MODELLING AND SEISMIC ANALYSIS OF 5- STORY BUILDING

A

PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of the degree

of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision

of

Dr. Ashok Kumar Gupta

Professor and Dean

&

Mr. Rohan Singhal

Assistant professor

by

ARNAV RAWAT (181632)

ABHAY KAITH (181615)

TO

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH, INDIA

MAY, 2022

DECLARATION

I hereby declare that the work presented in the Project report entitled **"MODELLING AND SEISMIC ANALYSIS OF 5-STORY BUILDING"** submitted for partial fulfillment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **(Dr. Ashok Kumar Gupta) & (Mr. Rohan Singhal)**. This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

RAWAT

ARNAV RAWAT (181632)

Department of Civil Engineering

Jaypee University of Information
Technology, Waknaghat, India

ABHAY KAITH (181615)

Department of Civil Engineering

Jaypee University of Information
Technology, Waknaghat, India

CERTIFICATE

This is to certify that the work which is being presented in the project report titled **“MODELLING AND SEISMIC ANALYSIS OF 5-STORY BUILDING”**in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **ARNAV RAWAT (181632) and ABHAY KAITH (181615)** during a period from July 2019 to November, 2019 under the supervision of **Mr. Rohan Singhal** (Assistant professor), Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

Date:

Mr. Rohan Singhal	Prof.(Dr.) Ashish Kumar
Assistant professor	Professor & Head of Department
Department of Civil Engineering	Department of Civil Engineering
JUIT, Waknaghat	JUIT, Waknaghat

ACKNOWLEDGEMENT

The success and final outcome of this project require a lot of guidance and assistance from many people and we are extremely privileged to have got this all along the completion of our project. All that we have done is only due to such supervision and assistance and we would not forget to thank them.

We would like to express our sincere gratitude to Mr. Rohan Singhal (Assistant Professor) for his valuable guidance.

We would like to extend our sincere thanks to sir. We are highly indebted to all of them for their guidance and constant support.

Date ________________

ABSTRACT

In recent years, there has been a lot of focus on the innovative work of structural control devices, with a focus on reducing wind and seismic response of structures.

Vibration-control strategies, including as passive, active, semi-active, and hybrid vibration control approaches, have been developed in recent years. During major earthquakes, passive vibration control keeps the structure elastomeric, and the fundamental frequency is lower than the set base frequency and ground motion frequencies. Base isolation is a passive vibration management technology that reduces seismic pressures on a wide scale.

On the framed structure, forced vibration research was conducted out using and experimentally testing the computer software ETABS 2017.

In the superstructure, the isolation mechanism reduces inter-story drift by a factor of at least two, and in many cases by a factor of at least five. Acceleration responses are frequently reduced by a quantity in the structure, but the extent of the reduction is determined by the force deflection characteristic of the isolator. In recent years, groundbreaking work on structural control gadgets has received a lot of attention, with a particular focus on wind relief and seismic response of structures. The building, on the other hand, is constructed with a fixed foundation and a base insulator, and all systems evaluate floor drift, displacement, velocity, and acceleration. The manual setting of the isolator is then done, and the isolator is evaluated in the ETABS programmer.

LIST OF FIGURES

TABLE OF CONTENTS

Chapter 1
INTRODUCTION

1.1. General

Earthquake is a natural occurrence that occurs in all circumstances. To develop the optimal solution, engineering design strives to combine economics, social, environmental, and safety factors. India is a massive nation. Nearly two-thirds of the country is prone to earthquakes. Low-rise buildings of one to three stories make up a substantial portion of both rural and urban structures. Many of them may not have been designed properly by professionals with experience in earthquake engineering. Building collapse is the leading cause of death and property damage in earthquakes. In India and other emerging countries throughout the world, the number of housing units and other small-scale buildings might treble in the next two decades.

This emphasizes the need for a straightforward engineering solution to make such structures earthquake-resistant at a reasonable cost.

The general form, scale, and geometry of a structure, as well as how seismic forces are transported to the ground, have a significant impact on its behavior during earthquakes. As a result, architects and structural engineers must collaborate throughout the planning stage to ensure that unfavorable elements are avoided and a desirable building layout is adopted.

The performance of outengineered structures during earthquakes will be highlighted in this presentation, as well as various solutions for reducing earthquake damage.

1.2. Seismic Effects on Structures:

I. Inertia forces in structures:

A ground vibration is caused by an earthquake. As a result, the building that rests on it will have movement at its foundation. According to Newton's First Law of Motion, even while the building's foundation moves with the earth, the roof tends to remain in its original place. The roof, however, is dragged along by the walls and columns since they are attached to it. Inertia refers to the roof's tendency to stay in its prior position. Because the walls or columns of the structure are flexible, the roof moves differently than the ground.

II. Effect of deformations in structures:

When a building undergoes an earthquake and the ground shakes, the structure's foundation moves with it. The roof, on the other hand, would move differently than the structure's foundation. Internal forces in columns are created by this difference in movement, which tend to restore the column to its initial location.

Internal forces are referred to as stiffness forces. As the size of the columns grows larger, the stiffness forces will increase. The column stiffness times the relative displacement between its ends equals the stiffness force in a column.

III. Horizontal and vertical shaking:

An earthquake shakes the ground in three directions: two horizontal directions (x and y) and one vertical direction (z). The ground rocks randomly back and forth in each of these directions during an earthquake. The primary purpose of all constructions is to carry gravity loads in the vertical direction. As a result, most buildings are able to withstand vertical shaking. Horizontal shaking in the x and y axes, on the other hand, is still a worry. Structures built to withstand gravity loads may not be able to withstand the impacts of horizontal earthquake shaking. As a result, the structural adequacy against horizontal earthquake impacts must be ensured.

1.3. Structure Modelling Methods

1.3.1. Fixed Base

A fixed-base building (one that is built directly on the ground) will move with the motion of an earthquake and may experience significant damage as a result.

1.3.2. Base Isolators

The base isolation device reduces the structure's stiffness while increasing its flexibility. The primary notion of the base isolation approach is to "extend time period and lower acceleration of fixed base structure," which results in a reduction in seismic effect on the structure. Base isolation, also known as seismic base disconnection or base detachment framework, is a well-known method for protecting a structure against earthquake impacts. The base isolation device, also known as dampers, is installed between the foundation and the building's superstructure in a base isolation building. The idea behind this approach is to remove the building from the ground and install dampers so that seismic energy is not transported up through the building.

Because the seismic isolation device is positioned beneath the building in many, but not all, applications, it is referred to as "base isolation." The base isolation device installed between a building's superstructure and foundation should have a reduced horizontal rigidity and better damping properties. The use of a base isolation device in a building minimizes base shear, accelerates the process, and extends the time period. It prevents the structure from being damaged by earthquakes.

1.3.3. Shear Wall

A shear wall is a structural element that resists lateral pressures, or forces that are parallel to the wall's plane. Shear walls withstand loads owing to Cantilever Action on narrow walls where bending distortion is greater. Shear walls, in other terms, are vertical components of a horizontal force-resisting structure.

In high-rise structures subjected to lateral wind and seismic stresses, shear walls are extremely critical. Shear walls are typically planar or flanged in form, whereas core walls are made up of channel sections. They also have enough strength and stiffness to keep lateral displacements under control.

1.4. Problem Statement

The majority of deaths in previous earthquakes were caused by the collapse of structures made of conventional materials such as stone, brick, adobe, and wood that were not specifically intended to be earthquake resistant. Given the continued use of such structures in the majority of countries around the world, earthquake resistance features must be included in their design.

Earthquakes continue to kill people and create massive property damage in many places of the world. The number of victims and the level of damage do not appear to be reducing with time; in fact, due to the ever-increasing concentration of people in cities, there is a risk that the extent of damage may increase. If the appropriate safety measures are not adopted in a timely manner, the seismic zones would undoubtedly face a major threat.

An earthquake's exact time, severity, and location cannot be predicted in advance. Of course, certain areas are known to be prone to earthquakes on a more or less regular basis. Earthquakes are given far greater attention in earthquake-prone areas than they are elsewhere; in fact, every effort is made to safeguard the populace from the devastation of earthquakes. However, in areas where earthquakes are relatively infrequent, i.e., when catastrophic earthquakes occur every one or more human generations, builders prefer to overlook or overlook the hazard of earthquakes. They frequently express the opinion that extra investment in anti-seismic structural strengthening is uneconomical and illogical, claiming that the seismic risk is negligible.

The realization of the design in line with earthquake-resistant engineering principles is insufficient if there is no guarantee that the design meets the criteria in terms of geometrical shape, dimensions, and, most importantly, the kind and quality of the material. Even the most brilliant design can be completely ruined by poor craftsmanship and materials. We are confronted with not only the issue of material quality, but also the difficulty of selecting acceptable material while keeping economic issues in mind. Engineers are well aware that, due to the high expense of transportation, they prefer to use local materials.

The study of the varied impacts of earthquakes has revealed that many traditional construction materials, such as brick and stone, are particularly unsafe from an earthquake safety viewpoint. Traditional whole bricks of regular form, which are extensively employed in enormous building, have shown to be completely inappropriate for earthquake-resistant construction. A brick wall has a large number of joints, each of which hides the threat of insufficient adhesion, as well as lowering the structure's carrying capability.

If we want to reduce the danger of damage, it is obvious that the number of joints should be reduced as much as feasible. We may deduce from this that, if we want to maintain brick as a construction material, we should utilize larger brick parts, because only this way can the number of risky joints be reduced significantly. The complete removal of this material in favor of new materials that are more ideal for earthquake-resistant construction would put certain locations at a significant disadvantage.

Given that we are still in a period when less-than-ideal materials for earthquake-resistant construction are available, we must ensure that only the highest-quality materials are used, and that the building techniques ensure the material's maximum effectiveness in the event of an earthquake.

The same may be said for materials that are currently thought to be more suited to earthquake-resistant construction. We should constantly be aware that, while deficiencies in the quality of materials or craftsmanship may go undetected under normal conditions, they might show suddenly and have devastating implications when the building is subjected to seismic pressures.

Finally, I'd want to stress that the issue of anti-seismic design and construction is one that is always evolving. Seismology and earthquake engineering advances should be closely monitored, and earthquake engineering successes should be put into practise as soon as possible. Only in this way, within the constraints given by economic circumstances, can human life and property be preserved from the devastation of earthquakes.

1.5. Objective Of The Present Work

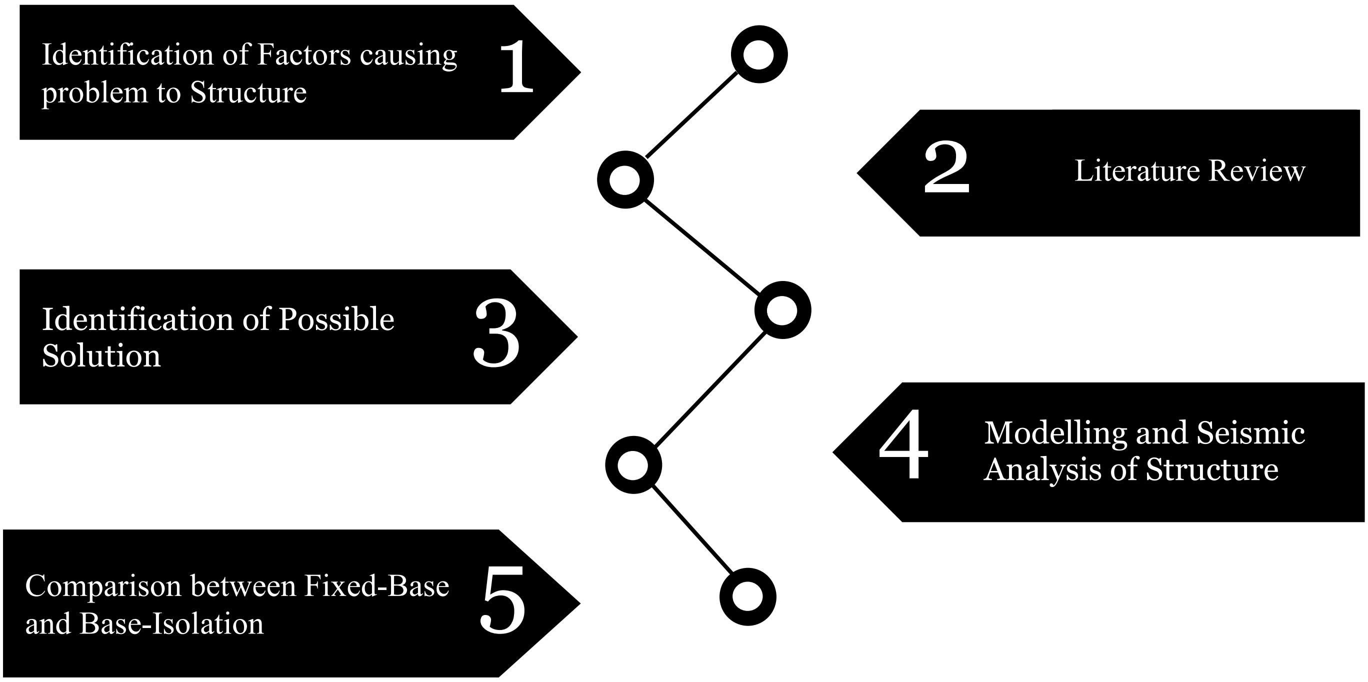
The major goal of seismic resistant construction is to prevent the building from collapsing during minor earthquakes. This also aids in averting catastrophic structural failure by providing adequate notice during major earthquakes, ultimately saving lives.

The primary goal of this research is to construct a suitably seismic-isolated multistory building on ETABS and to investigate the impact of seismic activity on the structure. The structure is constructed in ETABS, with the load of the structure taken at the end of one column and the Isolator manually designed to determine its dimensions. The model is then created in ETABS using the manual design, and the efficiency of the isolator is calculated to determine whether the constructed isolator is safe for the building.

Seismic analysis using **E-Tabs:-**

1. Fixed base
2. Base isolation techniques
3. Shear wall

1.6. Methodology



Chapter 2

LITERATURE REVIEW

2.1. The Earth and its Interior:

The differentiated Earth consists of the Inner Core (radius~1290km), the Outer Core (thickness ~2200km), the Mantle (thickness ~2900km) and the Crust (thickness ~5 to 40km). The Inner Core is solid and made up of heavy metals like nickel and iron, whereas the Crust is made up of lighter materials (e.g., basalts and granites). The Mantle has the ability to flow, while the Outer Core is liquid.

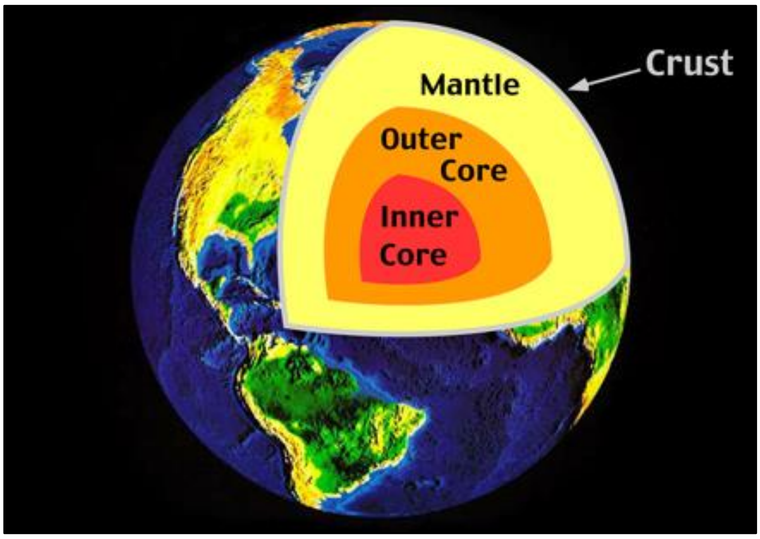


Fig 2.1. *Interior of the earth*

Source - http://eschool.iaspaper.net/hydrosphere/geosphere/

2.2. Plate Tectonics:

The convective flows of Mantle material cause the Crust and some portion of the Mantle, to slide on the hot molten outer core. Tectonic Plates are the portions of the Earth's mass that slide around. There are seven major tectonic plates on the Earth's surface, as well as numerous smaller ones. These plates move in different directions and at different speeds from those of the neighboring ones. The plate in front is sometimes slower than the plate behind it, and the two plates clash (and mountains are formed). On the other hand, two plates may occasionally move away from one another (and rifts are created). Two plates move side by side in another case, either in the same direction or in opposite directions. The convergent, divergent, and transform boundaries are the three forms of inter-plate interactions.

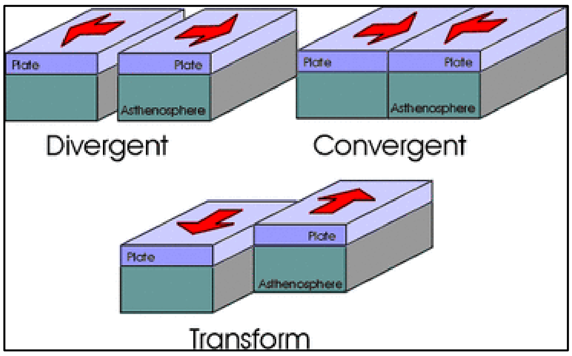


***Fig. 2** Types of Inter-Plate Boundaries*

Source- https://earthquakesandplates.wordpress.com/2008/05/13/plate-boundaries-and-their-many-motions/boundaries/

2.3. The Earthquake:

Earthquake tectonic plates are formed of brittle rocky material which is elastic. As a result, elastic strain energy is stored in them during the relative deformations caused by the Earth's massive tectonic plate motions. However, when the rocky material at the plate interface in the Earth's Crust reaches its strength, it fractures, and an abrupt movement occurs as the interface between the plates (called the fault) suddenly slips, releasing the large elastic strain energy trapped in the rocks at the interface. The earthquake is caused by a rapid slip at the fault... a strong shaking of the Earth in which large elastic strain energy is released and spreads out in the form of seismic waves that travel through the Earth's body and over its surface And, once the earthquake is complete, the process of strain build-up at this altered tectonic plate boundary begins all over again.

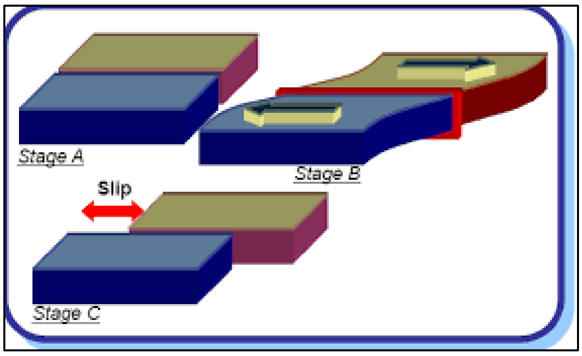


Fig. 3 Elastic Strain Build-Up and Brittle Rupture

Source- IITK-BMTPC

2.3.1. Types of Earthquakes and Faults:

Inter-plate Earthquakes are the most common type of earthquake that occurs along the boundaries of tectonic plates around the earth. Intra-plate Earthquakes are earthquakes that occur within the plate itself but outside of the plate boundaries. A tectonic plate separates the two. During both types of earthquakes, the fault slips in both vertical and horizontal directions, referred to as Dip Slip, and lateral directions, referred to as Strike Slip.

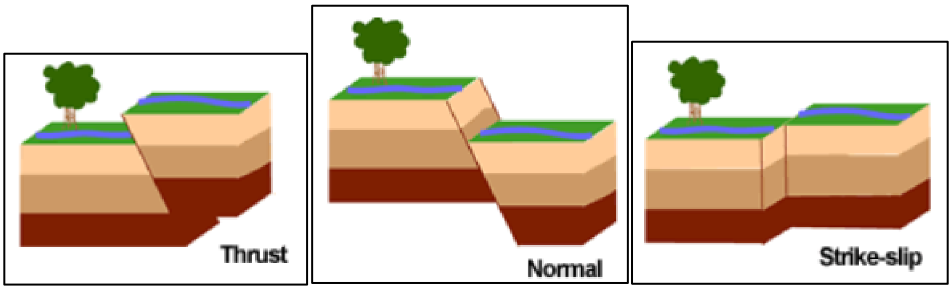


Fig.4 *Types of Fault*

Source- *https://www.ucl.ac.uk/seismin/explore/earthquakes.html*

2.4. Seismic Waves:

Large strain energy created by an earthquake travels through the Earth's layers as seismic waves in all directions, reflecting and refracting at each interface. Body waves and surface waves are the two types of waves. Primary Waves (P-waves) and Secondary Waves (S-waves) form up body waves, whereas Love waves and Rayleigh waves make up surface waves. Material particles are subjected to extensional and compressional strains along the direction of energy transmission in P-waves, but oscillate at right angles to it in S-waves. Love waves produce surface motions that are similar to S-waves but do not have a vertical component. In the vertical plane, a Rayleigh wave causes a material particle to oscillate in an elliptic path.

The fastest waves are P-waves, which are followed by S-, Love, and Rayleigh waves in that order. S-waves do not travel through liquids. By racking motion on the surface in both vertical and horizontal directions, S-waves do the most damage to structures when combined with Love wave effects. The majority of the energy of P- and S-waves is reflected back when they reach the Earth's surface. Reflections at different levels of soil and rock return a portion of this energy to the surface. At the Earth's surface, shaking is more intense (about twice as much) than at great depths.

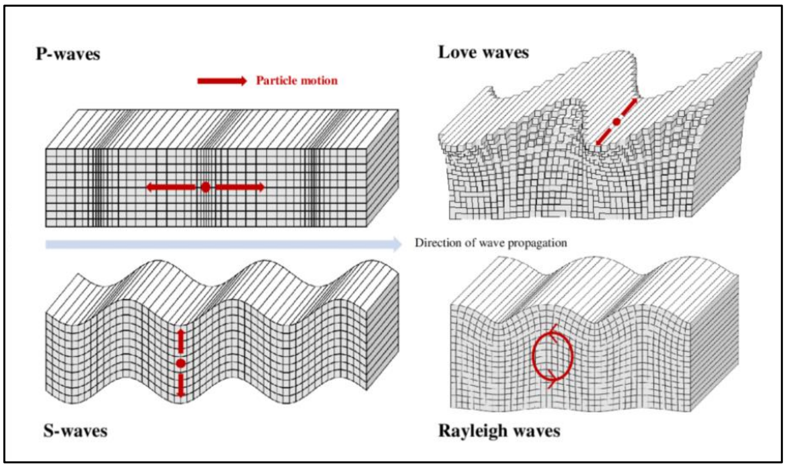


Fig. 5 *Motions caused by Body and Surface Waves*

Source- https://www.sciencefacts.net/seismic-waves.html

Terminology

The Focus or Hypocenter is the place on the fault where slide begins, and the Epicenter is the point vertically above this on the Earth's surface. Focal Depth, or the depth of focus from the epicentre, is a critical metric in assessing an earthquake's destructive potential. The majority of the devastating earthquakes have shallow focal depths of less than 70 kilometres. The epicentral distance is the distance between the epicentre and any location of interest. Before and after a large earthquake, a series of lesser earthquakes occur (i.e., the Main Shock). The ones that happen before the major one are known as Foreshocks, and the ones that happen afterward are known as Aftershocks.

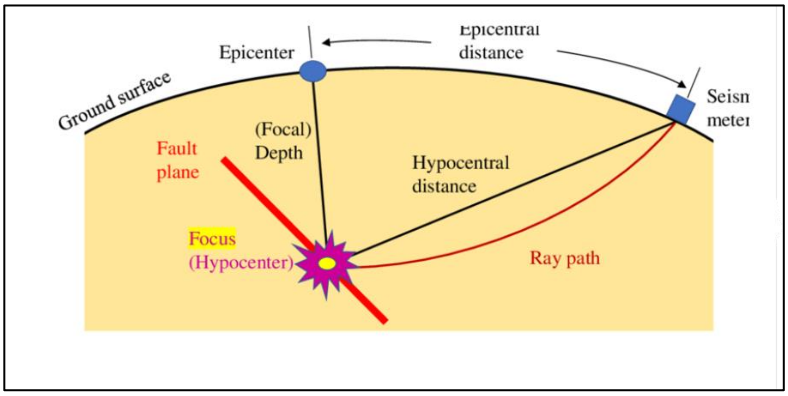


Fig. 6 *Basic terminology*

Source- IITK BMPTC

2.5. Importance of Seismic Design in Building Engineering

Seismic design is a critical structural analysis method used when constructing a structure that will be subjected to Earthquake ground vibrations and will continue to function and fulfil its purpose even after an earthquake.

Seismic Engineering has advanced throughout time, with tools like ETABS, STAAD. Pro, ROBOT, TEKLA, and others automating the complexity of analysis that used to need several cycles of formulas. These tools produce beneficial outcomes such as safe, stable, and long-lasting structures, as well as design optimization and cost-effective structures.

Hospitals and educational buildings are unique structures with a higher relevance factor than residential or commercial structures, ranging from 25 to 50 percent.

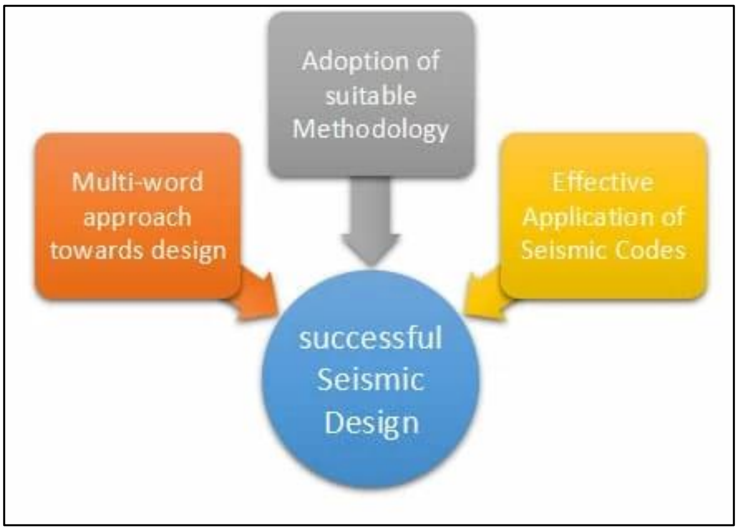


Fig 7. *: Flow chart of Seismic design*

SOURCE- https://www.enventure.com/blog/importance-of-seismic-design-in-building-engineering/

Different types of structural systems, such as seismic isolation systems, energy dissipation systems, and active control systems, can improve a building's seismic resistance by dispersing lateral forces without damaging structural elements. Non-traditional civil engineering materials and procedures will grow as novel structural systems and gadgets are developed. When simulated under seismic conditions, modern system approaches based on dynamic analysis provide a better approximation of the behavior.

2.6. Earthquake-Resistant Buildings:

Engineers do not attempt to design earthquake-resistant structures that would not be damaged even during a rare but powerful earthquake; such structures would be too large and expensive. Instead, the technical goal is to design buildings earthquake resistant; these structures will withstand the effects of ground shaking, even if they are severely damaged, and will not collapse during a big earthquake. As a result, earthquake-resistant structures ensure the safety of people and things, preventing a tragedy. Seismic design codes all around the world include this as a main goal.

2.7. Seismic Design Philosophy for Buildings:

1. The principal members of the building that carry vertical and horizontal forces should not be harmed during mild but frequent shaking; however, building parts that do not carry load may sustain repairable damage.

2. The primary members of the building may sustain repairable damage during moderate but infrequent shaking, but other parts of the building may be damaged to the point that they may need to be replaced after the earthquake.

3. The primary parts of the structure may suffer significant (even irreversible) damage in the event of a strong but infrequent earthquake, but the structure should not collapse. As a result, after moderate tremors, the building will be fully functioning in a short period, with little repair needs. After the damaged main members are repaired and strengthened, the building will be operational after moderate shaking. However, following a large earthquake, the structure may become unfit for further use, but it will remain standing so that people may be evacuated and property can be rescued. The effects of damage must be considered while developing a design philosophy. Important structures, such as hospitals and fire stations, for example, play a key part in post-seismic activities and must stay operational immediately following the earthquake. These constructions must withstand minimal damage and should be built to withstand earthquakes to a greater extent. Dam failure during earthquakes can result in flooding in downstream areas, which can be a secondary calamity. As a result, dams (as well as nuclear power facilities) should be designed to withstand much more earthquake motion.

2.7.1. Damage in Buildings: Unavoidable

Controlling the damage to acceptable levels at a reasonable cost is an important part of earthquake-resistant structure design. Engineers designing earthquake-resistant buildings know that some damage is unavoidable, contrary to popular belief that any fracture in a building after an earthquake signifies the building is hazardous for habitation. During earthquakes, different sorts of damage (often visible through fractures; especially in concrete and masonry constructions) occur in buildings. Some of these cracks are okay (both in terms of size and position), but others are not. For example, cracks between vertical columns and masonry filler walls are permissible in a reinforced concrete frame building with masonry filler walls between columns, but diagonal cracks running through the columns are not.

Qualified technical personnel are generally familiar with the causes and degree of damage in earthquake-resistant structures.

2.7.2. Acceptable Damage: Ductility

Buildings that are earthquake-resistant, particularly their primary elements, must be developed with ductility in mind. Such structures can sway back and forth during an earthquake and endure the effects of an earthquake with considerable damage but not collapse. One of the most critical aspects determining building performance is ductility. As a result, earthquake-resistant design aims to predict where damage will occur and then provide good detailing at these spots to ensure the building's ductile behaviour.

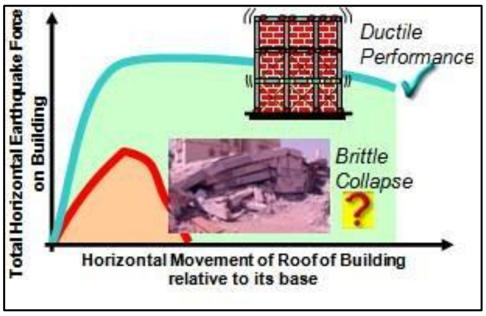


Fig.8 *Building performances during earthquakes: two extremes – the ductile and the brittle.*

Source - https://theconstructor.org/structural-engg/seismic-design-philosophy-for-buildings/2781/

2.8. Earthquake-Resistant Design of Buildings:

The proper building materials must be made ductile. A column's failure can impair the building's overall stability, whereas a beam's failure has a more restricted effect.

As a result, it is preferable to make beams the ductile weak links rather than columns. The strong-column weak-beam design approach is a way of developing RC buildings .

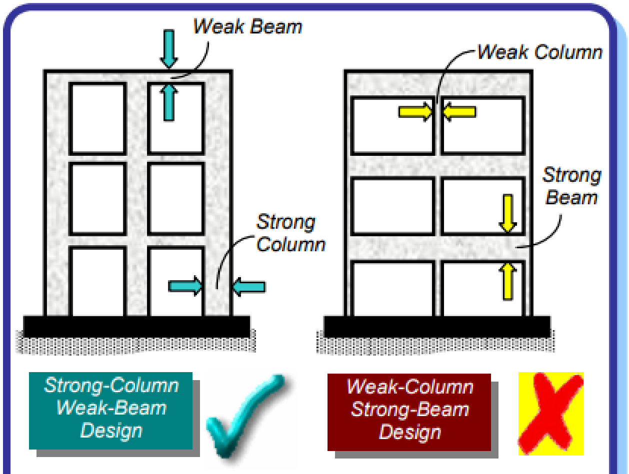


Figure 9: Reinforced Concrete Building Design: *the beams must be the weakest links and not the columns – this can be achieved by appropriately sizing the members and providing correct amount of steel reinforcement in them.*

Designers may not be able to construct a ductile structure by employing routine design codes (meant for non-earthquake effects). To aid designers in improving the ductility of the structure, special design provisions are required. Such rules are frequently included in a special seismic design code, such as IS:13920-1993 for reinforced concrete structures.

These rules also ensure that members with high ductility are used in areas where damage is likely.

2.9. Important Elements of Earthquake Resistant Buildings:

Diaphragms:

A diaphragm is a horizontal structural element that distributes lateral loads to a structure's vertical resisting elements. The floors and roofs are examples of diaphragms. These elements are placed on their own deck and are strengthened horizontally in earthquake-resistant buildings, allowing them to share force loads with vertical sections of the structure.

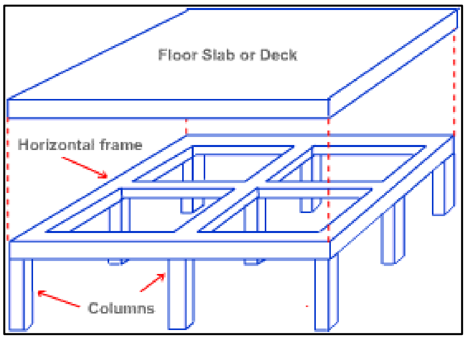


Fig. 10 *Diaphragm*

Source- *http://www.ideers.bris.ac.uk/resistant/strength_diaphrams.html*

Cross-Bracing:

A cross-bracing system has intersecting diagonal supports. A variety of columns, braces, and beams can be used to transport seismic loads back to the earth.

Shear Walls:

In-plane lateral forces are resisted by these vertical design components. By reinforcing the building's frame, these walls help to resist the swaying forces of earthquakes.

