JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

EFFECT OF BASE ISOLATION ON SOFT STOREY REINFORCED CONCRETE BUILDING AGAINST EARTHQUAKE

A Thesis Submitted to School of Graduate Studies of Jimma University in Partial Fulfilment of the Requirements for Masters of Science Degree in Structural Engineering

By: Lensa Feyisa

July 2021

Jimma, Ethiopia

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Co-Advisor: Engr. Haymanot G/Silasie, MSc

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DECLARATION

I hereby declare that all information in this document entitled "EFFECT OF BASE ISOLATION AGAINST EARTHQUAKE IN SOFT STOREY REINFORCED CONCRETE BUILDING" 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

Nowadays, many of reinforced concrete building in urban areas allotted parking, shopping mall areas in some of the stories, which requires large spacing between columns without infill and exterior walls in the structure. Due to this situation, these buildings will have low stiffness or the lateral load resisting systems at those stories is quite less than the stories above or below these stories by 70% percent which is called soft story. For this reason failure of structure starts at these points of weakness is due to discontinuity in mass, stiffness and geometry of structure.

The main objective of this study was to evaluate the effect of base isolation in soft storey of medium-rise moment resisting frame building using Response Spectrum Analysis under earthquake load. Adama town was selected as a study area since it is located in the rift valley of Ethiopia which is characterized by a high seismic zone. The study was done on 9-storey moment resisting building with a regular and vertically irregular building model by using ES EN, 2015 code. The core methodology of the research was carried out by modeling and analyzing building with base isolation and without base isolation using ETABS V.18 software.

According to analyses result the base isolation in the study increase the time period and storey displacement of the soft storey model due to horizontal flexibility of LRB, both type of soft storey type I &type II increase lateral displacement averagely by 52%-66% and also both soft storey time period increased by relative 45% than the fixed base . in this study the storey acceleration decreased by average 57.85to 64% for type I&II , the other parameter decreased & basic thing is base shear that may cause damage on structure but the base isolation reduce the base shear force by average 36.6%-48.6% that occur in fixed base .

Finally base isolation is effective in reducing the base shear, story acceleration, and increasing the fundamental period of fixed base structures. But, further study should be done by considering buildings with different type of vertical irregularity

Key words:-Soft Storey, Stiffness, Base Isolation,

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ACRONYM

CQC	Complete Quadratic Combination
DCM	Medium Ductility Class.
DCH	High Ductility Class.
ES EN	Ethiopian Standard based on European Norm.
ETABS	Extended 3D Analysis of building System
FB	Friction Pendulum
HDRB	High Damping Rubber Bearing
LRB	Lead Rubber Bearing
MER	Main Ethiopian Rift
MRF	Moment Resisting Frame.
NEHRP	National Earthquake Hazard Reduction Program
PGA	Peak Ground Acceleration
RB	Low rubber bearing
RC	Reinforced Concrete
RSA	Response Spectrum Analysis.
T	Vibration period of a linear single degree of freedom system
ao	Bedrock acceleration
q	Behavior factor.
qo:	Basic value of the behavior factor
γ_1	Importance factor

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Earthquakes is natural hazard and have potential to cause greatest damages, among all the natural hazards. Since earthquake forces are unpredictable in nature, it is uncontrollable and the main reason of structures damage across the world, especially in regions more susceptible to earthquake. In effect, significant lives and properties have been lost. So, earthquake design and analysis need more attention to prevent or reduce those damages.

Currently, many of reinforced concrete buildings in urban areas have parking, shopping malls, cinema hall and fire station in some of the stories. These parking and shopping malls often have large space between columns without provision of infill walls. Such buildings usually possess low stiffness and/or lateral resistance compared to regular buildings and as a result, structural damage or collapse occur during earthquake.

The relative flexibility or horizontal displacement of the storey which have stiffness irregularity much larger than the above or below storey. So, this type of building shows comparatively a higher tendency to collapse during a moderate to severe earthquake and the phenomenon known as soft story collapse.

The reduction of earthquake effects on building was an important engineering concern. Therefore, in order to increase resistant of the building by using of seismic isolation which is placed between the superstructure and the substructure to reduce the transmission of seismic forces from the soil to the structure. One of the aims of seismic isolation is to shift the fundamental period of a structure to a value that is much lower than both its fixed-base period and the predominant period of earthquakes. This is enabled by the low horizontal stiffness of the isolation systems.

The other aim of using an isolation system is to provide additional energy dissipation, which reduces the acceleration transmitted to the super structure(Komur1 13 April 2015).The isolation technique decouples the structure from the horizontal components of the ground motion by interposing structural element with low horizontal stiffness between the structure and the foundation. This gives the structure a fundamental frequency that is much lower than its fixed base frequency of the ground motion. The first dynamic mode of isolated structure involves deformation only in the isolation system, the structure above being to all intents and purposes rigid. The higher modes that produce deformation in the structure are orthogonal to the first model and, consequently, to the ground motion. (Sonawane and Walzade 2018)

There are various types of isolators but, in this study lead rubber bearing was used since it is widely applicable nowadays. Seismic isolation which can be considered as an important method in providing an effective engineering solution for the prevention of earthquake damage to a 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 base isolation size is depends on the design earthquakes. This study focuses on the soft-story behavior of RC structures with fixed-base and lead core rubber bearing (LRB) systems under different seismic loads and to determine the effect of the base isolation on soft storey RC building.

1.2 Statement of the Problem

Nowadays soft storey is a typical feature in the modern construction in urban areas. At the soft storey in buildings, there is a discontinuity in the stiffness of the structure due to absence or lack of infill walls (Ali et al. 2017). These provisions reduce the stiffness of the lateral load resisting system and a progressive collapse becomes unavoidable in a severe earthquake for such buildings due to soft storey (Halde and Deshmukh 2015). In order to counterbalance the structural collapse of such buildings under Earthquake, this thesis has aimed at appraising the effectiveness of base isolation in soft storey reinforced concrete buildings under seismic load.

1.3 Research Question

1) What are effects of base isolation against earthquake in soft storey reinforced concrete buildings?
2) Which type of soft storey with base isolation is effective?
3) Which storey level is more exposed to earth quake by the presence of soft storey in the building floor?
4) What are the differences in structural response of soft storey buildings and regular buildings with base isolation under seismic load?

1.4 Objective of the study

1.4.1 General Objective

The general objective of this study is to appraise effectiveness of base isolation against earthquake in soft storey reinforced concrete building.

1.4.2 Specific Objective

The specific objectives of this study are;

- To appraise effect of base isolation against earthquake in soft storey reinforced concrete buildings
- To compare the effectiveness of base isolation in different type of soft storey building.
- Illustrate the effect of soft storey location on earth quake response of reinforced concrete by using response spectrum analysis.
- To compare the effectiveness of base isolation on soft storey and regular to control the effect earthquake response.

1.5 Significance of the Study

The importance of this study is to play an important role in decreasing deaths, injuries and extensive property damage that could happened by earthquake through investigating and describing the effect of base isolation on soft storey RC building. Also this study enables the structural designer to consider the effect of masonry infill wall during design. Largely, this study will solve the problem of structural failure due to soft storey effect on RC building with base isolation, and this research will answer the question whether the base isolation have an effect on the response of soft story structure by reducing the effect of earth quake. The result of this study provide input on proper use of base isolation and significant effect of masonry infill wall on reinforced concrete building.

Additionally, it is useful to reduce the failure of building structures under seismic load due to stiffness irregularity on building caused by masonry infill. The study will help educational institutions and students to get an insight into the role of a base isolation and effect of masonry infill wall in reducing damage that happen in building during earthquake. It also helps students to give special attention to the masonry infill wall along the storey level like other primary structural members such as beams and columns.

1.6 Scope and Limitation of the study

The scope of this study focused on the effect of base isolation (LRB) on soft storey buildings which is limited to moment resisting frame of reinforced concrete building that lateral load resisted by frame of the building and also this research focus on soft storey from vertical irregularity and medium rise building. The source of seismic action to be considered in the analysis is earthquake-induced seismic action as provided by the design code mentioned and does not include other types of lateral load sources like wind load.

The direction of seismic force is also limited to horizontal seismic excitation. The study area is Adama town, because it is located in Seismic Hazard Zone 4 according to seismic hazard zonation which helps the study to consider maximum relatively peak ground acceleration coefficient. The study did not include the design of structural members but limited to analysis of the models to evaluate the effect of base isolation on reinforced concrete building. Earthquake response of medium rise MRF building analyzed using RSA which is linear.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Base Isolation

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(Shen-haw, Yuantien, and Hsieh 2020). Many studies had been done on the behavior of base isolated structures subjected to earthquake excitation. Some of them are discussed below. A popular earthquake resistant design concept is the use of seismic isolation devices that are placed between the superstructure and the substructure to reduce the transmission of seismic forces from the soil to the structure. One of the aims of seismic isolation is to shift the fundamental frequency of a structure to a value that is much lower than both its fixed-base frequency and the predominant frequency of earthquakes. This is enabled by the low horizontal stiffness of the isolation systems. The other aim of using an isolation system is to provide additional energy dissipation, which reduces the acceleration transmitted to the superstructure(Karabork, and Deneme 2011).

There are two basic technologies used to protect buildings from damaging earthquake effects. These are base isolation devices and seismic dampers. Many vibration-control measures like passive, active, and semi-active and hybrid vibration control methods have been developed.(Note 2006). Base isolation is a passive vibration control system. The isolator partially reflects and partially absorbs input seismic energy before it gets transmitted to the superstructure. The idea behind base isolation is to detach (isolate) the building from the ground in such a way that earthquake motions are not transmitted up through the building, or at least greatly reduced. Seismic dampers are special devices introduced in the building to absorb the energy provided by the ground motion to the building (Darshale and Shelke 2016)

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. 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 (M. A. Komur 2015).

The base-isolation techniques prove to be very effective for the seismic protection of new framed buildings as well as for the seismic retrofitting of existing ones(Mazza and Vulcano 2004)(Zhou and Wu 2017).Seismic isolation consists of essentially the installation of mechanisms such as isolators which decouple the structure from base. The seismic isolation system is mounted beneath the structure and is referred as Base Isolation‟. The idea of separating the superstructure from the substructure has dependably been an elegant thought in principle, at present it has been incorporated into a suitable solution. The objective is to have flexible material in the horizontal plane that is equipped for anticipating vitality stream into the superstructure. This flexibility expands the superstructure's period, which, thus, lessens the induced acceleration (Fetene 2016).

(Radmila, Garevski, 2008) 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.

(Sarno, E, and M.R. Pecce 2007)had presented the structural analysis of the complex irregular multistory 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-isolate d 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 et al. 2011)had creating a building model having a lot of open space to analyze 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 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 Property

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. 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.

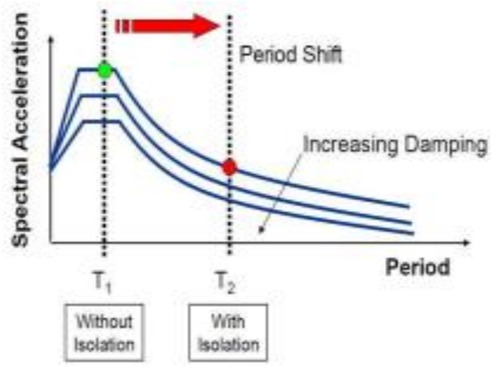
High-rise buildings or buildings rested on soft soil are not suitable for base isolation(Katti and Balapgol 2014). Base isolation is a technique that has been used around the world to protect the building structures from the damaging effects of earthquake. The installation of isolator in building at 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(Minal, Somwanshi, and Pantawane 2015).

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 super structure 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 (Fetene 2016).



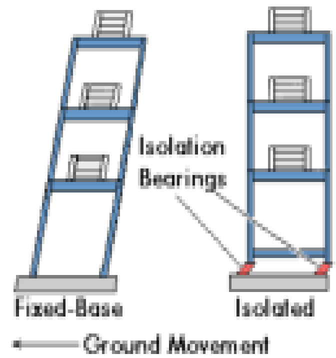


Figure 2. 1:Effect of seismic isolation on spectral acceleration(Katti and Balapgol 2014).

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(Abraham Susan 2018).

2.2.2 Type of base isolation

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(Fetene 2016)

2.2.2.1 Laminated Rubber 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.

2.2.2.2 Lead Rubber Bearing

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.(Lrb, n.d.)

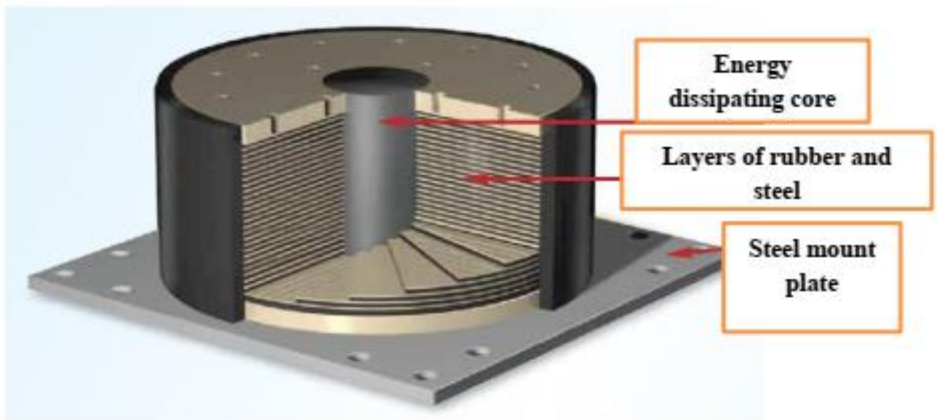


Figure 2. 2: Detail base isolation parts.

2.2.2.3 Friction pendulum system

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

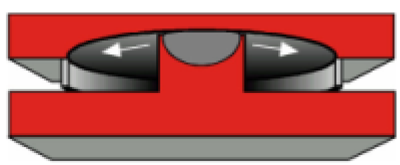


Figure 2. 3: Sliding friction pendulum system.

2.2.3 Basic Element of Seismic Isolation System

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

a) A flexible mounting so that the period of vibration of the total system is lengthened sufficiently to reduce the force response
b) A damper or energy dissipater so that the relative deflections between building and ground can be controlled to a practical design level

c) 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, 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(Fetene 2016).

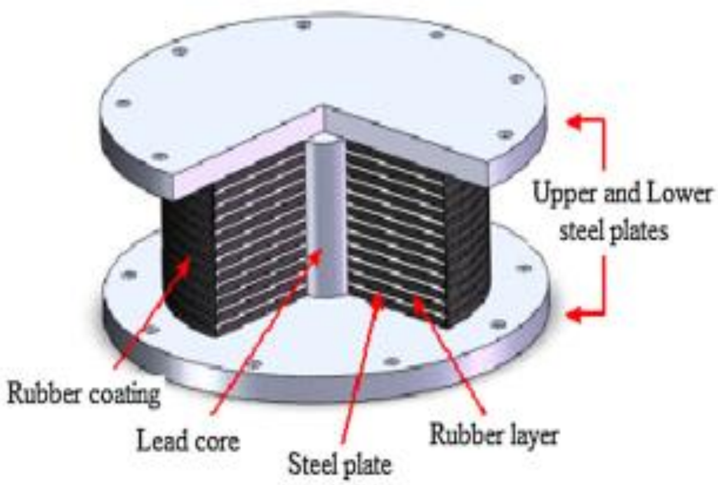


Figure 2. 4: Base isolation lead core rubber band (Ghalimath.A.G1 Sep-2015).

2.3 Irregularities in Structures

For the purpose seismic design, building structure are categorized into being regular or irregular buildings constitute a large portion of the modern urban infrastructure(Note 2006) The irregularity in the building structures is due to plan irregularity which is geometric and vertical irregular due to irregular (sudden change) distributions in their mass, strength and stiffness along the height of building. Irregular structures contribute a large portion of urban infrastructure. These irregularities are classified into two types plan irregular and vertical 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(ES EN-1998- Part 1: 2015 n.d.). 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 (Elnashai 2008). Plan irregularity: It comprises following types of irregularities.

- Torsion irregularity
- Re-entrant Corners
- Diaphragm Discontinuity
- Non parallel Systems (Omkar Sonawane1).

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, Stiffness irregularity results from a sudden change in stiffness between adjacent floors, such as setbacks in the elevation of a building (Elnashai 2008).
Vertical irregularity: It comprises following type of irregularities

- Stiffness Irregularity
- Mass Irregularity
- Vertical Geometric Irregularity
- In Plane discontinuity in vertical elements resisting lateral force
- Discontinuity in capacity-weak story (Sonawane and Walzade 2018)

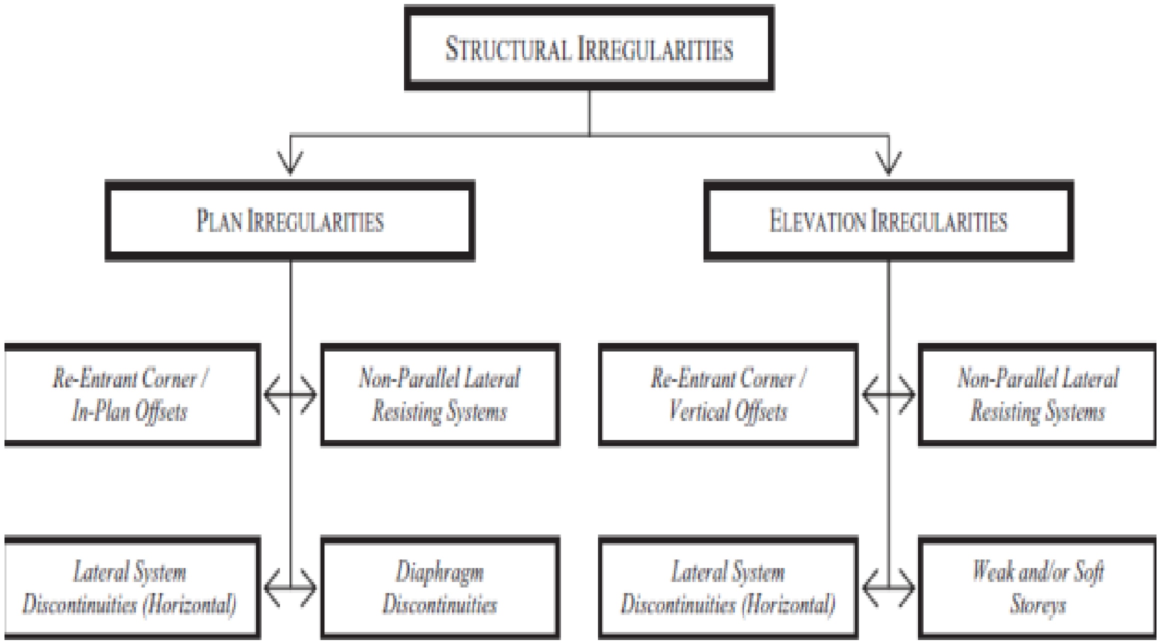


Figure 2. 5: Type of structural Irregularity.

