial FVD) integrates Fluid Viscous Dampers, effectively lowering both displacement and drift compared to the conventional model.

Model 5 (Full LRB + FVD) combines full base isolation with fluid damping, achieving substantial drift reduction but resulting in the highest roof displacement, particularly in the Y-direction.

This figure demonstrates the trade-offs and synergies between different seismic mitigation techniques, emphasizing the importance of balanced design for both displacement and drift control.

5.2 JOINT REACTIONS

5.2.1 MODEL-1

Table.7: Joint Reactions of Model-1

Story	Label	Output Case	Case Type	FZ
Unitless	Unitless	Unitless	Unitless	kN
Base	282	1 DL+LL	Combination	2738.9246
Base	283	1 DL+LL	Combination	2368.9269
Base	284	1 DL+LL	Combination	2763.5118
Base	294	1 DL+LL	Combination	2972.3021
Base	297	1 DL+LL	Combination	1884.1182
Base	299	1 DL+LL	Combination	1798.0983
Base	303	1 DL+LL	Combination	1954.2745
Base	311	1 DL+LL	Combination	4105.5105
Base	313	1 DL+LL	Combination	3887.293
Base	316	1 DL+LL	Combination	2802.5512
Base	317	1 DL+LL	Combination	3165.5545
Base	319	1 DL+LL	Combination	3576.0383
Base	324	1 DL+LL	Combination	3101.5494
Base	325	1 DL+LL	Combination	2405.9718
Base	328	1 DL+LL	Combination	1686.9514
Base	329	1 DL+LL	Combination	1627.9816
Base	342	1 DL+LL	Combination	2925.4701
Base	344	1 DL+LL	Combination	4116.8932
Base	354	1 DL+LL	Combination	4014.2905
Base	360	1 DL+LL	Combination	5345.6508
Base	373	1 DL+LL	Combination	3594.2082
Base	374	1 DL+LL	Combination	4919.4869
Base	377	1 DL+LL	Combination	2074.4254
Base	383	1 DL+LL	Combination	3140.832
Base	384	1 DL+LL	Combination	5680.8162
Base	405	1 DL+LL	Combination	3078.6785
Base	407	1 DL+LL	Combination	3002.4867
Base	409	1 DL+LL	Combination	2306.2765
Base	410	1 DL+LL	Combination	2229.8712
Base	415	1 DL+LL	Combination	2754.5573
Base	419	1 DL+LL	Combination	4128.0872
Base	420	1 DL+LL	Combination	4027.2528
Base	428	1 DL+LL	Combination	1425.9288
Base	429	1 DL+LL	Combination	1500.5117
Base	431	1 DL+LL	Combination	2478.9621
Base	432	1 DL+LL	Combination	2501.9736
Base	435	1 DL+LL	Combination	1309.8731
Base	438	1 DL+LL	Combination	2818.6002
Base	442	1 DL+LL	Combination	1369.925
Base	443	1 DL+LL	Combination	1928.8857
Base	445	1 DL+LL	Combination	1661.3533
Base	452	1 DL+LL	Combination	2171.0574
Base	458	1 DL+LL	Combination	2205.6721
Base	462	1 DL+LL	Combination	1467.6755
Base	469	1 DL+LL	Combination	2445.3967
Base	481	1 DL+LL	Combination	1022.4345
Base	484	1 DL+LL	Combination	1487.5116
Base	491	1 DL+LL	Combination	1639.0661
Base	495	1 DL+LL	Combination	1071.5901
Base	496	1 DL+LL	Combination	1237.3723
Base	499	1 DL+LL	Combination	1002.9228
Base	502	1 DL+LL	Combination	3127.5215
Base	503	1 DL+LL	Combination	5563.2476
Base	509	1 DL+LL	Combination	2693.428

This table.7 shows high base shear values in both X and Y directions, with larger reactions distributed across the corner and central joints. Since this is the uncontrolled model (no damping or isolation), all seismic forces are directly transferred to the base. The absence of energy dissipation mechanisms results in the highest overall reaction forces, indicating a more rigid and force-driven behavior.

5.2.2 MODEL-2

Table.8: Joint Reactions of Model-2

Story	Label	Unique Name	Output Case	Case Type	FZ
Unitless	Unitless	Unitless	Unitless	Unitless	kN
Base	518	2858	1 DL+LL	Combination	1467.528
Base	519	2861	1 DL+LL	Combination	1926.5905
Base	520	89	1 DL+LL	Combination	2203.4426
Base	521	47	1 DL+LL	Combination	12.0457
Base	522	45	1 DL+LL	Combination	4787.2518
Base	528	1992	1 DL+LL	Combination	2342.9475
Base	543	2072	1 DL+LL	Combination	2890.444
Base	547	55	1 DL+LL	Combination	3544.2919
Base	555	5923	1 DL+LL	Combination	11.2415
Base	556	2099	1 DL+LL	Combination	2344.1609
Base	563	2065	1 DL+LL	Combination	2530.7639
Base	564	218	1 DL+LL	Combination	745.2538
Base	570	2069	1 DL+LL	Combination	1947.5625
Base	575	2070	1 DL+LL	Combination	2855.1079
Base	577	1998	1 DL+LL	Combination	2866.8018
Base	581	2071	1 DL+LL	Combination	2111.2648
Base	591	2084	1 DL+LL	Combination	1664.4819
Base	597	2081	1 DL+LL	Combination	1480.9257
Base	599	58	1 DL+LL	Combination	1232.8041
Base	601	68	1 DL+LL	Combination	1110.5389
Base	611	2079	1 DL+LL	Combination	481.5383
Base	612	2080	1 DL+LL	Combination	3128.0541
Base	1462	5924	1 DL+LL	Combination	5328.5677
Base	1465	1982	1 DL+LL	Combination	8094.3043
Base	1472	1977	1 DL+LL	Combination	6559.8049
Base	1475	2105	1 DL+LL	Combination	7139.3417
Base	1476	2074	1 DL+LL	Combination	2655.4732
Base	4280	2067	1 DL+LL	Combination	3025.0724
Base	4282	1987	1 DL+LL	Combination	6438.3407
Base	4980	2060	1 DL+LL	Combination	1204.4567
Base	58	268	1 DL+LL	Combination	2015.1276
Base	60	263	1 DL+LL	Combination	4070.8209
Base	62	262	1 DL+LL	Combination	3722.617
Base	6841	2809	1 DL+LL	Combination	-126.0724
Base	6842	2810	1 DL+LL	Combination	190.5277
Base	6843	2811	1 DL+LL	Combination	101.9303
Base	6844	2812	1 DL+LL	Combination	162.7744
Base	6845	2813	1 DL+LL	Combination	162.7245
Base	6846	2814	1 DL+LL	Combination	134.9037
Base	6847	2815	1 DL+LL	Combination	334.5009
Base	6856	2823	1 DL+LL	Combination	937.5024
Base	6857	2824	1 DL+LL	Combination	164.5112
Base	6858	2825	1 DL+LL	Combination	456.8221

Table.8 shows the reactions are noticeably reduced compared to Model 1, especially at isolated joints. Only some joints are equipped with LRBs, leading to uneven force distribution. While this model improves performance over the conventional structure, it doesn't fully optimize seismic load reduction. The presence of unisolated joints still allows for significant force transfer.