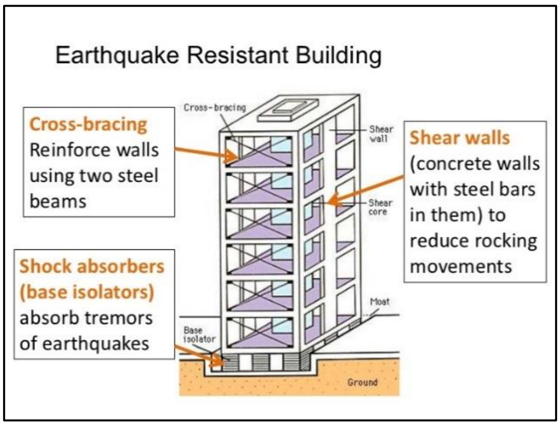


Fig. 11 *Components of Building*

Source- *https://earthqukesinindia-stsm.weebly.com/technology.html*

Trusses:

Trusses are designed to increase strength to the sections where the diaphragms are the weakest. These are usually diagonal structures that fit inside the frame's rectangular angles.

Moment-Resisting Frames:

An arrangement of beams and columns in which the beams are flexible but the columns are rigidly connected. The resulting frame resists lateral stresses by allowing flexible movement in the columns and beams while keeping the joints and connectors rigid.

Types of Moment-Resisting Frames –

a) **Ordinary Moment Resistant Frame:** These frames are unable to meet the ductile behavior requirements of the specification. Typical building framing is built with a closed system, and bending moment is rarely a concern.

b) **Special Moment Resisting Frame:** These frames can meet ductile behavior criteria with specific finishing. A bending moment is a measurement of the bending effect that can occur when a structural member is subjected to an external force. Moment design must be considered if there is an overhang or projection from a normal building frame.

2.10. Important Characteristics For Earthquake Resistance Building Designs

Stiffness and Strength

- Sufficient vertical and lateral stiffness and strength are required for building an earthquake-resistant structure.

Regularity

- Movement of the building moved in lateral directions.
- Building should move equally so as to equally dissipate the energy without having much effect on one side only.
- If building is not regular, building starts swaying will lead to heavy concentrated damage and building will be compromised.

Redundancy

- One of the most important safety characteristics.
- It guarantees alternate strategies in case if previous one fails.
- Reliable but expensive: Add to the cost of building.

Foundations

- A stable foundation considered as the most significant characteristic of a high-rise structure or building
- Ground movement and its response to any lateral load must be analysed in advance.
- For earthquake resistant design it is recommended to have deep foundations and driven piles.

Continuous Load Path

- For dissipation of inertial or lateral forces, all components including structural and nonstructural ones need to be inter-connected.
- Independent components respond independently to earthquake forces, can lead to structural collapse.
- It is important to ensure that the path should remain intact.

2.11. Reduce Earthquake Effects on Buildings:

Buildings are protected from devastating earthquake effects using two basic technologies. Base Isolation Devices and Seismic Dampers are the two types of devices. The goal behind base isolation is to remove (isolate) the building from the ground in such a way that earthquake vibrations are not, or at least considerably reduced, transferred up through the building. Seismic dampers are unique devices used in buildings to absorb the energy transmitted to them by ground motion.

Damping effect on structural response:

Increased damping lowers structural response (acceleration and displacement) The damping effect has little influence on spectrum amount at low frequencies (near to zero), while it has a small effect on response acceleration at high frequencies.

Base Isolation:

A base isolation system is a type of seismic protection that separates the structure (superstructure) from the foundation (foundation or substructure). The amount of energy delivered to the superstructure during an earthquake is greatly reduced when the structure is separated from its base.

These foundation isolation systems frequently feature one or more types of bearings to support the structure's weight. Elastomeric pads, sliding plates, and inverted pendulums are examples of these components. All of these components can provide some level of energy dissipation, although hysteretic damping is usually the sole option. Hysteretic damping has some limitations in terms of energy absorption and, in some instances, can stimulate higher modes.

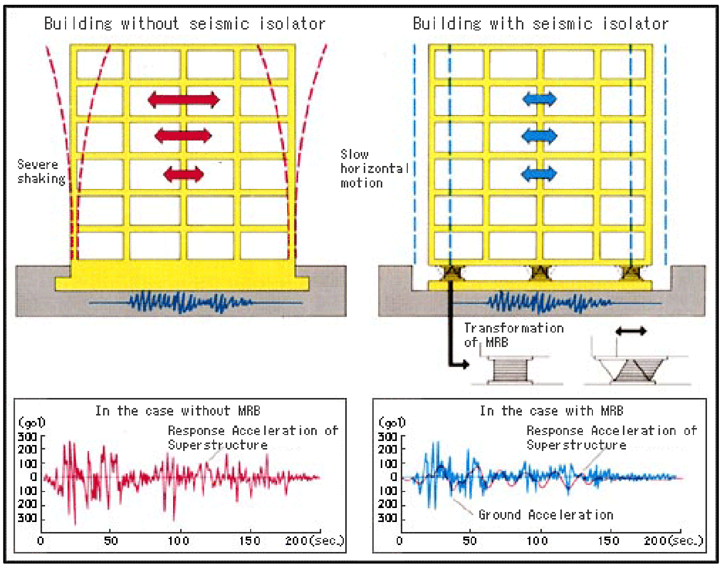


***Fig** 12. Seismic isolator base displacement at base level*

Source- https://www.bridgestone.com/products/diversified/antiseismic_rubber/method.html

2.12. Advantages Of Base Isolation:

Its purpose is to enable a structure to withstand a potentially annihilating seismic event by means of a proper initial plan or subsequent revisions. The usage of base separation can sometimes dramatically improve both a structure's seismic execution and seismic supportability. The following are the key benefits of using this base isolation mechanism:

- Apart from seismic activity, base isolation also protects structures against GSA blast loads, as the flexibility to move minimizes the explosion's overall impact on the structures.
- Because base isolated structures are predictable, they have a high level of reliability when compared to traditional structural components.
- By minimizing the seismic forces conveyed to the building, the need for strengthening measures such as frames, bracing, and shear walls is reduced.
- When compared to traditional constructions, seismic analysis is simplified by allowing structural elements to be reduced.
- In the event of large-scale, unanticipated seismic activity, damage is limited to the isolation system, where pieces can be easily replaced.
- Existing structures that are appropriate for base isolation can also be upgraded. Furthermore, the structure can be used during the construction process.

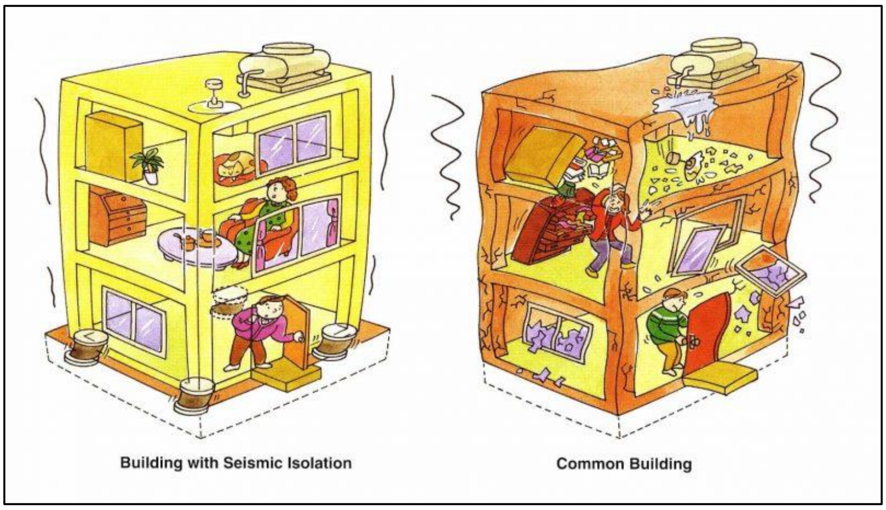


Fig 13 *Isolation reduced the damages caused during an earthquake*

Source- *https://civildigital.com/base-isolation-system-outline-on-principles-types-advantages-applications/*

2.13. Disadvantages Of Base Isolation :

- It is not possible to isolate the base of every structure; for example, structures resting on soft soils are not suitable for base isolation.
- For high-rise buildings, it becomes less efficient.
- Base isolation, unlike other retrofitting methods, cannot be applied to only a portion of the structure.
- It is difficult to implement in an efficient manner, and it frequently necessitates the use of highly experienced laborers and engineers.

2.14. Type of Base Isolation Systems

Basic requirements of an isolation system are

1. Flexibility
2. Damping
3. Resistance to Vertical or other service loads.

Elastomeric Rubber Bearings:

Horizontal layers of synthetic or natural rubber in thin layers bound between steel plates make up bearings. These bearings can withstand high vertical loads while exhibiting minimal distortion. Under lateral loads, these bearings are flexible. The rubber layers are kept from bulging by steel plates. Plain elastomeric bearings do not produce much damping, so lead cores are supplied to boost damping capacity. They are typically soft in the horizontal and rigid in the vertical directions.

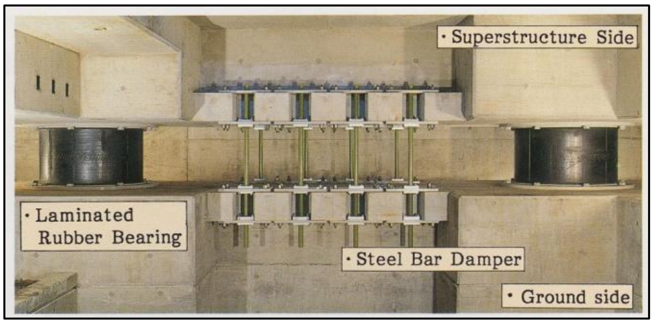


Fig. 14 *Elastomeric Rubber Bearing*

Source- https://civildigital.com/base-isolation-system-outline-on-principles-types-advantages-applications/

Roller and Ball Bearings:

Roller and ball bearings are employed for isolation purposes in machinery isolation. It has cylindrical rollers and balls in it. Depending on the material employed, it is sufficient to resist service motions and dampening.

Fig 15 *Roller and Ball Bearings*

Source- *https://civildigital.com/base-isolation-system-outline-on-principles-types-advantages-applications/*

Springs:

Steel springs are likely to be found in mechanical applications such as roller bearings. Because it is flexible in both vertical and horizontal directions, it is not used in structural applications. This will result in a higher number of service deflections.

Fig. 16 *Spring Isolators*

Source- *https://civildigital.com/base-isolation-system-outline-on-principles-types-advantages-applications/*

Sliding Bearing:

Sliding systems with a specified coefficient of friction can provide isolation by restricting the transfer of acceleration and forces. Sliders are capable of delivering resistance, flexibility, and force displacements by sliding action under service conditions. Because of their restorative effect, shaped or spherical sliders are frequently selected over flat sliding devices. Aftershocks can cause displacement with flat sliders since there is no restoring .

Fig*. *17 *Sliding Isolator*

Source-https://civildigital.com/base-isolation-system-outline-on-principles-types-advantages-applications/

2.15. Type of Base Isolation Devices

For seismic base isolation, there are six basic types of base isolation devices that are extensively used.

1) Elastomeric Bearings
2) High Damping Bearings
3) Lead Rubber Bearings
4) Flat Slider Bearings
5) Curved Slider Bearings or Pendulum Bearings
6) Ball & Roller Bearings

The two main components of a base isolation system are flexibility and damping. The isolation's flexibility has the most impact on response modification. To improve isolation, viscous or hysteretic dampers are frequently used. The stiffness of the structure has no bearing on the damper's ability to reduce response.

Types of Base Isolation System Dampers:

1. Steel Dampers
2. Oil Dampers
3. Lead Dampers
4. Friction Dampers with disc springs

Applications of Base isolation:

- Base isolation of bridges
- Base isolation of important buildings
- Enhancing response of historic structures
- Isolation in Machinery Field

2.16. Classification of Bearing:

Classification of bearing depends on two criteria:

- Degree of freedom.
- Manufacturing material used for the bearing.

On basis of Degree of Freedom:

Sl. No.	Type	Translation	Rotation
I.	Fixed	Not allowed	Allowed
II.	Free	Allowed	Allowed
III.	Rocker and Roller	Roller end free	Rocker end fixed

***Table** 1: Classification of bearing on basis of Degree of Freedom*

On basis of material employed in manufacturing

1. Steel
2. Rubber (e.g. elastomer)
3. Poly Tetra Fluor Ethylene (PTFE)
4. Combination of any of the above.

2.17. Shear Walls:

A shear wall is a vertical feature that resists lateral pressures operating on a building structure, such as wind and earthquake forces. It functions as a vertical cantilever beam that is supported at ground level and carries vertical loads with the help of columns. They're usually found in high-rise structures.

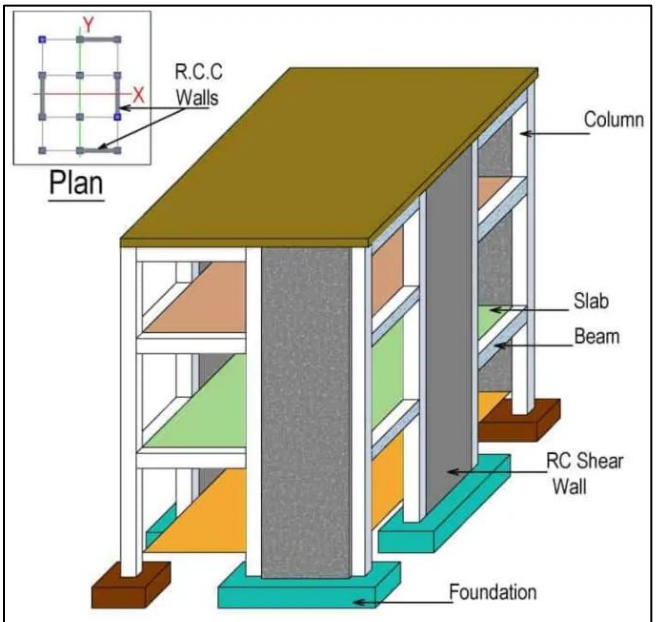


***Fig. 18** Reinforced Concrete Shear Wall*

***Source:** https://dailycivil.com*

Shear walls have been a common feature of high-rise structures over the last twenty years. These walls are included in building designs as component of an earthquake building system to help prevent lateral displacements during an earthquake.

2.18. Purpose of Shear Walls:

1. This wall withstand lateral stresses produced on the building by wind, earthquakes.
2. They are cost-effective when it comes to building.
3. Minimize structural damage to structural and non-structural elements like glass windows and building materials.
4. In strong seismic zones, structures with shear walls have performed well during earthquakes.
5. To withstand gravity or vertical stresses as a result of its own weight and the weight of other living or moving objects.
6. To withstand shear and uplift forces on the structure.
7. To improve a building's balance and durability.
8. To give the structure appropriate rigidity.

2.19. Functions of Shear Walls:

Main function of Shear Wall:

- Provide **Stiffness** to a building: Shear Walls give significant rigidity to buildings in the axis of their direction, reducing lateral movement and hence reducing structural damage.
- Provide **Strength** to a building: The building's shear wall must offer lateral shear strength to resist horizontal seismic and wind forces and transfer these pressures to the base.

2.20. Classification of Shear Walls:

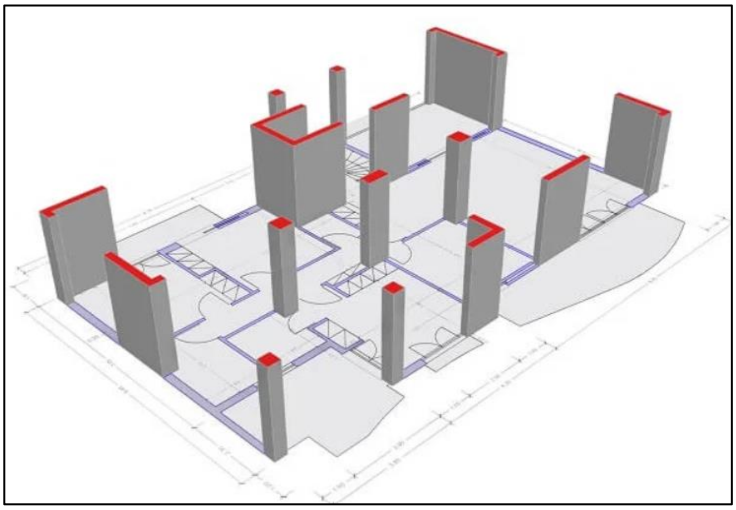


Fig. 19 *Column supported shear walls*

Source: ***https://wrengineers.in***

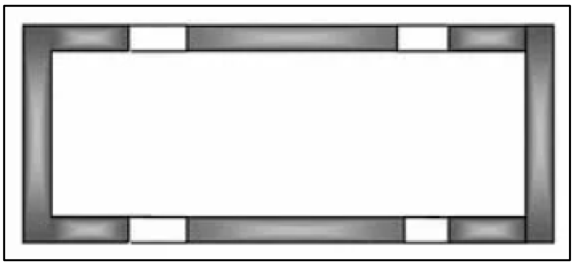


Fig. 20 *Core type shear walls*

Source: ***https://wrengineers.in***

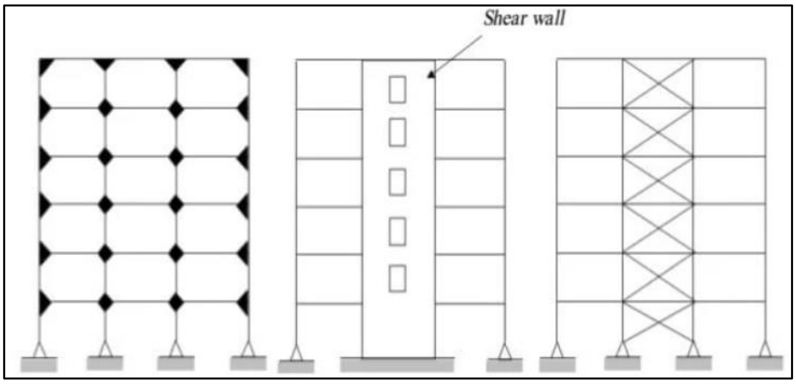


Fig. 21 *Rigid frame shear walls.*

Source: ***https://wrengineers.in***

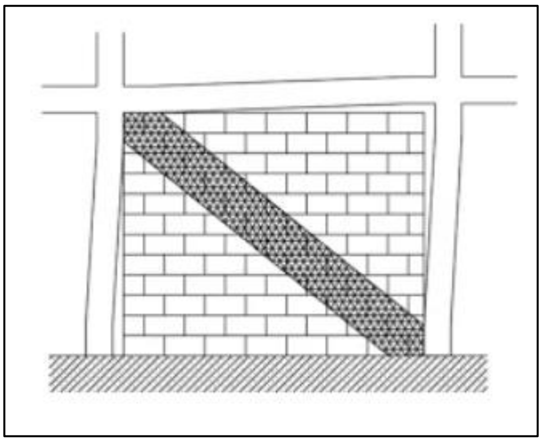


Fig. 22 *Framed walls with infilled frames.*

Source: ***https://wrengineers.in***

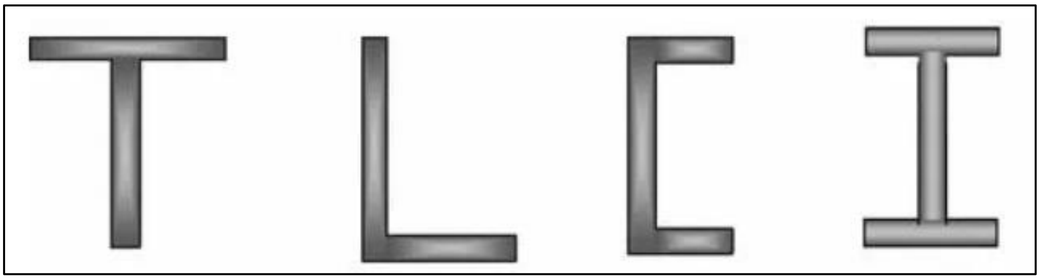


Fig. 23 *Simple rectangular types and flanged walls.*

Source: ***https://wrengineers.in***

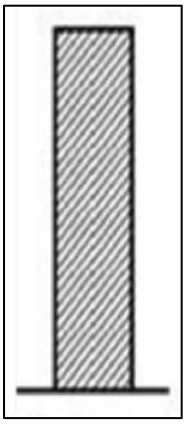


Fig. 24 *Cantilever Shear Wall*

Source: ***https://wrengineers.in***

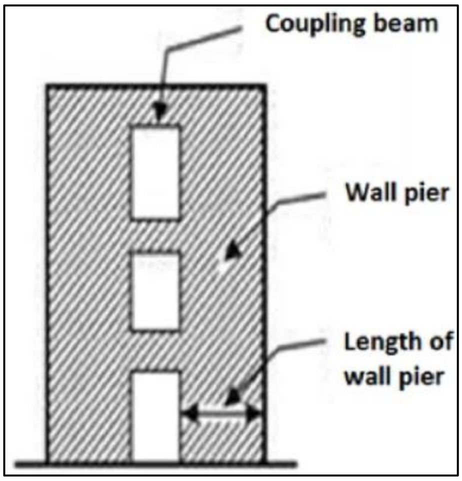


Fig. 25 *Coupled shear walls.*

Source: ***https://wrengineers.in***

2.21. Types of Shear Walls:

1. **RC Shear Wall:** Reinforced concrete walls and slabs make up an RC wall. The thickness of their walls varies from 140 mm to 500 mm, depending on the age of the building and the need for thermal insulation. These walls are usually the same height as the entire structure; however, some are lowered to the road front or bottom level to allow for commercial or parking spaces. Wall reinforcement generally consists of two layers of reinforcements spaced evenly throughout the wall's length. Near the door and window apertures on the wall end zones, vertical reinforcing bars are also available.

Fig. 26 *RC Shear Wall*

Source: [**https://wrengineers.in**](https://wrengineers.in)

2. **Plywood Shear Wall:** Plywood is the most common material used to construct shear walls. These walls have been strengthened by the invention of prefabricated shear panels that fall on both sides of the aperture. In terms of seismic resilience, using sheet steel plus steel-backed sheer panels at the positions has shown to be effective.

Fig. 27 *Plywood Shear Wall*

Source: [**https://wrengineers.in**](https://wrengineers.in)

3. **MIDPLY Shear Wall:** MIDPLY shear walls are enhanced wood shear walls that were created to redesign sheathing and frame member junctions. In normal wall testing, the types of failure identified cause lateral load values to generate fractures in normal walls. A ply of shielding materials is placed inside the center of the walls between a successions of pairs of studs orientated in a 90° reversed position relative to typical shear walls in the Midply shear walls design.

Fig. 28 *MIDPLY Shear Wall*

Source: https://dailycivil.com

4. **RC Hollow Concrete Block Masonry Walls:** Reinforcing hollow concrete block masonry in hollow places is used to build these walls. It necessitates the installation of stable metal rods in vertical and horizontal directions at structurally dynamic areas of wall panels, as well as fresh grout concrete in hollow masonry block locations. To safely resist earthquakes, their elements are built as load-bearing walls for gravity and seismic loads.

Fig. 29 *RC Hollow Concrete Block Shear Wall*

Source: ***https://wrengineers.in***

5. **Steel Plate Shear Walls:** Steel plate shear walls are typically made up of steel plate walls, a boundary column, and a horizontal backside beam, with the steel plate walls and boundary column serving as a vertical plate girder. The steel plate wall acts as the web of the vertical plate girder, while the columns serve as its flanges. In a plate girder, horizontal backside beams function similarly to transverse strainers.

Fig. 30 *Steel Plate Shear Wall*

Source: ***https://wrengineers.in***

2.21.1. Couples Shear Walls:

A coupled shear wall is made up of two shear walls that are joined by beams along their entire height. In the linked shear wall, coupling beams are the most important factor. To absorb energy and provide damping during an earthquake, these coupling beams should be built for ductile inelastic behavior. As a result, in contrast to SMRF and shear wall frame combination systems in buildings, linked shear wall is one of the viable solutions. Shear wall frame combinations and SMRF systems regulate shear and flexural behavior, whereas flexural behavior governs the behavior of connected shear walls. Furthermore, shear capacity governs the behavior of coupling beams linked shear walls, whereas flexural capacity governs the behavior of conventional beams both SMRF and shear walls frame combination systems.

2.21.2. Elastoplastic response of coupled shear wall:

Coupled shear walls subjected to seismic stress acquire ultimate strength through an acceptable mechanism with appropriate rotational capacity held by each of the needed plastic hinges. Two plastic hinges are required on each connecting beam to prevent additional shear. In addition, to complete the collapse mechanism, each of the cantilever walls should have one plastic hinge produced at its base. The relative strength and stiffness of any component determines the sequence in which hinges develop. The behaviour of some coupled shear walls subjected to seismic motion revealed that all or most coupling beams failed before the coupled shear wall reached its maximal strength.

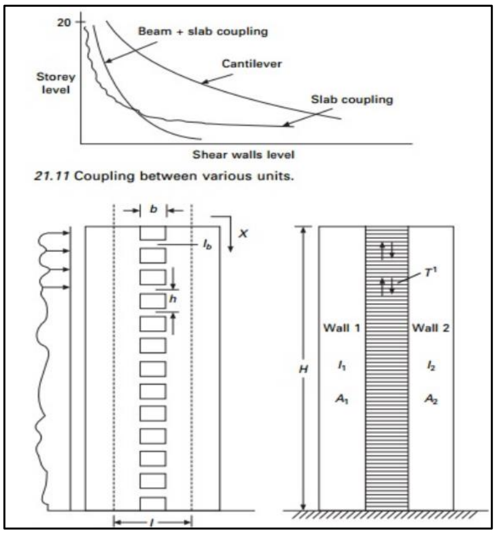


Fig. 31 *Coupled Shear Wall*

Source: ***https://brainkart.com***

2.22. Advantages of Shear Walls:

1. In the direction of orientation, shear walls give a lot of strength and stiffness.
2. It significantly lowers lateral sway.
3. They are simple to create and implement.
4. It is cost-effective in terms of construction and seismic damage reduction.
5. In addition, it gives strength and stiffness in the alignment direction.
6. The harm to structural and non-structural elements is minimized by these barriers.
7. They have enough reinforcements that are evenly dispersed.
8. It also takes less time to build.
9. These are the thinnest walls I've ever seen.
10. They're also quite light.

2.23. Disadvantages of Shear Walls:

1. Constructing shear walls is a demanding task.
2. They have a fragile look to them.
3. Also connected with the buckling of web plates are loud pounding sounds.
4. It is rigid and has a limited capability for energy dissipation.
5. Large moment connections are also required.

2.24. E-Tabs:

ETABS is a multi-story building analysis and design software tool developed by ETABS. The grid-like geometry specific to this form of construction is reflected in the modelling tools and templates, code-based load prescriptions, analysis methodologies, and solution strategies. ETABS can be used to evaluate basic or advanced systems under static or dynamic settings. Modal and direct-integration time-history analyses may be combined with P-Delta and Large Displacement effects for a more thorough assessment of seismic performance. Under monotonic or hysteretic behaviour, nonlinear connections and concentrated PMM or fibre hinges may capture material nonlinearity. Applications of any complexity can be implemented thanks to intuitive and integrated features. ETABS is a coordinated and productive tool for designs ranging from simple 2D frames to intricate modern high-rises thanks to its interoperability with a number of design and documentation systems.

Modeling of Structural Systems:

The assumption that multi-story structures often consist of identical or similar floor plans that repeat vertically is central to ETABS modelling. The following are some of the modelling characteristics that simplify the construction of analytical models and simulate advanced seismic systems:

- Templates for global-system and local-element modeling
- Customized section geometry and constitutive behavior
- Grouping of frame and shell objects
- Link assignment for modeling isolators, dampers, and other advanced seismic systems
- Nonlinear hinge specification
- Automatic meshing with manual options
- Editing and assignment features for plan, elevation, and 3D views.

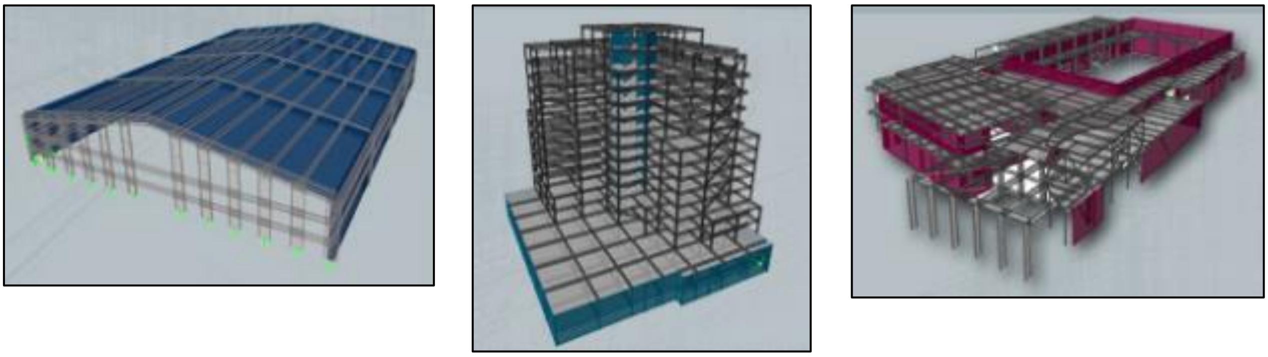


Fig 32

Loading, Analysis, and Design:

ETABS creates and assigns code-based loading conditions for gravity, seismic, wind, and thermal forces after the modelling is complete. The number of load situations and combinations that can be specified by the user is infinite.

Advanced nonlinear approaches for characterization of static-pushover and dynamic response are then available through analysis capabilities. Modal, response-spectrum, or time-history analysis are examples of dynamic considerations. Geometric nonlinearity is accounted for via the P-delta effect.

Create features will automatically scale elements and systems, design reinforcing schemes, and otherwise optimise the structure according to desired performance measurements given an encompassing specification.

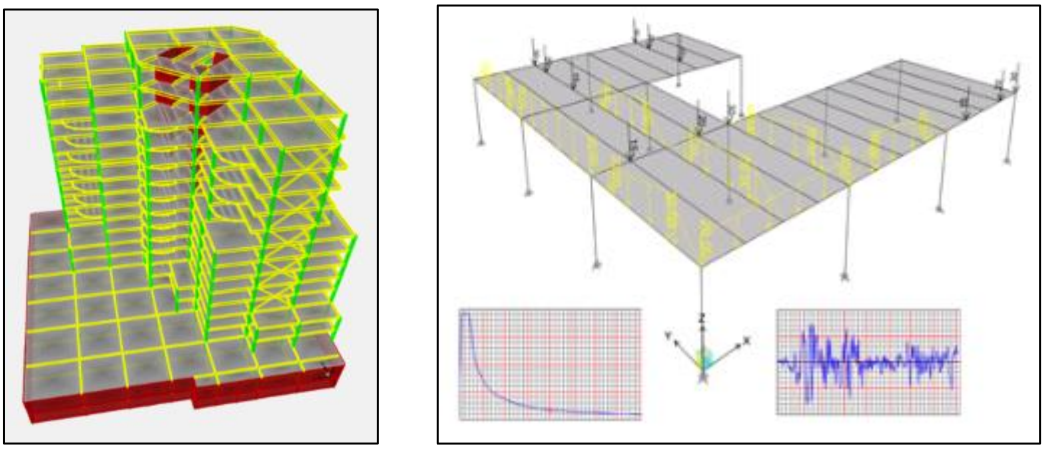


Fig 33

Output, Interoperability, and Versatility

The output and display formats are also simple and easy to use. Moment, shear, and axial force diagrams can be arranged into customizable reports in 2D and 3D views with accompanying data sets. Detail section cuts demonstrating various local reaction methods are also available. Global viewpoints displaying static displacement configurations or time-history response video animations are also available.

Interoperability with related software products is also a feature of ETABS, allowing for the import of architectural models from a variety of technical drawing tools, as well as export to a variety of platforms and file formats. One such option for export is SAFE, a floor and foundation slab design programmer with post-tensioning (PT) capability. Engineers may more extensively define, evaluate, and develop the distinct layers of an ETABS model using SAFE, which was coordinated by CSI to be used in conjunction with ETABS.

While ETABS has a number of advanced features, it may also be used to develop simple systems. From modest 2D frames to the most complicated high buildings, ETABS is the practical solution for all grid-like applications.

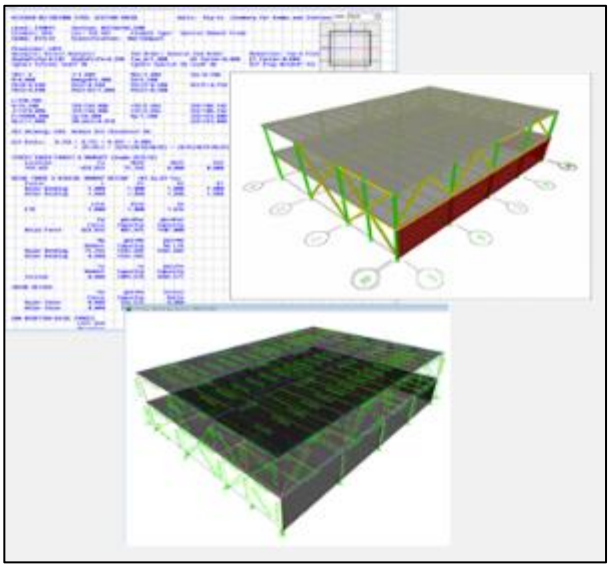


Fig 34

2.25. Research-Paper Work:

We discovered that the history of plate pattern on Earth during the last 200 million years may be separated into two groups: small and large plates. During the past 60 Myr, the smaller plates, which are largely created by randomness events, have shown a remarkable persistent statistical pattern (Seton et al., 2012). The size of the smaller plates is distributed according to a power law with an exponent of 0.25, which might imply an underlying fragmentation model or other complicated systems (Sornette and Pisarenko, 2003).