2.3.1.1 Stiffness Irregularity (Soft Storey)

It is the one which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storeys above. There are many practical reasons for having fewer walls at the ground level of a building. A building may have larger public spaces at this entry level, such as lobbies, large meeting rooms or open-plan retail space. In urban locations, residential buildings sometimes have fewer walls at the ground level to allow for parking underneath the building.

(Caterino and Cosenza 2013)Stiffness regularity in elevation, defined as a continuous variation of the storey stiffness along the height of the building without abrupt changes, reduces the likelihood of dangerous concentrations of plastic deformations in a few (more flexible) stories. One of the most common vertical structural irregularities is due to a large open space or car-parking (with less partition walls than the upper stories) located at the bottom of the building. The earthquake energy concentrates on highly demanded columns and walls at the more flexible stories where, as a consequence, the mechanism known as ‘soft-storey’ or ‘weak-storey’ may develop

The essential characteristic of a weak or soft storey consist of a discontinuity of strength or stiffness, which occurs at the second storey connections. This discontinuity is caused by lesser strength, or increased flexibility, the structure results in extreme deflections in the first storey of the structure, which in turn results in concentration of forces at the second storey connection. The soft storey effect in any building changes the behavior of frame action due to the relative changes of stiffness and lateral load distribution mechanism and thus may induce changes in phenomenon like lateral displacement and inter-storey drift ratio

(Varadharajan, 2013) 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.

(Chowdhury 2012) Also, soft story may arise due to many Different reasons such as change in load carrying and slab system between stories. The abrupt changes which take place in the amount of the infill walls between stories is also one of the frequent reasons of the soft storey (GhalimathAG and Hatti MA 2015).

(Tafheem et al. 2017)Soft storey is generally present at the entrance (bottom) floors of the buildings. Because entrance floors of the buildings are utilized as bank branches, storeys, restaurants, offices, car parking and the upper storeys are used as dwellings. Soft storey is an irregularity which affects the behavior of a construction during a quake and also increases the construction costs. Such features are highly undesirable in buildings built in seismically active areas; this has been verified in numerous experiences of strong shaking during the past earthquakes. For this reason, soft storey should be avoided as much as possible. In case it is necessary, irregularities can be eliminated by increasing the lateral rigidity of this storey by putting up additional walls between single structural elements on the soft storey; placing diagonals between the columns and shear walls; increasing the rigidity of the soft storey by increasing beam-column size of the soft storey. To fulfill the above objectives, a 9 storied RC frame building modeled with the finite element software ETABS (under the action of earthquake loads in equivalent static) is analyzed in this study. A comparative study is made implementing the above mentioned approaches on the analytical model to prevent the irregularity resulted due to a soft story at the first floor on the basis of the material cost as well as other structural parameter such as drift.

This open floor is characterized with little or no infill wall, that result to frame-infill interaction which may significantly affect both the stiffness and strength of frame building on resisting the lateral loads due to weakness of the open storey relative to the other storeys. Such multi-storey reinforced concrete buildings are often called buildings with soft storey.

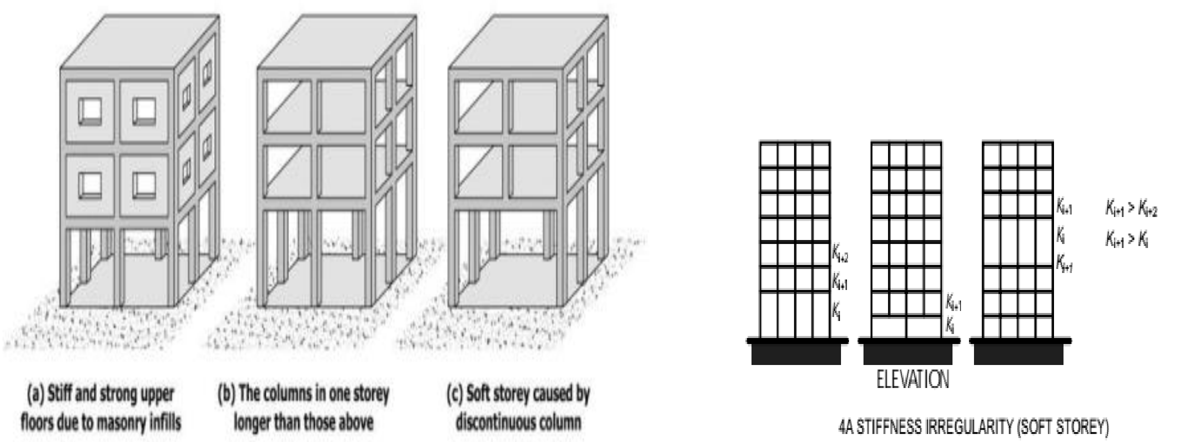


Figure 2. 6: Type of soft storey (Bhusnar et al. 2016).

2.4 Building collapse due to 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.. Damage to irregular structures caused by vertical 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.

Figure 2. 7: Failure of structure due to soft storey effect (GhalimathAG and Hatti MA 2015).

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(Genidy et al. 2015a).

2.5 Performance of Soft Storey Building

A large number of buildings with open ground storey have been built in India in recent years. Open ground storey buildings have consistently shown poor performance during past earthquakes. Huge number of similarly designed and constructed buildings exists in the various towns and cities situated in moderate to severe seismic zones of the country (Dande and Kodag 2013).

The phenomena of soft story may arise due to many Different reasons such as change in load carrying and slab system between stories. The abrupt changes which take place in the amount of the infill walls between stories is also one of the frequent reasons of the soft storey behavior RC frame buildings with open bottom storey are known to perform poorly during in strong earthquake shaking. A special arrangement needs to be made to increase the lateral strength and stiffness of the soft/open storey. Dynamics analysis of building is carried out including the strength and stiffness effects of infills and inelastic deformations in the members'. Particularly, those in the soft storey, and the members designed accordingly (GhalimathAG and Hatti MA 2015).

2.6 Analysis type

2.6.1 Linear Analysis

Linear analysis is also called elastic analysis. A linear elastic analysis is an analysis where a linear relation holds between applied forces and displacements. In practice, this is applicable to structural problems where stresses remain in the linear elastic range of the used material. Linear elastic can be divided into two:-

- Modal response spectra analysis
- Lateral force method

2.6.1.1 Lateral force analysis

All design against seismic loads must consider the dynamic nature of the load. However, for simple regular structures, analysis by equivalent linear static methods is often sufficient. This is permitted in most codes of practice for regular, low- to medium-rise building. It begins with an estimation of base shear load and its distribution on each story established by code requirements (ES EN-1998- Part 1: 2015, n.d.). Equivalent static analysis can, therefore, work well for low- to medium-rise buildings without significant coupled lateral-torsional modes, in which only the first mode in each direction is considered. The method is less suitable for tall building (over, say, 75 m), where second and higher modes can be important, or buildings with torsional effects; they require more complex methods to be used in these circumstances (Fernandes 2015).

2.6.1.2 Response spectrum analysis

This approach permits the multiple modes of response of a building to be taken into account. For each mode, a response is obtained from the design spectrum, corresponding to the modal frequency and the modal mass, and then they are combined to estimate the total response of the structure. Following are the types of combination methods: (a) absolute - peak values are added together (b) Square root of the sum of the squares (SRSS), (c) Complete quadratic combination (CQC) - a method that is an improvement on SRSS for closely spaced modes. (Mukundan and Manivel 2015).

2.6.2 Nonlinear analysis

A nonlinear analysis is an analysis where a nonlinear relation holds between applied forces and displacements. Nonlinear effects can originate from geometrical nonlinearity's (i.e. large deformations), material nonlinearity's (i.e. elasto-plastic material), and contact. These effects result in a stiffness matrix which is not constant during the load application. This is opposed to the linear static analysis, where the stiffness matrix remained constant. As a result, a different solving strategy is required for the nonlinear analysis and therefore a different solver.

Non-linear analysis is divided into two:-

- Pushover analysis
- Time history analysis

2.6.2.1 Pushover analysis

The simplified analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. Pushover analysis consists of a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure. A two or three dimensional model which includes bilinear or trainer load deformation diagrams of all lateral force resisting elements is first created and gravity loads are applied initially. Pushover analysis can be performed as force controlled or displacement controlled. In force controlled pushover procedure, full load combination is applied as specified, that is, force controlled procedure should be used when the load is known. Also, in force controlled pushover procedure some numerical .Problems that affect the accuracy of results occur since target displacement may be associated with a very small positive or even a negative lateral stiffness because of the development of mechanisms and P-delta effects. Pushover analysis is the preferred tool for seismic performance evaluation of structures (Bahador Bagheri 2012)

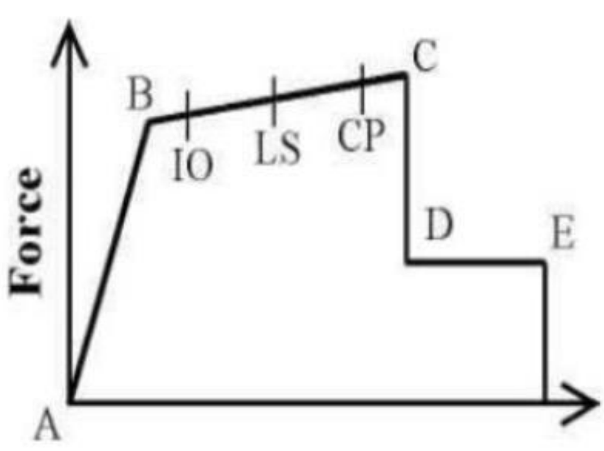


Figure 2. 8: Force-deformation curve (Dattatraya L. Bhusnar1 October 2016).

- Point A corresponds to unloaded condition.
- Point B represents yielding of the element.
- The ordinate at C corresponds to nominal strength and abscissa at C corresponds to the deformation at which significant strength degradation begins.
- The drop from C to D represents the initial failure of the element and resistance to lateral loads beyond point C is usually unreliable.
- The residual resistance from D to E allows the frame elements to sustain gravity loads. Beyond point E, the maximum deformation capacity (Bahador Bagheri 2012).

2.6.2.2 Time history analysis

As the thesis conducted in the past investigated time-history analysis is a procedural dynamic analysis of a structure to a specified loading that may vary with time and the analysis may be linear or non-linear but it should be dynamic not static In this analysis dynamic response of the building will be calculated at each time intervals. This analysis can be carried out by taking recorded ground motion data from past earthquake database. This analysis overcomes all disadvantages of response spectrum analysis if there is no involvement of nonlinear behavior. Hence this method requires greater efforts in calculating response of buildings in discrete time intervals (Fernandes 2015).

CHAPTER THREE

RESEARCH METHODOLOGY

This section aims to present the procedures, considerations, and methodology used for the investigation of the effect of base isolation on earthquake response of medium rise of soft storey reinforced concrete building using response spectrum analysis. All the necessary procedures and provisions recommended by the new version of the Ethiopian Standard (ES EN, 2015) are followed with justifications.

3.1 Study Area

Adama town was considered as the study area for this research since it is located in a great rift valley which is characterized by high seismic hazard. It is located at 08°32′29″N 39°16′08″E/ 8.54139°N 39.26889°E Latitude and Longitude respectively at an elevation of 1,712 meters (5,617 ft.), Southeast of Addis Ababa. The study area is selected based on ES EN 1998-1: 2015 for seismic hazard which bed rock acceleration is $\alpha_o = 0.15$.

3.2 Research Design

The type of this research was exploratory research as it intended to explore the effect of a base isolation on earthquake performance of soft storey Moment Resisting Frame (MRF). The effect was presented in terms of displacement, story drift, base shear, base overturning moment, story acceleration & time period . Since the research is associated with earthquake performance of soft storey, other sources of lateral loads was not considered. Response spectrum analysis (RSA) is used to as an earthquake analysis method for the investigation. Because RSA uses a dynamic analysis approach to yields the most reasonable result. It is also widely used since it is a linear seismic analysis method and a previous record of earthquake events is not required. All the analysis is executed by structural analysis software, ETABS, V.18 as per the newly revised Ethiopian Standard based on European Norm (ES EN-1998- Part 1: 2015, n.d.)

3.3 Study Variable

3.3.1 Dependent variable

The dependent variable of this study is

- Story displacement
- Story drift
- Story acceleration
- Time Period
- Base shear
- Overturning moment

3.3.2 Independent variable

The independent variables of this research are:-

- Story height
- Location of soft story
- Non isolated (Fixed base)
- LRB base isolation

3.4 Population and Sampling Method

3.4.1 Sample Size

The sample size of this research has a total of 14 model, 2 types of soft storey 2 types of building model (regular and vertical irregularity) were considered. In such a way that each plan type is modeled with and without base isolation to evaluate the effect of base isolation on two different type of soft storey modeling. The data that was used and analyzed in this research was obtained from ETABS v18 .01 software that helped to come up with important conclusion.

3.4.2 Sampling Procedure

The sampling procedure may not easily understand unless explained by a relevant diagram. As explained in the preceding section, the two buildings (regular and vertical irregular) will be modeled with base isolation and without base isolation to evaluate the overall effect on seismic response soft storey of RC building. The detailed sampling procedure is explained in the form of a flow chart follows.

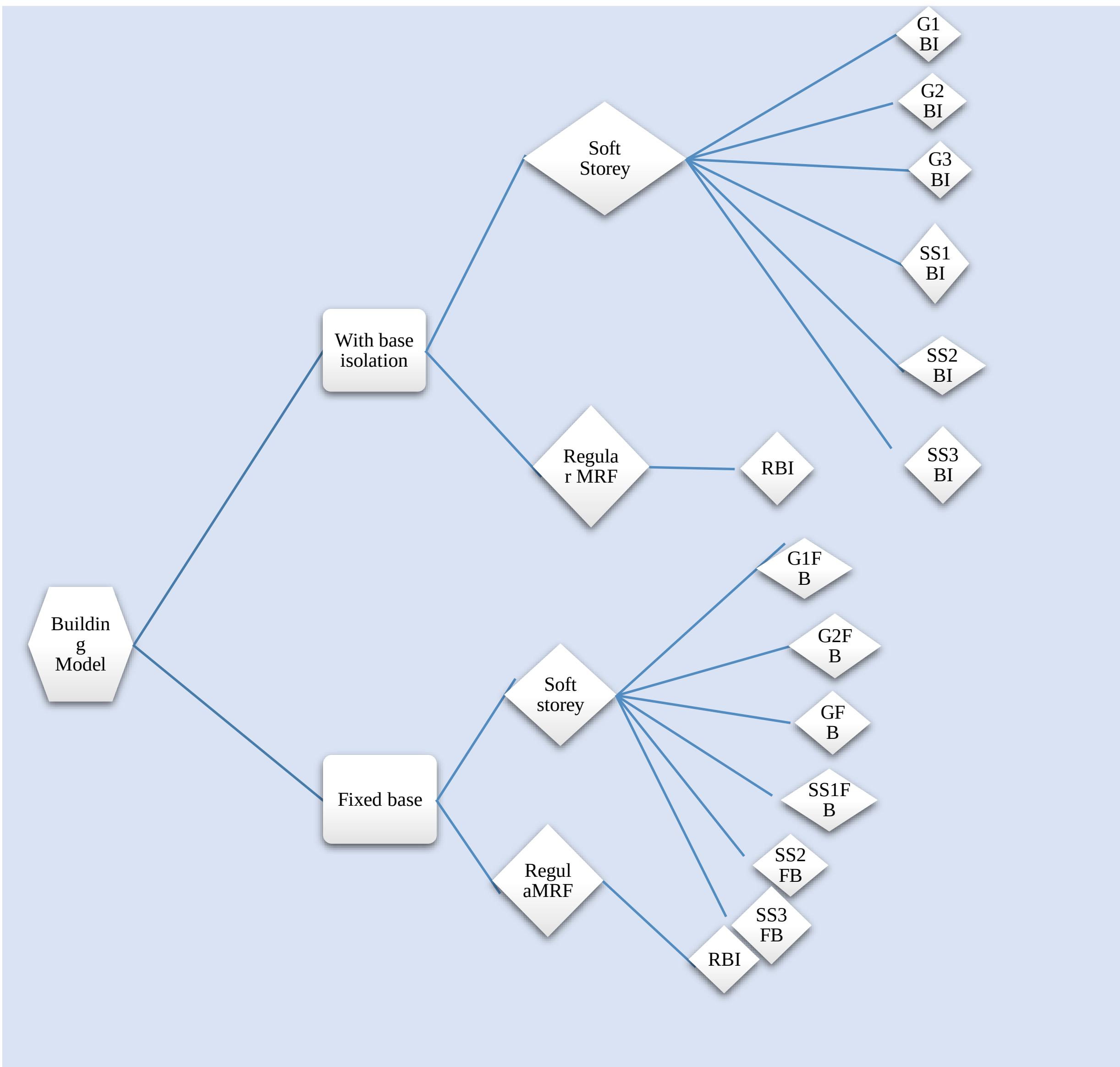


Figure 3. 1: Sample Modeling Diagram

Whereas: - Type I soft storey due to masonry infill

Type II soft storey masonry + storey height

Height of the storey for type I is 3m in all storey .

