SEISMIC BEHAVIOR OF BASE ISOLATED BUILDINGS WITH SOFT STORY FOR DHAKA REGION

ARIF AHMED KHAN

MASTER OF SCIENCE IN CIVIL ENGINEERING (STRUCTURAL)

DEPARTMENT OF CIVIL ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DHAKA-1000, BANGLADESH

JUNE 2017

SEISMIC BEHAVIOR OF BASE ISOLATED BUILDINGS WITH SOFT STORY FOR DHAKA REGION

A THESIS

BY

ARIF AHMED KHAN

A thesis submitted in partial fulfillment of the requirement for the degree of

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DECLARATION

It is hereby declared that excepts for the contents where specific reference has been made to the work embodied in this thesis is the research work carried out by the author under supervision of Dr. Syed Ishtiaq Ahmad, Professor, Department of Civil Engineering, BUET. Neither this thesis nor any part thereof has been submitted or is being concurrently submitted elsewhere for any other purposes except for publication.

June, 2017

(Arif Ahmed Khan)
Roll No: 040804318

ACKNOWLEDGEMENT

Author wishes to express his deepest gratitude to honored supervisor Dr. Syed Ishtiaq Ahmad, Professor, Department of Civil Engineering, BUET for his encouraging supervision all through the study. His systematic and invaluable guidance with affectionate persuasion have helped me greatly during the study.

My special gratitude to my parents, friends and all of my family members for source of inspiration for all my efforts and achievements.

ABSTRACT

Soft storey buildings are characterized by having a storey which is 70% less stiff than the floor above or below it. Information available in existing literature and experience from past earthquakes suggests that soft storey have high tendency of failure during earthquakes. In Dhaka, many buildings are constructed with a soft ground floor as walls are removed from this particular floor for creating car parking provision, making it vulnerable to earthquake damage. One way of mitigating such vulnerability may be by incorporating base isolation system to the building. In this thesis, a comparative study is presented between base isolated and non-isolated soft storey building in the context of Dhaka, Bangladesh. For analysis, time history of recently occurred Natore earthquake has been normalized for both EW and NS direction considering peak ground acceleration of 0.2g, the recommended value for Dhaka as per Bangladesh National Building Code (BNBC). Corresponding Response Spectrum (RS) has been evaluated from these two earthquake records. A prototype building of six storey height with and without soft storey was considered in this work. Lead rubber Isolator for such soft storey building was also designed using appropriate method. Non-linear time history and response spectrum analysis of this building was performed in the finite element software program SAP2000. Non linearity was considered only for the isolator part of the building. At first, a comparative study was conducted between isolated and non-isolated building. The study revealed that the values of structural parameters like moment and shear was reduced by 39% and 55% respectively in soft storey columns when isolator was used in the building. Use of Isolator was also found to be effective in reducing displacement. Displacement was found to reduce by 45% in fixed base soft storey building and 41% for fixed base without soft storey building when isolator was incorporated. Furthermore, storey drift was also found to be reduced by 43% whereas maximum acceleration was reduced by74% in fixed base soft storey building with isolator.

Next, a parametric study was conducted to evaluate the influence of different isolator parameters like initial and post yield stiffness, isolator yield force on overall behavior of soft storey building. It was found that peak shear, moment and displacement of columns decrease with increasing initial isolator stiffness. However, for changes in post peak isolator stiffness, variation in peak shear, moment and displacement of column did not show any particular trend. It was also observed that column peak shear, moment and displacement increased with increasing isolator yield force.

Lastly, a comparative cost study was performed between building with and without isolation system. Since use of isolator reduces overall peak shear, moment and displacement in columns and other structural elements of the building, reinforcement requirement is less than conventional non isolated building. Cost of isolator, on the other hand, is added to the isolated building. So, comparing the savings in reinforcement cost with that of isolator cost, it was found that use of base isolator can actually reduce the overall structural cost of the building by 3 to 4%.

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Chapter 1

INTRODUCTION

1.1 General

In high rise building or multi storey building, soft storey construction is a typical feature because of urbanization and the space occupancy considerations. 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. This storey level containing the concrete columns which were unable to provide adequate shear resistance, hence damage and collapse are most often observed in soft story buildings during the earthquake. In the current study the focus is on the investigation of the effect of a soft storey on the behavior of a structure and effect of masonry infill on structure.

Figure 1.1: Soft storey reinforced concrete buildings

In the present study, seismic performance of 3D building frame with intermediately infill frame was studied. Performance of RC frame was evaluated considering different models for the soft storey. The main objective of the study was to investigate the behavior of high rise, multi-bay soft storey building with and without in filled frames and to evaluate their performance levels when subjected to earthquake loading.

Many building structures having soft stories, suffered major structural damage and collapsed in the recent earthquakes. Large open areas with less infill and exterior walls in ground floor compared to upper floors are the cause of damages. In such buildings, the stiffness of the lateral load resisting systems at those stories is quite less than the stories above or below. During an earthquake, if abnormal inter-story drifts between adjacent stories occur, the lateral forces cannot be well distributed along the height of the structure. This situation causes the lateral forces to concentrate on the story having large displacement. In addition, if the local ductility demands are not met in the design of such a building structure for that story and the inter-story drifts are not limited, a local failure mechanism or, even worse, a story failure mechanism, which may lead to the collapse of the system, may be formed due to the high level of load deformation effects.

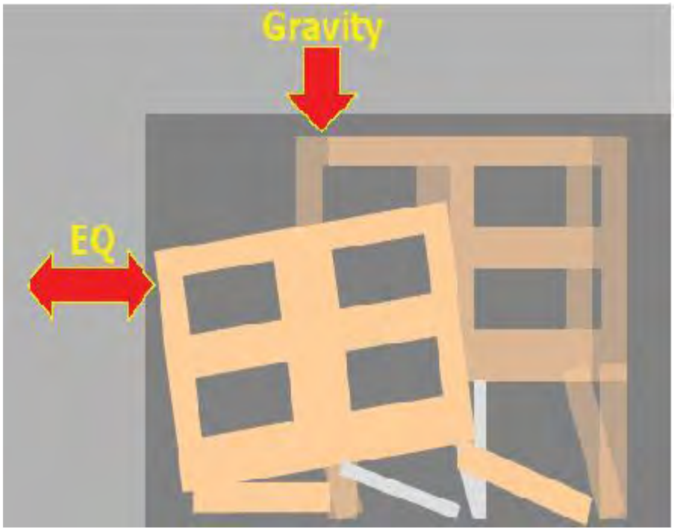


Figure 1.2: Collapse mechanism of a building structure having a soft story.

Lateral displacement of a story is a function of stiffness, mass and lateral force distributed on that story. It is also known that the lateral force distribution along the height of a building is directly related to mass and stiffness of each story. If the P-delta effect is considered to be the main reason for the dynamic collapse of building structures during earthquakes, accurately determined lateral displacements calculated in the elastic design process may provide very important information about the structural behavior of the system. Therefore, dynamic analysis procedure is required in many of the actual codes for accurate distribution of the earthquake forces along the building height, determining modal effects and local ductility demands efficiently. The upper stories move as single block as there is presence of infill masonry which makes it stiffer. Hence displacement is more in soft storey.

Figure 1.3: Failure due to large lateral displacement in soft storey

Again During an earthquake, more moment and shear strength fall on the columns and walls in the entrance floors than the one in the upper storey's. As the walls do not exist in the soft storey floor, columns are forced and severely stressed more those in those storeys. If the columns are not capable to resist shear they may be damaged or lead to collapse.

Figure 1.4: Damages in columns during earthquake

Most of the constructions damaged suffer from this irregularity. This irregularity is often found in buildings where open first or ground storey. As a result of investigation on this and other irregularities, it was observed that Codes of Earthquake are not sufficient. For this reason, it comes into forefront that it is necessary for these irregularities to be controlled at the stage of project and construction. It should be known that controlling is one stage in building quake-resistant constructions, and it should be applied.

If one storey is higher than others, or one storey is weaker than others. A soft or weak storey exists if the height of that storey is at least 15% greater than storey's above or below; or if it has at least 30% fewer columns in the case of a frame system, or at least 30% less full-height structural or infill wall length in the case of a wall or infill wall system.

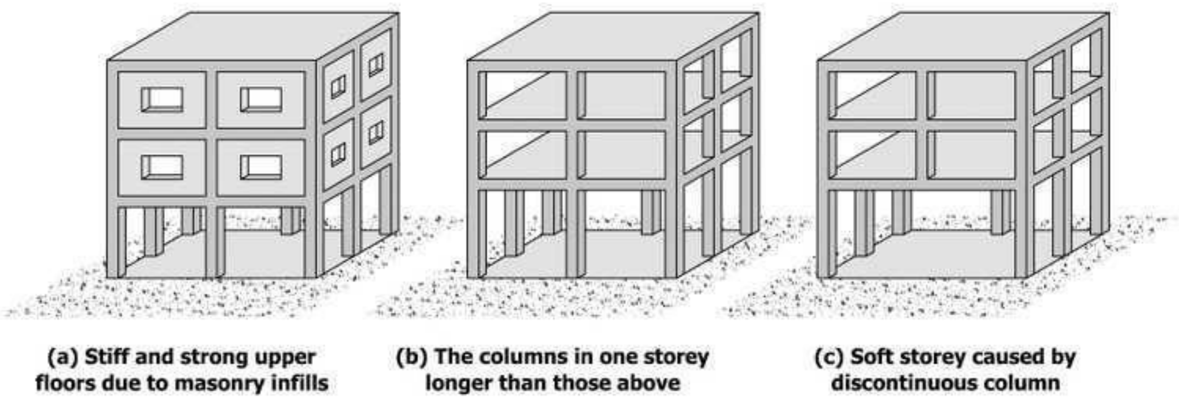


Figure 1.5: Irregularities in buildings

Present code of practice does not include provision of taking into consideration the effect of infill. It can be understood that if the effect of infill is taken into account in the analysis and design of frame, the resulting structures may be significantly different.

The common practice of building design considers infill as non-structural elements and building is designed as framed structures without regard to structural action of masonry infill walls. The soft storey effect and presence of infill in any building changes the behavior of frame action due to the relative changes of stiffness of the frame by a factor of three to four times and lateral load distribution. Such buildings are required to be analyzed by the dynamic analysis and designed carefully. As the dynamic ductility demand during probable earthquake gets concentrated in the soft storey and the upper storey tends to remain elastic. Hence the building is totally collapsed due to soft storey effect.

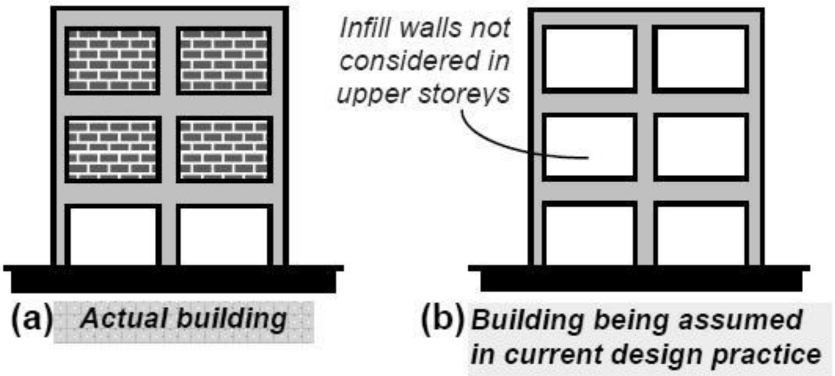


Figure 1.6: Assumptions made in current design practice are not consistent with the actual structure

- From the above it is seen that, when the effect of soft storey is considered then the deflection has increase at that particular floor.

- RC frame buildings with open first storeys are known to perform poorly during in strong earthquake shaking.
- The measures should take to improve capacities of the columns in the soft first storey.

- Since the behavior of the soft storey is different during a quake, the structural member undergoes damage and to provide member to withstand that additional forces due to soft storey heavy or bulky member need to be provided. This increase financial input.

- Thus proper care, expert design and detailing are needed in soft storey buildings

1.2 Back ground and present state of the problem

If any Concrete building has a floor which is 70% less stiff than the floor above or below it, it is considered as a soft storey (Fardis and Panagiotako 1997). While the unobstructed space of the soft storey might be aesthetically or commercially desirable, it also means that there is less opportunity to install walls to distribute lateral forces so that a building can cope up with the sway characteristics of an earthquake. Soft storey buildings are characterized by having a storey which has a lot of open spaces. This soft storey creates a major weak point in an event of a dynamic model as in the case of an earthquake (AIJ 1995; Jain et al. 2002; Kaushik and Jain 2007; Dolsek and Fajfar 2001). Since soft stories are classically associated with retail spaces and parking garages, they are often on the lower stories of a building, which means that when they collapse, they can take the whole building down with them, causing serious structural damage which may render the structure totally unusable.

The seismic isolation concept is aimed at a significant reduction of dynamic loads induced by the earthquake at the base of structure (Micheli et al. 2004). Seismic isolation separates the structure from the harmful motions of the ground by providing flexibility and energy dissipation capability through the insertion of the isolating device known as isolators between the foundation and the building structure (Ismail et al. 2010). The invention of lead rubber bearings (LRB 1970s) and high damping rubber bearings (HDRB 1980s) gave a new dimension to the seismic base isolation design of structure (Islam et al. 2011). It is now well documented in various research papers that inclusion of isolator decreases the dynamic loads on buildings. However, there has been little work on the behavior of a soft storey concrete building with an isolator attached with it. This is even truer for the moderate seismic country like Bangladesh where the use of isolator in buildings is not documented yet. Hence there are scopes of work to understand the behavior of concrete building with a soft storey that is fitted with an isolator for Dhaka region. How the building parameters responses to the inclusion of an isolator and how isolator properties affect the building dynamic properties are needed to be studied through extensive numerical modeling and rigorous analysis. Economic aspects of inclusion of isolators are also important points that need to be studied to examine the feasibility of the concept of inclusion of isolation system in buildings in Dhaka. Change in cost of construction with respect to the benefits due to inclusion of isolators does need to be compared to reach a conclusion regarding installation of isolators in buildings.

1.3 Objectives with specific aims and possible outcome

With the background stated in the previous section, the basic aim of this work would be to examine the behavior of concrete building with soft story that is attached with an isolator. In this regard, followings will be the objectives of this work:

- Examine the effect of different dynamic properties of a soft storey concrete building when subjected to the dynamic loading with and without isolator. These include deflection, storey drift, column moment etc.
- Examine the effect of different building parameter where subjected to the dynamic loading considering different isolator properties.
- Examine the economic aspects of incorporation of isolator for concrete building in Dhaka.

Possible Outcome:

How the dynamic behavior is affected after inclusion of isolator for a soft storey concrete building will be apparent from this work. Also, the effect of change of isolator properties on the dynamic behavior of building will also be clear from this work. How the construction cost is affected after incorporation of such isolator will also be obvious from this work.

1.4 Outline of Methodology/ Experimental Design

The project shall be carried out maintaining as per following steps:

- 3D Model Analysis of four kind of a concrete building using finite element platform named SAP2000.
    - Fixed base with soft storey building
    - Fixed base without soft storey building
    - Using isolator in the soft storey building
    - Using isolator without soft storey building.

- Establishment of appropriate earth quake time history and develop its corresponding response spectrum for Dhaka city.
- Response spectrum and nonlinear time history analysis of the modeled building with respect to the dynamic loading established as above.
- Parametric study of a prototype building with & without isolator
- Comparative cost analysis using cost estimation of both isolated and non-isolated building.

Chapter 2

BASE ISOLATION AS EARTHQUAKE PROTECTION DEVICE

2.1 Preface

Most structural engineers have at least a little knowledge of what base isolation is – a system of springs installed at the base of a structure to protect against earthquake damage. They know less about the when and why – when to use base isolation and why use it? When it comes to how, they either have too little knowledge or too much knowledge. Conflicting claims from promoters and manufacturers are confusing, contradictory and difficult to fully assess. Then, if a system can be selected from all the choices, there is the final set of how's – how to design the system, how to connect it to the structure, how to evaluate its performance and how to specify, test and build it. And, of course, the big how, how much does it cost?

These notes attempts to answer these questions, in sufficient detail for practicing structural engineers, with little prior knowledge of base isolation, to evaluate whether isolation is suitable for their projects; decide what is the best system; design and detail the system; and document the process for construction.

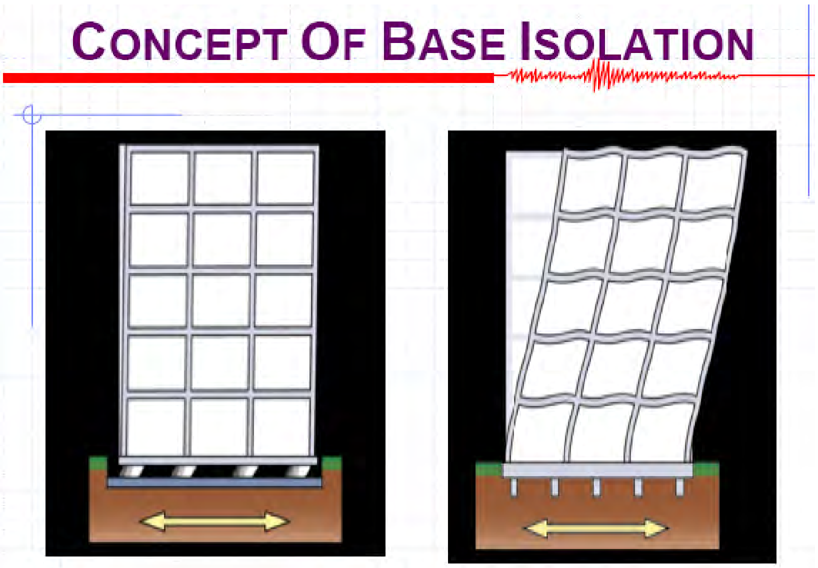


Figure 2.1: (From Wikipedia, the free encyclopedia) **Base Isolation**, also known as *Seismic* or *Base Isolation System*, is a collection of structural elements which should substantially decouple a superstructure from its substructure resting on a shaking ground thus protecting a building or non-building structure's integrity.

Figure 2.2: Snapshot of shake-table testing of a base-isolated (right) and a regular (left) building model

Base Isolation is the most powerful tool of the earthquake engineering pertaining to the passive structural vibration control technologies. It is meant to enable a building or non-building structure to survive a potentially devastating seismic impact through a proper initial design or subsequent modifications. In some cases, application of **Base Isolation** can raise both a structure's seismic performance and its seismic sustainability considerably.

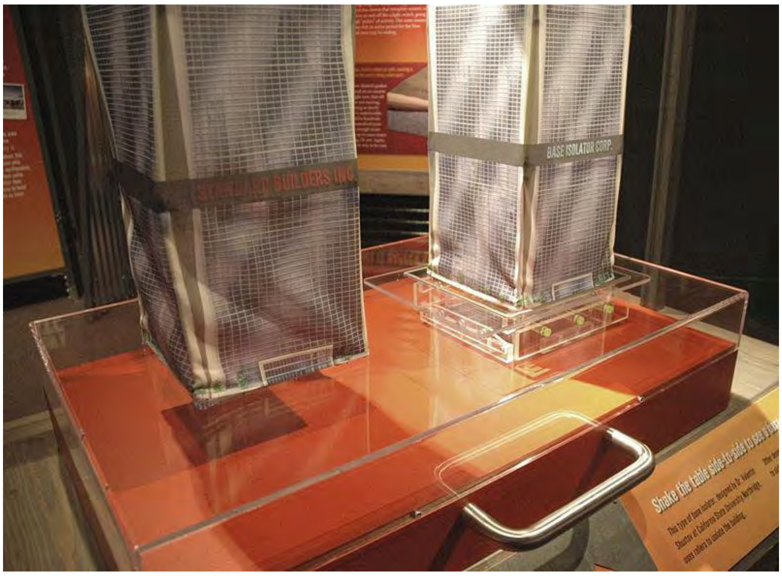


Figure 2.3: Base isolation demonstrations at The Field Museum

Base Isolation System consists of Isolation Units with or without Isolation Components, where:

1. *Isolation Units* are the basic elements of *Base Isolation System* which are intended to provide the mentioned decoupling effect to a building or non-building structure.

2. *Isolation Components* are the connections between *Isolation Units* and their parts having no decoupling effect of their own.

By their response to an earthquake impact, all *Isolation Units* may be divided into two basic categories: *Shear Units* and *Sliding Units*. The first evidence of architects using the principle of **Base Isolation** for earthquake protection was discovered in Pasargadae, a city in ancient Persia, now Iran: it goes back to VI century BC.

Figure 2.4: Mausoleum of Cyrus, the oldest base-isolated structure in the world

Figure 2.5: Base-isolated LA City Hall

This technology can be used both for new structural design and seismic retrofit. In process of seismic retrofit, some of the most prominent U.S. monuments like, e.g., Pasadena City Hall, San Francisco City Hall, Salt Lake City and County Building or LA City Hall were mounted on *Base Isolation Systems*. It required creating rigidity diaphragms and moats around the buildings, as well as making provisions against overturning and P-delta effect.

Base Isolation as a basic component of earthquake engineering structures can be also used for a valuable reinforcement of *Dispensable Structural System for Blast Debris Protection*.

Analytical research software called Earthquake Performance Evaluation Tool (**EPET**), which is publicly accessible online, enables concurrent virtual experiments on the building models *with* and *without* **Base Isolation**.

2.2 Concepts of Base Isolation

The term base isolation uses the word isolation in its meaning of the state of being separated and base as a part that supports from beneath or serves as a foundation for an object or structure (Concise Oxford Dictionary). As suggested in the literal sense, the structure (a building, bridge or piece of equipment) is separated from its foundation. The original terminology of base isolation is more commonly replaced with seismic isolation nowadays, reflecting that in some cases the separation is somewhere above the base – for example, in a bridge the superstructure may be separated from substructure columns. In another sense, the term seismic isolation is more accurate anyway in that the structure is separated from the effects of the seism, or earthquake.

Intuitively, the concept of separating the structure from the ground to avoid earthquake damage is quite simple to grasp. After all, in an earthquake the ground moves and it is this ground movement which causes most of the damage to structures. An airplane flying over an earthquake is not affected. So, the principle is simple. Separate the structure from the ground. The ground will move but the building will not move. As in so many things, the devil is in the detail. The only way a structure can be supported under gravity is to rest on the ground. Isolation conflicts with this fundamental structural engineering requirement. How can the structure be separated from the ground for earthquake loads but still resist gravity?

Ideal separation would be total. Perhaps an air gap, frictionless rollers, a well-oiled sliding surface, sky hooks, magnetic levitation. These all have practical restraints. An air gap would not provide vertical support; a sky-hook needs to hang from something; frictionless rollers, sliders or magnetic levitation would allow the building to move for blocks under a gust of wind.

So far, no one has solved the problems associated with ideal isolation systems and they are unlikely to be solved in the near future. In the meantime, earthquakes are causing damage to structures and their contents, even for well-designed buildings. So, these notes do not deal with ideals but rather with practical isolation systems, systems that provide a compromise between attachment to the ground to resist gravity and separation from the ground to resist earthquakes.

Defining a new concept is often helpful to compare it with known concepts. Seismic isolation is a means of reducing the seismic demand on the structure:

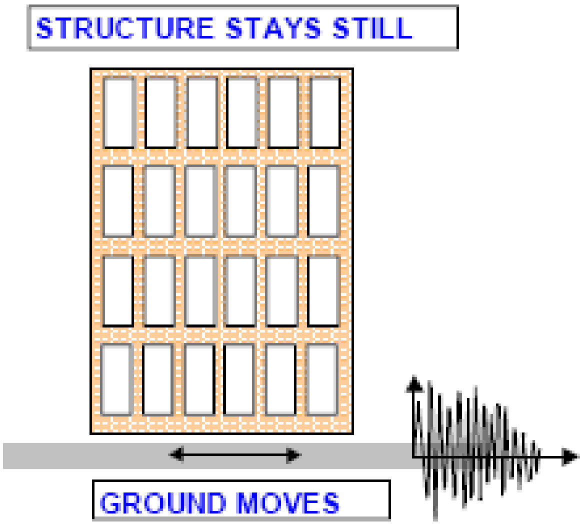


Figure 2.6: Base Isolation Strategy

2.3 Action of Base Isolation

Hence, Base Isolation or, seismic isolation separates upper structure from base or, from down structure by changing of fix joint with flexible one (Figure 2.7). Increasing of flexibility is done by the insertion of additional elements in structure, known as isolators. Usually, these isolators are inserted between upper structure and foundation. Seismic isolation system absorbs larger part of seismic energy. Therefore, vibration effects of soil to upper structure are drastically reduced.

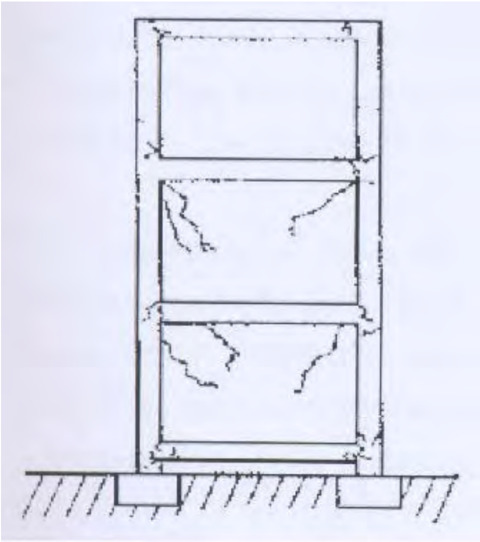


Figure 2.7: Failure Pattern of a Fixed Base Structure Non- Isolated Structure Due to Lateral Seismic Loading

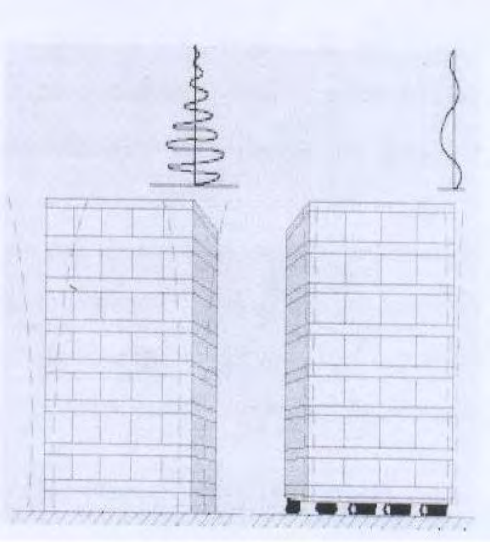


Figure 2.8: Fixed Base and Isolated Base

Earthquakes consist of random horizontal and vertical movements of the earth's surface. But seismic design mainly highlight the effects of horizontal ground motion, because the horizontal components of an earthquake usually exceed the vertical component and structures are usually much stiffer and stronger in response to vertical loads than they are in response to horizontal loads. From the past historical records of earthquake occurrences, it has been found that the horizontal components are more destructive.

As the ground moves, inertia tends to keep structures in place resulting in the imposition of structure with large displacements in different stories (Fig 2.8: left figure: dashed portion indicating displacements due to seismic loading). For base isolated structure the situation is quite different. In such cases, the whole upper structure gets a displacement (which naturally remains in limits) and the relative displacement of different stories is so small that the structure can withstand a comparatively high seismic tremor with a low seismic loading in a safe, efficient and economic manner.

2.4 Purpose of Base Isolation

A high proportion of the world is subjected to earthquakes and society expects that structural

Engineers will design our buildings so that they can survive the effects of these earthquakes. As for all the load cases we encounter in the design process, such as gravity and wind, we work to meet a single basic equation:

CAPACITY > DEMAND

We know that earthquakes happen and are uncontrollable. So, in that sense, we have to accept the demand and make sure that the capacity exceeds it. The earthquake causes inertia forces proportional to the product of the building mass and the earthquake ground accelerations. As the ground accelerations increases, the strength of the building, the capacity, must be increased to avoid structural damage.

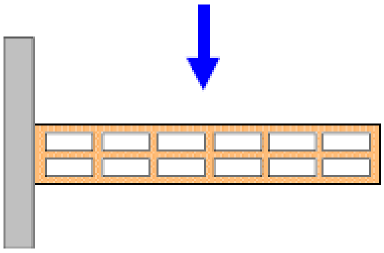


Figure 2.9: Design for 1g Earthquake load

It is not practical to continue to increase the strength of the building indefinitely. In high seismic zones the accelerations causing forces in the building may exceed one or even two times the acceleration due to gravity, g. It is easy to visualize the strength needed for this level of load – strength to resist 1g means than the building could resist gravity applied sideways, which means that the building could be tipped on its side and held horizontal without damage.

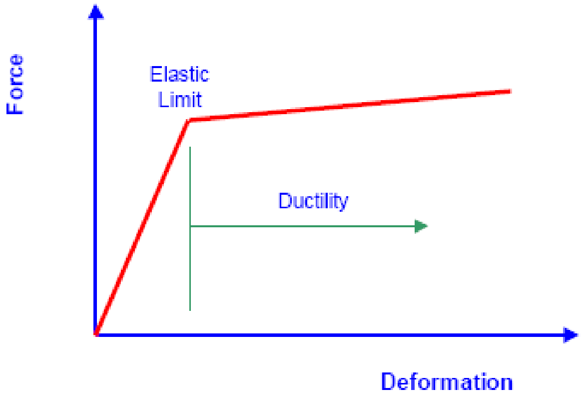


Figure 2.10: Ductility

Designing for this level of strength is not easy, nor cheap. So most codes allow engineers to use ductility to achieve the capacity. Ductility is a concept of allowing the structural elements to deform beyond their elastic limit in a controlled manner. Beyond this limit, the structural elements soften and the displacements increase with only a small increase in force.

The elastic limit is the load point up to which the effects of loads are non- permanent; that is, when the load is removed the material returns to its initial condition. Once this elastic limit is exceeded changes occur. These changes are permanent and non-reversible when the load is removed. These changes may be dramatic –when concrete exceeds its elastic limit in tension a crack forms – or subtle, such as when the flange of a steel girder yields.

For most structural materials, ductility equals structural damage, in that the effect of both is the same in terms of the definition of damage as that which impairs the usefulness of the object. Ductility will generally cause visible damage. The capacity of a structure to continue to resist loads will be impaired.

A design philosophy focused on capacity leads to a choice of two evils:

- Continue to increase the elastic strength. This is expensive and for buildings leads to higher floor accelerations. Mitigation of structural damage by further strengthening may cause more damage to the contents than would occur in a building with less strength.
- Limit the elastic strength and detail for ductility. This approach accepts damage to structural components, which may not be repairable.

Base isolation takes the opposite approach, it attempts to reduce the demand rather than increase the capacity. We cannot control the earthquake itself but we can modify the demand it makes on the structure by preventing the motions being transmitted from the foundation into the structure above.

So, the primary reason to use isolation is to mitigate earthquake effects. Naturally, there is a cost associated with isolation and so it only makes sense to use it when the benefits exceed this cost. And, of course, the cost benefit ratio must be more attractive than that available from alternative measures of providing earthquake resistance.