The interplay between top-down and bottom-up convection mechanisms, whose roles are measured by Marangoni and Rayleigh numbers, respectively, is thought to be the cause of this development. The alternation of tessellations is caused by the Earth's particular radial viscosity layering (strong lithosphere, weak upper mantle, stiffer lower mantle), according to our quantitative research.

A modal study of the framed structure is critical in order to examine the framed structure's behaviour under applied dynamic loads. To determine the efficacy of base isolation using rubber bearings, it is important to compare the reaction analysis approach (Experimental or Analytical) of a base isolated framed structure with a fixed base or otherwise identical framed structure. Structures that can withstand an earthquake while retaining and sustaining their operation are referred to as "earthquake resistant structures." Selecting adequate ground for the location, making them light, solid, and ductile, modifying the natural duration of the structures from the predominant period of seismic motion, and increasing the damping potential are the main elements of their architecture.

Because the brittle nature of masonry buildings is the leading cause of building collapse and loss of life, possible solutions in the construction of such structures are required. The horizontal bands are useful for keeping the walls together at junctions and preventing vertical and in-plane shear fractures from growing. However, they would not be enough to protect against out-of-plane flexure, specifically for horizontal flexure fractures. In this context, the Indian Institute of Science's Department of Civil Engineering established the idea of 'containment reinforcement' (Raghunath S et al 2000) to prevent flexural tension fractures from spreading. This has also aided in the transmission of ductility and the absorption of a large amount of energy during earthquakes.

Following the 2001 Bhuj (Gujarat) earthquake, which killed between 14000 and 20000 people, damaged over 1.2 million homes, and impacted nearly 8000 villages in Gujarat, west India, the massive earthquake killed between 14000 and 20000 people, damaged over 1.2 million houses, and impacted almost 8000 villages. A 281-bed district hospital, a 16-bed mental hospital in Bhuj, and 239 health centres were among the more than 3000 health facilities destroyed. The foundation isolation method was used to construct the four-story Bhuj Hospital building. The base isolation approach has been utilised in a number of dynamic engineering textbooks, and the number of researchers using it throughout the world is increasing.

The following conclusions may be formed based on studies of the damage inflicted to a range of masonry structures during the Bhuj earthquake:

Due to a lack of binding strength, mud mortar or lime mortar masonry constructions are prone to serious damage. The use of rounded stones in wythes that do not have through-stones can exacerbate the situation. Out-of-plane flexure is the primary cause of such structures failing.

Masonry using cement mortar (which has a higher tensile strength) has performed better in general, however this does not imply that strong masonry bonding is sufficient for seismic isolation.

The use of a lintel band, as recommended by the Bureau of Indian Standards (IS 13828:1993), appears to create a hard box-like behaviour in the top areas of the structure, whereas the area below the lintel band is severely broken. This band's horizontal reinforcement does not appear to increase ductility to the desired degree. This appears to indicate the need for more horizontal bands, probably at the sill and plinth levels.

Since the beginning of earthquake engineering, not just in India but also in industrialized nations, the construction of earthquake-resistant reinforced concrete buildings has been a topic of studies. Despite this, reinforced concrete structures are destroyed for a variety of causes. A recent example is the Bhuj earthquake in India on January 26, 2001, which severely destroyed reinforced concrete structures.

Damage was incurred by structures of a G+4 to G+10 story height. A Structural Response Recorder at Anjar reported a maximum acceleration of 0.547g in the epicentral zone (SRR). The acceleration measured on the bottom floor of the Regional Passport Office staff quarters building (G+9) at a height of 30 meters in Ahmedabad was 0.106g, which was amplified to almost three times on the roof. The observed and computed time histories on the building's 3rd and 9th levels are nearly identical. This validates the building's numerical simulations. The vibration in fundamental mode is prevalent in torsion, according to the dynamic analysis of a building on floating columns.

After a field survey, the following causes of failure were identified: (1) soft storey failure: lateral irregularity in stiffness/strength, (ii) floating column failure: complex load passageway to transmit of forces, (iii) mass improprieties: eccentric loading and P-A effect, (iv) poor and old construction: corrosion of reinforcement, (v) pounding: hammering of adjacent buildings, (vii) construction process involving Engineers, architects, planners, and builders might reduce the number of failures by increasing their technical expertise of earthquake-resistant design techniques.

The story overturning moment changes inversely with story height, according to the multi-story building's research. Furthermore, L-shape and I-shape structures have nearly identical responses to the overturning moment. Story drift displacement grew with floor height until the sixth storey, when it reached its maximum value, and then began to decline. Mode forms are constructed using dynamic analysis, and it may be deduced that asymmetrical designs deform more than symmetrical layouts. Irregular layouts should be used to account for gaps.

When considering the regular and irregular configurations, the regular structure has a higher base shear value. The structure has more uniform proportions as a result.

When the story drift value is compared between the regular and irregular configurations, the regular configuration has a higher value. The structure has extra dimensions as a result.

Active systems have shown to be more effective in controlling vibration than passive systems, however the expense and complexity of using active systems instead of passive systems can only be justified in situations when performance is crucial. Many of the performance improvements of active systems may be achieved using semi active systems that use modulated dissipation components as power generators. Semi-active systems should have more simpler and less expensive hardware than active systems since they just require signal processing and low-level power supply. Semi-active systems are usually nonlinear, although simulations have demonstrated that linear control principles may frequently be used to design them. However, it appears that direct computer modelling will be necessary to determine how nearly a semi-active system can mimic the performance of an active system. This method also enables the study of nonlinear feedback control schemes as well as the impact of hardware response constraints.

The idea of reinforcing the superstructure to improve base isolation efficiency was considered by Jain and Thakkar for structures with 10 to 20 stories. The strengthening of the superstructure may result in a smaller fixed base span if the base is detached, and such buildings may have a reduced seismic response.

In this study, Jangid and Kulkarni compared the seismic response of a multi-story base-isolated building by imagining the superstructure as rigid and fluid. To evaluate the influence of superstructure stability, the top floor acceleration and bearing displacement of the system are displayed for various system parameters and compared to the comparable reaction under static superstructure conditions.

Izumi Masonry researched the surviving material after the Nobi Earthquake (M=8.0) in 1981, and Kawai proposed the first foundation independent construction in the Architecture and Building Science Journal. He has rollers fixed on numerous levels by manually lengthwise and across the base mat of logs. J.A., an English doctor, was murdered in the San Francisco Earthquake (M=7.8). In 1909, the Calantarients patented a building that included talc between the foundations. The Fudo Bank Buildings in Himeji and Simonoseki, Japan, are the world's first isolated base structures, designed and built by R. The US Garevski Aetal was deployed during WWII. The Pestalozzi Elementary School in Skopje, built in 1969, was the world's first building to use natural rubber isolators to guard against significant earthquakes. The Foothill Neighborhoods of Law and Justice Center, built in 1985, has four floors, a full basement, and a sub-basement for an insulation system made up of 98 multilayered natural rubber bearings packed with steel plates, making it the United States' first foundation-free structure. The superstructure of the house is made up of a structural steel framework with braced frames in some bays. After the 1993 Killari (Maharashtra) earthquake, the base isolation approach was first demonstrated in India [EERI, 1999]. In the newly relocated Killari area, two single-story structures (one school building and another retail complex building) with rubber base isolators resting on hard ground were built. They were two brick buildings with a concrete roof.

The buckling isolation bearings theory was developed as a consequence of Haringx's 1947 investigation of the technical characteristics of helical steel springs and rubber rods used for vibration mountings. The results of this research were published in a series of publications, the third of which (Haringx 1948) dealt with the durability of solid rubber rods. Gent later applied the *Haringx* principle (1964) to the situation.

Extreme, impulsive seismic activity has resulted in a number of disastrous structure failures in recent years. Some studies, such as Hall et al. 1995 and Heaton et al. 1995, have highlighted doubts regarding seismic isolation's viability in such scenarios. These researchers hypothesized that base-isolated structures are prone to significant impulsive ground vibrations produced at nearsource sites based on evidence from the January 17, 1994 Northridge earthquake. Furthermore, due to the increased difficulty and cost of base-isolated buildings, new updates to the ICBO 1997 Standardized Building Code have made the criteria for base-isolation schemes more stringent than in previous iterations of ICBO 1994; Kelly 1999, making Kelly 1999b less commercially justified.

As one technique of implementing seismic response control technologies to heavy, inflexible buildings such as nuclear reactor buildings, a novel concept of seismic response control building, "a seismic response control building with soft upper steel frame," is introduced. The higher steel frame's rigidity and weight have been turned, allowing it to regulate the motion of the structure below the crane level, including the containment tank itself.

According to our estimates, the seismic response of the standard BWR was lowered by more than 20% when this technology was used. Because the installation of this technology has little impact on the current system, it might be one of the most effective approaches for improving the structural integrity of existing nuclear power stations.

The purpose of Brennan Hall research was to come up with a lateral force resisting system that was less expensive to construct than Brennan Hall's current moment frames. Preliminary experiments of a steel braced frame system and a reinforced concrete shear wall system were conducted first. The braced frame system was more rigid than the shear wall system. Following this realisation, I chose to explore shear walls since they would deliver appropriate outcomes with fewer frame placements. While it may appear that lowering the number of frame locations is beneficial, it also means that bigger percentages of the lateral loads are distributed over each shear wall. Each wall experienced overturning issues as a result of the huge weights. I had to add more shear walls, raise the mass of each shear wall, and increase the mass of each shear wall footing to counteract these overturning forces.

The concept of "Smart Base Isolation" includes a technique for protecting structures against strong earthquakes or maximum considered earthquakes (MCE) without sacrificing their performance during more common or moderate occurrences.

Traditional lead rubber bearings (elastomeric bearings with low damping) and clever controlled semi active dampers are used in this method. Smart dampers include magnetorheological fluid dampers. When compared to typical LRB systems, smart base isolation results in a considerable reduction in base drift without an increase in superstructure motion.

In order to satisfy the functional needs of a structure, a shear wall may need to have an opening.

Because of the aperture, there is a break in the reinforcement, and the concrete area is reduced, reducing the wall's strength and stiffness. A shear wall's strength and stiffness may be diminished as a result of inappropriate stress concentration, which implies that stress is concentrated more around the opening's corner, resulting in early induced fractures during the loading stage.

The reinforcements around the aperture have a significant impact on the ductility and shear strength of a shear wall. For vertical and horizontal reinforcement, strength is reduced to 20% of yield strength, and for vertical and horizontal reinforcement, it is reduced to 40% of yield strength for diagonal reinforcements.

Due to the concentration of absorbed energy in a few distinct points, such buildings might occasionally draw greater calamity (more lateral forces). If this occurs, the ductility requirement of that element may not be met, resulting in shear failure.

Elastoplastic Response of Linked Shear Walls is the ultimate strength of coupled shear walls subjected to seismic loading is attained by an acceptable mechanism possessed by each of the needed plastic hinges with suitable rotational capacity. Two plastic hinges are required on each connecting beam to prevent additional shear. In addition, to complete the collapse mechanism, each of the cantilever walls should have one plastic hinge produced at its base. The relative strength and stiffness of any component determines the sequence in which hinges develop.

Indian codes used in this study –

- **IS 1893: (revised in 2016)**
  - Indian Standard Criteria for Earthquake-resistant Design of Structures (fourth revision)
  - Structures should be able to respond, without structural damage, to shocks of moderate intensities, and without total collapse to shocks of heavy intensities.

- **IS 456:2000**
  - Indian Standard Earthquake-resistant Design and Construction of Buildings: Code of Practice.
  - This code is intended to cover the specified features of design and construction for earthquake resistance of buildings of conventional types.
  - Recommendations regarding restrictions on openings, provision of steel in various horizontal bands, and vertical steel in corners and junctions.

- **IS 13920: 1993**
  - Indian Standard Ductile Detailing of Reinforced Concrete Structures subjected to Seismic forces: Code of Practice.

- **UBC 1997**
  - The deficiencies in the design and detailing of RCC structures.
  - For providing adequate toughness and ductility provisions on detailing of beams and columns were revised.
  - Specifications on seismic design and detailing of RCC shear walls were included

CHAPTER – 3

MODELLING AND SEISMIC ANALYSIS OF 5-STORY BUILDING

3.1. Problem Definition:

In this section, a Five-story RCC building is modeled in ETABS 2017

a) With its based fixed to the ground.
b) With its base isolated from the ground.
c) With Shear walls at corners of building

This building example is taken from Jabalpur, Madhya Pradesh. The earthquake had occurred on May 22, 1997. It is a dip-slip type of earthquake of magnitude 5.6 and max intensity of 8 and in seismic zone 4. The building properties are:

- Number of Story = 5
- Height of Building = 18 m
- Number of Bays in X-Direction = 4
- Number of Bays in Y-Direction = 3
- Size of Beam = 0.25 x 0.45 m
- Size of Column = 0.45 X 0.45 m
- Grade of Concrete = M-30
- Steel Reinforcement grade = Fe-415
- Slab thickness = 0.150 m
- Seismic Zone = 4
- Building Frame Type = SMRF
- Dead Load = 1KN/m²
- Live Load = 3KN/m²
- Importance Factor = 1.2

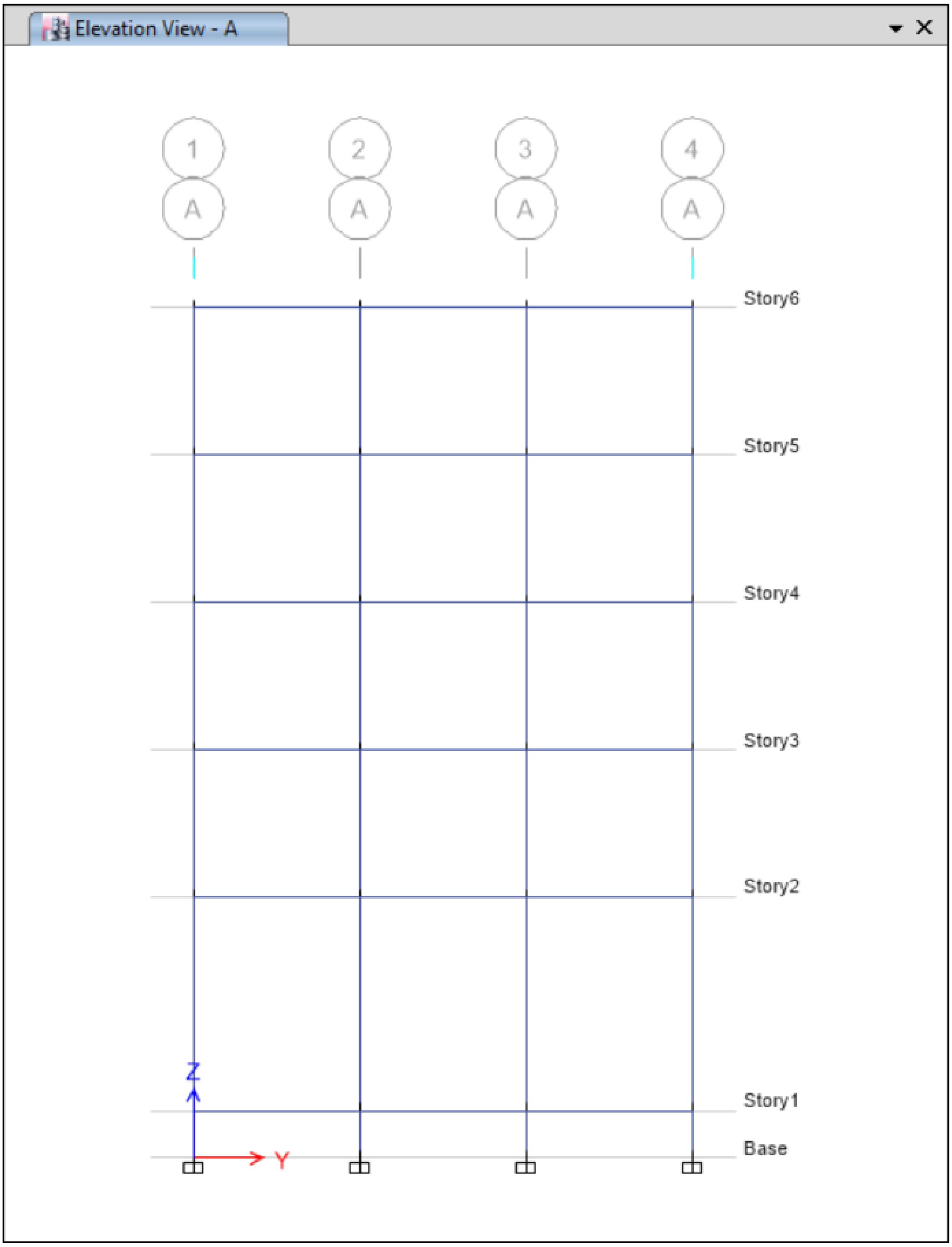


Fig. 35 *Elevation View of Structure*

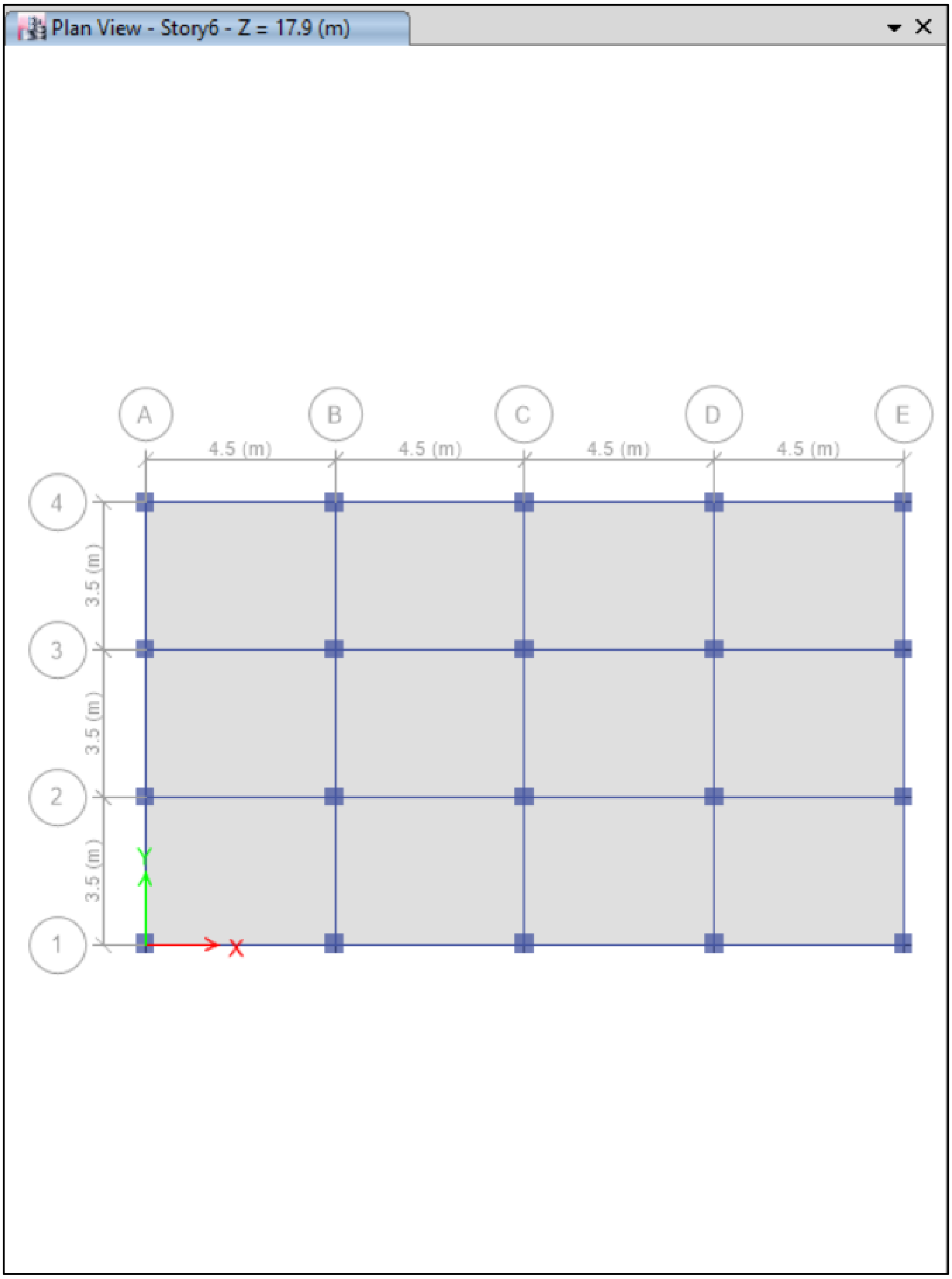


Fig.36 *Plan View – Story 6*

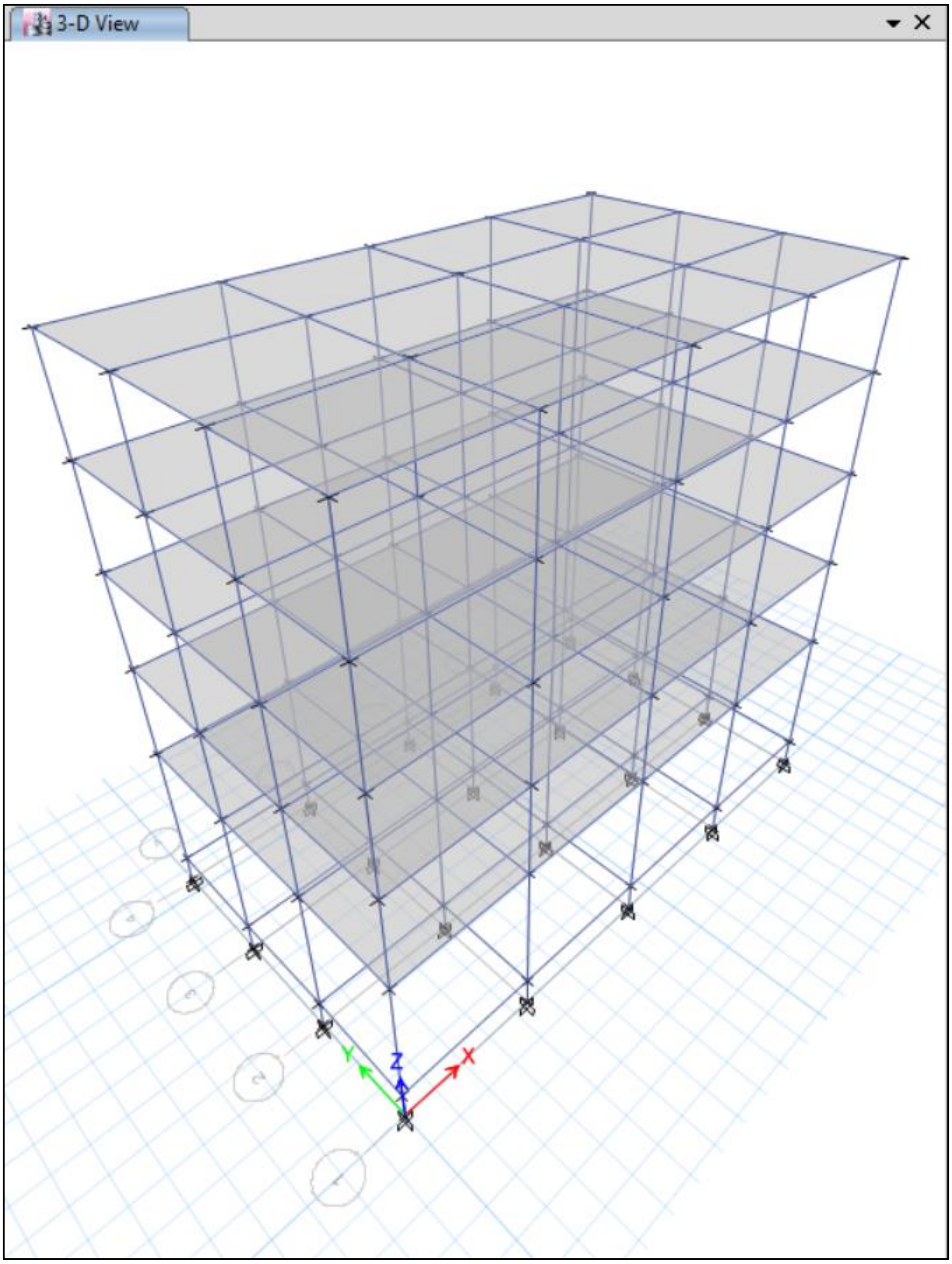


Fig.37 *3-D view of Structure*

- **Maximum Story Displacement:** It is the maximum lateral displacement of the story relative to the base.

- **Story Drift:** Story drift is the lateral displacement of a floor relative to the floor below. The story drift ratio is the story drift divided by the story height. It is a very relevant concept used in earthquake engineering for testing purposes.

- **Story Overturning:** By multiplying the story shear above the relevant height by the distance to the center of mass, the moments are found. These moment ratios are identical to the equivalent shear ratios for each structure, resulting in a nearly identical protection factor for shear and base overturning.

- **Story Shears:** It is the sum of the lateral forces of structure at all levels above the floor under consideration.

- **Story Stiffness:** It is the lateral force that causes unit lateral translational deformation in a story is measured as story stiffness.

- **Mode Shapes:** The shape of the mode is the deformation that the part exhibits when it vibrates at its normal frequency.
  The terms mode structure and normal vibration form are used in structural dynamics. A mode shape represents the deformation that the part will exhibit while vibrating at its natural frequency.

3.2. Response Spectrum Analysis Of Structure (Fixed Base)

Response-spectrum analysis is useful for design decision-making because it links structural type selection to dynamic performance. Structures with shorter periods undergo more acceleration, while those with longer periods experience more displacement.