5.2.3 MODEL-3

Table.9: Joint Reactions of Model-3

Story	Label	Unique Name	Output Case	Case Type	FZ
Unitless	Unitless	Unitless	Unitless	Unitless	kN
Base	282	5922	1 DL+LL	Combination	2658.0793
Base	283	61	1 DL+LL	Combination	2735.0247
Base	284	65	1 DL+LL	Combination	2743.6636
Base	294	1971	1 DL+LL	Combination	2749.6605
Base	297	1972	1 DL+LL	Combination	2744.7297
Base	299	2086	1 DL+LL	Combination	2689.7407
Base	303	1975	1 DL+LL	Combination	2687.3179
Base	311	2089	1 DL+LL	Combination	2648.3285
Base	313	2087	1 DL+LL	Combination	2657.352
Base	316	2093	1 DL+LL	Combination	2589.5899
Base	317	2094	1 DL+LL	Combination	2536.3321
Base	319	2091	1 DL+LL	Combination	2501.0018
Base	324	2090	1 DL+LL	Combination	2483.6525
Base	325	2092	1 DL+LL	Combination	2367.0067
Base	328	2083	1 DL+LL	Combination	2633.4151
Base	329	2085	1 DL+LL	Combination	2655.9289
Base	342	1983	1 DL+LL	Combination	2440.9152
Base	344	2073	1 DL+LL	Combination	2496.535
Base	354	1984	1 DL+LL	Combination	2733.7528
Base	360	1981	1 DL+LL	Combination	2618.6113
Base	373	2075	1 DL+LL	Combination	2581.1467
Base	374	2076	1 DL+LL	Combination	2460.7051
Base	377	2077	1 DL+LL	Combination	2373.0879
Base	383	1985	1 DL+LL	Combination	2347.185
Base	384	1986	1 DL+LL	Combination	2375.4193
Base	405	2095	1 DL+LL	Combination	2474.4467
Base	407	1970	1 DL+LL	Combination	2397.0131
Base	409	269	1 DL+LL	Combination	2570.7959
Base	410	266	1 DL+LL	Combination	2555.8423
Base	415	39	1 DL+LL	Combination	2517.5252
Base	419	41	1 DL+LL	Combination	2464.5424
Base	420	40	1 DL+LL	Combination	2430.0715
Base	428	2862	1 DL+LL	Combination	2353.6031
Base	429	2865	1 DL+LL	Combination	2379.3399
Base	431	43	1 DL+LL	Combination	2263.8756
Base	432	1988	1 DL+LL	Combination	2252.3578
Base	435	1994	1 DL+LL	Combination	2066.4436
Base	438	1993	1 DL+LL	Combination	2129.1785
Base	442	1995	1 DL+LL	Combination	1960.894
Base	443	1996	1 DL+LL	Combination	2021.3912
Base	445	2063	1 DL+LL	Combination	1958.1684
Base	452	2103	1 DL+LL	Combination	1895.4955
Base	458	2062	1 DL+LL	Combination	1782.6854
Base	462	2061	1 DL+LL	Combination	1739.9367
Base	469	2098	1 DL+LL	Combination	2118.0451
Base	481	50	1 DL+LL	Combination	1595.1137
Base	484	1997	1 DL+LL	Combination	1649.3981
Base	491	2104	1 DL+LL	Combination	1791.3245
Base	495	1973	1 DL+LL	Combination	2731.8946
Base	496	1974	1 DL+LL	Combination	2713.1494
Base	499	2082	1 DL+LL	Combination	2622.7166
Base	502	1979	1 DL+LL	Combination	2561.6674
Base	503	1978	1 DL+LL	Combination	2688.4861
Base	509	1969	1 DL+LL	Combination	2541.6518
Base	511	2088	1 DL+LL	Combination	2568.892
Base	513	267	1 DL+LL	Combination	2602.8523
Base	518	2858	1 DL+LL	Combination	2316.2391
Base	519	2861	1 DL+LL	Combination	2342.5423
Base	520	89	1 DL+LL	Combination	2307.2025
Base	521	47	1 DL+LL	Combination	2188.6867
Base	522	45	1 DL+LL	Combination	2137.4471
Base	528	1992	1 DL+LL	Combination	2285.8019
Base	543	2072	1 DL+LL	Combination	2145.8474
Base	547	55	1 DL+LL	Combination	2017.8711
Base	555	5923	1 DL+LL	Combination	2690.5644
Base	556	2099	1 DL+LL	Combination	2059.565
Base	563	2065	1 DL+LL	Combination	1924.2009
Base	564	218	1 DL+LL	Combination	1840.5016
Base	570	2069	1 DL+LL	Combination	1899.9154
Base	575	2070	1 DL+LL	Combination	2170.2658
Base	577	1998	1 DL+LL	Combination	2083.8996
Base	581	2071	1 DL+LL	Combination	2222.3821
Base	591	2084	1 DL+LL	Combination	2644.4129
Base	597	2081	1 DL+LL	Combination	2628.713
Base	599	58	1 DL+LL	Combination	2676.0467
Base	601	68	1 DL+LL	Combination	2623.6157
Base	611	2079	1 DL+LL	Combination	2634.4877
Base	612	2080	1 DL+LL	Combination	2625.2189
Base	1462	5924	1 DL+LL	Combination	2650.981
Base	1465	1982	1 DL+LL	Combination	2559.8392
Base	1472	1977	1 DL+LL	Combination	2635.9179
Base	1475	2105	1 DL+LL	Combination	2679.0624
Base	1476	2074	1 DL+LL	Combination	2620.4524
Base	4280	2067	1 DL+LL	Combination	1968.481
Base	4282	1987	1 DL+LL	Combination	2304.8585
Base	4980	2060	1 DL+LL	Combination	1897.0952
Base	58	268	1 DL+LL	Combination	2613.1337
Base	60	263	1 DL+LL	Combination	2416.0497
Base	62	262	1 DL+LL	Combination	2391.878
Base	6841	2809	1 DL+LL	Combination	2274.82
Base	6842	2810	1 DL+LL	Combination	2178.3935
Base	6843	2811	1 DL+LL	Combination	1901.0936
Base	6844	2812	1 DL+LL	Combination	1791.3521
Base	6845	2813	1 DL+LL	Combination	1723.5921
Base	6846	2814	1 DL+LL	Combination	1406.2047
Base	6847	2815	1 DL+LL	Combination	1537.0398
Base	6856	2823	1 DL+LL	Combination	2066.6046
Base	6857	2824	1 DL+LL	Combination	2253.1699
Base	6858	2825	1 DL+LL	Combination	2284.5495

Table.9 shows all base joints are equipped with Lead Rubber Bearings, resulting in a major reduction in joint reactions, especially in the horizontal direction (X and Y). The forces are more evenly distributed compared to Model 2. This indicates effective base isolation, which decouples the structure from ground motion and allows controlled flexibility and energy absorption.

5.2.4 MODEL-4

Table.10: Joint Reactions of Model-4

Story	Label	Output Case	Case Type	FZ
Unitless	Unitless	Unitless	Unitless	kN
Base	522	1 DL+LL	Combination	3179.115
Base	528	1 DL+LL	Combination	2199.5847
Base	543	1 DL+LL	Combination	2815.8558
Base	547	1 DL+LL	Combination	3613.7468
Base	555	1 DL+LL	Combination	4601.3766
Base	556	1 DL+LL	Combination	2266.0842
Base	563	1 DL+LL	Combination	2814.3544
Base	564	1 DL+LL	Combination	1247.6736
Base	570	1 DL+LL	Combination	1730.9729
Base	575	1 DL+LL	Combination	2532.6774
Base	577	1 DL+LL	Combination	3033.3531
Base	581	1 DL+LL	Combination	1775.3965
Base	591	1 DL+LL	Combination	1764.067
Base	597	1 DL+LL	Combination	1772.8042
Base	599	1 DL+LL	Combination	1145.2038
Base	601	1 DL+LL	Combination	1212.5979
Base	611	1 DL+LL	Combination	896.876
Base	612	1 DL+LL	Combination	693.4906
Base	1462	1 DL+LL	Combination	3862.9757
Base	1465	1 DL+LL	Combination	3522.2517
Base	1472	1 DL+LL	Combination	2748.0163
Base	1475	1 DL+LL	Combination	3772.4228
Base	1476	1 DL+LL	Combination	3172.7817
Base	4280	1 DL+LL	Combination	2765.9526
Base	4282	1 DL+LL	Combination	2487.2773
Base	4980	1 DL+LL	Combination	1353.6121
Base	58	1 DL+LL	Combination	1967.4218
Base	60	1 DL+LL	Combination	1512.3707
Base	62	1 DL+LL	Combination	1596.7633
Base	6841	1 DL+LL	Combination	143.3425
Base	6842	1 DL+LL	Combination	159.642
Base	6843	1 DL+LL	Combination	111.5026
Base	6844	1 DL+LL	Combination	157.7937
Base	6845	1 DL+LL	Combination	198.1645
Base	6846	1 DL+LL	Combination	149.1147
Base	6847	1 DL+LL	Combination	336.1546
Base	6856	1 DL+LL	Combination	475.582
Base	6857	1 DL+LL	Combination	200.4587
Base	6858	1 DL+LL	Combination	413.4939

This table.10 model uses dampers rather than isolators, and only at select joints. The reduction in joint reactions is moderate—better than the conventional model but not as significant as full LRB implementation. FVDs help dissipate seismic energy, reducing force spikes at specific joints, but without base isolation, some rigid behavior persists.

5.2.5 MODEL-5

Table.11: Joint Reactions of Model-5

Story	Label	Output Case	Case Type	FZ
Unitless	Unitless	Unitless	Unitless	kN
Base	547	1 DL+LL	Combination	2022.734
Base	555	1 DL+LL	Combination	2693.1666
Base	556	1 DL+LL	Combination	2061.1283
Base	563	1 DL+LL	Combination	1926.6366
Base	564	1 DL+LL	Combination	1842.7771
Base	570	1 DL+LL	Combination	1903.1095
Base	575	1 DL+LL	Combination	2174.5563
Base	577	1 DL+LL	Combination	2087.9248
Base	581	1 DL+LL	Combination	2227.8566
Base	591	1 DL+LL	Combination	2649.9023
Base	597	1 DL+LL	Combination	2635.4934
Base	599	1 DL+LL	Combination	2684.0761
Base	601	1 DL+LL	Combination	2631.8043
Base	611	1 DL+LL	Combination	2642.893
Base	612	1 DL+LL	Combination	2633.6537
Base	1462	1 DL+LL	Combination	2653.341
Base	1465	1 DL+LL	Combination	2566.3652
Base	1472	1 DL+LL	Combination	2641.0783
Base	1475	1 DL+LL	Combination	2687.2165
Base	1476	1 DL+LL	Combination	2628.5444
Base	4280	1 DL+LL	Combination	1971.5998
Base	4282	1 DL+LL	Combination	2310.1401
Base	4980	1 DL+LL	Combination	1896.2104
Base	58	1 DL+LL	Combination	2617.4306
Base	60	1 DL+LL	Combination	2420.48
Base	62	1 DL+LL	Combination	2395.6659
Base	6841	1 DL+LL	Combination	2281.1198
Base	6842	1 DL+LL	Combination	2184.2967
Base	6843	1 DL+LL	Combination	1905.7224
Base	6844	1 DL+LL	Combination	1794.509
Base	6845	1 DL+LL	Combination	1725.7822
Base	6846	1 DL+LL	Combination	1404.8828
Base	6847	1 DL+LL	Combination	1537.3838
Base	6856	1 DL+LL	Combination	2069.6073
Base	6857	1 DL+LL	Combination	2285.095
Base	6858	1 DL+LL	Combination	0

This table.11 is the most advanced model, combining full base isolation with energy dissipation. It shows the lowest joint reaction forces overall, indicating superior performance under seismic loading. The reactions are both minimal and well-distributed, reflecting the synergy between isolation and damping. This setup effectively limits both acceleration and force transmission to the base.

