ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

Influence of Plan Irregularity on The Seismic Response of Base Isolated Structures

A Thesis submitted to the School of Graduate Studies in Partial fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Structures stream)

By

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(October 2016)

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DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

Irregularities are not avoidable in the architectural design of building; however, the behavior of structures with these irregularities during earthquake needs to be studied especially for a structure with base isolation.

Buildings with plan irregularity behave differently as compared to regular buildings with base isolation. The influence of plan irregularity is examined for a ten-story reinforced concrete office building which composes of different plan configurations and support conditions (Nonlinear Supports and building with fixed support) when it is subjected to seismic loading. To compare the responses of the irregular base isolated, structure a regular structure is also considered. For seismic analysis of building time history analysis was carried out.

The structure consists of beams and columns with reinforced concrete slabs and isolated system supported provided. The analysis was done by using structural analysis software program ETABS 2015. Even though there are different types of base isolators lead rubber bearing was used as a Nonlinear Support. The structural response of the sample system is investigated hereafter with reference to the following performance parameters: Storey displacement, story acceleration, and natural period, base shear of the structure.

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CHAPTER ONE

INTRODUCTION

1.1.Background

Earthquakes are one of nature's greatest hazards; throughout historic time they have caused significant loss of life and severe damage to property, especially in the regions more susceptible to earthquake. This can be seen from the recent damages in Japan, Haiti and even in our country Hawassa. On the other hand, earthquakes provide architects and engineers with a number of important design criteria foreign to the normal design process. From well established procedures reviewed by many researchers, seismic isolation may be used to provide an effective solution for a wide range of seismic design problems.

The application of the base isolation techniques to protect structures against damage from earthquake attacks has been considered as one of the most effective approaches and has gained increasing acceptance around the world. This is because base isolation limits the effects of the earthquake attack, a flexible base largely decoupling the structure from the ground motion, and the structural response accelerations are usually less than the ground acceleration. In general, the increase of additional viscous damping in the structure may reduce displacement and acceleration responses of the structure.

Base isolation is one of the most widely accepted seismic protection systems in earthquake prone areas. It mitigates the effect of an earthquake by essentially isolating the structure from potentially dangerous ground motions, especially in frequency range where building is mostly affected. Seismic isolation is a design strategy, which uncouples the structure for the damaging effects of the ground motion. The term isolation refers to reduced interaction between structure and the ground. When the seismic isolation system is located under the structure, it is referred as "base isolation".

There are so many isolators but, in this study lead rubber bearing is used since it is widely used now a day. Seismic isolation which can be considered as an important method in providing an effective engineering solution for the prevention of earthquake damage to buildings. It has often been suggested that base isolation of buildings may be achieved by introducing base supports with large elastic flexibility for horizontal motions. The choice of the flexibility of the base mounts and of the effective force of the hysteretic dampers depends on the sizes of the design earthquakes, and on the characteristics and installed costs of the base-isolator components. A suitable compromise between building protection and isolator costs may be achieved with flexible mounts of laminated rubber.

The component of the building, which resists the seismic forces, is known as lateral force resisting system. The lateral force resisting system of the building may be of different types. The most common forms of these systems in a structure are special moment resisting frames, shear walls and frame-shear wall dual systems. The damage in a structure generally initiates at location of the structural weak planes present in the building systems. These weaknesses trigger further structural deterioration which leads to the structural collapse. These weaknesses often occur due to presence of the structural irregularities in stiffness, strength and mass in a building system. The structural irregularity can be broadly classified as plan and vertical irregularities.

1.2. Statement of the problem

Seismic isolation is a new trend in the earthquake resistant structural design, embodying a great potential for the future. Conventional approach in earthquake resistant structural design focuses on the prevention of total collapse of the structure under the impact of severe earthquake. As the performance shown by the structure, this approach, depends on the damage suffered by the structural members, it began to lose its acceptability gradually now a day. Briefly, this perception, while being adequate in building structures not collapsing under the earthquake; falls short when the structures not were being damaged in the earthquake are required. If the previously acceptable damage levels now becoming unacceptable for various reasons (due to the change in seismic zones of areas), this means that a need is born for. And due to the growth of population in seismic areas there is a need of building high-rise apartments and this leads to new methodology in the design of earthquake resistant structures.

Seismic isolation is now commonly used especially in the repair and strengthening projects of the historical structures for the purpose of protecting the original architectural characteristics of the structure and its sensitive and valuable content; even though it's not being used in Ethiopia someday there will be a need of using it.

1.3. Objective of the study

The main objective of this thesis is to evaluate the effect of plane irregularity on the response of base isolated structural system. This study is carried out by conducting a comprehensive literature survey and by making comparative analysis among the sample of buildings with different planar shapes. More specifically, this thesis examines whether the regular base isolated structure has better performance than the irregular base isolated structure when subjected to earthquake. To reach this understanding, the structures of a plane regular and plan irregular base-isolated office building of the same area and height but different plan shape were analyzed, and their seismic response is compared.

1.3.1. General objective:

1. To observe the effects of plan irregularities on the seismic response of a ten-story reinforced concrete office building structure.

1.3.2. Specific objective:

1. Investigate which of the plan irregularities under study cause more effect on the structure under seismic ground motion.
2. Assess the impact of base isolation on the response of the structure.
3. Investigate the responses of different plane irregular building frames with that of plane regular structures.

1.4. Significance of the thesis

All structures at some point are subjected to vibration. Recent destructive earthquakes in Haiti, Japan, and also in our country in Hawassa have shown how vulnerable structures and societies remain to natural phenomena. The enormous losses inflicted by such catastrophes have motivated ever more stringent requirements on the performance of structural systems, in an effort to reduce the loss of life, cost of repair and disruption. The cost and performance requirements for both buildings and equipment have motivated advances in the field of Structural Control, which deals with methodologies for the protection of high performance structural systems. even though base isolation has a good influence on isolating the structure from harmful vibration on fixed base structures. The combination of irregular structures with base isolation, may have different result. Thus, this research might answer the question of whether or not plane irregularity has an effect on the response of base isolated structure.

1.5. Methodology

1. In the present study, reinforced concrete moment resisting frame buildings of ten storey with and without base isolation are considered for the purpose of observing the effect of base isolation.
2. In addition, in order to assess the effects of plane irregularity on the response of base isolated structures, different plane irregular base isolated building structures are modeled, analyzed and evaluated. Dynamic characters of base isolated buildings are investigated using lead rubber bearings (LRB). Analysis is done by using ETABS 15.2.0 software. A Time history analysis is carried out for the 1940 El Centro earthquake. The results are tabulated in order to focus the parameters such as lateral story displacements, story acceleration, base shear, fundamental period and inter-storey drifts. The plan layout and elevated view of the buildings are shown in Figure 3.4-3.7.

1.6. Thesis organization

The thesis is divided into seven chapters as follows: -

This introductory chapter presents the background, statement of the problem, objectives of the study, methodology and significance of the thesis.

The first part of Chapter 2 discusses details about Effectiveness of base isolation as present in previous researches. The second part of this chapter presents about base isolation system and irregularities in structures

Chapter 3 presents models considered for analysis and properties of isolators used.

Chapter 4 presents the details of the results obtained in the analysis and the analysis of fixed base and base isolated structures to show the effect of base isolation. The second part of this chapter presents the comparison of different plane irregular base isolated structures response

Chapter 5 presents the conclusions obtained from the above study. It also presents recommendation.

The next two parts contain references considered during the work and appendices for assessment of certain information.

CHAPTER TWO

STATE OF THE ART

2.1. Introduction

The application of the base isolation techniques to protect structures against damage from earthquake attacks has been considered as one of the most effective approaches and has gained increasing acceptance during the last two decades. This is because base isolation limits the effects of the earthquake attack, a flexible base largely decoupling the structure from the ground motion, and the structural response accelerations are usually less than the ground acceleration.

Many studies had been done on the behavior of base isolated structures subjected to earthquake excitation. Some of them are discussed below.

Radmila B. Salic [3] had demonstrated the effect of dynamic response of the seven-story residential building under the earthquake ground motions. Mode shapes, natural frequencies and damping ratios of the existing fixed-base building are obtained. The fixed base model represents the dynamic behavior of the structure and seismic isolated model representing the dynamic behavior of the structure isolated by lead rubber bearing seismic isolation system. Dynamic analysis of both models has been performed by ETABS (Nonlinear version 9.0.4). The finite element model was chosen to satisfy the needs of this analysis. The Dynamic responses of fixed base and seismic isolated models have been calculated for real earthquake time history. The authors have showed that increase of natural period of structure increases flexibility of the same structure. In seismic isolated model, base shear force is highly reduced. Increased flexibility of the system led to increase of the total displacements due to the elasticity of the existing isolation. Implementation of the isolation system resulted into the reduction of the inter-storey drifts. Analysis of seismic isolated model has shown significant reduction of the story accelerations.

Abdolrahim Jalali and P. Narjabadifam [4] had presented comparative study of seismic base-isolation of multi-story buildings and fixed base building. Nonlinear time-history analysis of created models was conducted by using ETABS (8.5.0). Fundamental periods, modal participation factors and base-shears were studied for all of the model buildings. Base-isolation generally falls into the passive category of structural control, while it can be active or passive. In their investigation, the effects of superstructure characteristics on isolation performance, nonlinear time-history analyzed are conducted using ETABS (8.5.0). Comparing base-isolated building with fixed base building, the efficiency of isolation was examined. It has shown the results for fixed-base and base-isolated building. For first mode period in base-isolated building is 2.3 times longer than that of fixed-base building. Modal participation factor of the fundamental structural mode of base-isolated building is 0.4 times lesser than that of fixed-base building. Finally, conclusion was made that superstructure characteristics have a considerable effect on isolation performance.

Varadharajan S. [19] his study summarizes the research works done in the past regarding different types of structural irregularities i.e. Plan and vertical irregularities. Criteria and limits specified for these irregularities as defined by different codes of practice (IS1893:2002, EC8:2004 etc.) had been discussed briefly. He had observed that the limits of both Plan and vertical irregularities prescribed by these codes were comparable. Regarding the vertical irregularities, it was found that strength irregularity had the maximum impact and mass irregularity had the minimum impact on seismic response.

Di Sarno [5] had presented the structural analysis of the complex irregular multi-Storey RC frame used for the hospital building. It was carried out by means of modal analysis with response spectrum. The structure exhibits large mass eccentricity due to its irregularity in shape. The building is provided by circular shape high damping rubber bearing as per required diameter in accordance with Euro Code 8 to act as a base isolation system. The main objective of his study is to improve the earthquake resistant design approach by studying the properties like horizontal flexibility to increase structural period and reduce the transfer of seismic energy to the superstructure; second property is the energy dissipation (due to relatively high viscous damping) to reduce lateral displacements; and last one is the provision of sufficient stiffness at small displacements to provide adequate rigidity to the structure. This case study reveals that base isolation is an effective strategy to improve the seismic performance for relatively flexible framed structures at serviceability point of view. It also concluded that the relatively high horizontal flexibility of the superstructure apparently reduces the beneficial effects of the base isolation system. It is demonstrated that although the base-isolated and the fixed base construction may undergo the same maximum accelerations the structural and non-structural damage are prevented in the frame resting on rubber devices.

Saiful Islam [6] had creating a building model having lot of open spaces to analyze a soft Storey building for seismic loading. The soft Storey creates the major weak point in earthquake which means that during the event when soft Storey collapses, it can make the whole building down. It causes very severe structural damage and building becomes unusable. This research includes the placement of two types of isolators, first is lead rubber bearing (LRB) and second one is high damping lead rubber bearing (HDRB). Each storey is provided by isolators and its consequences were studied for different damping values. Finally, the study reveals that use of isolators is most beneficial tool to protect soft storey buildings under strong earthquake ground motions. Provision of lead rubber bearing is more efficient than high damping rubber bearing because as time period increases in high damping rubber bearing, acceleration also increases which is undesirable to protect building during earthquake. This condition is exactly reverse in case of lead rubber bearing. It has been also shown the response of base isolated building and arrangement of bearing in the building. As damping provides sufficient resistance to structure against service loading, various damping values are taken into account for this investigation. This study also deals with the main requirement for installation of isolators. Finally, it has concluded that the flexibility, damping and resistance to service loads are the main parameters which affects for practical isolation system to be incorporated in building structures.

2.2. Base isolation system

A large proportion of the world's population lives in the regions of seismic hazards. They are at risk from earthquakes of varying severity and frequency of occurrence. Earthquake causes significant loss of life and damage of property every year. The seismic wave’s first strike the building at foundation level. As the waves travel through the building, deformation happens. After the earthquake, the buildings turn out to be non-useful which may be dangerous in a few structures. Especially, irregular buildings are more vulnerable to earthquakes. Structural engineers are attempting to fabricate earthquake safe buildings by ceasing or by lessening the vibrations from the earthquake from coming to the building through different techniques. [8]

The concept of base isolation is explained through an example building resting on frictionless rollers. When the ground shakes, the rollers freely roll, but the building above does not move. Thus, no force is transferred to the building due to shaking of the ground; simply, the building does not experience the earthquake. Now, if the same building is rested on flexible pads that offer resistance against lateral movements, then some effect of the ground shaking will be transferred to the building above. If the flexible pads are properly chosen, the forces induced by ground shaking can be a few times smaller than that experienced by the building built directly on ground, namely a fixed base building. The flexible pads are called base-isolators, whereas the structures protected by means of these devices are called base-isolated buildings.

The main feature of the base isolation technology is that it introduces flexibility in the structure. As a result, a medium-rise reinforced concrete building becomes extremely flexible. The isolators are often designed to absorb energy and thus add damping to the system. This helps in further reducing the seismic response of the building. Several commercial brands of base isolators are available in the market, and many of them look like large rubber pads, although there are other types that are based on sliding of one part of the building relative to the other.

A careful study is required to identify the most suitable type of device for a particular building. Also, base isolation is not suitable for all buildings. Most suitable buildings for base-isolation are low to medium-rise buildings rested on hard soil underneath. High-rise buildings or buildings rested on soft soil are not suitable for base isolation. [2]

Base isolation is a technique that has been used around the world to protect the building structures from the damaging effects of earthquake. The installation of isolator in building at base level significantly increases the time period of the structure, which means it reduces the possibility of resonance of the structure giving rise to better seismic performance of the building.

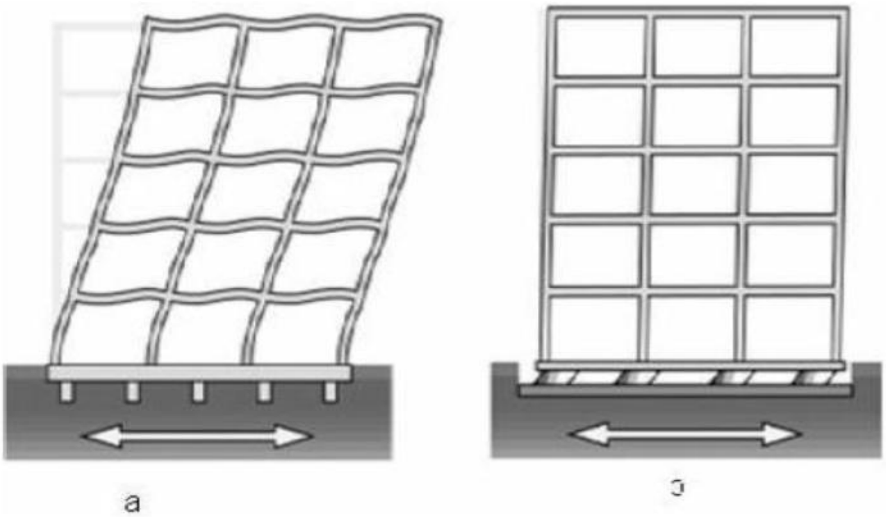


Figure 2.1: the behavior change of structure without isolator and with isolator incorporation

2.2.1. Principle of base isolation

The basic objective with seismic isolation is to introduce horizontally flexible with vertically stiff components that are base isolators at the base of a building to substantially uncouple the superstructure from high-frequency earthquake shaking. The basic concept of base isolation system is lengthening the natural period of the fixed base building. Increasing the period of the structure reduces the spectral acceleration for typical earthquake shaking.

Displacements in isolated structures are often large and efforts are made to add energy dissipation or damping in the isolation system to reduce displacements. The addition of damping to the isolation systems serves to reduce displacements in the seismic isolators, which can translate into smaller isolators. The traditional method of providing earthquake resistant to a structure is by increasing its strength as well as energy absorbing capacity, to reduce the damage of structure by increasing relative displacement of structure when subjected to earthquake, to save the structure from earthquake ground motion and keep it to minimum hazard level.