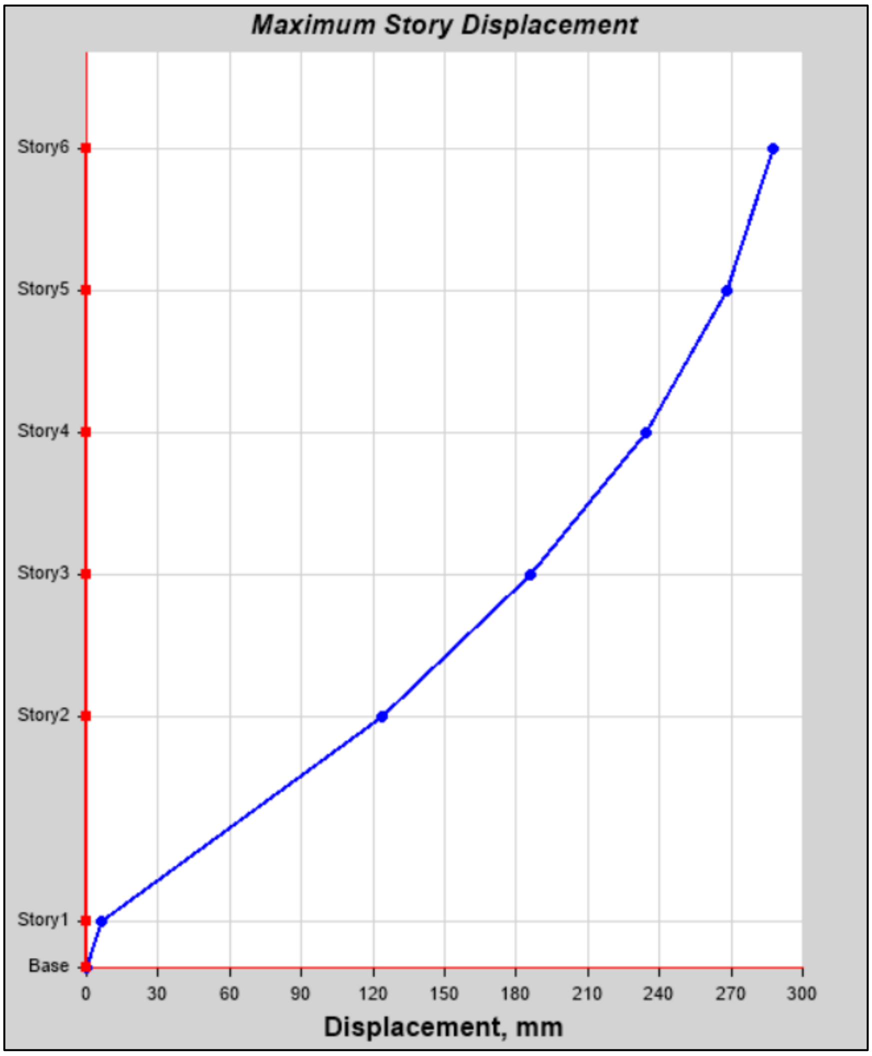


Fig. 38 *Maximum Story Displacement Fixed Based (287.31mm)*

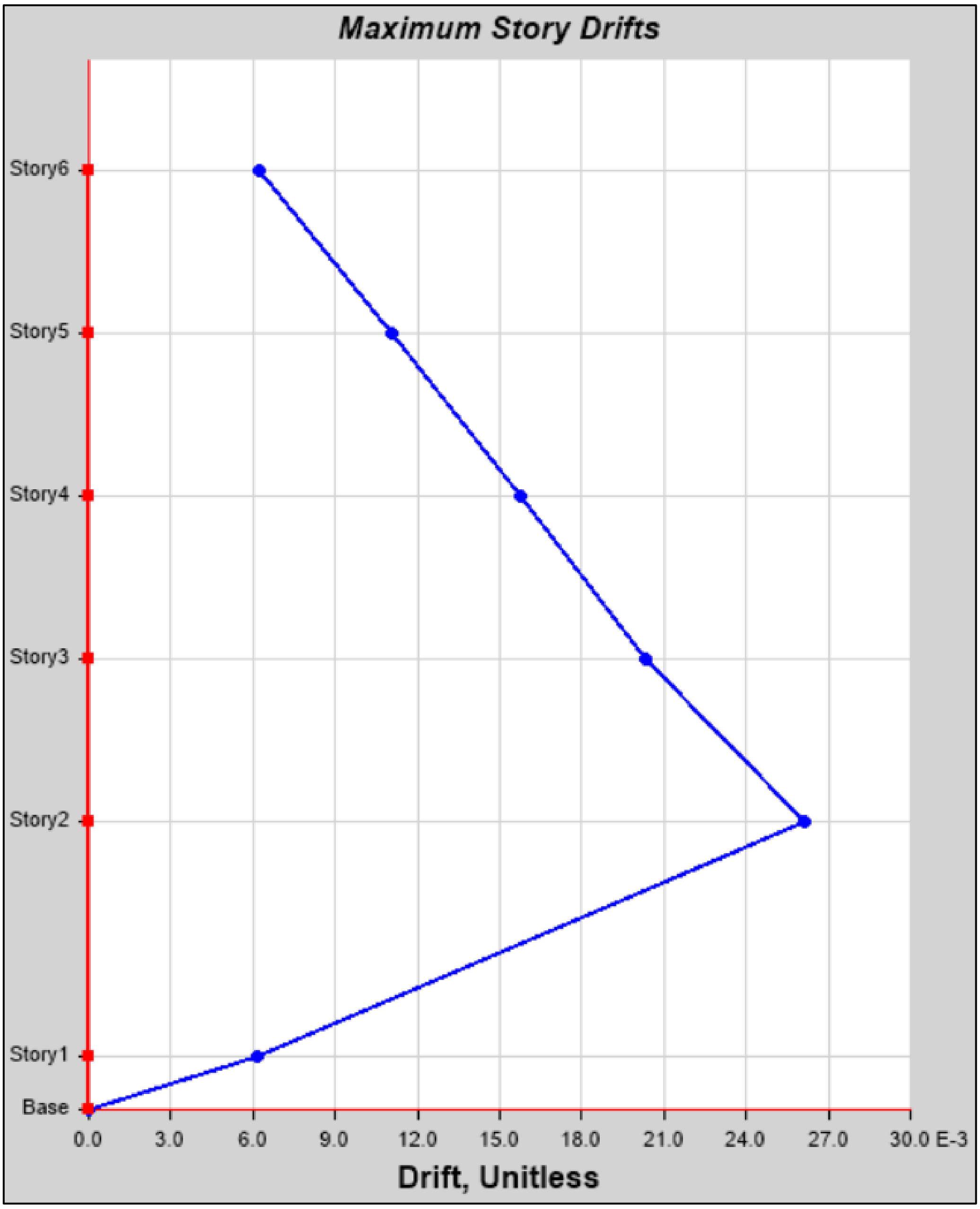


Fig.39 *Maximum Story Drift Fixed Base (0.026mm)*

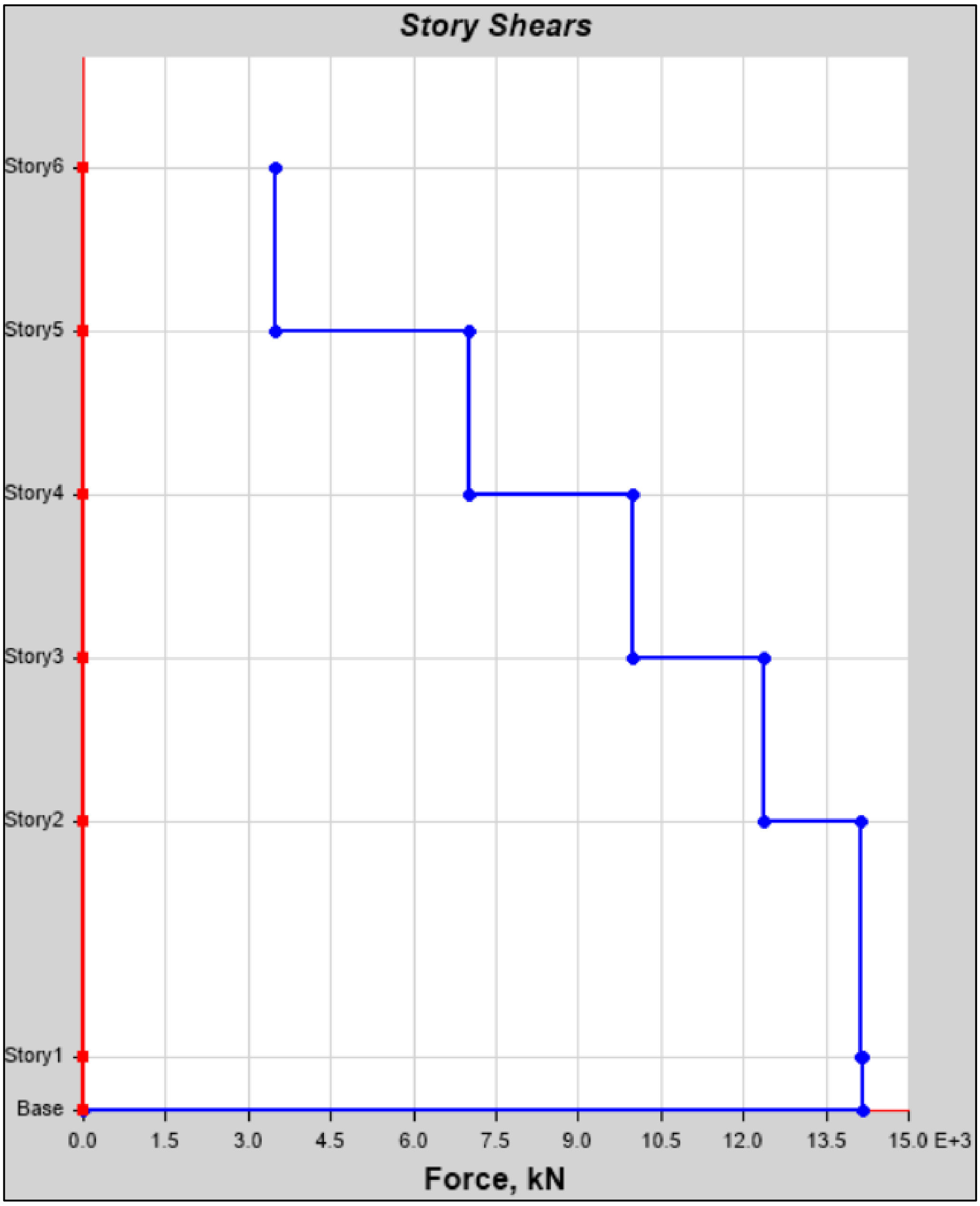


Fig. 40 *Maximum Story Shear Fixed Base (14159.59)*

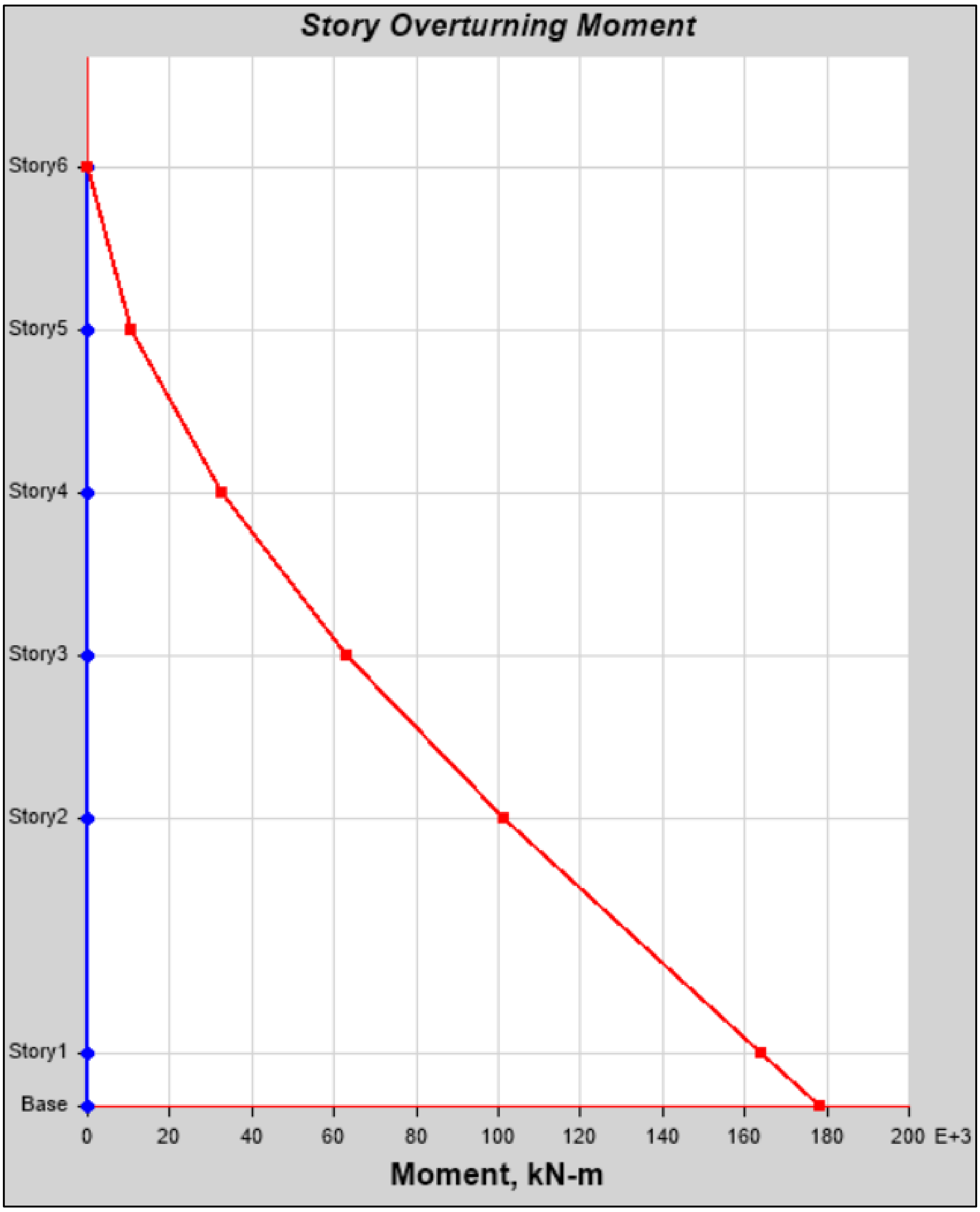


Fig. 41 *Maximum Story Overturning Moment Fixed Base (178355)*

3.2.1. MODE SHAPES (Fixed Base):

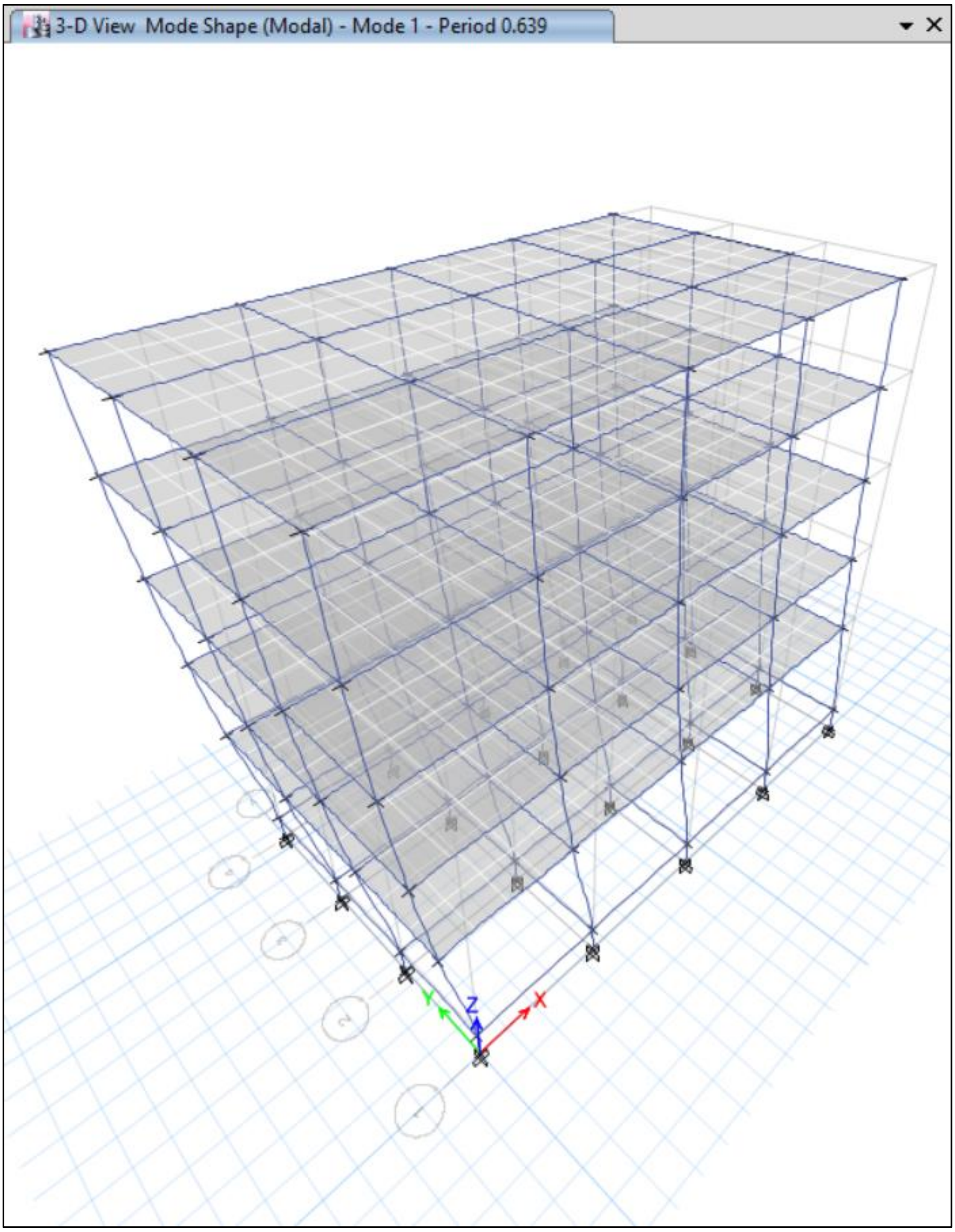


Fig. 42 Mode Shape 1 Fixed Base

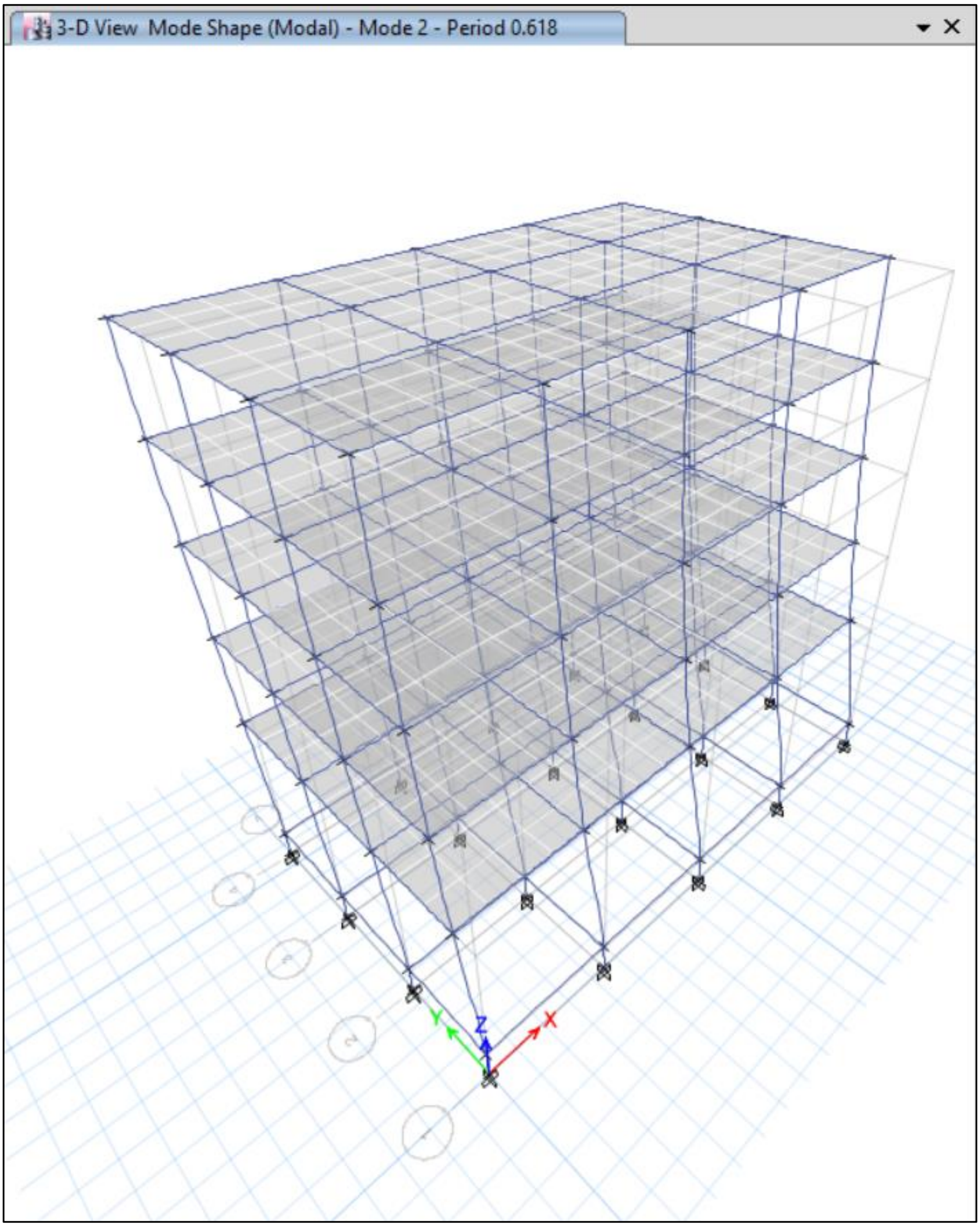


Fig. 43 *Mode Shape 2 Fixed Base*

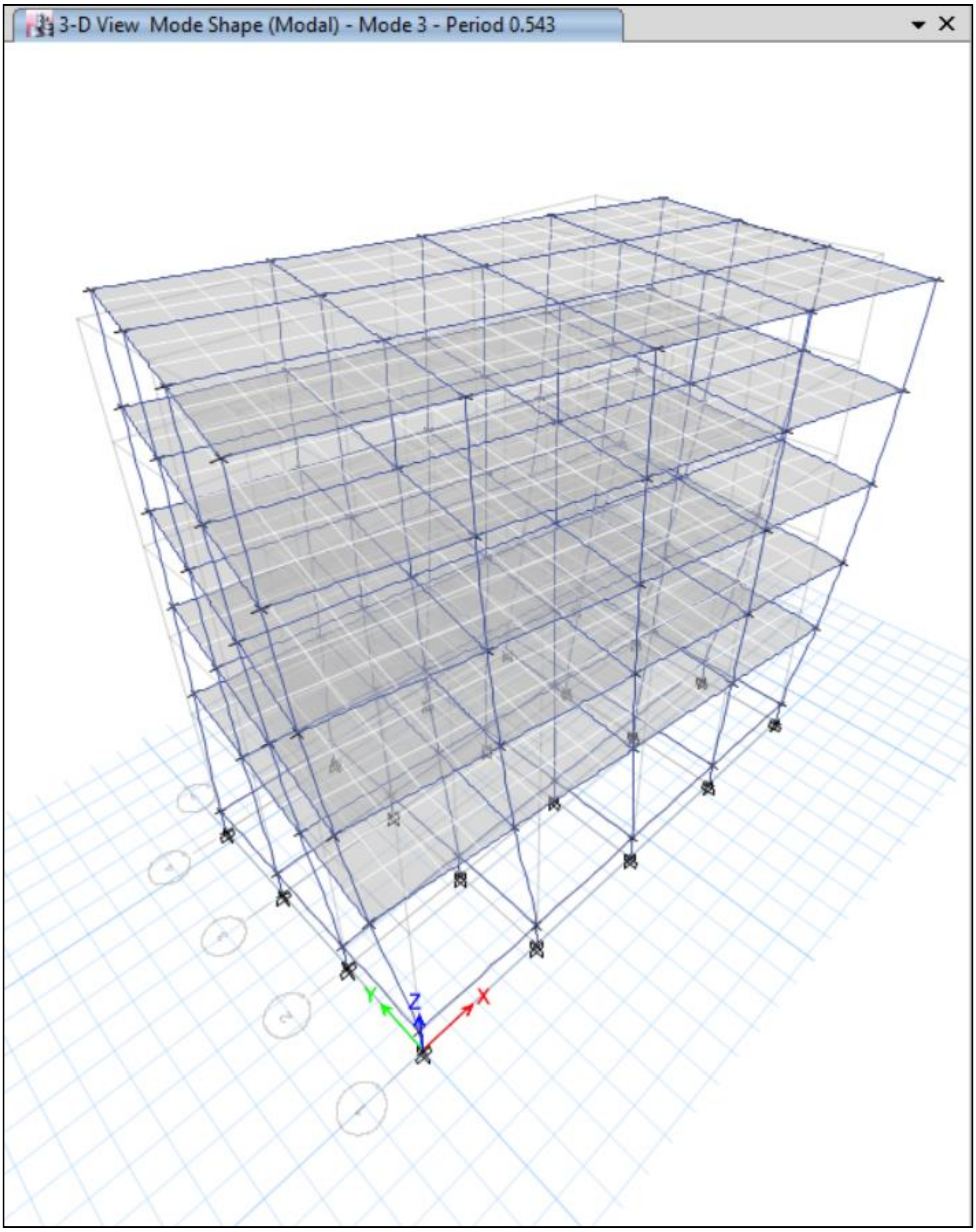


Fig. 44 *Mode Shape 3 Fixed Base*

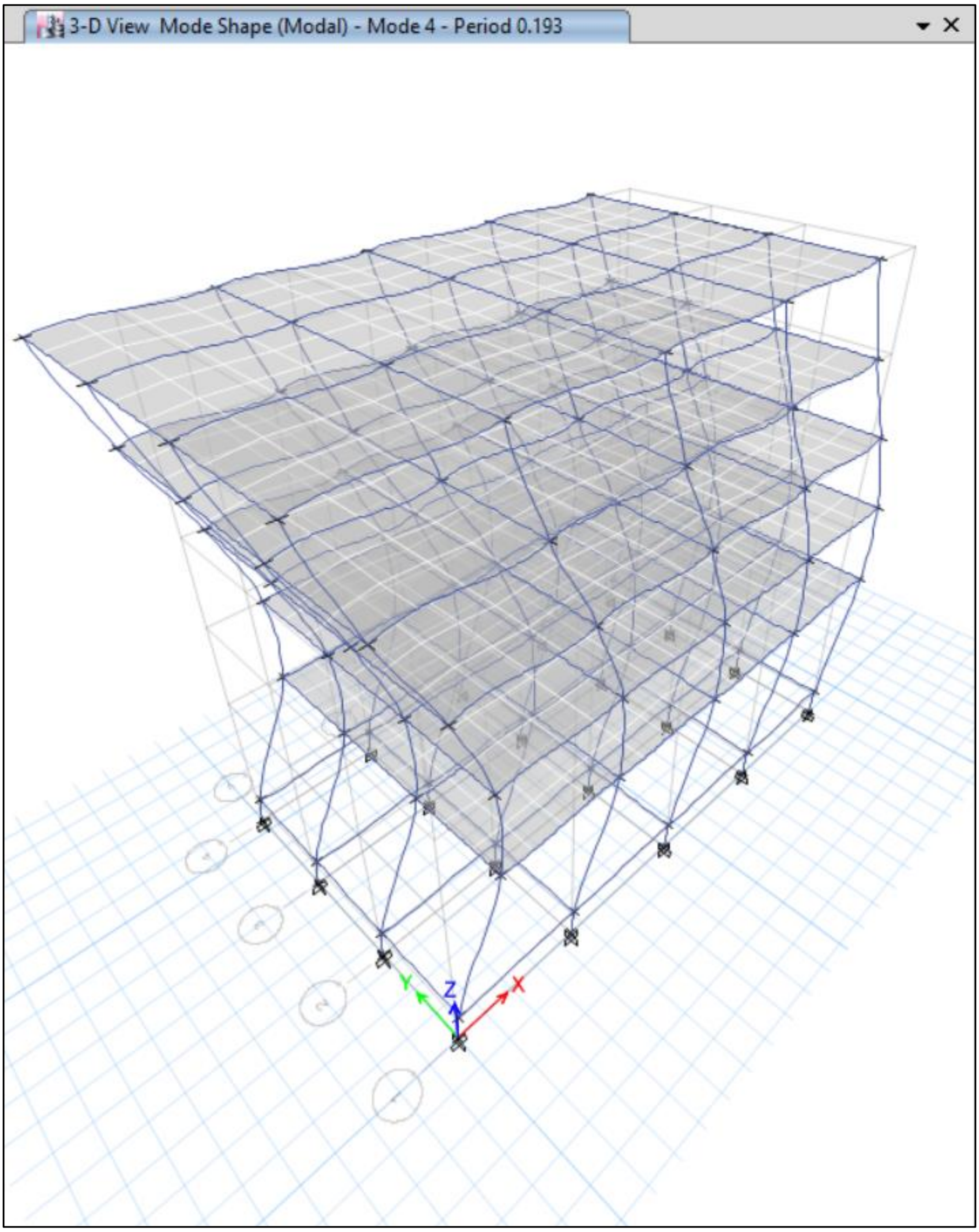
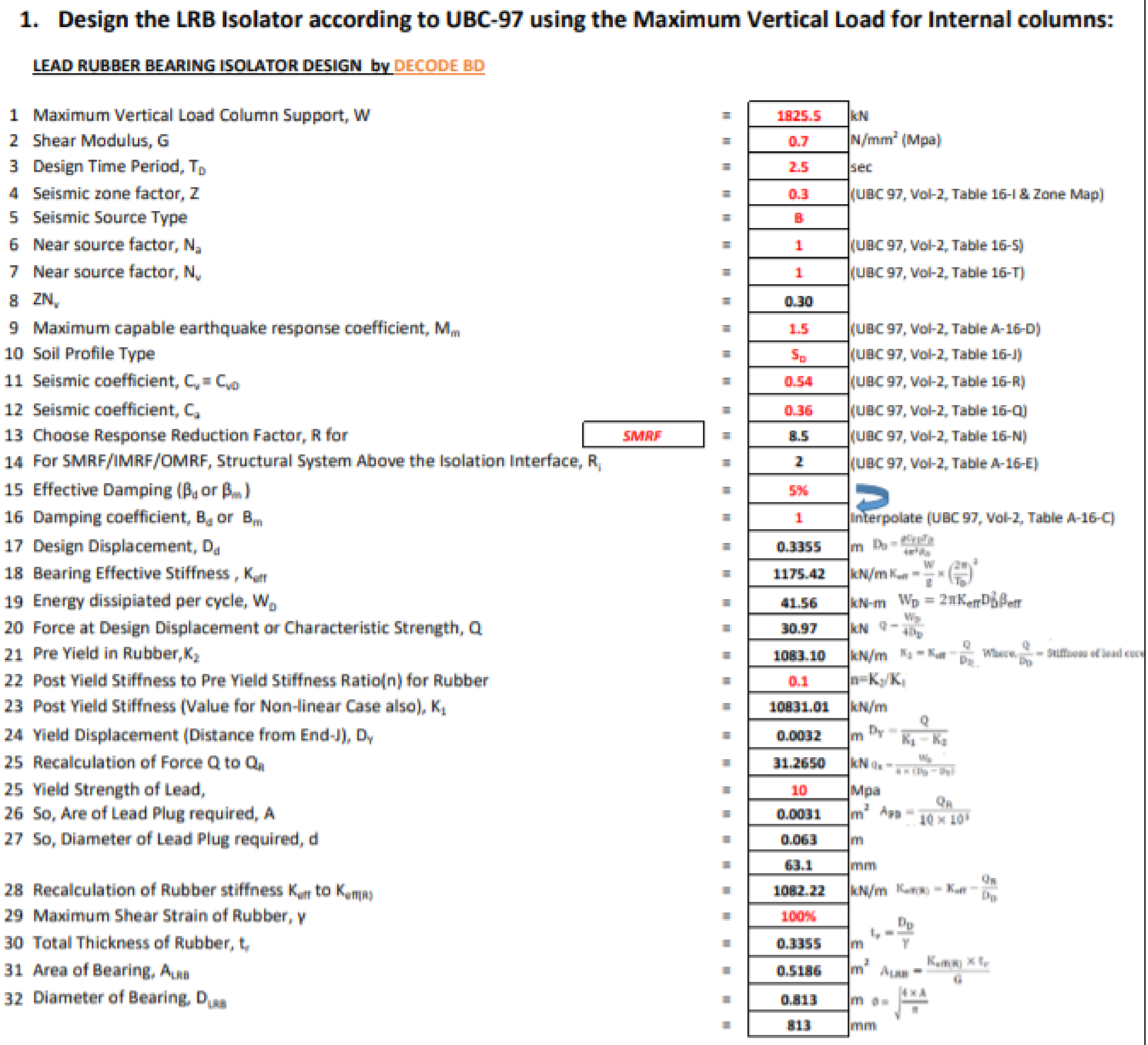


Fig. 45 *Mode Shape 4 Fixed Base*

3.3. Design of LRB Using UBC 1997 Code



1. Design the LRB Isolator according to UBC-97 using the Maximum Vertical Load for Internal columns:

LEAD RUBBER BEARING ISOLATOR DESIGN by DECODE BD

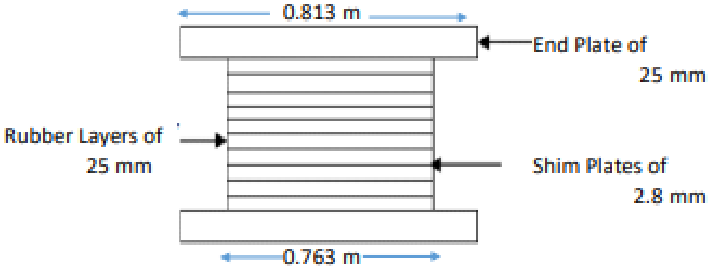
1	Maximum Vertical Load Column Support, W		=	1825.5	kN
2	Shear Modulus, G		=	0.7	N/mm^2 (Mpa)
3	Design Time Period, T_D		=	2.5	sec
4	Seismic zone factor, Z		=	0.3	(UBC 97, Vol-2, Table 16-I & Zone Map)
5	Seismic Source Type		=	B	
6	Near source factor, N_a		=	1	(UBC 97, Vol-2, Table 16-S)
7	Near source factor, N_v		=	1	(UBC 97, Vol-2, Table 16-T)
8	ZN_v		=	0.30	
9	Maximum capable earthquake response coefficient, M_m		=	1.5	(UBC 97, Vol-2, Table A-16-D)
10	Soil Profile Type		=	S_D	(UBC 97, Vol-2, Table 16-J)
11	Seismic coefficient, $C_v = C_{vD}$		=	0.54	(UBC 97, Vol-2, Table 16-R)
12	Seismic coefficient, C_a		=	0.36	(UBC 97, Vol-2, Table 16-Q)
13	Choose Response Reduction Factor, R for	*SMRF*	=	8.5	(UBC 97, Vol-2, Table 16-N)
14	For SMRF/IMRF/OMRF, Structural System Above the Isolation Interface, R_i		=	2	(UBC 97, Vol-2, Table A-16-E)
15	Effective Damping (β_d or β_m)		=	5%	
16	Damping coefficient, B_d or B_m		=	1	Interpolate (UBC 97, Vol-2, Table A-16-C)
17	Design Displacement, D_d		=	0.3355	m $D_D = \frac{g C_{VD} T_D}{4\pi^2 B_D}$
18	Bearing Effective Stiffness , K_{eff}		=	1175.42	kN/m $K_{eff} = \frac{W}{g} \times \left(\frac{2\pi}{T_D}\right)^2$
19	Energy dissipated per cycle, W_D		=	41.56	kN-m $W_D = 2\pi K_{eff} D_D^2 \beta_{eff}$
20	Force at Design Displacement or Characteristic Strength, Q		=	30.97	kN $Q = \frac{W_D}{4D_D}$
21	Pre Yield in Rubber, K_2		=	1083.10	kN/m $K_2 = K_{eff} - \frac{Q}{D_D}$ Where, $\frac{Q}{D_D}$ = Stiffness of lead core
22	Post Yield Stiffness to Pre Yield Stiffness Ratio(n) for Rubber		=	0.1	$n = K_2/K_1$
23	Post Yield Stiffness (Value for Non-linear Case also), K_1		=	10831.01	kN/m
24	Yield Displacement (Distance from End-J), D_y		=	0.0032	m $D_Y = \frac{Q}{K_1 - K_2}$
25	Recalculation of Force Q to Q_R		=	31.2650	kN $Q_R = \frac{W_D}{4 \times (D_D - D_Y)}$
25	Yield Strength of Lead,		=	10	Mpa
26	So, Are of Lead Plug required, A		=	0.0031	m^2 $A_{PB} = \frac{Q_R}{10 \times 10^3}$
27	So, Diameter of Lead Plug required, d		=	0.063	m
			=	63.1	mm
28	Recalculation of Rubber stiffness K_{eff} to $K_{eff(R)}$		=	1082.22	kN/m $K_{eff(R)} = K_{eff} - \frac{Q_R}{D_D}$
29	Maximum Shear Strain of Rubber, γ		=	100%	
30	Total Thickness of Rubber, t_r		=	0.3355	m $t_r = \frac{D_D}{\gamma}$
31	Area of Bearing, A_{LRB}		=	0.5186	m^2 $A_{LRB} = \frac{K_{eff(R)} \times t_r}{G}$
32	Diameter of Bearing, D_{LRB}		=	0.813	m $\emptyset = \sqrt{\frac{4 \times A}{\pi}}$
			=	813	mm

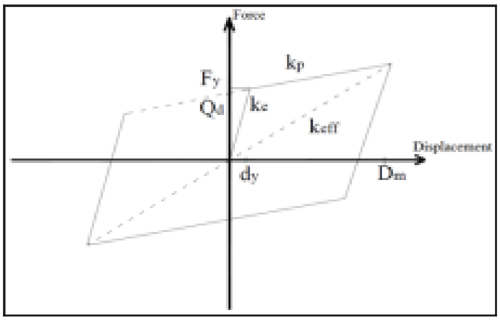
33	Horizontal Time Period Consider	=	2	sec	Take horizontal period to be 2 sec
34	Horizontal Frequency, f_h	=	0.50	Hz	$f_h = \frac{1}{2} = 0.5$ Hz
35	Set Vertical Frequency, f_v	=	10	Hz	
36	So, Shape Factor, S	=	8.33		$S = \frac{1}{2.4} \times \frac{f_v}{f_h}$
37	Single Layer of Rubber, t	=	24	mm	$t = \frac{Ø_{LRB}}{4S}$
38	So number of Rubber Layers, N	=	13.76		
		≈	14		
39	So, Provide Single Layer of Rubber (Round up to nearest 5)	=	25	mm	
40	Let, Thickness of Shim Plates	=	2.8	mm	
41	Number of Shim Plates, n	=	13	n=(N-1)	
42	End Plate Thickness is between 19mm to 38 mm, Choose	=	25	mm	
43	So Total Height of LRB, h	=	436.4	mm	
44	Bulk Modulus, K	=	2000	Mpa	
45	Compression Modulus, Ec	=	249131.9	kN/m^2	$E_c = 6GS^2\left(1 - \frac{6GS^2}{K}\right)$
46	Horizontal Stiffness, K_H	=	1082.219	kN/m	$K_H = \frac{GA_{LRB}}{t_r}$
47	Vertical Stiffness, K_v	=	385164.667	kN/m	
		=	385.165	MN/m	
48	Cover from Lead to End Plate	=	25	mm	
49	Bonded Diameter	=	0.763	m	
50	Moment of Inertia,I	=	1.660E+10	kN/mm	Cir.: $I=\pi B^4/64$
		=	0.016603	kN/m	
51	Area of Hysteresis Loop, A_h	=	41.162	kN-m	$A_h=4Q(D_d-D_y)$
54	Yield Strength, F_y	=	34.703	kN	$F_y=Q+K_2{*}D_y$