5.3 MODAL PARTICIPATING MASS RATIOS

5.3.1 MODEL-1

Table.12: Modal Participating Mass Ratio of Model-1

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
Modal	1	3.26	0.151	0.5513	0	0.151	0.5513	0	0.2239	0.0578	0.021	0.2239	0.0578	0.021
Modal	2	3.208	0.5523	0.1591	0	0.7033	0.7104	0	0.0647	0.208	0.0097	0.2886	0.2658	0.0308
Modal	3	3.102	0.0244	0.0021	0	0.7278	0.7125	0	0.0013	0.0077	0.6522	0.2899	0.2735	0.6829
Modal	4	1.003	0.0916	0.0267	0	0.8193	0.7392	0	0.0771	0.2962	0.0047	0.367	0.5697	0.6876
Modal	5	0.991	0.0295	0.0874	0	0.8489	0.8265	0	0.2555	0.0974	0.008	0.6226	0.6671	0.6956
Modal	6	0.943	0.0003	0.0147	0	0.8491	0.8412	0	0.0328	0.0009	0.1177	0.6554	0.668	0.8134
Modal	7	0.539	0.0534	0.0007	0	0.9026	0.8419	0	0.0011	0.0785	0.0001	0.6564	0.7465	0.8135
Modal	8	0.525	0.0009	0.0408	0	0.9035	0.8828	0	0.0619	0.0013	0.0102	0.7183	0.7478	0.8236
Modal	9	0.5	1.826E-06	0.0154	0	0.9035	0.8981	0	0.023	5.445E-06	0.0558	0.7413	0.7478	0.8794
Modal	10	0.348	0.0287	0.0001	0	0.9322	0.8982	0	0.0002	0.0774	0.0001	0.7415	0.8252	0.8795
Modal	11	0.337	2.608E-06	0.0198	0	0.9322	0.918	0	0.0507	1.247E-05	0.0082	0.7922	0.8252	0.8877
Modal	12	0.325	0.0001	0.0115	0	0.9323	0.9295	0	0.0266	0.0003	0.0278	0.8188	0.8255	0.9154

Dominant modes: Mode 1 and 2 primarily contribute to UY and UX respectively.
Cumulative Mass Participation: UX: 93.23%, UY: 92.95%
Torsional (RZ): Significant contribution from Mode 3 (65.22%) and Mode 6 (11.77%).
Efficient lateral mass participation. Torsional mode (Mode 3) is notably dominant, possibly indicating eccentricity or asymmetry.

5.3.2 MODEL-2

Table.13: Modal Participating Mass Ratio of Model-2

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
Modal	1	3.364	0.0615	0.6183	0	0.0615	0.6183	0	0.2476	0.0237	0.0486	0.2476	0.0237	0.0486
Modal	2	3.285	0.6401	0.0753	0	0.7016	0.6936	0	0.0302	0.2394	0.0099	0.2778	0.2631	0.0586
Modal	3	3.148	0.0271	0.0204	0	0.7287	0.7141	0	0.0099	0.0089	0.6258	0.2876	0.272	0.6844
Modal	4	1.015	0.0952	0.0252	0	0.824	0.7393	0	0.0734	0.3041	0.0057	0.3611	0.5761	0.6901
Modal	5	0.997	0.0287	0.0908	0	0.8527	0.8301	0	0.2647	0.0946	0.0075	0.6258	0.6707	0.6976
Modal	6	0.945	0.0006	0.0151	0	0.8533	0.8452	0	0.0328	0.002	0.1184	0.6586	0.6727	0.8161
Modal	7	0.543	0.0521	0.0011	0	0.9054	0.8463	0	0.0017	0.0791	0.0004	0.6603	0.7518	0.8165
Modal	8	0.53	0.0017	0.0401	0	0.9071	0.8864	0	0.0636	0.0025	0.0096	0.7239	0.7543	0.8261
Modal	9	0.502	4.288E-05	0.0154	0	0.9071	0.9018	0	0.0234	0.0001	0.0559	0.7473	0.7544	0.882
Modal	10	0.351	0.0281	0.0002	0	0.9352	0.902	0	0.0005	0.0763	6.158E-06	0.7477	0.8306	0.882
Modal	11	0.34	0.0001	0.0198	0	0.9354	0.9218	0	0.0514	0.0004	0.0077	0.7992	0.831	0.8897
Modal	12	0.327	4.773E-05	0.0112	0	0.9354	0.933	0	0.026	0.0001	0.0282	0.8251	0.8312	0.9179

Dominant modes: Mode 1 dominates UY, Mode 2 dominates UX.

Cumulative Mass Participation: UX: 93.54%, UY: 93.30%

Torsional (RZ): Mode 3 again is dominant (62.58%), with Mode 6 (11.84%) also contributing.

Very similar to Model 1. Balanced translational response, torsionally sensitive.

5.3.3 MODEL-3

Table.14: Modal Participating Mass Ratio of Model-3

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
Modal	1	12.583	0.0013	0.7547	0	0.0013	0.7547	0	0.2433	0.0003	0.0018	0.2433	0.0003	0.0018
Modal	2	8.075	0.8371	0.0012	0	0.8385	0.7559	0	0.0004	0.1606	0.0002	0.2437	0.161	0.002
Modal	3	4.903	0.0003	0.0004	0	0.8388	0.7563	0	5.05E-06	0.0002	0.7298	0.2437	0.1611	0.7318
Modal	4	1.953	0.1575	3.201E-06	0	0.9963	0.7563	0	1.29E-06	0.8233	0.0001	0.2437	0.9845	0.7319
Modal	5	1.086	3.505E-06	0.1304	0	0.9963	0.8868	0	0.4092	3.432E-06	0.0152	0.6529	0.9845	0.7471
Modal	6	1.035	1.348E-06	0.0169	0	0.9963	0.9037	0	0.051	1.584E-05	0.1386	0.704	0.9845	0.8857
Modal	7	0.745	0.0029	1.568E-05	0	0.9991	0.9037	0	4.37E-05	0.0097	0	0.704	0.9942	0.8857
Modal	8	0.584	1.006E-06	0.0351	0	0.9991	0.9388	0	0.1052	2.644E-06	0.0005	0.8092	0.9942	0.8862
Modal	9	0.571	0	0.0027	0	0.9991	0.9414	0	0.0077	2.995E-06	0.052	0.8169	0.9942	0.9382
Modal	10	0.462	0.0006	1.048E-05	0	0.9998	0.9414	0	2.638E-05	0.0044	3.103E-06	0.8169	0.9987	0.9382
Modal	11	0.364	0	0.0098	0	0.9998	0.9513	0	0.0309	0	0.0101	0.8478	0.9987	0.9483
Modal	12	0.357	0	0.0112	0	0.9998	0.9624	0	0.0346	0	0.0137	0.8824	0.9987	0.962

Dominant modes: Mode 2 is strongest for UX, Mode 1 for UY.

Cumulative Mass Participation: UX: 99.98%, UY: 96.24%

Torsional (RZ): Mode 3 contributes the most (72.98%), followed by Mode 6 (13.86%).

Excellent mass participation in translational directions. High torsional response in Mode 3, but some minor numerical anomalies (very small values for many other modes).

5.3.4 MODEL-4

Table.15: Modal Participating Mass Ratio of Model-4

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
Modal	1	3.26	0.151	0.5513	0	0.151	0.5513	0	0.2239	0.0578	0.021	0.2239	0.0578	0.021
Modal	2	3.208	0.5523	0.1591	0	0.7033	0.7104	0	0.0647	0.208	0.0097	0.2886	0.2658	0.0308
Modal	3	3.102	0.0244	0.0021	0	0.7278	0.7125	0	0.0013	0.0077	0.6522	0.2899	0.2735	0.6829
Modal	4	1.003	0.0916	0.0267	0	0.8193	0.7392	0	0.0771	0.2962	0.0047	0.367	0.5697	0.6876
Modal	5	0.991	0.0295	0.0874	0	0.8489	0.8265	0	0.2555	0.0974	0.008	0.6226	0.6671	0.6956
Modal	6	0.943	0.0003	0.0147	0	0.8491	0.8412	0	0.0328	0.0009	0.1177	0.6554	0.668	0.8134
Modal	7	0.539	0.0534	0.0007	0	0.9026	0.8419	0	0.0011	0.0785	0.0001	0.6564	0.7465	0.8135
Modal	8	0.525	0.0009	0.0408	0	0.9035	0.8828	0	0.0619	0.0013	0.0102	0.7183	0.7478	0.8236
Modal	9	0.5	1.826E-06	0.0154	0	0.9035	0.8981	0	0.023	5.445E-06	0.0558	0.7413	0.7478	0.8794
Modal	10	0.348	0.0287	0.0001	0	0.9322	0.8982	0	0.0002	0.0774	0.0001	0.7415	0.8252	0.8795
Modal	11	0.337	2.608E-06	0.0198	0	0.9322	0.918	0	0.0507	1.247E-05	0.0082	0.7922	0.8252	0.8877
Modal	12	0.325	0.0001	0.0115	0	0.9323	0.9295	0	0.0266	0.0003	0.0278	0.8188	0.8255	0.9154

Dominant modes: Mode 1 and 2 primarily contribute to UY and UX respectively.
Cumulative Mass Participation: UX: 93.23%, UY: 92.95%
Torsional (RZ): Significant contribution from Mode 3 (65.22%) and Mode 6 (11.77%).
Efficient lateral mass participation. Torsional mode (Mode 3) is notably dominant, possibly indicating eccentricity or asymmetry.