A seismic isolation system is the collection of all individual seismic isolators and may be composed entirely of one type of seismic isolator, a combination of different types of seismic isolators, or a combination of seismic isolators acting in parallel with energy dissipation devices. The most popular devices for seismic isolation classified as either elastomeric or sliding. Examples of elastomeric isolators include high-damping rubber bearings (HDR), low-damping rubber bearings (RB), or low-damping rubber bearings (LRB) with a lead core. Sliding isolators include flat assemblies or those with a curved surface, such as the friction pendulum.

The ultimate purpose of a base isolation system is to reduce the seismic forces exerted onto a building's superstructure. This reduction in seismic forces is achieved in part by reducing the superstructure's spectral accelerations. These accelerations are reduced both by increasing the effective fundamental period of the isolated structure and through damping caused by energy dissipated within the isolation bearings. The effect that both of these approaches have on spectral acceleration is shown in Figure 2.2.

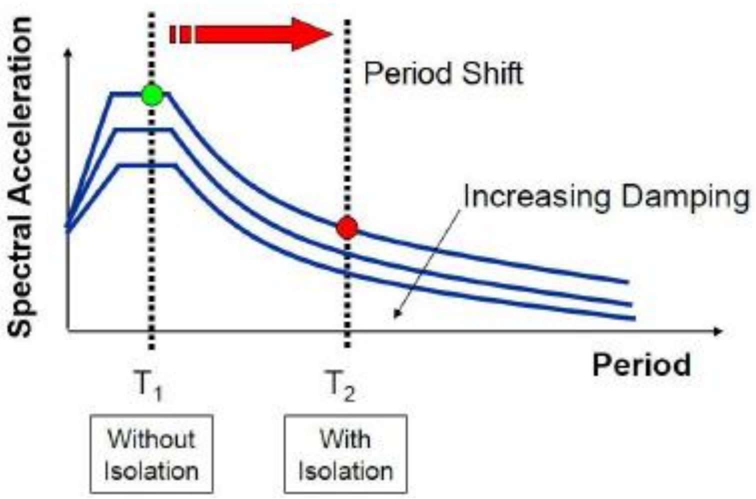


Figure 2.2: Effect of Seismic Isolation on Spectral Acceleration (Source: Symans 2003)

The effective period of the superstructure is increased due to the reduced lateral stiffness of the isolation system. Base isolation is most effective in stiff structures with small periods. The period and stiffness of a structure are inversely correlated, as shown by Equation below:

$$T = 2\pi\sqrt{\frac{M}{K}} \qquad \text{as } K \uparrow \Rightarrow T \downarrow$$

Where T- period

M=mass

K=stiffness

The most significant benefits obtained from isolation are in structures for which the fundamental period of vibration without base isolation is short. The natural period of a building generally increases with increasing height. Taller buildings reach a limit at which the natural period is long enough to attract low earthquake forces without isolation.

2.2.2. Basic elements of seismic isolation system

There are three basic elements in any practical seismic isolation system. These are:

1. A flexible mounting so that the period of vibration of the total system is lengthened sufficiently to reduce the force response;

2. A damper or energy dissipater so that the relative deflections between building and ground can be controlled to a practical design level; and

3. A means of providing rigidity under low (service) load levels such as wind and minor earthquakes.

Bridge structures have for a number of years been supported on elastomeric bearings, and as a consequence have already been designed with a flexible mount. It is equally possible to support buildings on elastomeric bearings, and numerous examples exist where buildings have been successfully mounted on pads. By increasing the thickness of the bearing, additional flexibility and period shift can be attained.

While the introduction of lateral flexibility may be highly desirable, additional vertical flexibility is not. Vertical rigidity is maintained by constructing the rubber bearing in layers and sandwiching steel shims between layers. The steel shims, which are bonded to each layer of rubber, constrain lateral deformation of the rubber under vertical load. This results in vertical stiffness.

2.2.3. Types of base isolators

A critical ingredient of seismic isolation is the introduction of a specially designed stratum
between the structure and the foundation that is both horizontally flexible and vertically stiff. A stratum with these properties is generally achieved through a series of manufactured isolation bearings, whose required performance is specified on a set of contract documents, and acceptance is verified through prototype (quality assurance) and production (quality control) testing.

Manufactured bearings primarily fall into two categories: elastomeric-based or sliding-based. Elastomeric-based bearings take advantage of the flexible properties of rubber to achieve isolation, while sliding-based bearings rely on the inherently low stiffness of a structure resting on its foundation with no connection other than friction at the interface.

The most common type of base isolators used in buildings are

- Laminated Rubber (Elastomeric) Bearing
- Lead Rubber Bearing (LRB)
- Friction Pendulum (FPS) System Bearing

2.2.3.1. Laminated Rubber (Elastomeric) Bearing:

It is composed of alternating layers of rubber that provide flexibility and steel reinforcing plates that provide vertical load-carrying capacity. At the top and bottom of these layers are steel laminated plates that distribute the vertical loads and transfer the sheer force to the internal rubber layer. On the top and bottom of the steel laminated plate is a rubber cover that provides protection for the steel laminated. The steel plates in the bearing force the lead plug to deform in shear. This bearing provides an elastic restoring force and also, by selection of the appropriate size of lead plug, produces required amount of damping.

Performance of LRB is maintained during repeated strong earthquakes, with proper durability and reliability. Sliding bearings: For small vibrations, shear deformation of the rubber layers provides the same isolation effect as conventional multilayer rubber bearings. For large vibrations, sliding materials slide to provide the same deformation performance as large-scale isolation systems. Maximum displacement capacity of this class of bearings is limited by either the plan or height dimensions: typical design capacities for medium seismicity areas range in the order of 200mm with ultimate capacities up to 300mm.The viscous damping is of the order of 5% for normal rubber and in the order of 15%-20% for high dissipating rubber.

2.2.3.2. Lead Rubber Bearing (LRB)

Lead rubber bearings (LRB) are low damping laminated rubber devices with a lead plug inserted in the core. Many isolators include lead-cores that deform in elastically during the earthquake induced motions and provide hysteretic damping. The main aim of the addition of lead is to increase both the stiffness and the energy dissipation capacity at relatively low horizontal force levels like to withstand wind action.

Governed either by the allowable shear strain in the rubber or by the global stability of the device under vertical load. Post-yielding stiffness corresponds to the rubber stiffness and the unloading branch of the force-displacement curve is approximately parallel to the initial stiffness branch up to yielding of the lead plug in the opposite direction. Referring to typical geometries and proportions between lead plug and rubber, the yield force is in the range of one half of the ultimate force and the post-yield stiffness in the range of one tenth of the initial stiffness.

It is also evident that the device has significant hysteretic dissipation. The capacity of lead rubber bearings depends on the ratio between post-yield and initial stiffness and on the ratio between ultimate and yield strength.

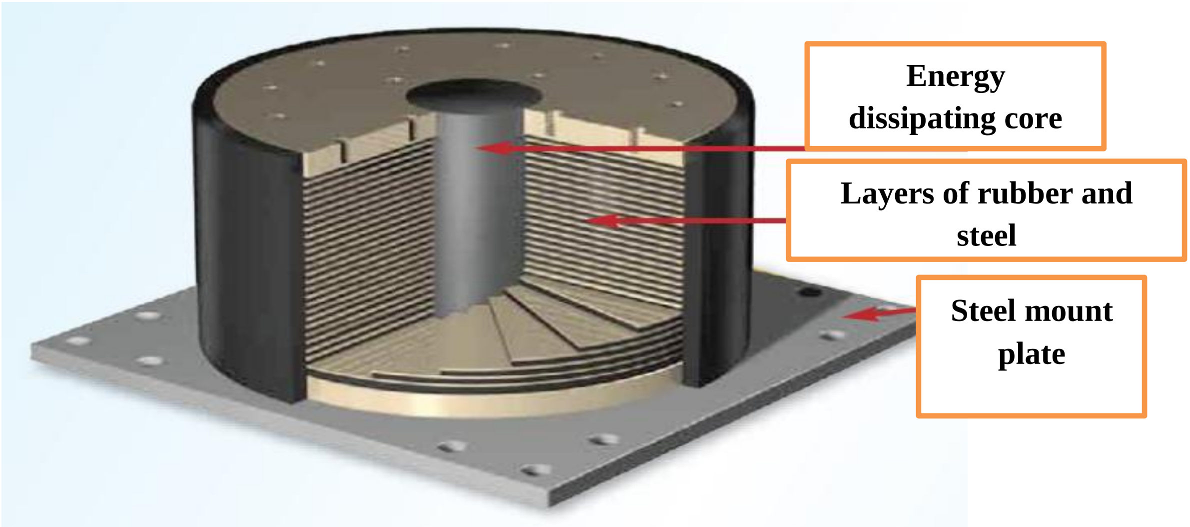


Figure 2.3: lead rubber bearing

2.2.3.3. Friction pendulum system (FPS):

Sliding friction pendulum isolation system is one type of flexible isolation system suitable for small to large-scale buildings. It combines a sliding action and a restoring force by geometry. The friction pendulum system (FPS) is conceptually based on the properties of pendulum motion.

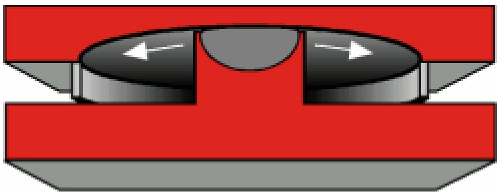


Figure 2.4: Friction pendulum isolator

2.2.4. Analysis of the isolation system

Structural analysis includes Seismic Analysis and is the calculation of the response of a building structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment in earthquake sensitive regions. Even though there are many analysis types the most preferred one for base isolated structure is non-linear time history analysis. Nonlinear Time History Analysis can be used for all isolation systems regardless of height, size, geometry, location, and nonlinearity of the isolation system. [1]

Results of Nonlinear Time History Analysis (NTH) constitute much bigger variation when compared with the other alternatives. If non-linear analysis is performed; it will be more appropriate to select from the manufacturing company's catalogue the ones most appropriate to these values, and to read the non-linear parameters from the laboratory test results of that isolator. [18]

2.3. Irregularities in structures

Different earthquake codes define structural configuration as either regular or irregular in terms of size and shape of the building, arrangement of the structural and non-structural elements within the structure, and distribution of mass in the building etc.

when a building is subjected to seismic excitation, horizontal inertia forces are generated in the building. The resultant of these forces is assumed to act through the center of mass of the structure. The vertical members in the structure resist these forces and the total resultant of these systems of forces act through a point called as center of stiffness. When the center of mass and center of stiffness does not coincide, eccentricities are developed in the buildings which further generate torsion. When the buildings are subjected to lateral loads, then phenomenon of torsional coupling occurs due to interaction between lateral loads and resistant forces. Torsional coupling generates greater damage in the buildings. Eccentricity may occur due to presence of structural irregularities. These irregularities may be broadly classified as Plan (Horizontal) and Vertical irregularity as shown in figure 2.5.

2.3.1. Vertical irregularity

Vertical irregularity results from the uneven distribution of mass, strength or stiffness along the elevation of a building structure. Mass irregularity results from a sudden change in mass between adjacent floors, such as mechanical plant on the roof of a structure. Stiffness irregularity results from a sudden change in stiffness between adjacent floors, such as setbacks in the elevation of a building.

2.3.2. Plan irregularity

Asymmetric or plan irregular structures are those in which seismic response is not only translational but also torsional, and is a result of stiffness and/or mass eccentricity in the structure.

Structures may have plan and elevation irregularities these depend on geometry, lateral stiffness and strength distributions, mass ratios along the height, mass - resistance eccentricity and discontinuity in diaphragm stiffness. Regular structures are likely to exhibit uniform energy distribution, hence uniform damage distribution under earthquake actions. [9]

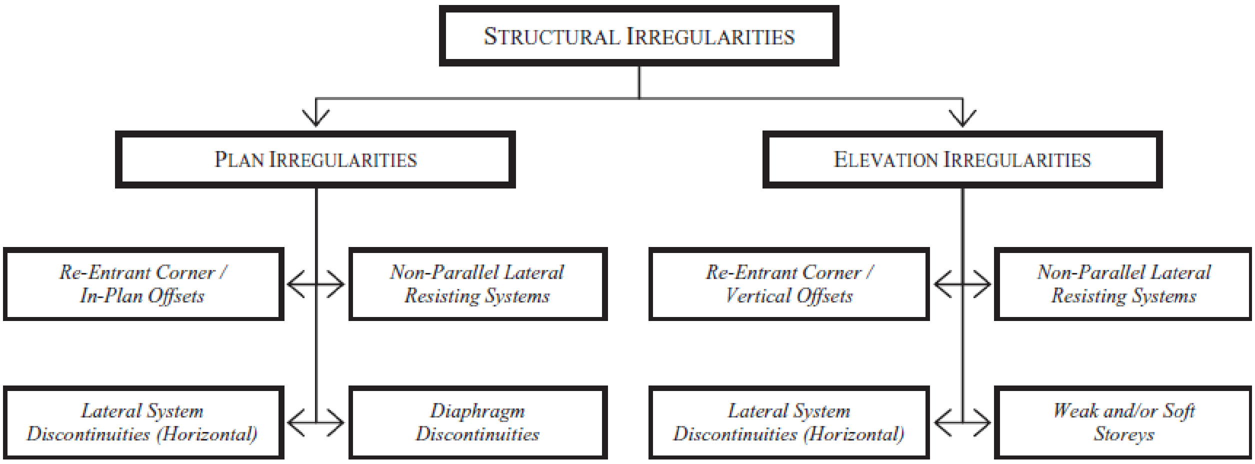


Figure 2.5: Typical structural irregularities

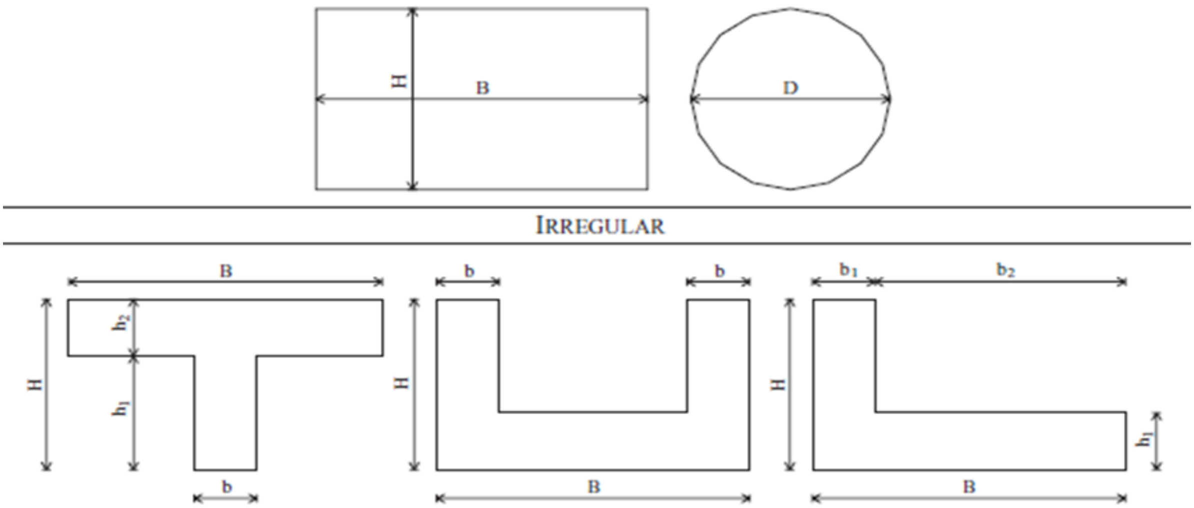


Figure 2.6: Common regular and irregular shapes for plan layout

Structures with regular plan configurations are compact, i.e. described by polygonal convex lines. Square, rectangular and circular shapes are compact. Square or rectangular configurations with minor re - entrant corners can still be considered regular. Large re - entrant corners creating crucifix forms give rise to irregular configurations. The dynamic response of the wings (also termed ‘multi - mass structures’) generally differs from that of the structure as a whole. Multi - mass structures are highly vulnerable at connections between wings. Relative displacements cause severe damage at the intersection of various blocks; torsional effects are likely to occur. Other plan configurations with geometrical Symmetry, e.g. I - and H - shapes, are also irregular because of the response of the wings. [9]

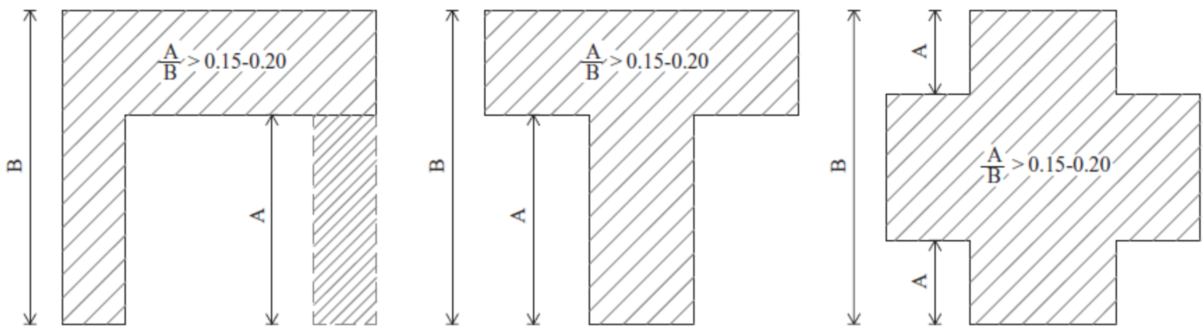


Figure 2.7: Typical limits for plan irregularities (adapted from FEMA 450, 2004)

Plan irregularities depend upon the size of setbacks, i.e. re - entrant corners and edge recesses. Limitations for the setbacks can be expressed as a function of their geometry. For example, for L -, T - and X - sections, the following limitation can be used:

$$\frac{A}{B} > 0.15 - 0.2 \qquad (1)$$

where A and B are the length and the depth of the re - entrance, respectively, as shown in Figure 2.7. Equation (1) provides the limitation included in seismic design recommendations in the USA (e.g. FEMA 450, 2004). Alternatively, regularity in plan may be assumed if, for each setback, the area between the outline of the floor and a convex polygonal line enveloping the floor does not exceed 5% of the total area. This criterion is adopted in European design practice (e.g. Eurocode 8, 2004).