Reference: UBC-97 & DESIGN OF SEISMIC ISOLATED STRUCTURE FROM THEORY OF PRACTICE by JAMES M.KELLY and FARZAD NAEIM

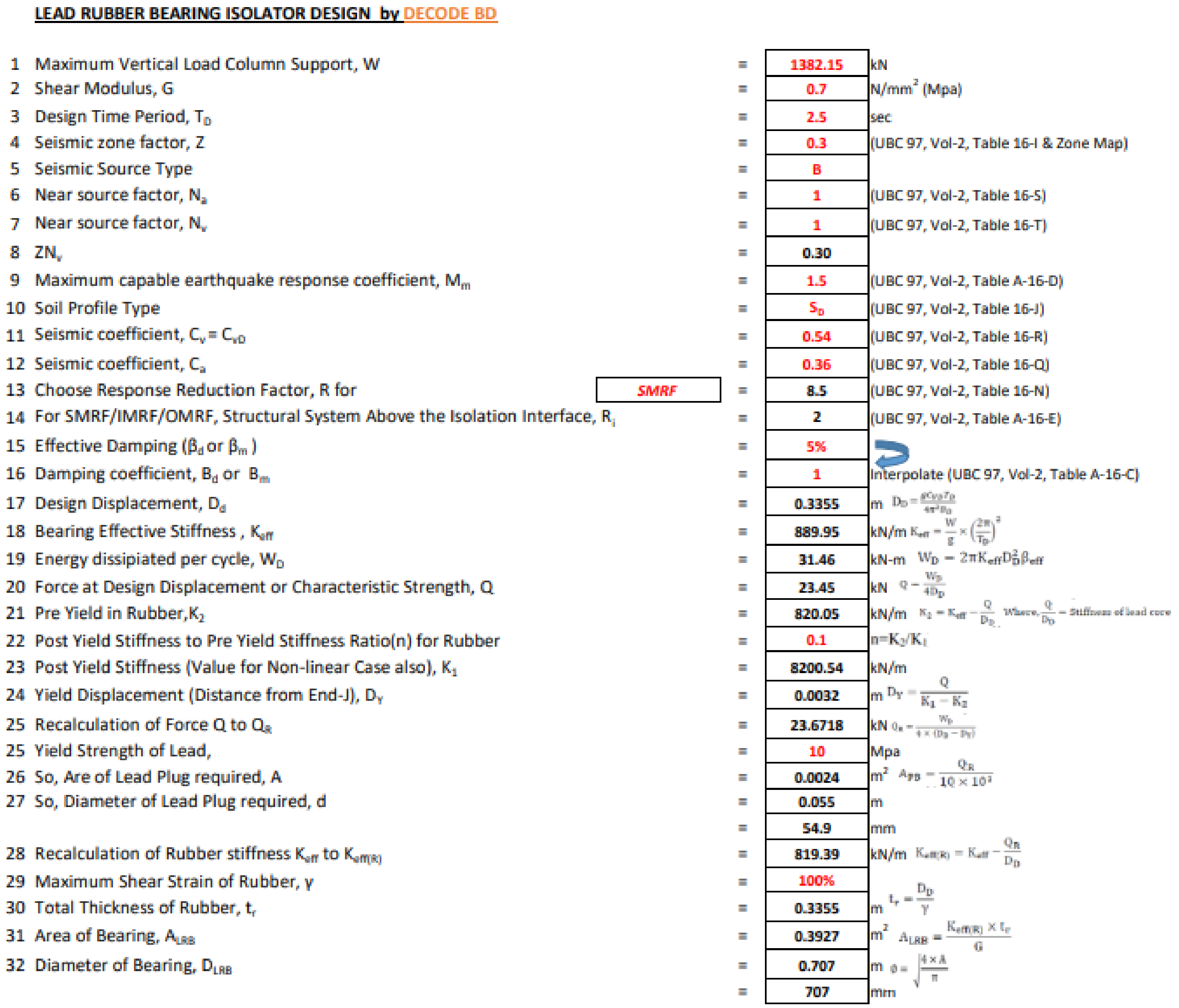
Finally input values for ETABS/SAP2000:

Rotational Inertia1	0.016603	kN/m
For U1 Effective Stiffness	1175418.57	kN/m
For U2 & U3 Effective Stiffness	1175.42	kN-m
For U2 & U3 Effective Damping	0.05	
For U2 & U3 Distance from End-J	0.00318	m
For U2 & U3 Stiffness	10831	kN/m
For U2 & U3 Yield Strength	34.70	kN



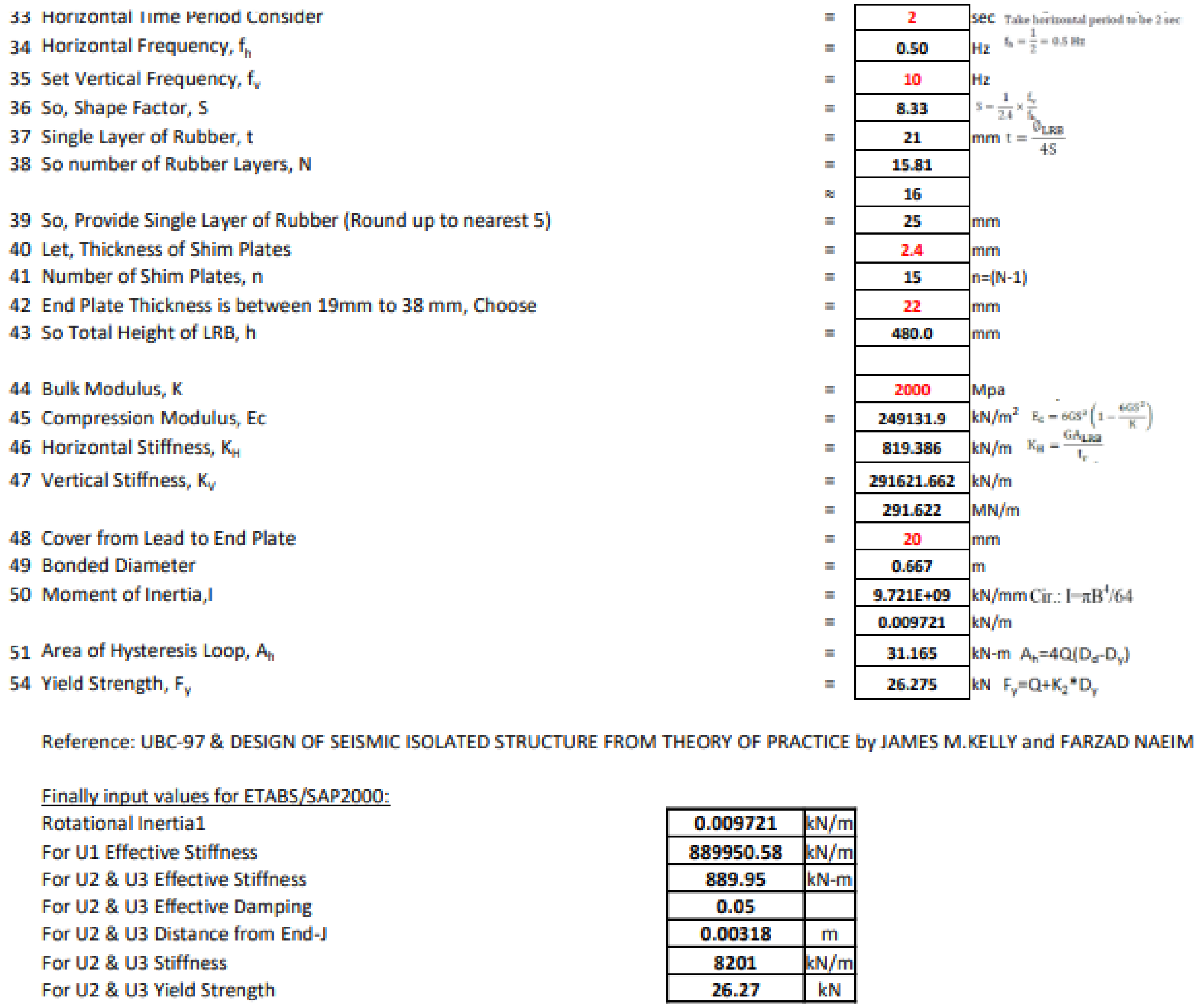


2. Design the LRB Isolator according to UBC-97 using the Maximum Vertical Load for External columns:



LEAD RUBBER BEARING ISOLATOR DESIGN by DECODE BD

1	Maximum Vertical Load Column Support, W	=	1382.15	kN
2	Shear Modulus, G	=	0.7	N/mm^2 (Mpa)
3	Design Time Period, T_D	=	2.5	sec
4	Seismic zone factor, Z	=	0.3	(UBC 97, Vol-2, Table 16-I & Zone Map)
5	Seismic Source Type	=	B	
6	Near source factor, N_a	=	1	(UBC 97, Vol-2, Table 16-S)
7	Near source factor, N_v	=	1	(UBC 97, Vol-2, Table 16-T)
8	ZN_v	=	0.30	
9	Maximum capable earthquake response coefficient, M_m	=	1.5	(UBC 97, Vol-2, Table A-16-D)
10	Soil Profile Type	=	S_D	(UBC 97, Vol-2, Table 16-J)
11	Seismic coefficient, $C_v = C_{vD}$	=	0.54	(UBC 97, Vol-2, Table 16-R)
12	Seismic coefficient, C_a	=	0.36	(UBC 97, Vol-2, Table 16-Q)
13	Choose Response Reduction Factor, R for *SMRF*	=	8.5	(UBC 97, Vol-2, Table 16-N)
14	For SMRF/IMRF/OMRF, Structural System Above the Isolation Interface, R_i	=	2	(UBC 97, Vol-2, Table A-16-E)
15	Effective Damping (β_d or β_m)	=	5%	
16	Damping coefficient, B_d or B_m	=	1	Interpolate (UBC 97, Vol-2, Table A-16-C)
17	Design Displacement, D_d	=	0.3355	m $D_D = \frac{gC_{VD}T_D}{4\pi^2 B_D}$
18	Bearing Effective Stiffness , K_{eff}	=	889.95	kN/m $K_{eff} = \frac{W}{g} \times \left(\frac{2\pi}{T_D}\right)^2$
19	Energy dissipiated per cycle, W_D	=	31.46	kN-m $W_D = 2\pi K_{eff} D_D^2 \beta_{eff}$
20	Force at Design Displacement or Characteristic Strength, Q	=	23.45	kN $Q = \frac{W_D}{4D_D}$
21	Pre Yield in Rubber, K_2	=	820.05	kN/m $K_2 = K_{eff} - \frac{Q}{D_D}$ Where, $\frac{Q}{D_D}$ = Stiffness of lead core
22	Post Yield Stiffness to Pre Yield Stiffness Ratio(n) for Rubber	=	0.1	$n=K_2/K_1$
23	Post Yield Stiffness (Value for Non-linear Case also), K_1	=	8200.54	kN/m
24	Yield Displacement (Distance from End-J), D_Y	=	0.0032	m $D_Y = \frac{Q}{K_1 - K_2}$
25	Recalculation of Force Q to Q_R	=	23.6718	kN $Q_R = \frac{W_D}{4 \times (D_D - D_Y)}$
25	Yield Strength of Lead,	=	10	Mpa
26	So, Are of Lead Plug required, A	=	0.0024	m^2 $A_{PB} = \frac{Q_R}{10 \times 10^3}$
27	So, Diameter of Lead Plug required, d	=	0.055	m
		=	54.9	mm
28	Recalculation of Rubber stiffness K_{eff} to $K_{eff(R)}$	=	819.39	kN/m $K_{eff(R)} = K_{eff} - \frac{Q_R}{D_D}$
29	Maximum Shear Strain of Rubber, γ	=	100%	
30	Total Thickness of Rubber, t_r	=	0.3355	m $t_r = \frac{D_D}{\gamma}$
31	Area of Bearing, A_{LRB}	=	0.3927	m^2 $A_{LRB} = \frac{K_{eff(R)} \times t_r}{G}$
32	Diameter of Bearing, D_{LRB}	=	0.707	m $\phi = \sqrt{\frac{4 \times A}{\pi}}$
		=	707	mm

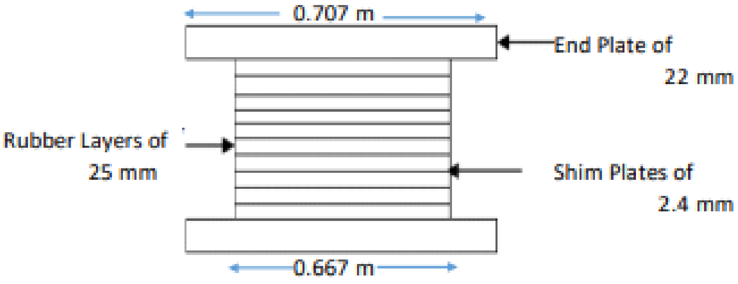


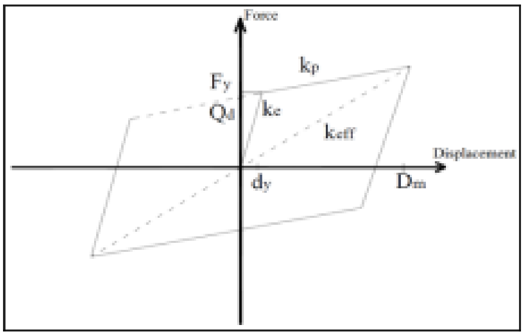
33	Horizontal Time Period Consider	=	2	sec	Take horizontal period to be 2 sec
34	Horizontal Frequency, f_h	=	0.50	Hz	$f_h = \frac{1}{2} = 0.5$ Hz
35	Set Vertical Frequency, f_v	=	10	Hz	
36	So, Shape Factor, S	=	8.33		$S = \frac{1}{2.4} \times \frac{f_v}{f_h}$
37	Single Layer of Rubber, t	=	21	mm	$t = \frac{\emptyset_{LRB}}{4S}$
38	So number of Rubber Layers, N	=	15.81		
		≈	16		
39	So, Provide Single Layer of Rubber (Round up to nearest 5)	=	25	mm	
40	Let, Thickness of Shim Plates	=	2.4	mm	
41	Number of Shim Plates, n	=	15	n=(N-1)	
42	End Plate Thickness is between 19mm to 38 mm, Choose	=	22	mm	
43	So Total Height of LRB, h	=	480.0	mm	
44	Bulk Modulus, K	=	2000	Mpa	
45	Compression Modulus, Ec	=	249131.9	kN/m^2	$E_c = 6GS^2\left(1 - \frac{6GS^2}{K}\right)$
46	Horizontal Stiffness, K_H	=	819.386	kN/m	$K_H = \frac{GA_{LRB}}{t_r}$
47	Vertical Stiffness, K_V	=	291621.662	kN/m	
		=	291.622	MN/m	
48	Cover from Lead to End Plate	=	20	mm	
49	Bonded Diameter	=	0.667	m	
50	Moment of Inertia,I	=	9.721E+09	kN/mm	Cir.: $I = \pi B^4/64$
		=	0.009721	kN/m	
51	Area of Hysteresis Loop, A_h	=	31.165	kN-m	$A_h = 4Q(D_d - D_y)$
54	Yield Strength, F_y	=	26.275	kN	$F_y = Q + K_2 * D_y$

Reference: UBC-97 & DESIGN OF SEISMIC ISOLATED STRUCTURE FROM THEORY OF PRACTICE by JAMES M.KELLY and FARZAD NAEIM

Finally input values for ETABS/SAP2000:

Rotational Inertia1	0.009721	kN/m
For U1 Effective Stiffness	889950.58	kN/m
For U2 & U3 Effective Stiffness	889.95	kN-m
For U2 & U3 Effective Damping	0.05	
For U2 & U3 Distance from End-J	0.00318	m
For U2 & U3 Stiffness	8201	kN/m
For U2 & U3 Yield Strength	26.27	kN