Height of the storey for type II is 4.5m at soft storey.

G1: - soft storey at ground floor **SS1:-**soft storey due to height+ Masonry. at ground floor

G2:-soft storey at third floor **SS2:-** soft storey due to height+ Masonry at third floor

G3:-soft storey at sixth floor **SS3:-** soft storey due to height+ Masonry at six floor

FB: - Fixed base

BI: - Base isolated

3.5 Source of Data

The data used for this research is obtained from ES EN 2016, code and different literature. The necessary data required for the investigation, is present the way the buildings to be modeled with respective material and section of structural members.

3.5.1 Seismic and Structural Data

The structural and the seismic data used as input for the ETABS software is organized in Table 3.1 below

Table3. 1: Data used in research

Material Property		
Concrete Grade	C25/30	γ=24KN/m^3 f_{ck}=25Mpa E= 31000Mpa ν = 0.2
Reinforcing steel Grade	S-400	f_{yk}=400Mpa E=210Gpa ν =0.3
External wall	Brick wall(Hejazi et al. 2011)	γ=20kN/m^3, f_m=13N/mm^2, E=5500Mpa ν=0.2
Section Properties		
Beam	300mm*400mm	
Column	450mm*450mm	
Slab	150mm	
Thickness of Brick wall	t_b = 230mm ,Wds = 495mm	
Storey Height	Type I = HC= 3m Type II= Hv =4.5m, 3m used	
Loading		
Dead load	Self-weight of the structure	
Line load (wall load) on beam	0.23*20*2.6 =11.96KN/m^2	
Live load	5KN/$m^2$for typical floor 1KN/m^2 for roof	Section 4.2.5 category D ES EN 1991-1-1:2016

Seismic Load factor (According to ES EN 1998-1: 2016)		
Seismic Zone	IV Adama (Study Area)	(ES EN-1998- Part 1: 2015 n.d.)
Peak Ground Acceleration	0.15	Annex D1
Importance factor	1.2	Sec:4.2.5
Spectrum type	I	Sec :3.2.2.2
Ground type	C	Sec :3.2.2
Behavioral factor *q*	Regular =3.9 Irregular =(3.9)*0.8 = 3.12	Sec:5.2.2.2
Ductility class	Medium ductility class (DCM)	Sec: 5.2.2.
Lower bound factor /beta *(β)*	0.2	Sec :3.2.2.5
Correction factor /lambda *(λ)*	0.85	Sec:4.3.3.2.2

3.5.2 Building layout

The model have 9-storey buildings with two type building model which have a regular stiffness and irregular stiffness are considered in the analysis. The plan of building regular. The section of all structural members including slab thickness is given in the modeling section of this research. The functional class of building is a mixed-use building which categorized as Category ‘D’ as per (ES EN-1998- Part 1: 2015, n.d.).The regular plan and irregular in vertical due to masonry infill wall. This plan have 4 bay in two direction

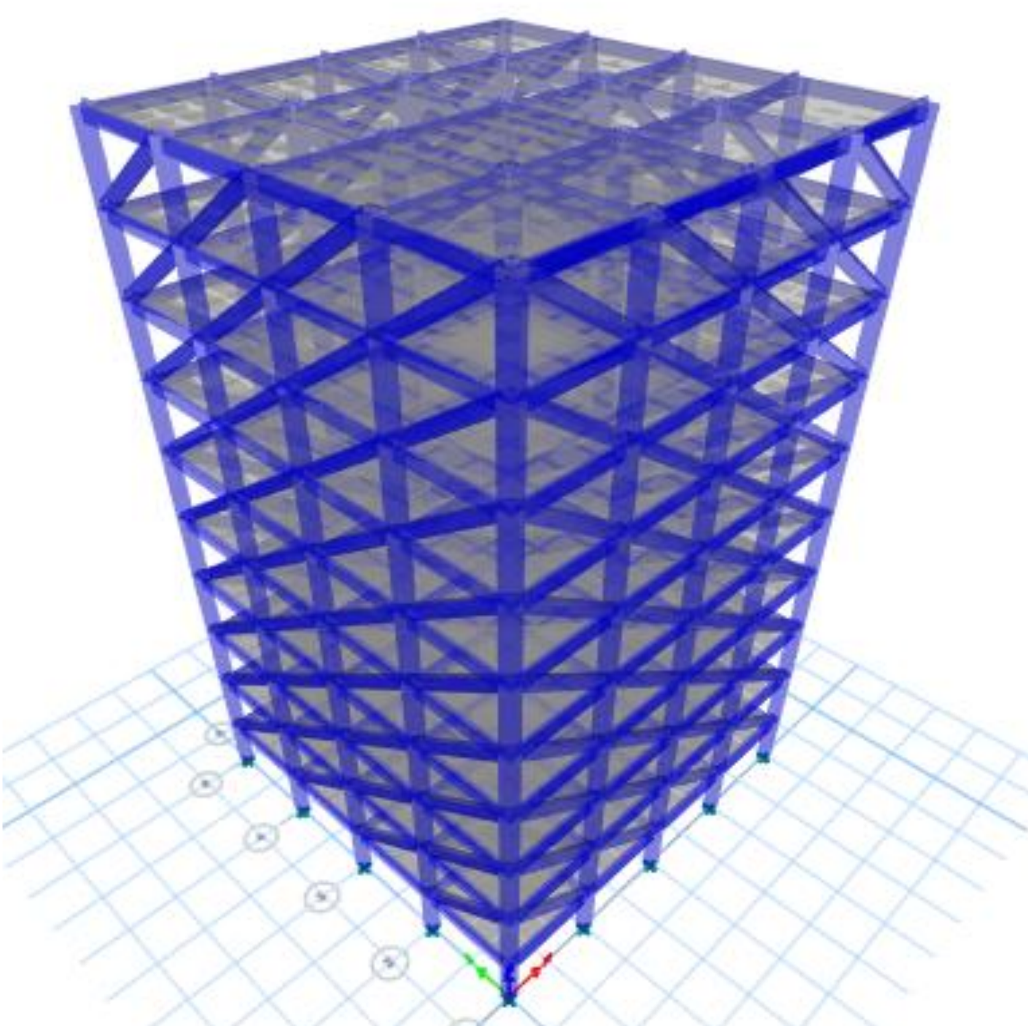
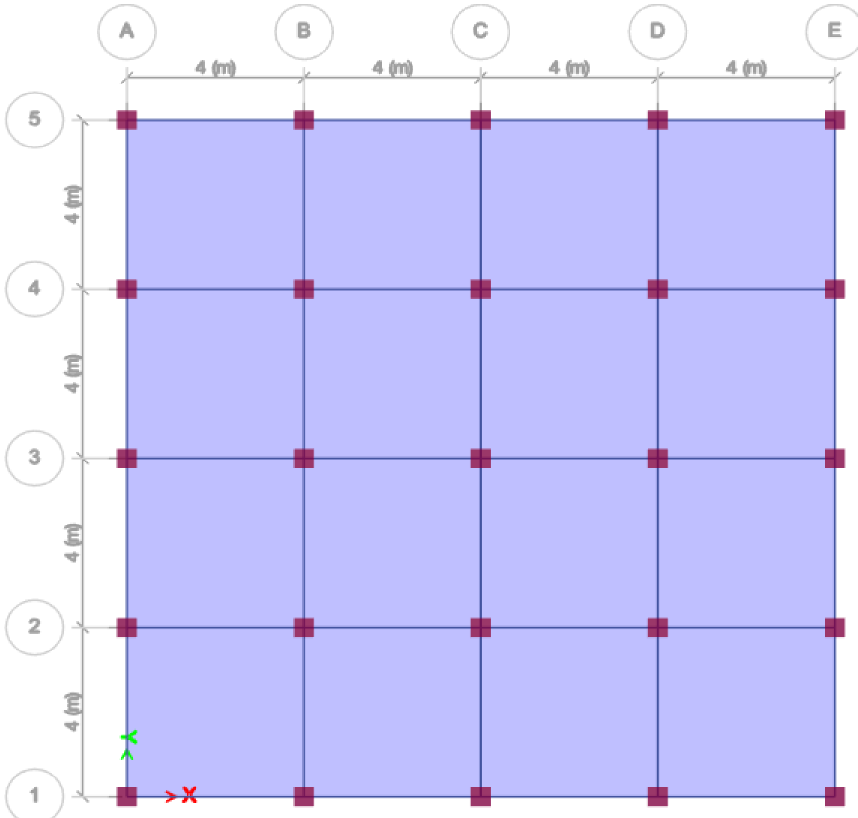


Figure3.2: 3D Model



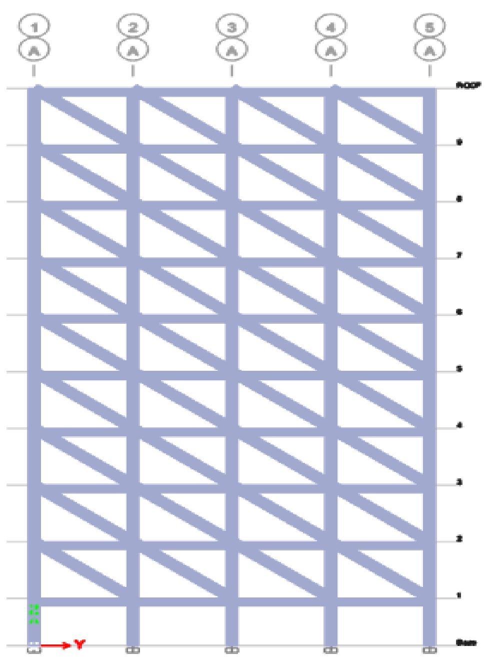
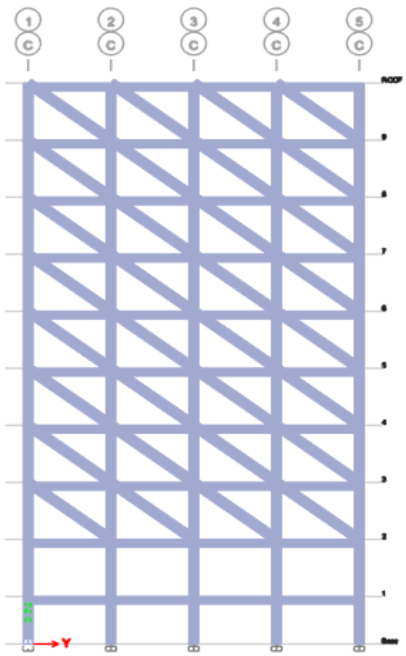
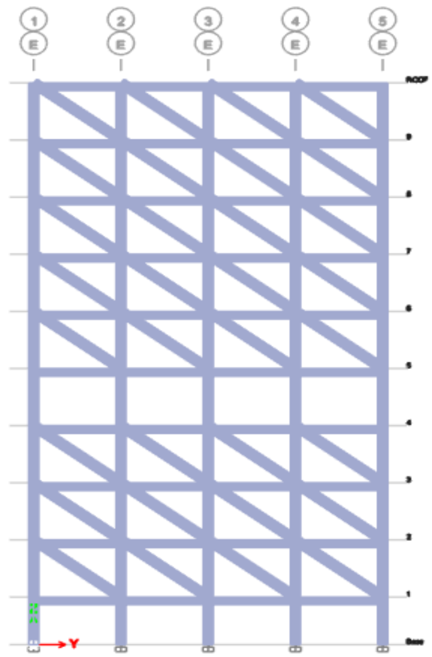


Figure3. 3: Plan model for research and Regular building model frame.

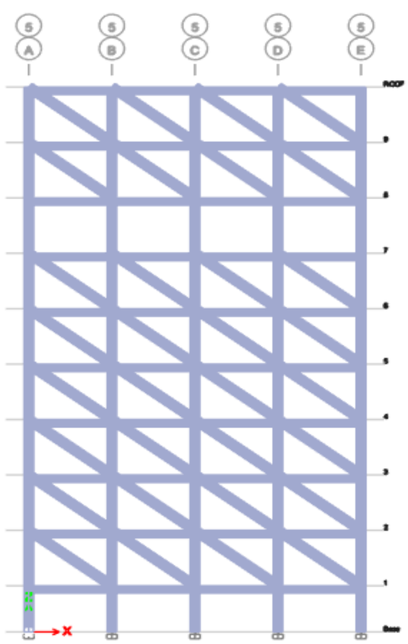
Type I: soft storey due to masonry infill only



a) soft storey at ground (G1)



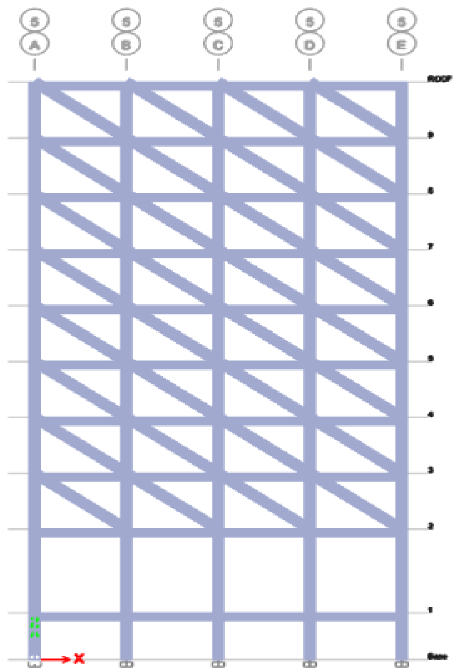
b) soft storey at third floor (G2)



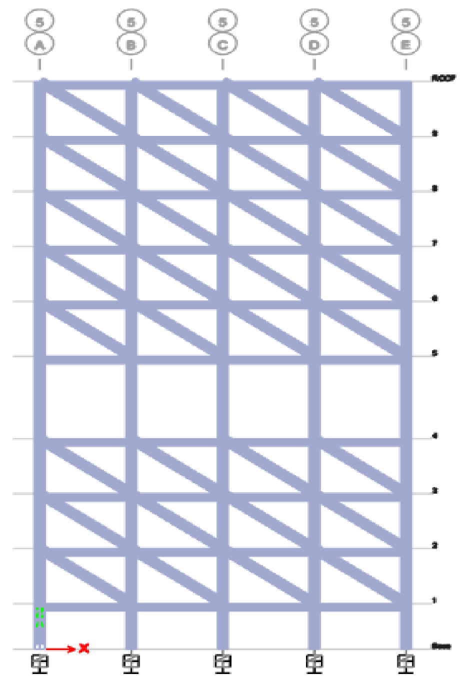
c)soft storey at sixth floor G3

Figure3. 4: Type I soft storey

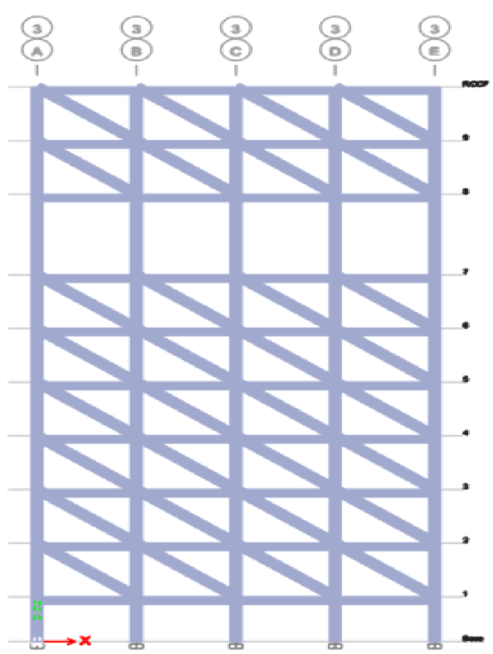
Type II Soft storey due to the height of the storey



a) SS1 soft store at ground floor



b) SS2 soft storey at third floor



c) SS3 soft storey at sixth floor

Figure3. 5: Type II Soft storey

3.6 Data Collection Procedure

The method engaged in this research involves quantitative data. The necessary data for the research is collected through a literature review related to the title and from codes. The necessary data and provisions available on the new version of the Ethiopian Standard based on European Norm (ES EN, 2015) was used.

3.7 Data Analysis and Presentation

3.7.1 Data Analysis

Analysis of the data of this thesis is executed by structural analysis software package, ETABS V.18 based on the new version of the Ethiopian standard (ES EN, 2015). Response spectrum analysis (RSA) is adopted as a seismic analysis method. All the seismic parameters are properly defined on the software for data analysis. The seismic analysis is performed by response spectrum load case whereas the modal combination used is Complete Quadratic Combination (CQC) because it is a modal combination technique that accounts for modal damping and the most realist approach. Since mass source in the seismic analysis is accounted from self-weight of the building and externally applied loads, the possible weight of floor finishing and partition load are considered and assigned to be added on dead load. Live load is also assigned since it should be added to mass source in seismic analysis with the factor recommended by the code depending on the functional class and importance factor of the building.

3.7.2 Data presentation

The result of this thesis is presented using tables, graphs, and charts. Presentation of the investigation compared the output data gathered from the software in terms of the following seismic response parameters so that, conclusion and recommendation will be drawn.

- Storey Displacement
- Storey drift
- Storey acceleration
- Time period
- Base shear
- Base overturning moment.

3.8 Detail modeling method and data used in the modeling

Under this section detail data used through analysis is briefly explained with their sources. The source of these modeling data obtained from ES EN, 2015 of different sections and IS 1893 (Indian standard).

3.8.1 Cross section of primary members

Primary members are selected in order to satisfy deflection and ductility requirement.

3.8.1.1 Ductility Class

The ductility class of all primary members are medium ductility class (DCM) that specified by code. Concrete of a class lower than C 16/20 shall not be used in primary seismic elements (ES EN-1998- Part 1: 2015 n.d.) Sec5.4. In this thesis C25/30 was used for the beam, column and slab

3.8.1.2 Deflection requirements

Minimum depth of flexural members is calculated using the following formula as provided by the code.