A building structure may have a symmetrical geometric shape without re - entrant corners and wings but can still be classified as irregular in plan, since the distribution of mass or vertical seismic resisting elements may be asymmetric. Torsional effects due to earthquake motions can occur even when static centers of mass C M and resistance C R coincide. For example, ground - motion waves acting at an angle to the building axis also cause torsion, as may crack and yield in a non - symmetrical fashion. Additionally, these effects can magnify torsion due to eccentricity between the static centers. Generally speaking, buildings having an eccentricity between the static center of mass and the static Centre of resistance in excess of 10% of the building dimension perpendicular to the direction of the seismic force are considered irregular. [9]

For a building to be categorized as being regular in plan, it shall satisfy all the conditions.

1. With respect to the lateral stiffness and mass distribution, the building structure shall be approximately symmetrical in plan with respect to two orthogonal axes.
2. The plan configuration shall be compact, i.e., each floor shall be delimited by a polygonal convex line. If in plan set-backs (re-entrant corners or edge recesses) exist, regularity in plan may still be considered as being satisfied,

provided that these setbacks do not affect the floor in-plan stiffness and that, for each set-back, the area between the outline of the floor and a convex polygonal line enveloping the floor does not exceed 5 % of the floor area.

3. The in-plan stiffness of the floors shall be sufficiently large in comparison with the lateral stiffness of the vertical structural elements, so that the deformation of the floor shall have a small effect on the distribution of the forces among the vertical structural elements. In this respect, the L, C, H, I, and X plan shapes should be carefully examined.
4. The slenderness $\lambda = \frac{L_{max}}{L_{min}}$ of the building in plan shall be not higher than 4, where L_{max} and L_{min} are respectively the larger and smaller in plan dimension of the building, measured in orthogonal directions.
5. At each level and for each direction of analysis *x* and *y*, the structural eccentricity e_o and the torsional radius *r* shall be in accordance with the two conditions below, which are expressed for the direction of analysis *y*:

$e_{ox} \leq 0.3 \cdot r_x$

$r_x \geq l_x$

Where

e_{ox} is the distance between the center of stiffness and the center of mass, measured along the x direction, which is normal to the direction of analysis considered;

r_x is the square root of the ratio of the torsional stiffness to the lateral stiffness in the y direction ("torsional radius"); and

l_s is the radius of gyration of the floor mass in plan (square root of the ratio of the polar moment of inertia of the floor mass in plan with respect to the center of mass of the floor to the floor mass). [14]

2.4. Collapses due to plane irregularity

A building structure may collapse or suffer severe damage under the action of seismic forces due to sudden change in mass, stiffness and strength along vertical or a horizontal plane. As discussed in the previous section, presence of structural irregularities trigger the structural collapse. The next subsections give some examples of building failures that have occurred during the past earthquakes due to presence of plan irregularities.

Damage to irregular structures caused by plan irregularity has been observed during many major and minor earthquakes. The non-coincident centers of mass and stiffness in a structure generate plan asymmetry which causes torsional vibration resulting in severe damage to structural components in the more laterally flexible regions of the structure.

Figure 2.8: Damage due to irregularity during Guatemala earthquake 1976; Collapse of second storey due to shear failure of column

Figure 2.9: Damage from irregularity during 1978 Miyagi – Ken – Oki Japan earthquake (Ellingwood 1980):

Figure 3.0: Damage from Irregularity during 2010 Haiti earthquake (Mid America Earthquake Engineering Center, University of Illinois at Urbana Champaign)

CHAPTER THREE

MODELLING AND ANALYSIS OF THE STRUCTURE

This chapter includes the modeling and analysis of the structures that are selected using ETABS 2015 structural analysis software. Materials properties and section properties are defined and assigned. Reinforced concrete frame elements are modeled as beam and column element. Slab is modeled as area element. Modal analysis and time history analysis are performed on models. The structural analysis tool was used to analyze the structure under time history loading. This powerful tool has a nonlinear analysis module ideal for understanding the behavior of isolators, or nonlinear elements. The (Nllink) system that is usually used to model nonlinear local behavior in structures such as gaps, dampers, isolators and others was used to simulated seismic isolation. Every (Nllink) part consists one node representing single spring fixed to earth. Any link part has very small length or consists of two nodes connected together by a link. [10]

The (Nllink) system consists of six springs or dampers. Every one represents a degree of freedom (an axial force, two shear forces, a torque or an overturning moment). In the present study, the (Nllink) system was used to simulate the base isolation produced by lead rubber bearing pad.

3.1. Modal analysis

Modal analysis is the study of the dynamic properties of structures under vibration excitation. In structural engineering, modal analysis uses the overall mass and stiffness of a structure to find the various periods at which it will naturally resonate. A normal mode of an oscillating system is a pattern of motion in which all parts of the system move sinusoidally with the same frequency. Eigenvector analysis determines the undamped free vibration mode shapes and frequencies of the system. These natural modes provide an excellent insight into the behavior of the structure.

3.2. Time history analysis

Time history analysis of the frame was carried out to determine the response of the frame under a given dynamic loading. Time history analysis is the most natural and intuitive approach. The response history is divided into time increments Δt and the structure is subjected to a sequence of individual time-independent force pulses. The nonlinear response is thus approximated by series of piecewise linear systems. In this study, The El Centro 1940 earthquake record was chosen to be part of the analysis as it is regarded as a typical large excitation earthquake. This was used as a basis for many early analyses until larger earthquakes occurred, however due to the extensive use to which this record was used as a benchmark it still has significant usage in many analyses to date.

The time history of El Centro is shown in figure 3.1. The characteristics of this earthquake were recorded and are supplied in the earthquake-input module in ETABS. Time history analysis is more accurate than response spectrum analysis because of the non-periodic nature of earthquakes.

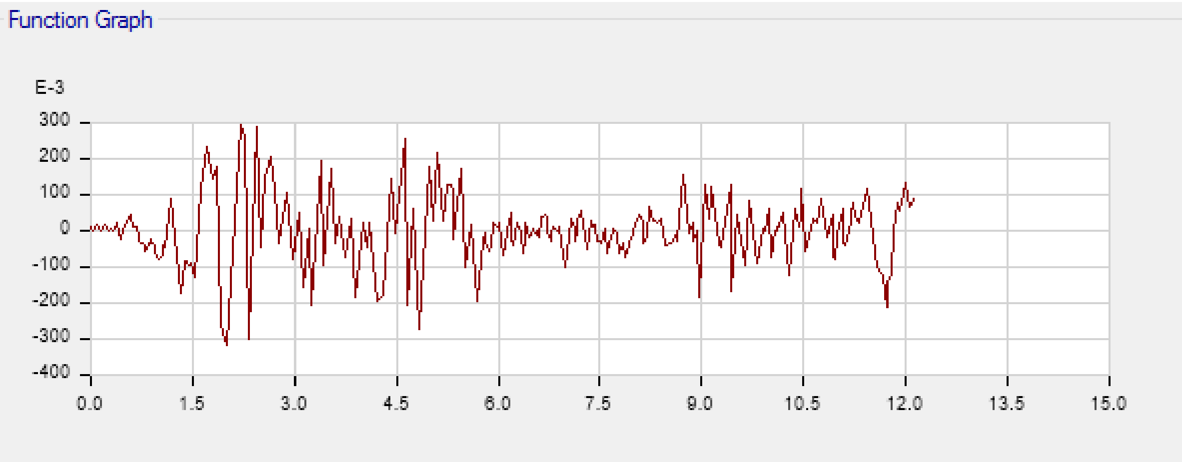


Figure 3.1: Time history function record of El-Centro (from ETABS 2015 window)

3.3. Models considered for analysis

In this study a plane irregular reinforced concrete moment resisting frame buildings of ten stories with and without base isolation are considered. Shear-wall structures and braced-frame structures are generally stiffer than moment frames of equivalent height, and so, for shear walls and braced frames isolation may be effective up to 12 to 15 stories, whereas with moment frames the cut-off is generally about 8 to 10 stories. A total of four types of building models had been considered for the comparison.