3.4. Response Spectrum Analysis of Structure (Base Isolators)

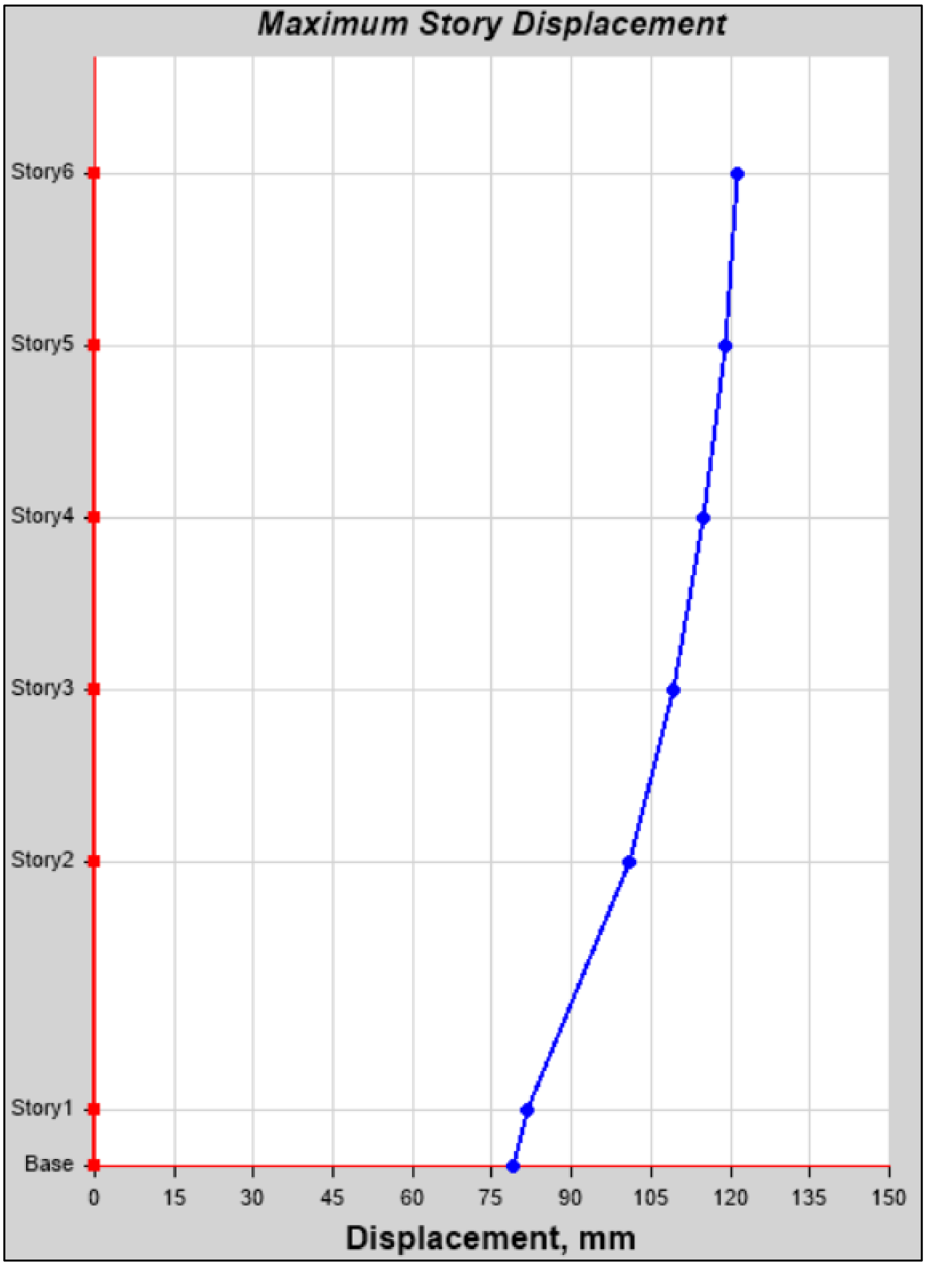


Fig. 46 *Maximum Story Displacement Base Isolators (121.17mm)*

Fig. 47 *Maximum Story Drift Base Isolators (0.004)*

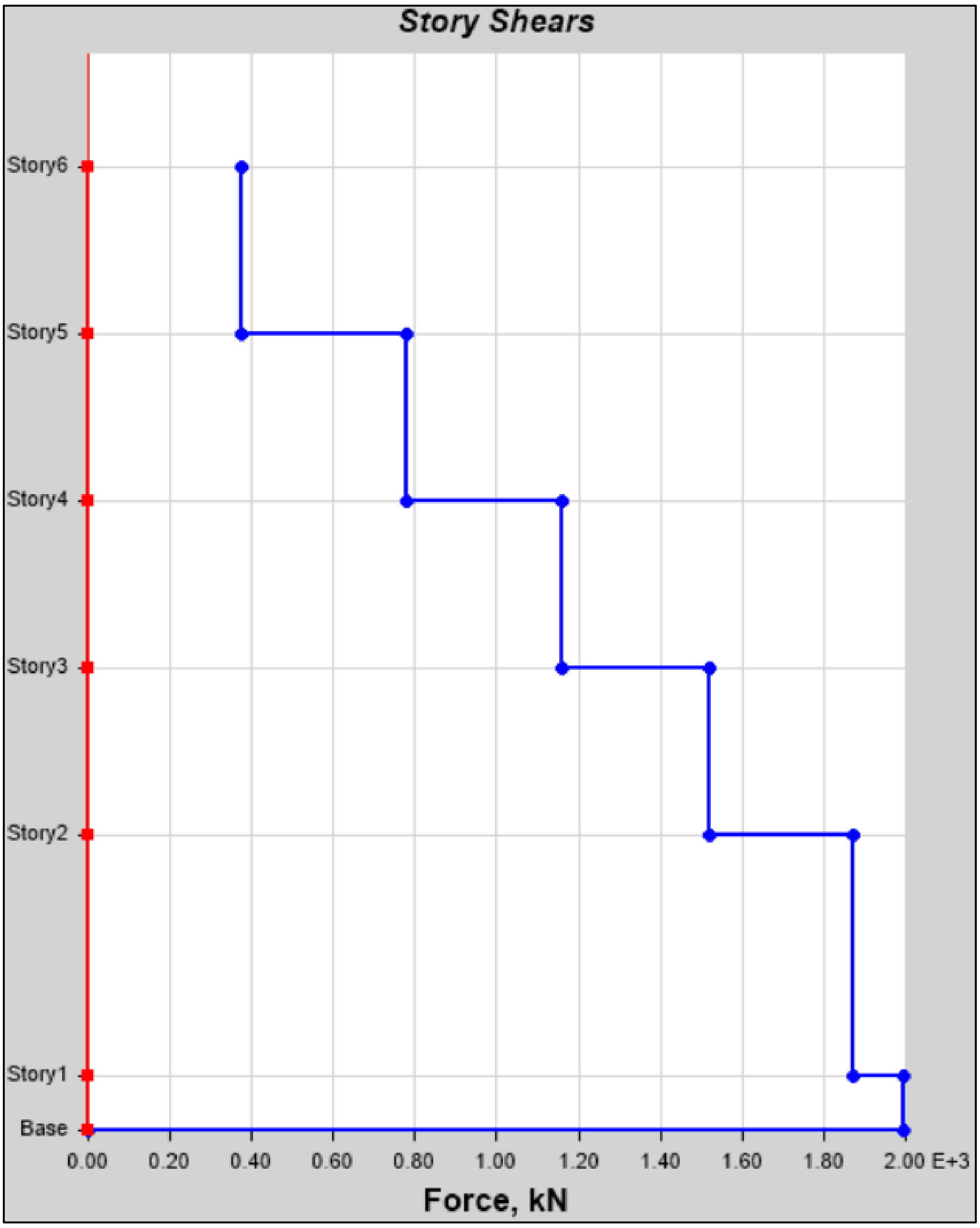


Fig. 48 *Maximum Story Shear Base Isolators (1993.46 kN)*

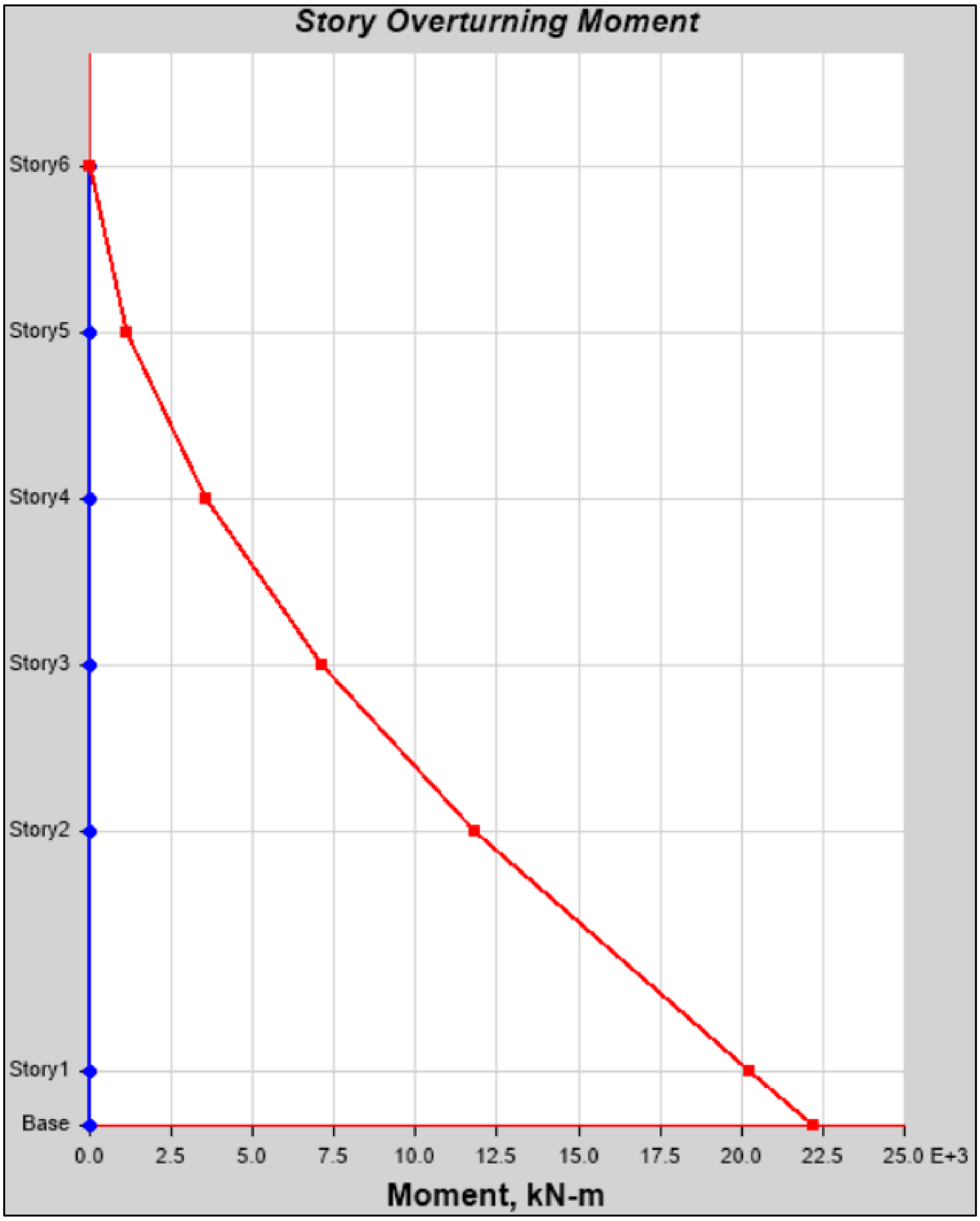


Fig. 49 *Maximum Story Overturning Moment Base Isolators (22207.5kN)*

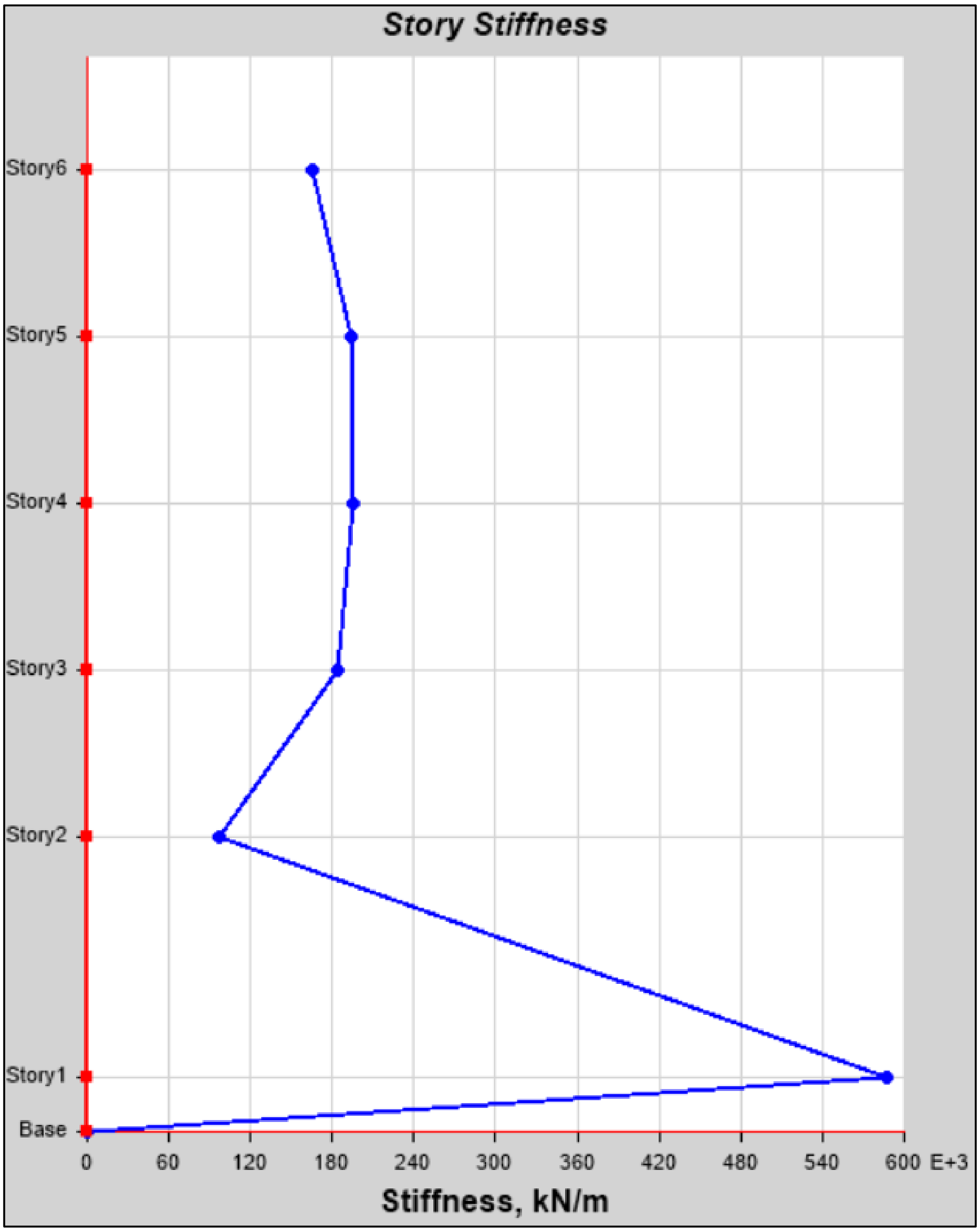


Fig. 50 *Maximum Story Stiffness Base Isolators (586932 kN/m)*

3.4.1. Mode Shapes (Base Isolators):

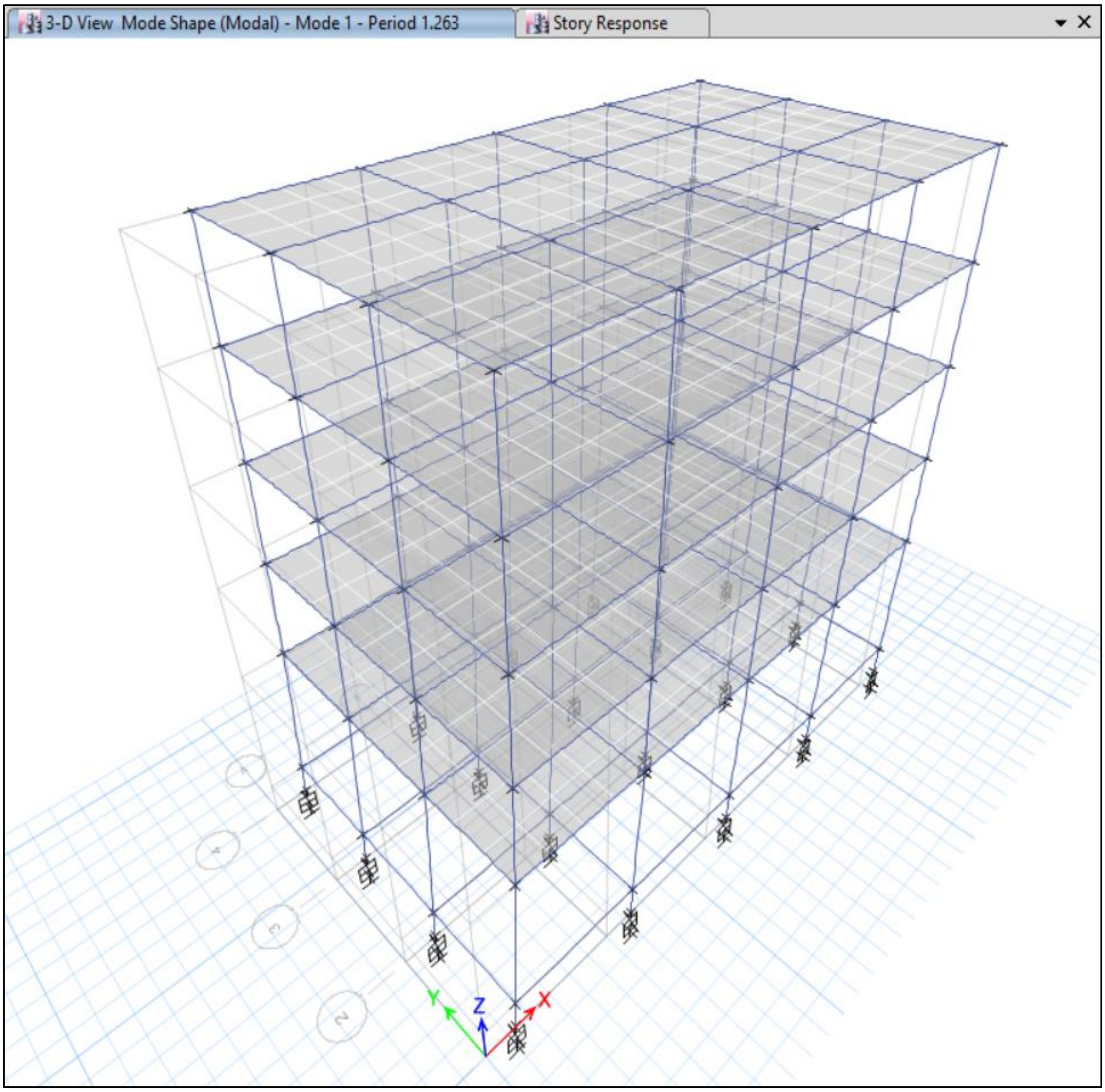


Fig. 51 *Mode Shape 1 Base Isolators*

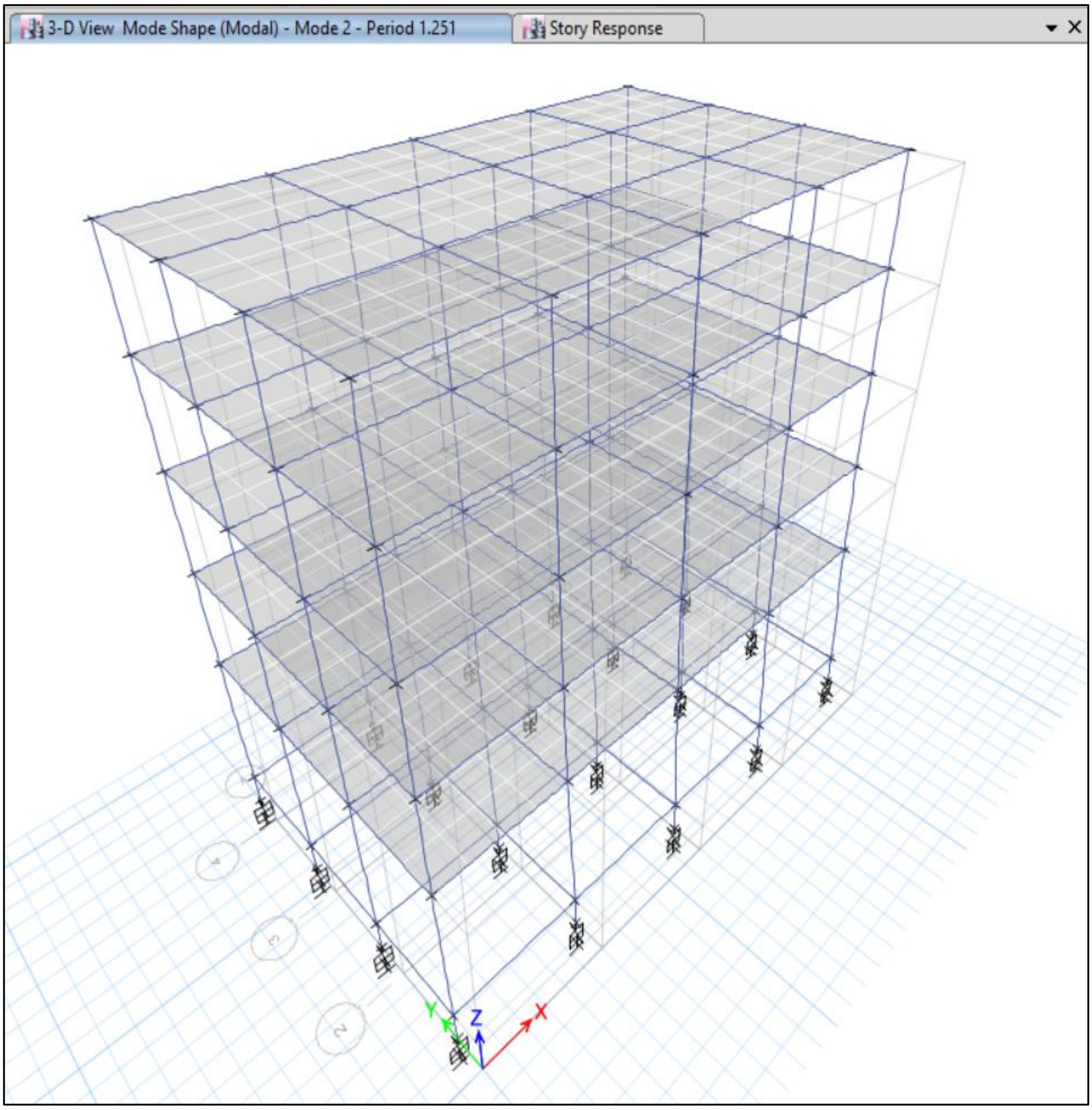


__Fig. 52__ Mode Shape 2 Base Isolators

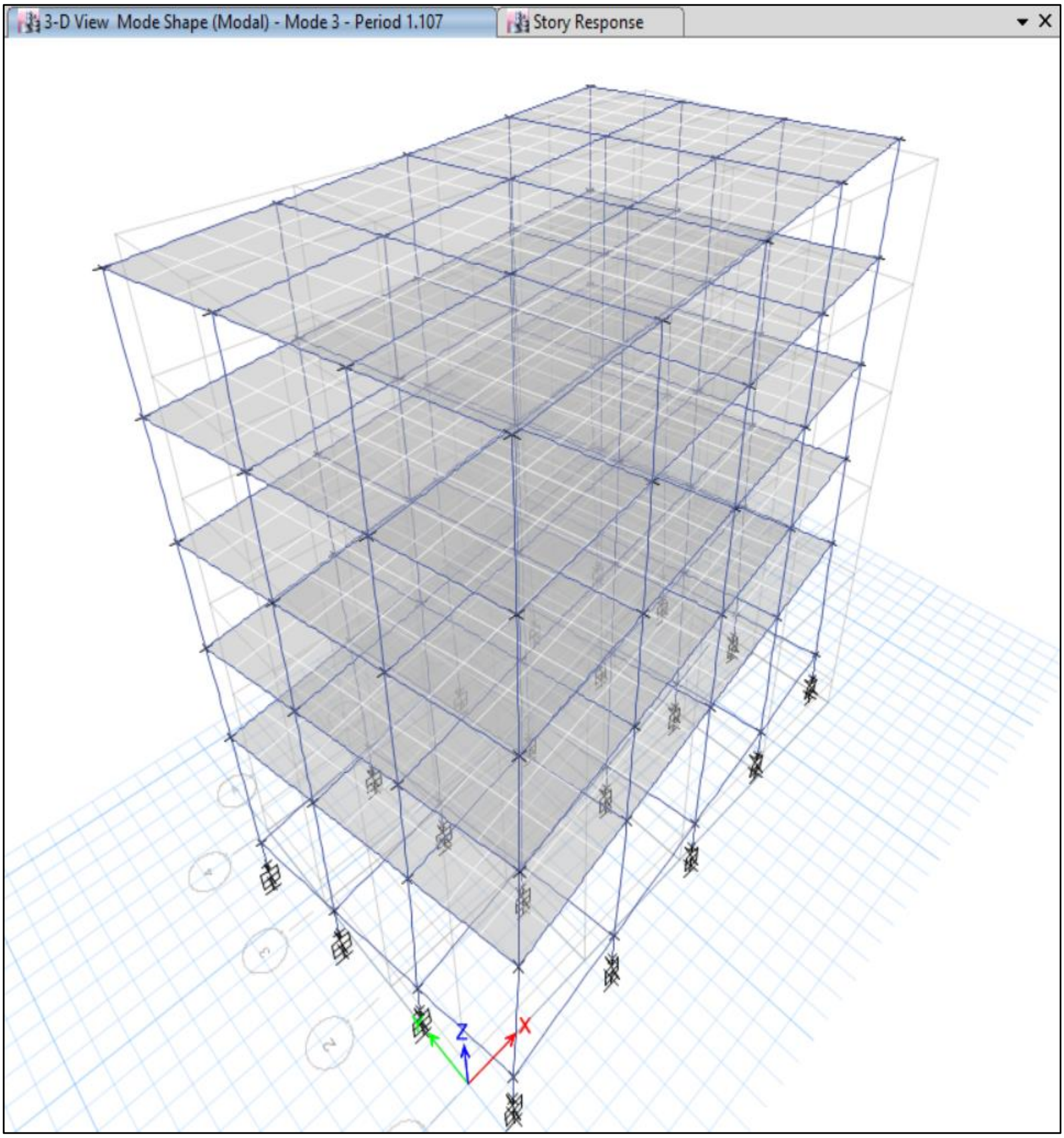


__Fig. 53__ Mode Shape 3 Base Isolators

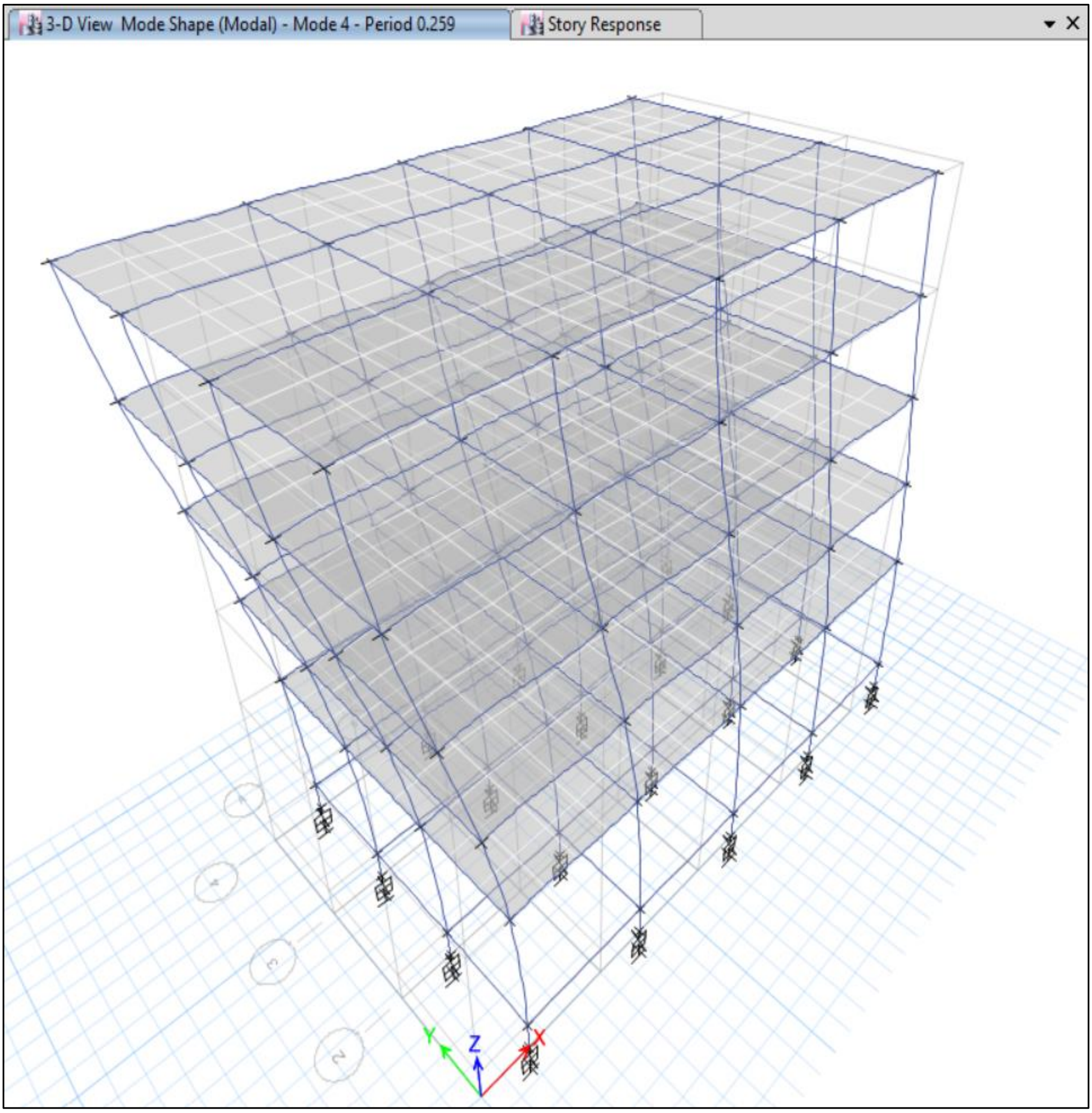


Fig. 54 *Mode Shape 4 Base Isolators*

3.5. Response Spectrum Analysis of Structure (Shear Wall)

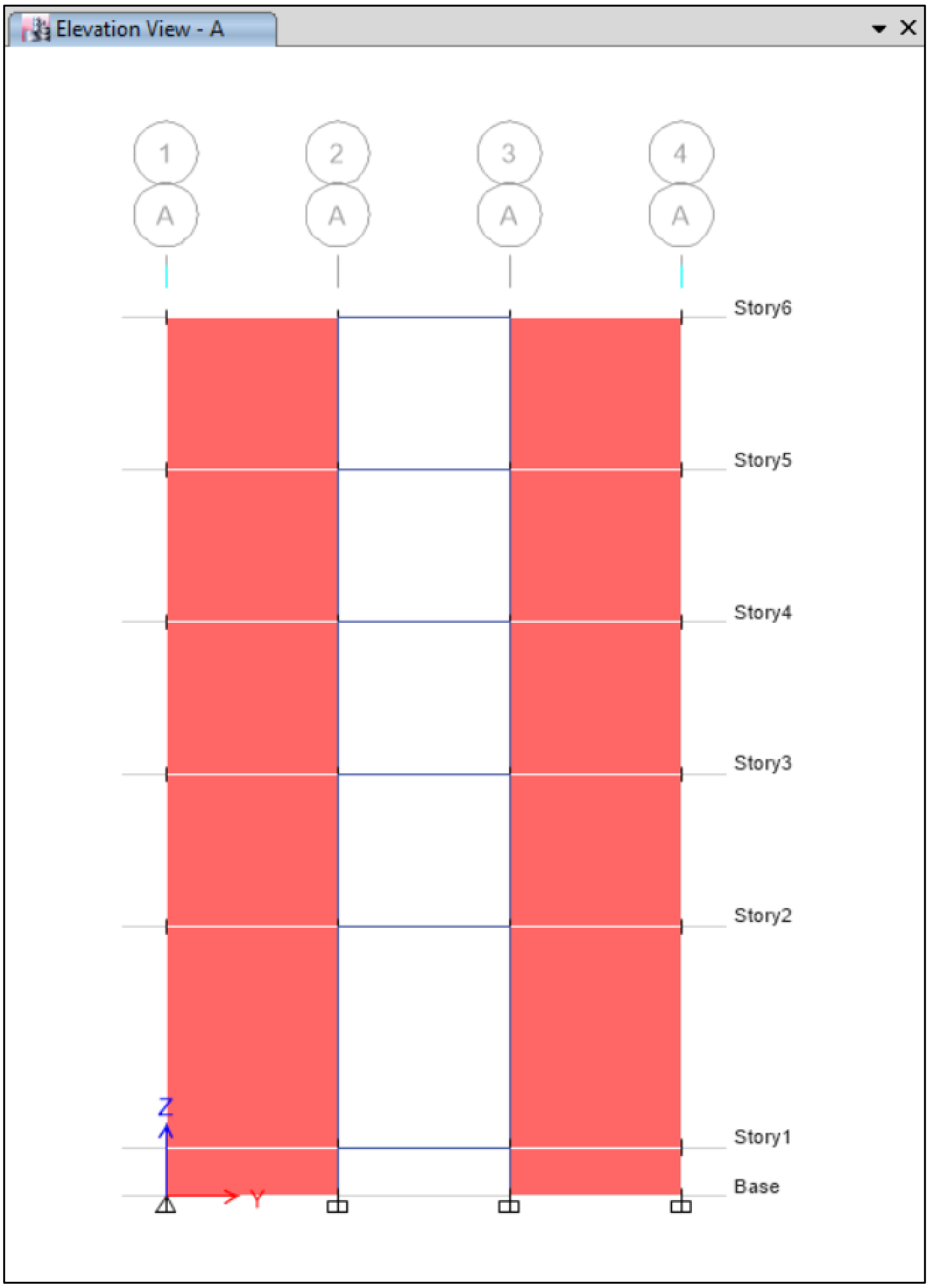


***Fig. 55** Elevation View with shear walls*

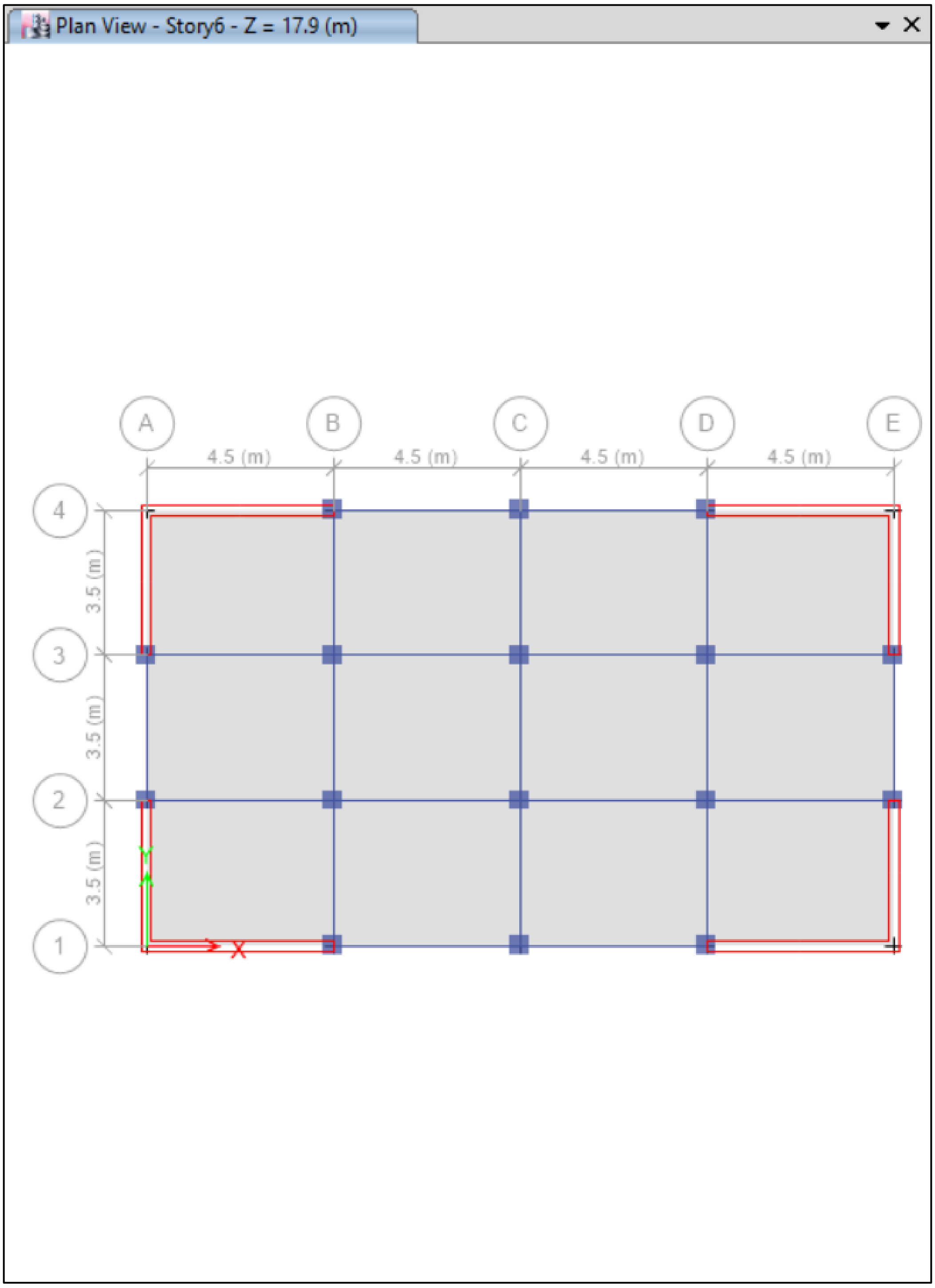


Fig. 56 Plane View with Shear Wall

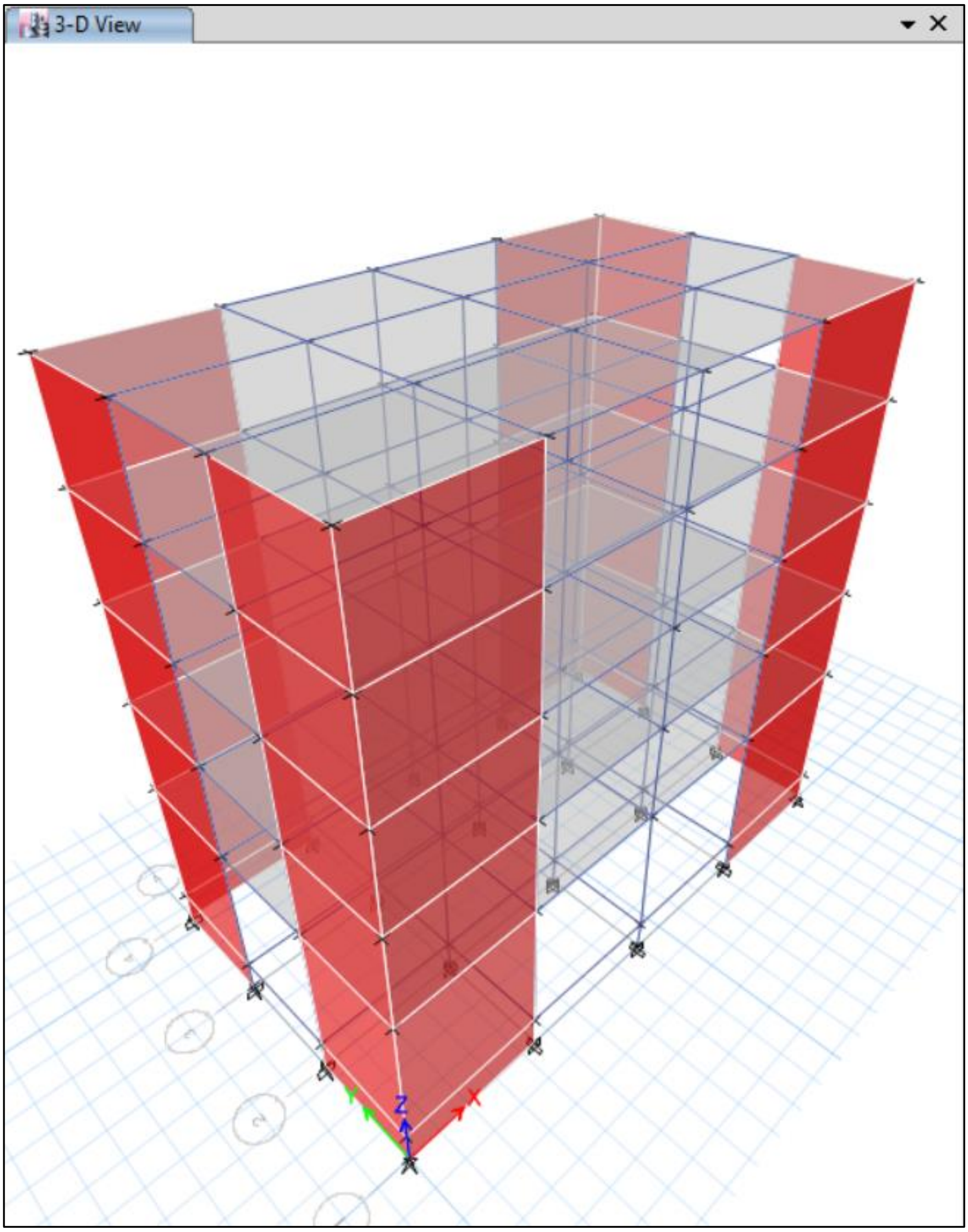


__Fig. 57__ 3-D View with Shear Wall

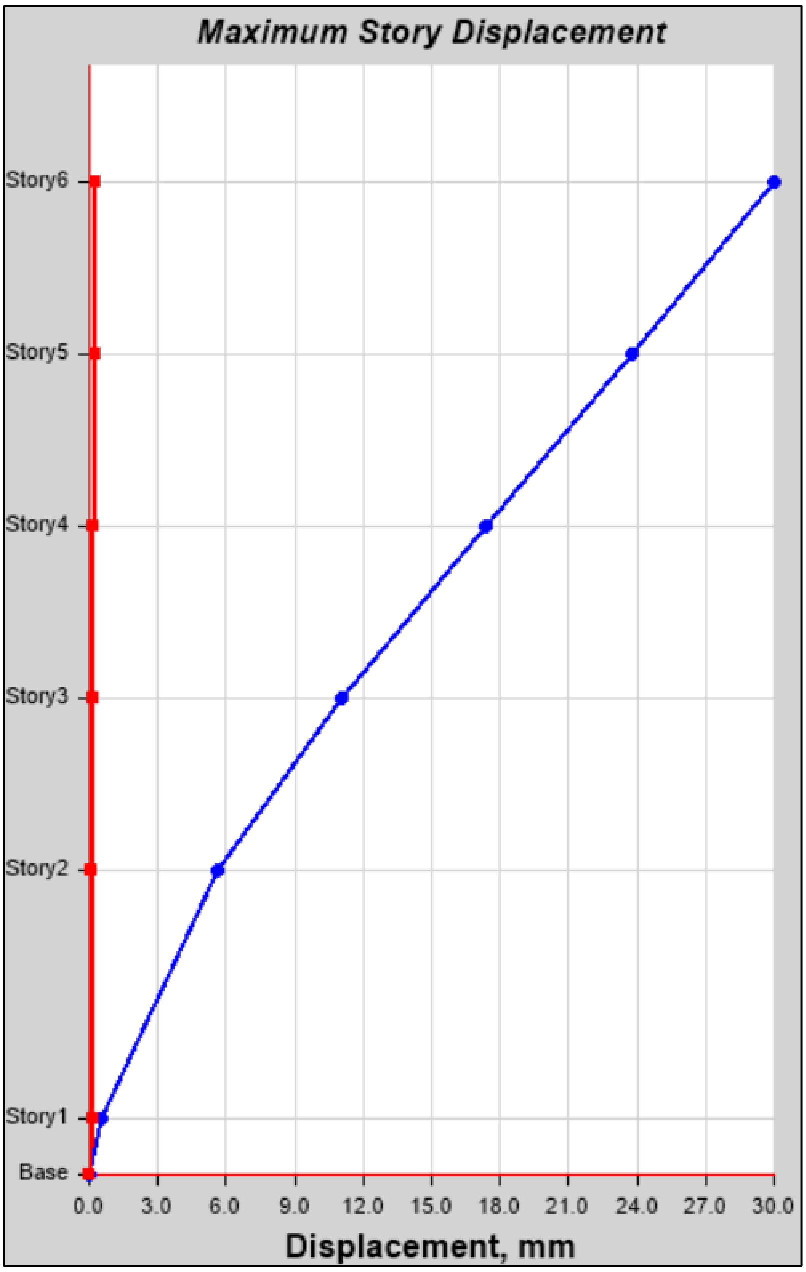


Fig. 58 *Maximum Story Displacement Shear Wall (29.97mm)*

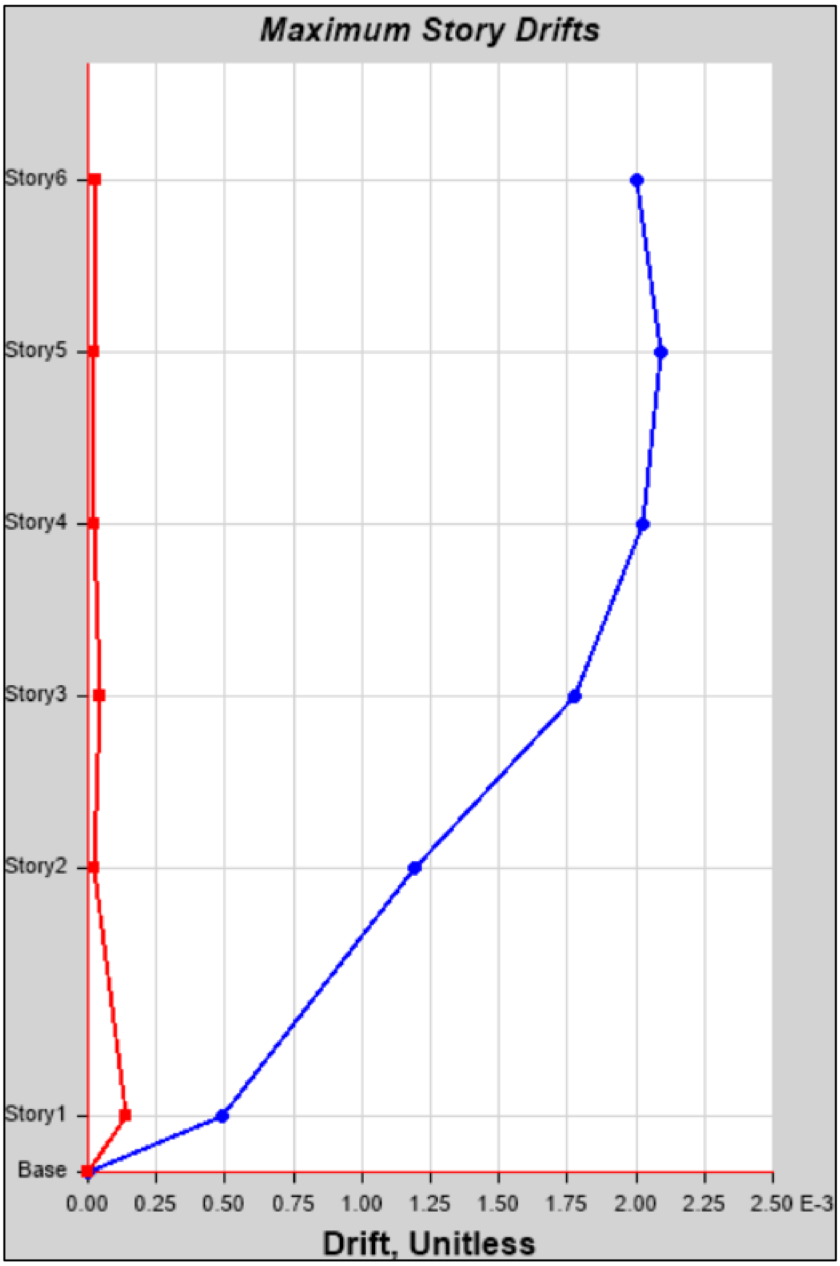


Fig. 59 *Maximum Story Drift Shear Wall (0.00209)*

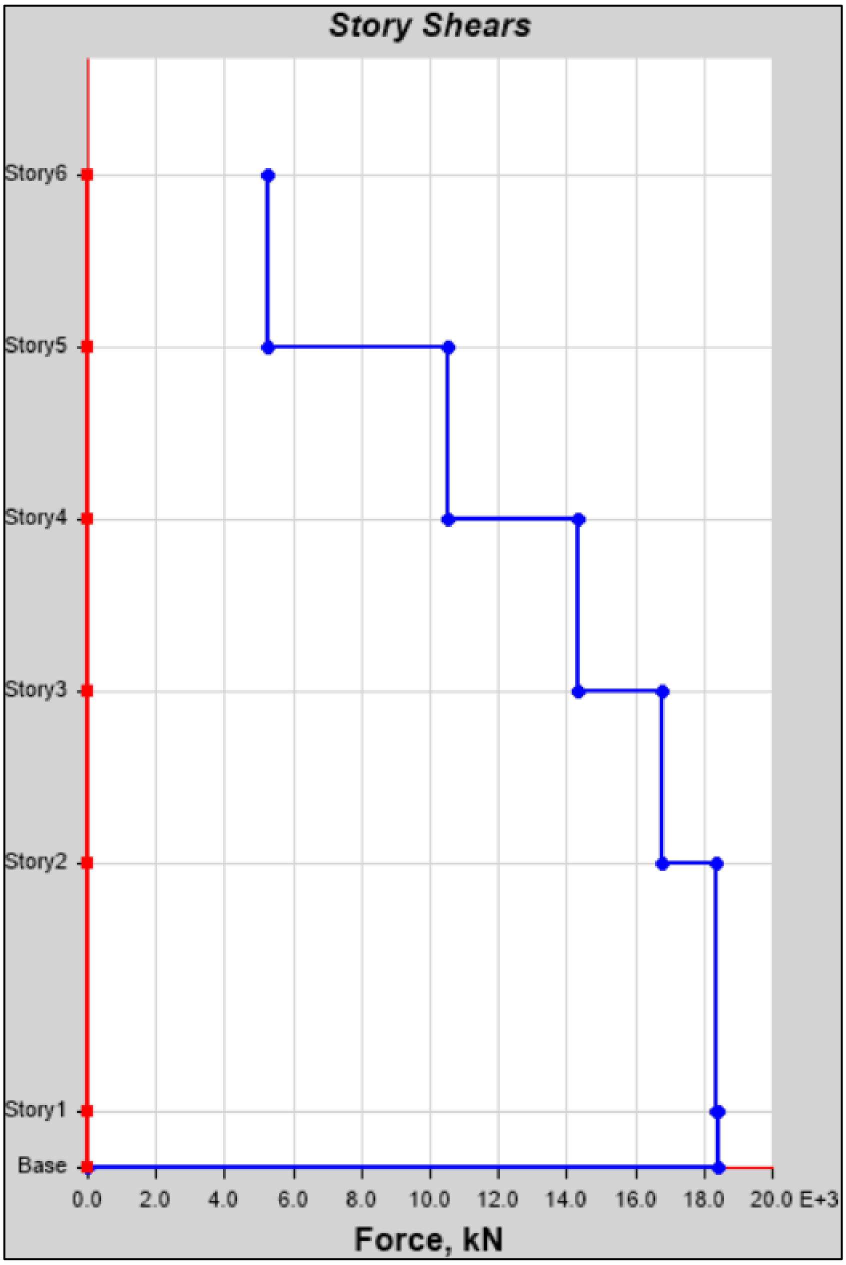


Fig. 60 *Maximum Story Shear Shear Wall (18417.09kN)*

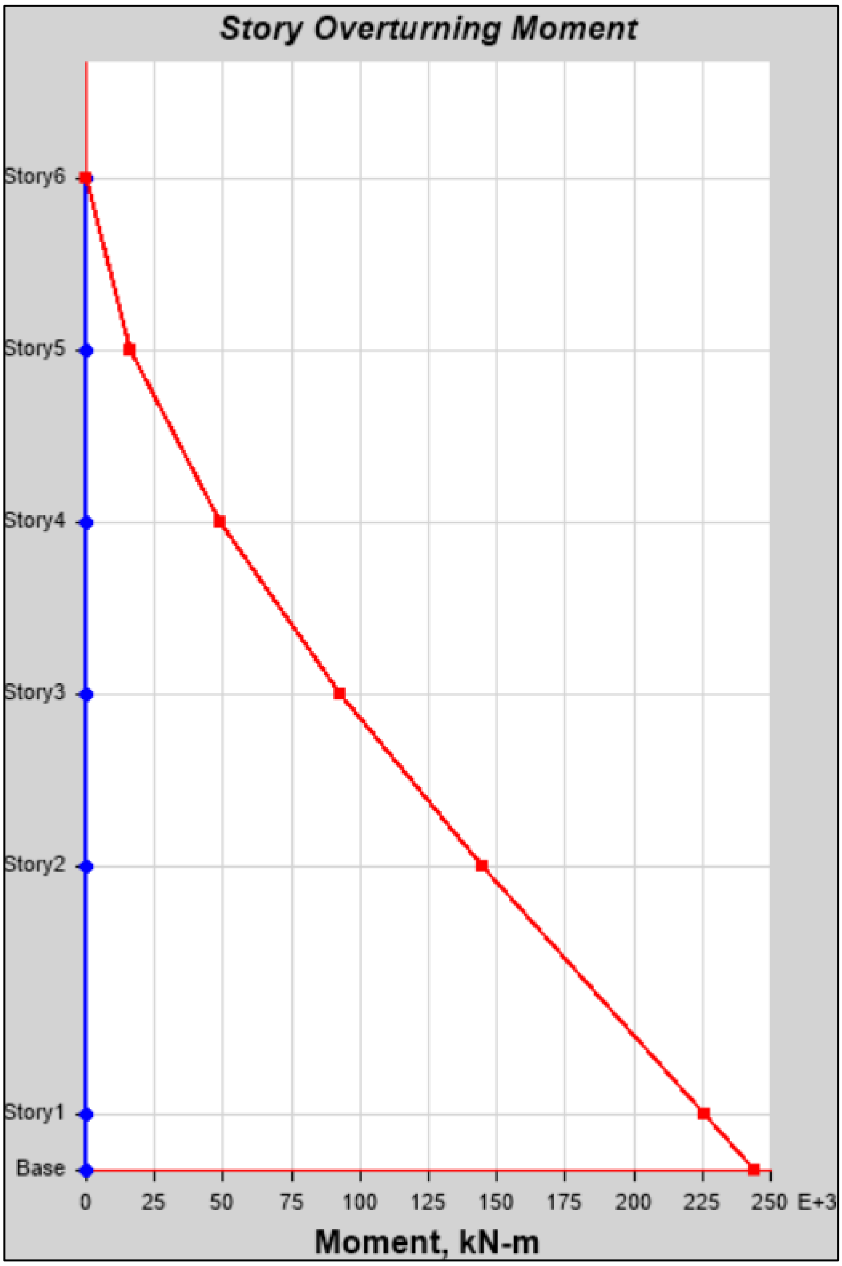


Fig. 61 *Maximum Story Overturning Momentum Shear Wall (244329kN-m)*

Fig. 62 *Maximum Story Stiffness Shear Wall (51333374kN/m)*

3.5.1. Mode Shapes (Shear Walls):

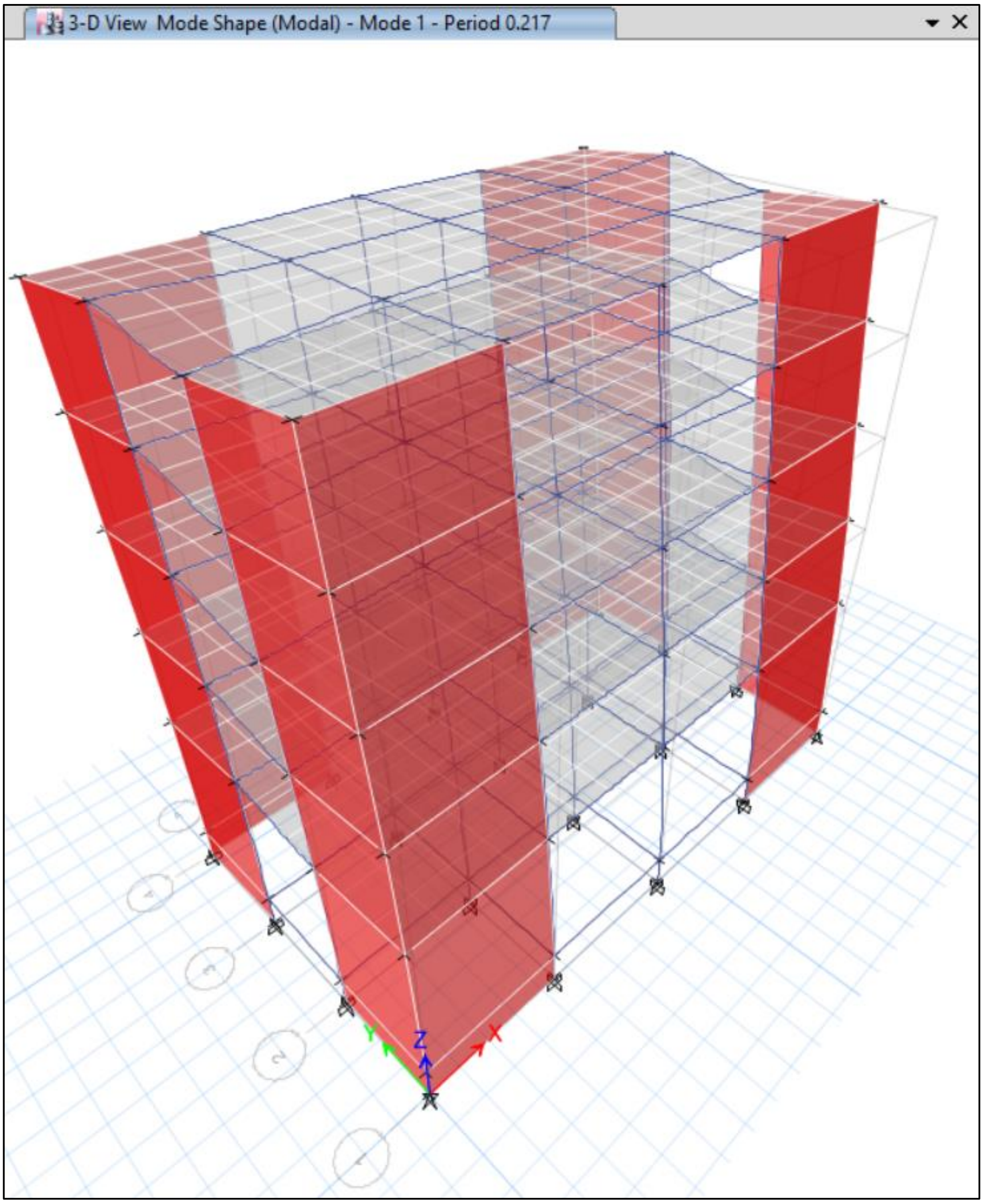


Fig. 63 *Mode Shape 1 Shear Wall*

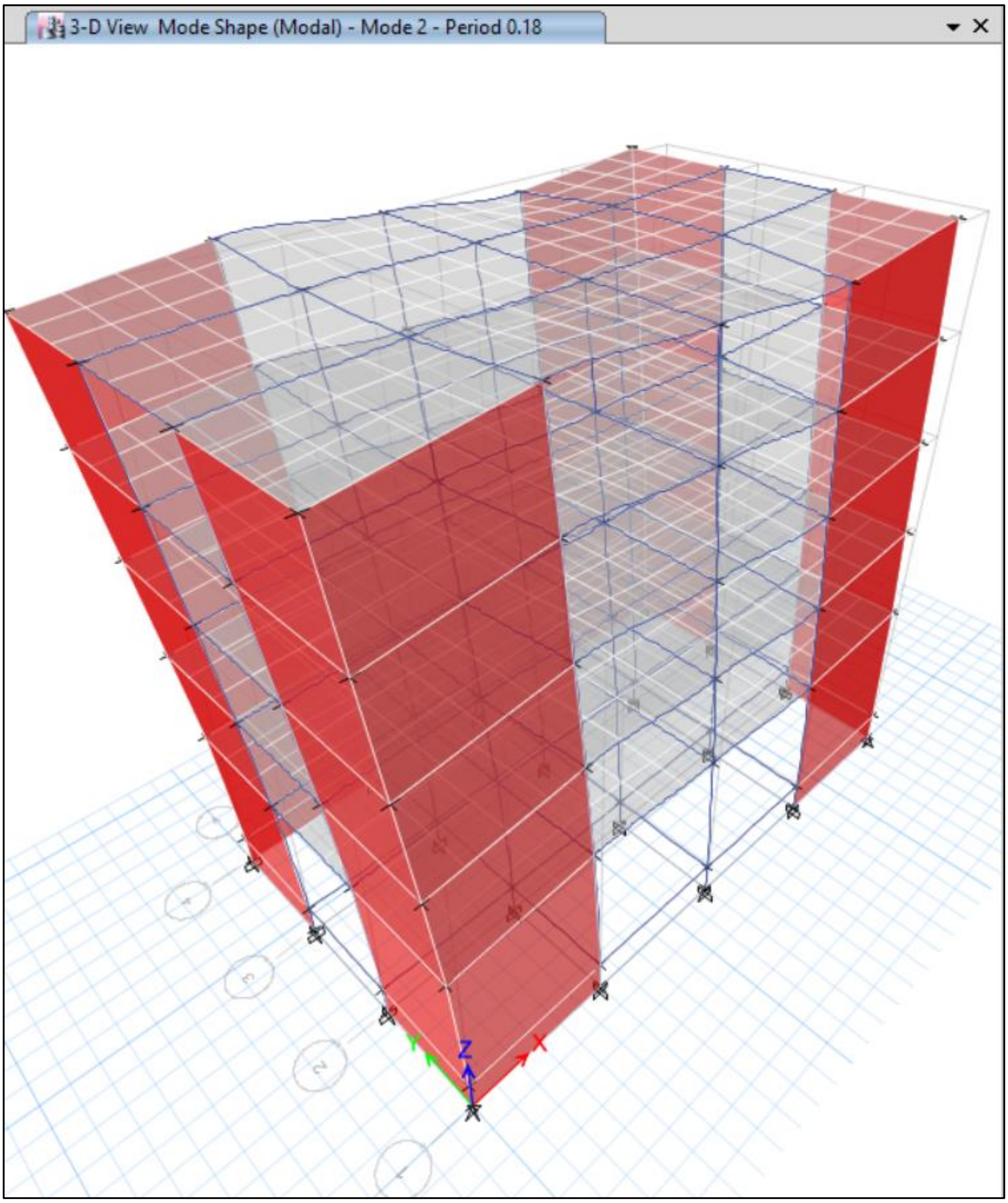


Fig. 64 *Mode Shape 2 Shear Wall*

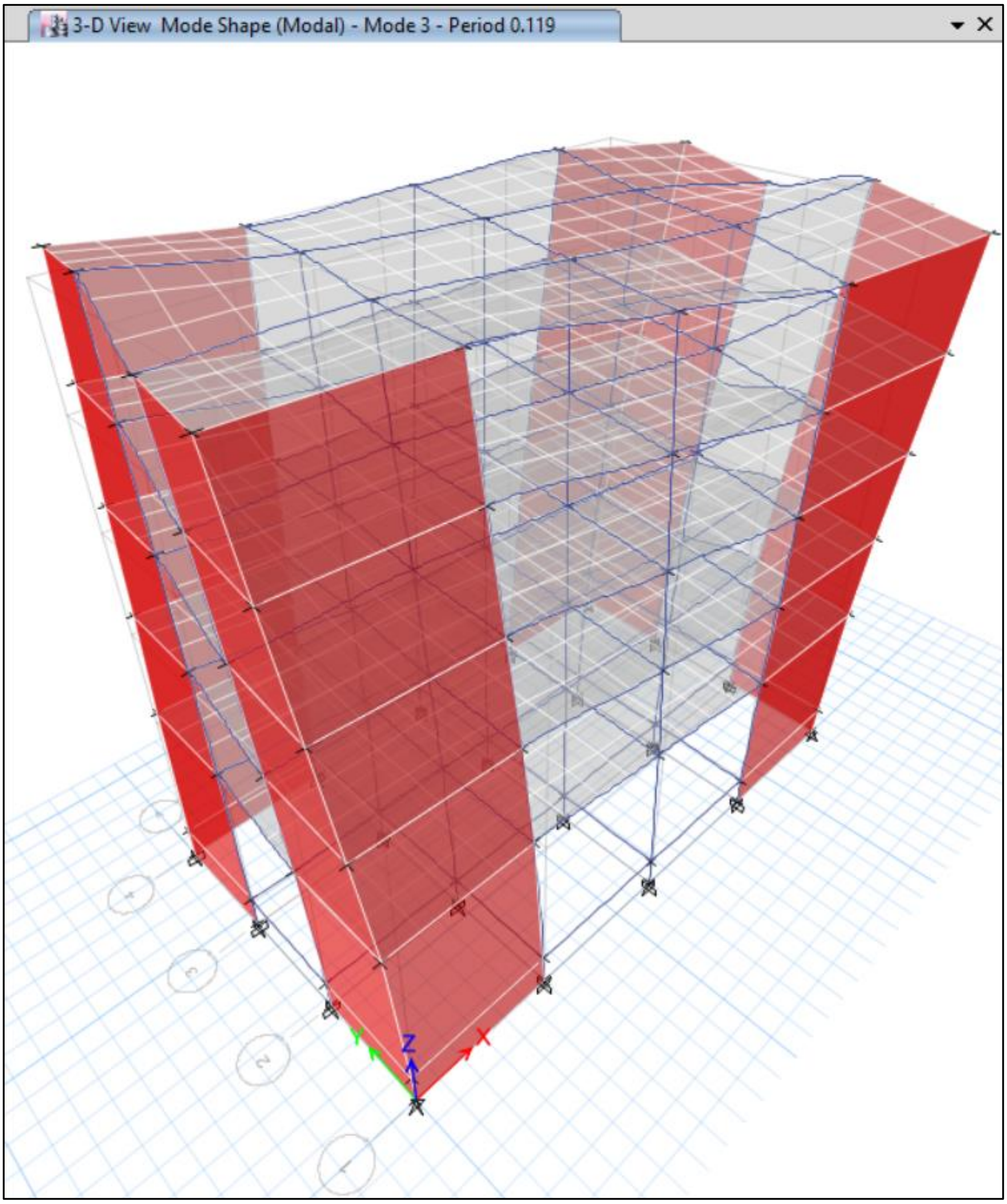
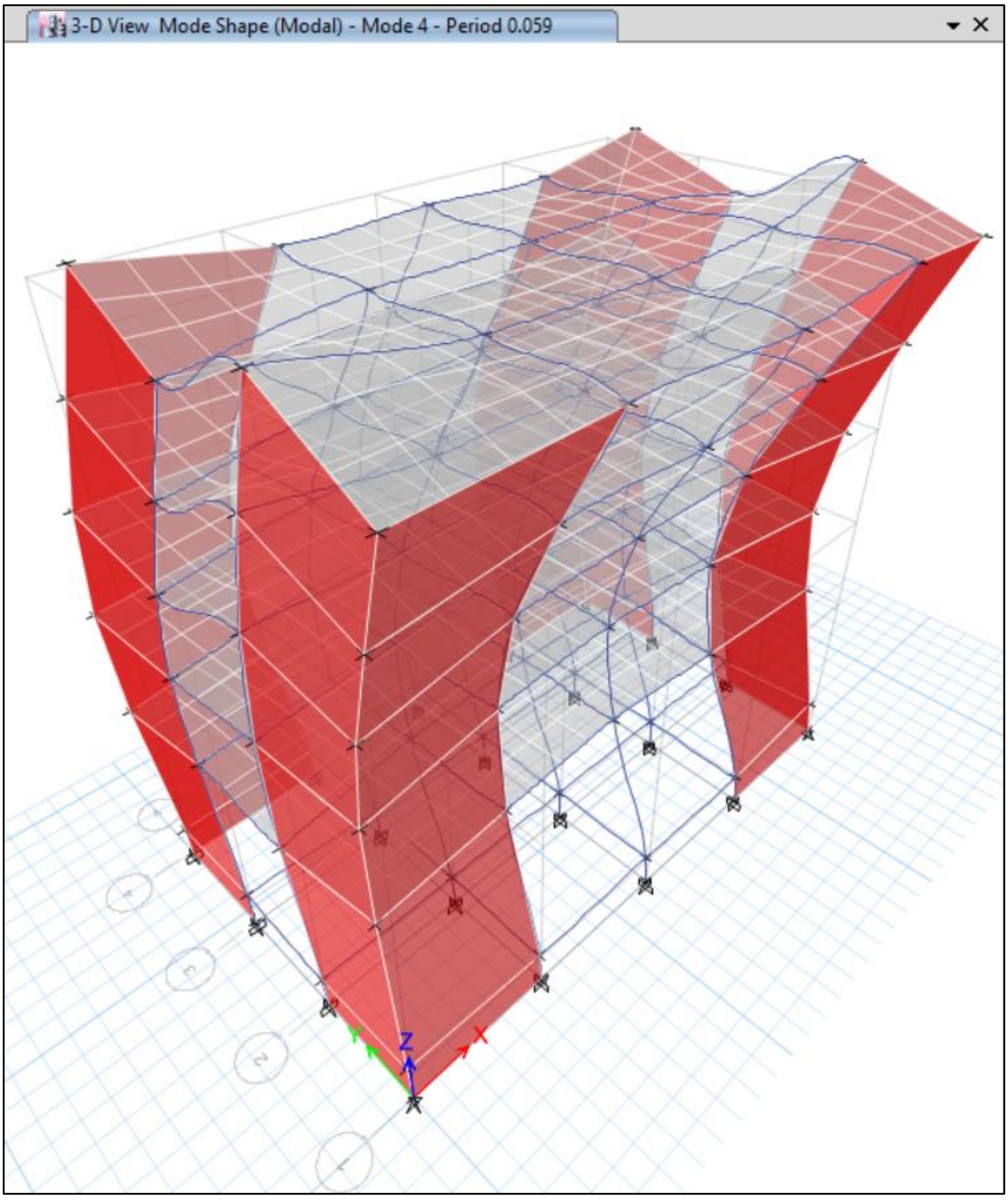


Fig. 65 *Mode Shape 3 Shear Wall*



3-D View Mode Shape (Modal) - Mode 4 - Period 0.059

Fig. 66 Mode Shape 4 Shear Wall

3.6. Comparative Analysis of 5-Story Building