5.3.5 MODEL-5

Table-16: Modal Participating Mass Ratio of Model-5

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
Modal	1	12.601	0.0014	0.7549	0	0.0014	0.7549	0	0.2431	0.0003	0.0018	0.2431	0.0003	0.0018
Modal	2	8.086	0.8372	0.0012	0	0.8385	0.7561	0	0.0004	0.1606	0.0002	0.2435	0.1609	0.002
Modal	3	4.905	0.0003	0.0004	0	0.8388	0.7565	0	7.175E-06	0.0002	0.73	0.2435	0.1611	0.732
Modal	4	1.955	0.1574	3.209E-06	0	0.9963	0.7565	0	1.261E-06	0.8233	0.0001	0.2435	0.9844	0.732
Modal	5	1.088	3.71E-06	0.1309	0	0.9963	0.8874	0	0.4109	3.82E-06	0.0146	0.6544	0.9844	0.7466
Modal	6	1.036	1.802E-06	0.0163	0	0.9963	0.9037	0	0.0493	1.885E-05	0.139	0.7038	0.9844	0.8857
Modal	7	0.746	0.0029	1.542E-05	0	0.9991	0.9037	0	4.303E-05	0.0098	0	0.7038	0.9942	0.8857
Modal	8	0.585	1.019E-06	0.0353	0	0.9991	0.9391	0	0.106	2.611E-06	0.0004	0.8098	0.9942	0.8861
Modal	9	0.572	0	0.0024	0	0.9991	0.9415	0	0.007	3.175E-06	0.0521	0.8168	0.9942	0.9382
Modal	10	0.462	0.0006	1.053E-05	0	0.9998	0.9415	0	2.657E-05	0.0044	2.425E-06	0.8168	0.9987	0.9382
Modal	11	0.364	0	0.0103	0	0.9998	0.9518	0	0.0323	0	0.0096	0.8491	0.9987	0.9478
Modal	12	0.357	0	0.0107	0	0.9998	0.9625	0	0.0332	0	0.0142	0.8824	0.9987	0.962

Nearly identical to Model 3 in structure and response.
Cumulative Mass Participation: UX: 99.98%, UY: 96.25%
Torsional (RZ): Mode 3 again dominant (73.00%), with Mode 6 at 13.9%.
Matches Model 3 almost exactly, indicating similar geometry and mass distribution.

5.4 MODAL PERIODS AND FREQUENCIES

5.4.1 MODEL-1

Table.17: Modal Periods and frequencies of Model-1

Case	Mode	Period	Frequency	CircFreq	Eigenvalue
Unitless	Unitless	sec	cyc/sec	rad/sec	rad²/sec²
Modal	1	3.26	0.307	1.9274	3.715
Modal	2	3.208	0.312	1.9588	3.837
Modal	3	3.102	0.322	2.0257	4.1036
Modal	4	1.003	0.997	6.2616	39.2082
Modal	5	0.991	1.009	6.3413	40.2126
Modal	6	0.943	1.061	6.6657	44.4316
Modal	7	0.539	1.857	11.6678	136.1385
Modal	8	0.525	1.904	11.9639	143.1339
Modal	9	0.5	1.999	12.5582	157.7085
Modal	10	0.348	2.871	18.0371	325.3376
Modal	11	0.337	2.965	18.632	347.1513
Modal	12	0.325	3.073	19.3082	372.8067

Table.17 have periods around 3.26 seconds, indicating moderate stiffness and flexibility.

Higher modes decrease quickly to sub-second periods, showing a well-distributed modal response. These models likely represent conventional structures without significant flexibility or added damping. They show a balanced dynamic behavior suitable for general structural performance.

5.4.2 MODEL-2

Table.18: Modal Periods and frequencies of Model-2

Case	Mode	Period	Frequency	CircFreq	Eigenvalue
Unitless	Unitless	sec	cyc/sec	rad/sec	rad²/sec²
Modal	1	3.364	0.297	1.868	3.4893
Modal	2	3.285	0.304	1.9126	3.658
Modal	3	3.148	0.318	1.9961	3.9845
Modal	4	1.015	0.986	6.1932	38.3552
Modal	5	0.997	1.003	6.3033	39.732
Modal	6	0.945	1.058	6.6474	44.1882
Modal	7	0.543	1.841	11.5662	133.7778
Modal	8	0.53	1.888	11.8639	140.7522
Modal	9	0.502	1.991	12.5104	156.5106
Modal	10	0.351	2.847	17.8903	320.0617
Modal	11	0.34	2.942	18.4836	341.6436
Modal	12	0.327	3.061	19.2324	369.8851

Table.18: Similar to Model 1, but with slightly longer modal periods (first mode at 3.364s). This indicates slightly more flexibility than Model 1/4. Suggests minor structural modifications (possibly dampers or base isolators with minimal effect on overall stiffness).

5.4.3 MODEL-3

Table.19: Modal Periods and frequencies of Model-3

Case	Mode	Period	Frequency	CircFreq	Eigenvalue
Unitless	Unitless	sec	cyc/sec	rad/sec	rad²/sec²
Modal	1	12.583	0.079	0.4994	0.2494
Modal	2	8.075	0.124	0.7781	0.6055
Modal	3	4.903	0.204	1.2814	1.642
Modal	4	1.953	0.512	3.2171	10.35
Modal	5	1.086	0.921	5.7837	33.4512
Modal	6	1.035	0.966	6.0709	36.8553
Modal	7	0.745	1.342	8.4311	71.0831
Modal	8	0.584	1.711	10.7518	115.6014
Modal	9	0.571	1.75	10.9944	120.8775
Modal	10	0.462	2.166	13.6113	185.2677
Modal	11	0.364	2.749	17.271	298.289
Modal	12	0.357	2.805	17.6246	310.6273

Table.19 Significantly higher first-mode period of 12.583 s, and second mode at 8.075 s.
This shows a highly flexible structure, possibly due to base isolation or flexible dampers.
Reflects major intervention to shift natural frequencies away from the dominant range of seismic excitation. Strong damping or isolation system present, making the structure resilient to low-frequency seismic energy.

5.4.4 MODEL-4

Table.20: Modal Periods and frequencies of Model-4

Case	Mode	Period	Frequency	CircFreq	Eigenvalue
Unitless	Unitless	sec	cyc/sec	rad/sec	rad²/sec²
Modal	1	3.26	0.307	1.9274	3.715
Modal	2	3.208	0.312	1.9588	3.837
Modal	3	3.102	0.322	2.0257	4.1036
Modal	4	1.003	0.997	6.2616	39.2082
Modal	5	0.991	1.009	6.3413	40.2126
Modal	6	0.943	1.061	6.6657	44.4316
Modal	7	0.539	1.857	11.6678	136.1385
Modal	8	0.525	1.904	11.9639	143.1339
Modal	9	0.5	1.999	12.5582	157.7085
Modal	10	0.348	2.871	18.0371	325.3376
Modal	11	0.337	2.965	18.632	347.1513
Modal	12	0.325	3.073	19.3082	372.8067

Table.20 shows First three modes have periods around 3.1–3.26 seconds, indicating moderate stiffness and flexibility. Higher modes decrease quickly to sub-second periods, showing a well-distributed modal response. These models likely represent conventional structures without significant flexibility or added damping. They show a balanced dynamic behavior suitable for general structural performance.

5.4.5 MODEL-5

Table.21: Modal Periods and frequencies of Model-5

Case	Mode	Period	Frequency	CircFreq	Eigenvalue
Unitless	Unitless	sec	cyc/sec	rad/sec	rad²/sec²
Modal	1	12.601	0.079	0.4986	0.2486
Modal	2	8.086	0.124	0.7771	0.6039
Modal	3	4.905	0.204	1.2808	1.6406
Modal	4	1.955	0.512	3.2145	10.3333
Modal	5	1.088	0.919	5.7752	33.3533
Modal	6	1.036	0.965	6.066	36.7962
Modal	7	0.746	1.34	8.4203	70.9017
Modal	8	0.585	1.71	10.7432	115.4172
Modal	9	0.572	1.749	10.9906	120.7941
Modal	10	0.462	2.164	13.5966	184.8685
Modal	11	0.364	2.746	17.2559	297.7658
Modal	12	0.357	2.802	17.6039	309.8983

Table.21 shows that nearly identical to Model 3 with a first-mode period of 12.601 s. Again, indicates a very flexible and isolated/damped structure. Minor differences in periods and frequencies suggest small tuning differences (e.g., damper settings or mass distribution).