2.5 Bearing as Base Isolator

The lead rubber bearing (LRB) was invented in the 1970's and this allowed the flexibility and damping to be included in a single unit. About the same time the first applications using rubber bearings for isolation were constructed. However, these had the drawback of little inherent damping and were not rigid enough to resist service loads such as wind.

In the early 1980's developments in rubber technology lead to new rubber compounds which were termed "high damping rubber" (HDR). These compounds produced bearings that had a high stiffness at low shear strains but a reduced stiffness at higher strain levels. On unloading, these bearings formed a hysteresis loop that had a significant amount of damping. The first building and bridge applications in the U.S. in the early 1980's used either LRBs or HDR bearings.

Some early projects used sliding bearings in parallel with LRBs or HDR bearings, typically to support light components such as stairs. Sliding bearings were not used alone as the isolation system because, although they have high levels of damping, they do not have a restoring force. A structure on sliding bearings would likely end up in a different location after an earthquake and continue to dislocate under aftershocks.

The development of the friction pendulum system (FPS) shaped the sliding bearing into a spherical surface, overcoming this major disadvantage of sliding bearings. As the bearing moved laterally it was lifted vertically. This provided a restoring force.

Although many other systems have been promulgated, based on rollers, cables etc., the market for base isolation now is mainly distributed among variations of LRBs, HDR bearings, flat sliding bearings and FPS. In terms of supply, the LRB is now out of patent and so there are competing suppliers in most parts of the world. Although specific HDR compounds may be protected, a number of manufacturers have proprietary compounds that provide the same general level of performance. The FPS system is patented but there are licensees in most parts of the world.

2.6 Isolation System durability

Many isolation systems use materials which are not traditionally used in structural engineering, such as natural or synthetic rubber or polytetrafluoroethylene (PTFE, which is used for sliding bearings, usually known as Teflon ©, which is DuPont's trade name for PTFE). An often expressed concern of structural engineers considering the use of isolation is that these components may not have a design life as long as other structural components, usually considered to be 50 years or more. Natural rubber has been used as an engineering material since the 1840's and some of these early components remained in service for nearly a century in spite of their manufacturers lacking any knowledge of protecting elastomers against degradation. Natural rubber bearings used for applications such as gun mountings from the 1940's remain in service today.

Elastomeric (layered rubber and steel) bearings have been in use for about 40 years for bridges and have proved satisfactory over this period. Shear testing on 37 year old bridge bearings showed an average increase in stiffness of only 7% and also showed that oxidation was restricted to distances from 10 mm to 20 mm from the surface. Since these early bearings were manufactured technology for providing resistance to oxygen and ozone degradation has improved and so it is expected that modern isolation bearings would easily exceed a 50 year design life.

Some early bridge bearings were cold bonded (glued, rather than vulcanized) and these bearings had premature failures, damping the reputation of isolation bearings. The manufacture of all elastomeric bearings isolation bearings is by vulcanization; the steel plates are sand blasted and de-greased, stacked in a mold in parallel with the rubber layers and the assembly is then cured under heat and pressure. Curing may take 24 hours or more for very large isolators.

Some bridge bearings are manufactured from synthetic rubbers, usually neoprene. There are reports that neoprene will stiffen with age to a far greater extent than natural rubber and this material does not appear to have been used for isolation bearings for this reason. If a manufacturer suggests a synthetic elastomer, be sure to request extensive data on the effects of age on the properties.

PTFE was invented in 1938 and has been used extensively for all types of applications since the 1940's. It is virtually inert to all chemicals and is about the best material known to man for corrosion resistance, which is why there is difficulty in etching and bonding it. Given these properties, it should last almost indefinitely. In base isolation applications the PTFE slides on a stainless steel surface under high pressure and velocity and there is some flaking of the PTFE and these flakes are deposited on the stainless steel surface. Eventually the bearing will wear out but indications are that this will occur after travel of between 10 km and 20 km. For buildings this is not a concern as sliding occurs only during earthquake and the total travel is measured in meters rather than kilometers. For bridges the PTFE is often lubricated with silicone grease contained by dimples in the PTFE.

2.7 Types of Isolator

In this century of rapid technological progress, various types of Isolators have been invented and developed. This development in isolators ensured the properties required for the achievement of perfect base isolation. The following chart (Chart 2.1) details the various types of Isolators used throughout the world. A brief description along with their basic functions and advantages is also included just after the chart. The present research work is mainly highlighting the use of Rubber isolator. So, special attention is given to the characteristics of rubber Isolator.

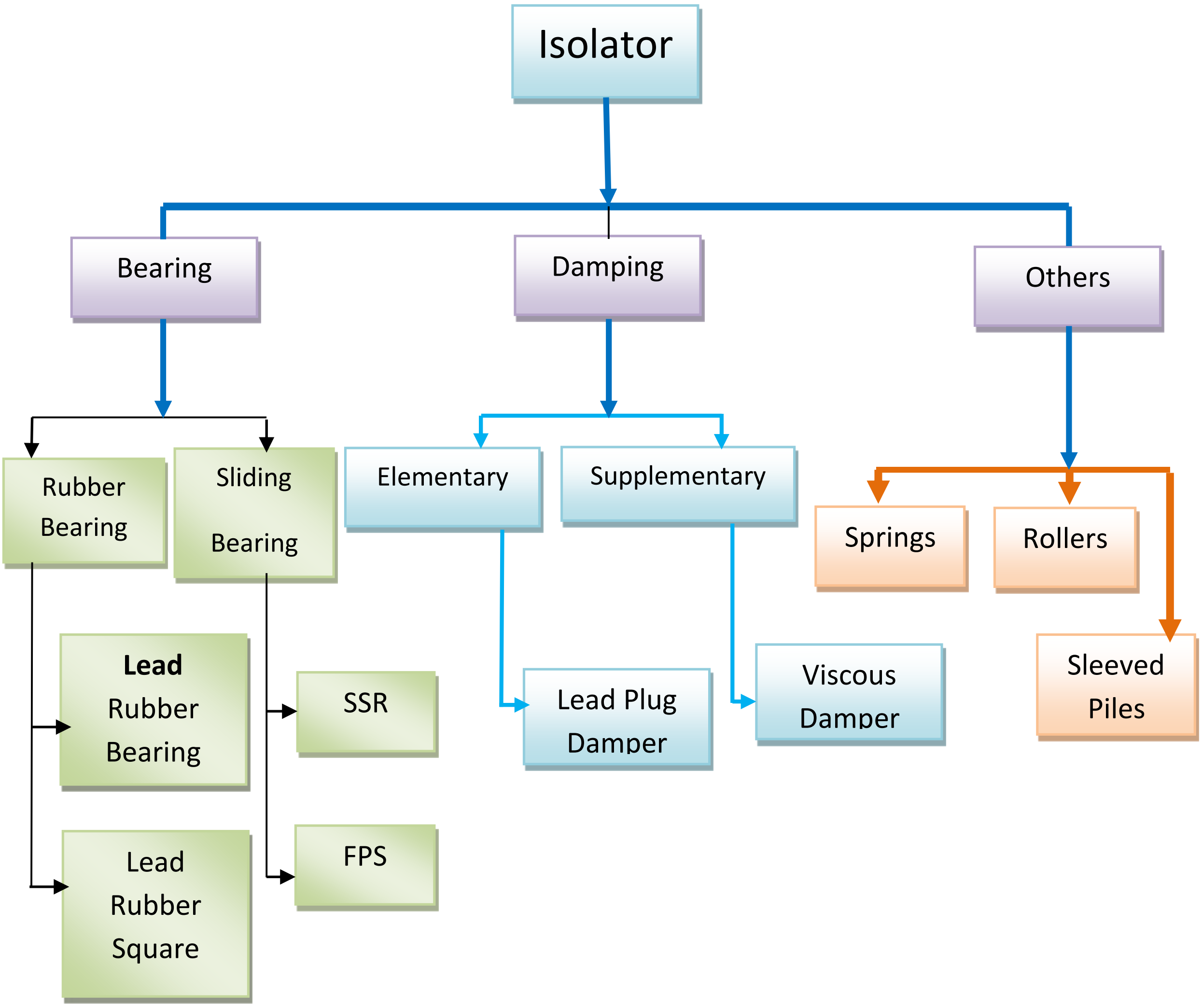


Chart 2.1: Schematic Diagram showing various types of Isolators used throughout the world

2.8 Bearing type

2.8.1 Elastomeric (Rubber) Bearings

Rubber bearings are formed of horizontal layers of natural or synthetic rubber in thin layers bonded between steel plates. The steel plates prevent the rubber layers from blown up or busting. In such mechanism the bearing is capable to support higher vertical loads with only smaller deflection (typically 1 mm to 3 mm under full gravity load). The internal steel layers do not restrict horizontal deformations of the rubber layers in shear. So, the bearings are much more flexible under lateral loads than vertical loads. This is why; the bearing works as a flexible unit.

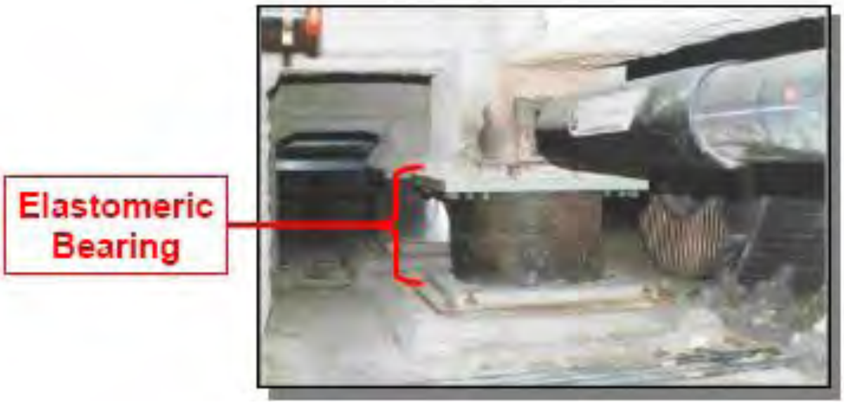


Figure 2.11: Installed Elastomeric bearing

Characteristics of Rubber Isolator: As described earlier, Isolation system works with the principle that a rigid mass is isolated from a flexible supporting structure. Optimum isolation of a building from ground may be achieved by choosing a rubber bearing isolator based on the knowledge of its static and dynamic characteristics determined from laboratory experiments. For this reason, understanding the properties of rubber isolators is necessary for the vibration analysis. Some of the important properties are as follows.

1) **Load capacity and Size of Rubber Bearings:** For most bearing types the plan size required increases as vertical load increases but the height or radius is constant regardless of vertical loads. This is because all bearings at such stages subjected to the same displacement. Therefore, the bearing can be sized according to the vertical loads they support. Fig 2.12 gives a typical relationship between vertical load and bearing diameter. Three types of curves are seen in the plot. All the curves are showing that the lower the vertical load, the lower the required bearing diameter.

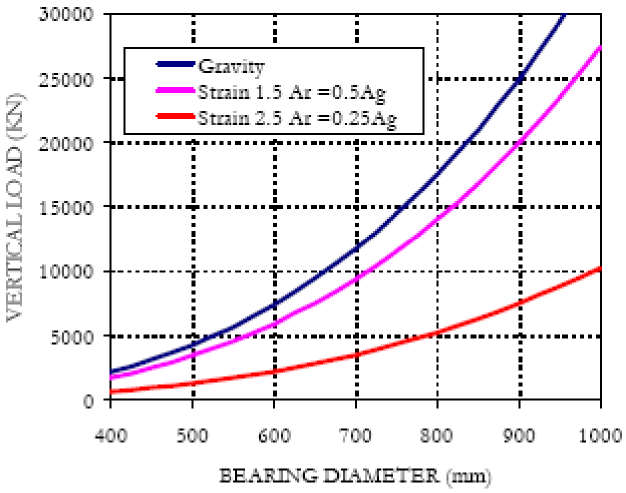


Figure 2.12: Load Capacity of Elastomeric Bearings (Vertical load absorbed as per bearing diameter)

2) **Shock Absorption:** Shocks originating due to the occurrence of an earthquake can be controlled if substantial additional damping is introduced into the isolation system. A high damping rubber isolator provides a substantial level of damping through hysteretic energy dissipation. 'Hysteretic' refers to the offset between the loading and unloading curves under cyclic loading. Fig 2.13 shows an idealized force- displacement loop where the enclosed area is measure of the energy dissipated during one cycle of motion.

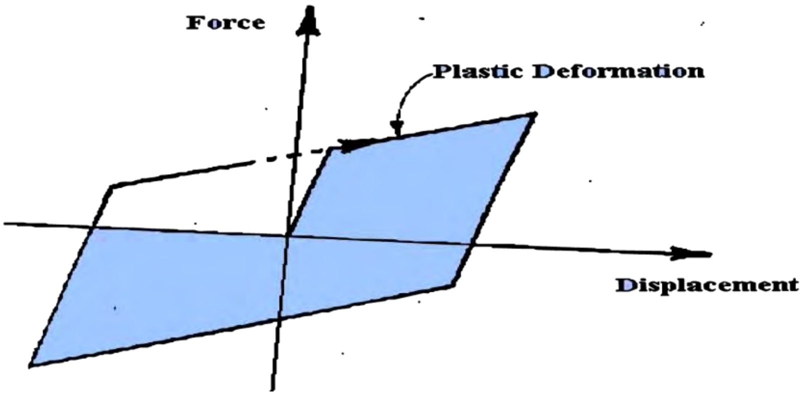


Figure 2.13: Idealized Hysteresis loop

3) **Durability under cyclic loading:** Rubber isolator remains more or less stable under cyclic loading. Results of cyclic displacement test applied, to a rubber isolator shows that at a speed equivalent to an actual seismic event the friction factor remains stable. Fig 2.14 shows a typical friction factor versus number of cycles in a cyclic loading test of rubber isolator. The figure represents that rubber isolator is durable.

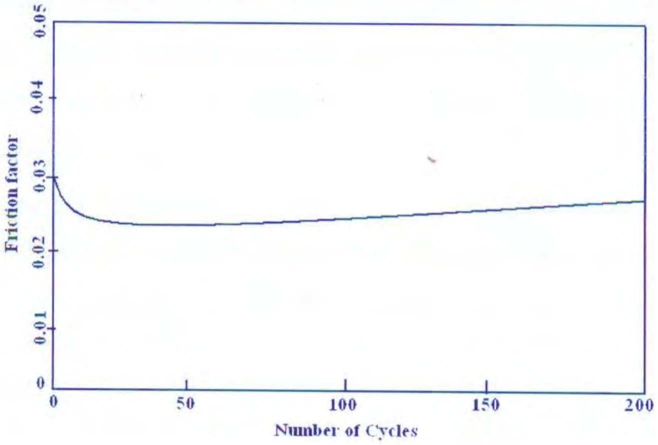
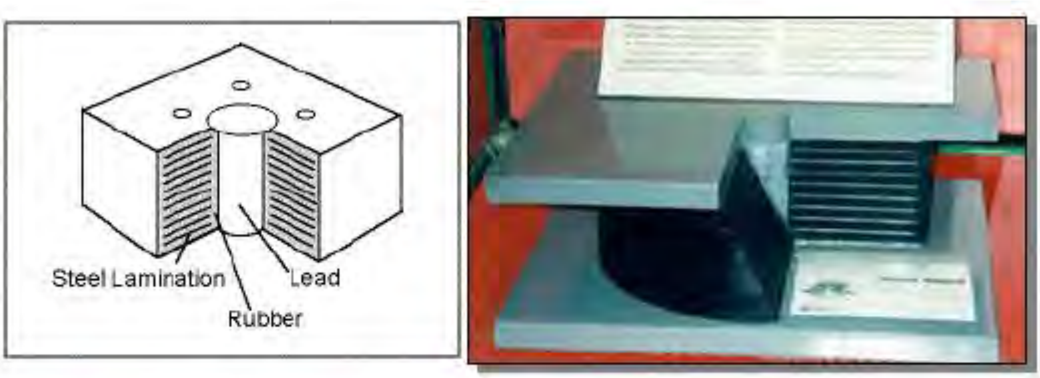


Figure 2.14: Typical Cyclic Durability Test Graph

There are mainly two types of Rubber Bearing. They are -

i) **Lead Rubber Bearing (LRB):** Isolators Made of Multilayer Natural Rubber with an internal Lead Plug is known as Lead Rubber Bearing. (Figure 2.15) Performance of LRB is maintained during repeated strong earthquakes, with proper durability and reliability.

Figure 2.15: Geometry of Lead Rubber Bearing



Major Components:

- Rubber Layers: Provide lateral flexibility
- Steel Shims: Provide vertical stiffness to support building weight while limiting lateral bulging of rubber
- Lead plug: Provides source of energy dissipation

Basic Functions of LRB:

- *Load supporting function:* Rubber reinforced with steel plates provides stable support for structures. Multilayer construction rather than single layer rubber pads provides better vertical rigidity for supporting a building.
- *Horizontal elasticity function (prolonged oscillation period):* With the help of LRB earthquake vibration is converted to low speed motion. As horizontal stiffness of the multi- layer rubber bearing is low, strong earthquake vibration is lightened and the oscillation period of the building is increased.
- *Restoration function:* Horizontal elasticity of LRB returns the building to its original position. In a LRB, elasticity mainly comes from restoring force of the rubber layers. After an earthquake this restoring force returns the building to the original position.

Advantages of LRB:

- LRB possesses a wide range of bearing capacity (about 100 - 2000 tons/unit). Bearings can be designed according to the size and characteristics of the building.

- Integration of the rubber bearing and a lead plug damper can save the installation space.

Lead rubber bearings mainly are of two shapes. One is conventional round LRB, which has been described in the previous paragraph and the other type is square LRB. Though their basic function remains same, yet changes in shapes are advantageous in many occasions.

A brief description of LRB Square with its advantages is given below.

ii) Lead Rubber Square (LRB-S): LRB-S is a square-shaped lead rubber bearing. It is a multilayer natural rubber construction with internal Lead Plug like general LRB isolators. It is generally used for the advanced seismic isolation stages.

Advantages:

- Support with Isolation system can be provided economically, with the same performance as of round LRB.
- Stability is provided in all horizontal directions and capacity for large deformations is also provided.
- Due to the square geometry, fire protection can be provided at reasonably lower cost.
- A smaller square bearing can be made with the same characteristics of round LRB, which is economical in the sense that it is saving space and reducing cost.

2.8.2 Sliding Bearings

Sliding system is simple in concept and it has a theoretical appeal. A layer with a defined coefficient of friction will limit the acceleration to this value and the forces, which can be transmitted, will also be limited to the coefficient of friction multiplied by weight. Following are some of the utilities of using sliders.

- Sliding movement provides flexibility and the force-displacement traces a rectangular shape that is the optimum for equivalent viscous damping.
- A pure sliding system will have unbounded displacements, with an upper limit equal to the maximum ground displacements for a coefficient of friction close to zero.

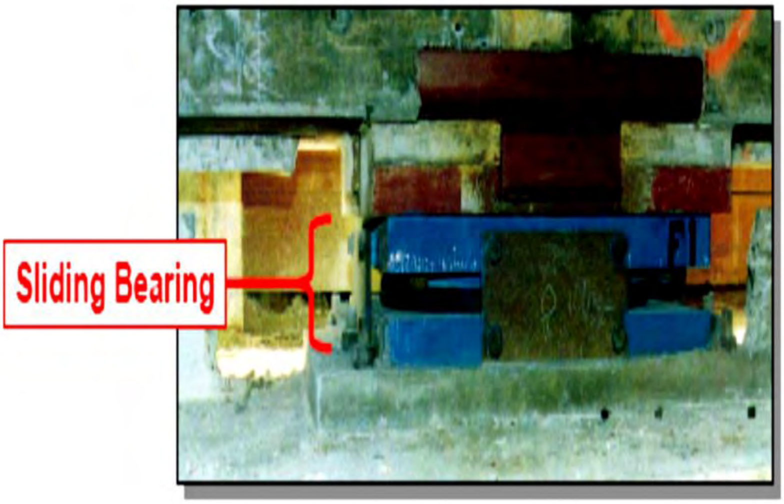


Figure 2.16: Installed Sliding Bearing

Two types of sliding systems are commonly used. A brief description with their basic functions, advantages and suitability is as follows.

i) Sliding Support with Rubber-Pad (SSR): When sliding base isolation system incorporates multilayer natural rubber pad then it is known as SSR. Advantages of such bearings are:

- SSR can provide vibration isolation for light loads as well as large deformation performance like a large-scale isolation system.
- It provides protection against a wide range of tremors from small vibrations to major earthquakes.
- It can be used in conjunction with other isolation systems such as RB, LRB and LRB-S.

Basic Functions of SSR: 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.

ii) Friction Pendulum System (FPS): Sliding pendulum isolation system is one type of flexible isolation system suitable for small to large-scale buildings. Functions of FPS are same as SSR system.

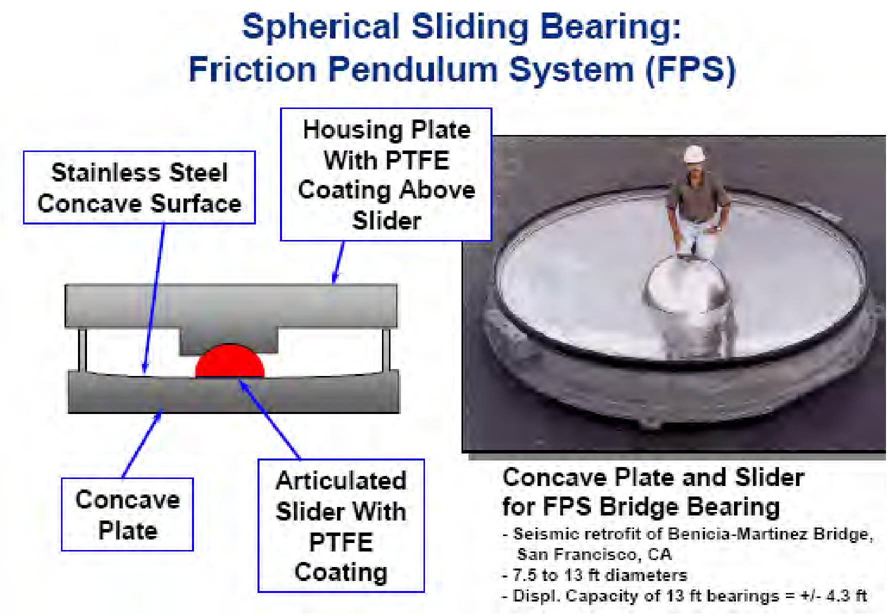


Figure 2.17: Spherical Sliding Bearing

Advantages of FPS includes...

- It is possible to set the oscillation period of a building regardless of its weight.
- This system can reduce costs not only because of the low cost of its device but also due to the low cost of installation.
- The device is simple, works well and easy to install. Furthermore, it saves space and is practical for a seismic reinforcement
- Performance of such device is stable due to the high durability of the device.
- It requires only a simple visual check to maintain the device. Hence, maintenance is very easy.

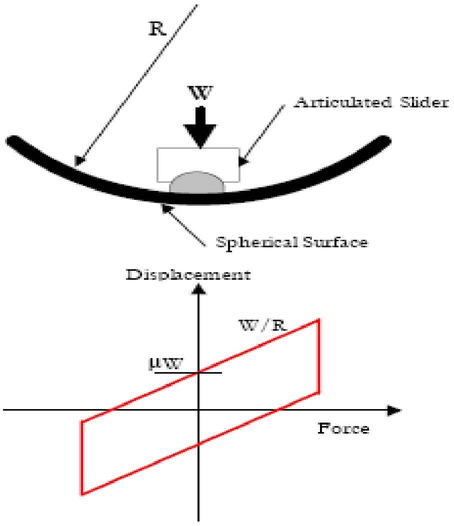


Figure 2.18: Curved (FPS) Sliding Bearing with Hysteresis Shape

2.9 Damping Type

Damping provides sufficient resistance to structure against service loading. The effect of damping on dynamic response is beneficial. Generally all structural systems exhibit damping to various degrees. It is assumed that, structural damping is viscous by nature. Damping coefficient relates force to velocity. If damping coefficient is sufficiently large, it is possible to totally restrain the oscillatory motion. Damping that suppress totally the oscillatory motion is termed as critical damping. Damping is usually neglected in frequency and period calculations unless it exceeds about 20%. Normally two types of damping are used in building. A brief description follows.

2.9.1 Elementary Damping

This really means damping as a whole, i.e. the device (each & every elements) itself acts as a purely damping device rather than an isolator. Purely damping devices can be used in low weight buildings to restrain the oscillating motion of the building. Another option may be using in conjunction with rubber bearing so-called as High Damping Rubber bearing (HDR). In such devices amount of damping is significantly high, usually from 8% to 15% of critical damping. Lead plug damper is one of the forms of elementary damping.

The basic function of such damper includes….

a) Vibration damping Junction: Lead plug damper absorbs large vibration of the building. As the layers of rubber are distorted, the lead plug is plastically deformed and at such stage it absorbs the earthquake energy and quickly damps the vibration.

b) *Trigger function:* It also reduces vibration form source other than earthquake. For example: when vibration is generated by strong winds, the relative rigidity of the lead plug reduces the effect of such vibration.

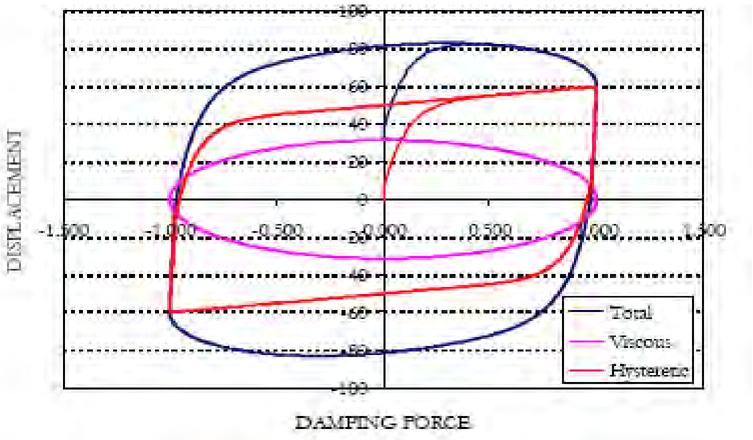


Figure 2.19: Viscous in parallel with the yielding system

2.9.2 Supplementary Damping

There are some types of isolators (discussed in bearing portion), which are capable of providing flexibility but not significant damping, or resistance to service loads. In order to strengthen the damping phenomena, supplementary devices are included with general Isolators. Damping of such type can be termed as supplementary damping. One of the most popular types of supplementary damping is viscous damping. This device provides damping but not service load resistance. It does not have any elastic stiffness and for this reasons it adds less force to the system than other devices.

2.9.3 Other Types:

Apart from bearing and sliding type, there are some other types of isolators, which are also used in building but rarely. Springs, rollers, sleeved piles are some examples of such isolators. A brief description of them is also included here.

Springs:

Spring isolators are devices whose working mechanism is based on steel springs. They are mostly used for machinery isolation. The main drawbacks of springs are two. Firstly, they are most flexible in both the vertical and horizontal directions. Secondly, springs alone have little damping and will move excessively under service loads.

Rollers:

Cylindrical rollers and ball bearings are of this type. Like springs they are commonly used for machinery isolation. The resistance to movement and damping of rollers and ball bearings are sufficient under service loads.

Sleeved Piles:

The pin ended structural members i.e. piles inside a sleeve provide flexibility and allow movement of the soft first story in a building. This type of piles is known as sleeved piles. Sleeved piles provide flexibility but no damping. Hence damping devices are required to use along with sleeved piles.

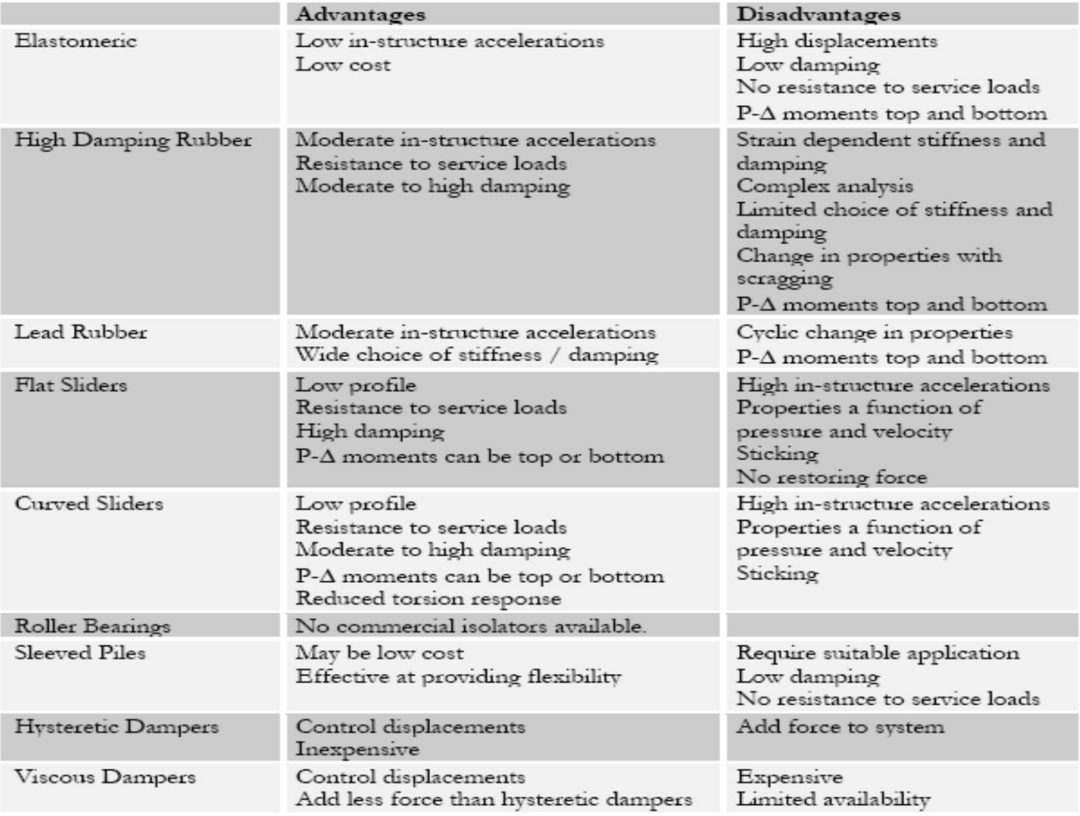
2.10 Advantages and Disadvantages of Devices

Table 2-1 summarizes the advantages and disadvantages of the most commonly used device types. Note that although disadvantages may apply to a generic type, some manufacturers may have specific procedures to alleviate the disadvantage. For example, static friction is a potential disadvantage of sliding bearings in general but manufactures of devices such as the Friction Pendulum System may be able to produce sliding surfaces that are not subject to this effect.

Some factors listed in Table 2-1 are not disadvantages of the device itself but may be a design disadvantage for some projects. For example, the LRBs and HDR bearings produce primary and secondary (P-Δ) moments which are distributed equally to the top and bottom of the bearing and so these moments will need to be designed for in both the foundation and structure above the isolators. For sliding systems the total P-Δ moment is the same but the sliding surface can be oriented so that the full moment is resisted by the foundation and none by the structure above (or vice versa).