Modeling of the building – Using the model used in this research, the mass and stiffness distributions were examined while considering dynamic interaction. The number of columns, beams, slabs, walls, and other elements in the structure were inputted using E-tabs. Story loads were calculated by entering fixed loads as well as loads on floors based on the purpose of each room.

DISPLACEMENT DATA						
	Story 1	**Story 2**	**Story 3**	**Story 4**	**Story 5**	**Story 6**
Fixed Base	6.169	123.398	186.238	234.663	268.519	287.319
Base Isolators	81.708	100.907	109.138	115.014	118.975	121.179
Shear Wall	0.489	5.586	11.081	17.338	23.8	29.974
VELOCITY DATA						
Fixed Base	60.36	1234.02	1843.02	2308.47	2641.24	2834.39
Base Isolators	408.36	502.71	543.14	572.15	592.16	603.64
Shear Wall	9.46	204.09	391.98	605.34	829.07	1046.46
ACCELERATION DATA						
Fixed Base	763.23	14546.11	19475.1	23108.17	26253.91	29108.79
Base Isolators	2312.5	2594.69	2739.44	2858.42	2986.4	3111.71
Shear Wall	888.72	11500.97	16804.98	22189.97	29078.09	37946.29

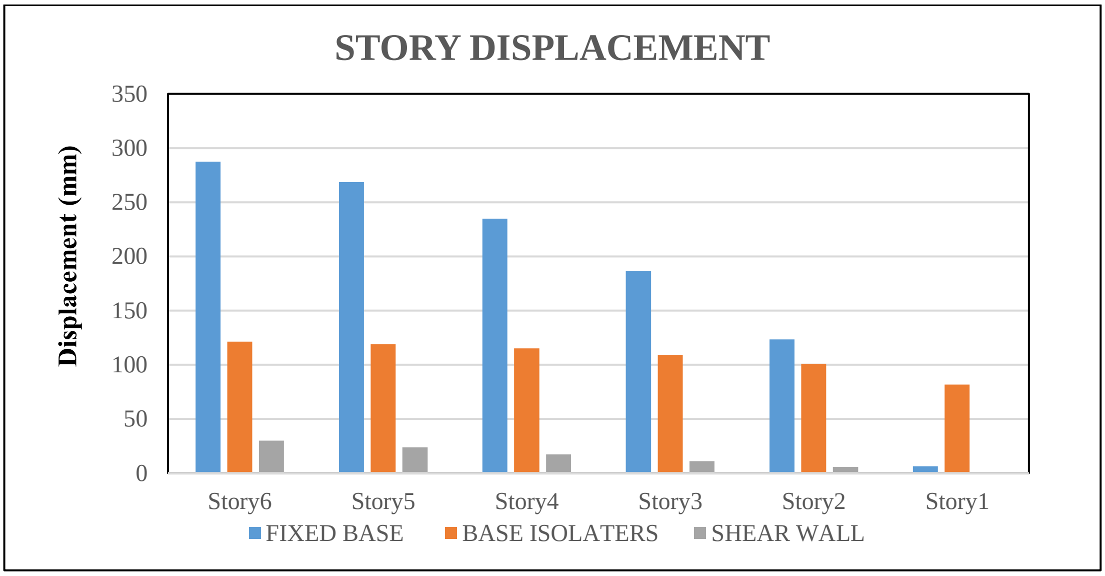


Fig. 67 *Displacement Graph (Fixed Base vs Base Isolators vs Shear wall)*

The overall displacement on each floor in relation to the ground or a fixed foundation is shown here. According to IS standards, a particular value is only authorized, and any construction that exceeds that amount will result in the structure failing.

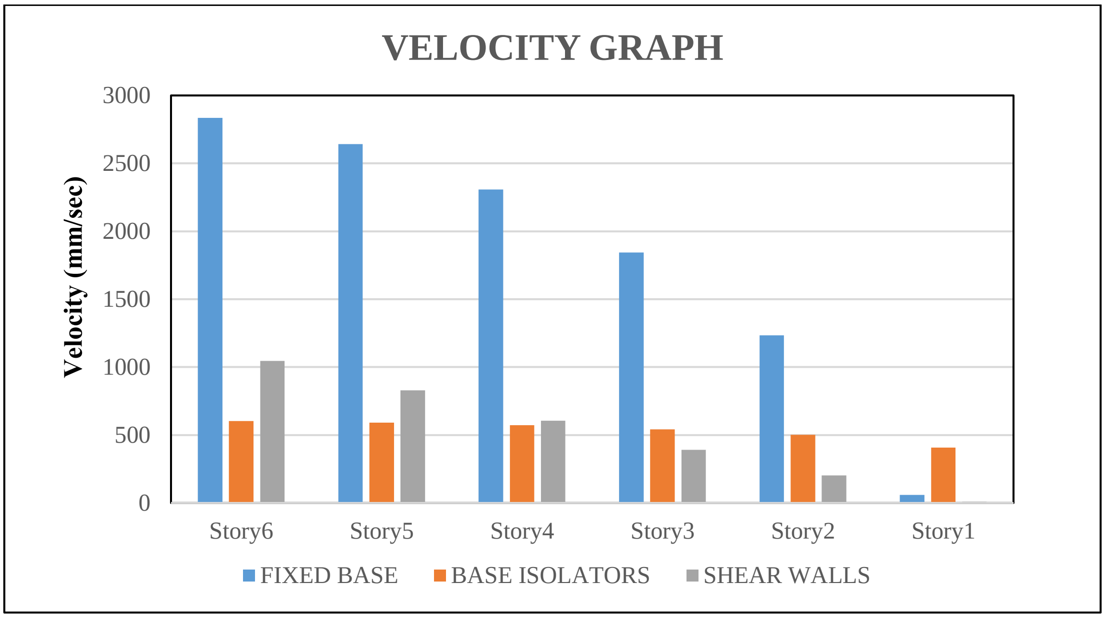


Fig. 68 *Velocity Graph (Fixed Base vs Base Isolators vs Shear wall)*

Regarding the graph of velocity

As we are examining the structure in 3D, the velocity in each direction is different. We have a graph comparison here where the change is readily visible.

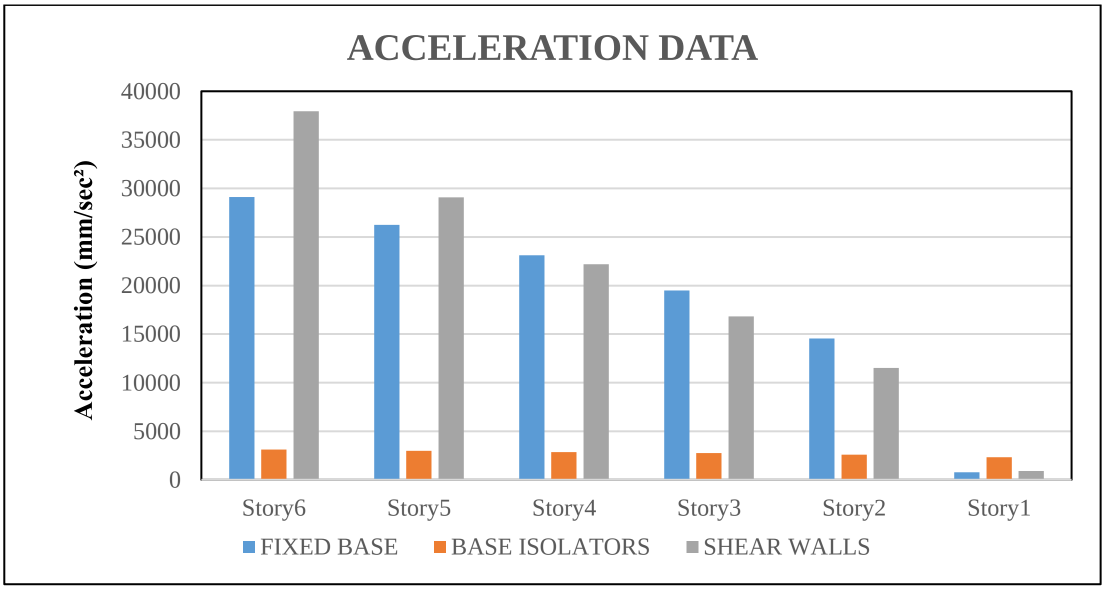


Fig. 69 *Acceleration Graph (Fixed Base vs Base Isolators vs Shear wall)*

Each floor's acceleration is also lowering to a significant degree, which is a positive indicator.

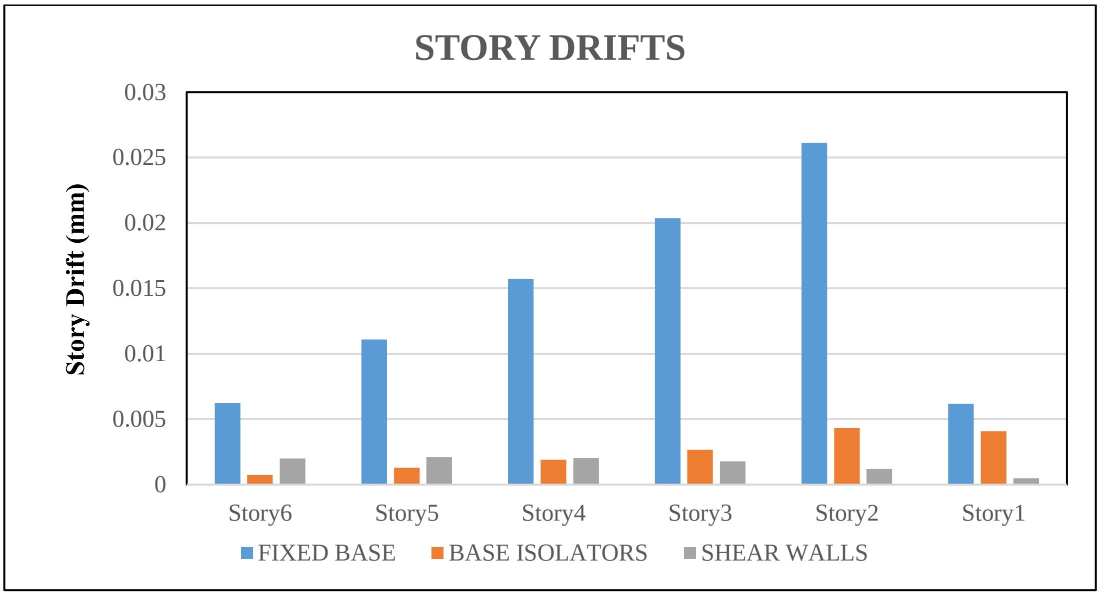


Fig. 70 *Story Drift Graph (Fixed Base vs Base Isolators vs Shear wall)*

It is the relative displacement of one level in relation to another level (level above or below). The greater the story displacement, the greater the structural damage.