5.5 STORY SHEARS

5.5.1 MODEL-1

Story Response - Story Shears EQX

Display Type	Story shears	Story Range	All Stories
Load Case	EQ X	Top Story	HEADROOM
Output Type	Step Number 1	Bottom Story	Base

Plot

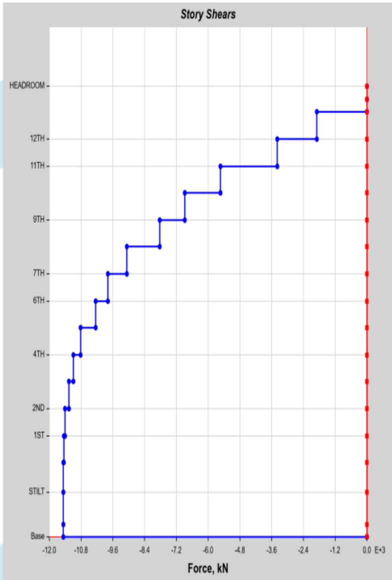


Fig-39: Model-1 Story Response - Story Shears EQX

Table.18: Model-1 Story Response - Story Shears EQX

Story	Elevation	Location	X-Dir	Y-Dir
	m		kN	kN
HEADROOM	53.0776	Top	0	0
		Bottom	0	0
LIFT BOTTOM SLAB	51.5536	Top	0	0
		Bottom	0	0
TERRACE	50.0296	Top	-1893.5046	0
		Bottom	-1893.5046	0
12TH	46.8546	Top	-3386.3574	0
		Bottom	-3386.3574	0
11TH	43.6796	Top	-5534.4329	0
		Bottom	-5534.4329	0
1OTH	40.5046	Top	-6878.4361	0
		Bottom	-6878.4361	0
9TH	37.3296	Top	-7832.4415	0
		Bottom	-7832.4415	0
8TH	34.1546	Top	-9074.0791	0
		Bottom	-9074.0791	0
7TH	30.9796	Top	-9789.4295	5.04E-07
		Bottom	-9789.4295	5.04E-07
6TH	27.8046	Top	-10260.5881	5.365E-07
		Bottom	-10260.5881	5.365E-07
5TH	24.6296	Top	-10818.0802	5.507E-07
		Bottom	-10818.0802	5.507E-07
4TH	21.4546	Top	-11101.377	5.898E-07
		Bottom	-11101.377	5.898E-07
3RD	18.2796	Top	-11258.2625	5.926E-07
		Bottom	-11258.2625	5.926E-07
2ND	15.1046	Top	-11401.9187	5.109E-07
		Bottom	-11401.9187	5.109E-07
1ST	11.9296	Top	-11449.7609	5.249E-07
		Bottom	-11449.7609	5.249E-07
GR	8.7546	Top	-11467.8355	5.236E-07
		Bottom	-11467.8355	5.236E-07
STILT	5.2846	Top	-11467.8355	5.237E-07
		Bottom	-11467.8355	5.237E-07
PLINTH	1.5	Top	-11467.8355	5.237E-07
		Bottom	-11467.8355	5.237E-07
Base	0	Top	0	0
		Bottom	0	0

Story Response - Story Shears-EQY

Display Type	Story shears	Story Range	All Stories
Load Case	EQ Y	Top Story	HEADROOM
Output Type	Step Number 1	Bottom Story	Base

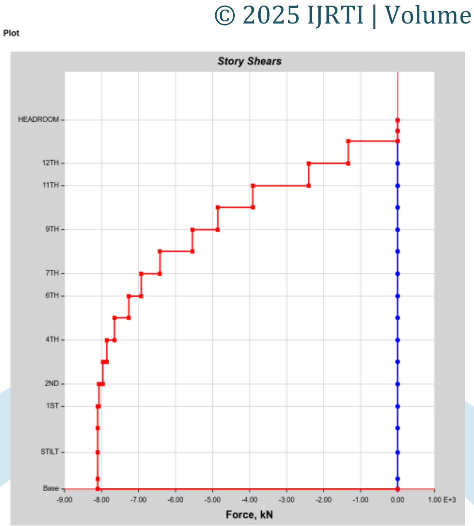


Fig-40: Model-1 Story Response - Story Shears EQY

Table-19: Model-1 Story Response - Story Shears EQY

Story	Elevation	Location	X-Dir	Y-Dir
	m		kN	kN
HEADROOM	53.0776	Top	0	0
		Bottom	0	0
LIFT BOTTOM SLAB	51.5536	Top	0	0
		Bottom	0	0
TERRACE	50.0296	Top	0	-1339.3082
		Bottom	0	-1339.3082
12TH	46.8546	Top	0	-2395.2284
		Bottom	0	-2395.2284
11TH	43.6796	Top	0	-3914.5988
		Bottom	0	-3914.5988
1OTH	40.5046	Top	0	-4865.2352
		Bottom	0	-4865.2352
9TH	37.3296	Top	0	-5540.0196
		Bottom	0	-5540.0196
8TH	34.1546	Top	6.029E-07	-6418.251
		Bottom	6.029E-07	-6418.251
7TH	30.9796	Top	5.19E-07	-6924.2306
		Bottom	5.19E-07	-6924.2306
6TH	27.8046	Top	5.491E-07	-7257.4891
		Bottom	5.491E-07	-7257.4891
5TH	24.6296	Top	5.49E-07	-7651.8128
		Bottom	5.49E-07	-7651.8128
4TH	21.4546	Top	5.92E-07	-7852.1935
		Bottom	5.92E-07	-7852.1935
3RD	18.2796	Top	5.932E-07	-7963.1613
		Bottom	5.932E-07	-7963.1613
2ND	15.1046	Top	6.408E-07	-8064.7717
		Bottom	6.408E-07	-8064.7717
1ST	11.9296	Top	6.662E-07	-8098.6114
		Bottom	6.662E-07	-8098.6114
GR	8.7546	Top	6.744E-07	-8111.3958
		Bottom	6.744E-07	-8111.3958
STILT	5.2846	Top	6.821E-07	-8111.3958
		Bottom	6.821E-07	-8111.3958
PLINTH	1.5	Top	6.821E-07	-8111.3958
		Bottom	6.821E-07	-8111.3958
Base	0	Top	0	0
		Bottom	0	0

From table.18 and table.19 we observe that the maximum story shear in EQX is 648.28 kN, while in EQY it's 394.68 kN, both occurring at the ground level. The structure experiences higher lateral force in the EQX direction. The shear values decrease toward the top floors, as expected in a typical dynamic response.

5.5.2 MODEL-2

Story Response - Story Shears-EQX

Display Type	Story shears	Story Range	All Stories
Load Case	EQ X	Top Story	HEADROOM
Output Type	Step Number 1	Bottom Story	Base

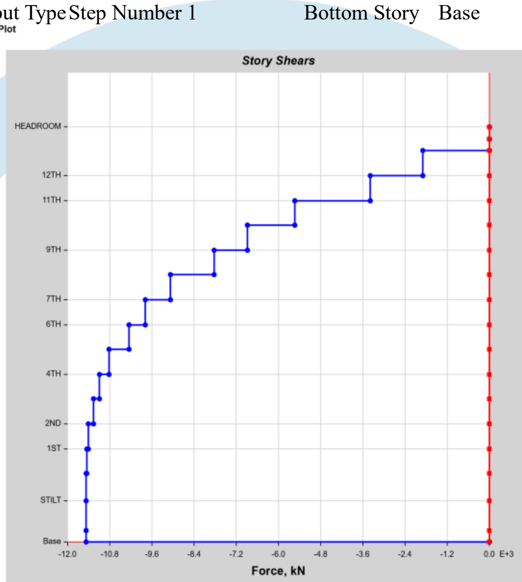


Fig-41: Model-2 Story Response - Story Shears EQX

Table.20: Model-2 Story Response - Story Shears EQX

Story	Elevation	Location	X-Dir	Y-Dir
	m		kN	kN
HEADROOM	53.0776	Top	0	0
		Bottom	0	0
LIFT BOTTOM SLAB	51.5536	Top	0	0
		Bottom	0	0
TERRACE	50.0296	Top	-1893.5047	0
		Bottom	-1893.5047	0
12TH	46.8546	Top	-3386.3574	0
		Bottom	-3386.3574	0
11TH	43.6796	Top	-5534.4329	0
		Bottom	-5534.4329	0
10TH	40.5046	Top	-6878.4361	0
		Bottom	-6878.4361	0
9TH	37.3296	Top	-7832.4416	0
		Bottom	-7832.4416	0
8TH	34.1546	Top	-9074.0791	0
		Bottom	-9074.0791	0
7TH	30.9796	Top	-9789.4296	0
		Bottom	-9789.4296	0
6TH	27.8046	Top	-10260.5881	0
		Bottom	-10260.5881	0
5TH	24.6296	Top	-10818.0802	0
		Bottom	-10818.0802	0
4TH	21.4546	Top	-11101.377	0
		Bottom	-11101.377	0
3RD	18.2796	Top	-11258.2625	0
		Bottom	-11258.2625	0
2ND	15.1046	Top	-11401.9187	0
		Bottom	-11401.9187	0
1ST	11.9296	Top	-11449.761	0
		Bottom	-11449.761	0
GR	8.7546	Top	-11467.8355	0
		Bottom	-11467.8355	0
STILT	5.2846	Top	-11467.8355	0
		Bottom	-11467.8355	0
PLINTH	1.5	Top	-11467.8355	0
		Bottom	-11467.8355	0
Base	0	Top	0	0
		Bottom	0	0