The advantages and disadvantages listed in Table 2.1 are general and may not be comprehensive. On each project, some characteristics will be more important than others. For these reasons, it is not advisable to rule out specific devices too early in the design development phase. It is usually worthwhile to consider at least a preliminary design for several type of isolation system until it is obvious which system(s) appear to be optimum. It may be advisable to contact manufacturers of devices at the early stage to get assistance and ensure that the most up-to-date information is used.

Table 2.1 Device Advantages and Disadvantages



	Advantages	**Disadvantages**
Elastomeric	Low in-structure accelerations Low cost	High displacements Low damping No resistance to service loads P-Δ moments top and bottom
High Damping Rubber	Moderate in-structure accelerations Resistance to service loads Moderate to high damping	Strain dependent stiffness and damping Complex analysis Limited choice of stiffness and damping Change in properties with scragging P-Δ moments top and bottom
Lead Rubber	Moderate in-structure accelerations Wide choice of stiffness / damping	Cyclic change in properties P-Δ moments top and bottom
Flat Sliders	Low profile Resistance to service loads High damping P-Δ moments can be top or bottom	High in-structure accelerations Properties a function of pressure and velocity Sticking No restoring force
Curved Sliders	Low profile Resistance to service loads Moderate to high damping P-Δ moments can be top or bottom Reduced torsion response	High in-structure accelerations Properties a function of pressure and velocity Sticking
Roller Bearings	No commercial isolators available.	
Sleeved Piles	May be low cost Effective at providing flexibility	Require suitable application Low damping No resistance to service loads
Hysteretic Dampers	Control displacements Inexpensive	Add force to system
Viscous Dampers	Control displacements Add less force than hysteretic dampers	Expensive Limited availability

2.11 Worldwide Suppliers of Isolation system

The invention of isolation system opens the door for the businessman to produce varieties of isolation systems. There are continual changes in the list of isolation system suppliers as new entrants commence supply and existing suppliers extend their product range. The system suppliers listed in Table 2.2 are companies which we have used in our isolation projects, who have supplied to major projects for other engineers or who have qualified in the HITEC program. HITEC is a program operated in the U.S. by the Highway Technology Innovation Center for qualification of isolation and energy dissipation systems for bridges.

Given the changes in the industry, this list may be outdated quickly. Current information on these suppliers can be found from the web and may also identify suppliers not listed below. The project specifications should ensure that potential suppliers have the quality of product and resources to supply in a timely fashion. This may require a pre-qualification process. There are a large number of manufacturers of elastomeric bearings worldwide as these bearings are widely used for bridge pads and bearings for non-isolation purposes. These manufacturers may offer to supply isolation systems such as lead-rubber and high damping rubber bearings. However, standard bridge bearings are designed to operate at relatively low strain levels of about 25%. Isolation bearings in high seismic zones may be required to operate at strain levels ten times this level, up to 250%. The manufacturing processes required to achieve this level of performance are much more stringent than for the lower strain levels. In particular, the bonding techniques are critical and the facilities must be of clean-room standard to ensure no contamination of components during assembly. Manufacturers not included in Table 2.2 should be required to provide evidence that their product can achieve the performance levels required of seismic isolators.

Table 2.2 List of some suppliers of Isolation System

Products	Company
High Damping Rubber	Bridgestone (Japan) BTR Andre (UK) Scougal Rubber Corporation (US)
Lead Rubber	Robinson Seismic (NZ)
Friction pendulum System	Earthquake Protection System, Inc(US)
Lead rubber, high damping rubber	Dynamic Isolation Systems, Inc (US) Skellerup Industries (NZ) Seismic Energy Products (US)

Pot (Sliding) Bearings	Hercules Engineering (Australia)
Sliding Bearings	R J Watson, Inc(LJS) FIP-Energy Absorption Systems (US)
Viscous Dampers	Taylor Devices, Inc (US) Enidine, Inc (US)

2.12 Design of Lead-Rubber (ELASTOMERIC) Isolator

A lead-rubber isolator is an elastomeric bearing with a lead core inserted on its vertical centerline. When the bearing and lead core are deformed in shear, the elastic stiffness of the lead provides the initial stiffness (*Ku*).With increasing lateral load the lead yields almost perfectly plastically, and the post-yield stiffness K_d is given by the rubber alone.

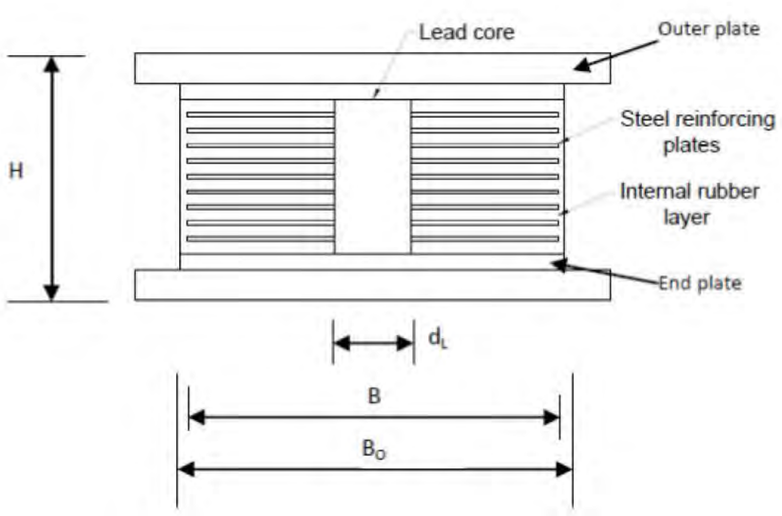


Figure 2.20: Isolator

While both circular and rectangular bearings are commercially available, circular bearings are more commonly used. Consequently the procedure given below focuses on circular bearings. The same steps can be followed for rectangular bearings, but some modifications will be necessary. When sizing the physical dimensions of the bearing, plan dimensions (B, d_L) should be rounded up to the next 1/4” increment, while the total thickness of elastomer, T_r, is specified in multiples of the layer thickness. Typical layer thicknesses for bearings with lead cores are 1/4” and 3/8”. High quality natural rubber should be specified for the elastomer. It should have a shear modulus in the range 60-120 psi and an ultimate elongation-at-break in excess of 5.5.

The following design procedure assumes the isolators are bolted to the masonry and sole plates. Isolators that use shear-only connections (and not bolts) require additional design checks for stability which are not included below

Note that the procedure given in this step is intended for preliminary design only. Final design details and material selection should be checked with the manufacturer.

A1. Required Properties

Obtain from previous work the properties required of

the isolation system to achieve the specified

Performance criteria (Step A1).

- Required characteristic strength, Q_d/ isolator
- Required post-elastic stiffness, K_d/ isolator
- Total design displacement, *dt*, for each isolator
- Maximum applied dead and live load (*PDL*, P_{LL}) and seismic load (P_{SL}) which includes seismic live load (if any) and overturning forces due to seismic loads, at each isolator, and maximum wind load, *PWL*

A2. Isolator Sizing

A2.1 Lead Core Diameter

Determine the required diameter of the lead plug, d_L,

using:

$$d_L=\sqrt{(Q_d/0.9)} \qquad (1)$$

See Step A2.5 for limitations on d_L

A2.2 Plan Area and Isolator Diameter

Although no limits are placed on compressive stress in the GSID, (maximum strain criteria are used instead, see Step A3) it is useful to begin the sizing process by Assuming an allowable stress of, say, 1.6 ksi.

Then the bonded area of the isolator is given by:

$$A_b= (P_{DL}+ P_{LL})/1.6 \text{ in}^2 \qquad (2)$$

and the corresponding bonded diameter (taking into account the hole required to accommodate the lead core) is given by:

$$B= \sqrt{(4A_b/\pi+d_L^2)} \qquad (3)$$

Round the bonded diameter, B, to nearest quarter inch, and recalculate actual bonded area using

$A_b = \pi/4(B^2 - d_L^2)$ (4)

Note that the overall diameter is equal to the bonded diameter plus the thickness of the side cover layers (usually 1/2 inch each side). In this case the overall diameter, *Bo* is given by:

$B_0 = B + 1.0$ (5)

A2.3 Elastomer Thickness and Number of Layers

Since the shear stiffness of the elastomeric bearing is given by:

$K_d = G.A_b/T_r$ (6)

Where, G = shear modulus of the rubber, and

Tr= the total thickness of elastomer,

It follows Eq. A-5 may be used to obtain Tr given are quired value for K_d

$T_r = G.A_b/K_d$ (7)

If the layer thickness is tr, the number of layers, n, is given by:

$n = T_r/t_r$ (8)

Rounded up to the nearest integer. Note that because of rounding the plan dimensions and the number of layers, the actual stiffness, *Kd*, will not be exactly as required. Reanalysis may be necessary if the differences are large.

A2.4 Overall Height

The overall height of the isolator, H, is given by:

$H = nt_r + (n-1)t_s + 2t_c$ (9)

Where, t_s = thickness of an internal shim (usually about 1/8 in), and t_c= combined thickness of end cover plate (0.5in) and outer plate (1.0 in)

A2.5 Lead Core Size Check

Experience has shown that for optimum performance of the lead core it must not be too small or too large. The recommended range for the diameter is as follows:

$B/3 \geq d_L \geq B/6$ (10)

A3. Strain Limit Check

GSID requires that the total applied shear strain from all sources in a single layer of elastomer should not exceed 5.5, i.e.

$\gamma_c + \gamma_{s,eq} + 0.5\gamma_r \leq 5.5$ (11)

Where γ_c, $\gamma_{s,eq}$, $\gamma_r$are defined below.

(a) γ_c is the maximum shear strain in the layer due to compression and is given by:

$$\gamma_c=D_c\sigma_s/GS \tag{12}$$

Where, D_c is shape coefficient for compression in circular bearings = 1.0, $\sigma_s= P_{DL}/A_b$, G is shear modulus, and S is the layer shape factor given by:

$$S= A_b/\pi Bt_r \tag{13}$$

(b) $\gamma_{s,eq}$ is the shear strain due to earthquake loads and is given by:

$$\gamma_{s,eq}= d_t/T_r \tag{14}$$

(c) γ_r is the shear strain due to rotation and is given by:

$$\gamma_r = D_rB^2\Theta/t_rT_r \tag{15}$$

Where, D_r is shape coefficient for rotation in circular bearings = 0.375 and Θ is design rotation due to DL, LL and construction effects. Actual value for Θ may not be known at this time and a value of 0.01 is suggested as an interim measure, including uncertainties.

A4. Vertical Load Stability Check

The vertical load capacity of all isolators be at least 3 times the applied vertical loads (DL and LL) in the laterally un-deformed state. Further, the isolation system shall be stable under 1.2(DL+SL) at a horizontal displacement equal to Either 2 x total design displacement, *dt*, if in Seismic Zone 1 or 2, or 1.5 x total design displacement, *dt*, if in Seismic Zone 3 or 4.

A4.1 Vertical Load Stability in Un-Deformed State

The critical load capacity of an elastomeric isolator at zero shear displacement is given by

$$P_{cr(\Delta=0)} = K_dH_{eff}/2 \left[\sqrt{(1+ 4\pi^2K_\Theta/K_dH_{eff}^2)}-1\right] \tag{16}$$

Where,

$H_{eff} = T_r+T_s$

T_s= total shim thickness

$K_\Theta=E_bI/T_r$

$E_b = E\,(1+0.67S^2)$

E = elastic modulus of elastomer = $3G$

$I= \pi B^4/64$

It is noted that typical elastomeric isolators have high shape factors, *S*, in which case:

$4\pi^2 K_\Theta / K_d H_{eff}^2 >> 1$ (17)

and Eq. 16 reduces to:

$P_{cr(\Delta=0)} = \pi\sqrt{(K_d K_\Theta)}$ (18)

Check that:

$P_{cr(\Delta=0)} / (P_{DL}+P_{LL}) \geq 3$ (19)

A4.2 Vertical Load Stability in Deformed State

The critical load capacity of an elastomeric isolator at shear displacement Δ may be approximated by:

$P_{cr(\Delta)}=(A_r/A_{gross})P_{cr(\Delta=0)}$ (20)

Where,

A_r= overlap area between top and bottom plates

of isolator at displacement

$= B^2 (\delta-\sin\delta)/4$

$\delta =2\cos^{-1}(\Delta/B)$

$A_{gross}= \pi (B^2/4)$

It follows that:

$A_r/A_{gross}= (\delta-\sin\delta)/\pi$ (21)

Check that:

$P_{cr} (\Delta)/ (1.2P_{DL}+P_{SL}) \geq 1$ (22)

This is the design steps for Isolator design.

2.13 Properties of Isolators

1. Lead Rubber Isolator

As discussed in point 2.12 figure 2.20

2. Spherical Friction Isolator

Friction Pendulum bearings are seismic isolators that are installed between a structure and its foundation to protect the supported structure from earthquake ground shaking. Using Friction Pendulum technology, it is cost-effective to build structures to elastically resist earthquake ground motions without structural damage.

Friction Pendulum bearings use the characteristics of a pendulum to lengthen the natural period of the isolated structure so as to avoid the strongest earthquake forces. During an earthquake, the supported structure moves with small pendulum motions. Since earthquake induced displacements occur primarily in the bearings, lateral loads transmitted to the structure are greatly reduced.

There are three types of Friction Isolator

- Triple Pendulum Bearing
- Single Pendulum Bearing
- Tension Capable Bearing

a. Triple Pendulum Bearing:

The Triple Pendulum bearing incorporates three pendulums in one bearing, each with properties selected to optimize the structure's response for different earthquake strengths and frequencies.

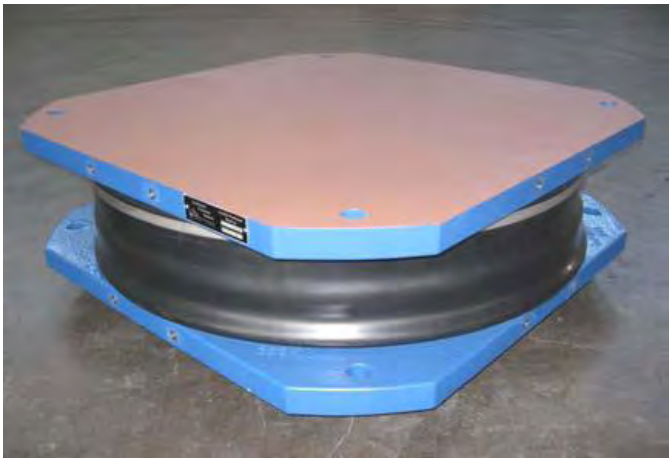


Figure 2.21: Triple Pendulum Bearing

b. Single Pendulum Bearing

The Single Pendulum Bearing is the original Friction Pendulum bearing. The single slider maintains the vertical load support at the center of the structural member. This offers construction cost advantages if one structural system is weaker, either above or below the bearing. The bearing also has a low height, which can be advantageous in some installations.

Figure 2.22 Single Pendulum Bearing

c. Tension Capable Bearing

The Tension Capable Bearing can accommodate structure vertical loads that vary from compression to tension during seismic movements. This bearing can substantially reduce structural framing costs by preventing uplift of a primary structural member, and can eliminate concerns regarding potential structure overturning or large vertical earthquake motions.

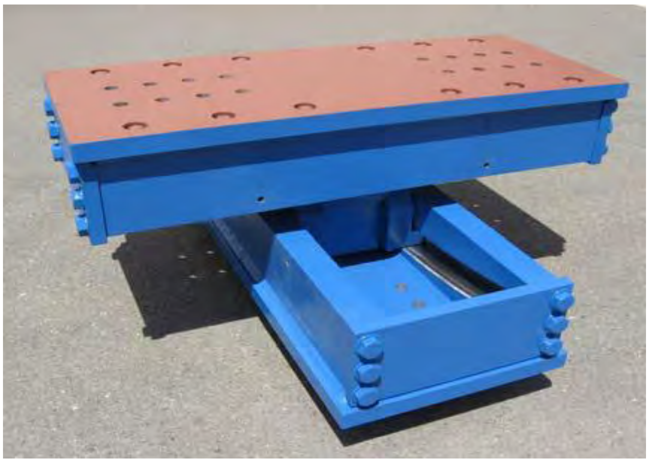


Figure 2.23: Tension Capable Bearing

2.14 Principle of Base isolation and its Suitability

The term 'Isolation' means the state of separation. Hence, Base Isolation or, seismic isolation is the separation of upper structure from base or, from down structure by changing fix joint with flexible one.

The intent of this chapter is to provide a guideline about how and when to use isolation system for structure.

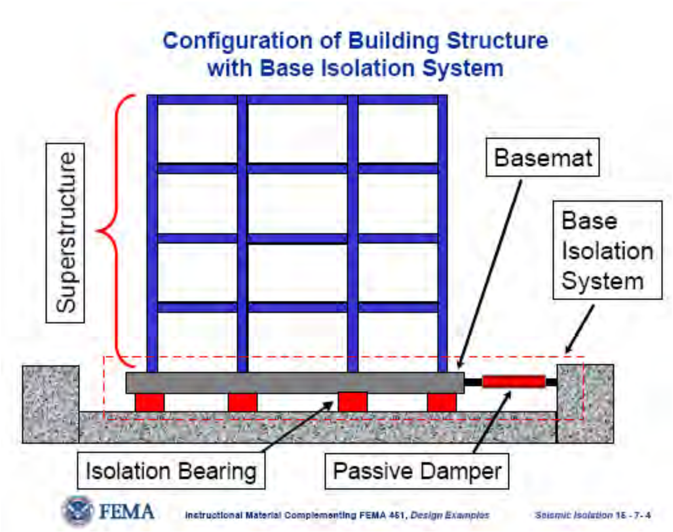


Figure 2.24: Configuration of Building structure with Base Isolation System

2.14.1 The Basic Principle

The basic principle of seismic Isolation is to modify the building's response in such a manner that the ground can move below the building without transmitting the potentially damaging earthquake ground motion into the structure. In actual cases it is really impossible to isolate the whole structure from the ground because there needs to be some contact between the structure and the ground. But, in this age of modem technology it is not a great problem. Introduction of flexible elements at the base of a structure in the horizontal direction and at the same time ensuring enough damping is probably the best option for the seismic isolation technique. The device that is capable to meet such criteria is known as isolator.

2.14.2 Behavior of Rigid and Flexible structure due to ground motion

Before discussing the criteria, one thing must be very clear to the readers that a building in the real world rather than in theory is neither perfectly rigid nor perfectly flexible. For a perfectly rigid structure, when the ground moves the acceleration induced in the structure will be equal to the ground acceleration. But for a perfectly flexible structure, when the ground beneath the structure moves there will be zero ground acceleration induced in the 'structure. So the real problem lies in between this two.

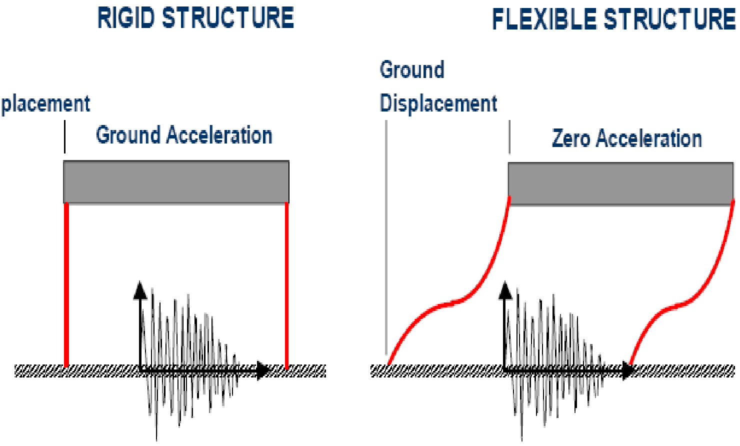


Figure 2.25: Transmission of Ground Motion

For periods between zero and infinity, the maximum accelerations and displacements relative to the ground are a function of the earthquake, as shown conceptually in Figure 2.26. For most earthquakes there be a range of periods at which the acceleration in the structure will be amplified beyond the maximum ground acceleration. The relative displacements will generally not exceed the peak ground displacement, that is the infinite period displacement, but there are some exceptions to this, particularly for soft soil sites and site which are located close to the fault generating the earthquake.

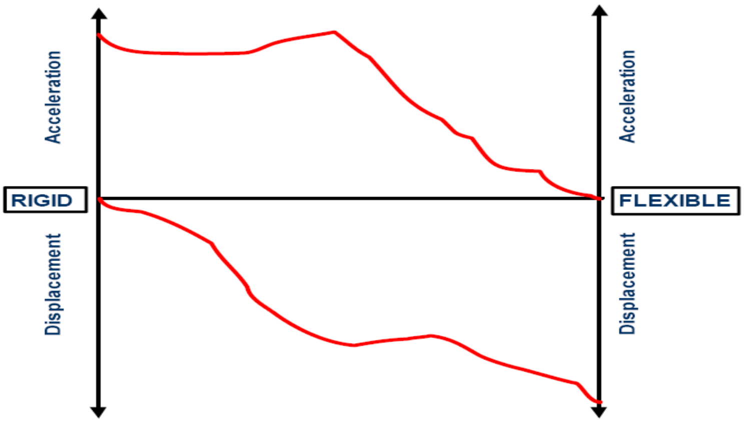


Figure 2.26: Displacement

2.15 Criteria to Select a Base Isolation System

Base isolation is a passive vibration control technique generally used as a modification of conventional structures (Chart 2.2). Isolation is needed when it provides a more effective and economical alternative than other methods for providing earthquake safety

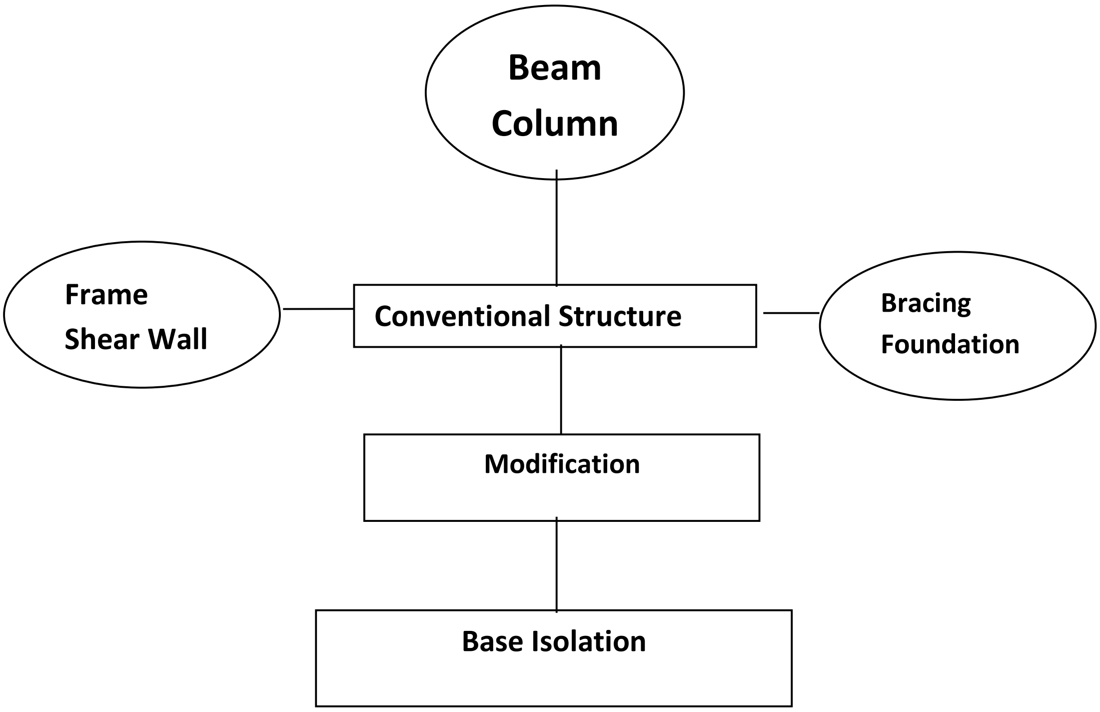


Chart 2.2: Modification of a conventional structure through Base Isolation

The major steps that should be followed to asses a structure whether it is suitable for isolation or not, is listed below. One can easily take a decision whether to go for isolation or not, by simply following the given decision chart (Chart 2.2)

2.15.1 The weight of the structure:

Practically used most of the isolation systems work best with heavy masses. To obtain an effective isolation a long period of response is needed. The period is proportional to the square root of the mass M and inversely proportional to the square root of the stiffness K.

$$T = 2\pi\sqrt{(\mathbf{M} / K)}$$

To achieve a given isolated period, a low mass must be associated with a low stiffness. Isolators do not have an infinite range of stiffness. Lightweight buildings may be able to be isolated with sliding systems. However, even these will not to be cost effective for light buildings for different reasons. Regardless of the weight of the building, the displacement is the same for a given effective period and so the size of the slide plates (the most expensive part of sliding bearings). In real terms, this usually makes the isolators more expensive as a proportion of first cost for light buildings.

2.15.2 The Period of the structure:

The most suitable structures for base isolation are those with a short natural period, especially less than about 1 second. For buildings, that is usually less than 10 stories and for flexible types of structure, such as steel moment frames, probably less than 5 stories.

Practical isolation systems don't provide an infinite period; rather they shift the period to the 1.5 to 3.5 second range. If the structure in question is already in this period range, then provision of base isolation won't give much benefit, although in some cases energy dissipation at the base may help.

2.15.3 Subsoil Conditions:

Isolation works best on rock and stiff soil sites. Soft soil has a similar effect to the basin type conditions. (Alluvial basins have a travel path from the epicenter such that the earthquake motion at this site has long period motion, which can cause resonance in the isolated period range) It will modify the earthquake waves so that there is an increase in long period motion compared to stiff sites. Soft soil does not rule out isolation in itself but the efficiency and effectiveness will be reduced.

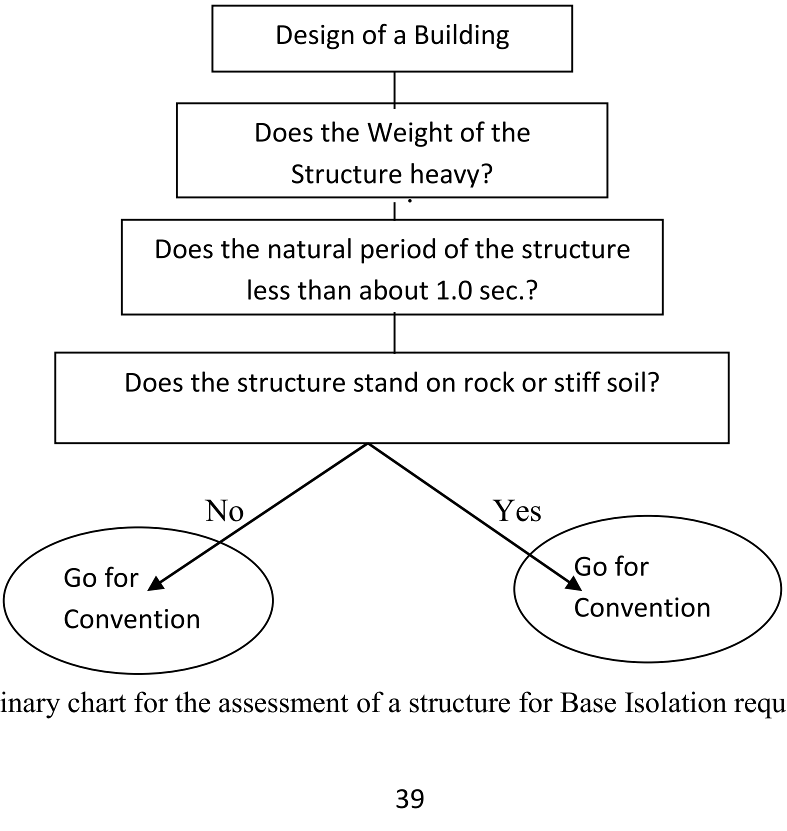


Chart 2.3 Preliminary chart for the assessment of a structure for Base Isolation requirement

2.16 Near fault Effect:

One of the most controversial aspects of base isolation is that system will operate if the earthquake occurs close to the structure (within about 5 km). Close to the fault, a phenomenon termed " fling" (a long period, high velocity pulse in the ground acceleration record) can occure. Isolation is being used in near fault locations, but the cost is usually higher and the evaluation is more complex.In reality, any structure near to a fault should be evaluated for the "fling" effect.

2.17 Suitability of seismic isolation

Earthquake protection of structures using base isolation technique is generally suitable if the following conditions are fulfilled:

- The subsoil does not produce a predominance of long period ground motion
- The structure is fairly thick with sufficiently high column load
- The site permits horizontal displacements at the base of the order of 200 mm (50 in) or more
- Lateral loads due to wind are less than approximately 10% of the weight of the structure.

Buildings which are most suitable for Isolation from other general buildings because of their particular characteristics are listed in Table 2.3

Table 2.3 Suitable Buildings for Isolation

Building Type	Reasons for Isolating
Buildings Type provide Essential Facilities	Functionally High Importance factor, I
Buildings Type provide Healthcare Facilities	Functionally High Importance factor, I
Old Buildings	Preservation for low R
Museums	Valuable Contents
Building Type provide Manufacturing Facilities	Contained function high Value Contents

2.18 Isolation Techniques

The main requirement for installation of a base isolation system i.e. Isolator is that the building be able to move horizontally relative to the ground, usually at least 100 mm and in some instance up to 1 meter. A plane of separation must be selected to permit this movement. Final selection of the location of this plane depends on the structure.

2.18.1 Isolator Installation techniques

Figure 2.27: Isolator Installation in Building

The most common configuration is to install a diaphragm immediately above the isolators. This permits earthquake loads to be distributed to the isolators according to their stiffness. For a building without a basement, the isolators are mounted on foundation pads and the structure is constructed above them (Fig 2.28). If the building has a basement then the options are to install the isolators at the top, bottom or mid height of the basements, columns and walls (Fig 2.29).

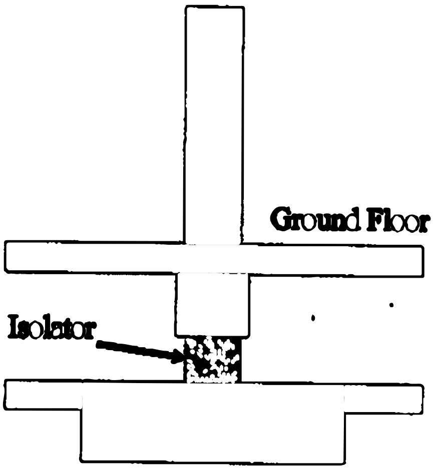


Figure 2.28: Isolator Installation location in Building with no Basement

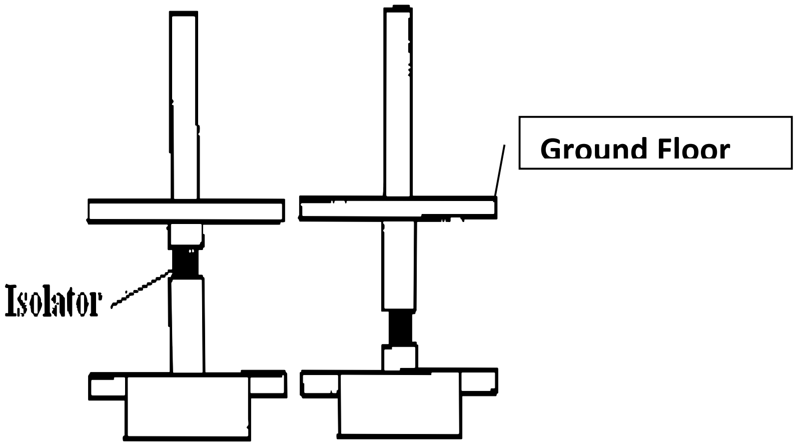


Figure 2.29: Isolator Installation location in Building having Basement

In this study Isolation Techniques will be discussed for a building without a Basement as well as a building which has a Basement presenting the practical Example mentioning sequence in details.