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{fck}\frac{\rho o}{\rho} + 3.2\sqrt{fck}\left(\frac{\rho o}{\rho} - 1\right)^{\frac{3}{2}}\right] \text{if } \rho \leq \rho o \qquad \text{Eq3. 1}$$

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{fck}\frac{\rho o}{\rho - \rho\prime} + \frac{1}{12}\sqrt{fck}\frac{\sqrt{\rho\prime}}{\rho o}\right] \text{if } \rho > \rho o \qquad \text{Eq3. 2}$$

Where:-

- *l/d* is the limit span/depth.
- *K* is the factor to taken in to account the different structural system
- $\rho 0$ is the reference reinforcement ratio = $10^{-3}\sqrt{fck}$
- ρ' is the required tension reinforcement ratio at mid span to resist moment due to the design loads (at support for cantilever)
- fck is in MPa units

Assume ρ = $\rho 0$ and fck = 25 MPa By using first equation (3.1) $\frac{l}{d}$ =18.5K and correction factor for fyk<500Mpa

$$\frac{500}{fyk} = \frac{500}{300} = \frac{5}{3}$$

$$\frac{l}{d} = 18.50K * \frac{5}{3} = 30.833K$$

$$d = \frac{l}{30.833K} =$$

Depending on support type the K value will be variable

K = 1 for simply supported

K = 1.3 for end span

K = 1.5 for interior span

K = 0.4 for cantilever

Table3. 2: Determination depth of slab

Slab	Le (m)	Ly(m)	Span ratio	Slab type	Slab type based on location	K	Effective depth ,d(mm)
Center panel	4.5	4.5	1	Two way slab	Interior	1.3	112.26
Edge and corner panels	4.5	4.5	1	Two way slab	End span	1.5	97.29

Considering $12mm\ \Phi$ reinforcement diameter and 15mm concrete cover the depth of slab is

dmax =112.26mm

D=$112.26 + 15 + 12/2$= 133.261mm

D_{used} = 150mm

3.8.2 Cross section for secondary members

3.8.2.1 Unreinforced Masonry Infill

Two methods have been proposed in order to properly simulate the behavior of masonry-infill walls namely, those are micro model method and the macro model method. Although the micro model method is producing the better results and can be used for understanding local and global response, the macro model method, also called the equivalent diagonal strut method, has been developed to study the global response of masonry-infilled frame buildings. The current study, walls are modelled as panel elements without any opening.(Genidy et al. 2015b) .End of the diagonal strut considered to be pin jointed to RC frame (Standard 2016)

The thickness of the strut can be written in terms of the column height between centerlines of beams and the length of panel as:

$$\mathrm{Wds} = \alpha \quad = 0.175(\alpha \mathrm{h})^{-0.4}\mathrm{Lds} \qquad \text{Eq3. 3}$$

$$\mathrm{ah} = \lambda 1 = \mathrm{h}\left(\left(\frac{\mathrm{Emtsin}2\theta}{4\mathrm{EfIc\,h}}\right)^{\frac{1}{4}}\right) \qquad \text{Eq3. 4}$$

$$\mathrm{Lds} = \mathrm{rinf} = \sqrt{(\mathrm{Linf})^2 + (\mathrm{hinf})^2} \qquad \text{Eq3. 5}$$

Where:-

- Em – modulus of elasticity of the material of the URM infill and RC MRF,
- Lds – diagonal length of infill strut
- Wds -width of eqivalent diagonal sturt
- Ic – moment of inertia of adjoining column
- t- thickness of infill wall
- $\theta -$ the angle of the diagonal strut with the horizontal

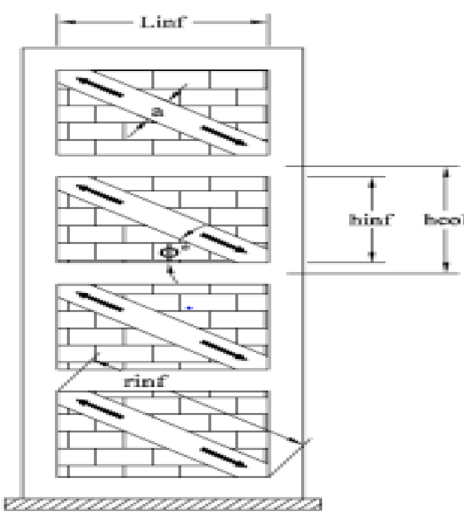


Figure3. 6: Equivalent diagonal compressive strut model (Standard 2016)

Using this formulas the width of the strut $W_{ds=}$495mm

3.8.3 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); at each floor has got three degrees of freedom (two translations and one rotation). The base isolation 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 (Fetene 2016).

Parametric Design of Lead Rubber Bearing Base Isolators (Standard 2016)

1. The maximum vertical reaction R of the footing is estimated for the fixed base structure.
2. The effective stiffness of the isolator is calculated by

$$\mathrm{Keff} = \frac{4\pi^2 \mathrm{W1}}{\mathrm{gTeff}^2} \qquad \text{Eq3. 6}$$

3. From the response spectrum curves of the fixed base isolation system, the design (maximum) displacement or design displacement of the base isolator is,

$$\mathrm{dbd} = \frac{\mathrm{SaTeff}}{2\pi} \qquad \text{Eq3. 7}$$

4. E_D= Dissipated energy per cycle at the design displacement (d_{bd})

$$\mathrm{Ed} = 2\mathrm{Keff}\,\mathrm{dbd}^2\beta \qquad \text{Eq3. 8}$$

5. The short term yield force Fo is

$$Qd = \frac{Ed}{4dbd} \qquad \text{Eq3. 9}$$

6. Stiffness of lead core of lead –rubber bearing

$$Kpb = \frac{Fo}{dbd} \qquad \text{Eq3. 10}$$

7. Kr = stiffness of rubber in LRB

$$Kr = Keff - Kpb \qquad \text{Eq3. 11}$$

8. $t_{r=}$ thickness of LRB(total lead rubber bearing

$$tr = \frac{dbd}{\gamma} \qquad \text{Eq3. 12}$$

9. $D_{bearing}$ diameter of lead rubber bearing

$$Dbearing = \left(\frac{Krtr}{400\pi}\right)^2 \qquad \text{Eq3. 13}$$

10. Total loaded area (A_L)

$$Dpb = \left(\frac{4Fo}{\pi\sigma pb}\right)^2 \qquad \text{Eq3. 14}$$

- σpb =Total yield stress in lead, it is assumed to be 11 pa
- Area of lead core $Apb = \frac{\pi}{4} * Dpb^2$

11. S_i=shape factor

$$S_{i=}\frac{AL}{cr} \qquad \text{Eq3. 15}$$

12. Bearing horizontal stiffness (Kb)

$$Kb = \frac{GAr}{H} \qquad \text{Eq3. 16}$$

- G = shear modulus (varying from 0.4 to 1.1 Mpa)Adopting 1 Mpa

13. Total bearing vertical stiffness

$$Kv = \frac{GSi^2Ark6}{(6GSi^2+k)H} \qquad \text{Eq3. 17}$$

- k = rubber compression modulus = 2000 MPa

Table3. 3: Summary of LRB parameters that used for input in ETHABS V18

Required stiffness	Keff
Bearing horizontal stiffness	Kb
Vertical stiffness	Kv
Yield force	Fo
Stiffness ratio	0.1
Damping	0.05

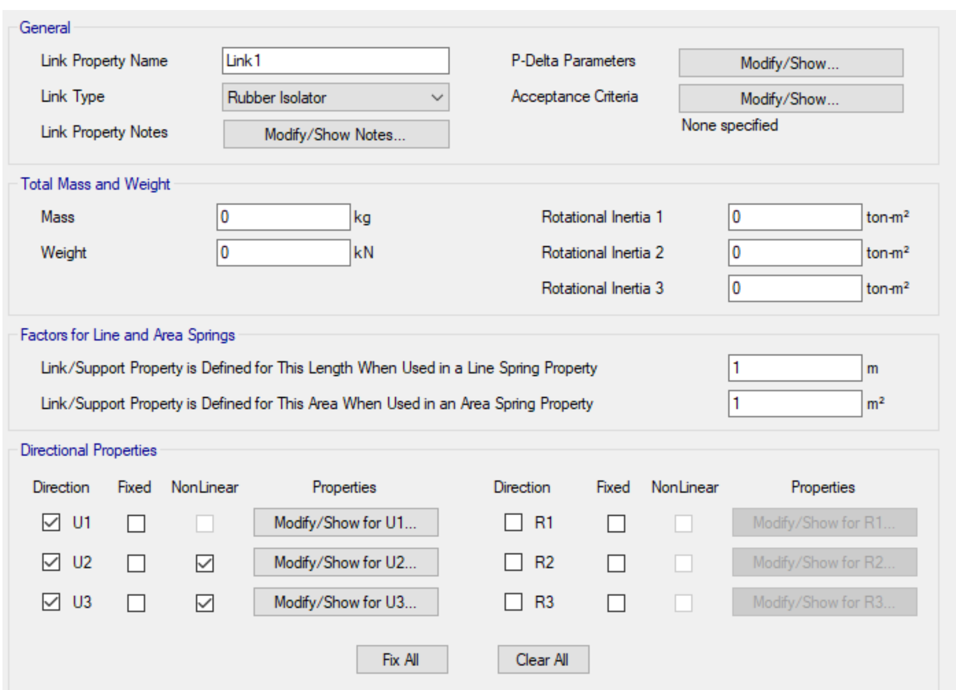


Figure3. 7: LRB Property on ETHABS V18

3.8.4 Load Calculation

3.8.4.1 Live Load

The function purpose of the buildings considered in this investigation for mixed –use which is taken as category D for shopping mall

For category: D Live load = 5KN/m^2 (Edition n.d.)

3.8.4.2 Dead Load Calculation

Depending on material used for floor finishing and possible existence of partition loading dead load on the building is calculated separately for typical floor and flat roof.

Table3. 4: Dead Load Calculation for typical floor

Material Used	Thickness (mm)	Unit weight (KN/m^3)	Uniform Load(KN/m^2)
RC slab	150	24	3.6
Floor marble tiling	20	27	0.69
Cement Screed	30	23	0.54
Ceiling Plastering	30	23	0.69
Partition wall load			1
Gypsum board	10	18	0.18
		Total Dead Load	6.7

Table3. 5: Dead Load Calculation for Flat Roof

Material used	**Thickness (mm)**	**Unit weight (KN/m^3)**	**Uniform load (KN/m^2)**
RC Slab	150	25	3.6
Cement screed	30	23	0.69
Ceiling plastering	20	23	0.46
Parapet wall			1
Rubber roof covering	1.5	17	0.0255
Gypsum board	10	18	0.18
Total Dead Load			6.194

3.8.5 Response Spectrum Function

The function of the response spectrum is defined on ETABS V.18 software using the necessary data obtained from code for seismic analysis. These necessary data are presented below along with brief explanation.

3.8.5.1 Seismic zone

For earthquake analysis, the country has been subdivided into different seismic zones depending on the local hazard. The hazard map is preliminary and is processed from an instrumentally recorded earthquake catalog. The seismic hazard map is divided into 5 zones, where the ratio of the design bedrock acceleration to the acceleration of gravity for the respective zone is indicated in table D1 on ES EN 1998-1: 2015

Table4. 1 Bedrock acceleration ratio, α_o(ES EN-1998- Part 1: 2015 n.d.)

Zone	**5**	**4**	**3**	**2**	**1**	**0**
$\alpha_o=\frac{ag}{g}$	0.2	**0.15**	0.1	0.07	0.04	0

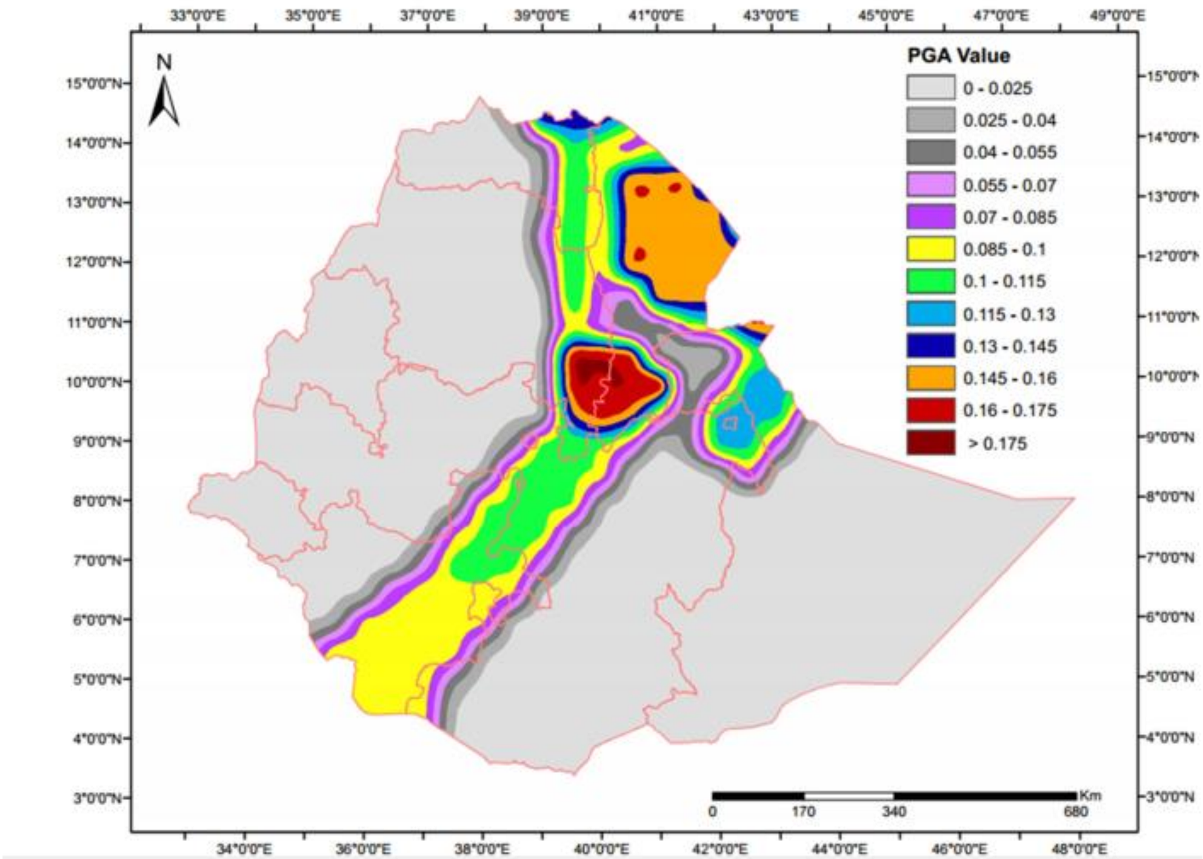


Figure3.8*:* Ethiopia Seismic hazard map in terms of peak ground acceleration(ES EN-1998-Part 1: 2015 n.d.)

Table3. 6: Seismic zone

Region	Zone	Town	Longitude	Latitude	Seismic Zone
OROMIA	Adama	Adama	39.2682	8.5386	4

3.8.5.2 Peak Ground Acceleration

The reference peak ground acceleration chosen for seismic zone corresponds to the reference return period of T_{NCR} of the seismic action for no-collapse requirement (or equivalent the reference probability of exceedance in 50 years, P_{NCR})

3.8.5.3 Spectrum Type

According to the ES EN 1998 code there are two type of spectra based on surface wave magnitude. Those are Type 1 and Type 2. If the earthquakes that contribute most to the seismic hazard defined for the site for the purpose of probabilistic hazard assessment have a surface-wave magnitude, Ms. not greater than 5.5. If the earthquake the assessment has surface-wave velocity magnitude, M_S greater than 5.5, it is recommended that the type 1 spectrum is adopted. Depend on the literatures on seismic hazard history of the research area, Type 1 spectrum is adopted have surface-wave velocity magnitude, M_S greater than 5.5

3.8.5.4 Ground Types

Ground types A, B, C, D, and E, described by the stratigraphic profiles and used to account for the influence of local ground conditions on the seismic action. This may also be done by additionally taking into account the influence of deep geology on the seismic action. the values of the parameters S, T_B, T_C and T_D defining the horizontal and vertical elastic response spectra (ES EN-1998- Part 1: 2015 n.d.)According to the NEHRP the soil can be categorized into class C and D, with the major part of the study area falling into site class **C**

According to the code and literatures seismic hazard assessment in Adama town, the ground is taken as type C which described by the code as “Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meters.”

3.8.5.5 Behavior Factor for horizontal seismic actions

The behavior factor, q depend up on the frame system and ductility class considered in this research.

$$q = qoKw \geq 1.5 \qquad \text{Eq3. 18}$$

Where:

- q_o: is basic value of behavior factor, depends on the type of structural system and on its irregularity
- k_w: is the factor reflecting the prevailing failure mode in structural system with walls. k_w = 1 for frame and frame equivalent dual system.

Since the building is moment resisting frame system in which all lateral load is resisted by frame system through bending of columns and beams, the basic value of behavior factor, q_o corresponding frame system was obtained from the code.(ES EN-1998- Part 1: 2015, n.d.)

Table3. 7: Ductility table(ES EN: 2015.)

Structural type	**DCM**	**DCH**
Frame system, dual system, coupled wall system	3.0αu/α1	4.5αu/α1
Uncoupled wall system	3.0	4.0αu/α1
Torsional flexible system	2.0	3.0
Inverted pendulum system	1.5	2.0

Frames or frame-equivalent dual systems

- One-story buildings: $\alpha_u/\alpha_1=1.1$
- multistory, one-bay frames: $\alpha_u/\alpha_1=1.2$;
- multistory, multi-bay frames or frame-equivalent dual structures: $\alpha_u/\alpha_1=1.3$

Then behavior factor, *q* calculated using the equation above and the factor given above are:

- ✓ for Regular building, $q = 3(1.3) = 3.9$
- ✓ For buildings which are not regular in elevation, the value of q_o should be reduced by 20% so irregular in elevation building ,$q=3(1.3)*0.8 = 3.12$

3.8.5.6 Response Spectrum Periods

Based on ground type and spectral type response spectrum periods listed below in the table.