Model I: “square” shaped RC building

Model II: “H” shaped RC building

Model III: “L” shaped RC building

Model IV: “U” shaped RC building

3.3.1. The Three-Dimension views of all the models used are shown below.

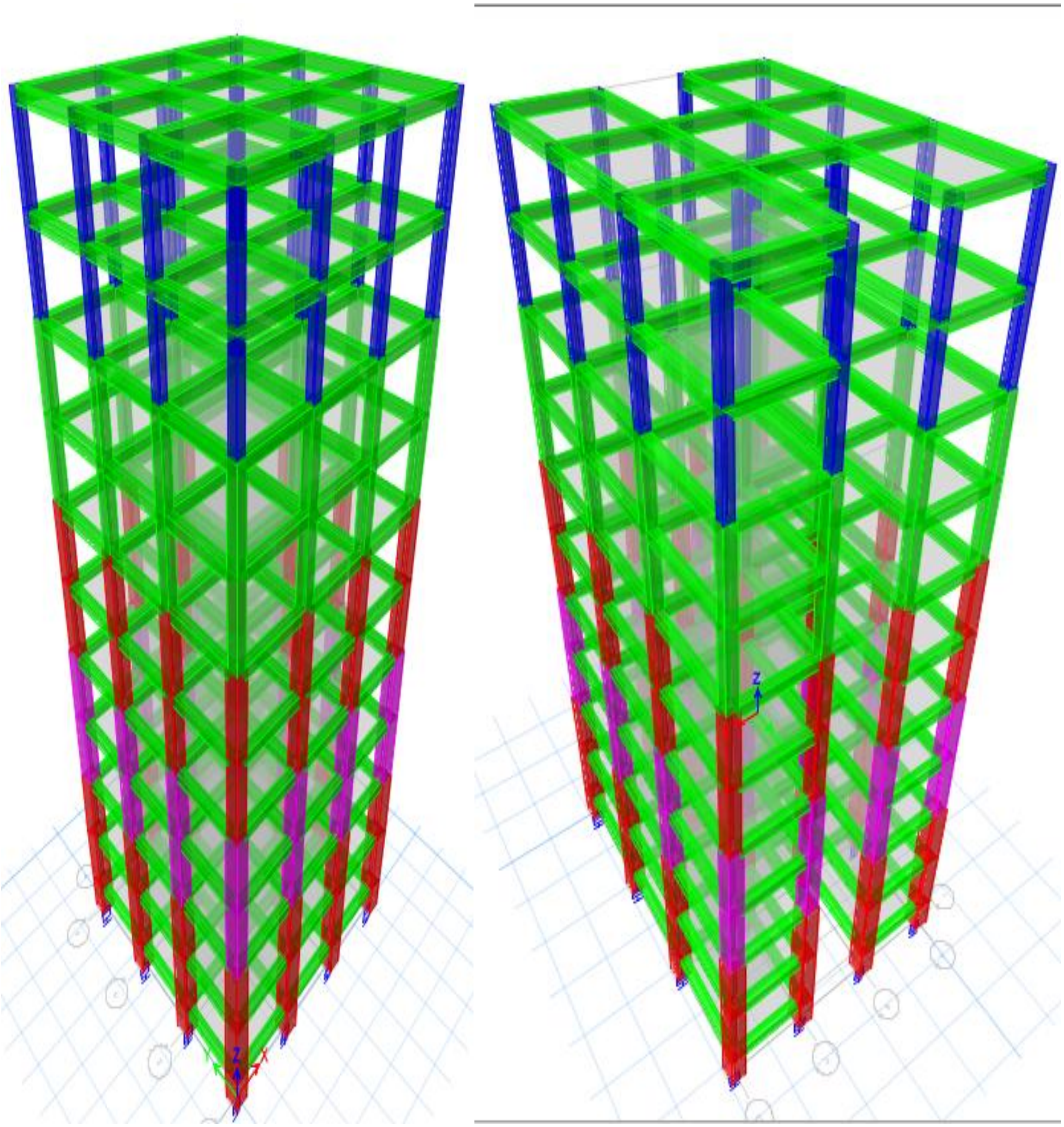


Figure 3.2: Three-dimensional model of Model I and Model II

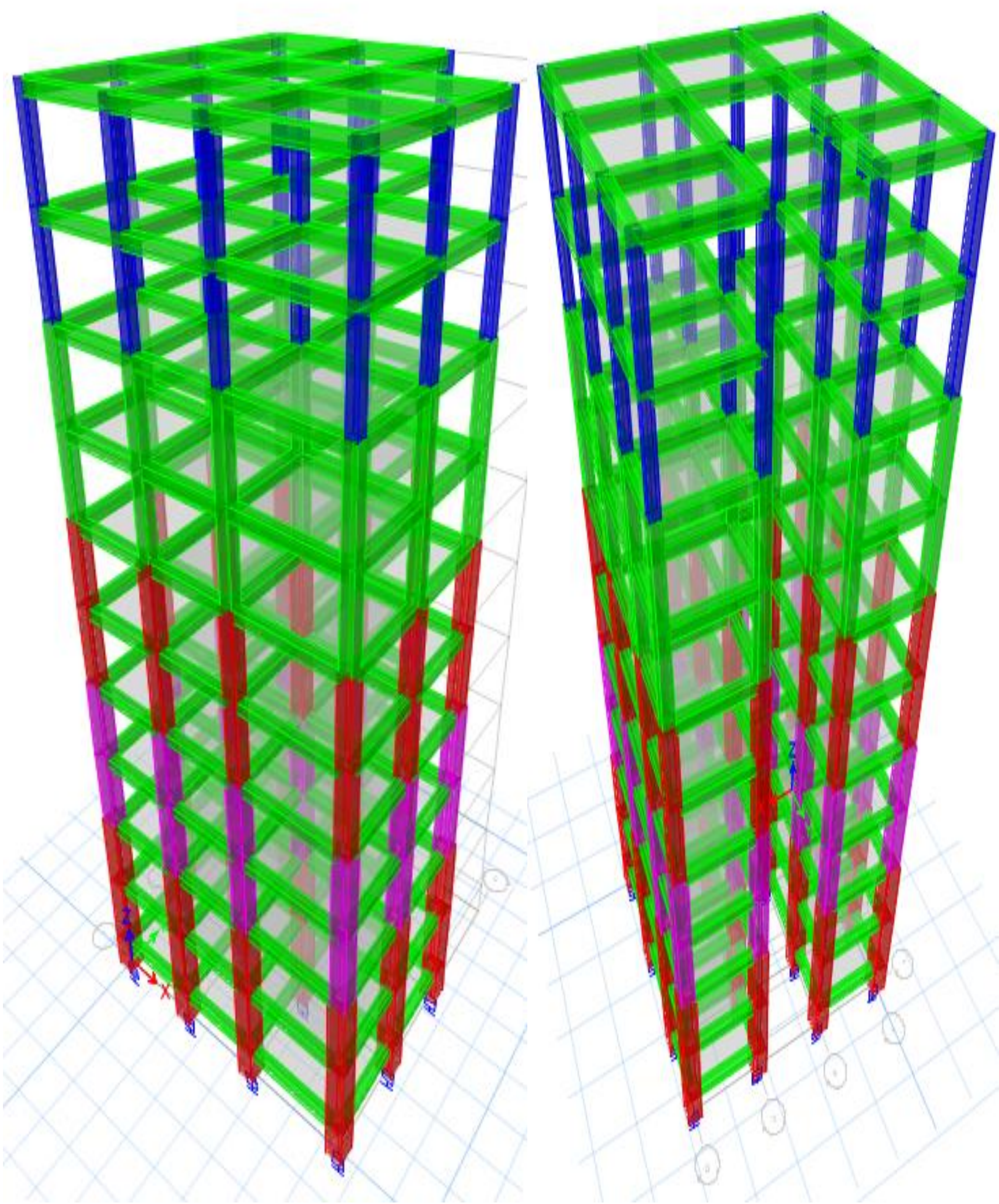


Figure 3.3: Three-dimensional model of Model III and Model IV

3.3.2. Plan view of all the models are shown below

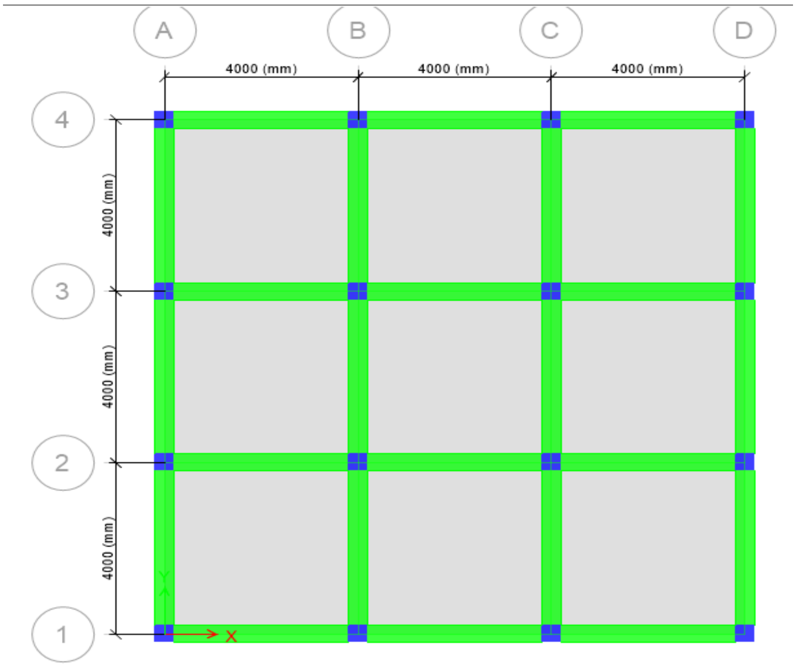


Figure 3.4: planar view of square shaped model

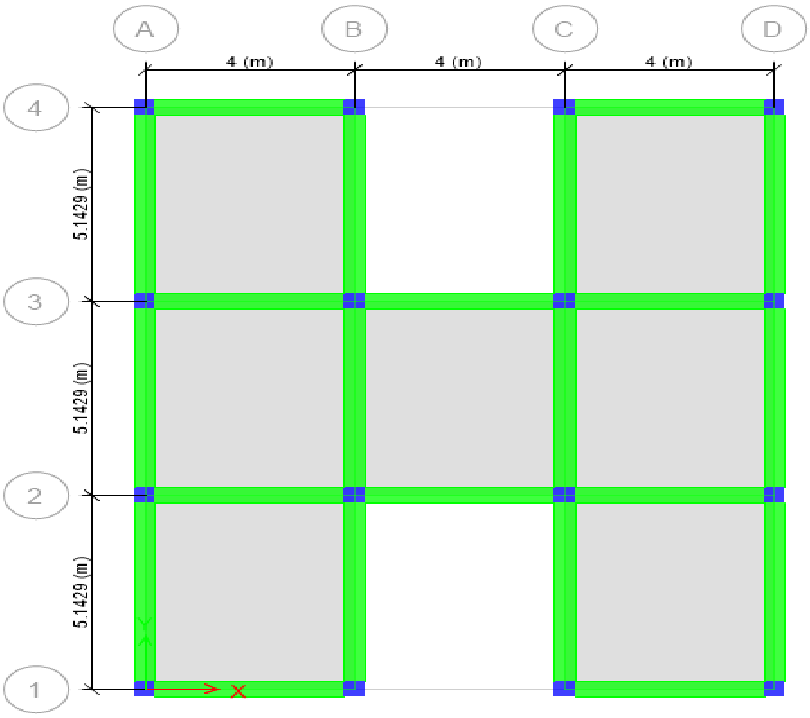


Figure 3.5: planar view of H shaped model

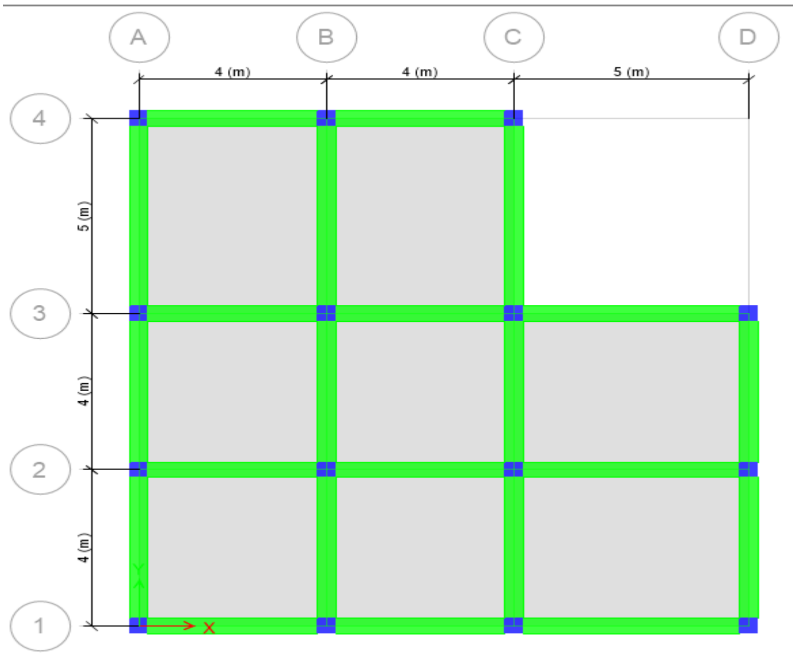


Figure 3.6: planar view of L shaped model

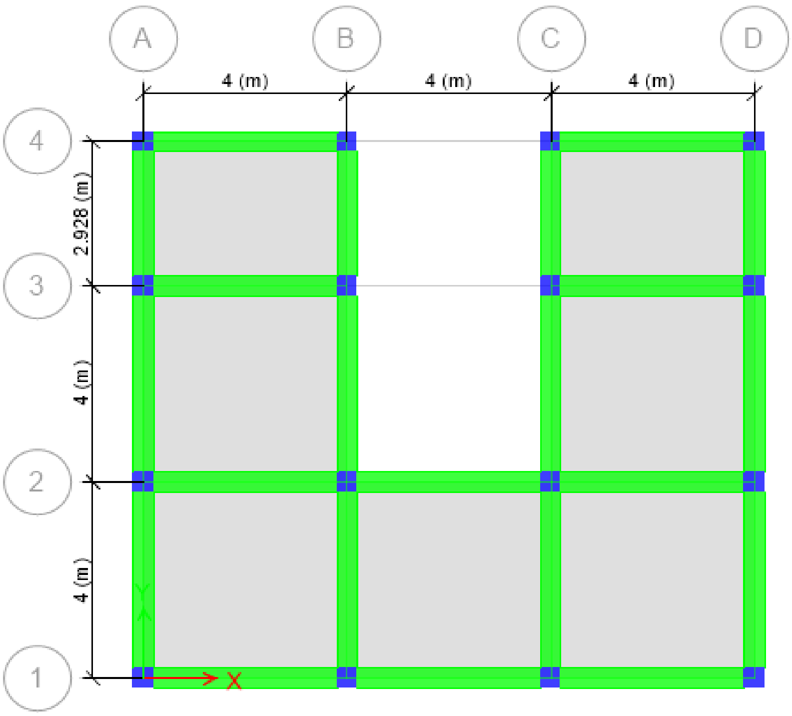


Figure 3.7: planar view of U shaped model

3.4. Section properties

The structures plane area is the same but it has different plane shape. The height of the stories is 3m. The thickness of the floor and the wall is 250mm and 200mm respectively on all stories. The cross-section of the columns used in the structure varies along the height of the structure ,800x800mm, 700x700mm, 600x600mm, 500x500mm,400x400 mm, for each two storey starting from the ground floor. The cross section of the beam is 400x400mm for all stories.

3.5. Structural loading and material properties

The dead load of the slab is 7.89 KN/m^2 including the finishing materials, while the live load value is equal to 3KN/m^2 and 1.5KN/m^2 uniformly applied to slabs for floors other than the roof and the roof respectively. The weight of the slab was distributed as triangular and trapezoidal load to the surrounding beams.

Table 3.1: slab loading data

Components included in the slab weight	Unit weight (γ) (KN/m^3)	Thickness (m)	Force per area (KN/m^2)
Soffit plaster	22	0.02	0.44
Marble	27	0.02	0.54
Cement screed	22	0.03	0.66
Slab	25	0.25	6.25
		Total load	7.89

A wall load of 7.84 KN/m is applied to all the peripheral beams except for the roof which is 1.68KN/m. These loads are taken by assuming the building is to produce similar service at each level of the floors systems.

C25/30 is selected as concrete material with modulus of elasticity of 31GPa and for steel reinforcement S-420.

The lead rubber bearings are modeled using the biaxial model for elastomeric bearings. In the present study, bilinear isolators such as the commonly used lead rubber bearing (LRB) isolation systems were used. The introduction of LRB isolators in the nonlinear time-history analysis was achieved by activating the nonlinear link element of ETABS 2015. The lead rubber properties are, Post yield stiffness ratio is 0.10, having elastic stiffness of 53170.1 kN/m and having effective stiffness 6425.01 kN/m.

Table 3.2: Lead rubber isolator dimensions

Total height of the bearing(cm)	40
Diameter of the bearing (cm)	50
Number of rubber layers	32
Number of steel plates	31
Thickness of steel plates(mm)	2
Diameter of the lead core(cm)	20
Thickness of individual layers(cm)	1
Thickness of the top and bottom cover plate(cm)	2.5

3.6. Lead rubber bearing used for analysis

A variety of isolation devices including elastomeric bearings (with and without lead core), frictional/sliding bearings and roller bearings have been developed and used practically for a seismic design of buildings during the last 25 years. [13] Among the various base isolation systems, the lead rubber bearings (LRB) had been used extensively. It consists of alternate layers of rubber and steel plates with one or more lead plugs that are inserted into the holes. The lead core deforms in shear providing the bilinear response (i.e. adds hysteretic damping in the isolated structure) and also provides the initial rigidity against minor earthquakes and strong winds. The steel plates in the elastomeric bearing gives large plastic deformations.

In this study, the isolators were initially designed to follow some available recommendations of the euro code. For design and analysis, the shape of the nonlinear force–deflection relationship, termed the hysteresis loop (represented as a bilinear curve as shown in Fig. 3.8), that has elastic (or unloading) stiffness K1and a yielded (or post-elastic) stiffness K2 was used.

3.6.1. Mechanical properties of lead rubber bearing

The rubber sheets may be made of natural rubber or artificial elastomer. Due to the presence of steel plates, they have a high bearing capacity, of about 10 MPa in service conditions. Their ultimate shear strain is roughly 500%. A lead core is used to increase the damping by 30%. Ageing and temperature may affect the properties of rubber. In particular, the shear modulus may increase up to 30% over a period of 100 years. The design of the pads aims in particular at obtaining low degradability with time and reliability of properties. The elastomeric properties like shear strain, shear modulus, ultimate elongation, material constant, elastic modulus, bulk modulus, can be taken from manufacturers. [11]

The hysteresis behavior of lead is dependent on the rate of loading. During the high velocity, seismic motion, the yield stress ranges from 10-14Mpa providing significant level of damping. For thermal movements, the yield stress is in the range of 4 to 6 MPa, which imposes small forces on the structure. Intermediate: values of lead stress resist service loads such as wind and braking.

Lead rubber bearings are usually made of alternating layers of steel plates and natural rubber with a central hole into which the lead core is press-fitted. When subjected to lateral shear forces, the lead core deforms almost in pure shear, yields at low level of shear stresses, and produces rather stable hysteretic deformation behavior over a number of cycles. One feature of the lead core is that it can recrystallize at normal temperature and will not encounter the problem of fatigue failure under cyclic loadings. Sufficient rigidity is always ensured by the LRBs for the structure under service loads.

Shear strain is the isolator lateral deformation divided by the rubber height. Design shear strain are up to 250% - 500%. At 500% strain each layer of rubber is deformed laterally to five times its thickness. In high seismic zones, such as san Francisco, Tokyo, Istanbul the isolator displacement is up to 750mm.for structures located farther from fault or on better soil, the isolator displacements are up to 500mm.on low seismic zone such as eastern united states, movements are in a range of 50 to 150mm. [14]

3.6.2. Modeling of lead rubber bearing

For the analysis of base isolated building, the following assumptions are made. Firstly, there is a diaphragm at each floor level to connect all frame substructures (rigid in its own plane). Then, for center of mass (floor mass); each floor has got three degrees of freedom (two translations and one rotation). Second, the isolators are assumed rigid in the vertical direction.

Lead plug bearing or lead rubber bearing are always modeled as bilinear-element with their characteristics based on three parameters K1, K2, and Q. The elastic stiffness K1 is difficult to measure and is usually taken to be an empirical multiple of K2, the post yield stiffness which can be accurately estimated from shear modulus of the rubber and the bearing design. The characteristic strength Q is the intercept of the hysteresis loop and the force axis and is accurately estimated from the yield stress of the lead and the lead plug area. the effective stiffness of the lead plug bearing, defined on basic parameters k1, k2 and Q, it is given by

$$K_{eff} = K_2 \frac{Q}{d_{dc}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots d_{dc} d_y \quad (1)$$

$d_{y=}$ is the yield displacement

The effective damping β_{eff} for $d_{dc} \leq d_y$ is defined to be

$$\beta_{eff=} \frac{(\text{area of hysteresis loop})}{(2\pi \ K_{eff} \ d_{dc}^2)} \quad (2)$$

The area of hysteresis loop is given by $4Q(d_{dc} - d_y)$ to put β_{eff} in terms of these basic parameters we note that

$$d_y = \frac{F_y}{K_1} F_y = Q + K_2 d_y \quad (3)$$

So that $d_y = Q/(K_1 - K_2)$ (4)

Using the definition β_{eff} and the result for K_{eff} we have

$$\beta_{eff} = \frac{4Q(d_{dc} - d_y)}{2\pi(K_2 d_{dc} + Q) d_{dc}} \quad (5)$$

Elastic stiffness is taken as 10k2[2], so that $d_y = \frac{Q}{9K_2}$

$$\beta_{eff} = \frac{4Q(d_{dc} - \frac{Q}{9K_2})}{2\pi(K_2 d_{dc} + Q)d_{dc}} \quad (6)$$

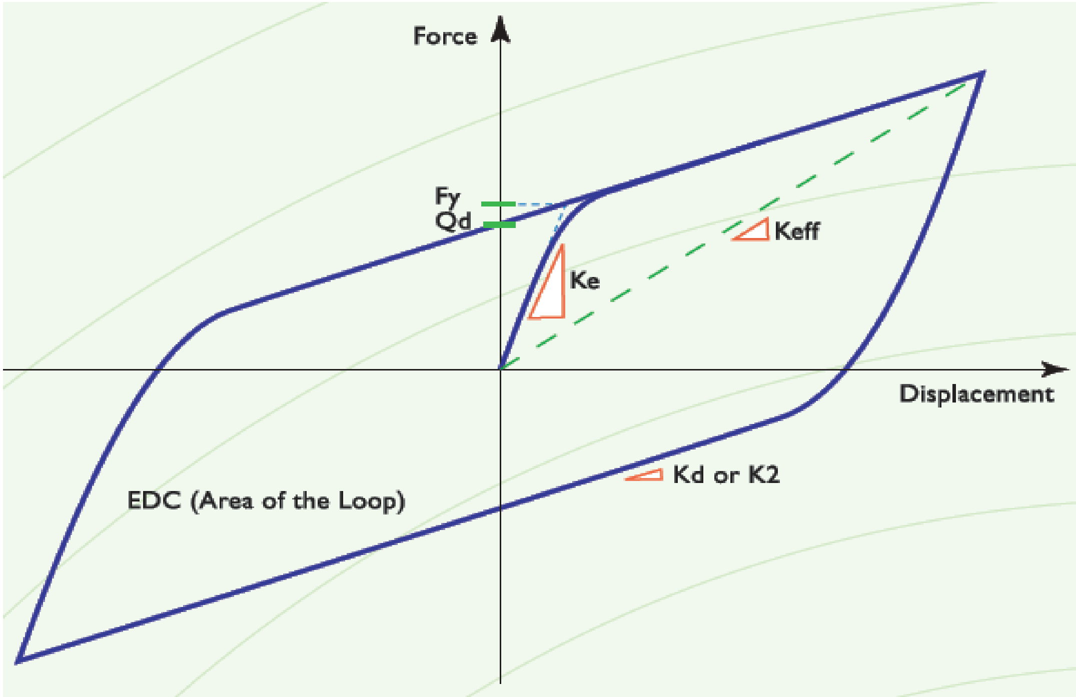


Figure 3.8: hysteresis loops.