Story Response - Story Shears-EQY

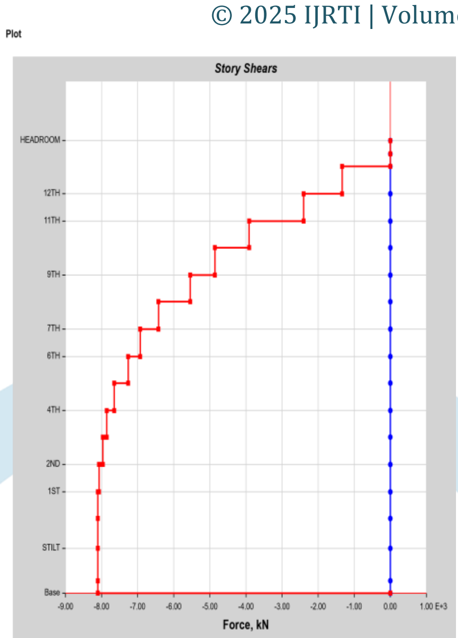


Fig-42: Model-2 Story Response - Story Shears EQY

Table.21: Model-2 Story Response - Story Shears EQY

Story	Elevation	Location	X-Dir	Y-Dir
	m		kN	kN
HEADROOM	53.0776	Top	0	0
		Bottom	0	0
LIFT BOTTOM SLAB	51.5536	Top	0	0
		Bottom	0	0
TERRACE	50.0296	Top	0	-1339.3082
		Bottom	0	-1339.3082
12TH	46.8546	Top	5.504E-07	-2395.2284
		Bottom	5.504E-07	-2395.2284
11TH	43.6796	Top	8.285E-07	-3914.5988
		Bottom	8.285E-07	-3914.5988
1OTH	40.5046	Top	9.099E-07	-4865.2353
		Bottom	9.099E-07	-4865.2353
9TH	37.3296	Top	9.44E-07	-5540.0196
		Bottom	9.44E-07	-5540.0196
8TH	34.1546	Top	8.077E-07	-6418.251
		Bottom	8.077E-07	-6418.251
7TH	30.9796	Top	6.892E-07	-6924.2306
		Bottom	6.892E-07	-6924.2306
6TH	27.8046	Top	7.032E-07	-7257.4891
		Bottom	7.032E-07	-7257.4891
5TH	24.6296	Top	6.931E-07	-7651.8128
		Bottom	6.931E-07	-7651.8128
4TH	21.4546	Top	7.444E-07	-7852.1934
		Bottom	7.444E-07	-7852.1934
3RD	18.2796	Top	7.413E-07	-7963.1613
		Bottom	7.413E-07	-7963.1613
2ND	15.1046	Top	7.979E-07	-8064.7717
		Bottom	7.979E-07	-8064.7717
1ST	11.9296	Top	8.299E-07	-8098.6114
		Bottom	8.299E-07	-8098.6114
GR	8.7546	Top	8.429E-07	-8111.3958
		Bottom	8.429E-07	-8111.3958
STILT	5.2846	Top	8.452E-07	-8111.3958
		Bottom	8.452E-07	-8111.3958
PLINTH	1.5	Top	8.452E-07	-8111.3958
		Bottom	8.452E-07	-8111.3958
Base	0	Top	0	0
		Bottom	0	0

From table.20 and table.21 we observe that the Increased base shear compared to Model 1, indicating higher lateral demand. Maximum EQX shear is 737.12 kN, EQY is 482.83 kN. Still, EQX shear exceeds EQY, showing greater stiffness or mass in X-direction.

5.5.3 MODEL-3

Story Response - Story Shears-EQX

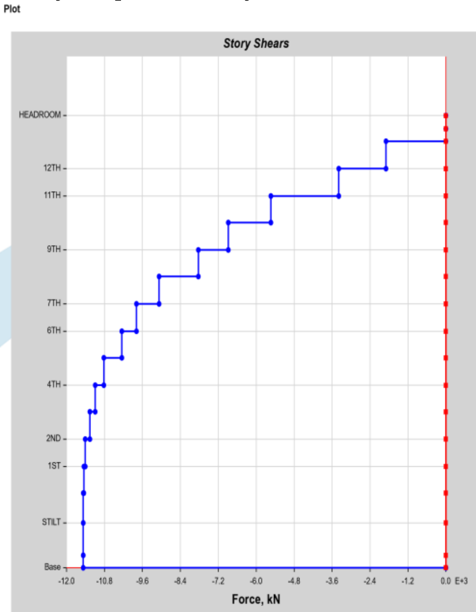


FIG-43: Model-3 Story Response - Story Shears EQX

Table.22: Model-3 Story Response - Story Shears EQX

Story	Elevation	Location	X-Dir	Y-Dir
	m		kN	kN
HEADROOM	53.0776	Top	0	0
		Bottom	0	0
LIFT BOTTOM SLAB	51.5536	Top	0	0
		Bottom	0	0
TERRACE	50.0296	Top	-1893.5047	-5.189E-07
		Bottom	-1893.5047	-5.189E-07
12TH	46.8546	Top	-3386.3574	-4.223E-06
		Bottom	-3386.3574	-4.223E-06
11TH	43.6796	Top	-5534.4331	1.198E-06
		Bottom	-5534.4331	1.198E-06
1OTH	40.5046	Top	-6878.4363	3.775E-06
		Bottom	-6878.4363	3.775E-06
9TH	37.3296	Top	-7832.4418	4.957E-06
		Bottom	-7832.4418	4.957E-06
8TH	34.1546	Top	-9074.0792	8.35E-06
		Bottom	-9074.0792	8.35E-06
7TH	30.9796	Top	-9789.4297	7.626E-06
		Bottom	-9789.4297	7.626E-06
6TH	27.8046	Top	-10260.5882	8.517E-06
		Bottom	-10260.5882	8.517E-06
5TH	24.6296	Top	-10818.0803	8.474E-06
		Bottom	-10818.0803	8.474E-06
4TH	21.4546	Top	-11101.377	6.427E-06
		Bottom	-11101.377	6.427E-06
3RD	18.2796	Top	-11258.2626	6.504E-06
		Bottom	-11258.2626	6.504E-06
2ND	15.1046	Top	-11401.9187	8.062E-06
		Bottom	-11401.9187	8.062E-06
1ST	11.9296	Top	-11449.761	7.767E-06
		Bottom	-11449.761	7.767E-06
GR	8.7546	Top	-11467.8355	8.131E-06
		Bottom	-11467.8355	8.131E-06
STILT	5.2846	Top	-11467.8355	8.081E-06
		Bottom	-11467.8355	8.081E-06
PLINTH	1.5	Top	-11467.8355	8.08E-06
		Bottom	-11467.8355	8.08E-06
Base	0	Top	0	0
		Bottom	0	0

Story Response - Story Shears-EQY

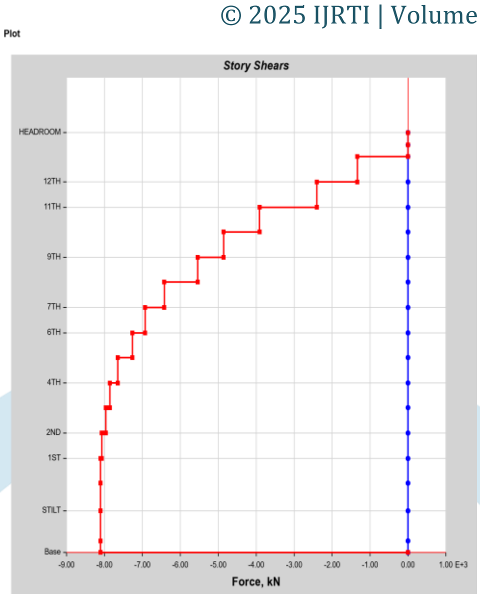


FIG-44: Model-3 Story Response - Story Shears EQY

Table.23: Model-3 Story Response - Story Shears EQY

Story	Elevation	Location	X-Dir	Y-Dir
	m		kN	kN
HEADROOM	53.0776	Top	0	-1.1E-06
		Bottom	0	-1.1E-06
LIFT BOTTOM SLAB	51.5536	Top	0	-1.396E-06
		Bottom	0	-1.396E-06
TERRACE	50.0296	Top	1.939E-06	-1339.3081
		Bottom	1.939E-06	-1339.3081
12TH	46.8546	Top	3.428E-06	-2395.2282
		Bottom	3.428E-06	-2395.2282
11TH	43.6796	Top	9.531E-06	-3914.5988
		Bottom	9.531E-06	-3914.5988
1OTH	40.5046	Top	1.161E-05	-4865.2353
		Bottom	1.161E-05	-4865.2353
9TH	37.3296	Top	1.312E-05	-5540.0197
		Bottom	1.312E-05	-5540.0197
8TH	34.1546	Top	6.316E-06	-6418.2512
		Bottom	6.316E-06	-6418.2512
7TH	30.9796	Top	8.829E-06	-6924.2308
		Bottom	8.829E-06	-6924.2308
6TH	27.8046	Top	7.924E-06	-7257.4893
		Bottom	7.924E-06	-7257.4893
5TH	24.6296	Top	7.903E-06	-7651.813
		Bottom	7.903E-06	-7651.813
4TH	21.4546	Top	3.767E-06	-7852.1936
		Bottom	3.767E-06	-7852.1936
3RD	18.2796	Top	4.45E-06	-7963.1614
		Bottom	4.45E-06	-7963.1614
2ND	15.1046	Top	2.89E-06	-8064.7719
		Bottom	2.89E-06	-8064.7719
1ST	11.9296	Top	3.889E-06	-8098.6115
		Bottom	3.889E-06	-8098.6115
GR	8.7546	Top	3.736E-06	-8111.396
		Bottom	3.736E-06	-8111.396
STILT	5.2846	Top	4.02E-06	-8111.396
		Bottom	4.02E-06	-8111.396
PLINTH	1.5	Top	4.019E-06	-8111.396
		Bottom	4.019E-06	-8111.396
Base	0	Top	0	0
		Bottom	0	0

From table.22 and table.23 we observe that the Similar EQY base shear to Model 2 but slightly reduced EQX values. Consistent pattern of decreasing shear from base to top. EQX shear remains higher than EQY, though the gap is narrowing compared to earlier models.