Table3. 8: ground type and spectra type

Ground Type	S	T_B	T_C	T_D
A	1	0.15	0.4	2.0
B	1.2	0.15	0.5	2.0
C	**1.15**	**0.2**	**0.6**	**2.0**
D	1.35	0.2	0.8	2.0
E	1.4	0.15	0.5	2.0

Accordingly, value of soil factor, S and time periods corresponding spectral type 1 and ground type C for horizontal elastic response spectrum are: S = 1.15, T_B = 0.2sec, T_C = 0.6sec, T_D =2.0sec

3.8.5.7 Response Spectrum function and curves

Design spectrum, $S_d(T)$ of horizontal components of the seismic action was defined by the following expressions provided by code:

$0 \le T \le TB$: $$Sd(T) = ag.S.\left[\frac{2}{.} + \frac{T}{TB}.\left(\frac{2.5}{q} - \frac{2}{3}\right)\right]$$ Eq3. 19

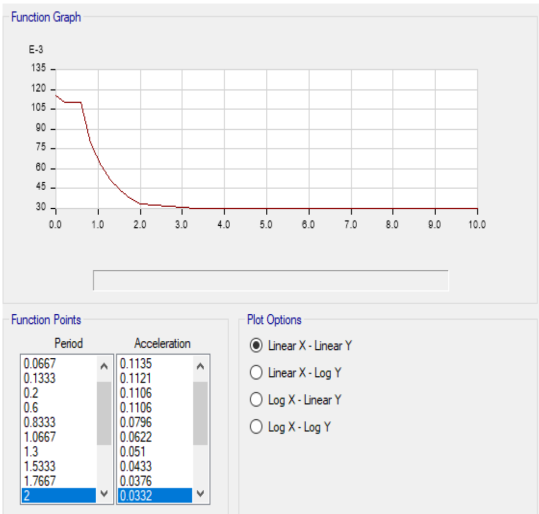
$TB \le T \le Tc$: $$Sd(T) = ag.S.\eta.2.5/q$$ Eq3. 20

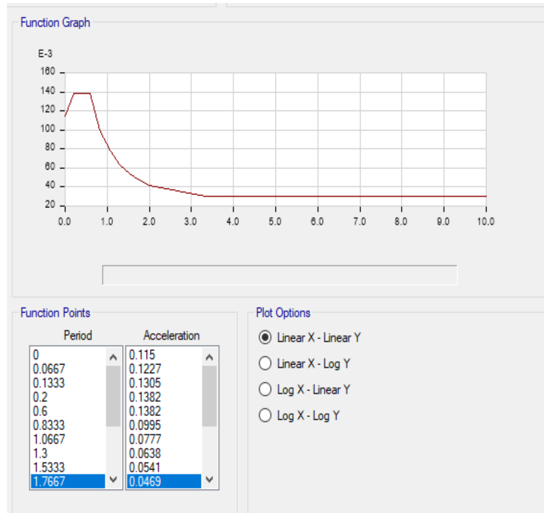
$TB \le T \le Tc$: $$Sd(T) = \begin{Bmatrix} ag.S.\frac{2.5}{q}.\left[\frac{Tc}{T}\right] \\ \ge \beta.ag \end{Bmatrix}$$ Eq3. 21

$Tcd \le T$: $$Sd(T) = \begin{Bmatrix} ag.S.\frac{2.5}{q}.\left[\frac{TcTD}{T^2}\right] \\ \ge \beta.ag \end{Bmatrix}$$ Eq3. 22

Where:

- $S_d(T)$ is the design spectrum
- T is the vibration period of a linear single-degree-of-freedom system;
- a_g is the design ground acceleration on type A ground ($a_g = \gamma_I.a_{gR}$)
- T_B is the lower limit of the period of the constant spectral acceleration branch;
- T_C is the upper limit of the period of the constant spectral acceleration branch;
- T_D is the value defining the beginning of the constant displacement response range of the spectrum;
- S is the soil factor;
- η I s the damping correction factor with a reference value of $\eta = 1$ for 5% viscous
- q is behavior factor;
- β is lower bound factor for horizontal design spectrum, recommended value is 0.2





a) RSA for Irregular RC building. b) RSA for Regular building.

Figure3. 9: RSA graph for both Irregular and Regular building model.

3.8.6 Combination for Variable Action

Load combination for seismic analysis is required for mass source definition. An appropriate coefficient of variable action is considered in this research as provided in the design code to be added as additional mass from service load. These coefficients depend on the important factor of each story and the functional class of the building.

$$\sum Gk,j \,+\, \sum \psi\, Ei.Qk,i \qquad \text{Eq3. 23}$$

$$\psi\, Ei = \varphi.\psi 2i \qquad \text{Eq3. 24}$$

Where:

Ψ: - is combination coefficient of variable action

φ = 1, for Categories D-F* (Table 4.2 of ES EN 1998-1, 2015)

$\psi 2i$ = 0.6, for Categories D (Table 4.2 of ES EN 1998-1, 2015)

3.8.7 Modal and Load Case Definition

The total number of modes considered in the response spectrum analysis depends on degrees of freedom at every floor level and direction of the seismic force. Since horizontal seismic force is considered in this research, three modes per floor which are two translation (X and Y-directions) and one rotation in the Z-direction. Accordingly, the total number of modes assigned for the building with eight-story is 27. Eigenvalue analysis method is used as modal analysis method. Since the scope of this study is limited to story displacement, story drift, base shear, base overturning moment, story stiffness and time period response of the structure. CQC methods provide good estimates of maximum response for both regular and irregular structural models as compared to other modal combination methods such as Square Root of Sum Square, Absolute Sum, etc.

CHAPTER FOUR

RESULTS AND DISCUSSION

The analysis of structure is performed according to the methodology discussed in the previous section. The response of the structures for selected parameters obtained from the analysis are discussed in this chapter in the form of a table, graph, and chart. As discussed earlier, the seismic analysis is elastic response spectrum and response will be discussed in terms of story displacement, story drift, base shear, base overturning moment, and story stiffness, storey acceleration and the structural periods.

4.1 Comparison of Fixed Base and Base Isolated Soft Storey Structure

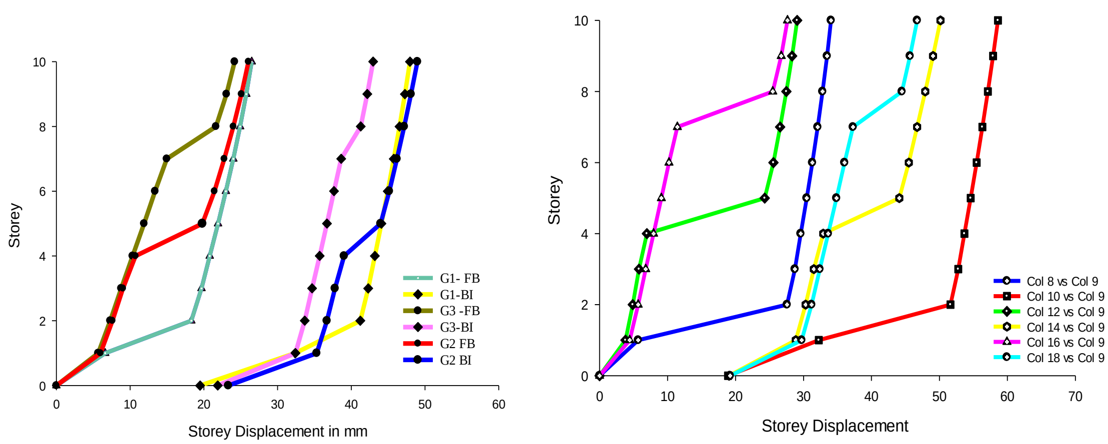
The dynamic response of building with irregular stiffness means soft storey is evaluated for both cases, isolated and fixed ones, to show the effect of isolation on the response of those building model. Parameter discussed under this are storey displacement, storey drift, storey shear,storey acceleration ,base shear , time period and overturning moment .

4.1.1 Storey Displacement

Storey displacement is lateral displacement of the storey relative to the base and is consider as one of the most important response of structures under earthquake excitation. The seismic isolation is introduced horizontally flexible with vertically stiff components. Owning to this reason, both types of soft storey building model the displacement of the framed at each floor is more as compared to its fixed base. But, increase rate of displacement is more uniform in isolated base as compared to the fixed base framed structure and also it has been observed that lateral displacements along the whole building increase significantly in fixed base building as compare to base isolated building.

From the analysis result, it is observed that for both type of soft storey models fixed base building have zero displacement at base of building whereas, in base isolated building models shows visible lateral displacements at base. When the lateral displacement reduce during earthquake the expected damages on the structural as well as nonstructural is minimized. But the displacement increases more uniformly with small rate. Storey displacement at every floor level is displayed in graphical form for best illustration of base isolation effect on the building modeled with and without base isolation.

In case of both soft storey structure, the displacement of the moment resisting framed structure at each floor is more as compared to its corresponding fixed base one with respect to the base of the frame similar to the regular building. The storey displacement on type I soft story building model for G1,G2,&G3 which means at ground, third story, sixth story increased by 52%,61%&,64% more in base isolated than that of the fixed base.



a) Storey displacement for type I b) Storey displacement for type II

Figure4. 1: Graph of soft storey displacement.

Table4.1: Average percentage change in displacement for both type of soft storey

Average in %	**Increment of Storey Displacement (mm)**					
	G1	G2	G3	SS1	SS2	SS3
	52%	61%	64%	48%	59%	66%

Similarly, for type II soft story due to storey height at ground, third storey and sixth storey is also increase averagely by 48% , 59% and 66% than the fixed base. The rate of increment in fixed base Type I soft storey in average in G1FB is 2.21 mm ,for G2FB 2.23mm and G3FB 2.05mm along the storey but this increment is not include the ground floor. Slowly than the fixed base which will reduce damage on the building.

Table4. 2: Average rate of increment displacement

Average in %	**Increment rate in average on Storey Displacement (mm)**					
	G1 FB	G1 BI	G2 FB	G2 BI	G3 FB	G3 BI
	2.21	1.73	2.23	1.52	2.06	1.17
	SS1FB	SS1BI	SS2 FB	SS2 BI	SS3FB	SS3BI
	3.15	2.93	2.81	2.37	2.58	1.89

From the result comparisons on the effectiveness of base isolation on those model is explained as below:-

For type I soft storey :-

- GlBI (soft storey at the ground floor) shows high storey displacement at the ground floor by 80% great than the fixed base and the increasing rate is higher infixed base by 24% than the base isolation
- G2BI (soft storey at third floor) the third floor displaced increase in 73% than the fixed base. the increasing rate is higher infixed base by 45% than the base isolation
- G3BI (soft storey at sixth floor) the displacement in base isolation increase in 61%than the fixed base. The increasing rate is higher infixed base by 60 % than the base isolation

For type II soft storey which have variable storey height:-

- SSl BI (soft storey at the ground floor) shows high storey displacement at the ground floor by 82% great than the fixed base the increasing rate is higher infixed base by 11% than the base isolation.
- SS2BI (soft storey at third floor) the third floor displaced increase in 79% than the fixed base. The increasing rate is higher infixed base by 35% than the base isolation.
- SS3BI (soft storey at sixth floor) the displacement in base isolation increase in 69%than the fixed base. The increasing rate is higher infixed base by 24% than the base isolation.

Generally ,this result shows type II soft storey which have variable floor height gain great storey displacement than the type I soft storey and also floor which have soft storey show large storey displacement due to lack of stiffness. Additionally, the location of soft storey affect the storey displacement highly as the graph below shows and also soft storey at ground floor is high. The P-∆ effect will increase the displacement relative to the ground and reduce the effectiveness of base isolation system.(Bhatt, Paul, and Bhowmick 2018)

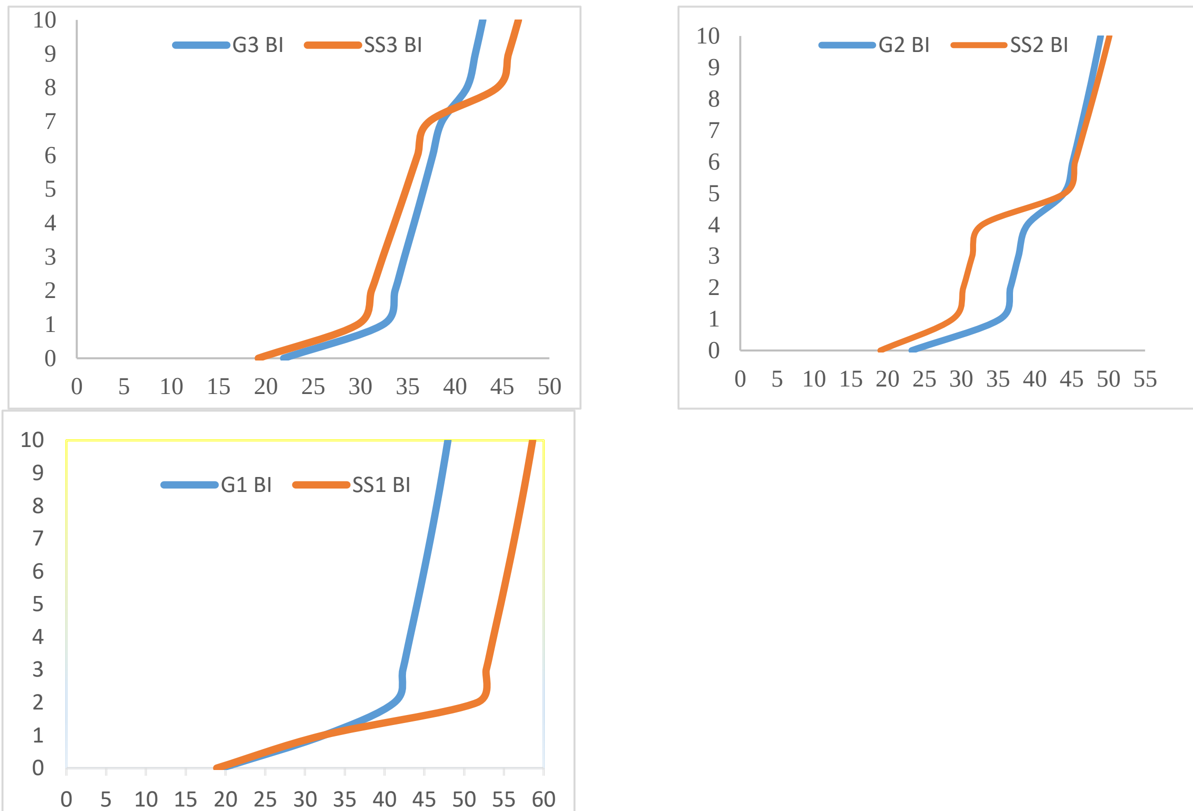


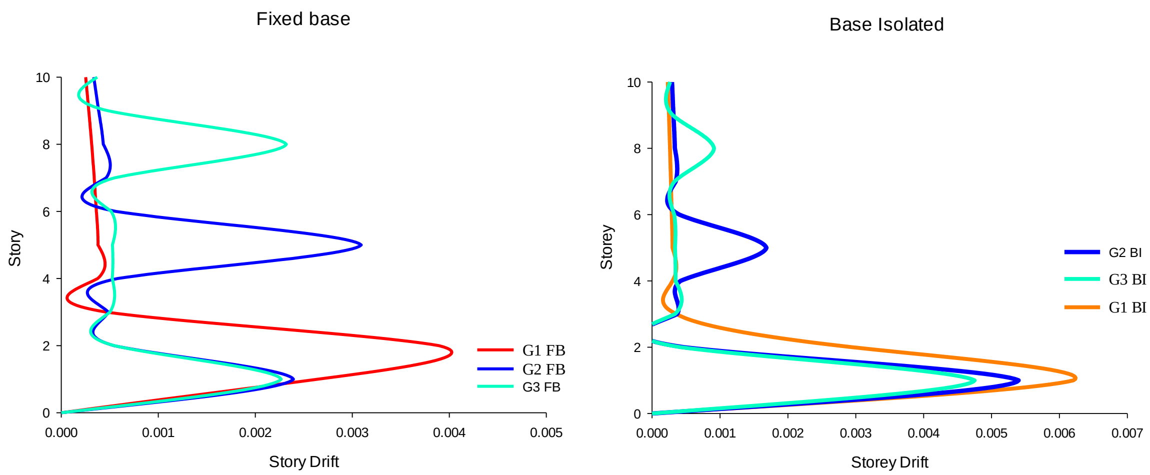
Figure4. 2:- story displacement for each type of soft story to compare effectiveness.