The modeling must be such that damping is not included twice, as viscous and hysteretic. Element damping is applied to the rubber component, which has some associated viscous damping, but not to the lead component. [11]

To design the needed lead rubber property for isolation system first thing to do is selecting the spectral acceleration for the site and assuming possible values of period and damping and also calculating the maximum displacement of the superstructure. Suppose that T,β and d_{dc} are specified and it is necessary to calculate the parameter of the model, namely K_2 and Q to prove these values with the period specified, the effective stiffness K_{eff} is given by

$$K_{eff} = \frac{W}{g}(\frac{2\pi}{T})^2 \quad (7)$$

Then $w_d = 2\pi K_{eff} {d_{dc}}^2 \beta$ can be calculated leading to

$$4Q\left(d_{dc} - d_y\right) = 2\pi(\frac{W}{g})(\frac{2\pi}{T})^2 {d_{dc}}^2\beta \quad (8)$$

At this point we neglect d_y and estimate Q from

$$Q = \frac{w_d}{4d_{dc}} = \frac{1}{2} K_{eff} d_{dc} \beta \quad (9)$$

Leading to an initial value of Q/W this is then possible to estimate $K_2 = K_{eff} - \frac{Q}{d_{dc}}$ and d_y

Assuming $K_1 = 10K_2$ for lead rubber bearing [11]

Displacement of the superstructure will be calculated using

$$d_{dc} = \frac{Ms_e(T_{eff}, \xi_{eff})}{K_{eff,min}} \quad (10)$$

The spectral acceleration is chosen based on the seismic action that is the Type of spectrum, the soil type, the bed rock acceleration (a_g).

Increased reliability is required for the isolating devices. This shall be affected by applying a magnification factor $\gamma_x$on seismic displacements of each unit. For buildings, the recommended value is $\gamma_x = 1.2$.[12]

Calculate the total height of rubber layers, in the bearing according to the design displacement (d_{dc})And design shear strain (γ_{max})

$$t_r = \frac{d_{dc}}{\gamma_{max}} \quad (11)$$

The total cross-sectional area of the pad and the required diameter of the bearing are determined from

$$A = \frac{t_r K_{eff}}{G} \quad (12)$$

The area of the lead plug is determined by dividing the characteristic strength (Q) that we got above with the yield level of lead plug (σ_{ld})

$$A_{pb} = \frac{Q}{\sigma_{ld}} \quad (13)$$

The properties of the lead rubber bearing are taken from the isolator manufacture's brochure rather than with the calculation of hand since there test of isolators undergo laboratory test.in this paper the properties were taken from the company called Dynamic Isolation Systems

CHAPTER FOUR

RESULT AND DISCUSSION

The isolated structure period, maximum story displacement, story acceleration, story drift and the base shear characterize the seismic performance of the isolated structure.

4.1. Comparison of fixed-base and base isolated structure

The dynamic response of a plane regular structures was evaluated for both cases (isolated and fixed ones) to show the effect of isolation on the response of fixed structure. The response includes value of the maximum translation at each story, and value of base shear, and period of the structure. The maximum values at each story were evaluated.

4.1.1. Maximum story displacement

In case of isolated framed structure, the displacement of the framed structure at each floor is more as compared to its corresponding fixed base one with respect to the base of the frame. The increase in displacement is more uniform in isolated base as compared to the fixed base framed structure. Story displacement of the regular building is both X and Y direction are the same. The increase in displacement is uniform in both base isolated and fixed base structure.

Table 4.1: story displacement results for model I of fixed and isolated structure

Square shaped		
X-direction		
Floor level	Fixed(mm)	Isolated(mm)
11	152.853	232.215
10	143.898	229.76
9	128.404	225.083
8	116.762	217.915
7	100.48	209.758
6	82.583	198.729
5	63.091	185.453
4	44.143	171.518
3	26.229	153.118

Square shaped		
Y-direction		
Floor level	Fixed(mm)	Isolated(mm)
11	152.853	232.215
10	143.898	229.76
9	128.404	225.083
8	116.762	217.915
7	100.48	209.758
6	82.583	198.729
5	63.091	185.453
4	44.143	171.518
3	26.229	153.118

2	11.378	129.3
1	1.544	101.442
0	0	86.236

2	11.378	129.3
1	1.544	101.442
0	0	86.236

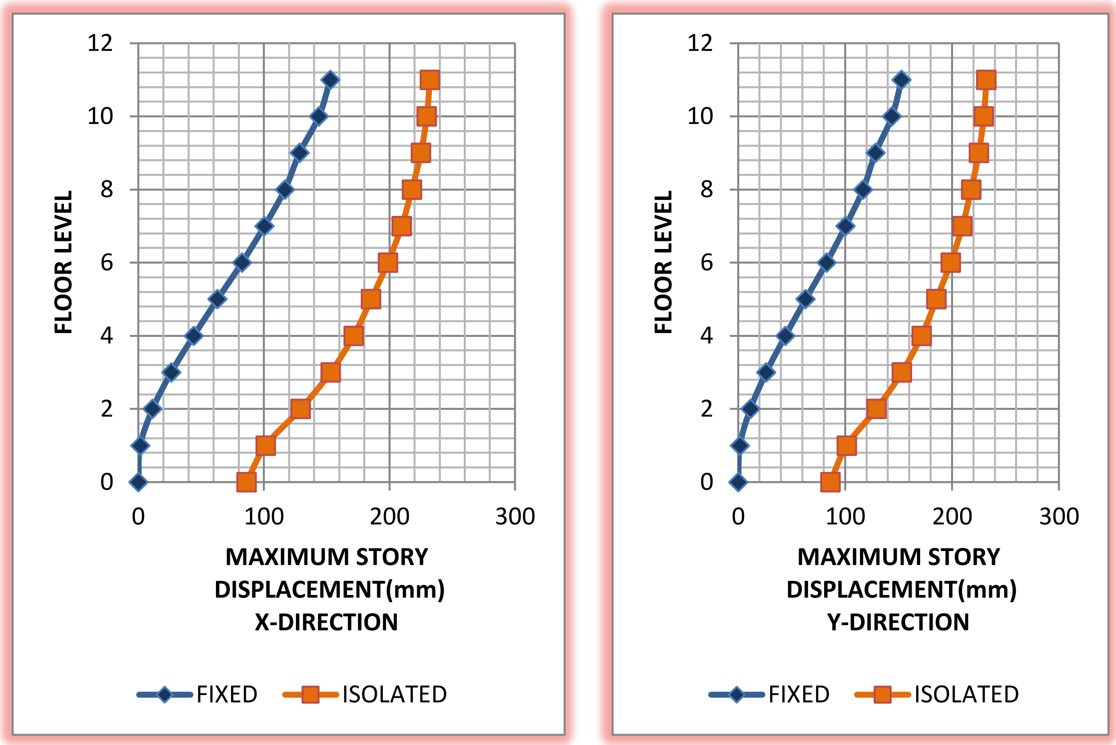


Figure 4.1: maximum story displacement of fixed and base isolated

4.1.2. Story acceleration

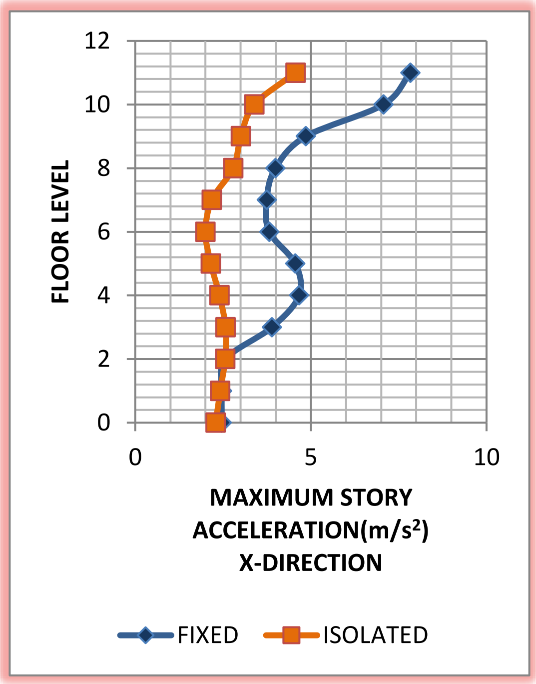
Maximum storey acceleration in fixed base and base isolated building are shown in table below, it is observed that maximum storey acceleration in base isolated building is decreased by maximum of 52.81% in both X and Y direction in comparison to fixed base building model. It has been observed that base isolation process is very effective in reducing the story acceleration.

In case of base isolated framed structure, the acceleration at each floor is less as compared to its corresponding fixed base one with respect to the ground.

Table 4.2: story acceleration results for model I of fixed and isolated structure

Square shaped X-direction			
Floor level	Fixed	Isolated	Reduction (%)
11	7.83573	4.56	41.81
10	7.06449	3.39	52.01
9	4.85805	3.01	38.04
8	3.99137	2.79	30.1
7	3.74106	2.18	41.73
6	3.81557	2	47.58
5	4.55579	2.15	52.81
4	4.66768	2.4	48.58
3	3.89233	2.57	33.97
2	2.57	2.55	0.45
1	2.46861	2.42	1.97
0	2.46111	2.29	6.95

Square shaped Y-direction			
Floor level	Fixed	Isolated	Reduction (%)
11	7.83573	4.56	41.81
10	7.06449	3.39	52.01
9	4.85804	3.01	38.04
8	3.99137	2.79	30.1
7	3.74106	2.18	41.73
6	3.81557	2	47.58
5	4.5558	2.15	52.81
4	4.66768	2.4	48.58
3	3.89233	2.57	33.97
2	2.57	2.55	0.45
1	2.46861	2.42	1.97
0	2.46111	2.29	6.95



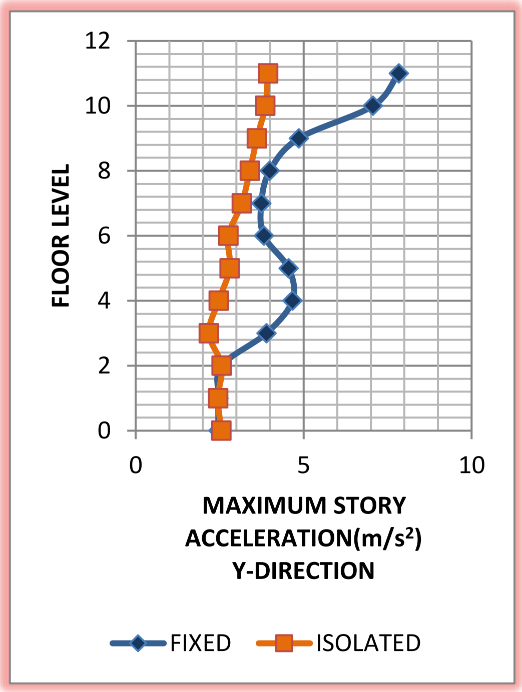


Figure 4.2: maximum story acceleration of fixed and base isolated

4.1.3. Base shear

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. It has been observed that base isolation process is very effective in reducing the base shear as compared to conventional fixed base structure. As a result, the Maximum base shear has been decreased by 54.04% and minimum base shear by 49.68% which implies the potential damage to the bottom level of ten-storey frame is reduced. Reduction in base shear is the same in both direction of the structure

The summary of the base shear response of model 1 presented in TABLE 4.3 as follow

Table 4.3: base shear results for model I of fixed and isolated structure

Square shaped	
X-direction	
Fixed (kN)	Isolated (kN)
3019.6395	1388.2359

Square shaped	
Y-direction	
Fixed (kN)	Isolated (kN)
3019.639	1388.2363

		Fixed	Isolated
Maximum	base shear(KN)	3019.6395	1388.236
	Reduction in base shear (%)		54.03
Minimum	base shear(KN)	-2742.981	-1380.21
	Reduction in base shear (%)		49.68

4.1.4. Period

Base isolation shifts the fundamental period of the structure from the dominant period of the earthquake. The fundamental period of the fixed structure is increased by 51.01% which leads to the structure to avoid sever earthquake due to period shift provided by isolation; this dramatically reduces the floor accelerations. The table below shows, the shift in time period is shown for successive 3 modes.

Table 4.4: fundamental period results for model I of fixed and isolated structure

Square shaped	
Fixed-base	
Mode	Period(sec)
1	1.144
2	1.144
3	1.113

Square shaped	
Base isolated	
Mode	Period(sec)
1	2.335
2	2.335
3	2.284

	isolated	Fixed
period	2.335	1.144
Increment (%)		51.01

4.2. Comparison of plane irregular and regular isolated structures

The data that was sourced from the Output files were storey displacement, floor acceleration, inter-storey drift, base shear forces, and fundamental period of the model building are taken as comparison criteria, which allows for comparison between the four main structural models, with different shapes, U, L, H and square shaped. The obtained results are given in tables and Figures below.

4.2.1. Maximum story displacement

The storey displacement is greater for H, and L-shaped models in both X and Y-direction. The H shaped model has increased by maximum of 43.75% and 45.4% in the X and Y- direction respectively while the L-shaped model has increased by maximum of 21.39% in both the X and Y- direction respectively. It has the same response in both directions.

The response of the U-shaped model is increased by maximum of 41.95% in X-direction and has a variable response along the height of the structure in the Y-direction as shown in the table 4.5 and table 4.6 below. Only H, and L-shaped model has a uniform response of story displacement along the height.