2.18.2 Practical Example of Isolator Installation in Building:

The following example gives an idea about the installation of an isolator in an existing building. This real example has been taken from isolator installation in Turkey's International Airport Terminal Building. The installation sequence for a typical LRB into a reinforced concrete column is described below:

a) Temporary steel columns on suitable foundations were installed to either side of the reinforced concrete column into which the bearing was to be installed (Fig 2.30). Hydraulic jacks were placed at the heads of the temporary columns, bearing onto the beams at first floor level, and stressed to a predetermined level, calculated as the gravity load in the permanent column from the SAP 2000 analysis. The hydraulic fluid in the jacks was locked off. (Fig 2.30)

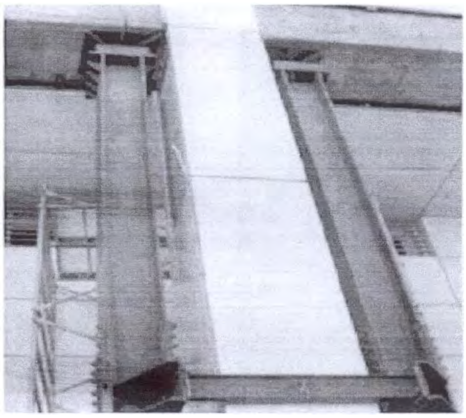
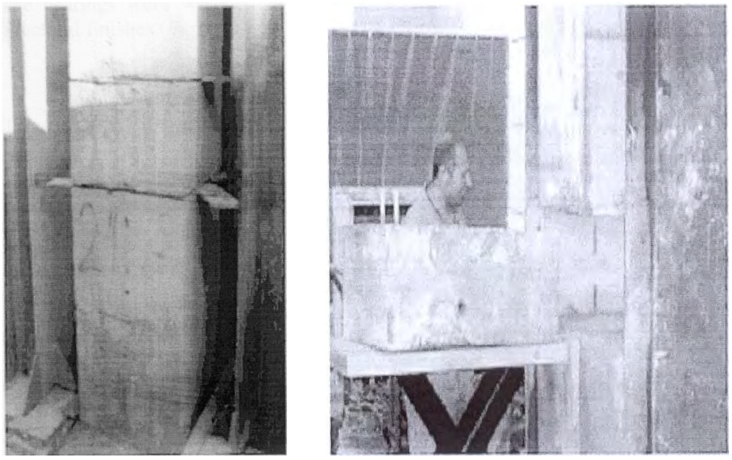


Figure 2.30: Installation of temporary steel Column

b) Bench marks were introduced on to the column just above and below the final position of the bearing, and measurements taken, to enable subsequent checks to be performed of possible movements of the column.

c) Two horizontal cuts were made in the column using a diamond chain saw (Fig 2.31 (a)). The block of concrete in between was removed (Fig 4.31 (b)). The movements of the column above and below the cuts were then measured; in most cases this was small, but could reach as much as 6mm (0.24 in.). This was considered acceptable. A bed of epoxy mortar was placed on the lower half of the cut surface, and the LRB was then rolled into place on steel ball bearings. The gap above the bearing was then filled with epoxy mortar. The hydraulic jacks in the steel props were released and the props were removed after curing of the epoxy mortar.



(a) Saw cuts through Concrete Column (b) Removal of Concrete Block

Figure 2.31: Cutting and removal of concrete block

d) Steel jackets was welded into place above and below the bearing, and grouted to the column, to accommodate the stress concentrations at the cut surfaces of the column arising from the bearing and to replace the reinforcement that had been cut in step c (Fig 2.32)

Figure 2.32 Steel Jackets replacing severed reinforcing bars

e) The bearings were wrapped in fire insulation, and brackets introduced to support architectural finishes (Figure 2.33).

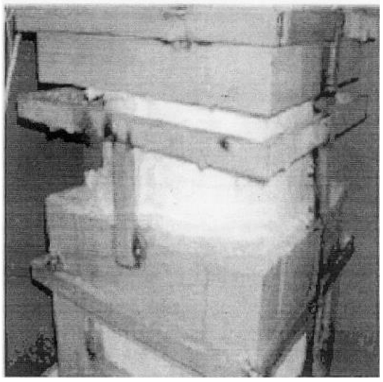


Figure 2.33 Installation of fire proofing elements

2.19 Elaborate description of Base isolation design

The basic aim of seismic design, as in any engineering design, is to ensure that the resistant of the structure is greater than the loads applied to it. This is complicated in seismic design by the fact that earthquake loads are dynamic and not deterministic, i.e. it is really complicated to predict it. Hence, it is utmost important to be able to analyze a building for dynamic loads.

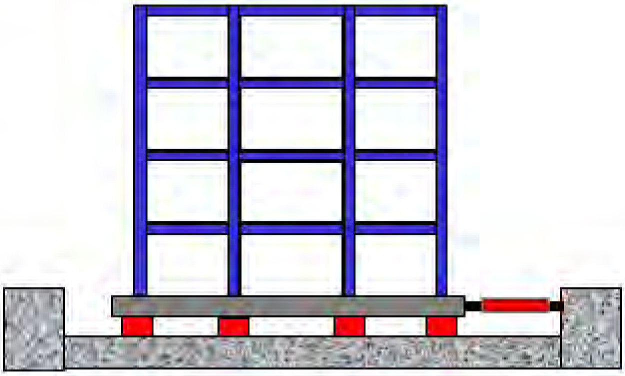


Figure 2.34 Seismic Isolation system in Building

So the purpose of this lesson is to represent the design of a base Isolation system related to code provisions along with their detail contents. This chapter will also give the required charts and tables for the design of a Base isolator and a detail analysis procedure of structures prone to earthquake.

Chapter 3

SOFT STORY BUILDING

3.1 Introduction

Soft storey buildings are characterized by having a storey which has a lot of open spaces. This soft storey creates a major weak point in an earthquake. Since soft stories are classically associated with retail spaces and parking garages, they are often on the lower stories of a building, which means that when they collapse, they can take the whole building down with them, causing serious structural damage which may render the structure totally unusable. In this study, efforts have been given to examine the effect of incorporation of isolator on the seismic behavior of buildings subjected to the appropriate earthquake for medium risk seismicity region. It duly ensures incorporating isolator with all relevant properties as per respective isolators along with its time period and damping ratio. Effort has also been made here to build up a relationship for increasing storey height and the changes for incorporating isolator with same time period and damping ratio for lead rubber bearing (LRB). Dynamic analyses have been carried over using response spectrum and time history analysis. Behavioral changes of structural parameters are investigated. The study reveals that the values of structural parameters reduce a large amount while using isolator. The structure experiences huge storey drift at the soft storey level that may be severe and cause immature failure. The amount of masonry infill is very vital for soft storey buildings as its decrement increases reasonable displacements.

If any building has a floor which is 70% less stiff than the floor above it, it is considered a soft storey building. While the unobstructed space of the soft storey might be aesthetically or commercially desirable, it also means that there is less opportunity to install walls to distribute lateral forces so that a building can cope up with the swaying characteristic of an earthquake (Micheli et al.2004). Seismic base isolation system has been rarely considered in research for buildings with soft storey. Increasing tendency of soft storey utilization is uncertain in context of structural feasibility in base isolated (BI) building. Through study in this concern is very burning matter. It may come as a surprise that these rubber foundation elements can actually help to minimize earthquake damage to buildings, considering the tremendous forces that these buildings must endure in a major quake.

3.2 Soft Storey effect

Once a general investigation of the results of the quakes that occurred so far is conducted, it can be seen that the biggest damage to human beings has always come from weakness buildings. Thus, the most effective way of protection against quakes is not to build resistant constructions. It is only possible to build a resistant construction if we take quakes into consideration at the stages of design, project, construction, and occupancy. There are essential specifications which should be taken into consideration at these stages. These are short column, strong column-weak beam, and torsion. Soft storey irregularity is one of these. Short storey is an irregularity which should definitely be taken into consideration if the construction is to be a resistant one. It is only possible to build a quake resistant construction if all these irregularities are considered. If structural irregularities are not taken into consideration, a construction cannot be said to be a resistant one no matter the highest quality concrete is used. Just like an illness in one part of the body affects the whole body, so does an irregularity in a constructions. Because a construction is the whole with its ground and its super structure.

Soft storey is the one of which the rigidity is lower than any other storeys due to the fact that it has not got the walls with the same properties the other ones have. If vertical load bearing structural elements and the partitioning wall continue in all the storeys, there is no soft storey in the construction. Soft storeys are generally present at the entrance floors of the buildings. This situation depends on the constructional properties of the cities and countries. If dwellings and trade centers are at the same building, soft storeys are more common, if not, soft storeys are rare. Since dwellings and trade centers are in the same building in general in Turkey, most of the constructions have soft floors. Because entrance floors of the buildings are used as bank branches, stores, restaurants, offices and the upper storeys are used as dwellings. Since the business stores and the dwellings are not the two sections with the same properties, there exist soft storeys. This aspect of construction in Turkey was observed clearly when we investigate the Izmit-quake results of soft storeys. Nearly 85-90 % of the collapsed and damaged buildings had soft storeys in them (Fig.3.1).

During an earthquake, more moment and shear strength fall on the columns and walls in the entrance floors than the one in the upper storeys. If the walls that exist in other storeys do not exist in the entrance floor, these columns are forced more those in other storeys. Due to the fact that there is less rigidity in soft storeys, the structure is divided into two sections in terms of structural behaviour; the lower and the upper part of the soft storey. This can be called dangerous storey instead of soft storey Figure 3.1.

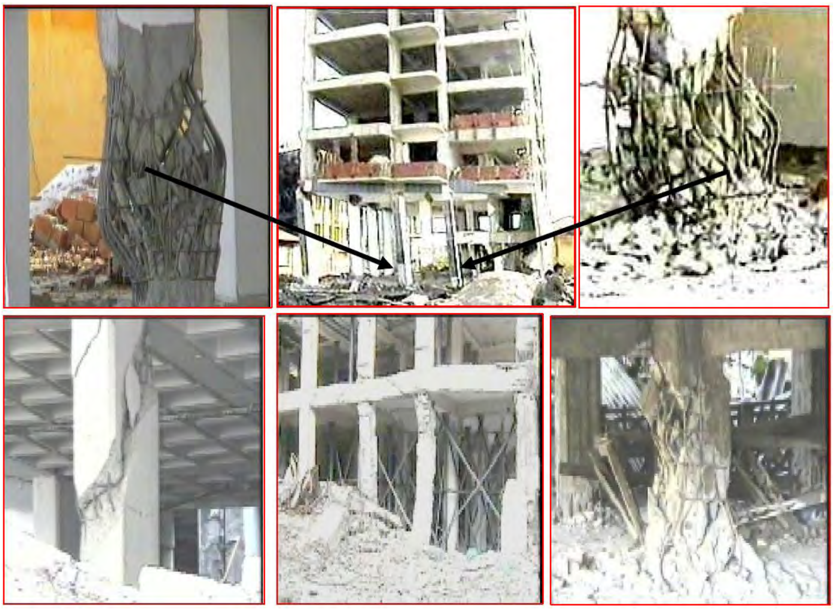


Figure 3.1: Damage of Izmit Earthquake (Adapazarı) in soft storey location

3.3 Quake behaviour of the construction with soft storeys

Symmetrical constructions in both plan and hight show a better resistance during an earthquake than those that do not have this symmetry. Since the presence of a soft storey which has less rigidity than other storeys spoils the perpendicular symmetry of the construction, and if this fact was not taken into consideration, it causes the construction to be affected by the quake. Because the columns in this part are forced by the quake more than the ones in the other parts of the building. studies conducted suggest that walls increase the rigidity at a certain degree in the construction That is to say, there is 15 % difference of rigidity between a storey with walls and the one without any walls.

A construction is divided into two parts from the point where there is a soft storey (Fig.3.2). Of the constructions with equal rigidity between the storeys, the displacement of the peak points at the moment of a quake causes the other building with a soft storey to get damaged because the construction with a soft storey cannot shoe the same rigidity (Fig.3.2). For example the top point of a ten-storey building with no soft storey performs 3 cm displacement, another building with the same specification but having a soft storey at the entrance floor and with no necessary precaution can show the same displacement 3 cm at this floor. According to this result, a soft storey in upper storeys of the building is not so effective. Quake damages investigated verify this conclusion. U is displacements.

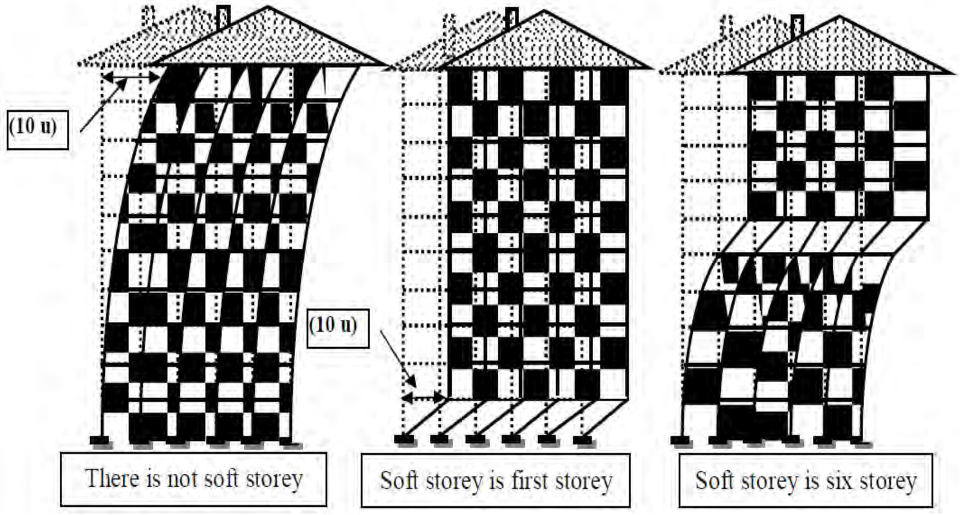


Figure 3.2: Behaviour of soft storeys to Earthquake

Since soft storeys affect in great extend the behaviour of the buildings during a quake, this fact is given detailed place in Codes of Earthquakes Table1. Despite all this, still most of the constructions damaged suffer from this irregularity (Fig.3.3-3.5). As a result of investigation on this and other irregularities, it was observed that Codes of Earthquake are not sufficient, especially in Turkey. For this reason, it comes into forefront that it is necessary for these irregularities to be controlled at the stage of project and construction. It should be known that controlling is one stage in building quake-resistant constructions, and it should be applied.

Figure 3.3: Damage of Izmit earthquake (Adapazarı)

Figure 3.4: Damage to soft storey of Izmit Earthquake (Yalova-Gölcük)

Figure 3.5: Soft storey failure

Soft storeys in constructions came into being in two ways:

- Columns, shears and walls showing difference between storeys (Fig.3.6.a)
- Rigidity between the storeys of the construction being different, resulting graters displacements (Fig.3.6.b)

At the stage of projecting a structure, certain solutions should be worked out as regards the quake region, importance and the function of the building, and irregularities should be eliminated. It cannot be said that storeys being constructed with the same physical properties are not soft storeys. For this two kinds of control should be carried out. The ratio of number of columns, shears, and walls on one storey of the building parallel to the quake to the ones on the other storeys (SS). The ideal ratio is 1 (Eqn.1). But, as it is not always possible to materialise this, this ratio can be taken less than 1. This ratio is taken as 0.80 in Turkish Code of Earthquake. When this ratio is lower, additional precautions should be taken or the design of the building should be reviewed. In case the soft storey irregularities are on the entrance floor, this ratio should be 0.8-0.9, according to the importance of the construction.

This ratio being bigger than one brings irregularities to the construction. For this reason, this ratio should be analyzed well at the stage of design. This does not necessarily mean that the construction would not be built with a certain desired appearance or it would not involve stores on the first storey.

Taking necessary precaution, this ratio should be brought to the desired level. Otherwise, the construction could undergo damage due to these irregularities. Total ratio of irregularity as the total of ΣA_c = total area of cross sections of shear and column at one storey taken in the parallel direction to the quake and ΣA_w = total area of beam fillings (spaces of doors and windows excluded) at any storey taken in the parallel direction to the quake (SS) is calculated as follows:

$$SS = \frac{(\sum S)_i}{(\sum S)_{i+1}} \quad (\Sigma S = \Sigma A_c + 0.15\, \Sigma A_w) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

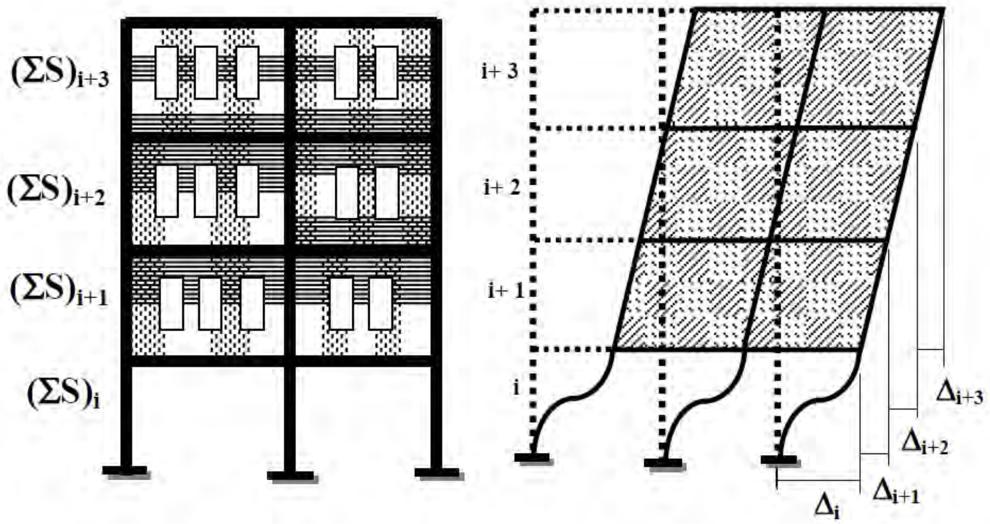


Figure 3.6: Soft Storeys

3.4 Preventing soft storey irregularities

In constructions where it is necessary to build a soft storey, lateral rigidity of this particular storey should be brought to the rigidity level of the other storeys. To be able to do this, the number of columns and shear walls should be increased. Because of this increase, longitudinal and lateral reinforcement should also be increased. These raise the cost of the construction. Soft storey is an irregularity which affects the behaviour of a construction during a quake and also increases the construction costs. For this reason, soft storeys should be avoided as much as possible. In case it is necessary, by the controls to be performed as a result of calculation made, irregularities can be eliminated as follows:

- Building additional walls (Fig.3.7.a)
- Increasing the rigidity of the columns and the shear walls on the soft storey (Fig.3.7.b)
- Regulating the dimensions of the columns and shear walls by longitudinal and lateral reinforcement so that the soft floor would show a ductile behaviour (Fig.3.7.c)
- Preventing cracking by placing the wall at a certain distance from columns and walls that are on the soft storey (Fig.3.7.d)

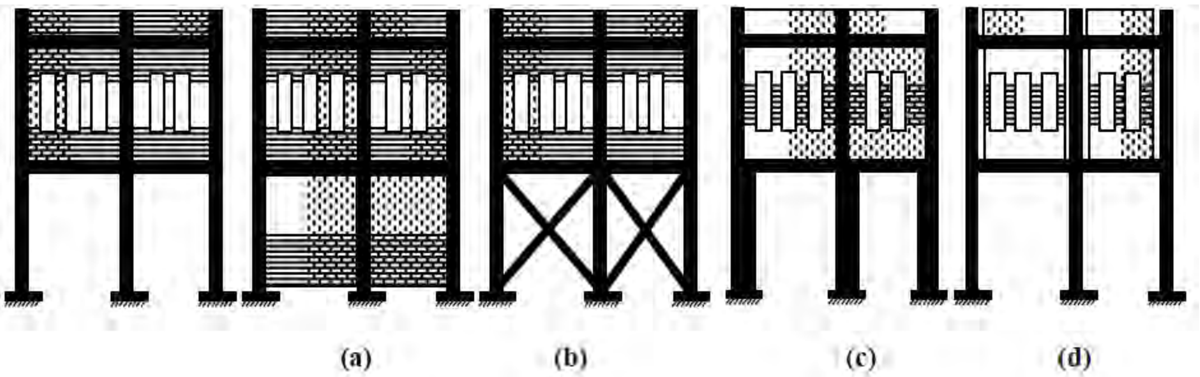


Figure 3.7: Methods of preventing soft storey irregularities

Now that we cannot leave the already present buildings, we should turn them into resisting ones according to the Code of Earthquake. Since the codes and regulations are changed as a result of technological advances and examination of the quake results, those constructions which are considered resistant according to the previous regulations can be weakness according to the new regulations. To be able to do this, present irregularities should be eliminated.

To bring the present buildings into resistant state of being, proper one of the following method is applied:

- Increasing the lateral rigidity of this storey by putting up additional walls between single structural elements on the soft storey
- Increasing the lateral rigidity of this storey by placing steel diagonals between the columns and shear walls

- Putting flexible material between columns and walls on the storey atop the soft storey thus preventing it to work together with the soft storey
- Increasing the rigidity of the soft storey by reinforcing the columns of the soft storey.

3.5 Masonry Infill walls

It is well-established fact that masonry infill walls play an important role in lateral load resistance of RC buildings. Nevertheless, masonry infill walls are widely used as partitions to fill the gap between RC frames, and used either to divide the spaces to any required purposes or to protect inside of the structure from environment. Although the structural contribution of masonry infill walls is often overlooked in the structural analysis and design of such structures, it affects both the structural and non-structural performance of RC structures and alters the load resisting mechanism and failure pattern of the RC frame. Treating infill walls as architectural elements is reasonable and justifiable assumption under gravity loads and neglecting their influence on the behavior of the structure under lateral load can lead to uneconomical design as well as unexpected behavior and even catastrophic collapse. Recent researches have clearly shown that the damages done to the buildings with masonry infill walls were considerable less than those without masonry infill and the difference was quite a bit significant. This can be due to the dramatic increase in the global strength, stiffness, damping and the dissipated energy of the structures with masonry infill walls. Therefore, in moderate and high seismicity regions, the structural contribution of infill walls cannot simply be neglected. Although the inclusion of such masonry infill interaction may improve the performance of the structure under seismic actions, it may cause some negative effects such as the induced torsional effect due to in plan-irregularity. In addition, the discontinuity of infill throughout the building height due to existence of a soft storey may induce irregularities in elevation. Moreover, short columns effect due to openings may arise. Under seismic loads, the existence of masonry walls changes the structural mechanism of transferring the induced lateral forces from a frame action mechanism into truss action mechanism (see Figure 3.8)

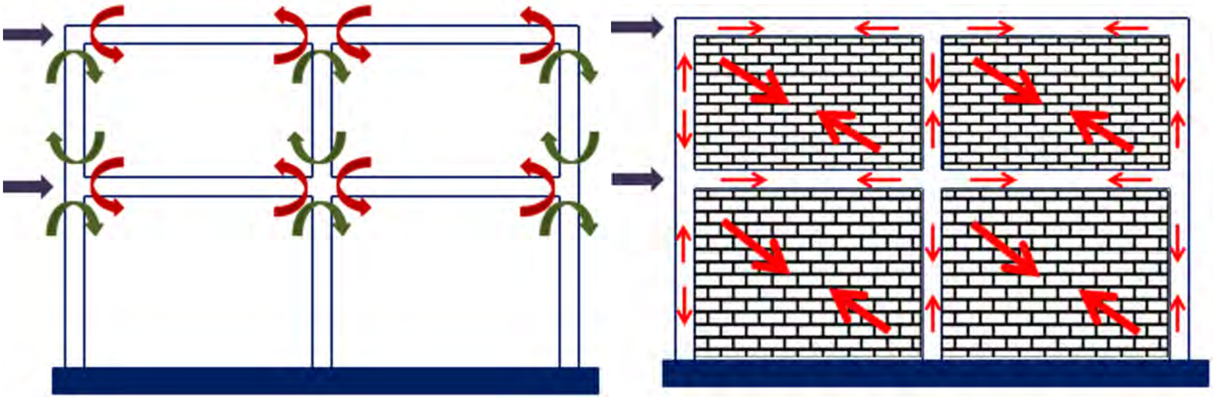

(a) **(b)**

Figure 3.8. Lateral load transfer mechanisms due to ignorance and inclusion of infill actions: (a) Frame action as in bare frame (b) Truss action as in infilled frame.

Such change in load transfer mechanism leads to reduction in the induced straining actions in terms of bending moments and shearing forces but with increase in axial forces. Although the capacity of the structure to the applied lateral loads gets increase, it may result in attracting part of the lateral shear forces due to seismic or wind actions to undesired parts of the building structure causing structural deficiency. To deal with the subject of masonry infill walls, the buildings national codes can be classified into two groups or categories. One group considers the role of masonry infill walls during design stages. This group of codes requires the structural designer to appropriately include the beneficial effects of masonry infill action, such as the added initial stiffness, during analysis and design procedures and to mitigate the detrimental effects due to such inclusion. The philosophy of these codes of design is to maximize the benefits of masonry infill actions and to minimize the detrimental effects through proper selection of their layout and quality control. The other group of codes, isolates the masonry infill actions and hence the role of the stiffness of masonry walls is not considered during design procedures. The isolation of masonry infill actions prevents the detrimental effects associated with brittle behavior and asymmetric placement of masonry infill walls.

A large number of buildings had soft stories at the first-floor level due to the absence of masonry infill walls in this storey, i.e., columns in the ground story do not have any partition walls between them. This happens because the stiffness of such storey is less than 70% of the storey above or less than 80% of the combined stiffness of three storeys above. In a multistoried building, soft storey is adopted to accommodate parking which is an unavoidable feature, especially in the developing countries, and then heavy masonry infill walls start immediately above the soft storey. This open ground storey is vulnerable to collapse during earthquake. Moreover, absence of masonry infill in a first storey result in increased deformation demands significantly, and formation of plastic hinges and finally collapse. The primary objective of this study is to investigate the interaction effect between the masonry infill walls and RC on the dynamic response of framed building structures as bare frame, masonry infill frame and infilled frame models with open first story. First, in the category of bare frame the three-dimensional (3D) finite element model of the building without stiffness and strength contributions of the infill walls are considered. However, infill wall masses on each floor are added to the mass of the corresponding floor. Second, in the category of masonry infill frame, the 3D structure is modeled considering the effects of strength and stiffness of infill masonry walls, as well as their masses. Finally, in the category of infill wall model with absence of infill masonry action only in first storey is also considered. The interaction between masonry infill walls and the analyzed RC structures are modelled with the finite element modeling technique using SAP 2000 software. Two types of dynamic analysis namely; RS analysis and the dynamic TH analysis have been used to perform the current study in both X and Y directions in next chapter.

Modeling of infill wall many of the structural engineering designers consider the infill walls typically as nonstructural elements during analysis and design of reinforced concrete framed structures. However, due to expected interaction between bounding frames and filling walls in between, these infills can significantly change the mechanism describing the resisting behavior of RC structures subjected to seismic loads as well as failure modes. For modelling of such interaction between infill walls and bounding frames, several methods have been proposed. Micro-models, and macro-models are the two main categories grouping these methods. The micro-models category is mainly based on the commonly used analysis tool for complex engineering problems namely; the finite element method which enables the Micro-models to simulate the structural behavior with great detail. In order to represent the infilled frames behavior under dynamic lateral load, three different kinds of elements in which a beam element is used to represent the frame, a plane element represents the infill and an interface element or one-dimensional joint element to simulate the interface behavior. One of the main disadvantages of the previously described micro-models category is the needed extensive computations. In addition, this category of methods is difficult to be applied numerically for structures with large scales. On the contrary, the second category namely macro-models are based on the equivalent diagonal strut method. This modelling strategy are simplicity in performing computations and capability of employing and utilizing the masonry mechanical properties obtained from experimental tests. In addition, this strategy helps in describing the most common modes of failure of the modelled panels with infills Thus, the MI walls, which are enclosed by two columns and two beams, are usually modeled as equivalent diagonal compression strut as shown in Fig 3.9.

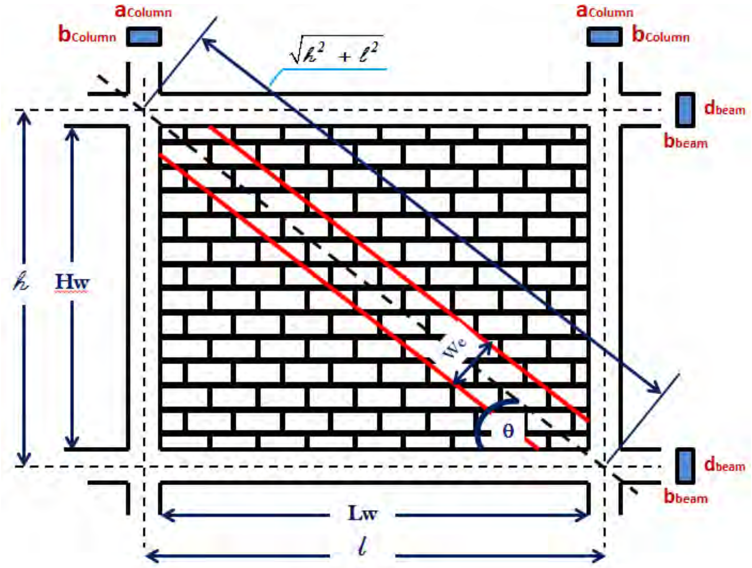


Figure 3.9 Equivalent strut model for masonry infill walls in frame building structures

Typical multi-storey reinforced concrete framed building is considered in the analysis. Three different configurations of the considered framed building have been developed. A framed building model with infill walls distributed uniformly throughout the whole storeys is one of the considered configurations. Since most of the design codes commonly ignore the contribution of infill walls to the global strength and stiffness of the building, a framed building model with infill walls modelled as nonstructural elements, commonly called bare frame, is another configuration to be considered in this study. A building model with masonry walls filling the framed panels except for the first storey is the third configuration considered.

3.6. Bare frame model

The capability of the bare frame building model to predict the dynamic response behavior under lateral seismic loads is investigated. In bare frame building model (see Fig. 3.10), infill walls are modelled as nonstructural elements although the masses of infill walls are included in the model. In such a case, the mechanism to resist the dynamic lateral loads known as frame action mechanism in which bending moments and shear forces are developed in beams and columns by means of rigid joint action.