4.1.2 Story Drift

Storey drift is the relative displacement at the top of given storey to its bottom of the storey. Storey drift ratio which described in the following expression is used as dependent variable in this research. Storey displacement, *d*, and drift basically depend on lateral stiffness and storey shear of the building structure. The more the structure is stiff the less it will deflect. The importance of storey drift is in design of partitions/ curtain walls. They must be so designed as to accommodate the storey drift, else they will crack. For structural glazing, brick walls on external surfaces is recommended.

$$\text{Story drift} = \text{dtop} - \text{dbottom} \qquad \text{Eq4. 1}$$

$$\text{Story drift ratio} = \left(\frac{\text{dt} - \text{db}}{\text{h}}\right) \qquad \text{Eq4. 2}$$



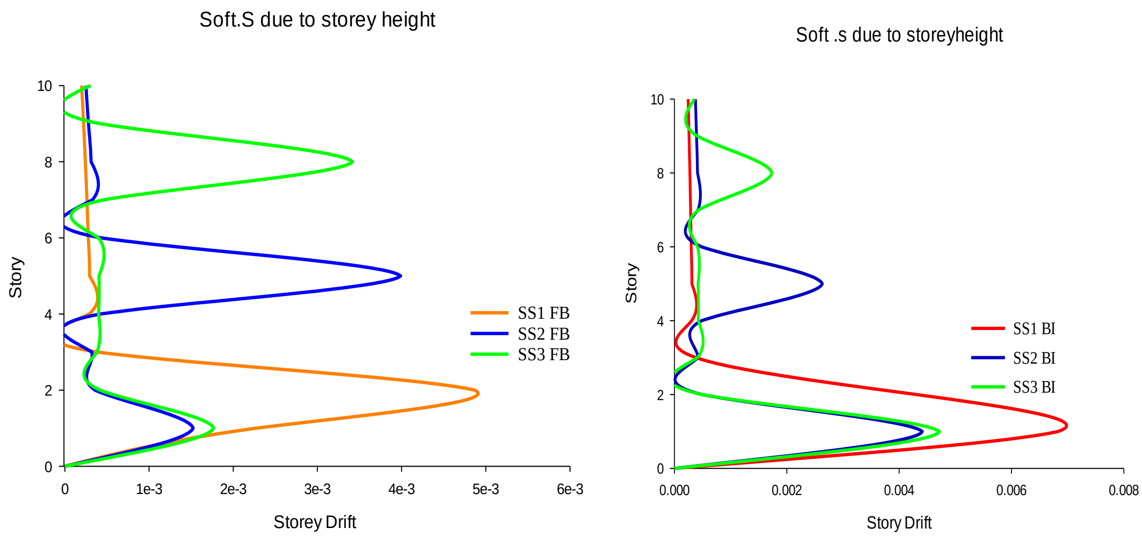
a) Storey drift for fixed base in type I b) Storey drift for fixed base in type I

Figure4. 3: Type I Soft Storey drift

Table4. 3**:** Average percentage change in drift for Type I of soft storey

Average in %	**Increment of Storey Drift (mm) at ground floor**		
	G1	G2	G3
	57%	56%	52%
	Decrement of Storey Drift (mm)		
	18%	24%	37%

From the graph is shown in Figure 4.3 for soft storey type one due to stiffness irregularity caused by masonry infill the storey drift at the storey one is increase by 57%, 56% and 52% for G1, G2 and G3 than fixed base . Furthermore, as storey height increase the storey drift decrease more in base isolated. The average decrease by 18%, 24%, and 37% with respect to fixed base for respective G1,G2, and G3.



a) Storey drift for fixed base in type II b) Storey drift for fixed base in type II

Figure4.4: Storey Drift Graph

Table4.4: Average percentage change in drift for Type II of soft storey

Average in %	**Increment of Storey Drift (mm) at ground floor**		
	G1	G2	G3
	67%	65%	63%
	Decrement of Storey Drift (mm)		
	11%	34%	49%

Second type of soft storey is due to stiffness irregularity related to storey height difference is show in Figure 4.4 similar to soft storey type one. The storey drift is high rate at storey one. The drift rises by 67%, 65%, and 63 % respectively SS1, SS2, and SS3 but the rest of the storey drift is decreased uniformly in base isolated than the fixed base one. The drift of soft storey located at different floor decrease by 11% ground floor, third floor 34% and 49% for the sixth floor.

However, type II soft storey shows more drift on structure than the soft storey type one. The SS1BI store drift is higher than the G1BI in 9% whereas, the SS2BI is higher by14%and SS3BI also 24% higher than G1BI andG2 BI respectively. This is due to height of the floor which affect the stiffness of the floor when it added with the effect of masonry infill along the storey. Stiffness of the floor affect the values structure drift.

4.1.3 Storey Shear

Storey shear show how much lateral load act per storey. This will be used to design and visualize possible governing lateral load of structure safely in order to resist the lateral force. Figure 4.5 below shows that the base isolation (LRB) decrease significantly with the storey shear of building model in Type I soft storey.The base isolation reduce seismic load transmission by decoupling the sub- structure from super structure.

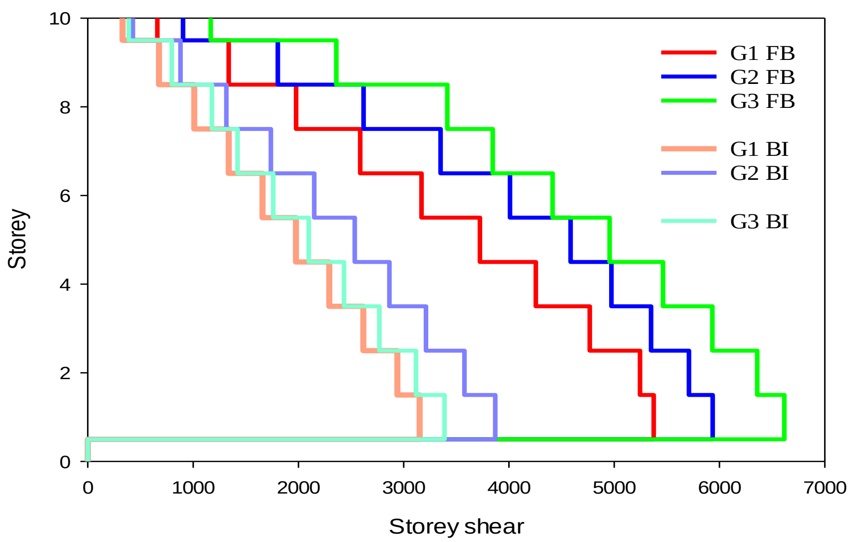


Figure4.5: Storey shear Graph for type I

Table4.5: Average percentage change in storey shear for type I of soft storey

Average in %	**Reduction in Storey Shear**		
	G1	G2	G3
	47%	45%	59%

According to Table 4.5, the building model G3 with soft storey at sixth floor shows maximum reduction in average of 59% of storey shear for base isolated than the fixed base. Whereas, for G1 and G2, the storey shear reduce 47% to 45% of the storey shear. In relation to this G1 storey shear is less than both G2 and G3 an average by 23%, 44%. This show that the presence of soft storey decreases the storey shear on the building(Genidy et al. 2015b). As the soft storey location far away from the ground floor, the storey shear increases so as the location of the soft storey affect storey shear highly. .

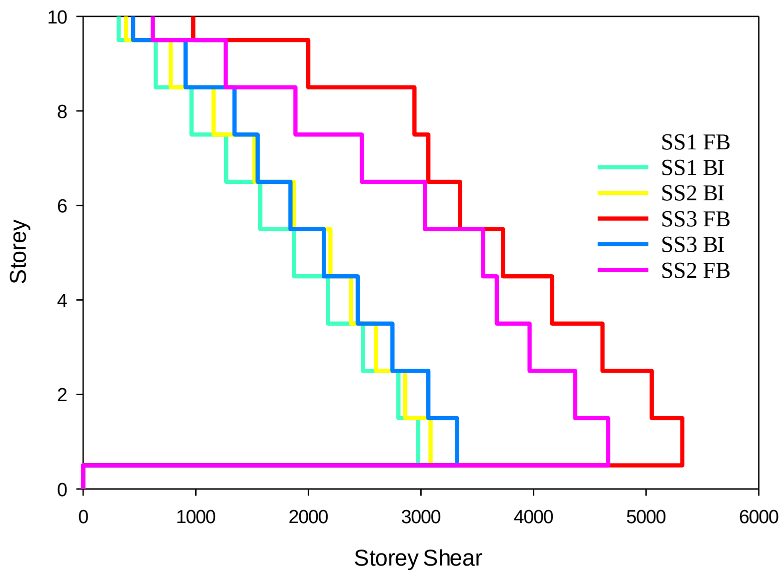


Figure4. 6: Storey Shear for Type II soft storey

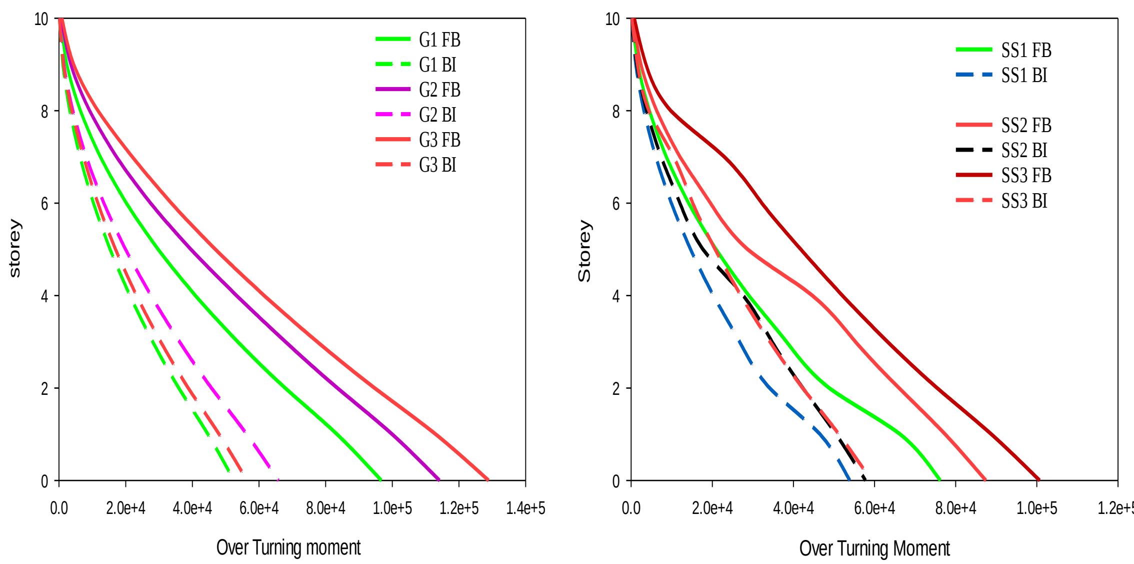
Table4. 6**:** Average percentage change in storey shear for Type II of soft storey

Average in %	**Reduction in Storey Shear**		
	SS1	SS2	SS3
	30%	37%	47%

Similar to the Type I soft storey, the base isolation decreases the storey shear effectively. The great reduction of storey shear which is long slender storey located at sixth floor SS3 by 47% and for SS1 storey shear reduced by 30% and 37%for SS2. In relation to this, the SS1 shows less storey shear along the whole storey. SS1 is less in average of 26 % than SS2 and 62% SS3.the storey shear is higher more in type I soft storey than the type II soft storey in addition to this when soft storey found at ground floor for both type of soft story the storey shear is lower than SS located at third and sixth floor.

4.1.4 Overturning Moment

It is observed that the soft storey building with maximum overturning moment in base isolated buildings is decreased by 50%, 52% and 65% for respective Type I Soft storey G1,G2 and G3 in comparison to fixed base building model. Similarly, for Type II model, the maximum overturning moment in base isolated buildings is decrease by 32%, 41% and 52% for each type II SS1, SS2, and SS3 building model.

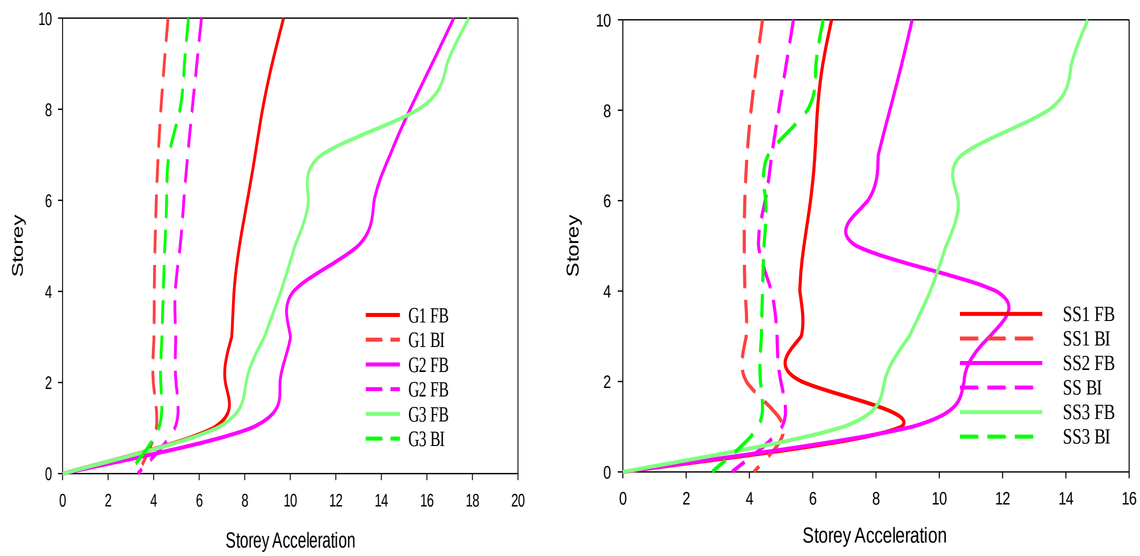


a) For type I soft storey b) For type II soft storey

Figure4. 7: Over turning graph for both type of storey

4.1.5 Storey Acceleration

The floor level versus storey acceleration graph of fixed and base isolated building for fixed base and base isolated building model is shown in Figure 4.7 which shows that storey acceleration in base isolated building model decreases by 48% 56% and by 57 % in Type I soft storey for G1,G2 and G3 and also the same to soft storey Type II which is decreases by 34 % 47 % and 53% for each SS1, SS2 and SS3 building model comparing with fixed base building for same storey level. There is a large difference in storey acceleration for fixed base building model from bottom to top storey. In base isolated model, the storey accelerations are nearly same from bottom to top storey.



a) Type I soft storey b) Type II soft storey

Figure4. 8: Storey Acceleration graph for both soft storey type

4.1.6 Time period

Base isolation shifts the fundamental period of the structure from the dominant period of the earthquake. 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 number of modes depends upon the number of degrees of freedom.

The fundamental period of the fixed structure is increased by an average of 31%, 34% and 32% for each Type I soft storey building model, G1, G2, and G3. Also the time period increases by 41% for SS1 and equal increment by 45% for SS2 and SS3. Table 4.7 and Table 4.8 below show the shift in time period for successive 5 modes.

Table4. 7: Time Period for Type I soft storey

	Time Period								
Modal	G1FB	G1BI	%incr.	G2FB	G2BI	%incr.	G3FB	G3BI	%incr.
1	1.07	2.083	49%	0.865	1.837	53%	0.757	1.812	58%
2	1.062	2.079	49%	0.795	1.83	57%	0.747	1.806	59%
3	0.893	1.762	49%	0.634	1.524	58%	0.572	1.495	62%
4	0.282	0.369	24%	0.266	0.442	40%	0.315	0.451	30%
5	0.278	0.365	24%	0.253	0.438	42%	0.311	0.447	30%

Table4. 8: Time Period for Type II soft storey

	Time Period								
Modal	SS1FB	SS1BI	% incr.	SS2 FB	SS2 BI	% incr.	SS3 FB	SS3 BI	% incr.
1	1.17	2.391	51%	1.146	2.026	43%	0.895	1.824	51%
2	1.152	2.386	52%	1.138	2.019	44%	0.887	1.817	51%
3	0.953	2.023	53%	0.931	1.634	43%	0.695	1.472	53%
4	0.282	0.379	26%	0.295	0.586	50%	0.392	0.604	35%
5	0.278	0.375	26%	0.291	0.583	50%	0.387	0.601	36%

This leads to the structure avoid severe earthquake due to period shift provided by isolation. This reduces the floor accelerations. 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; which means that the higher modes do not affect the response of the structure much as for fixed base structure.

4.1.7 Base shear

Base shear is an expected maximum 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 fixed base structure**.** Maximum base shear in fixed base and base isolated in soft storey building are shown in Figure 4.8, From Figure 4.8 it is observed that for soft storey building model with base isolated model is decreased in average by 45%, 49% and 52% in Type I while 31% 38% and 41% in Type II compare to fixed base building model. The base isolation reduce the base shear for type I than type II soft storey this show the effectiveness of base isolation in Type I is more.

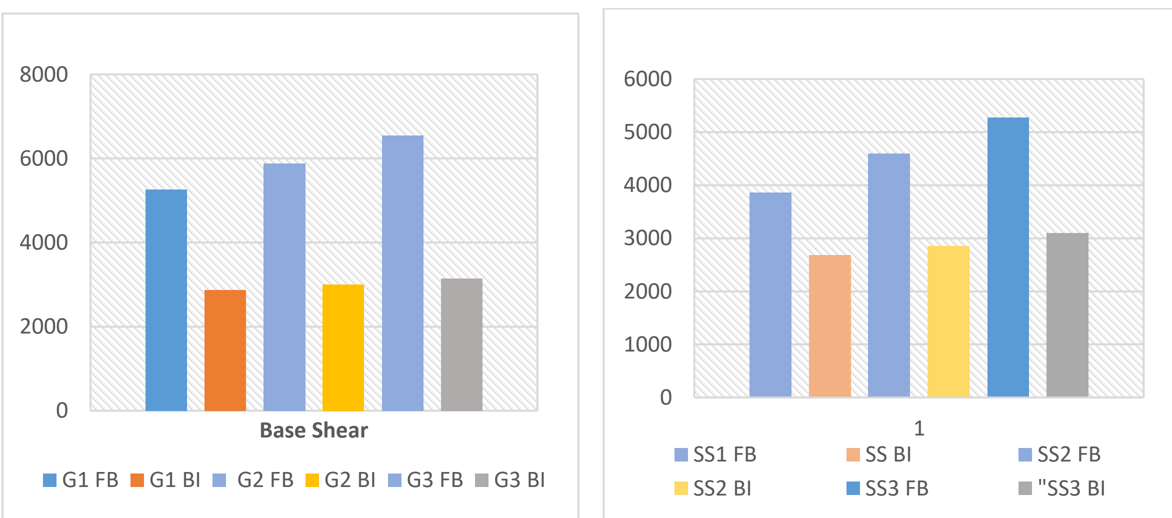


Figure4. 9: Base shear graph for both Type I and II soft storey.