5.5.4 MODEL-4

Story Response - Story Shears

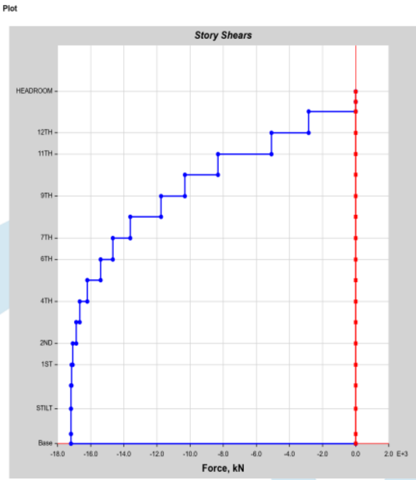


FIG-45: Model-4 Story Response - Story Shears EQX

TABLE-24: Model-4 Story Response - Story Shears EQX

Story	Elevation	Location	X-Dir	Y-Dir
	m		kN	kN
HEADROOM	53.0776	Top	0	0
		Bottom	0	0
LIFT BOTTOM SLAB	51.5536	Top	0	0
		Bottom	0	0
TERRACE	50.0296	Top	-2840.257	0
		Bottom	-2840.257	0
12TH	46.8546	Top	-5079.536	0
		Bottom	-5079.536	0
11TH	43.6796	Top	-8301.6493	0
		Bottom	-8301.6493	0
1OTH	40.5046	Top	-10317.6541	0
		Bottom	-10317.6541	0
9TH	37.3296	Top	-11748.6622	5.193E-07
		Bottom	-11748.6622	5.193E-07
8TH	34.1546	Top	-13611.1186	0
		Bottom	-13611.1186	0
7TH	30.9796	Top	-14684.1442	0
		Bottom	-14684.1442	0
6TH	27.8046	Top	-15390.8821	0
		Bottom	-15390.8821	0
5TH	24.6296	Top	-16227.1203	0
		Bottom	-16227.1203	0
4TH	21.4546	Top	-16652.0654	0
		Bottom	-16652.0654	0
3RD	18.2796	Top	-16887.3937	0
		Bottom	-16887.3937	0
2ND	15.1046	Top	-17102.8779	0
		Bottom	-17102.8779	0
1ST	11.9296	Top	-17174.6413	0
		Bottom	-17174.6413	0
GR	8.7546	Top	-17201.7531	0
		Bottom	-17201.7531	0
STILT	5.2846	Top	-17201.7531	0
		Bottom	-17201.7531	0
PLINTH	1.5	Top	-17201.7531	0
		Bottom	-17201.7531	0
Base	0	Top	0	0
		Bottom	0	0

Story Response - Story Shears-EQY

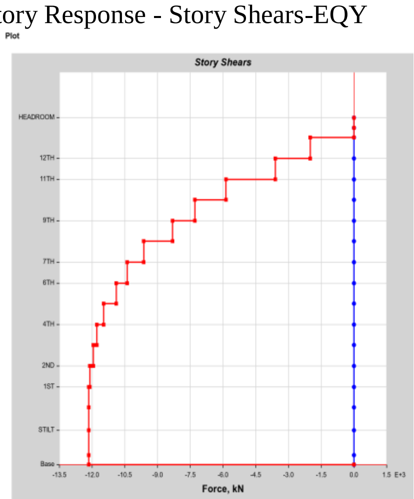


Fig.46: Model-4 Story Response - Story Shears EQY

Table.25: Model-4 Story Response - Story Shears EQY

Story	Elevation	Location	X-Dir	Y-Dir
	m		kN	kN
HEADROOM	53.0776	Top	0	0
		Bottom	0	0
LIFT BOTTOM SLAB	51.5536	Top	0	0
		Bottom	0	0
TERRACE	50.0296	Top	0	-2008.9622
		Bottom	0	-2008.9622
12TH	46.8546	Top	0	-3592.8426
		Bottom	0	-3592.8426
11TH	43.6796	Top	0	-5871.8983
		Bottom	0	-5871.8983
1OTH	40.5046	Top	0	-7297.8529
		Bottom	0	-7297.8529
9TH	37.3296	Top	0	-8310.0294
		Bottom	0	-8310.0294
8TH	34.1546	Top	0	-9627.3766
		Bottom	0	-9627.3766
7TH	30.9796	Top	5.155E-07	-10386.3459
		Bottom	5.155E-07	-10386.3459
6TH	27.8046	Top	5.607E-07	-10886.2336
		Bottom	5.607E-07	-10886.2336
5TH	24.6296	Top	5.601E-07	-11477.7192
		Bottom	5.601E-07	-11477.7192
4TH	21.4546	Top	0	-11778.2902
		Bottom	0	-11778.2902
3RD	18.2796	Top	0	-11944.7419
		Bottom	0	-11944.7419
2ND	15.1046	Top	0	-12097.1576
		Bottom	0	-12097.1576
1ST	11.9296	Top	0	-12147.917
		Bottom	0	-12147.917
GR	8.7546	Top	0	-12167.0937
		Bottom	0	-12167.0937
STILT	5.2846	Top	0	-12167.0937
		Bottom	0	-12167.0937
PLINTH	1.5	Top	0	-12167.0937
		Bottom	0	-12167.0937
Base	0	Top	0	0
		Bottom	0	0

From table.24 and table.25 we observe that the Highest shear values so far: 772.45 kN in EQX, 521.55 kN in EQY. Suggests this model may have increased stiffness or mass participation. Narrowing difference between EQX and EQY indicates more symmetrical behavior.

5.5.5 MODEL-5

Story Response - Story Shears-EQX

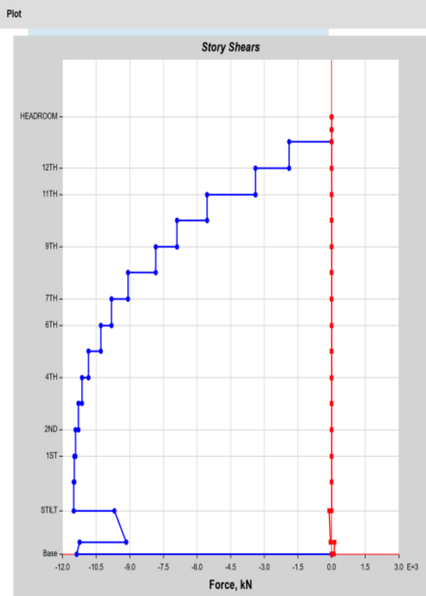


Fig.47: Model-5 Story Response - Story Shears EQX

Table.26: Model-5 Story Response - Story Shears EQX

Story	Elevation	Location	X-Dir	Y-Dir
	m		kN	kN
HEADROOM	53.0776	Top	0	0
		Bottom	0	0
LIFT BOTTOM SLAB	51.5536	Top	0	0
		Bottom	0	0
TERRACE	50.0296	Top	-1899.8063	6.793E-07
		Bottom	-1899.8063	6.793E-07
12TH	46.8546	Top	-3400.3931	1.591E-06
		Bottom	-3400.3931	1.591E-06
11TH	43.6796	Top	-5552.579	-2.906E-06
		Bottom	-5552.579	-2.906E-06
10TH	40.5046	Top	-6897.2141	0
		Bottom	-6897.2141	0
9TH	37.3296	Top	-7850.5493	8.624E-07
		Bottom	-7850.5493	8.624E-07
8TH	34.1546	Top	-9091.3145	-1.912E-06
		Bottom	-9091.3145	-1.912E-06
7TH	30.9796	Top	-9806.1624	-2.638E-06
		Bottom	-9806.1624	-2.638E-06
6TH	27.8046	Top	-10278.2788	-1.658E-06
		Bottom	-10278.2788	-1.658E-06
5TH	24.6296	Top	-10837.2813	-1.696E-06
		Bottom	-10837.2813	-1.696E-06
4TH	21.4546	Top	-11121.708	0
		Bottom	-11121.708	0
3RD	18.2796	Top	-11278.9124	0
		Bottom	-11278.9124	0
2ND	15.1046	Top	-11422.4676	-1.073E-06
		Bottom	-11422.4676	-1.073E-06
1ST	11.9296	Top	-11470.2763	0
		Bottom	-11470.2763	0
GR	8.7546	Top	-11488.3381	0
		Bottom	-11488.3381	0
STILT	5.2846	Top	-9687.2026	-99.8458
		Bottom	-9155.3559	-45.9139
PLINTH	1.5	Top	-11236.119	135.1099
		Bottom	-11362.5428	93.6094
Base	0	Top	0	0
		Bottom	0	0