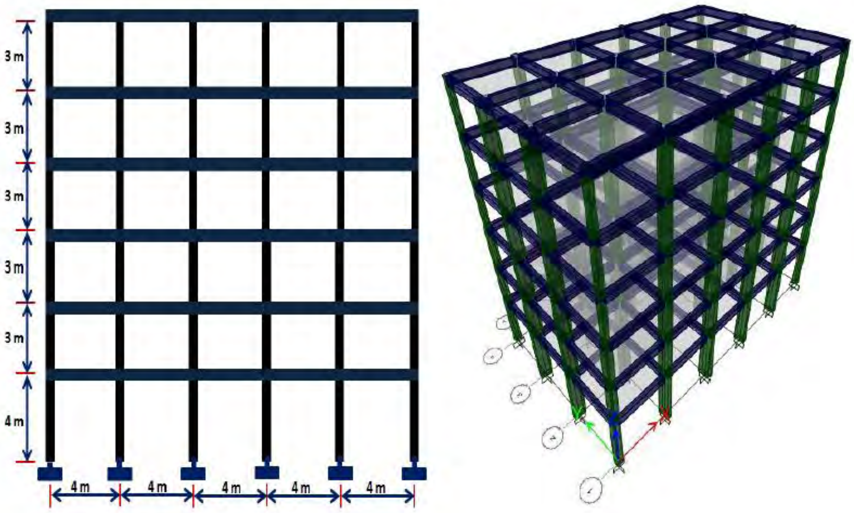


Figure 3.10 Schematic representation of typical front view and 3D view of the bare frame building model for the 6-storey residential building

3.7 Fully infilled building model

The Fully infilled framed building presented in Fig.3.11 refers to the presence of infill walls distributed throughout the whole storeys. The truss action mechanism in which the frame panel with masonry infill behaves in such a way like a diagonal strut. In this mechanism, the induced bending moments in beams and columns are reduced while the induced axial forces are increased.

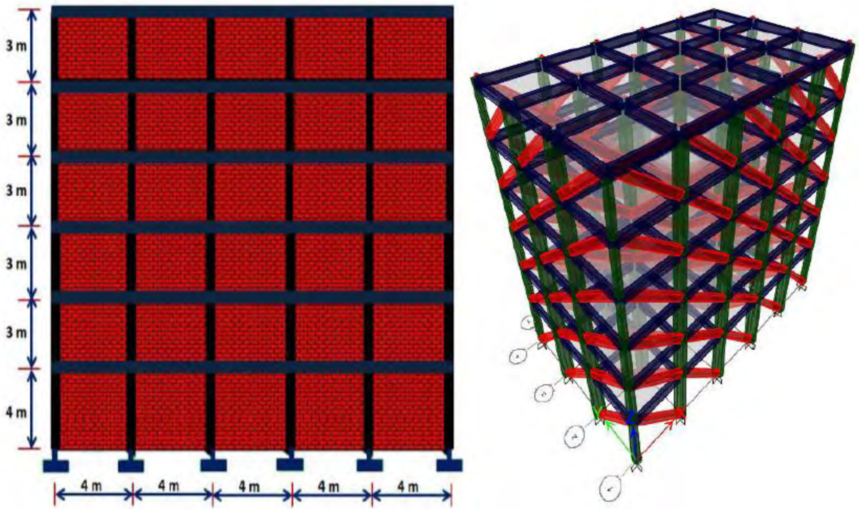


Figure 3.11 Schematic representation of typical front view and 3-D view of the bare frame building model for the 6-storey residential building

3.8. Open first storey building model

In the open first storey building shown in Figure 3.12, similarly to the fully infilled framed building model, full brick infill masonry walls are distributed throughout the whole storeys except for the first storey.

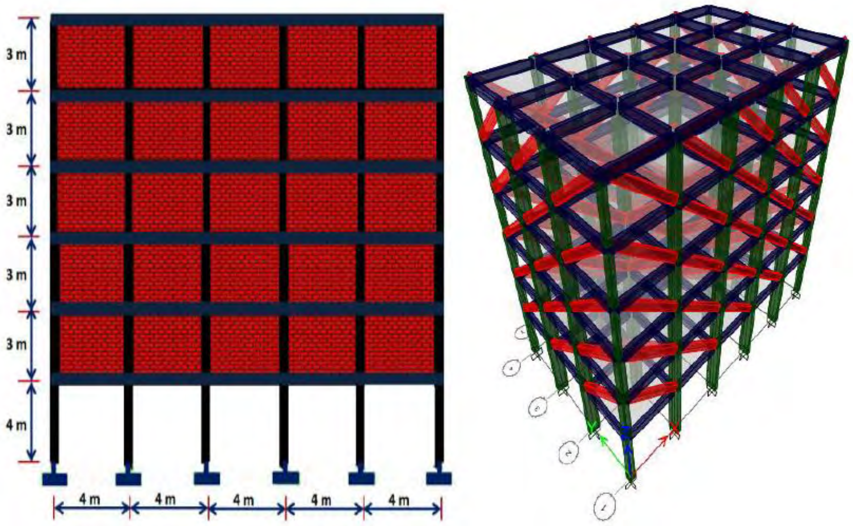


Figure 3.12 Schematic representation of typical front view and 3-D view of the masonry infill frame building model with open first storey for the 6-storey residential building.

3.9 Building Modeling

Two types of 6-storey RCC building (Isolated and Non-isolated building, Fig 3.13) with same dimension has been modelled using computer aided analysis program SAP 2000. The building dimension is 14.64mX14.64m with four equal column grid in both directions. Building height is consider 18m from finish ground level with 3m floor height. Location of the foundation considered at 1.5m depth and for Isolated building Lead rubber bearing (LRB) placed in column at 0.75m below grade beam. Three different properties of LRB (LRB1 for corner column, LRB2 for exterior column and LRB3 for interior column) used for different column (Table 4.2). Masonry infill properties (Table 4.1) used as a brick wall for these buildings modeling.

Figure 3.13: Isolated and non-isolated building with soft storey.

Chapter 4

ANALYSIS OF ISOLATED AND NON- ISOLATED BUILDINGS WITH SOFT STORY

4.1 General

In this chapter three dimensional non-linear dynamic analysis is performed for isolated and non-isolated building considering the design parameters for Dhaka region. Non linearity is considered only for isolated system. For time history data of Dhaka earthquake is taken considering 0.2g peak ground acceleration. For response spectrum analysis, specification given in BNBC is used. 3D models are generated in computer aided analysis program SAP 2000 for analysis as well as design purpose. This chapter describes the difference in seismic behavior of isolated and non-isolated building. It also specifies the permeable benefits that may arise from isolated buildings.

4.2 Earthquake Loads

A specially developed isolation system for this analysis consisted of 25 high-damping natural rubber bearings, which were connected to the columns and foundation using recessed-type connections at the ground level. The seismic isolation provisions from the 1997 Uniform Building Code were adapted to complement the Seismic Code requirements for this project, and site-specific spectra were developed and used for the design of the isolation system.

According to BNBC, since the building is located in Dhaka, which is in Zone 2, the zone coefficient (Z) for the building as for zone-2 is **0.20g**. The importance coefficient (I) for the residential building is found as **1.0**. For S_3 soil profile site coefficient is **1.5**. 'Seismic Source Type' can be considered as '**A**'. Also the distance of epicenter of major earthquakes affecting Bangladesh from Dhaka is found **greater than 15 Km**. For closest distance to seismic source> 15 Km and seismic source type 'A' both the values of Na and N_V are found as 1.0. Maximum capable earthquake (MCE) coefficient MM is found as **2.0**. Spectral Seismic Coefficient C_A & C_V found as **0.24** and **0.32** respectively. The value of damping coefficient (B_D) is found as. **1.35** (by linear interpolation). Wind load is not consider here for its less effect. A non-linear time History analysis is performed by choosing appropriate time history i.e. ground motion that almost resembles the site condition of Dhaka. For the present analysis, the most recently occurred Natore Earthquake (Islam et al., 2010) which is nearest of Dhaka region has been properly scaled to produce the desired earthquake load for buildings in Dhaka. Time history and corresponding response spectrum for 5% damping is shown in Figure 4.1 and 4.2 respectively for this record. This is the Design Basis Earthquake (DBE) which is used to evaluate the structural response. The Maximum Capable Earthquake (MCE) which is a function of DBE is used to obtain maximum isolator displacements.

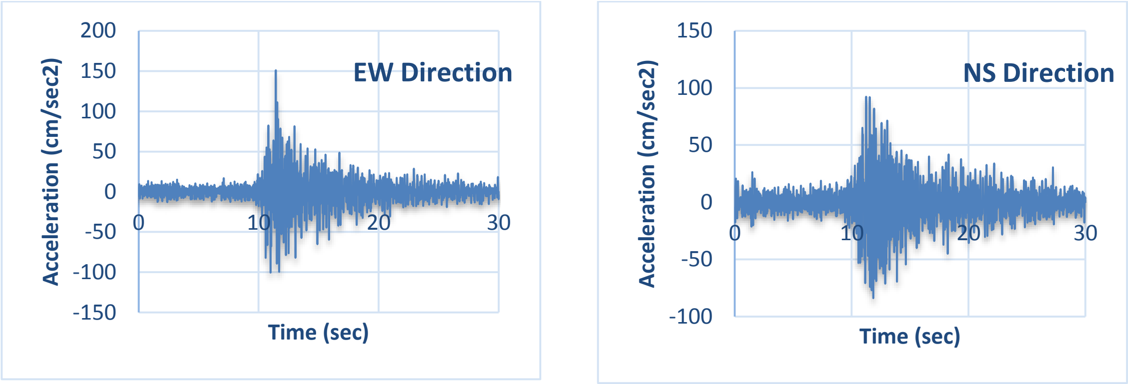


Figure 4.1. Selected Time History for Dhaka EQ

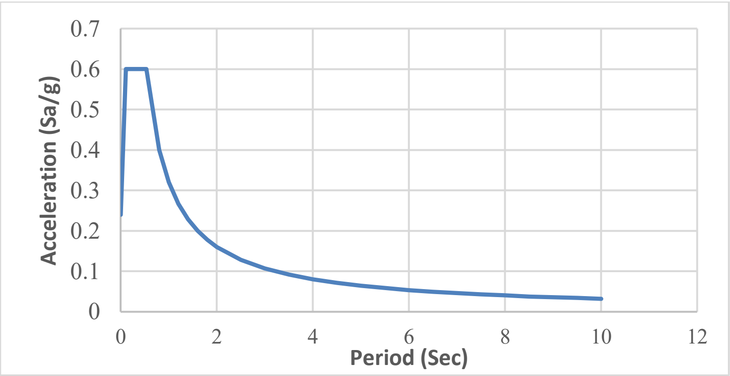


Figure 4.2. Response Spectrum for Dhaka EQ **(0.2g)**

4.3 Masonry infill properties

Different ways for modeling infill in a building are provided in section 3.5. In this work micro models have been used. Under this method masonry walls are modeled as three dimensional brick matrix element. The properties of brick matrix (Jain, 2006; Jain et al., 2006) are provided in table 4.1.

Table 4.1. Masonry infill properties

Parameters	**Values with unit**	**Comments**
Compressive Strength	f'_m = 7.5 MPa	Mix properties 1:4
Modulus of Elasticity	E_m = 5,625 N/mm^2	750*f'_m
Shear Modulus	G = 2,250 N/mm^2	0.4*E_m
Unit weight	γ = 18.85 KN/m3	

4.4 Isolator properties

At first isolator properties are evaluated for different columns i.e. Corner, Exterior and Interior. In this work lead rubber bearing (LRB) type isolator is being used. The designs (Kelly, 2001; Kelly et al., 2006) of isolator for different columns were performed using the excel spreadsheet which implements the design procedures as per UBC, 1997. The design basis includes S3 type soil profile for Dhaka having seismic zone coefficient, **Z = 0.20** and beyond 15 Km of a Type A fault (BNBC, 2015).

Each isolation system was defined with effective periods of 2.0 seconds, which covers the usual range of isolation system period. Table 4.2 lists the variations considered in the evaluation and the hysteresis parameters used for modeling for different columns.

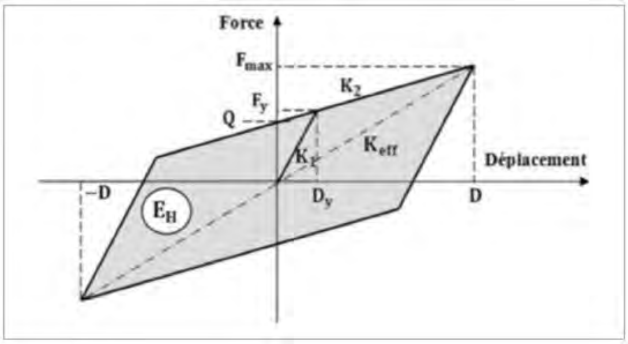


Figure 4.3. Isolator properties

Table 4.2. Isolator Properties variations

System Title	Characteristic Strength (Q_d)	Period of Isolator (sec)	Initial Stiffness, K_1 (KN/mm)	Post-yield Stiffness, K_2 (KN/mm)	Yield Force F_y (KN)
LRB1 (Corner Column)	0.050	2	12.20158	1.11331	328
LRB2 (Exterior Column)	0.075	2	12.20158	1.11331	492
LRB3 (Interior Column)	0.100	2	12.20158	1.11331	656.1

4.5 Evaluation procedure

The procedures for evaluating isolated structures are, in increasing order of complexity, (1) static analysis, (2) response spectrum analysis and (3) time-history analysis. Only response spectrum and time history analysis is considered here.

Load Combination:

A. 1.4(DL + LL + Time History) B. 1.4(DL + LL + Response Spectrum)

4.6 Description of buildings

Four kinds of a reinforced concrete six storey buildings with equal grid spacing (4@3.66m span) and storey height were modeled in three dimensional finite element software called SAP2000. The plan and elevation of the building is given in Figure 4.4 and building elements description in table 4.3. Four cases are considered in this work, i.e. (i) Fixed base with soft story building; (ii) Fixed base without soft story building; (iii) Using isolator in the soft story building and (iv) Using isolator without soft story building. Lead Rubber Bearing (LRB) isolator for each of the column were designed using appropriate method and their properties are reported in Table 4.2.

Table 4.3: Building elements and load information

Building Elements	**Dimensions/Values**
Span	4@3.66 m
Interior Column	380mm X 508mm
Exterior Column	300mm X 508mm
Corner Column	300mm X 457mm
Beam	250mm X 300mm
Floor height	3m
Slab thickness	125mm
Live Load	2.39 KN/m^2
Dead Load (Excluding Self weight)	7.18 KN/m^2
Compressive Strength of Concrete f'_c	27,579 KN/m^2
Yield Strength f_y	413,685 KN/m^2
Isolator type	LRB
Isolator location on Column	0.76m below GB

Four kinds of buildings figures area as below:

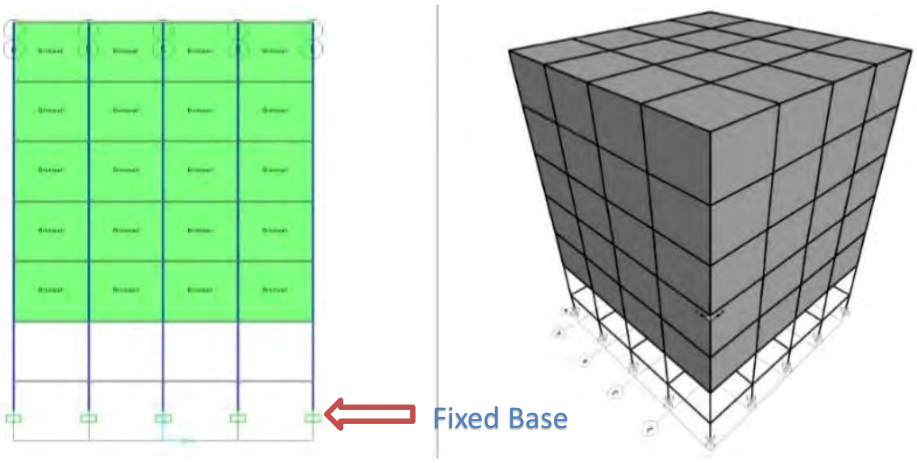


Figure 4.4 (a) Fixed base with soft story building

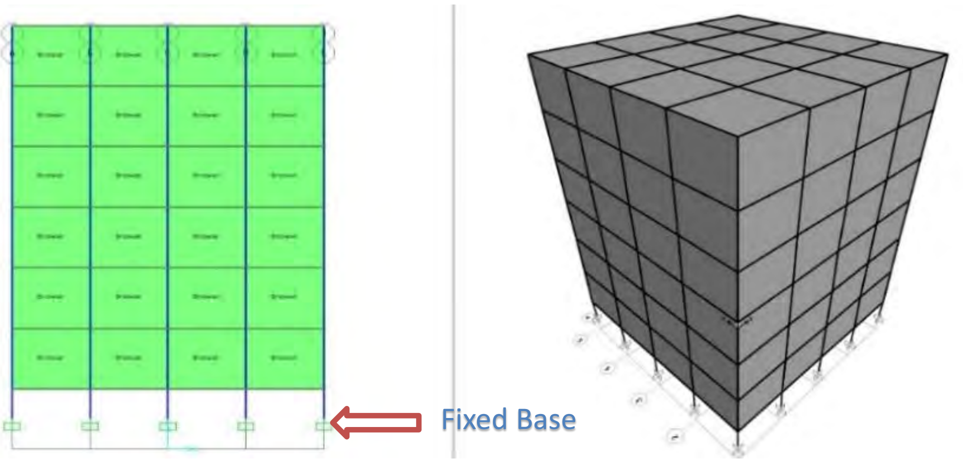


Figure 4.4 (b) Fixed base without soft story building

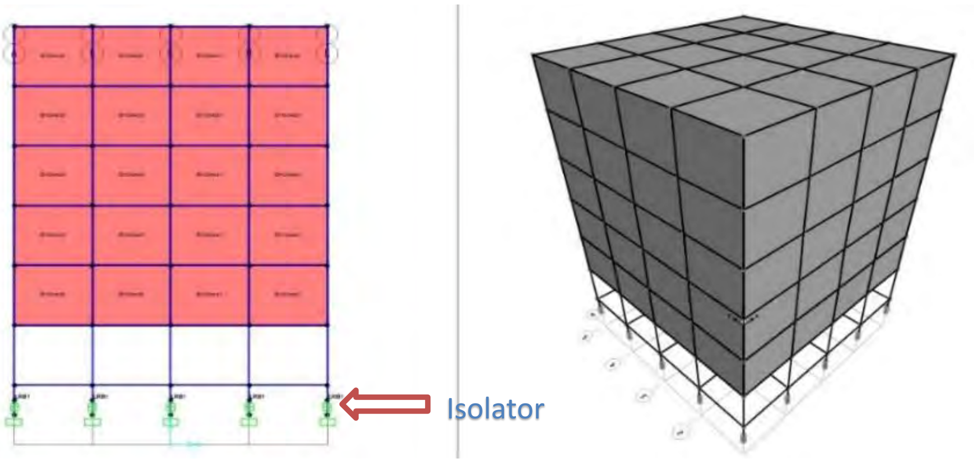


Figure 4.4 (c) Using isolator in the soft story building

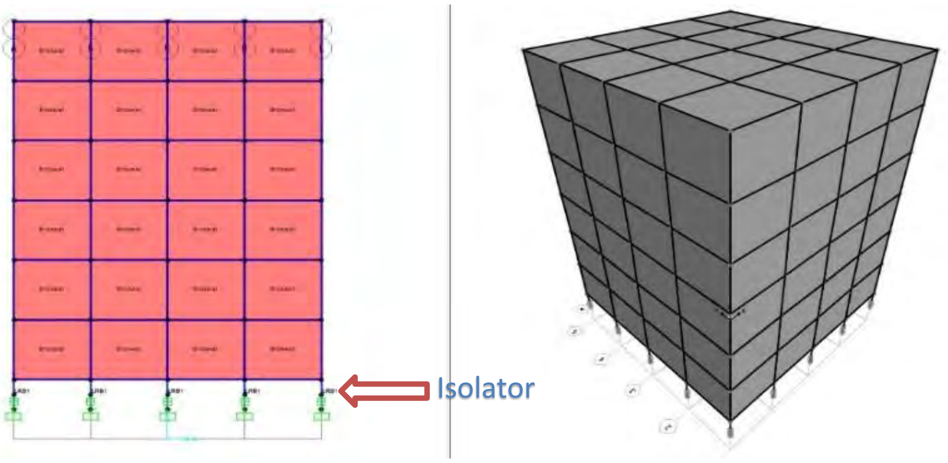


Figure 4.4 (d) Using isolator without soft story building

4.7 Column Moment

4.7.1 Column Moments for Four Kinds of Building

In time period response spectra analysis, it is found that there is a moment value different in between soft storey and without soft storey building (Figures 4.5 to 4.36). So there is a soft storey effect found in time history and response spectrum analysis and moment is higher in soft storey building than without soft storey building.

If we compare with isolated building and non-isolated fixed base building, higher moment value found from non-isolated building where in non-isolated soft storey building moment 39% higher than isolated soft storey building and non-isolated without soft storey building moment is more than 41% higher than isolated without soft storey building. Moment value in time history analysis found 1.35 times less than moment from response spectrum analysis.

Column Moments for four kinds of buildings for assign Time History and Response Spectrum:

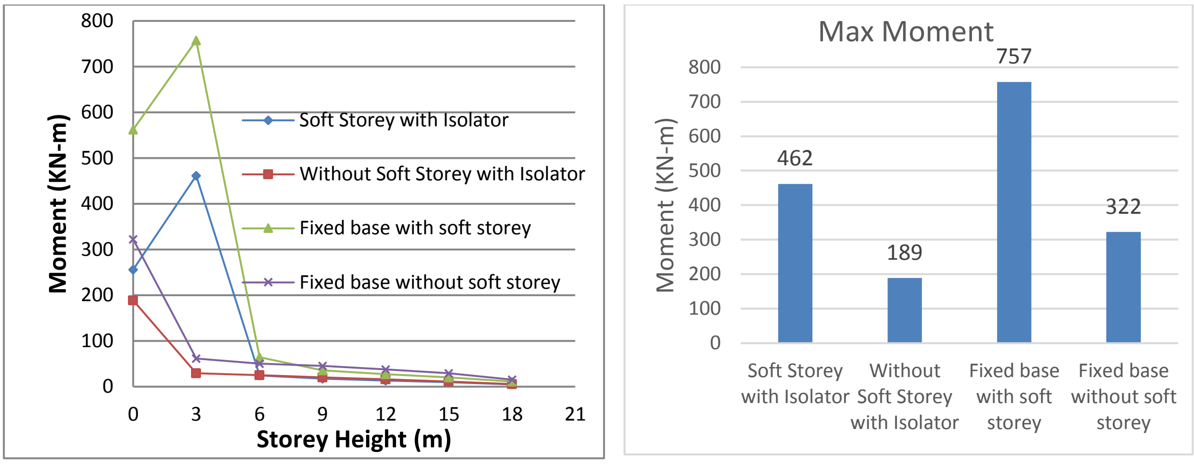


Figure 4.5: Interior Column Moments for four kinds of buildings for assign Time History

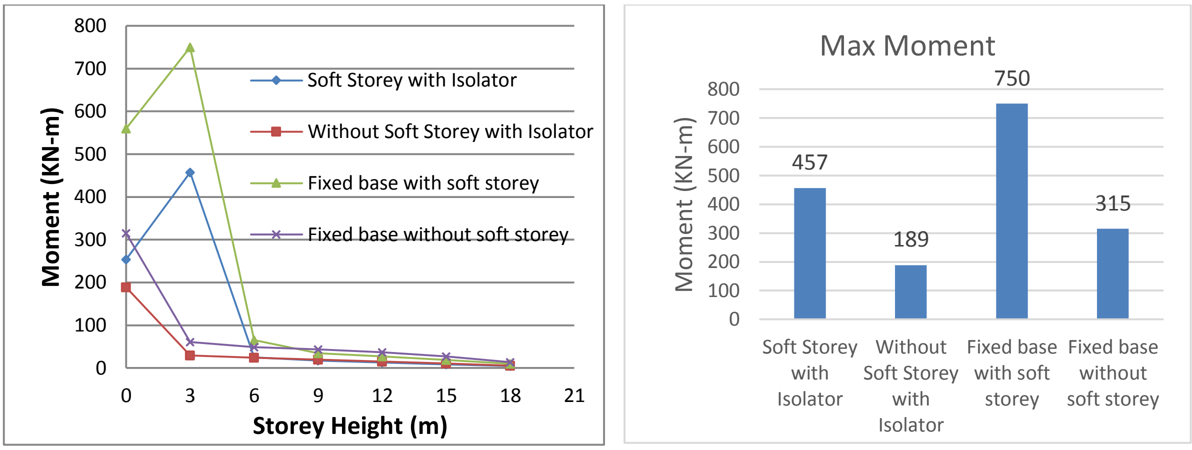


Figure 4.6: Exterior middle Column Moments for four kinds of buildings for assign Time History

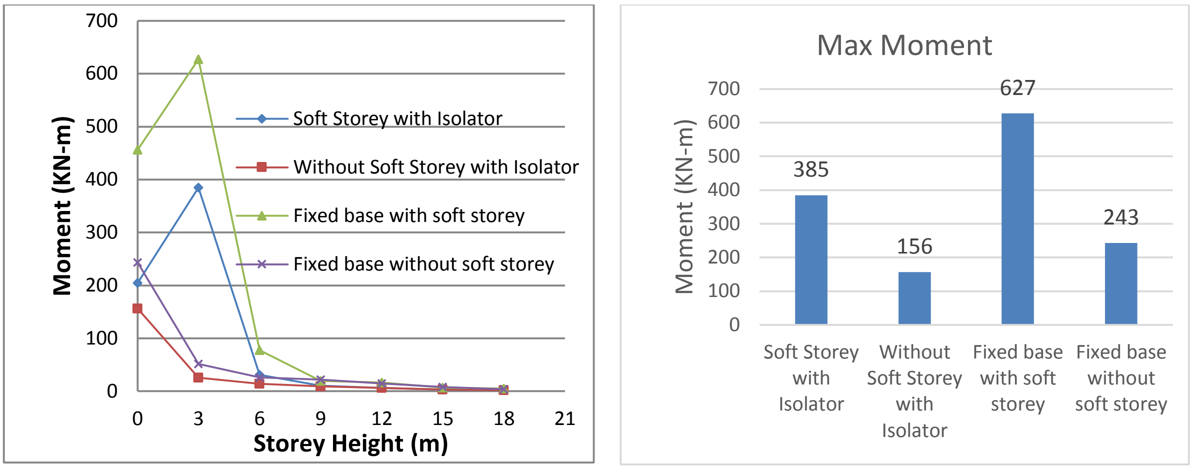


Figure 4.7: Corner Column Moments for four kinds of buildings for assign Time History

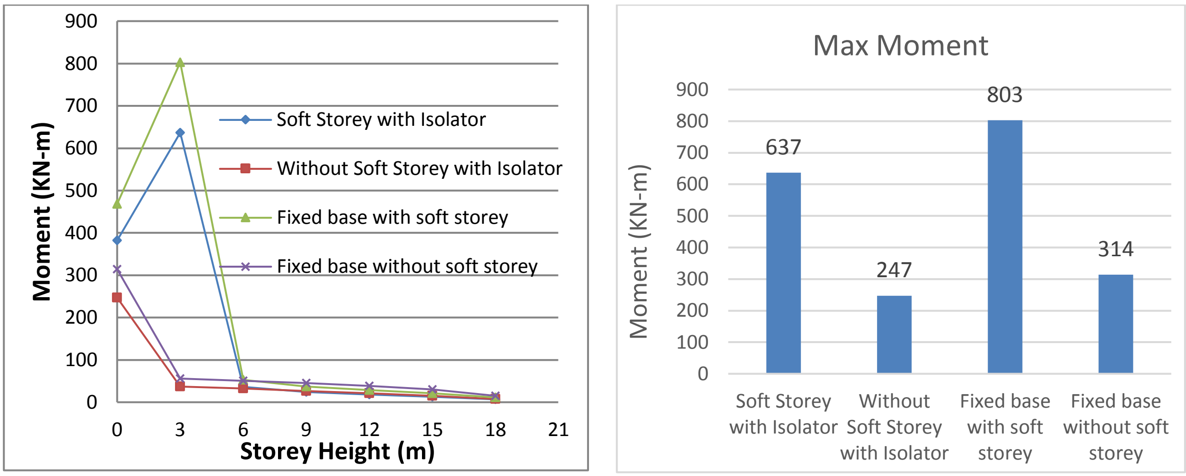


Figure 4.8: Interior Column Moments for four kinds of buildings for assign Response Spectrum

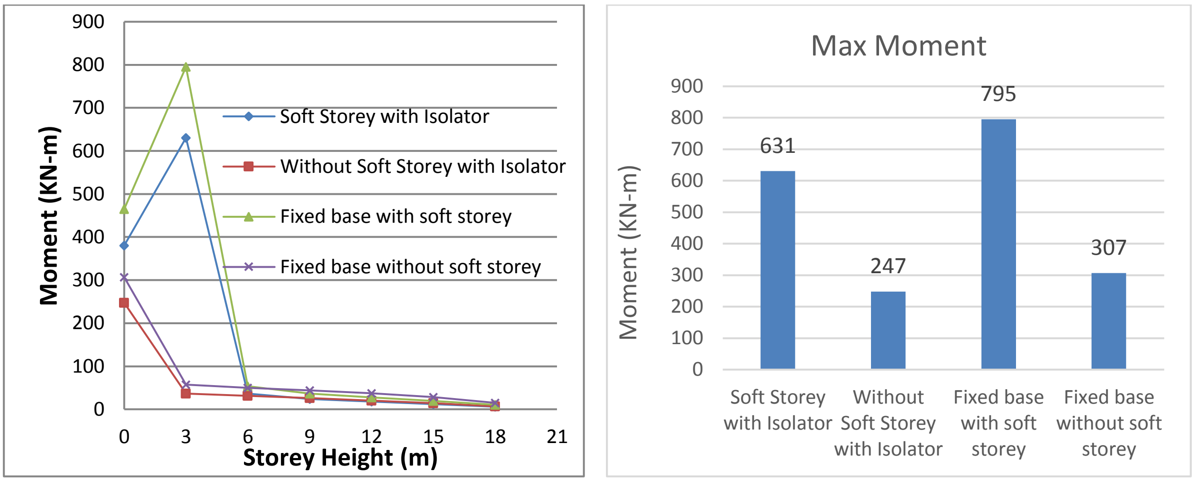


Figure 4.9: Exterior middle Column Moments for four kinds of buildings for assign RS

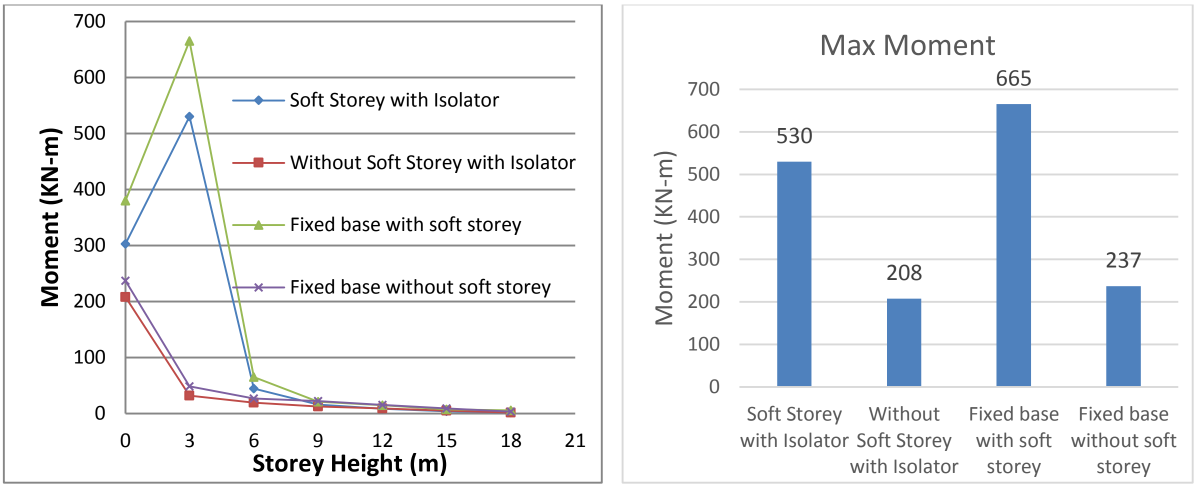


Figure 4.10: Corner Column Moments for four kinds of buildings for assign Response Spectrum

4.7.2 Maximum Column Moment Variation for Four Kinds of Buildings

In time history and response spectrum analysis, maximum column moment found in fixed base with soft storey building both for corner, exterior middle and for interior column.