Table 4.5: maximum story displacement of all base isolated models X-direction

Isolated X-direction					Increment (%)		
Floor level	square shape	H shape	L shape	U shape	H shape	L shape	U shape
11	232.215	412.8	287.3	400	43.75	19.17	41.95
10	229.76	402.7	284.4	400	42.95	19.21	42.56
9	225.083	387.8	278.6	400	41.96	19.21	43.73
8	217.915	375.2	270.2	300	41.92	19.35	27.36
7	209.758	360.5	260.5	300	41.81	19.48	30.08
6	198.729	340.5	247.6	300	41.64	19.74	33.76
5	185.453	311.4	232	300	40.45	20.06	38.18
4	171.518	275.6	215	300	37.77	20.22	42.83
3	153.118	235.4	192.5	200	34.95	20.46	23.44
2	129.3	194.2	163.4	200	33.42	20.87	35.35
1	101.442	151.4	128.8	200	33	21.24	49.28
0	86.236	128.7	109.7	100	32.99	21.39	13.76

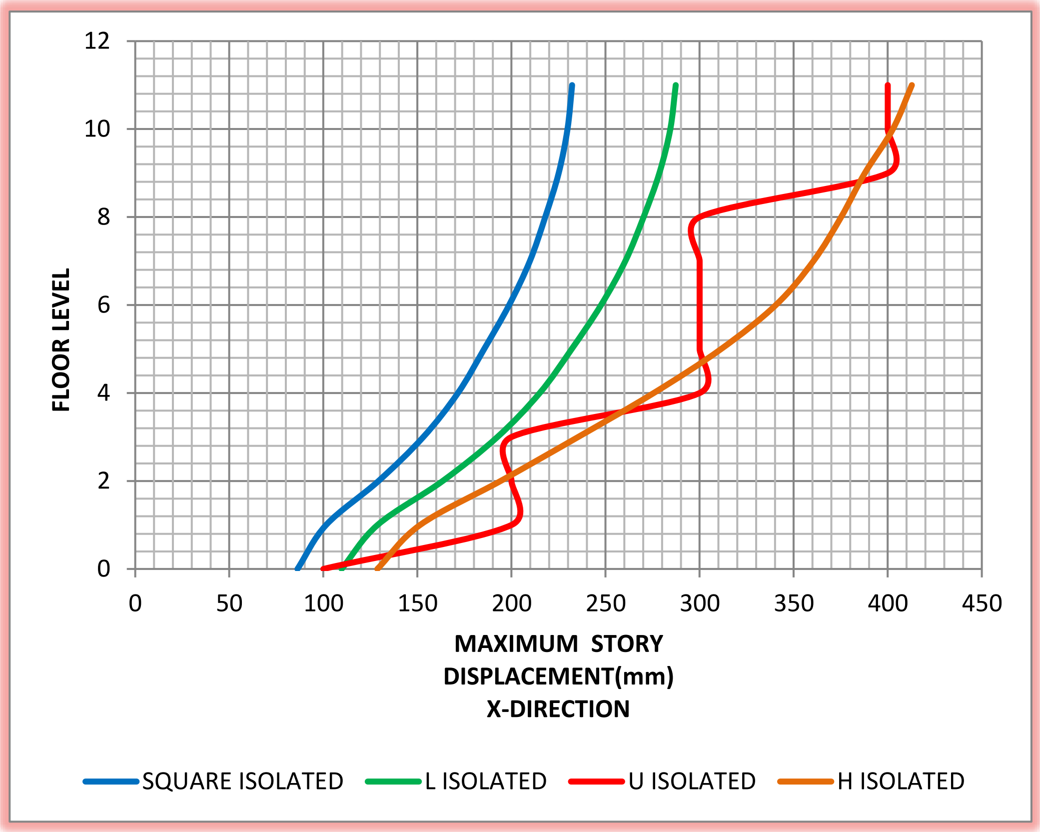


Figure 4.3: maximum story displacement of all base isolated models in X-direction

Table 4.6: maximum story displacement of all base isolated models in Y-direction

Isolated Y-direction					Increment (%)		
Floor level	square shape	H shape	L shape	U shape	H shape	L shape	U shape
11	232.215	424.5	287.3	200	45.3	19.17	-16.11
10	229.76	415.3	284.4	200	44.68	19.21	-14.88
9	225.083	401.2	278.6	200	43.9	19.21	-12.54
8	217.915	389.5	270.2	200	44.05	19.35	-8.96
7	209.758	375.5	260.5	200	44.14	19.48	-4.88
6	198.729	355.8	247.6	200	44.15	19.74	0.64
5	185.453	326.4	232	200	43.18	20.06	7.27
4	171.518	289.5	215	200	40.75	20.22	14.24
3	153.118	247.7	192.5	100	38.18	20.46	-53.12
2	129.3	204.5	163.4	100	36.77	20.87	-29.3
1	101.442	159.2	128.8	100	36.28	21.24	-1.44
0	86.236	134.9	109.7	100	36.07	21.39	13.76

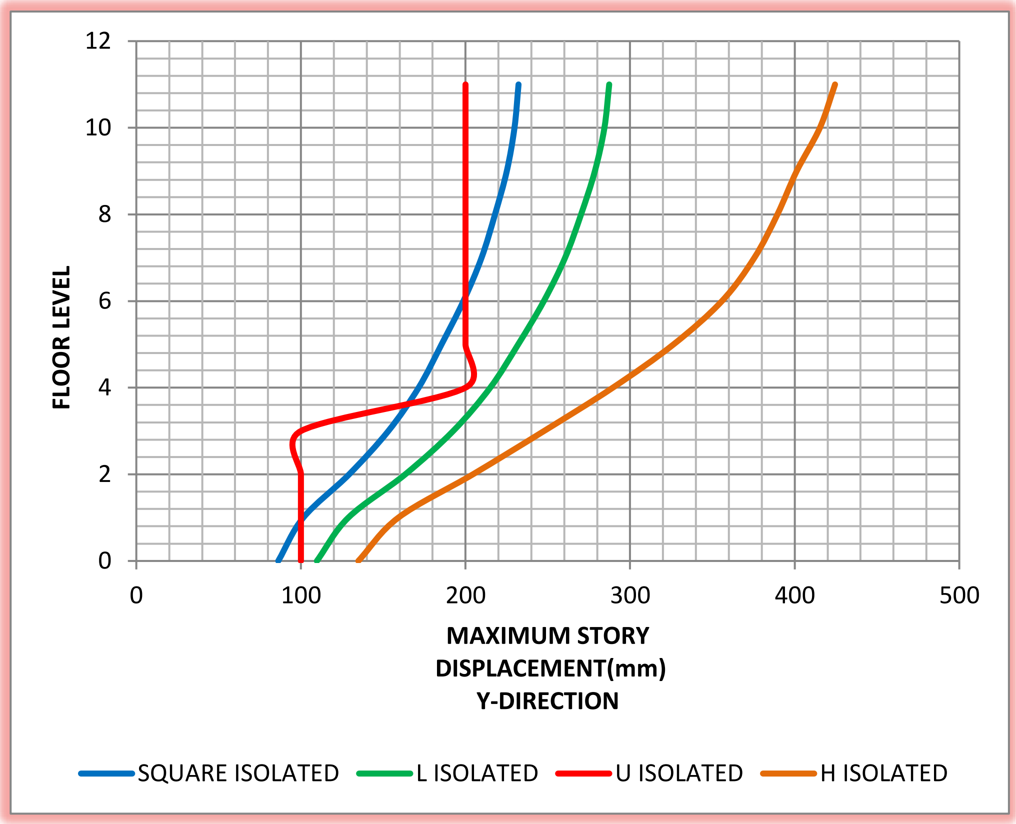


Figure 4.4: maximum story displacement of all base isolated models in Y-direction

4.2.2. Story drift

The storey drifts have been used to calculate expected damage to the structure during earthquake events. In this study, all plane irregular structures have increased in their story drift in x-direction as it shown in table 4.7.the story drift of H and L shaped structure has also increased in Y-direction but for U shaped structure it has only increased for the top four stories.

Table 4.7: Story drift of all base isolated models in X-direction

Isolated X-direction					Decrement (%)		
Floor level	square shape	H shape	L shape	U shape	H shape	L shape	U shape
11	0.001095	0.003346	0.001278	0.002106	-205.57	-16.71	-92.33
10	0.001966	0.004975	0.002455	0.003309	-153.05	-24.87	-68.31
9	0.002557	0.004209	0.003247	0.004317	-64.61	-26.98	-68.83
8	0.002844	0.004912	0.003492	0.004732	-72.71	-22.78	-66.39
7	0.003677	0.006666	0.004281	0.006193	-81.29	-16.43	-68.43
6	0.004425	0.009672	0.005198	0.00743	-118.58	-17.47	-67.91

5	0.004645	0.01194	0.005665	0.007974	-157.05	-21.96	-71.67
4	0.006133	0.013409	0.007502	0.010337	-118.64	-22.32	-68.55
3	0.007985	0.013738	0.009722	0.013202	-72.05	-21.75	-65.34
2	0.009332	0.014292	0.011522	0.015119	-53.15	-23.47	-62.01
1	0.010468	0.015656	0.013229	0.016367	-49.56	-26.38	-56.35
0	0	0	0	0	0	0	0

Figure 4.5: Story drift of all base isolated models in X-direction

Table 4.8: Story drift of all base isolated models in Y-direction

Isolated Y-direction					Decrement (%)		
Floor level	square shape	H shape	L shape	U shape	H shape	L shape	U shape
11	0.001095	0.003069	0.001278	0.001752	-180.27	-16.71	-60
10	0.001966	0.004699	0.002455	0.002745	-139.01	-24.87	-39.62
9	0.002557	0.004003	0.003247	0.003065	-56.55	-26.98	-19.87
8	0.002844	0.004775	0.003492	0.003071	-67.9	-22.78	-7.98
7	0.003677	0.006603	0.004281	0.003499	-79.58	-16.43	4.84
6	0.004425	0.00979	0.005198	0.004118	-121.24	-17.47	6.94
5	0.004645	0.012287	0.005665	0.004287	-164.52	-21.96	7.71
4	0.006133	0.013938	0.007502	0.005601	-127.26	-22.32	8.67
3	0.007985	0.014415	0.009722	0.007237	-80.53	-21.75	9.37

2	0.009332	0.015083	0.011522	0.008574	-61.63	-23.47	8.12
1	0.010468	0.016612	0.013229	0.0098	-58.69	-26.38	6.38
0	0	0	0	0	0	0	0

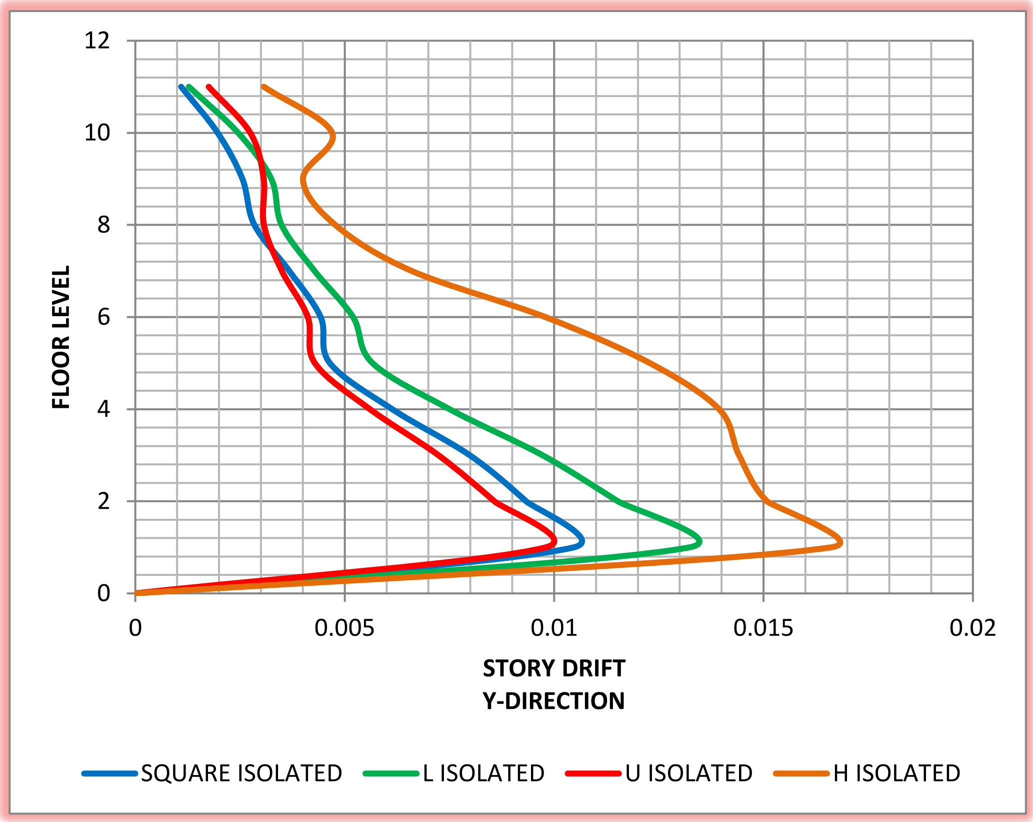


Figure 4.6: Story drift of all base isolated models in Y-direction

4.2.3. Base shear

The base shear has increased in all plane irregular models. The base shear of H-shaped model has increased by 14.54% and 15.4% for maximum and minimum base shear respectively in X-direction and with 18.35% and 17.21% in Y- direction.

Also in L-shaped model, it has increased by 23.75% and 15.4% for maximum and minimum base shear respectively in X and Y-direction. It has the same response in both directions.

For U-shaped model, it has increased by 31.15% and 17.42% for maximum and minimum base shear respectively in X-direction and by 0.03% and 0.11% for maximum and minimum base shear respectively in Y-direction.

Table 4.9: Base shear of all base isolated models in X-direction

Isolated X-direction					Reduction in base shear (%)		
Floor level	square shape	H shape	L shape	U shape	H shape	L shape	U shape
maximum	1388.236	1590.1107	1717.94	1820.698	-14.54	-23.75	-31.15
minimum	-1380.21	-1592.7459	- 1592.75	-1620.69	-15.4	-15.4	-17.42

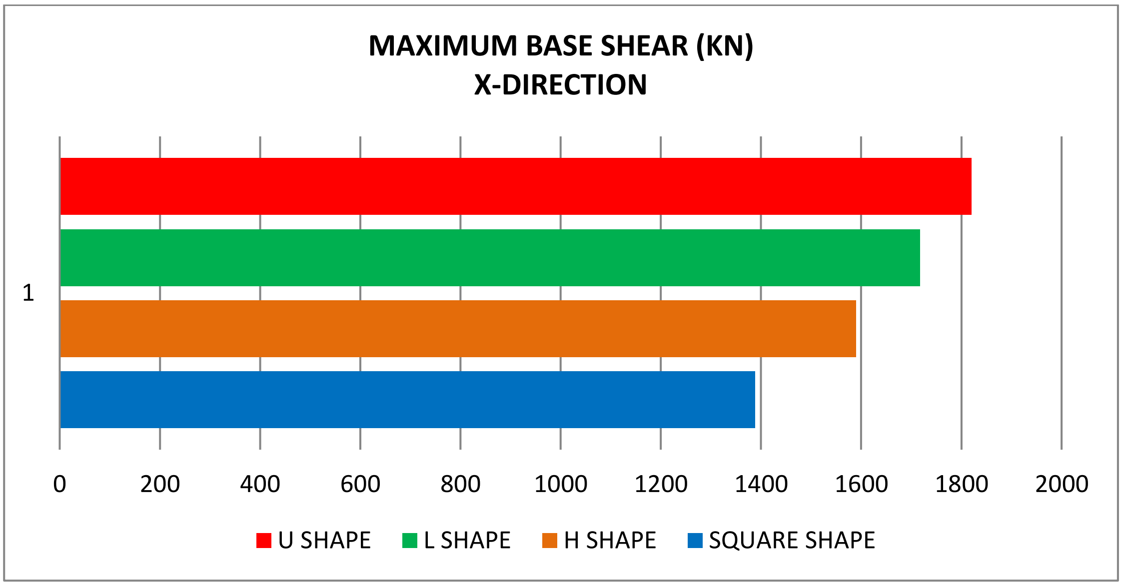


Figure 4.7: Maximum base shear of all base isolated models in X-direction

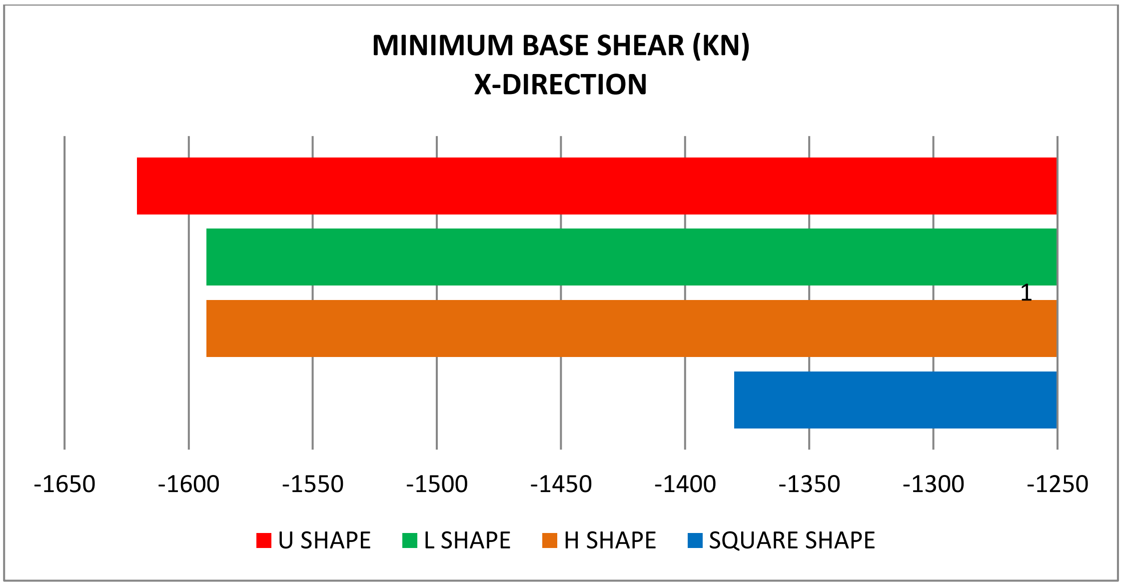


Figure 4.8: Minimum base shear of all base isolated models in X-direction

Table 4.10: Base shear of all base isolated models in Y-direction

Isolated Y-direction					Reduction in base shear (%)		
Floor level	square shape	H shape	L shape	U shape	H shape	L shape	U shape
maximum	1388.236	1643.0142	1717.94	1388.786	-18.35	-23.75	-0.03
minimum	-1380.21	-1617.7811	- 1592.75	-1381.78	-17.21	-15.4	-0.11