Story Response - Story Shears- EQY

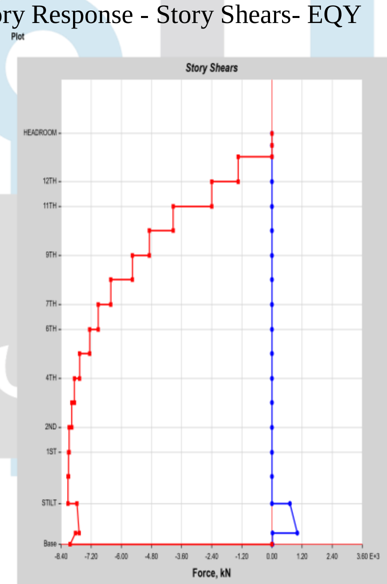


Fig.48: Model-5 Story Response - Story Shears EQY

Table.27: Model-5 Story Response - Story Shears EQY

Story	Elevation	Location	X-Dir	Y-Dir
	m		kN	kN
HEADROOM	53.0776	Top	0	-1.113E-06
		Bottom	0	-1.113E-06
LIFT BOTTOM SLAB	51.5536	Top	0	-1.359E-06
		Bottom	0	-1.359E-06
TERRACE	50.0296	Top	4.366E-06	-1343.7654
		Bottom	4.366E-06	-1343.7654
12TH	46.8546	Top	2.343E-06	-2405.1561
		Bottom	2.343E-06	-2405.1561
11TH	43.6796	Top	6.593E-06	-3927.4337
		Bottom	6.593E-06	-3927.4337
10TH	40.5046	Top	8.464E-06	-4878.5171
		Bottom	8.464E-06	-4878.5171
9TH	37.3296	Top	9.986E-06	-5552.8274
		Bottom	9.986E-06	-5552.8274
8TH	34.1546	Top	6.57E-06	-6430.4418
		Bottom	6.57E-06	-6430.4418
7TH	30.9796	Top	9.094E-06	-6936.0658
		Bottom	9.094E-06	-6936.0658
6TH	27.8046	Top	1.04E-05	-7270.0018
		Bottom	1.04E-05	-7270.0018
5TH	24.6296	Top	1.036E-05	-7665.3938
		Bottom	1.036E-05	-7665.3938
4TH	21.4546	Top	1.132E-05	-7866.5737
		Bottom	1.132E-05	-7866.5737
3RD	18.2796	Top	1.237E-05	-7977.7671
		Bottom	1.237E-05	-7977.7671
2ND	15.1046	Top	1.122E-05	-8079.3061
		Bottom	1.122E-05	-8079.3061
1ST	11.9296	Top	1.191E-05	-8113.122
		Bottom	1.191E-05	-8113.122
GR	8.7546	Top	1.175E-05	-8125.8975
		Bottom	1.175E-05	-8125.8975
STILT	5.2846	Top	711.1523	-7776.7348
		Bottom	1003.2251	-7691.0815
PLINTH	1.5	Top	17.7573	-7824.5908
		Bottom	11.4325	-8038.2802
Base	0	Top	0	0
		Bottom	0	0

Highest shear demands among all models. EQX: 798.25 kN, EQY: 548.48 kN at the ground. Both directions show increased forces, indicating this model is potentially stiffer or designed for higher seismic demand. EQX still governs, but the gap is the narrowest.

VI. CONCLUSION AND FUTURE SCOPE

6.1 Summary of Findings

The hybrid approach significantly improved seismic performance and reduced structural stress.

This study involved a comparative seismic performance analysis of a G+13 building located in Seismic Zone IV on Soil Type 2, through five structural models incorporating varying configurations of Lead Rubber Bearings (LRBs) and Fluid Viscous Dampers (FVDs).

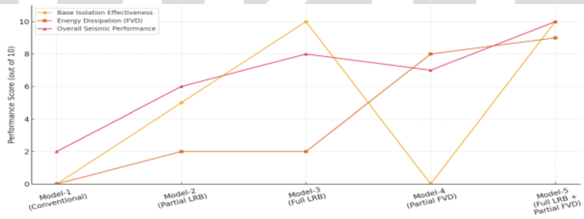


Fig.49: Comparitive Performance of Structural Models

Based on the comparative performance analysis:

Model-1 (Conventional) is the least effective in both base isolation and energy dissipation, resulting in the lowest overall seismic performance.

Model-2 (Partial LRB) improves base isolation moderately but lacks energy dissipation capacity.

Model-3 (Full LRB) offers excellent base isolation, enhancing performance over Model-2, though energy dissipation remains minimal.

Model-4 (Partial FVD) focuses on energy dissipation with no base isolation. It improves performance over the conventional model but doesn't match the base-isolated models.

Model-5 (Full LRB + Partial FVD) combines both strategies, achieving the highest effectiveness in both base isolation and energy dissipation—making it the most robust and efficient model in seismic performance.

Model-1 (Conventional Structural System)

This model serves as the baseline or reference case and represents a typical high-rise structure without any specialized seismic control devices. It lacks both base isolation and energy dissipation systems, meaning it is fully fixed to the ground and directly transmits seismic forces to the superstructure.

Seismic Performance: Poor. The structure experiences significant inter-storey drifts, base shear, and floor accelerations during an earthquake.

Energy Dissipation: Minimal. Almost all the energy from seismic activity is absorbed by the structural members, increasing the risk of damage.

Suitability: Only viable in low to moderate seismic zones, or where cost is a strict constraint and performance trade-offs are acceptable.

Model-2 (Partial LRB – Lead Rubber Bearings under Heavily Loaded Columns Only)

This model introduces partial base isolation, placing LRBs only beneath columns that experience higher axial loads. The goal is to reduce the seismic forces where they are most critical, without implementing isolation throughout.

Seismic Performance: Improved compared to Model-1. Reduced seismic demand at targeted areas helps in limiting damage.

Energy Dissipation: Still lacking, as LRBs primarily function as isolators and not as energy dissipators.

Cost-Effectiveness: More economical than full isolation but offers limited improvement in global performance.

Model-3 (Full LRB – Lead Rubber Bearings under All Columns)

This model fully integrates base isolation across the structure, placing LRBs beneath all columns. The entire building is decoupled from ground motion to a significant extent.

Seismic Performance: Significantly enhanced. Reduction in base shear, inter-storey drifts, and acceleration due to the flexibility and damping of LRBs.

Energy Dissipation: Still moderate, as LRBs are not primarily designed to dissipate large amounts of energy but to shift the structure's natural period.

Advantages: Ideal for critical infrastructure, such as hospitals or emergency facilities, where maintaining structural integrity is essential.

Model-4 (Partial FVD – Fluid Viscous Dampers at Select Storeys)

This model focuses on energy dissipation by installing FVDs at key storey levels (e.g., 4th–6th and 12th–13th floors). Unlike LRBs, FVDs absorb and dissipate seismic energy rather than isolate the building.

Seismic Performance: Offers noticeable improvement in reducing inter-storey drift and floor accelerations.

Base Isolation: None. The building remains fixed to the ground, so it still transmits some seismic forces.

Advantages: Useful in retrofitting or where base isolation is not feasible due to site or design constraints.

Model-5 (Full LRB + Partial FVD – Combined System)

This hybrid model combines full base isolation (LRBs under all columns) with targeted energy dissipation (FVDs at specific storeys).

Seismic Performance: Outstanding. Offers the best of both worlds—reduced seismic input due to isolation and controlled structural response through damping.

Energy Dissipation & Isolation Synergy: The system not only reduces the seismic demand but also manages residual motion effectively.

Best Use Case: High-risk seismic zones, tall or irregular structures, or buildings where operational continuity post-earthquake is crucial.

Model-1, the conventional structure without any seismic control measures, shows the lowest performance under seismic loading due to full force transmission from the ground and minimal energy dissipation. In contrast, Model-5 incorporates both Lead Rubber Bearings (LRBs) at the base and Fluid Viscous Dampers (FVDs) at specific floors, effectively combining base isolation and energy dissipation strategies. This dual system reduces seismic forces, inter-story drift, and displacements significantly, offering the highest level of structural protection and post-earthquake functionality. Thus, Model-5 stands out as the most effective and resilient model among all, providing superior seismic performance.

6.2 Conclusion

A G+13 building was successfully designed incorporating Lead Rubber Bearings (LRBs) and Fluid Viscous Dampers (FVDs) to enhance seismic performance.

The structural models were evaluated under Seismic Zone-4 conditions, ensuring realistic assessment of seismic vulnerability and control efficiency.

Multiple hybrid configurations of LRBs and FVDs were analyzed and compared for their effectiveness in reducing seismic forces, inter-story drift, and displacements.

Among all models, Model-5, which combines LRBs at the base and FVDs at specific floors, demonstrated the highest performance in terms of energy dissipation and structural stability.

The integrated use of base isolation and supplemental damping in Model-5 provided the most resilient and accurate solution, significantly enhancing post-earthquake functionality.

The results confirm that hybrid seismic control systems offer superior protection over conventional or single-technology systems in high-seismic-risk areas.

6.3 Future Scope

Experimental Validation: Conduct physical shake table testing or full-scale prototype experiments to validate the simulated performance of LRBs and FVDs.

Life-Cycle Cost Analysis: Investigate the long-term cost-effectiveness and maintenance needs of hybrid seismic systems compared to traditional methods.

Multi-Hazard Assessment: Extend the study to evaluate performance under combined hazards such as seismic and wind loads or aftershock sequences.

Material Innovations: Explore the use of advanced materials (e.g., smart dampers, shape memory alloys) in LRBs and FVDs to further improve efficiency and adaptability.

Integration with Smart Monitoring: Develop models incorporating sensors and IoT-based monitoring systems for real-time performance evaluation during seismic events.

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