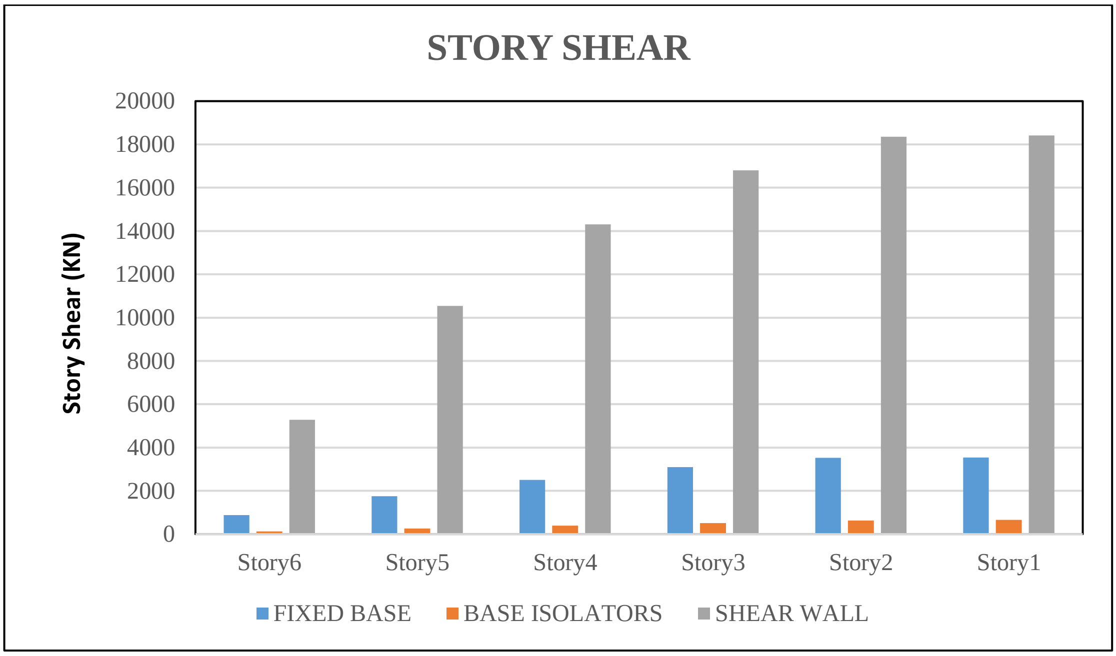


Fig. 71 *Story Shear Graph (Fixed Base vs Base Isolators vs Shear wall)*

Total shear on each level - This shows the total lateral load governing in a certain direction, which is decreasing in the Shear wall structure as compared to the fixed foundation.

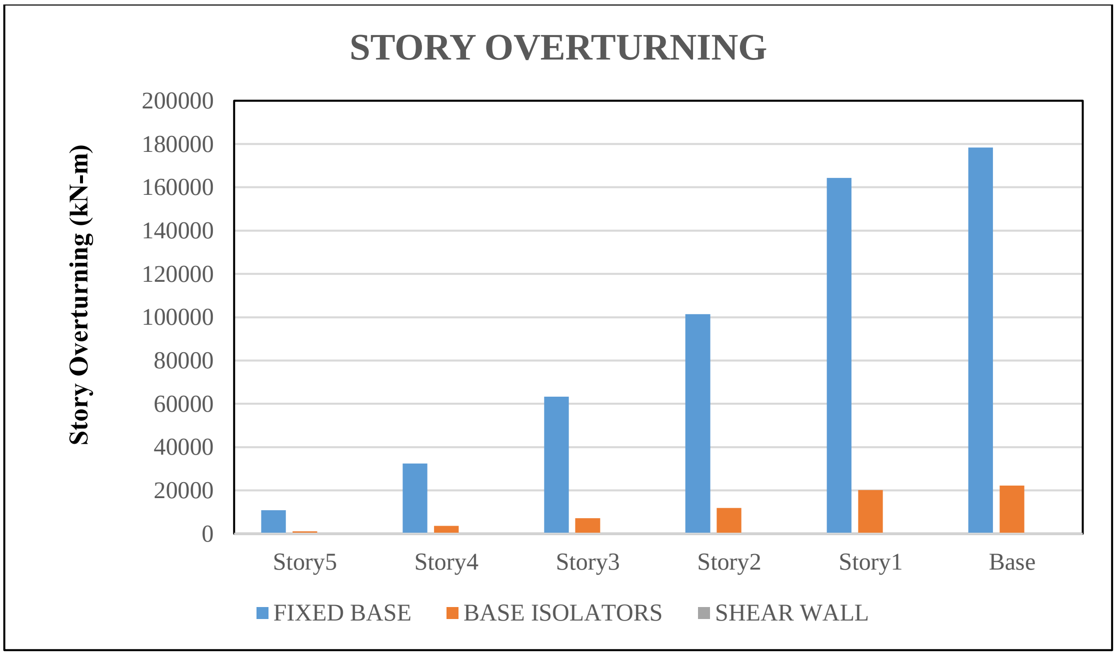


Fig. 72 *Story Overturning Graph (Fixed Base vs Base Isolators vs Shear wall)*

Each floor's Overturning is also lowering to a significant degree, which is a positive indicator.

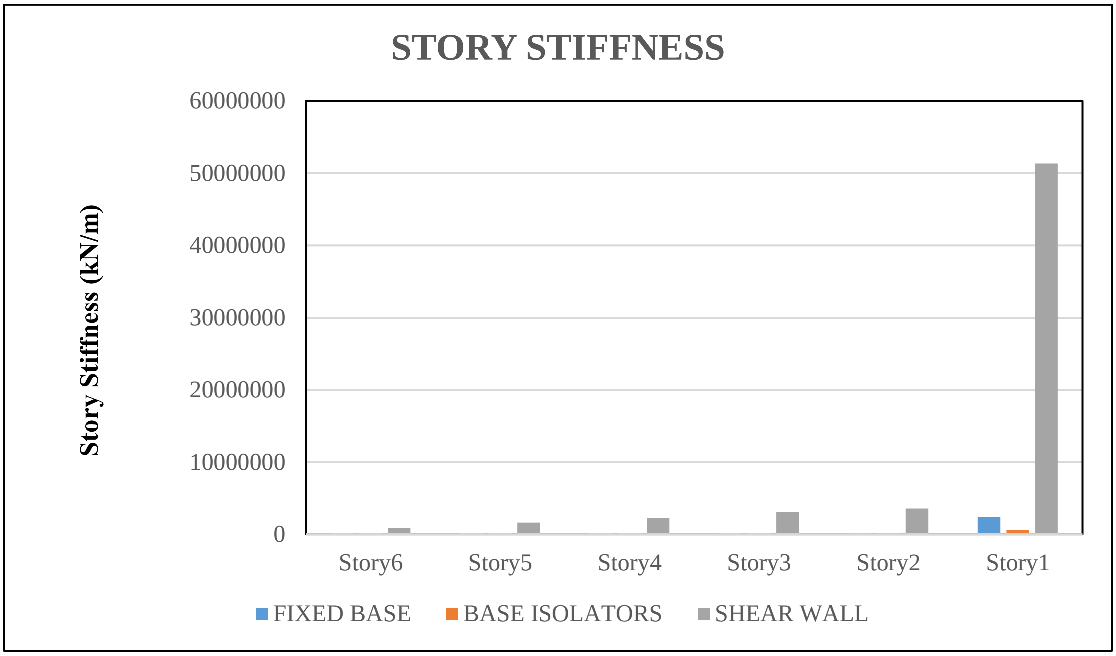


Fig. 73 *Story Stiffness Graph (Fixed Base vs Base Isolators vs Shear wall)*

RESULT:

We'll look at the differences between Model-1, which has a fixed base, Model-2, which has Base Isolators, and Model-3, which has a Shear wall. The results show that the 3rd Model has reduced variance in Story Displacement, Story Drift, and Story Overturning. The building's rigidity will be increased in the third model. However, as compared to the fixed base mode and Base Isolator, the variance in the maximum displacement of stories in the model is quite minimal.

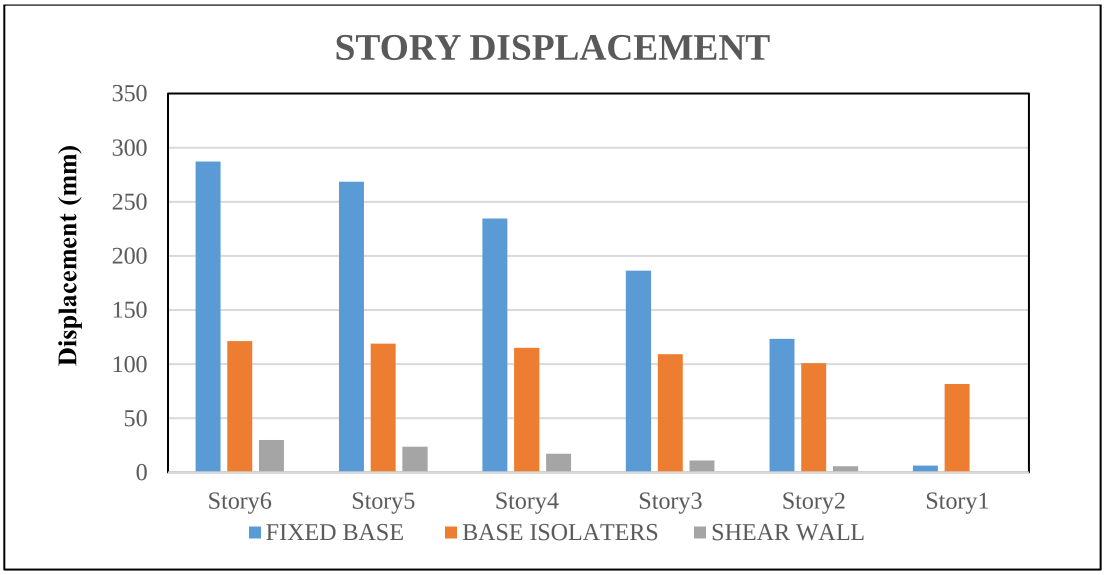


Fig. 74 *Story Displacement Graph*

We can deduct from the graph above that including a shear wall into our building design will reduce the displacement response of each story throughout the earthquake period.

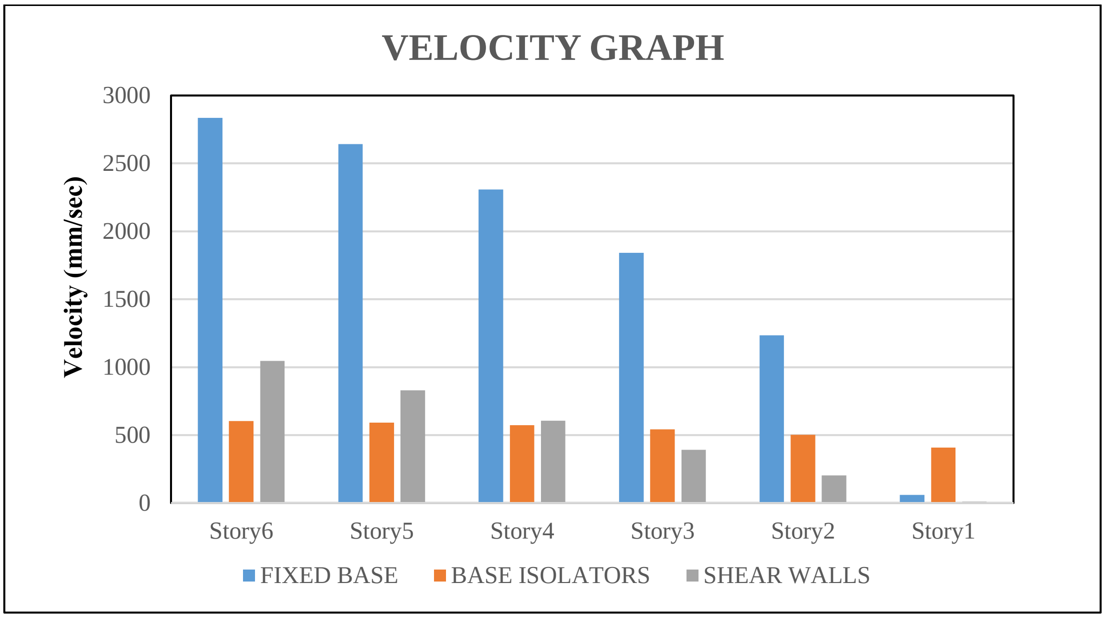


Fig. 75 *Story Velocity Graph*

During the seismic period, a shear wall provides the structure with the lowest velocity response when compared to a fixed base and base isolation.

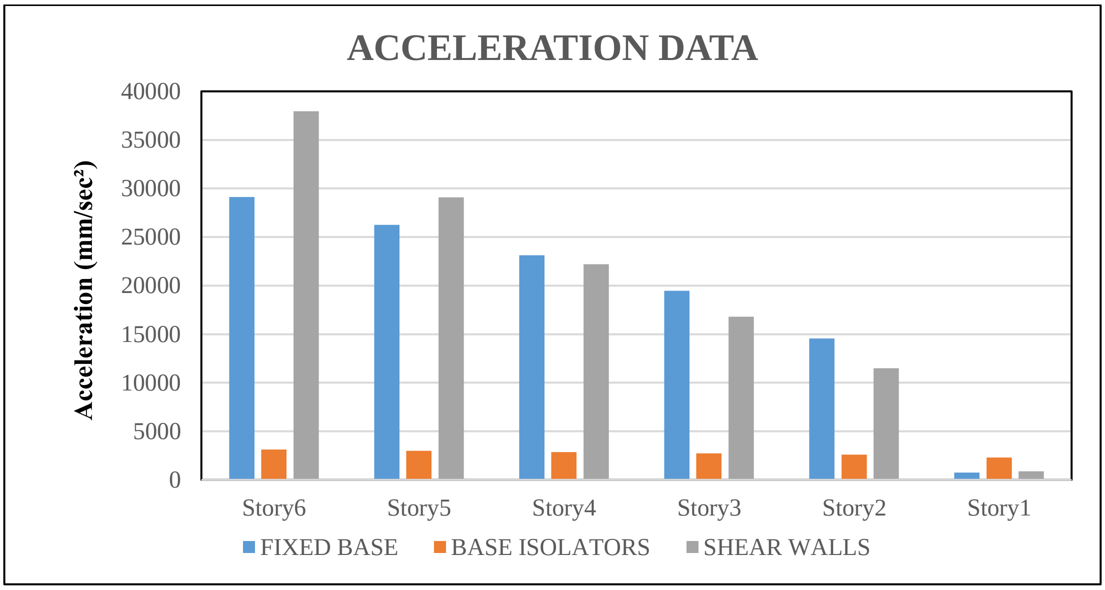


Fig. 76 *Story Acceleration Graph*

We can see from the graph that when we use a shear wall in our building design, we receive the highest value of acceleration response during the earthquake period when compared to fixed base and base isolation.

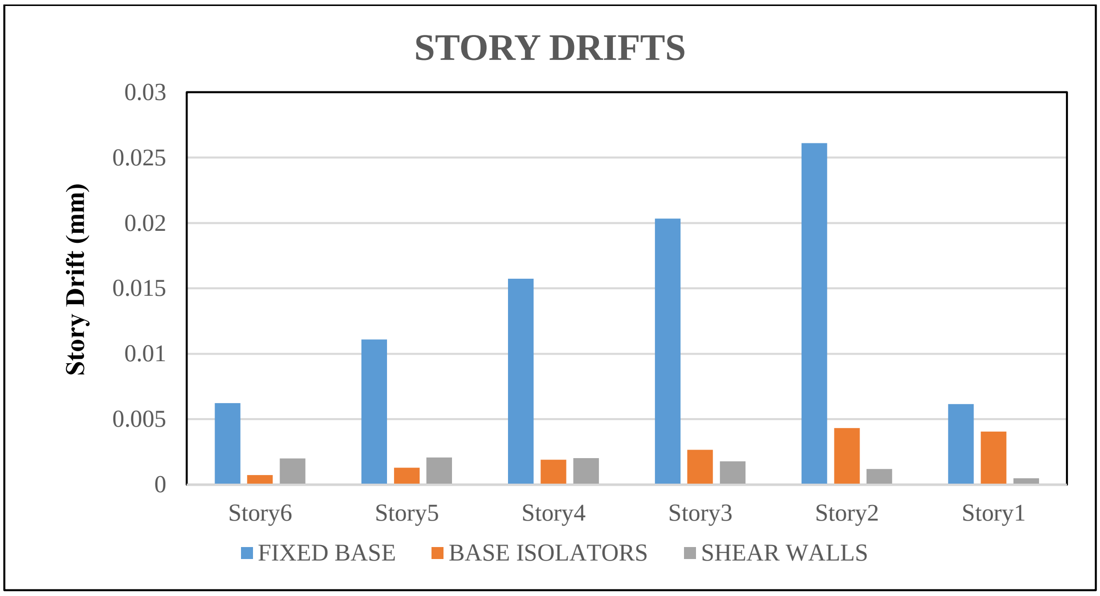


Fig. 77 *Story Drift Graph*

In comparison to fixed base and base isolation, adopting a shear wall in our building design results in the least amount of story drift during a seismic event.

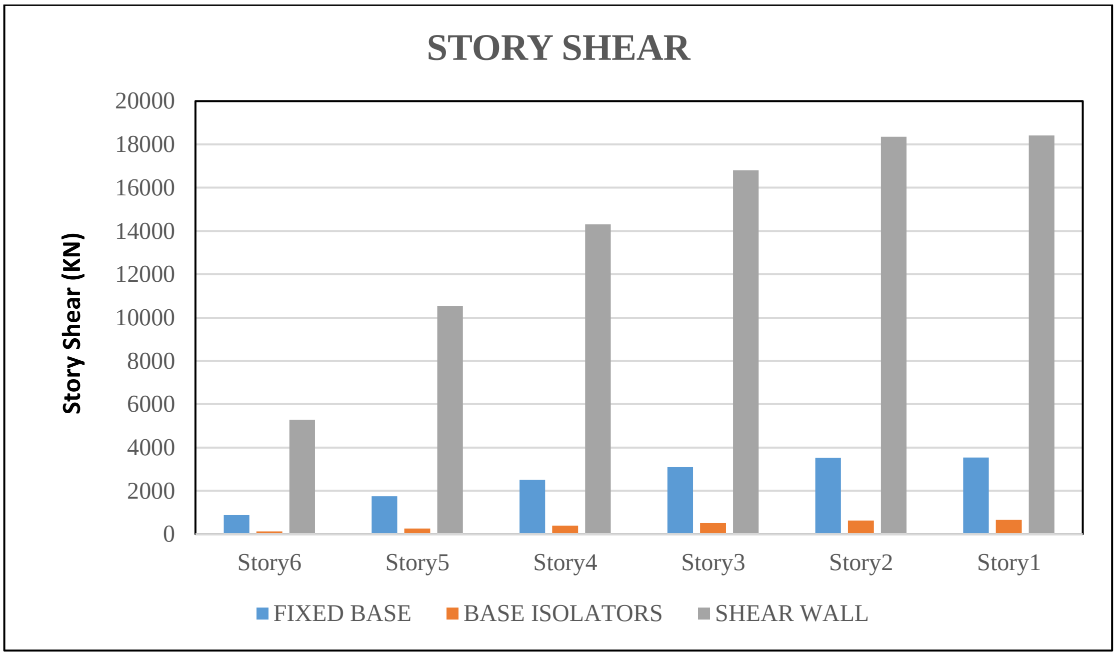


Fig. 78 *Story Shear Graph*

Based on the graph above, we can conclude that with a fixed base, base isolation, and shear wall, we can achieve the highest possible story shear during an earthquake.

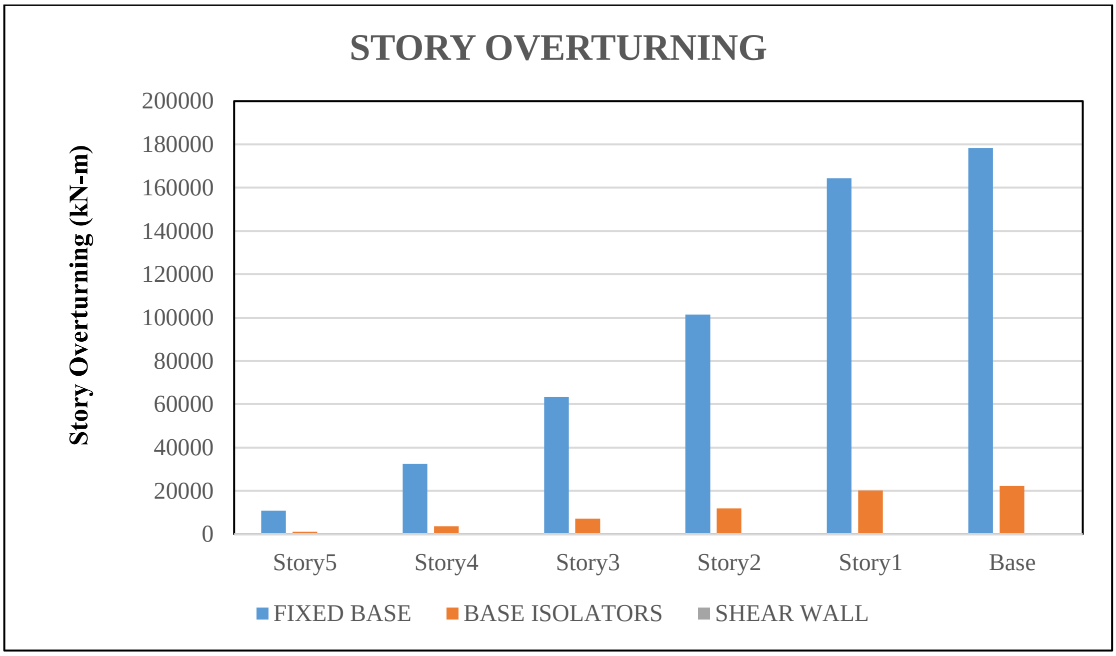


Fig. 79 *Story Overturning Graph*

We acquire a minimal story overturning reaction of the structure during the earthquake period by employing a shear wall in our construction. As a result, the likelihood of the structure collapsing is lowered.

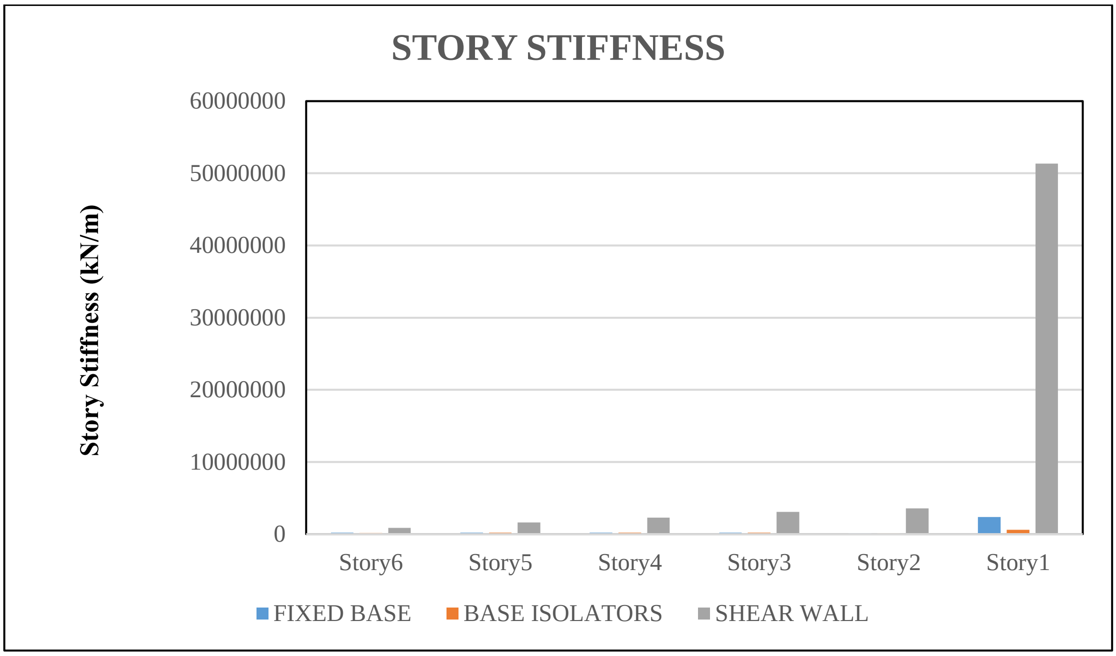


Fig. 80 *Story Stiffness Graph*

The total stiffness of the structure is strengthened by employing a shear wall in our building design to withstand lateral pressures, uplift force, story shear, and other seismic forces, which strengthens and enhances the durability of our construction.

CHAPTER- 4

CONCLUSION

- ☐ Shear walls are particularly critical in high-rise buildings, although base isolation is appropriate for both tall and small structures.
- ☐ We achieve lowest levels of displacement, velocity, story drift, and other seismic parameters by building shear walls into our construction.
- ☐ In comparison to a shear wall, we receive the least amount of acceleration, story forces, and story overturning moments when we use base isolation in our structure design.
- ☐ The additional rigidity given by the shear wall reduces a building's lateral sway, making it stronger and more durable during a seismic event.
- ☐ The Lead Rubber Bearing (LRB) helps to reduce tale shear, hence boosting earthquake resilience. The system is earthquake-resistant because story drift in upper stories is avoided.
- ☐ After LRB is used as a base isolation mechanism, the base isolator boosts structural resilience and reduces strengthening, making the construction more cost-effective.

References:

- ASCE-41. 2006. Seismic Rehabilitation of Existing Buildings. In *ASCE/SEI 41*: Structural Engineering Institute
- BIS (2002a) IS 1893 (Part1), Criteria for earthquake resistant design of structures – part 1
- Birajdar, B. G., and S. S. Nalawade. 2004. Seismic Analysis of Buildings Resting on Sloping Ground. In Thirteenth World Conference on Earthquake Engineering (13WCEE). Vancouver, Canada
- Detlof von Winterfeldt, Nels Rosewnd, and Alica Kitsuse. 2003. Framing Earthquake Retrofitting Decisions: The case of Hillside Homes in Loss Angeles. Pacific Earthquake Engineering Reasearch Center
- Dalal Sejal P , Vasanwala S A, Desai A K Performance based seismic design of structure: A review Evolution of Performance Based Plastic Design (PBPD)
- “Earthquake Resistant Design of Structures” by Aggarwal P
- “Earthquake Resistant Design of Structures” by Shashikant K Duggal
- Kumar A, Sharma ML (ed) (2010) Earthquake engineering, vol 1. In: Proceedings of the 14th symposium on EQ engineering, IIT Roorkee, Elite Publishing House, Pvt Ltd, Delhi
- Kumar, Satish 1996. Seismic analysis of setback and setback buildings, Earthquake engineering, University of Roorkee, Roorkee.
- KSCE Journal of Civil Engineering (2008) 12(3):187-196
- Paul, D. K., and Kumar S. (1997). Stability analysis of slope with building loads. Soil Dynamics and Earthquake Engineering 16:(6), 395-405.
- Radmila B. SALIC , Mihail A. GAREVSKI and Zoran V. MILUTINOVIC RESPONSE OF LEAD-RUBBER BEARING ISOLATED STRUCTURE
- Dall'Asta A, Ragni L (2008). Nonlinear behaviour of dynamic systems with high damping rubber devices. Eng. Struct.

- 3610-3618. 29. Deb S (2004). Seismic base isolation-an overview. Current Sci., 87(10): 1426-1430.
- Dicleli M, Buddaram S (2007). Comprehensive evaluation of equivalent linear analysis method for seismic-isolated structures represented by sdof systems. Eng. Struct., 29: 1653-1663.
- Hong W, Kim H (2004). Performance of a multi-storey structure with a resilient-friction base isolation system. Comput. Struct., 82: 2271-2283.
- Hussain RR, Islam ABMS, Ahmad SI (2010). Base Isolators as Earthquake Protection Devices in Buildings: VDM Publishing House Ltd. Benoit Novel, simultaneously published in USA & U.K.
- Islam ABMS, Ahmad SI, Al-Hussaini TM (2010a). Effect of Isolation on Buildings in Dhaka In: 3rd International earthquake Symposium, BES; 5-6 March; Bangladesh, Dhaka pp. 465-472.
- Hidalgo., “An analytical model to predict the inelastic seismic behaviour of shear wall, reinforced concrete structures”, Earthquake resistant structures, 29,87-92, 2002
- Martinez “An analytical model to predict the inelastic seismic behaviour of Shear-wall, reinforced concrete structures” Engineering Structures 24 (2002) 85–98
- Duggal S. K.(2010), “ Earthquake Resistant Design of Structures”. Oxforrd University press YMCA library building, Jai Singh road, New Delhi.
- Jangid RS, Kelly JM. “Base isolation for near-fault motions.” Earthquake Engineering and Structural Dynamics 2001; 30: 691-707.
- Earthquake Engng Struct. Dyn. 2006; 35:1403–1424 Published online 19 June 2006 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/eqe.589
- Detlef von Winterfield, Nels Rosewnd, and Alica Kitsuse. 2003. Framing Earthquake Retrofitting Decisions: The case of Hillside Homes in Loss Angeles. Pacific Earthquake Engineering Reasearch Center.
- Kumar, S., and D.K Paul. (1998). “A Simplified Method for Elastic Seismic Analysis of Hill Buildings”, Journal of Earthquake Engineering 2:(2), 241-266.
- Kumar, Satish 1996. Seismic analysis of setback and setback buildings, Earthquake engineering, University of Roorkee, Roorkee.
- Mukherjee Sushovan, and Vinay K. Gupta. (2002). “Wavelet-based generation of spectrum-compatible time-histories” Soil Dynamics and Earthquake Engineering 22:(9– 12), 799-804.
- Paul, D. K., and Kumar S. (1997). “Stability analysis of slope with building loads” Soil Dynamics and Earthquake Engineering 16:(6), 395-405.

- Dall'Asta A, Ragni L (2006). "Experimental tests and analytical model of high damping rubber dissipating devices" Eng. Struct., 28: 1874-1884
- J. Enrique Martinez-Rueda and A. S. Elnashai. A novel technique for Retrofitting of Reinforced Concrete Structure. Engineering Structures, Vol. 17, No. 5, pp. 359-371 (1995).
- Jaswant N. Arlekar, Sudhir K. Jain and CVR Murty Effect of Infill walls on Soft Ground Storey Buildings. Proceedings of the CBRI, Golden Jubilee Conference on Natural Hazards in Urban Habitat (1997).

  Traver E. Kelly, R.Evan Skinner & Bill (W.H) Robinson. Seismic isolation for Designers and Structural engineers.
- R. S. Jangid and T.K. Datta. Seismic behaviour of base isolated building - A-state-of-the-art-review. Journal of Structures and Buildings, Institution of Civil Engineers, UK, Vol. 110, pp. 186-203, (1995).
- R.S. Jangid and J.M. Kelly. Base isolation for near-fault motions. Earthquake Engineering and Structural Dynamics, USA, Vol. 30, pp. 691-707 (2001).
- M.K. Shrimali and R.S. Jangid. Seismic response of liquid storage tanks isolated by sliding bearings. Engineering Structures, USA, Vol. 24, pp. 909-921 (2002).
- James M. Kelly. A seismic base isolation: review and bibliography. Soil Dynamics and Earthquake Engineering, Vol. 5, Issue 4, pp. 202- 216 (1986).

Figure Sources:

Fig 1. Interior of the earth: http://eschool.iaspaper.net/hydrosphere/geosphere/

Fig. 2 Types of Inter-Plate Boundaries: https://earthquakesandplates.wordpress.com/2008/05/13/plate-boundaries-and-their-manymotions/boundaries/

Fig. 3 Elastic Strain Built up and Elastic Rapture: IITK-BMTPC

Fig.4 Types of Fault: https://www.ucl.ac.uk/seismin/explore/earthquakes.html

Fig. 5 Motions caused by Body and Surface Waves: https://www.sciencefacts.net/seismic-waves.html

Fig. 6 Basic terminology Source- IITK BMPTC

Fig 7. : Flow chart of Seismic design: https://www.enventure.com/blog/importance-of-seismic-design-in-building-engineering/

Fig.8 Building performances during earthquakes: two extremes – the ductile and the brittle: https://theconstructor.org/structural-engg/seismic-design-philosophy-for-buildings/2781/

Fig. 10 Diaphragm Sourcehttp://www.ideers.bris.ac.uk/resistant/stren gth_diaphrams.html

Fig. 11 Components of Building: https://earthqukesinindia-stsm.weebly.com/technology.html

Fig 12. Seismic isolator base displacement at base level: https://www.bridgestone.com/products/diversified/antiseismic_rubber/method.html

Fig 13 Isolation reduced the damages caused during an earthquake: https://civildigital.com/base-isolation-system-outline-on-principles-types-advantagesapplications/

Fig. 14 Elastomeric Rubber Bearing: https://civildigital.com/base-isolation-system-outline-on-principles-types-advantagesapplications/

Fig 15 Roller and Ball Bearings: https://civildigital.com/base-isolation-system-outline-on-principles-types-advantagesapplications/

Fig. 16 Spring Isolators: https://civildigital.com/base-isolation-system-outlineon-principles-types-advantages-applications/

Fig. 17 Sliding Isolator: https://civildigital.com/base-isolation-system-outline-on-principles-types-advantagesapplications/

Fig. 18 Reinforced Concrete Shear Wall: https://dailycivil.com

Fig. 19 Column supported shear walls: https://wrengineers.in

Fig. 20 Core type shear walls: https://wrengineers.in

Fig. 21 Rigid frame shear walls: https://wrengineers.in

Fig. 22 Framed walls with infilled frames: https://wrengineers.in

Fig. 23 Simple rectangular types and flanged walls: https://wrengineers.in

Fig. 24 Cantilever Shear Wall: https://wrengineers.in

Fig. 25 Coupled shear walls: https://wrengineers.in

Fig. 26 RC Shear Wall: https://wrengineers.in

Fig. 27 Plywood Shear Wall: https://wrengineers.i

Fig. 28 MIDPLY Shear Wall: https://dailycivil.com

Fig. 29 RC Hollow Concrete Block Shear Wall: https://wrengineers.in

Fig. 30 Steel Plate Shear Wall: https://wrengineers.in

Fig. 31 Coupled Shear Wall: https://brainkart.com