4.2 Comparison of Soft Storey and Regular isolated structures

The data that was sourced from the output files were storey drift, storey stiffness, storey shear, time period and base shear of building model used as comparison criteria between stiffness irregular and regular building . The obtained results are given in the succeeding tables.

4.2.1 Storey drift

In this study, the storey drift which is the ratio or relative displacement between the storey is increased in case of open ground storey (G1) by average 25% than the regular building model. In addition to this, at ground storey (storey 2) the inter story drift increased by 89 % than the regular. This is due to the effect of infill wall that causes stiffness irregularity between the storeys. While the structure stiff more the less storey drift or displacement is. The G2 and G3 is increase by 29% and 37% beside to this at Storey 4 and Storey 8 the drift increase by 85% and 75% than the regular building model.

Table4. 9: Storey drift of Regular and Type I soft storey of base isolated model

Storey	**Storey Drift**						
		soft storey MI			% Increment		
	Regular	G1	G2	G3	G1	G2	G3
storey10	0.000195	0.000231	0.000293	0.000266	16%	33%	27%
storey 9	0.00021	0.000248	0.000314	0.000303	15%	33%	31%
storey 8	0.000225	0.000263	0.000335	0.000912	14%	33%	75%
storey 7	0.000238	0.000277	0.000348	0.00033	14%	32%	28%
storey 6	0.000249	0.000289	0.000401	0.000325	14%	38%	23%
storey 5	0.000257	0.0003	0.001683	0.000337	14%	85%	24%
storey 4	0.000264	0.0003	0.000418	0.000344	12%	37%	23%
storey 3	0.000257	0.000362	0.000369	0.000336	29%	30%	24%
storey 2	0.000332	0.002951	0.000467	0.000421	89%	29%	21%
storey 1	0.004166	0.006206	0.005399	0.004752	33%	23%	12%

Beside to Type I soft storey, the Type II soft storey drift is higher than the regular building. This is also similar to the G1 where the SS1 drift is 92% more than the regular building at soft storey because the storey height of the ground floor is higher and did not have infill wall as a which will reduce the stiffness of at ground floor and reduce the resistance of the column to lateral force during earthquake . As well as in the SS1, both SS2 and SS3 is higher drift at Storey 4 and Storey 8 where the soft storey located. This increment in 44% and 42% in average than the regular building model one.

Table4. 10: Storey drift of Regular and Type II soft storey of base isolated model

Storey	**Storey Drift**						
		soft storey MI			% Increment		
	Regular	SS1 BI	SS2 BI	SS3 BI	SS1BI	SS2BI	SS3BI
storey10	0.000195	0.000243	0.000373	0.000355	20%	48%	45%
storey 9	0.00021	0.000259	0.000392	0.000406	19%	46%	48%
storey 8	0.000225	0.000274	0.00041	0.001735	18%	45%	87%
storey 7	0.000238	0.000287	0.000419	0.000432	17%	43%	45%
storey 6	0.000249	0.000298	0.000482	0.000411	16%	48%	39%
storey 5	0.000257	0.000309	0.002633	0.00042	17%	90%	39%
storey 4	0.000264	0.000306	0.000484	0.000423	14%	45%	38%
storey 3	0.000257	0.000384	0.000419	0.000411	33%	39%	37%
storey 2	0.000332	0.004312	0.000492	0.00049	92%	33%	32%
storey 1	0.004166	0.006829	0.004415	0.00472	39%	6%	12%

In addition to soft storey, the regular building model soft storey reduces significantly as shown in Table 4.11below. But at storey one, the storey drift of base isolated is higher than the fixed base, for the reason that base isolation is more flexible in horizontal. This is used to keep the top of the storey to drift more uniformly and less in drift numerically. Storey drift obtained from the analysis of the frame building modelled with regular masonry infill action is lower than the soft storey at any level.

Table4. 11: Story Drift for Regular Building Model

Regular			
Storey	F B	B I	Reduction%
storey10	0.000333	0.000195	41%
storey 9	0.000378	0.00021	44%
storey 8	0.000419	0.000225	46%
storey 7	0.000451	0.000238	47%
storey 6	0.000475	0.000249	48%
storey 5	0.000488	0.000257	47%
storey 4	0.000491	0.000264	46%
storey 3	0.000473	0.000257	46%
storey 2	0.000519	0.000332	36%
storey 1	0.002196	0.004166	-90%

4.2.2 Storey Shear

The lateral force which acts on each storey due to seismic force is decrease compared to the base isolated (LRB) used in the building model. This base isolation is effective for the regular building model reducing the storey shear in average by 61% than the fixed one. Additionally, the Type I storey shear is reduced by 47%, 45% and 59%, for each soft storey location G1BI, G2BI and G3BI. The soft storey shows less reduction to the regular building model. This shows that the effect of infill wall have effect on energy dissipation and resist the storey shear by increasing the stiffness of the column along with the height of the building. In this study, G1 soft storey is located at the ground floor so the column stiffness is less than those upper floor receive small storey shear force than those two which are the G2 and G2. As the soft storey location distant from the ground floor, the effect will be reduced because the storey shear decreases in the upper floor. The other thing is base isolation reduce more in the upper storey shear than at the ground floor.

Table4. 12: Comparison between regular and Type I soft storey

Storey	**Storey Shear in KN**							
		soft storey MI			**% Decreased**			
	Regular	G1 BI	G2 BI	G3 BI	RBI	G1BI	G2BI	G3 BI
storey 10	306.9901	329.095	428.346	387.943	67%	53%	50%	67%
storey 9	630.2915	675.078	879.253	796.781	66%	51%	50%	66%
storey 8	943.7068	1010.56	1315.82	1177.49	65%	50%	49%	66%
storey 7	1248.0278	1337.44	1738.65	1421.47	63%	48%	48%	63%
storey 6	1544.4878	1658.19	2149.34	1760.99	62%	46%	48%	60%
storey 5	1834.7453	1975.62	2534.03	2097.33	61%	45%	47%	58%
storey 4	2121.0386	2292.97	2863.10	2432.02	59%	42%	46%	55%
storey 3	2406.6787	2615.27	3211.35	2768.42	57%	40%	45%	53%
storey 2	2698.98	2939.35	3577.38	3115.05	55%	37%	44%	51%
storey 1	3010.7932	3150.20	3870.64	3388.48	53%	35%	41%	49%
				Average	61%	45%	47%	59%

In the case of Type II due variable storey height, it shows low reduction than the regular building model. This shows storey height, in addition to the masonry infill, have more effect on resistance of building model the regular building model which shows reduction by 61% than the fixed base. Also, the SS1, SS2 and SS3 decrease by average 30%, 37% and 46% respectively.

Table4. 13: Comparison between regular and type II soft storey

Storey	**Storey Shear in KN**							
	Soft Storey MI				% Decrease			
	Regular	SS1 BI	SS2 BI	SS3 BI	RBI	SS1BI	SS2BI	SS3BI
storey10	306.9901	314.9741	380.7042	443.6042	67%	31%	38%	55%
storey 9	630.2916	644.1574	777.4846	908.6112	66%	31%	39%	55%
storey 8	943.7067	961.7054	1157.525	1343.717	65%	31%	39%	54%
storey 7	1248.028	1270.006	1521.234	1549.13	63%	31%	38%	49%
storey 6	1544.488	1572.315	1869.978	1839.633	62%	31%	38%	45%
storey 5	1834.745	1872.412	2195.452	2136.549	61%	31%	38%	43%
storey 4	2121.039	2174.403	2378.924	2438.223	59%	30%	35%	41%
storey 3	2406.679	2483.413	2599.419	2746.04	57%	29%	34%	40%
storey 2	2698.98	2798.408	2860.082	3066.706	55%	29%	35%	39%
storey 1	3010.793	2975.681	3085.965	3320.475	53%	26%	34%	38%
		Aver.			61%	30%	37%	46%

4.2.3 Time Period

This study demonstrated that the overall response was mainly affected by the incorporation of rubber bearings as base isolators. The predominant time period has been lengthened for the seismic isolated building as expected. Table 4:13 and Table 4.14 show that the fundamental time period of the base-isolated structure has been increased by approximately 39% - 49% compared to the fixed base building model. For the base-isolated building, time periods of all other modes were also greater than those for the conventional system. For the regular base isolated situation, fundamental periods were in the range between 1.738s and 0.36 s and 2.083s- 0.447s for Type I soft storey.

Table4. 14: Comparing time period of type I and Regular building model

Modal	RBI	G1BI	G2BI	G3FB	RBI	G1BI	G2BI	G3FB
1	1.738	2.083	1.837	1.812	59%	49%	53%	58%
2	1.731	2.079	1.83	1.806	59%	49%	57%	59%
3	1.45	1.762	1.524	1.495	63%	49%	58%	62%
4	0.367	0.369	0.442	0.451	31%	24%	40%	30%
5	0.363	0.365	0.438	0.447	31%	24%	42%	30%
AVERAGE					49%	39%	48%	48%

In case of Type II soft storey, 41-49% increment in time period compared to fixed base building model is observed for constant damping ratio. The most important aim of a base isolation system is to increase the fundamental time period of a structure, which can eliminate and reduce the earthquake effects.

Table4. 15: Comparing time period of type I and Regular building model

	Time Period					**% increase**		
Modal	RBI	SS1BI	SS2 BI	SS3 BI	RBI	SS1BI	SS2 BI	SS3 BI
1	1.738	2.291	2.026	1.824	59%	51%	43%	51%
2	1.731	2.386	2.019	1.817	59%	52%	44%	51%
3	1.45	2.023	1.634	1.472	63%	53%	43%	53%
4	0.367	0.379	0.586	0.604	31%	26%	50%	35%
5	0.363	0.375	0.583	0.601	31%	26%	50%	36%
Average					49%	41%	46%	45%

4.2.4 Storey Acceleration

Lengthening of the fundamental time period of a building structure results in reduction of the induced story acceleration and in turn, the earthquake-induced inertia forces of the building. It has been observed that the story accelerations were drastically reduced at all floors when the rubber bearings were applied. As seen in Table 4.15, the regular building model is reduced by an average of maximum value of joint acceleration at the top floor in the isolated building was 438cm/s2 which was far less than the peak acceleration value of 1434cm/s2 obtained from the base fixed building. The top story acceleration has been reduced by 69% due to the base isolation. Also the same is true for Type I soft storey for G1 52%, G2 and G3. 69% reduction is considered due to base isolation.

Table4. 16: Comparison of Storey Acceleration Type I and Regular Building

Floor Level	RBI	%Decr.	G1 BI	% Decr.	G2 BI	%Decr.	G3 BI	% Decr.
10	438.82	69%	462.47	52%	609.29	69%	552.47	69%
9	424.51	68%	445.96	52%	588.92	68%	534.69	68%
8	410.7	66%	431.15	51%	568.53	67%	515.02	67%
7	398.22	64%	419.4	50%	549.12	59%	466.69	59%
6	387.52	62%	411.03	49%	531.9	58%	456.58	58%
5	378.87	60%	405.62	48%	515.82	56%	448.52	56%
4	372.18	57%	402.37	47%	494.22	54%	441.92	54%
3	366.84	55%	400.86	46%	496.62	51%	436.1	51%
2	362.64	51%	398.28	44%	498.03	47%	431	47%
1	354.82	44%	410.87	38%	492.7	38%	421.87	38%
0	227.46	100%	330.44	100%	330.57	100%	287.89	100%

Table4. 17: Comparison of Storey Acceleration Type II and Regular Building

Floor Level	RBI	%Decr.	SS1 BI	%Decr.	SS2 BI	%Decr.	SS3 BI	%Decr.
10	438.82	69%	440.91	33%	538.66	41%	632.61	57%
9	424.51	68%	421.56	33%	515.46	41%	609.48	57%
8	410.7	66%	404.54	34%	492.21	42%	582.65	57%
7	398.22	64%	391.99	35%	469.73	42%	458.52	57%
6	387.52	62%	385.06	35%	449.2	42%	451.25	57%
5	378.87	60%	383.44	33%	428.8	42%	445.33	56%
4	372.18	57%	385.51	31%	469.1	60%	441.04	55%
3	366.84	55%	389.42	31%	487.28	58%	437.58	52%
2	362.64	51%	390.14	31%	499.36	54%	434.85	47%
1	354.82	44%	507.91	42%	502.7	45%	427.54	39%
0	227.46	-100%	414.43	-100%	345.05	-100%	282.31	-100%

4.2.5 Base shear

Rubber isolators reduced induced base shear of the structure during the vibration of an earthquake. As seen in Table 4.18 and 4.19 below, the maximum value of base shear in the isolated building for regular was 2803.03kN which is far less than the maximum shear value of 6288.21 kN obtained from the fixed base building. For the studied building, base shear has been reduced approximately 55% due to the insertion of a rubber isolator. The same is true for both soft storey, 45-52% for Type 1 soft storey and as the soft storey location is far from the ground the base isolation effectiveness also increases. Therefore, the base isolation is effective for Type I soft storey.

Table4. 18: Base shear comparision beteween type I and Regular building

Type of base support	Base Shear soft storey MI							
	Regular		Ground		3rd Floor		6th floor	
	Fx	Fy	Fx	Fy	Fx	Fy	Fx	Fy
RSA (Fixed)	6288.218	6288.218	5260.921	5260.921	5874.148	5879.855	6552.244	6552.244
RSA (LRB)	2803.027	2803.027	2875.24	2875.24	3002.3	3001.511	3150.927	3150.927
% Reduction	55%	55%	45%	45%	49%	49%	52%	52%

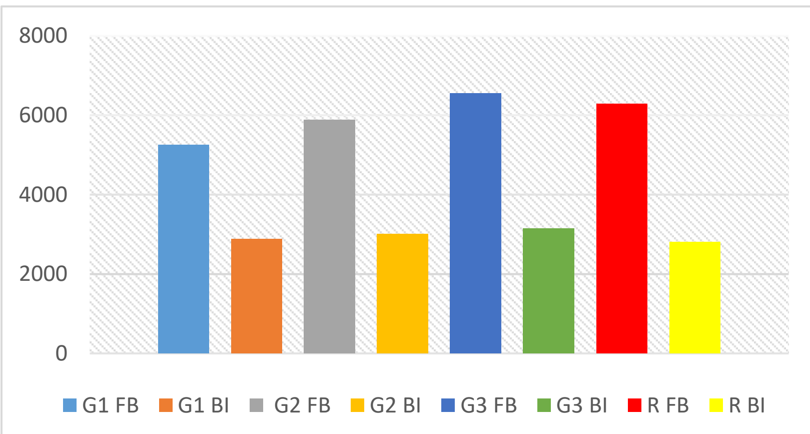


Figure4. 10: Base Shear Graph

For the Type II soft storey, the rate of the effectiveness less than that of the regular and Type I soft storey, but it reduces approximately around 31% to 41% of the base shear in base isolation case. The amount of percent reduction is depend on the effect of the soft storey available on building structure whereas while the height of the building is varying or abrupt changing in the reduction of the stiffness of structure in addition to masonry infill through the structural mode. This is briefly shown in the Table 4.19 below.

Table4. 19: Base shear comparisons of Type II soft storey

Type of base support	Base Shear					
	soft storey SH					
	Ground		3rd Floor.		6th floor	
	Fx	Fy	Fx	Fy	Fx	Fy
RSA (Fixed)	3859.611	3859.611	4598.12	4598.12	5269.701	5269.701
RSA (LRB)	2680.156	2680.156	2852.72	2852.72	3095.951	3095.951
% Reduction	31%	31%	38%	38%	41%	41%

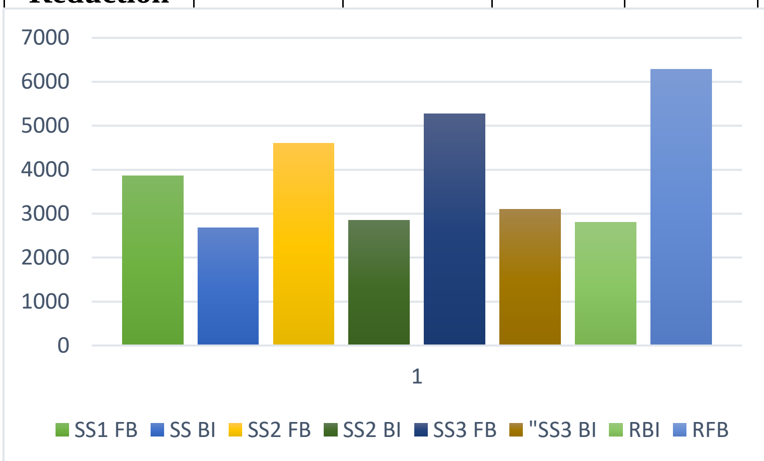


Figure4. 11: Base shear for type II soft storey and Regular building model.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the result and discussion presented in this thesis the effectiveness of base isolation technique against earthquake in soft storey Reinforced Building response is evaluated and compared by different parameters.

The following conclusions are obtained below:-

- ✓ Base isolation increase the floor displacement of both type of soft storey but the percentage increase varying , the type I soft storey which have constant storey height the displacement increased by 52%,61%,&64% for G1,G2 &G3 respectively. Similarly for type II with variable storey height increased by 48%, 59%&66% correspondingly for SS1,SS2&SS3.
- ✓ Using base isolation decrease the storey drift in upper floor except the ground floor by 18%, 24%, &37% for type I soft storey and the same for type II decrease by 11%, 34%&49% on three different location.
- ✓ From the comparisons, the base isolation is effective in reducing storey shear, storey acceleration, base shear and the overturning moment for both soft storey building against earth quake. Also the base isolation is increase the time period of the soft storey building and used to prevent structure from damage during earthquake.
- ✓ Base isolation is effective on type I soft storey that have constant storey height along the storey than Type II soft storey with variable storey height.
- ✓ The presence of soft storey on ground floor is highly exposed to earth quake damage and reduce the effectiveness of base isolation on both type of soft storey.
- ✓ The base isolation is more effective on building which have regular stiffness along their storey than irregular stiffness(soft storey) in the building.