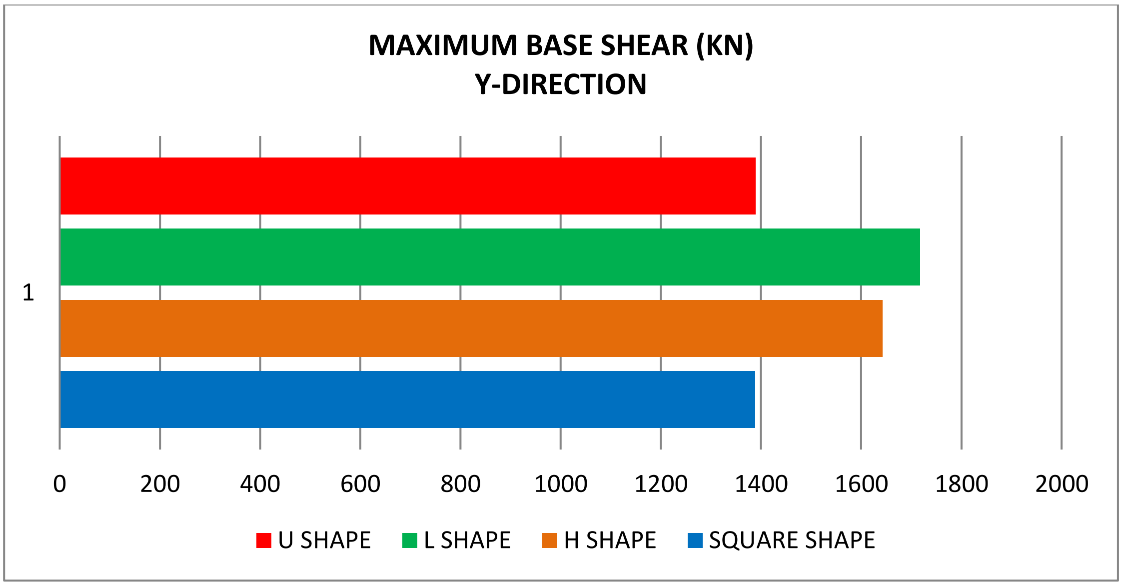


Figure4.9: Maximum base shear of all base isolated models in Y-direction

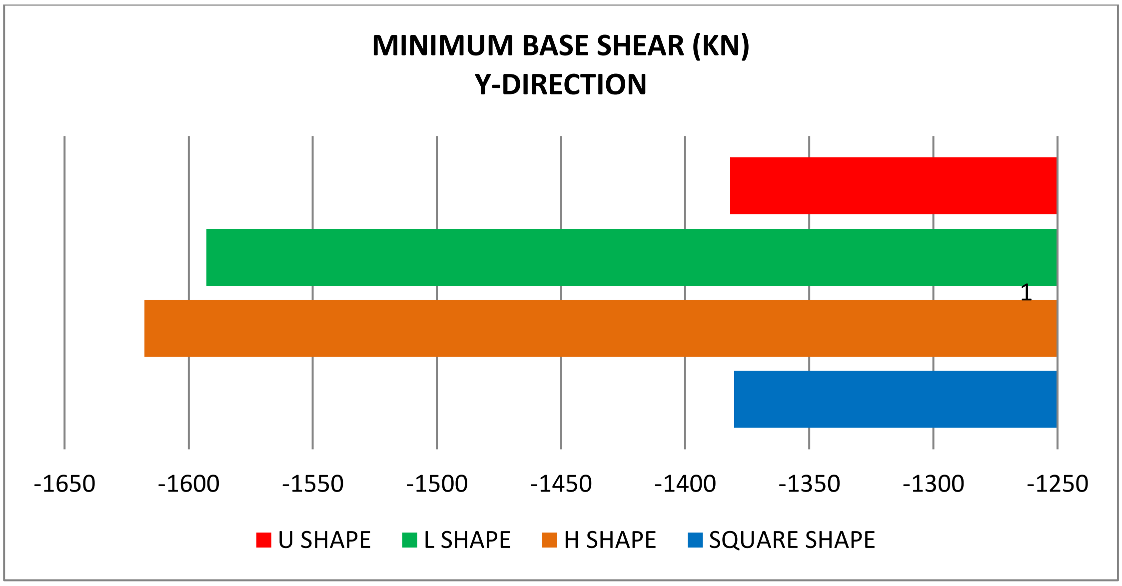


Figure 4.10: Minimum base shear of all base isolated models in Y-direction

4.2.4. Period

For base isolated structures, there is a significant effect of the base isolator on the modes of free vibration of the structure. This is because of the initial shift of the base, which means that the first period now dominates most of the response of the structure; this means that the higher modes do not affect the response of the structure as much as for fixed base structure.

The time required to complete one complete cycle of vibration is called time period. Under free vibration the structure always vibrates in single mode called its fundamental mode and the corresponding time period is called fundamental period of the structure. The fundamental period is the longest period of the structure. The no of modes depends upon the no of degrees of freedom.

For the H, L, and U-shaped models, the fundamental period is 2.77,2.497, and 2.566 seconds respectively compared to 2.355 seconds of square shaped frame building. That means the fundamental period has increased by 18.63%, 6.94%, and 9.89% for H, L, and U-shaped models respectively.

Table 4.10 shows how the effect of a plane irregularity affects the fundamental period of base isolated structure. As it can be seen there is a significant period shift when the plane is irregular in the structure.

Table 4.11: Fundamental period of all base isolated models

	Isolated X-direction				Increment (%)		
	square shape	H shape	L shape	U shape	H shape	L shape	U shape
PERIOD	2.335	2.77	2.497	2.566	18.63	6.94	9.89

4.2.5. Story acceleration

The story acceleration of the plane irregular building of H- shaped model has varied along the height of the building, it has decreased at second and top floor of the structure, and increased in all other floors in both the x and y- direction respectively.

The story acceleration of the plane irregular building of L- shaped model has varied along the height of the building, it has increased from fifth to seventh floor of the structure, and decreased in all other floors in both the x and y- direction respectively.

The story acceleration of the plane irregular building of U- shaped model has varied along the height of the building; it has increased from fifth to tenth floor of the structure, and decreased in all other floors in both the X- direction and increased in fifth and sixth and increased in all other floors in Y-direction.

Table 4.12: Maximum story acceleration of all base isolated models in X-direction

Isolated X-direction					Decrement (%)		
Floor level	square shape	H shape	L shape	U shape	H shape	L shape	U shape
11	4.56	3.8	3.49412	3.6588	16.67	23.37	19.76
10	3.39	3.76	3.10238	3.508	-10.91	8.48	-3.48
9	3.01	3.55	2.73315	3.11627	-17.94	9.2	-3.53
8	2.79	3.21	2.64247	3.23264	-15.05	5.29	-15.87
7	2.18	3.09	2.51845	3.12764	-41.74	-15.53	-43.47
6	2	2.81	2.16019	2.67341	-40.5	-8.01	-33.67
5	2.15	2.77	2.32006	2.27146	-28.84	-7.91	-5.65
4	2.4	2.47	2.18564	2.11765	-2.92	8.93	11.76
3	2.57	2.24	2.23671	2.2376	12.84	12.97	12.93
2	2.57	2.71	2.44639	2.42503	-5.45	4.81	5.64
1	2.42	2.79	2.18432	2.15448	-15.29	9.74	10.97
0	2.29	2.6	2.03467	1.91944	-13.54	11.15	16.18

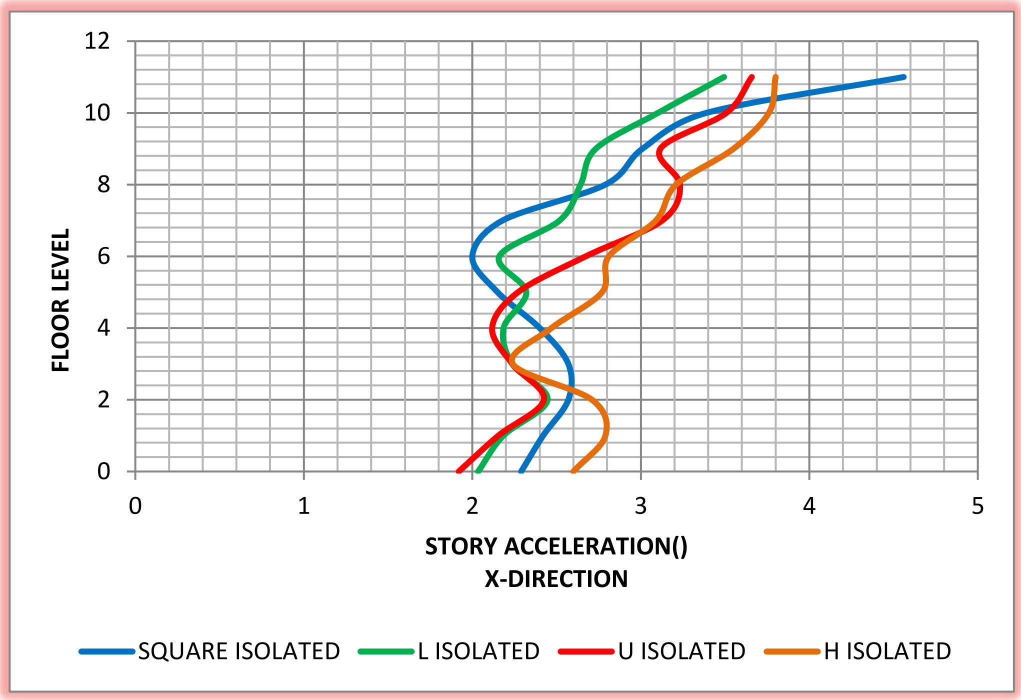


Figure 4.11: Maximum story acceleration of all base isolated models in X-direction

Table 4.13: Maximum story acceleration of all base isolated models in Y-direction

Isolated Y-direction					Decrement (%)		
Floor level	square shape	H shape	L shape	U shape	H shape	L shape	U shape
11	4.56	3.94	3.49412	3.4871	13.6	23.37	23.53
10	3.39	3.86	3.10238	3.27793	-13.86	8.48	3.31
9	3.01	3.61	2.73315	2.94231	-19.93	9.2	2.25
8	2.79	3.4	2.64247	2.4201	-21.86	5.29	13.26
7	2.18	3.16	2.51844	1.93026	-44.95	-15.52	11.46
6	2	2.76	2.16019	2.29607	-38	-8.01	-14.8
5	2.15	2.8	2.32006	2.38828	-30.23	-7.91	-11.08
4	2.4	2.47	2.18564	2.37675	-2.92	8.93	0.97
3	2.57	2.18	2.23671	2.4825	15.18	12.97	3.4
2	2.57	2.63	2.44639	2.39557	-2.33	4.81	6.79
1	2.42	2.74	2.18432	2.19322	-13.22	9.74	9.37
0	2.29	2.55	2.03467	2.06457	-11.35	11.15	9.84

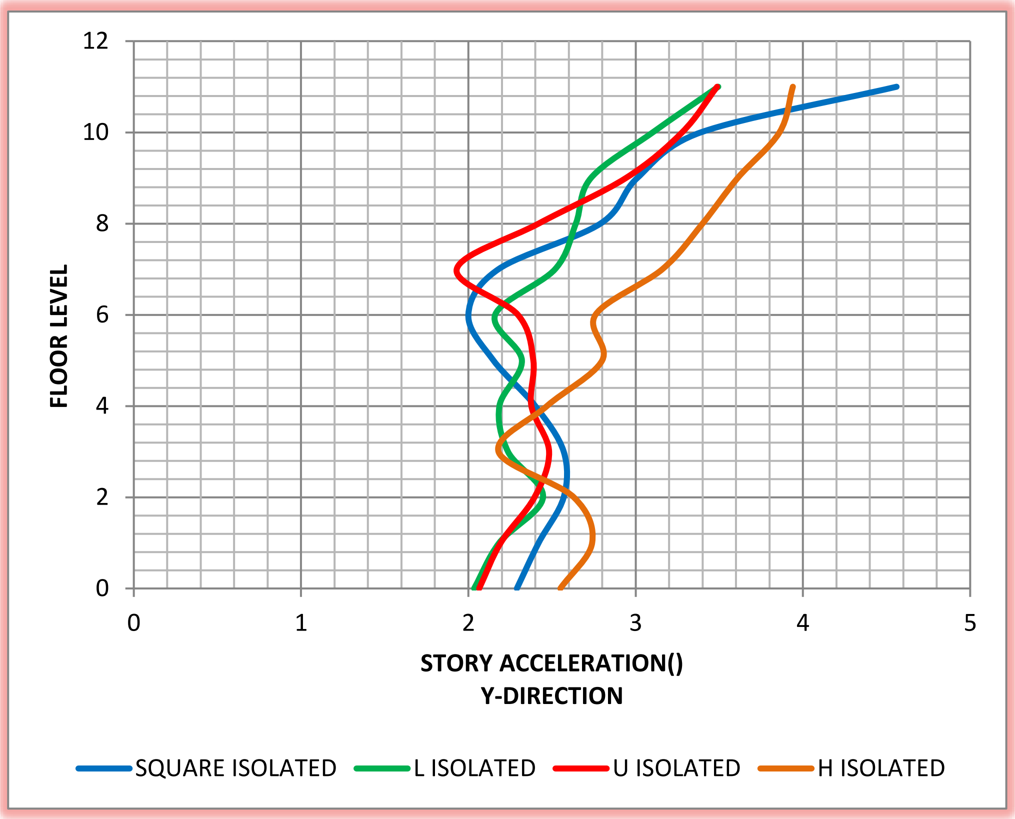


Figure 4.12: Maximum story acceleration of all base isolated models in Y-direction

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In this study detailed analytical study on plane irregular buildings have been carried out to address the response of plane irregular and regular base isolated ten storey building is performed. The responses of the models were compared with each other under El-Centro earthquake. All the irregular models are compared with the regular one and also fixed and base isolated model are compared to show the effect of base isolation.

The results from the analysis of the ten storey structure shows how the main effect of base isolation is to greatly reduce the damage due to inter storey drift and the effects of natural period change on floor acceleration. The floor acceleration and the inter story drift was used to show how the structure responded to base isolation; this is because while inter storey drifts are indicative of structural damage, floor acceleration is the cause of movement of and damage to non-structural items such as furniture, equipment and people.

The main conclusions are as follows:

1- Increase of the flexibility of the building in the horizontal plane at level of isolation led to reduction of the value of absolute maximum acceleration of floors in an isolated building by about 52.81%(I.e. decrease of inertial forces).In case of base isolated framed structure, the acceleration at each floor is less as compared to its corresponding fixed base one with respect to the ground but in the case of plane irregular base isolated structure it varies along the height of the structure, giving non-uniform response.

2- The story displacement values of H-shaped model and L-shaped model have increased with in comparison to the plane regular structure (square shaped). But for U-shaped model it has increased in the X-direction and varies along the height of the building in the Y-direction.

3- All the irregular models used were increased in inter-story drift, except for U shaped building where it only increased for the top four floors in the Y-direction. Which implies the irregular models can cause structural damage and also their responses depend on their shape.

4- Even with the use of base isolation the base shear of all plane irregular building models has increased; this shows that plane irregularity has significant influence on the base shear. Thus, it is better to avoid buildings with shape like H, U, and L since earthquakes often damage buildings at this level.

5- The story acceleration of all plane irregular base isolated models varies along the height of the structures;

6- The fundamental period has increased in all irregular buildings.