In time history analysis, fixed base with soft storey building column moment is 39% higher than soft storey isolated building.

In response spectrum analysis, fixed base with soft storey building column moment is 21% higher than soft storey isolated building.

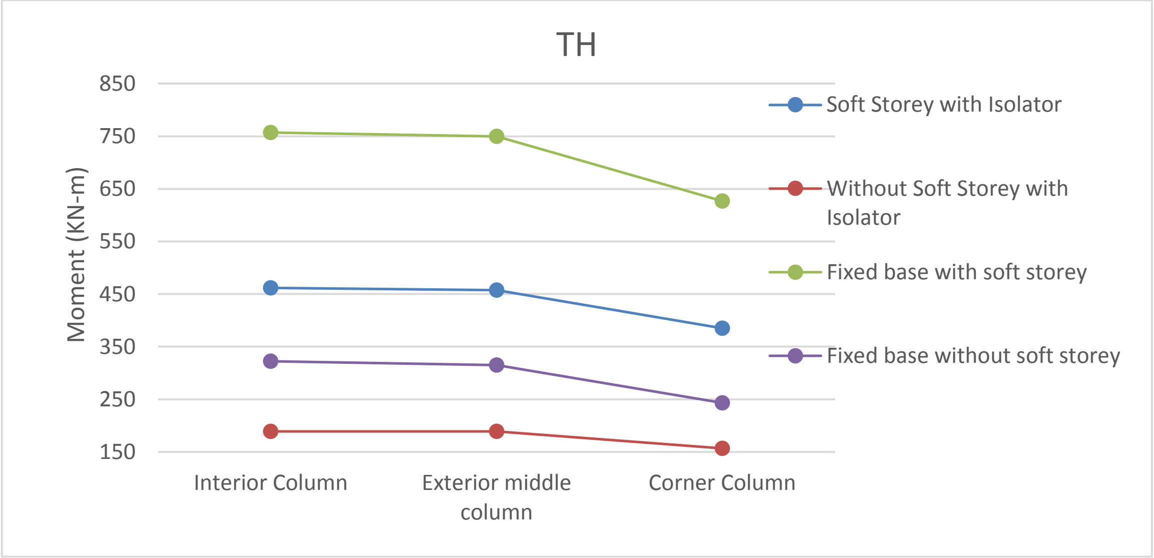


Figure 4.11: Maximum Column Moments for four kinds of buildings for assign TH

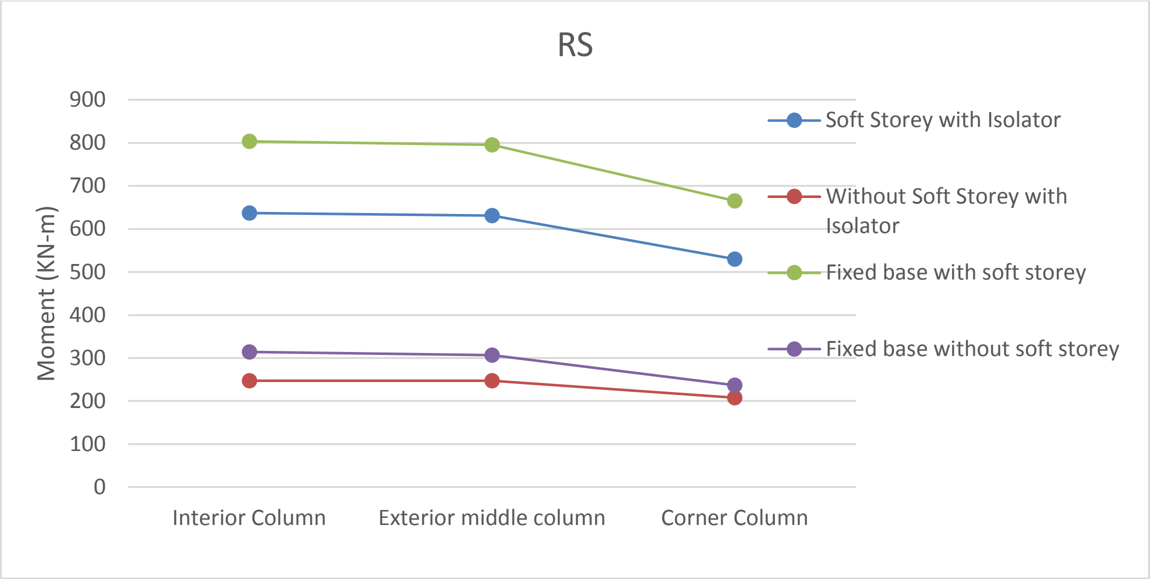
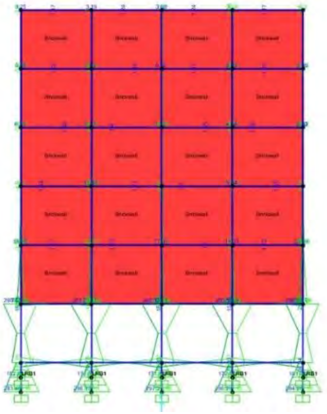
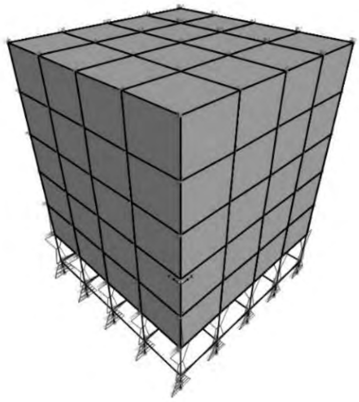


Figure 4.12: Maximum Column Moments for four kinds of buildings for assign RS

4.7.3 Column Moment for Soft Storey Building





If we saw the column Moment for **Soft Storey** building both for isolated and for fixed base building for assign time history and response spectrum, it is found that fixed base soft storey building column moment is higher than soft storey isolated building both for corner, exterior middle and for interior column.

In time History analysis, column moment in fixed base building at soft storey location is found 39% higher than column moment in soft storey isolated building (Figure 4.13 to 4.15). Column moment is reduced its value after soft storey location and comes to a nominal value in top storey where also column moment is almost 39% higher value in fixed base soft storey building than column moment in isolated soft storey building.

In response spectrum analysis, column moment in fixed base building at soft storey location is found 21% higher than column moment in soft storey isolated soft storey building (Figure 4.16 to 4.18). Column moment is reduced its value after soft storey location and comes to a nominal value in top storey where also column moment is almost 21% higher value in fixed base soft storey building than column moment in isolated soft storey building.

So, in this analysis we found the moment variation for isolator effect and also for soft storey for the building. Isolator reduce the building column moment and infill properties also reduce moment at the same time. If we use isolator with infill building, moment reduce level is higher than other three kinds of building (Described on next article- 4.7.4, Column Moment for Without Soft Storey building).

Column Moments for Soft Storey Buildings for Assign Time History and Response Spectrum:

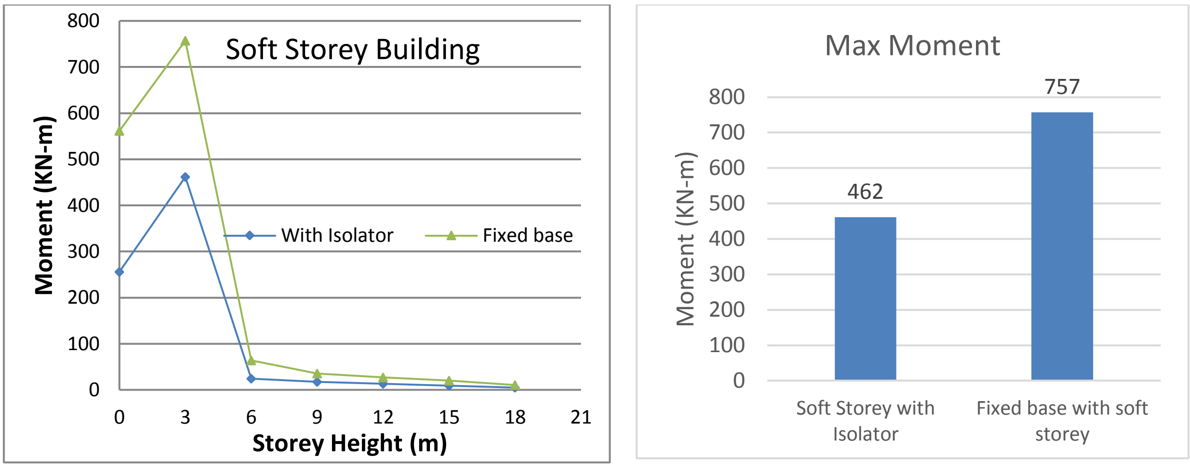


Figure 4.13: Interior Column Moments for Soft Storey Building for assign Time History

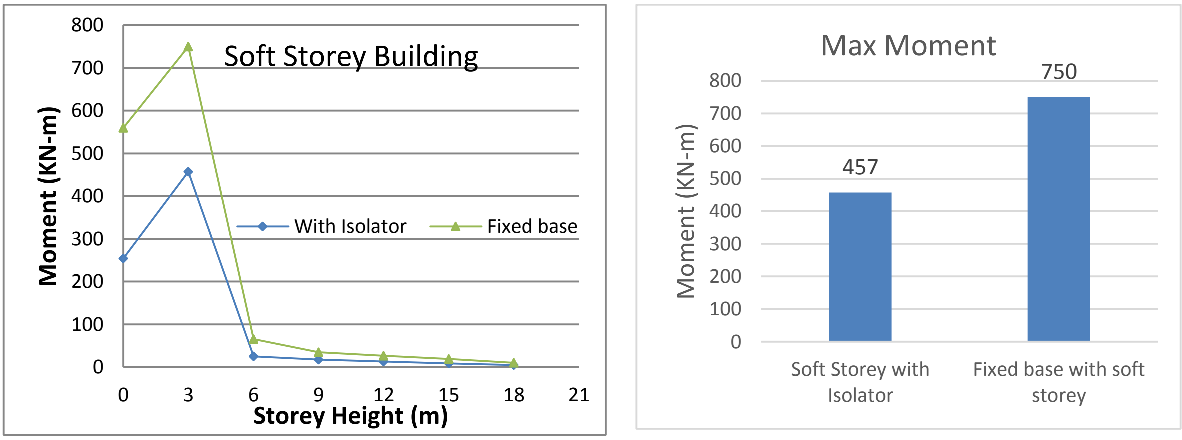


Figure 4.14: Exterior middle Column Moments for Soft Storey Building for assign Time History

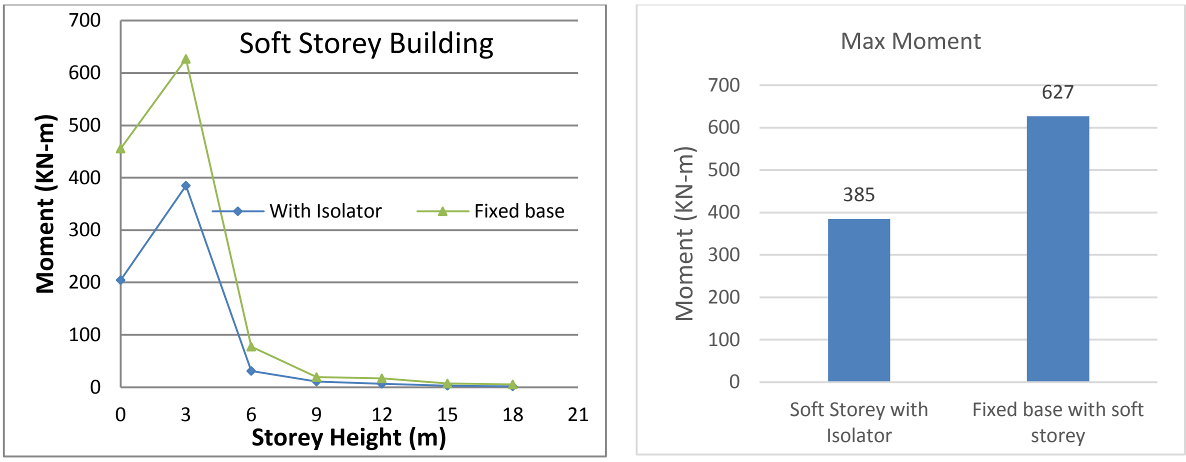


Figure 4.15: Corner Column Moments for Soft Storey Building for assign Time History

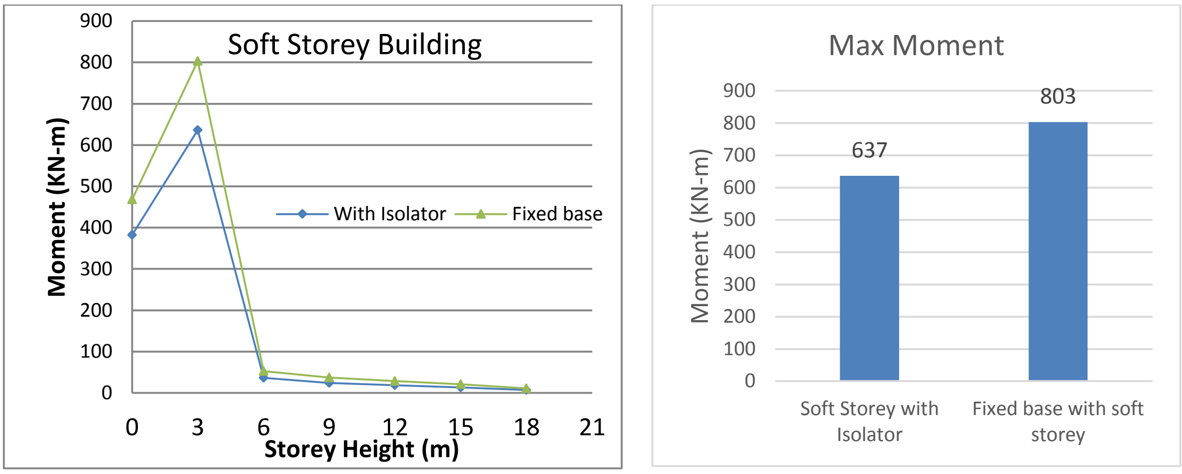


Figure 4.16: Interior Column Moments for Soft Storey Building for assign Response Spectrum

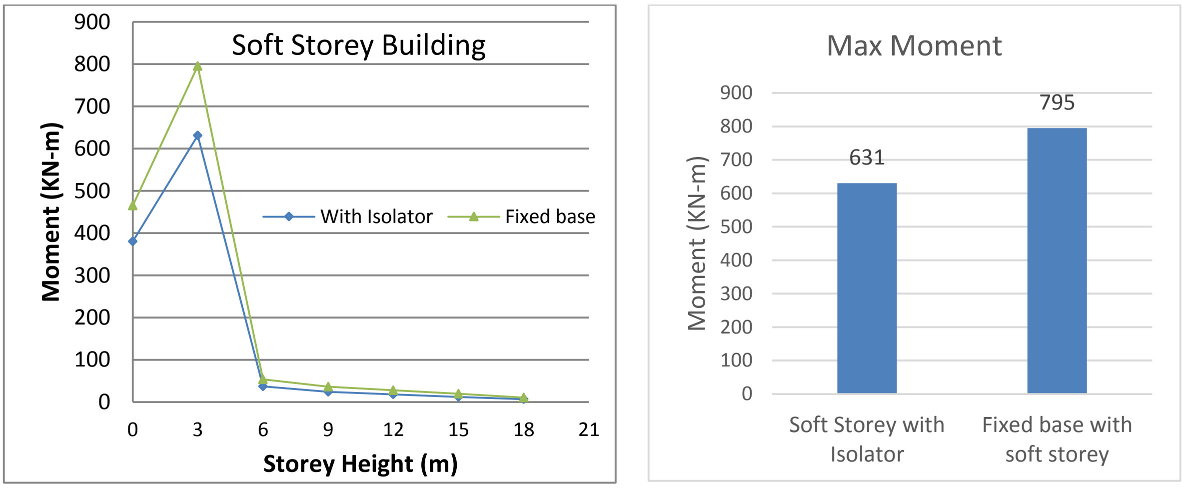


Figure 4.17: Exterior middle Column Moments for Soft Storey Building for assign Response Spectrum

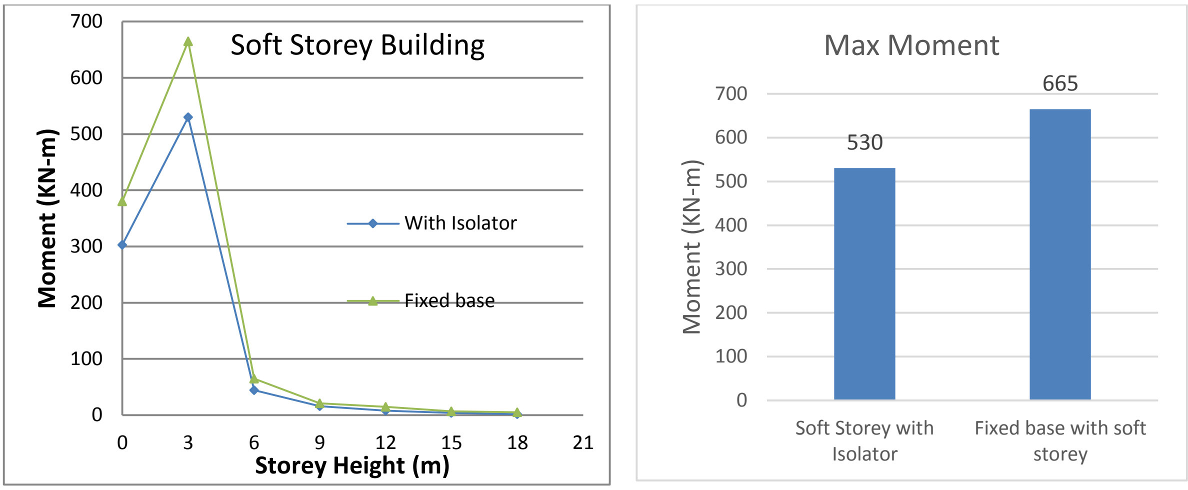
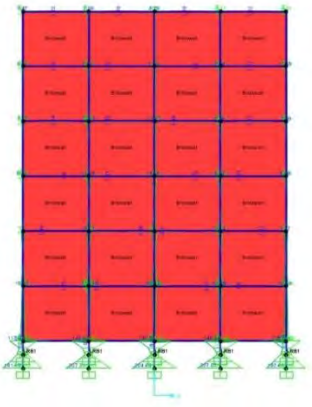
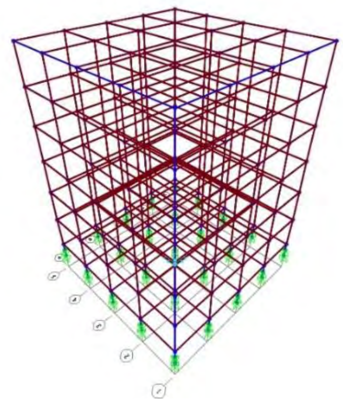


Figure 4.18: Corner Column Moments for Soft Storey Building for assign Response Spectrum

4.7.4 Column Moment for Without Soft Storey Building





If we axiom the column Moment for **without Soft Storey** infill building both for isolated and for fixed base building for assign time history and response spectrum, it is found that fixed base without soft storey building column moment is higher than without soft storey isolated building both for corner, exterior middle and for interior column.

In time History analysis, maximum column moment in fixed base infill building found in bottom storey location and it is found that fixed base infill building column moment is 41% higher than column moment in without soft storey isolated infill building at bottom storey (Figure 4.19 to 4.21). Column moment is reduced its value from bottom storey location and comes to a nominal value in top storey where also column moment is almost 41% higher value in fixed base infill building than column moment in isolated infill building. It’s reduced its 80% of the moment from bottom storey to first storey.

In response spectrum analysis, maximum column moment found in fixed base without soft storey infill building at bottom storey location and it is found that fixed base infill building column moment is 21% higher than column moment in infill isolated building (Figure 4.22 to 4.24). Column moment is reduced its value and comes to a nominal value in top storey where also column moment is almost 21% higher value in fixed base soft storey building than column moment in isolated soft storey building. It’s reduced its 82% of the moment from bottom storey to first storey.

Here also we found the Isolator and infill effect to reduce column moment both for time history & response spectrum analysis.

Column Moments for Without Soft Storey Buildings for assign Time History and Response Spectrum:

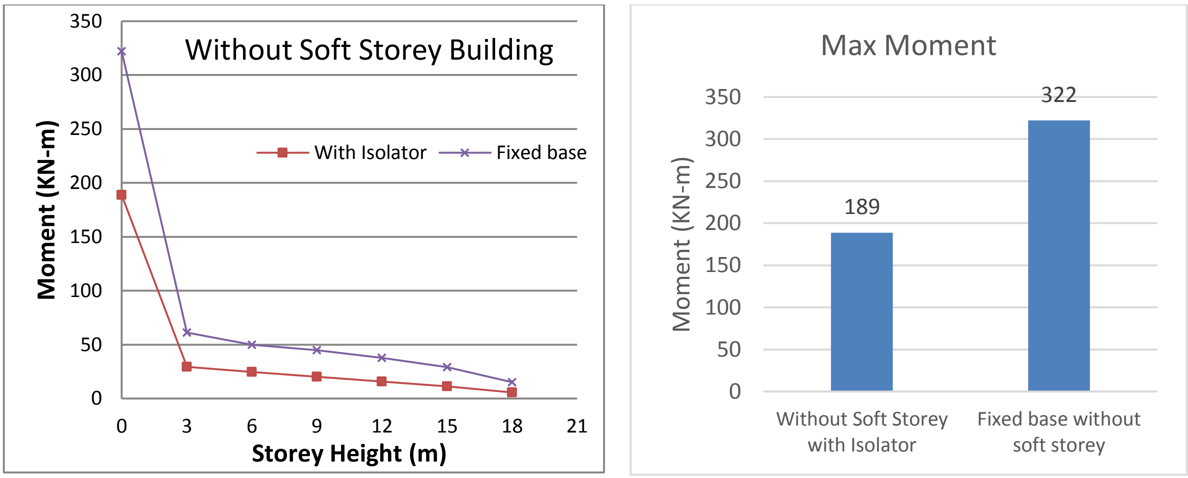


Figure 4.19: Interior Column Moment for without Soft Storey Building for assign Time History

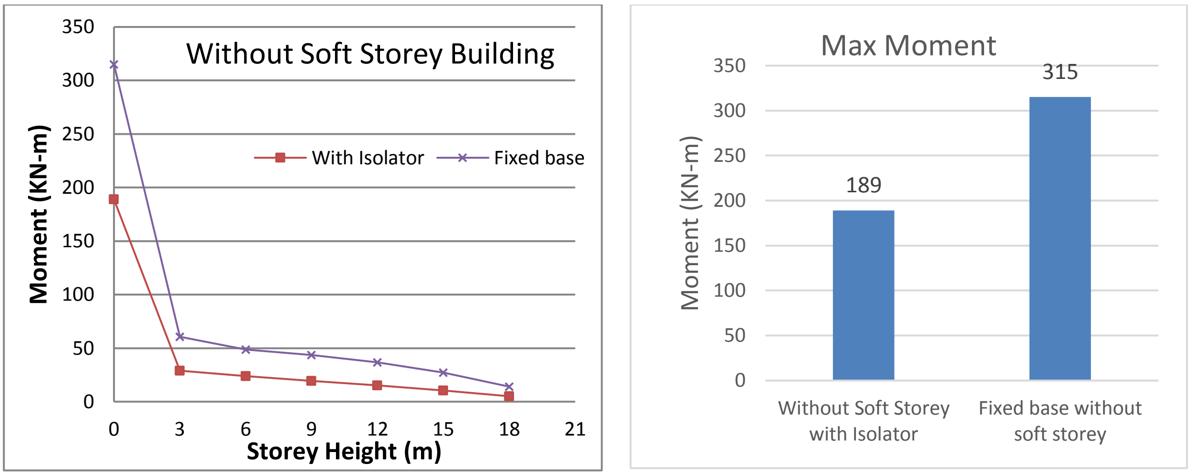


Figure 4.20: Exterior middle Column Moment for without Soft Storey Building for assign Time History

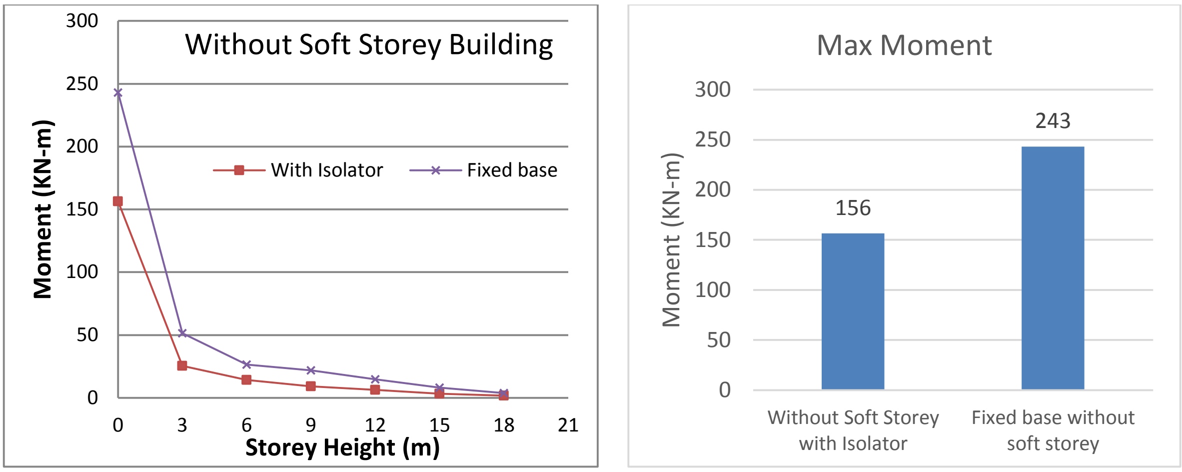


Figure 4.21: Corner Column Moment for without Soft Storey Building for assign Time History

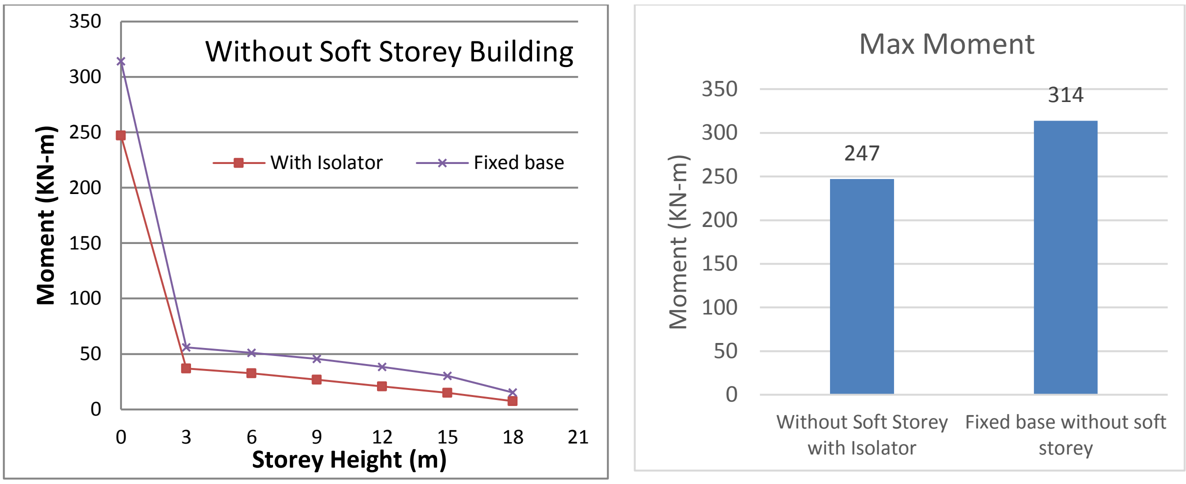


Figure 4.22: Interior Column Moment for without Soft Storey Building for assign Response Spectrum

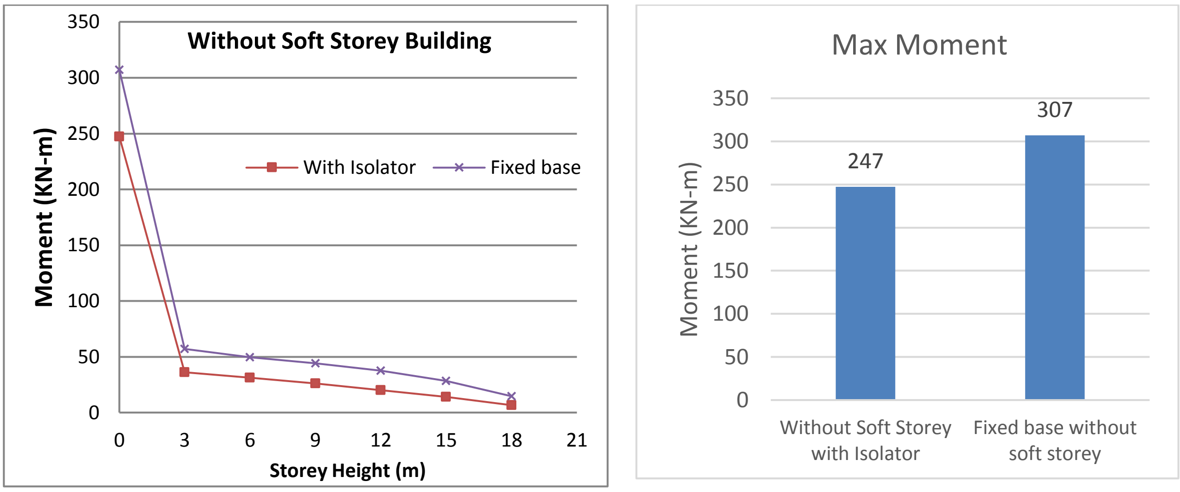


Figure 4.23: Exterior middle Column Moment for without Soft Storey Building for assign Response Spectrum

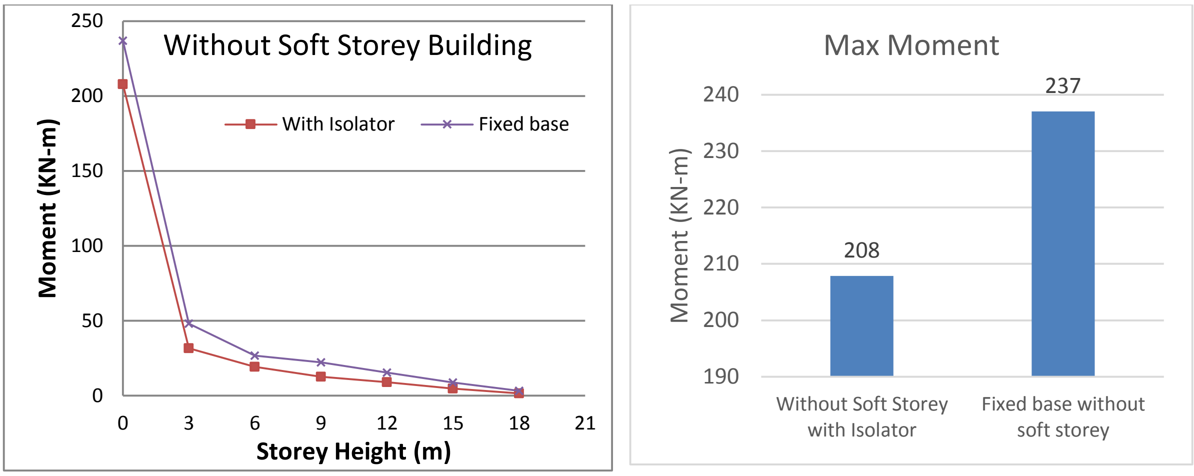


Figure 4.24: Corner Column Moment for without Soft Storey Building for assign Response Spectrum

4.7.5 Column Moment- Time History Vs Response Spectrum

In time history and response spectrum analysis, column moment variation found in four different kinds of buildings and it is found that column moment value is higher in response spectrum analysis for soft storey building and column moment is less in response spectrum analysis in infill building for corner, exterior middle and interior column (Figure 4.25 to 4.36).