Generally, the presence of soft storey(stiffness irregular) in building reduce the effectiveness of the base isolation

5.2 Recommendation

- It has been observed that base isolation is effective in reducing the base shear, story acceleration, and increasing the fundamental period of fixed base structures. But, further study should be done by considering buildings with different type of vertical irregularity and by different earth quake analysis in order to address all possible type of responses of base isolated structures to irregularity in structure.
- The non-structural masonry infill effect on contribution in stiffness and ductility on the structure that mainly affect the performance of the structure during earthquake.
- The study cover only for moment resisting frame system further study should be done by relating with soft storey structural.
- In this study the lead rubber bearing is used from the base isolation type which shows that the study only cover the effectiveness of one type base isolation for further study should be done for other type of base isolation and also comparing the efficiency.

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Appendix A

Table A. 1: Storey Stiffness of Regular building

Story Response of Fixed Base					Story Response of Base Isolation				
Story	**Elevation**	**Location**	**X-Dir**	**Y-Dir**	**Story**	**Elevation**	**Location**	**X-Dir**	**Y-Dir**
	(m)		kN/m	kN/m		m		kN/m	kN/m
ROOF	29.5	Top	937223.2	937223.1	ROOF	29.5	Top	526262.7	526262.7
9	26.5	Top	1665017	1665017	9	26.5	Top	1007077	1007076
8	23.5	Top	2212384	2212384	8	23.5	Top	1419772	1419772
7	20.5	Top	2662257	2662257	7	20.5	Top	1789183	1789183
6	17.5	Top	3069558	3069558	6	17.5	Top	2135998	2135998
5	14.5	Top	3478662	3478662	5	14.5	Top	2482066	2482066
4	11.5	Top	3916827	3916827	4	11.5	Top	2827350	2827350
3	8.5	Top	4537667	4537667	3	8.5	Top	3357341	3357341
2	5.5	Top	4487196	4487196	2	5.5	Top	2908089	2908089
1	2.5	Top	1239816	1239816	1	2.5	Top	310626.6	310626.6
Base	0	Top	0	0	Base	0	Top	0	0

Table A. 2 : storey stiffness for soft storey G1

Story Response of Fixed Base					Story Response of Base Isolation				
Story	**Elevation**	**Location**	**X-Dir**	**Y-Dir**	**Story**	**Elevation**	**Location**	**X-Dir**	**Y-Dir**
	(m)		kN/m	kN/m		M		kN/m	kN/m
ROOF	29.5	Top	937223.2	937223.1	ROOF	29.5	Top	475628.3	475628.2
9	26.5	Top	1665017	1665017	9	26.5	Top	915187.5	915187.6
8	23.5	Top	2212384	2212384	8	23.5	Top	1296107	1296107
7	20.5	Top	2662257	2662257	7	20.5	Top	1639375	1639375
6	17.5	Top	3069558	3069558	6	17.5	Top	1964351	1964352
5	14.5	Top	3478662	3478662	5	14.5	Top	2278104	2278104
4	11.5	Top	3916827	3916827	4	11.5	Top	2677988	2677988
3	8.5	Top	4537667	4537667	3	8.5	Top	2540731	2540731
2	5.5	Top	4487196	4487196	2	5.5	Top	334622.8	334622.8
1	2.5	Top	1239816	1239816	1	2.5	Top	223305.4	223305.4
Base	0	Top	0	0	Base	0	Top	0	0

Table A. 3: storey stiffness for G2 soft storey

Story Response of Fixed Base					Story Response of Base Isolation				
Story	**Elevation**	**Location**	**X-Dir**	**Y-Dir**	**Story**	**Elevation**	**Location**	**X-Dir**	**Y-Dir**
	(m)		kN/m	kN/m		M		kN/m	kN/m
ROOF	29.5	Top	929106	929106	ROOF	29.5	Top	489777.4	489777.2
9	26.5	Top	1646515	1646515	9	26.5	Top	941631.9	941632.2
8	23.5	Top	2174221	2174221	8	23.5	Top	1328796	1328796
7	20.5	Top	2627975	2627975	7	20.5	Top	1700347	1700347
6	17.5	Top	2783775	2783775	6	17.5	Top	1838048	1838048
5	14.5	Top	770586.4	770586.4	5	14.5	Top	509292.7	509292.7
4	11.5	Top	3452336	3452336	4	11.5	Top	2398503	2398503
3	8.5	Top	4307760	4307760	3	8.5	Top	3110657	3110657
2	5.5	Top	4157769	4157769	2	5.5	Top	2732040	2732040
1	2.5	Top	1123416	1123416	1	2.5	Top	308507.7	308507.7
Base	0	Top	0	0	Base	0	Top	0	0

Table A. 4: storey stiffness for G3 soft storey

Story Response of Fixed Base					Story Response of Base Isolation				
Story	**Elevation**	**Location**	**X-Dir**	**Y-Dir**	**Story**	**Elevation**	**Location**	**X-Dir**	**Y-Dir**
	(m)		kN/m	kN/m		M		kN/m	kN/m
ROOF	29.5	Top	1060761	1060761	ROOF	29.5	Top	487200	487200
9	26.5	Top	1681856	1681856	9	26.5	Top	885024.4	885024.4
8	23.5	Top	512193	512193	8	23.5	Top	435571.8	435571.8
7	20.5	Top	2465541	2465541	7	20.5	Top	1464486	1464486
6	17.5	Top	3078213	3078213	6	17.5	Top	1858935	1858935
5	14.5	Top	3427099	3427100	5	14.5	Top	2158933	2158933
4	11.5	Top	3873824	3873824	4	11.5	Top	2475023	2475023
3	8.5	Top	4504102	4504102	3	8.5	Top	2929081	2929081
2	5.5	Top	4488690	4488690	2	5.5	Top	2633501	2633501
1	2.5	Top	1241843	1241843	1	2.5	Top	307309.3	307309.3
Base	0	Top	0	0	Base	0	Top	0	0

Table A. 5: storey stiffness for SS1 soft storey

Story Response of Fixed Base					**Story Response of Base Isolation**				
Story	**Elevation**	**Location**	**X-Dir**	**Y-Dir**	**Story**	**Elevation**	**Location**	**X-Dir**	**Y-Dir**
	(m)		kN/m	kN/m		M		kN/m	kN/m
ROOF	31	Top	769107	782427.6	ROOF	31	Top	432535.8	432535.8
9	28	Top	1414536	1450283	9	28	Top	834825.9	834825.9
8	25	Top	1937333	1994602	8	25	Top	1185132	1185132
7	22	Top	2395787	2467393	7	22	Top	1501662	1501662
6	19	Top	2829032	2909233	6	19	Top	1802113	1802113
5	16	Top	3238728	3328543	5	16	Top	2090683	2090683
4	13	Top	3854372	3946386	4	13	Top	2474816	2474816
3	10	Top	3257982	3409275	3	10	Top	2258243	2258242
2	7	Top	181271.6	239719.8	2	7	Top	145080.9	145080.9
1	2.5	Top	714830.6	751156	1	2.5	Top	196667.5	196667.5
Base	0	Top	0	0	Base	0	Top		

Table A. 6: storey stiffness for SS2 soft storey

Story Response of Fixed Base					**Story Response of Base Isolation**				
Story	**Elevation**	**Location**	**X-Dir**	**Y-Dir**	**Story**	**Elevation**	**Location**	**X-Dir**	**Y-Dir**
	(m)		kN/m	kN/m		M		kN/m	kN/m
ROOF	31	Top	829329.26	829329.146	ROOF	31	Top	487200	487200
9	28	Top	1522898.5	1522898.35	9	28	Top	885024.4	885024.4
8	25	Top	2064355.8	2064355.80	8	25	Top	435571.8	435571.8

7	22	Top	2612613.3	2612613.35	7	22	Top	1464486	1464486
6	19	Top	2461906.2	2461906.26	6	19	Top	1858935	1858935
5	16	Top	204099.35	204099.359	5	16	Top	2158933	2158933
4	11.5	Top	3158937.8	3158937.84	4	11.5	Top	2475023	2475023
3	8.5	Top	4650804.2	4650804.37	3	8.5	Top	2929081	2929081
2	5.5	Top	4563923.5	4563923.69	2	5.5	Top	2633501	2633501
1	2.5	Top	1258240.7	1258240.78	1	2.5	Top	307309.3	307309.3
Base	0	Top	0	0	Base	0	Top	0	0

Table A. 7: storey stiffness for SS3 soft storey

Story Response of Fixed Base					**Story Response of Base Isolation**				
Story	**Elevation**	**Location**	**X-Dir**	**Y-Dir**	**Story**	**Elevation**	**Location**	**X-Dir**	**Y-Dir**
	(m)		kN/m	kN/m		M		kN/m	kN/m
ROOF	31	Top	1078744.083	1078744.112	ROOF	31	Top	417744.1	417744.1
9	28	Top	1629290.587	1629290.607	9	28	Top	751976.9	751976.9
8	25	Top	197852.482	197852.482	8	25	Top	173966.8	173966.8
7	20.5	Top	2330343.727	2330343.717	7	20.5	Top	1220276	1220276
6	17.5	Top	3000542.003	3000542.001	6	17.5	Top	1535635	1535635
5	14.5	Top	3339398.938	3339398.938	5	14.5	Top	1758870	1758870
4	11.5	Top	3846814.356	3846814.35	4	11.5	Top	2010007	2010007
3	8.5	Top	4547416.06	4547416.064	3	8.5	Top	2357202	2357202
2	5.5	Top	4561730.928	4561730.932	2	5.5	Top	2215443	2215443
1	2.5	Top	1251971.708	1251971.708	1	2.5	Top	302383.8	302383.8

Base	0	Top	0	0	Base	0	Top	0	0

Appendix B

Table B. 1 LRB design

LRB DESIGN			
T*eff*	2		
Sa	0.32		
π	3.14	B	0.05
W	3572.767		
G	9.81		
Dbd	0.10191083	dbd^2	0.01038582
Keff	9.8596		
	364.196432	3590.83	
Ed	3.72937147		
Fo	9.14861438		
Kb	89.7707786		
Kr	3501.06036		
Tr	0.06794055		
$D_{bearing}$	0.435180589		
D_{pb}	0.032549663		
A_{pb}	0.000831692		
Dff	0.415180589		
Aff	0.135314313		
Al	0.134482621		
Cf	0.01303667		
Si	10.31571835	106.414	
T	0.01		
Ts	0.003		
Tap	0.04		
N	Tr will be	0.2	
N	20	No	
Ht	0.337	M	

Kb	399.0582223	kN/m
G	1000	Mpa
K	2000	Mpa
Kv	171730076.2	193.1354
	2638484.27	
keff required stiffness	3590.831143	
Bearing horizontal stiffness kb	399.0582223	
vertical stiffness **Kv**	193.1354307	
yield force	9.148614377	
stiffness ratio	0.1	
damping	0.05	

Appendix C

Deformed shape of models

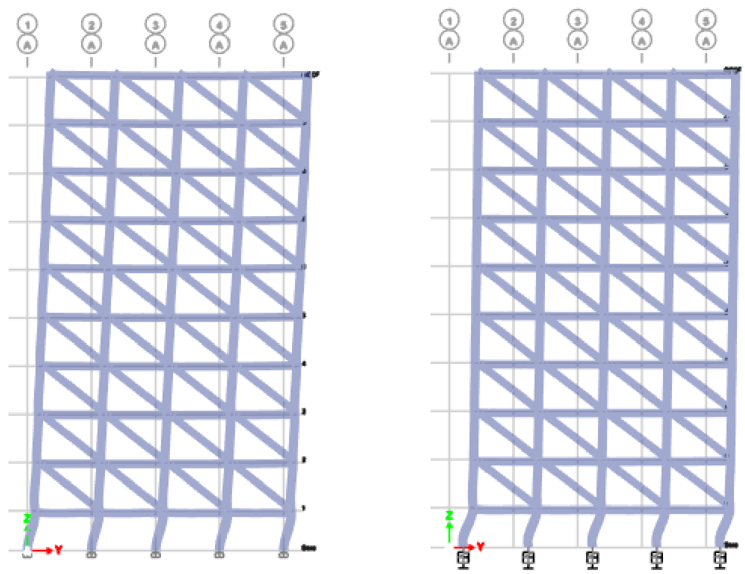


Figure C. 1 Regular Building with LRB and Fixed Base of deformed shape

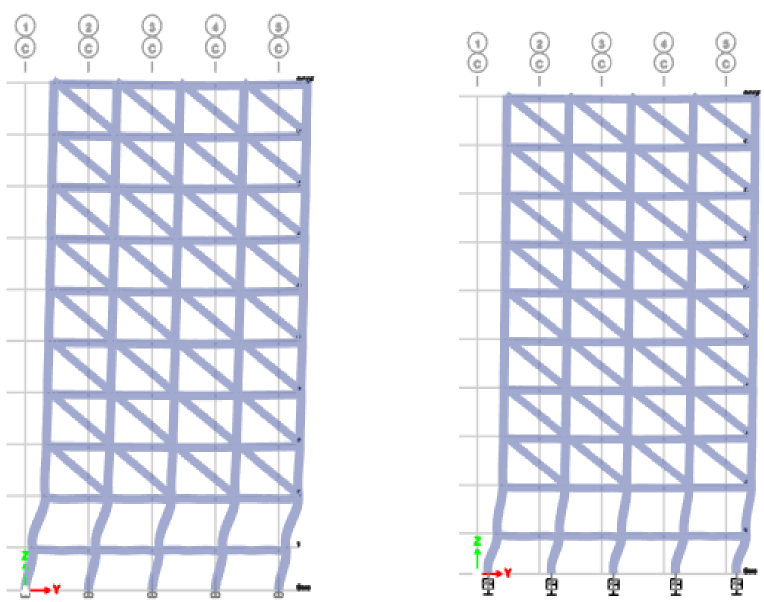
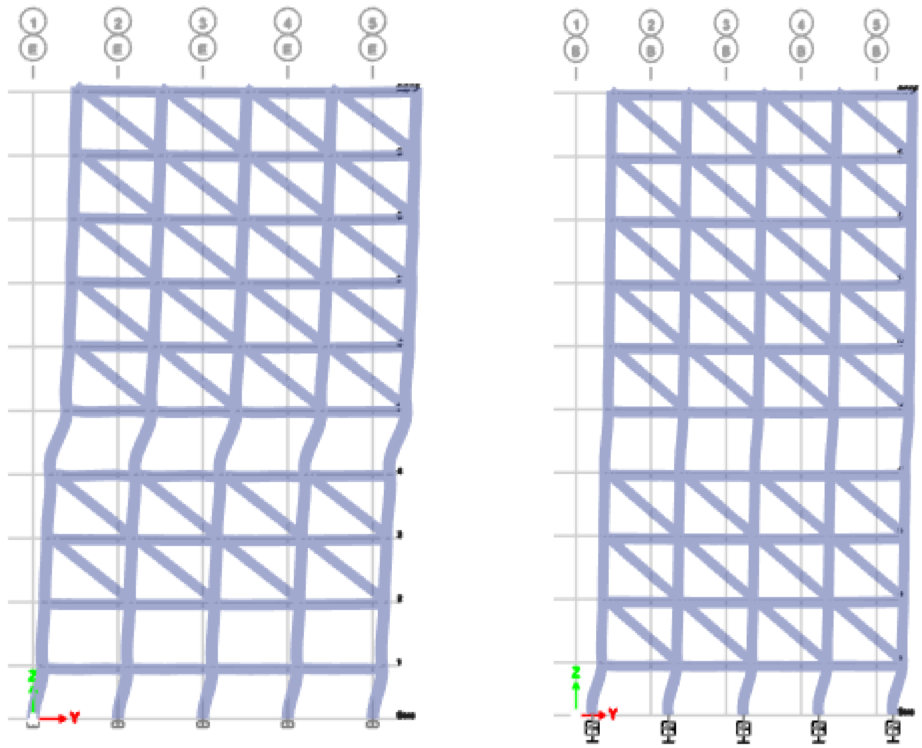


Figure C. 2: G1 soft storey model with LRB and Fixed Base



FigureC. 3: G2 soft storey model with LRB and Fixed Base

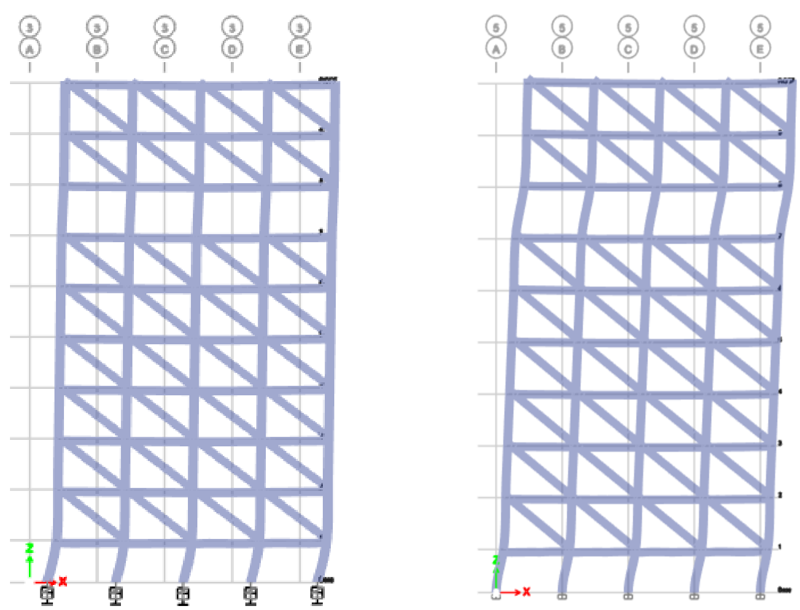


Figure C. 4 G3 soft storey