5.2. Recommendation

1. It has been observed that base isolation is very effective in reducing the base shear s, story acceleration, and increasing the fundamental period of fixed base structures. But, further study should be done by considering buildings with vertical irregularity to in order to address all possible type of responses of base isolated structures to irregularity in structure.
2. The change in our code brings most of structures that were designed with the previous code into question, about their performance especially in earthquake sensitive regions, therefore the government should have to investigate deeply and appropriate measures must be taken in order to avoid collapse of structures and loss of life during the occurrence of the expected seismic excitation and one of these measures is the use of base isolators.
3. Its recommended to use Simple & symmetrical building plans since it gives more uniform seismic response.

REFERENCE

[1]- Subramani T., Jothi M. Kavitha "Earthquake Analysis of Structure by Base Isolation Technique in SAP"

[2]- Minal Ashok Somwanshi and Mrs. Rina N. Pantawane "Seismic Analysis of Fixed Based and Base Isolated Building Structures"

[3]- Salic R. B., Garevski M. A. And Milutinovic Z. V., "Response of Lead-Rubber Bearing isolated Structure," The 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.

[4]- Jalali A. and Narjabadifam P., "Optimum Modal Characteristics for Multi-Story Buildings Isolated with Lead rubber bearings", 4th International Conference on Earthquake Engineering, Taipei, Taiwan, October 12-13, 2006, Paper No. 187.

[5]- Di Sarno L., Cosenza E. and Pecce, M.R., "Application of Base Isolation to A large hospital in Naples, Italy," 10^{th} World Conference on Seismic Isolation, Energy Dissipation and active Vibrations Control of Structures, Istanbul, Turkey, May 27-30, 2007.

[6]- Saiful Islam A. B. M., Jameel M., Ahmad S.I. And Jumaat M. Z., "Study on Corollary of Seismic Base Isolation System on Buildings with Soft Storey," International Journal of the Physical Sciences Vol. 6(11), pp. 2654-2661, 4 June, 2011 ISSN1992-1950 ©2011 Academic Journals.

[7]- Vinod Kumar Parma, G.S. Hiremath, Post - Graduate student, Department of Structural Engineering, Basaveshwar Engineering College, Bagalkot, Karnataka, India "effect of base isolation in multi storied RC irregular building using time history analysis "

[8]- Naveen K., R Prabhakara, and Dr. H Eramma "base isolation of mass irregular RC multi-storey building"

[9]- Amr S. Elnashai "Fundamentals of Earthquake Engineering"

[10]- Erik Anders nelson, civil engineering Washington. "Seismic base isolation: a five story building example"

[11]- Naeim F. and Kelly J. M. "design of seismic isolated structures from theory to practice"

[12]- Eurocode 8: design of structures for earthquake resisting –part 1: general rules, seismic actions and rules for building. Ref. No. prEN 1998-1:2003 E

[13]- Darshale S. D., Shelke "Seismic Response Control of Vertically Irregular R.C.C. Structure using Base Isolation" Civil Engineering Department, Dr. D. Y. Patil School of Engineering and Technology, Charholi(Bk) Pune, India

[14]- Dynamic isolation system company brochures

[15]- Earthquake engineering handbook, edited by Wai-Fah-chen and Charles scawthotn

[16]- Torunbalci N. and Ozpalanlar. G. Assoc. Professor Dr., Dept. of Structural Engineering, Faculty of Architecture, Istanbul Technical University "Evaluation of earthquake response analysis methods for low-rise base isolated buildings"

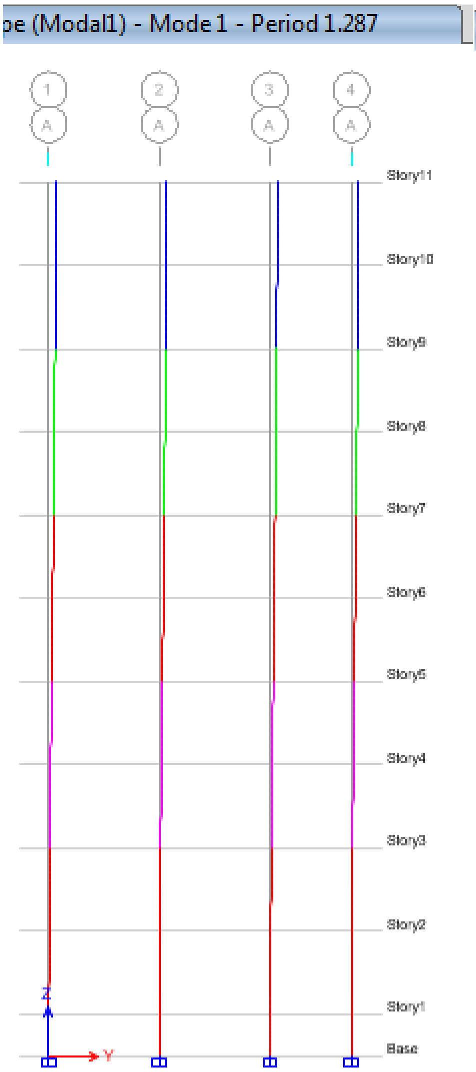
[17]- Gabriele Attanasi "An Innovative Super Elastic System for Base Isolation"

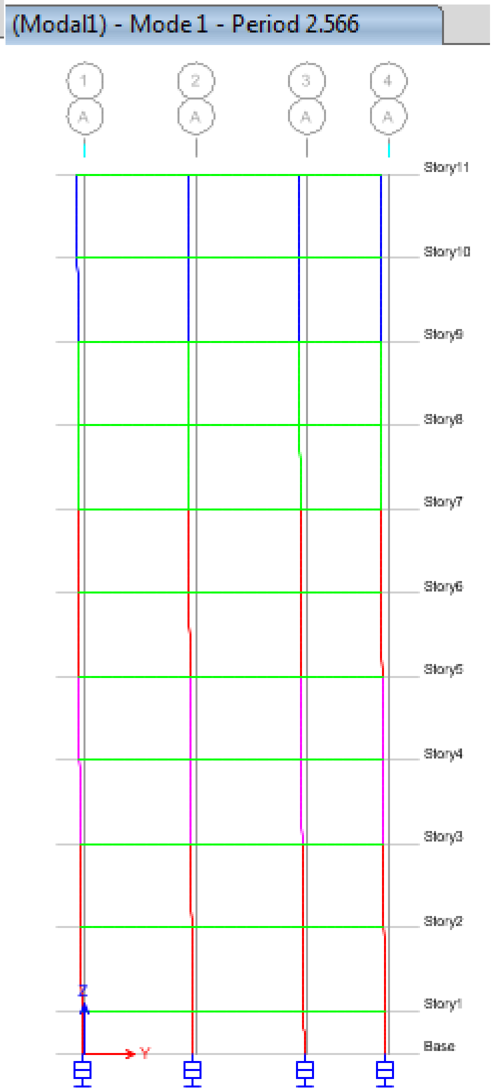
[18]- Troy A. Morgan "The Use of Base Isolation Systems to Achieve Complex Seismic Performance Objectives" , Center for Urban Earthquake Engineering Tokyo Institute of Technology and Stephen A. Mahin Department of Civil and Environmental Engineering University of California, Berkeley

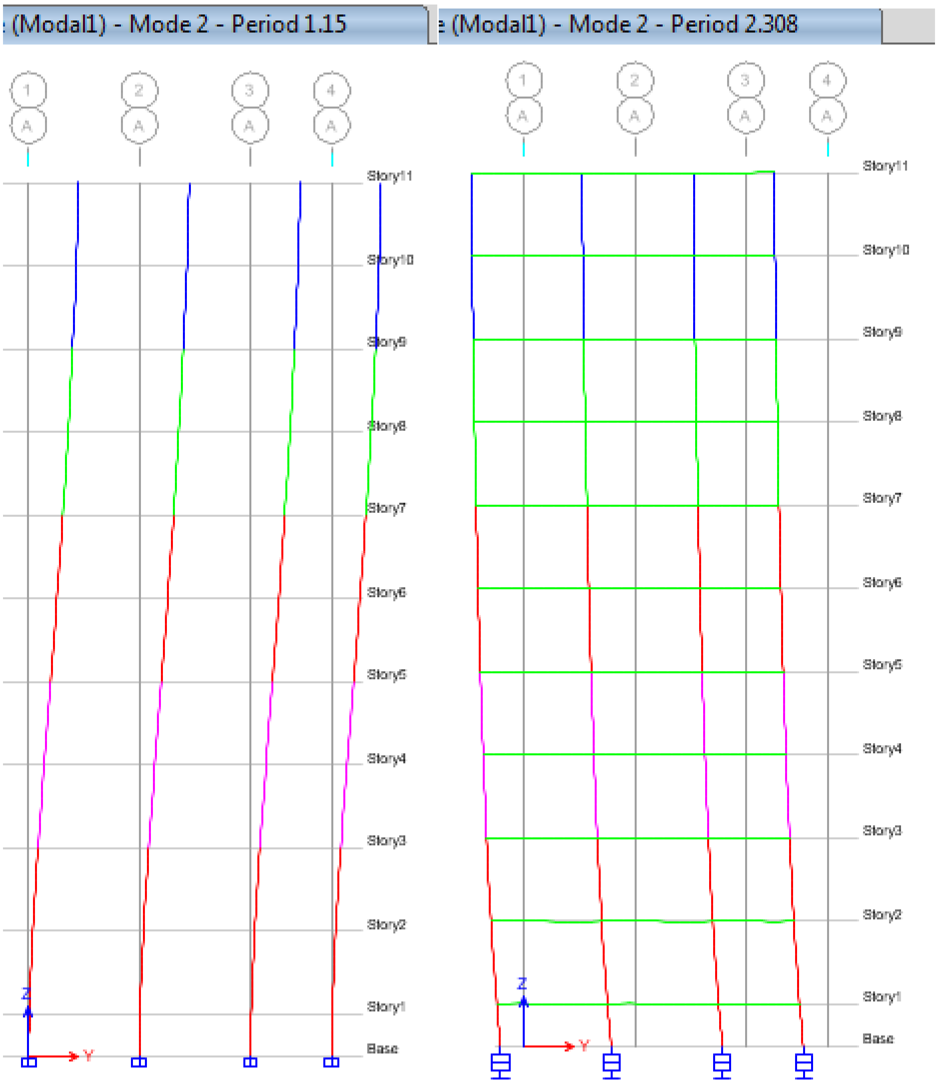
[19]- Varadharajan S. " Review of different Structural irregularities in buildings"

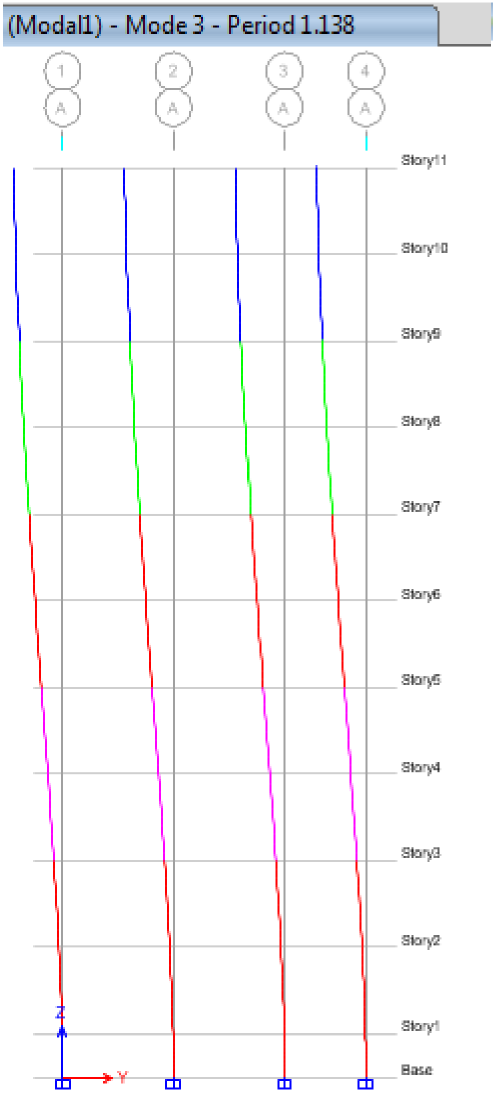
APPENDIX

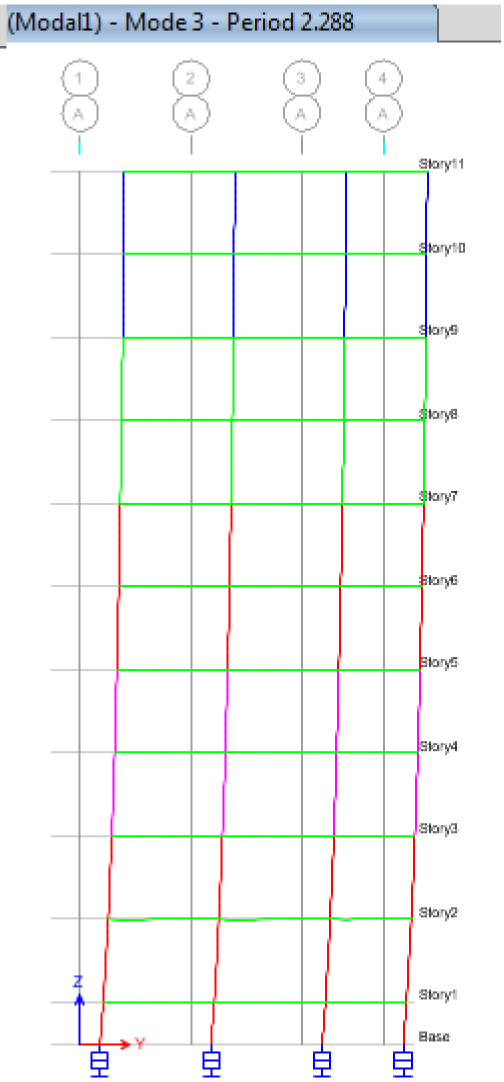
APPENDIX A-DEFORMED SHAPE OF FIXED AND ISOLATED BASE OF THE SAME STRUCTURE






(Modal1) - Mode 2 - Period 1.15
(Modal1) - Mode 2 - Period 2.308
Story11
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base
Z
Y


(Modal1) - Mode 3 - Period 1.138
Story11
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base


(Modal1) - Mode 3 - Period 2.288
Story11
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base

APPENDIX B-LEAD RUBBER BEARING DESIGN TEMPLATE

ISOLATOR PROPERTIES						
ELASTOMER PROPERTIES(MATERIAL)			ISOLATOR DIMENSIONS		DESIGN ASSUMPTION	
UNITS	MPa	KN,mm	UNIT	mm	UNIT	KN,mm
SHEAR STRAIN(%)	50	50	PLANE SHAPE	circular	MAXIMUM APPLIED DIS,Dm	300
SHEAR MODULUS,G	0.707	0.000707	PLANE SDIMENSION(d-b)	1160	STRUCTURAL DAMPING,β(%)	0.05
ULTIMATE ELONGATION	5	5	RUBBER COVER,Th	10		
MATERIAL CONSTANT,K	0.7	0.7	NO. OF RUBBER LAYERS	32		
ELASTIC MODULUS,E	2.63	0.00263	RUBBER LAYER THICKNESS,tr	9		
BULK MODULUS,E_∞	1500	1.5	NO. OF MID STEEL Pl	31		
DAMPING	0.05	0.05	MID STEEL Pl.THIKNESS,ts	2		
LEAD YIELD STRENGTH,σ_{pl}	8	0.008	LEAD CORE DIAMETER,dpl	230		
GRAVITY	9810	9810	TOTAL HEIGHT	400		

BEARING PROPERTY	
GROSS AREA A_g	1056831.549
PLUGE AREA A_{pl}	41547.5628
RUBBER AREA A_r	1015283.986
TOTAL RUBBER THICKNESS,T_r	288

HESTERESIS LOOP PROPERTIES(KN/mm)		
CHARACTERSTIC STRENGTH,Q_d	332.3805024	
POST YIELD STIFFNES,K_p	2.492381174	
ELASTIC STIFFNESS,K_e	24.92381174	ke=10kp
YIELD DISPLACEMENT,D_y	14.81762393	
YIELD FORCE,F_y	369.3116693	
MAXIMUM FORCE,F_m	1080.094855	
EFFECTIVE STIFFNESS,K_{eff}	3.600316182	
AREA HYSTERESIS LOOP,A_h	379156.2457	
EQUIVELENT VISCOUS DAMPING,β_{eff}	0.18623238	