It is found that, in without soft storey isolated building, column moment is maximum at storey height 0 m (bottom storey). Maximum column moment found higher in response spectrum analysis compared to time history analysis (Figure 4.25 to 4.27). Where maximum column moment value in response spectrum analysis is 24% higher compared to time history analysis.

In soft storey isolated building, column moment is maximum at soft storey location (at 3m height). Column moment found higher in response spectrum analysis compared to time history (Figure 4.28 to 4.30). Where maximum column moment value in response spectrum analysis is 28% higher compared to time history analysis.

In without soft storey fixed base building, column moment is maximum bottom level location (at 0m height). Column moment found slidely higher in time history analysis compared to response spectrum (Figure 4.31 to 4.33). Where maximum column moment value in time history analysis is 2.5% higher compared to response spectrum analysis.

In soft storey fixed base building, column moment is maximum at bottom storey (at 0m height) and in soft storey location (at 3m height) moment is higher compared to other storey. Column moment found higher in response spectrum analysis compared to time history (Figure 4.34 to 4.36). Where maximum column moment value in time history analysis is 5.5% less compared to response spectrum analysis.

So in four types of building we found the soft storey effect and isolator effect for column moment variation for both time history and response spectrum analysis and moment variation of these two analysis load combination (Load combination 3 and 4).

Column Moments for Time History Vs Response Spectrum without Soft Storey Isolated Building:

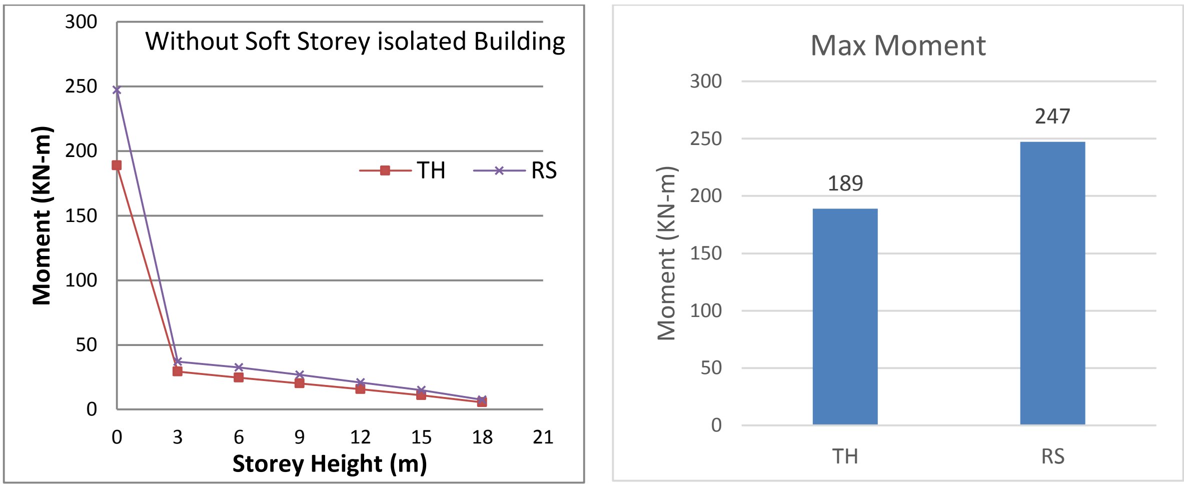


Figure 4.25: Interior Column Moment (TH vs RS) for without Soft Storey Isolated Building

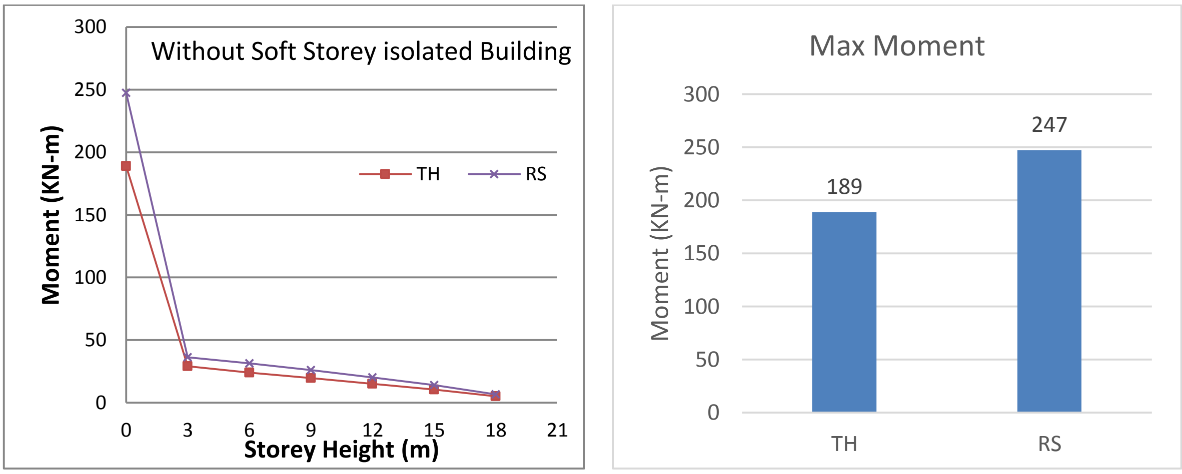


Figure 4.26: Exterior middle Column Moment (TH vs RS) for without Soft Storey Isolated Building

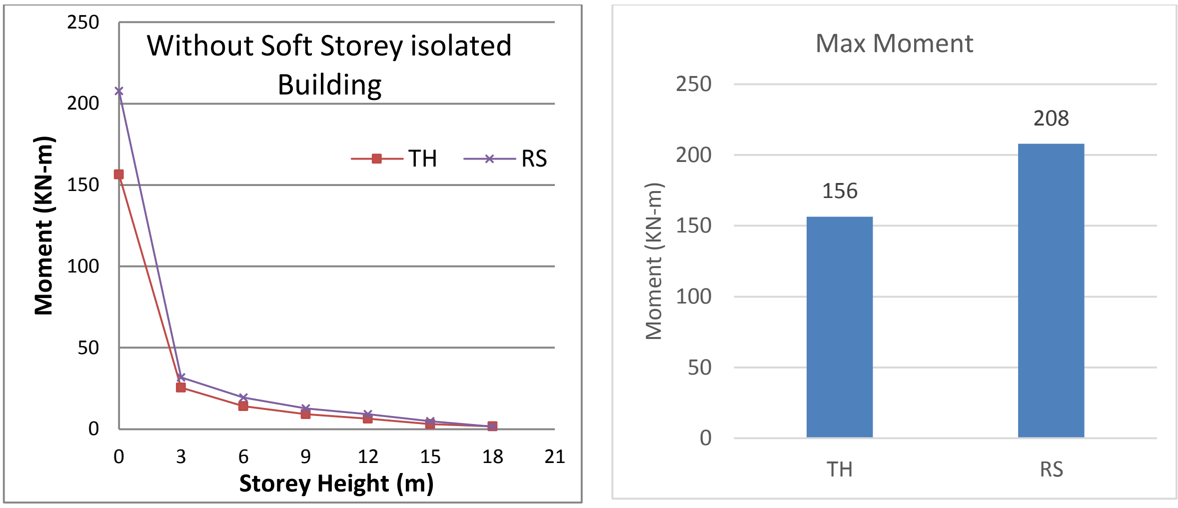


Figure 4.27: Corner Column Moment (TH vs RS) for without Soft Storey Isolated Building

Column Moment for Time History Vs Response Spectrum with Soft Storey Isolated Building

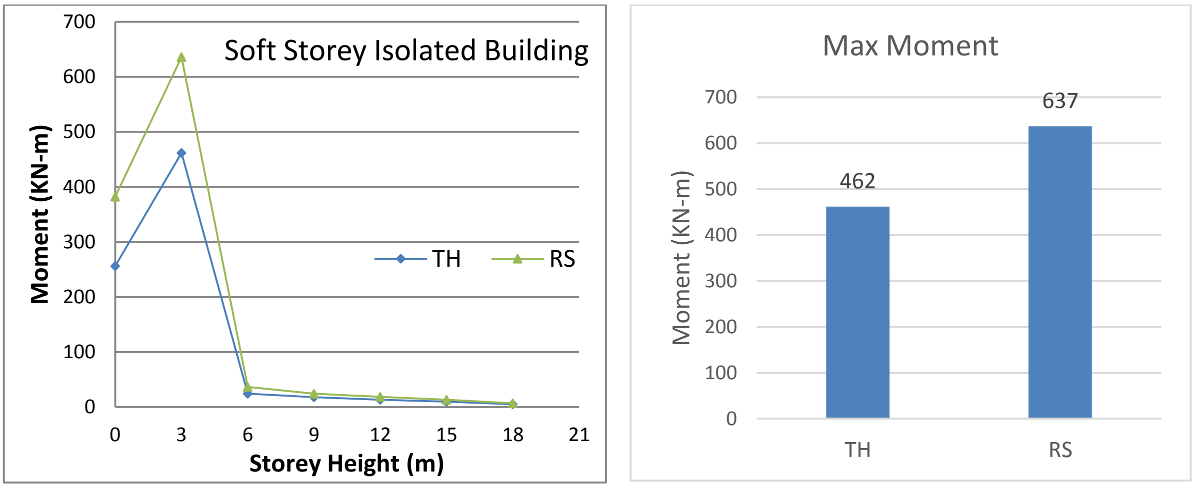


Figure 4.28: Interior Column Moment (TH vs RS) for Soft Storey Isolated Building

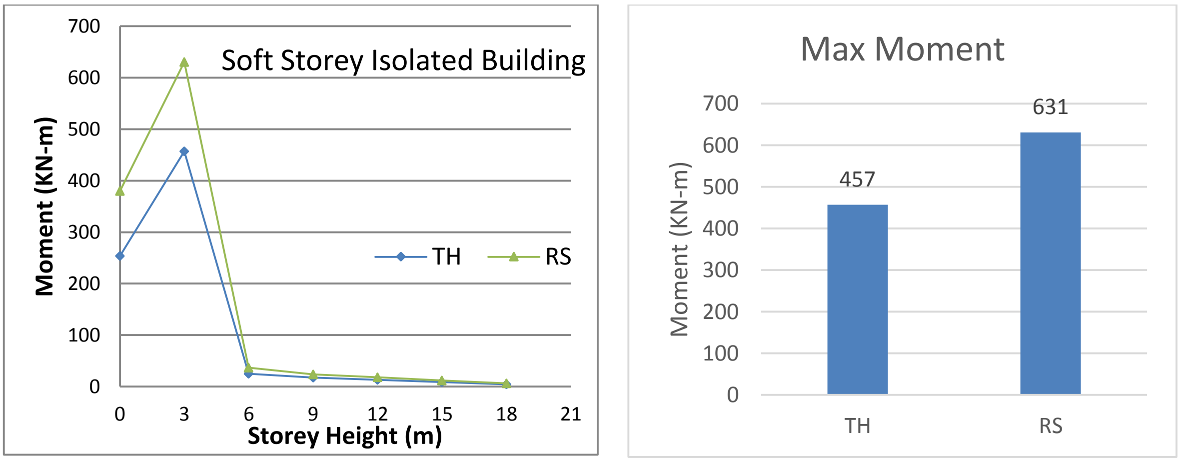


Figure 4.29: Exterior middle Column Moment (TH vs RS) for Soft Storey Isolated Building

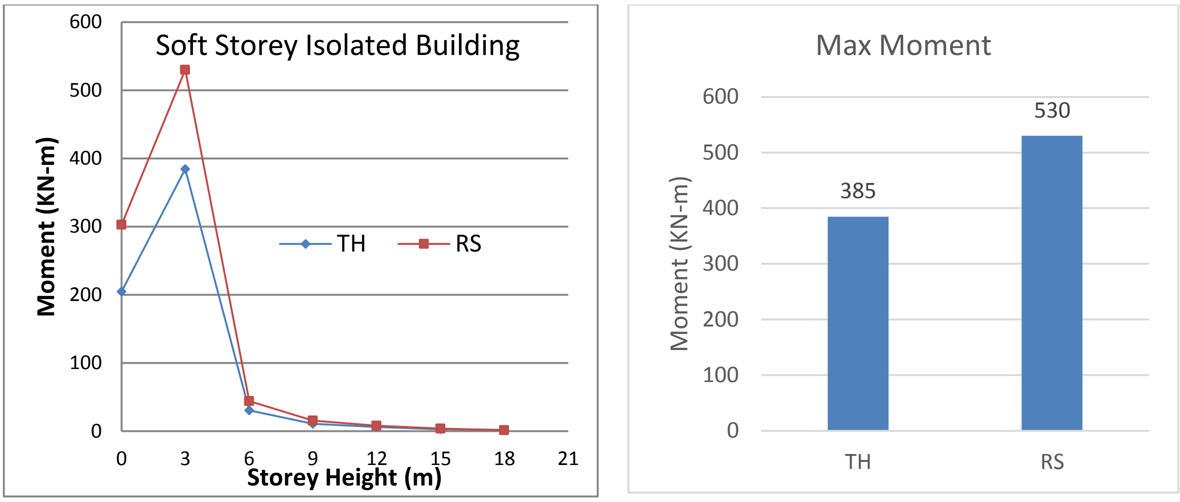


Figure 4.30: Corner Column Moment (TH vs RS) for Soft Storey Isolated Building

Column Moment for Time History Vs Response Spectrum Fixed Base without Soft Storey Building:

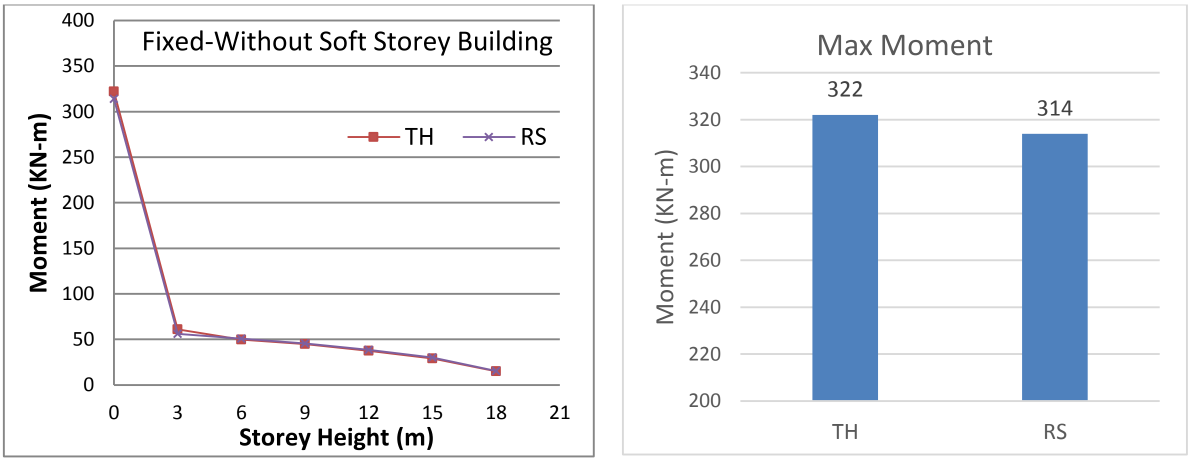


Figure 4.31: Interior Column Moment (TH vs RS) for Fixed Base without Soft Storey Building

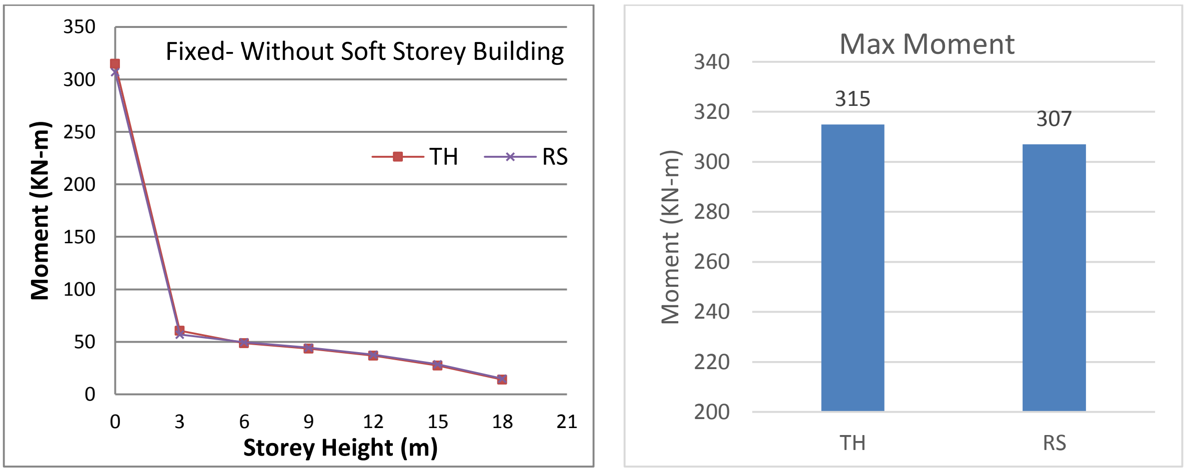


Figure 4.32: Exterior middle Column Moment (TH vs RS) for Fixed Base without Soft Storey Building

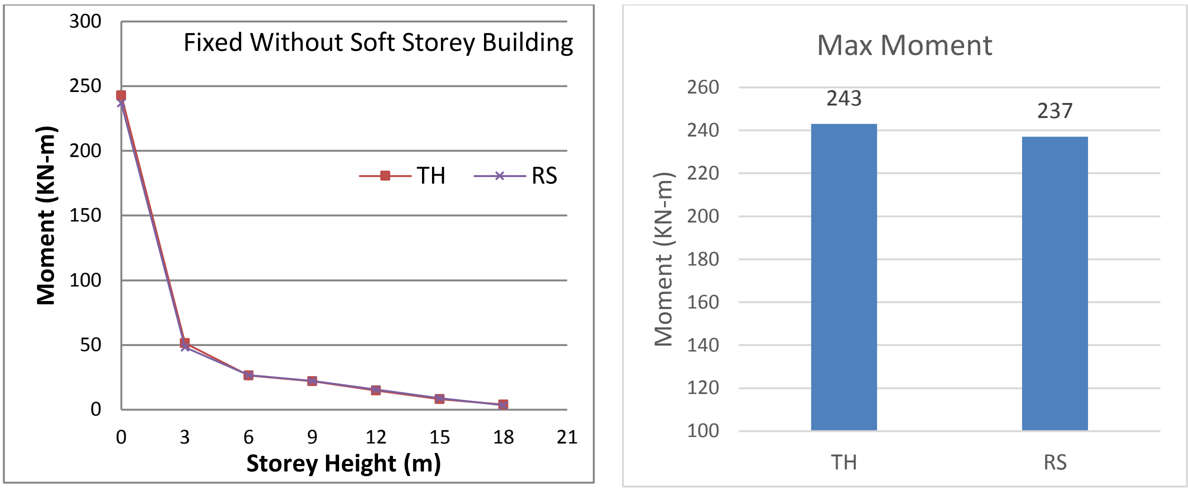


Figure 4.33: Corner Column Moment (TH vs RS) for Fixed Base without Soft Storey Building

Column Moment for TH Vs RS Fixed Base with Soft Storey Building:

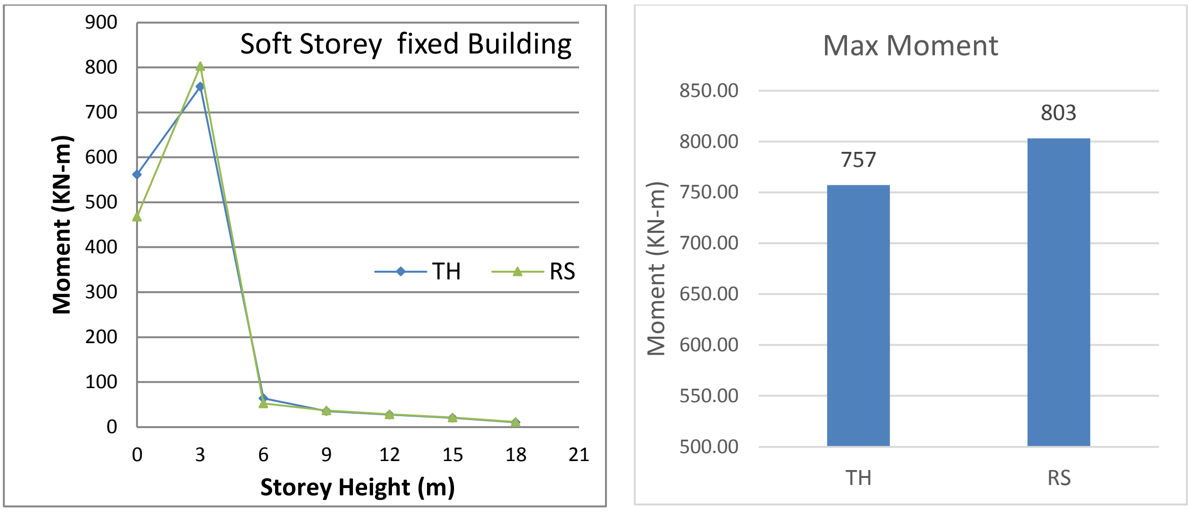


Figure 4.34: Interior Column Moment (TH vs RS) for Fixed Base Soft Storey Building

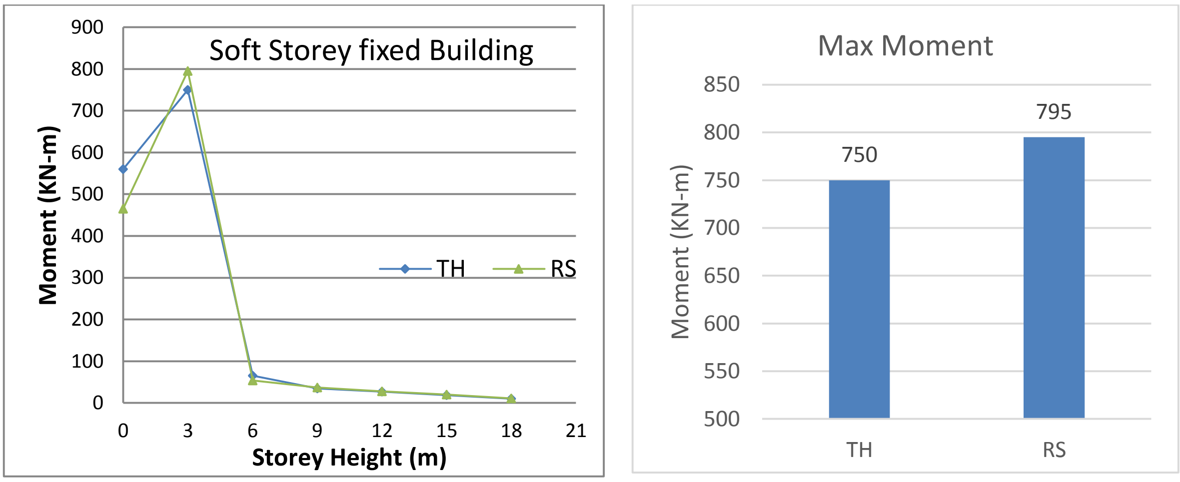


Figure 4.35: Exterior middle Column Moment (TH vs RS) for Fixed Base Soft Storey Building

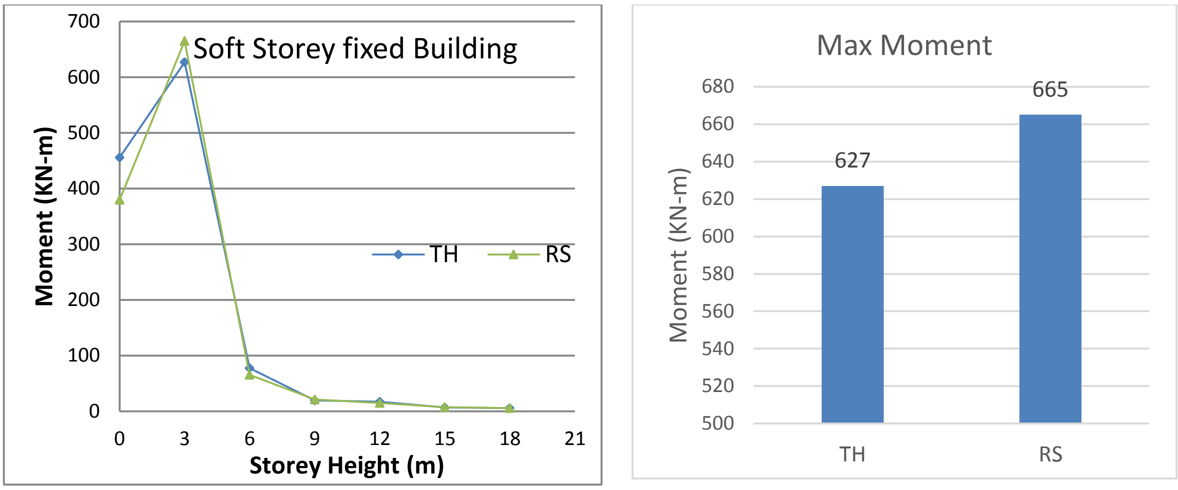


Figure 4.36: Corner Column Moment (TH vs RS) for Fixed Base Soft Storey Building

4.8 Column Shear

4.8.1 Column Shears for Four Kinds of Buildings

In time period response spectra analysis, it is found that there is a column shear value different in between soft storey and without soft storey building (figure 4.37 to 4.42). Where we found islolator, soft storey and infill effect both for time history and response spectrum analysis and column shear is higher in soft storey building than without soft storey infill building.

If we compare with isolated and non isolated fixed base building, higher shear value found from non-isolated building, for soft storey fixed base building column shear is 55% higher than soft storey isolated building and for infill fixed base building column shear is more than 52% higher than infill isolated building. Maximum column shear value in response spectrum analysis found 1.5 times higher than time history analysis.

Column shear is high up to soft storey height compared with without soft storey infill building. Shear value decrease after soft storey location, which shows the soft storey effect of the building.

In time history analysis, maximum shear value found in bottom storey column, where in soft storey building the shear value is high compared to the without soft storey infill building. And column shear is higher in fixed base compared to the isolated building (Figure 4.37 to 4.39) both for corner, exterior middle and interior column. Maximum shear in soft storey isolated building is 12 times higher than without soft storey isolated building and maximum shear in fixed base soft storey building is 13 times higher than fixed base without soft storey building.

In response spectrum analysis, maximum column shear value also found in bottom storey, where in soft storey building the shear value is maximum compared to the without soft storey building. And column shear is higher in fixed base compared to the isolated building (Figure 4.40 to 4.42) both for corner, exterior middle and interior column. Maximum shear in soft storey isolated building is 15 times higher than without soft storey isolated building and maximum shear in fixed base soft storey building is 12 times higher than fixed base without soft storey building. Fixed base building column shear is higher than isolated building.

So it is found that for column shear there is soft storey and isolated support effect for column shear value variations.

Column Shears for Four Kinds of Building for assign Time History and Response Spectrum

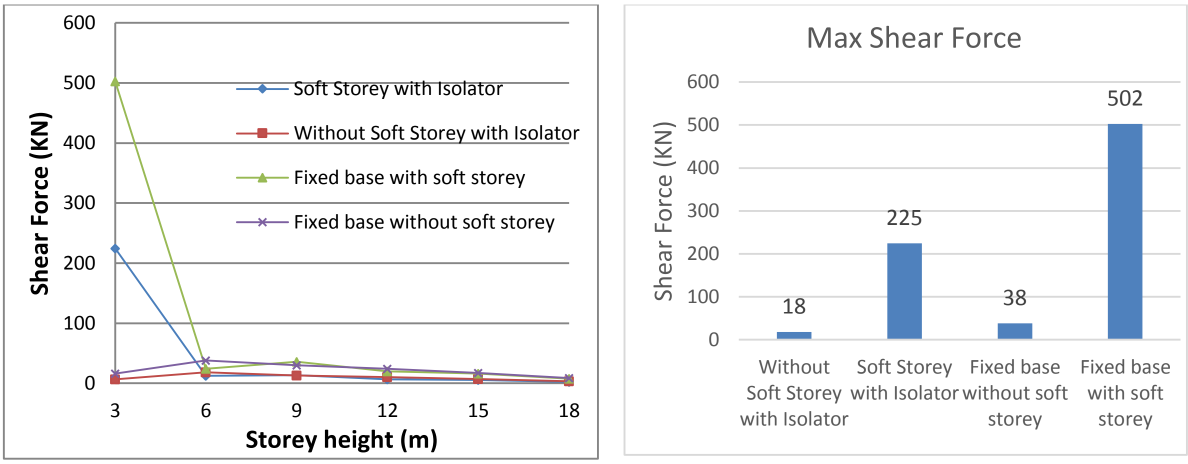


Figure 4.37: Interior Column Shears for four kinds of buildings for assign Time History

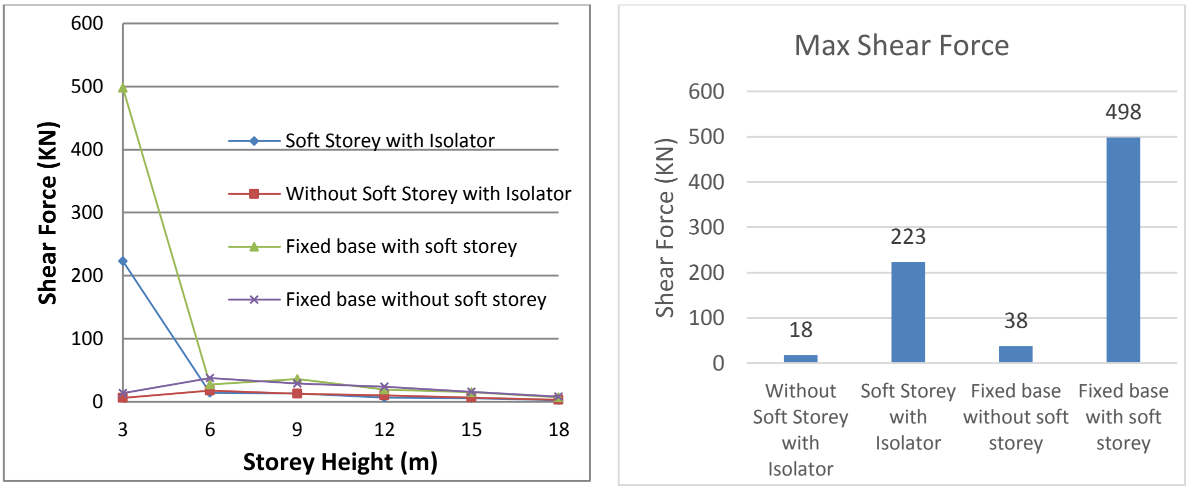


Figure 4.38: Exterior middle Column Shears for four kinds of buildings for assign Time History

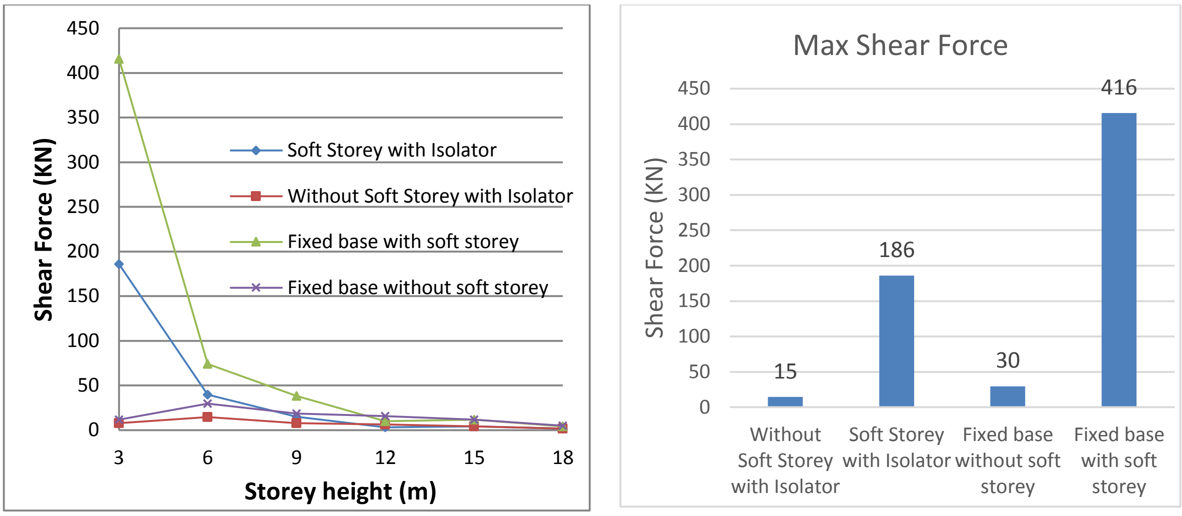


Figure 4.39: Corner Column Shears for four kinds of buildings for assign Time History

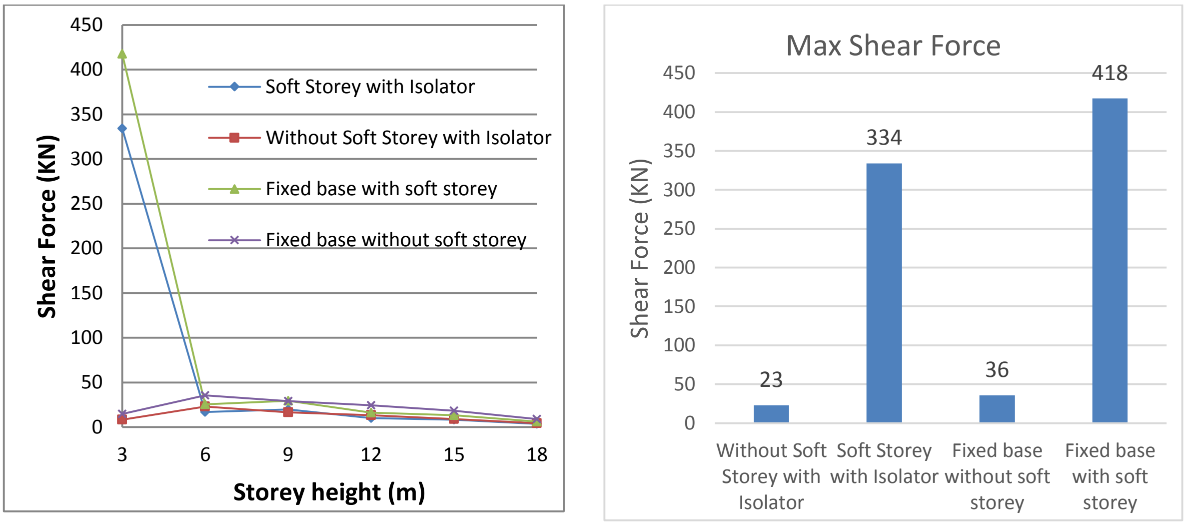


Figure 4.40: Interior Column Shear for four kinds of buildings for assign Response Spectrum

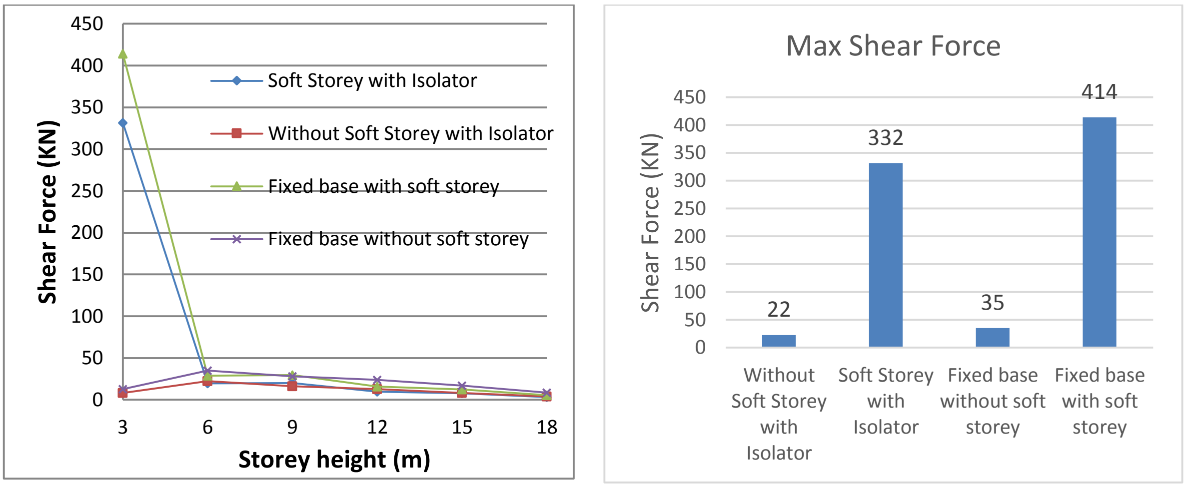


Figure 4.41: Exterior middle Column Shear for four kinds of buildings for assign Response Spectrum

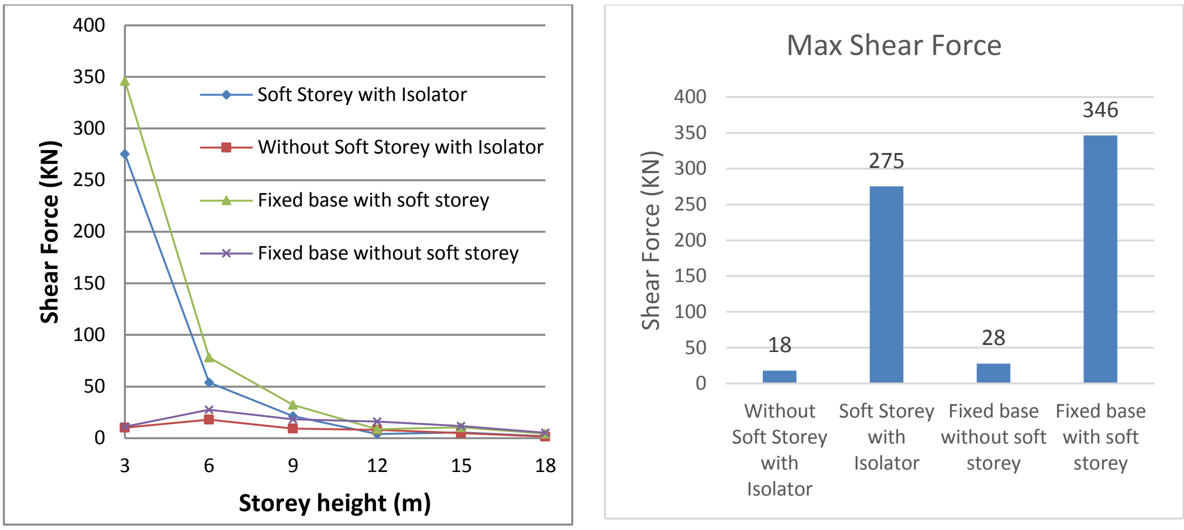


Figure 4.42: Corner Column Shear for four kinds of buildings for assign Response Spectrum

4.8.2 Maximum Column Shear for Four Kinds of Buildings

In time history and response spectrum analysis, maximum column shear found in fixed base with soft storey building both for corner, exterior middle and for interior column.

In time history analysis, fixed base with soft storey building column shear is 55% higher than soft storey isolated building (Figure 4.43)

In response spectrum analysis, fixed base with soft storey building column shear is 20% higher than soft storey isolated building. (Figure 4.44)

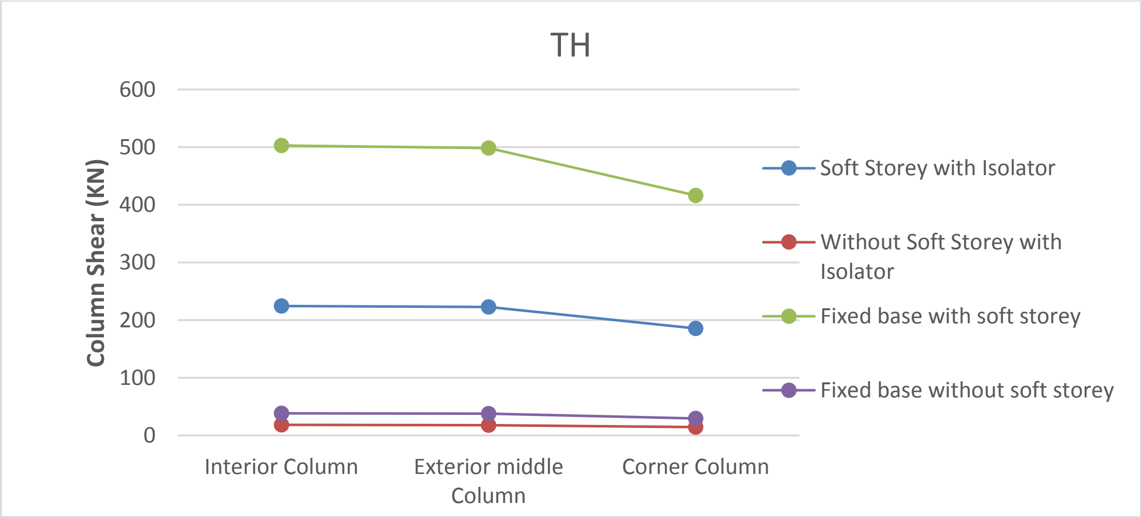


Figure 4.43: Maximum Column shear for four kinds of building for assign Time History

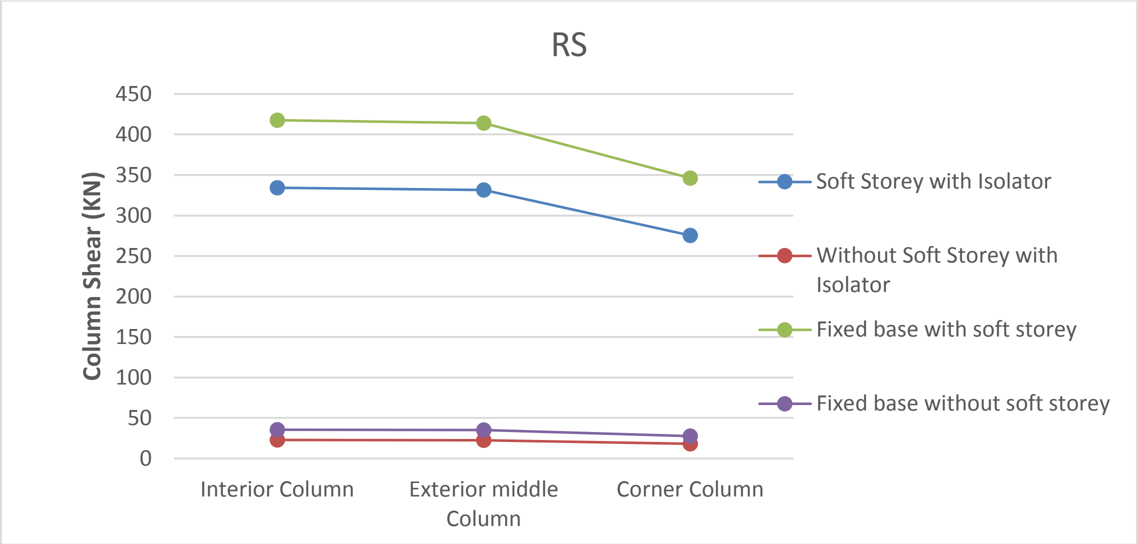
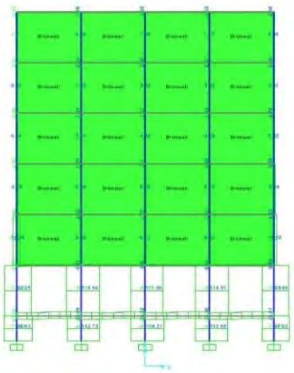
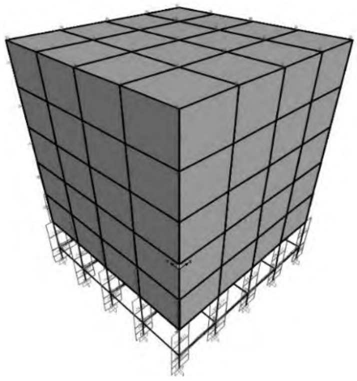


Figure 4.44: Maximum Column shear for four kinds of building for assign Response Spectrum

4.8.3 Column Shear for Soft Storey Buildings





In time history and response spectrum analysis column shear is found maximum in bottom storey location. And column shear value reduces after soft bottom storey in a decreasing manner (Figure 4.45 to 4.50)

If we saw the column shear for **Soft Storey** building both for isolated and for fixed base building for assign time history and response spectrum, it is seen that fixed base soft storey building column shear is higher than soft storey isolated building both for corner, exterior middle and for interior column.

In time History analysis, column shear in fixed base building soft storey location is found 55% higher than column shear is soft storey isolated building (Figure 4.45 to 4.47). Column shear is reduced its value after soft storey location and comes to a nominal value in top storey where also column shear is almost 55% higher value in fixed base soft storey building than column shear in isolated soft storey building.

In response spectrum analysis, column shear in fixed base building soft storey location is found 20% higher than column shear is soft storey isolated building (Figure 4.48 to 4.50). Column moment is reduced its value after soft storey location and comes to a nominal value in top storey where also column shear is almost 20% higher value in fixed base soft storey building than column shear in isolated soft storey building.

So there is soft storey and isolator support effect in shear values variation both in time history and response spectrum analysis.

Column Shear for Soft Storey Building for assign TH and RS:

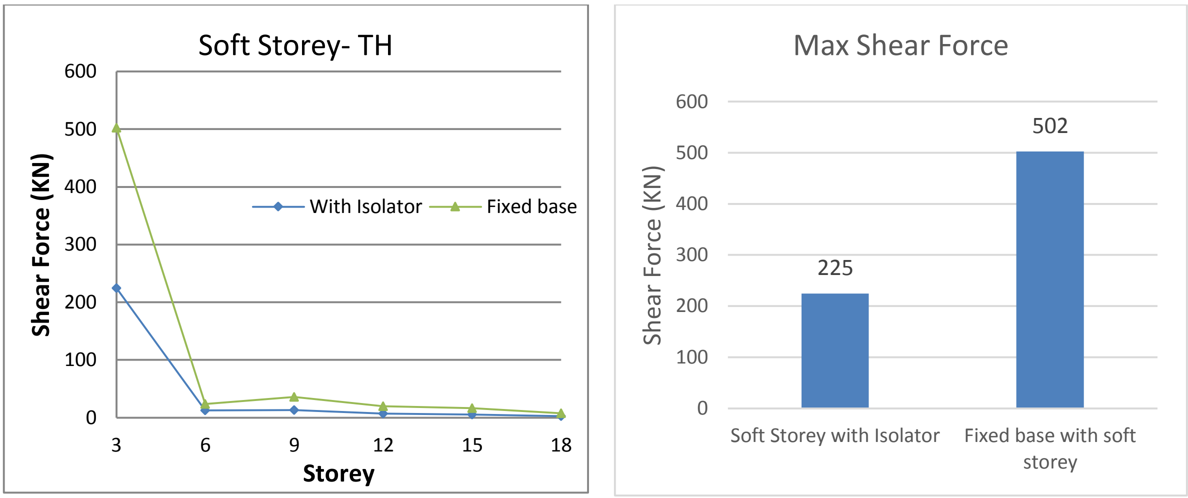


Figure 4.45: Interior Column Shear for **Soft Storey** buildings for assign Time History

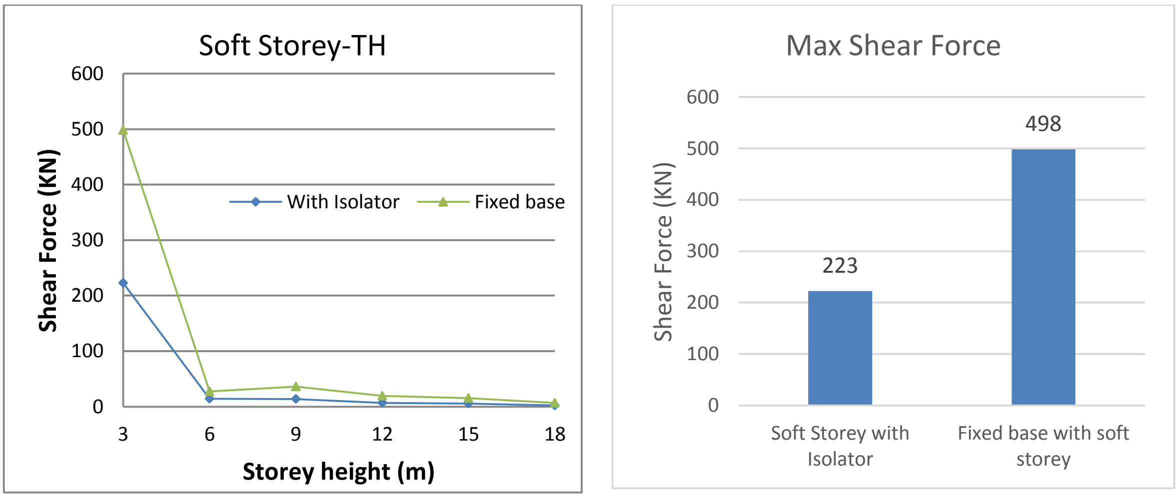


Figure 4.46: Exterior middle Column Shear for **Soft Storey** buildings for assign Time History

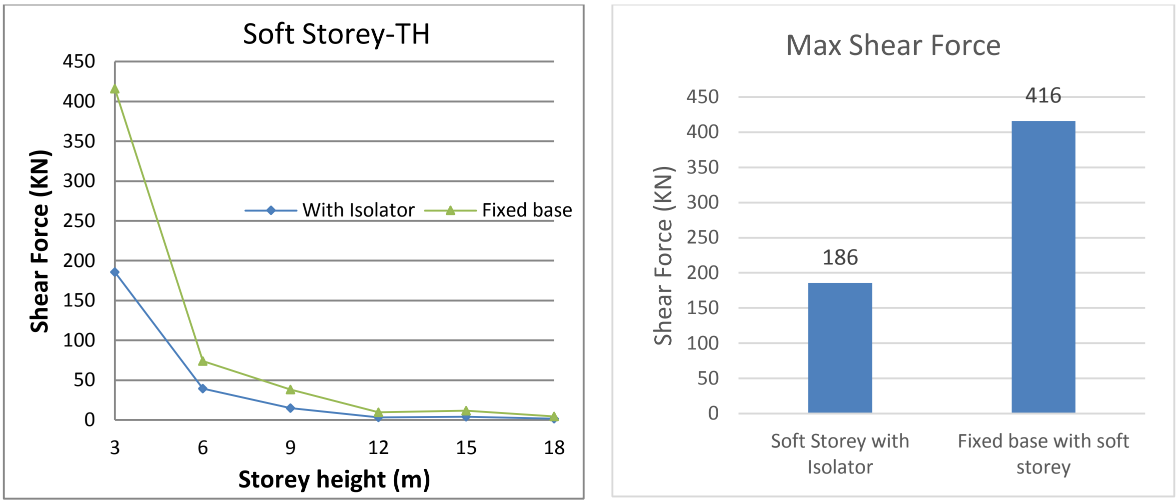


Figure 4.47: Corner Column Shear for **Soft Storey** buildings for assign Time History

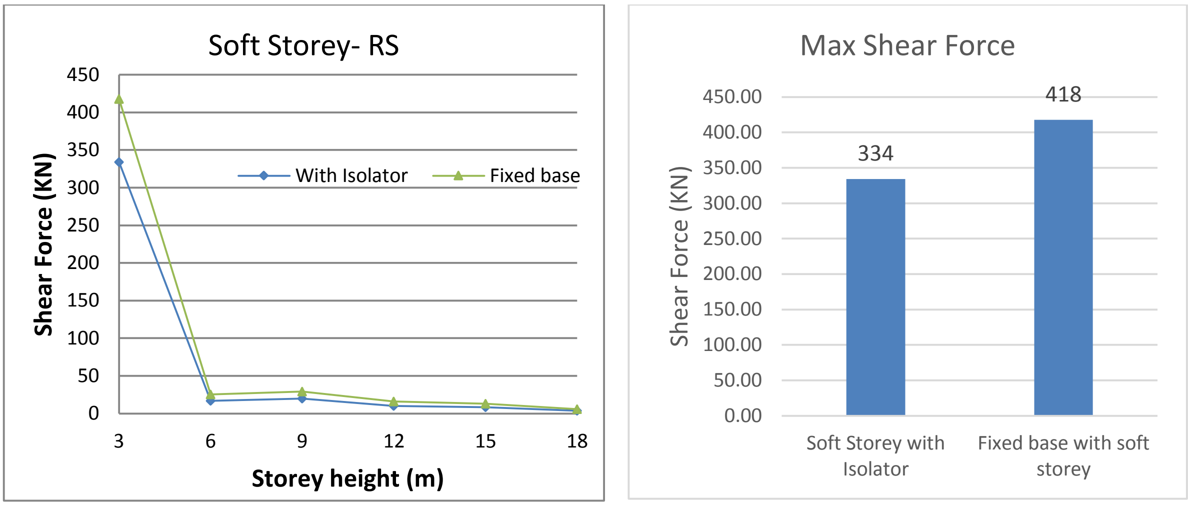


Figure 4.48: Interior Column Shear for **Soft Storey** buildings for assign Response Spectrum

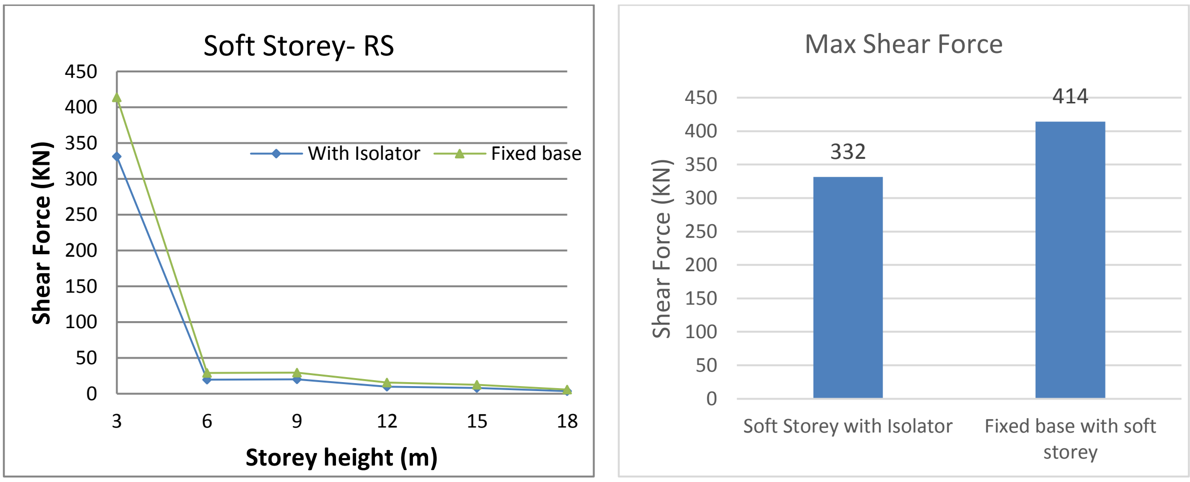


Figure 4.49: Exterior middle Column Shear for **Soft Storey** buildings for assign Response Spectrum

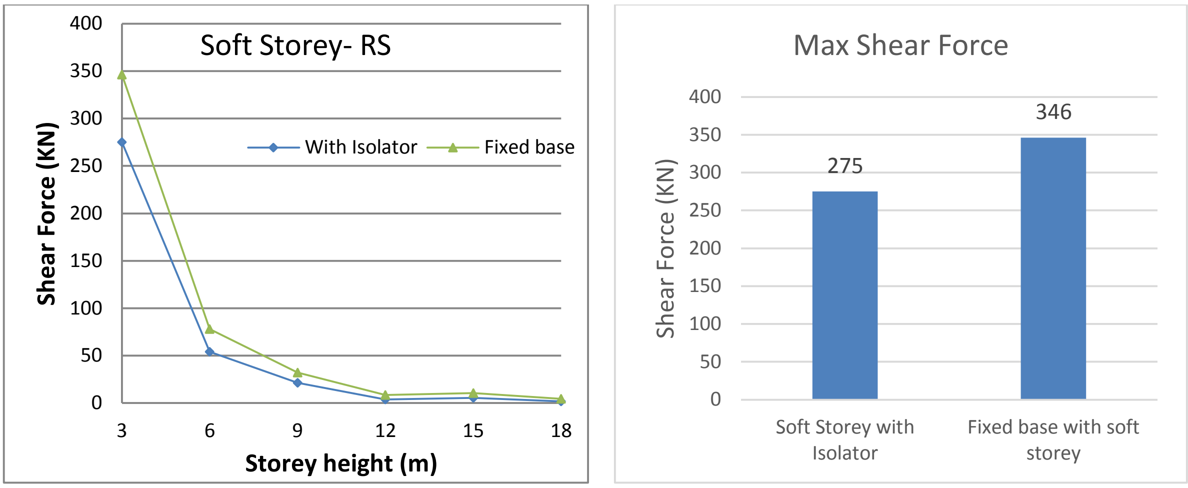
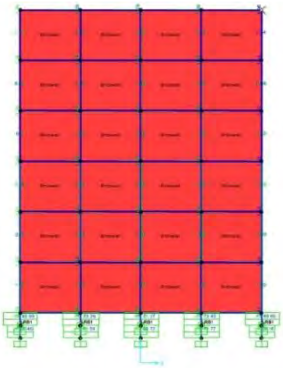
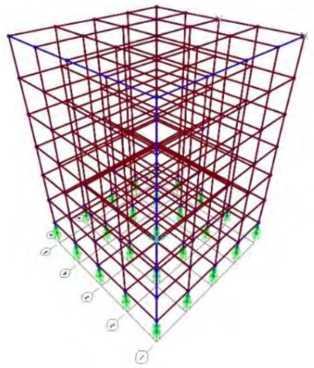


Figure 4.50: Corner Column Shear for **Soft Storey** buildings for assign Response Spectrum

4.8.4 Column Shears for Without Soft Storey Buildings





If we saw the column shear for **without Soft Storey** building both for isolated and for fixed base building for assign time history and response spectrum, it is found that fixed base without soft storey infill building column shear is higher than without soft storey isolated infill building both for corner, exterior middle and for interior column.

In time History analysis, maximum column shear in fixed base building found in bottom storey location and is found almost 53% higher than column shear in without soft storey isolated infill building 1st storey (3 to 6m height) (Figure 4.51 to 4.53). Column shear is reduced its value from bottom storey location and comes to a nominal value in top storey where also column shear is almost 53% higher value in fixed base soft storey building than column shear in isolated soft storey building.

In response spectrum analysis, maximum column shear found in fixed base without soft storey infill building at 1st storey (3 to 6m height) location and it is found that fixed base infill building column moment is 36% higher than column shear in infill isolated building (Figure 4.54 to 4.56). Column shear is reduced its value and comes to a nominal value in top storey where also column shear is almost 36% higher value in fixed base soft storey building than column shear in isolated soft storey building. It’s reduced its 82% of the shear from bottom storey to first storey.

So there is soft storey and isolator support effect in shear values variation both in for assign time history and response spectrum.

Column Shear for without Soft Storey Building for assign Time History and Response Spectrum:

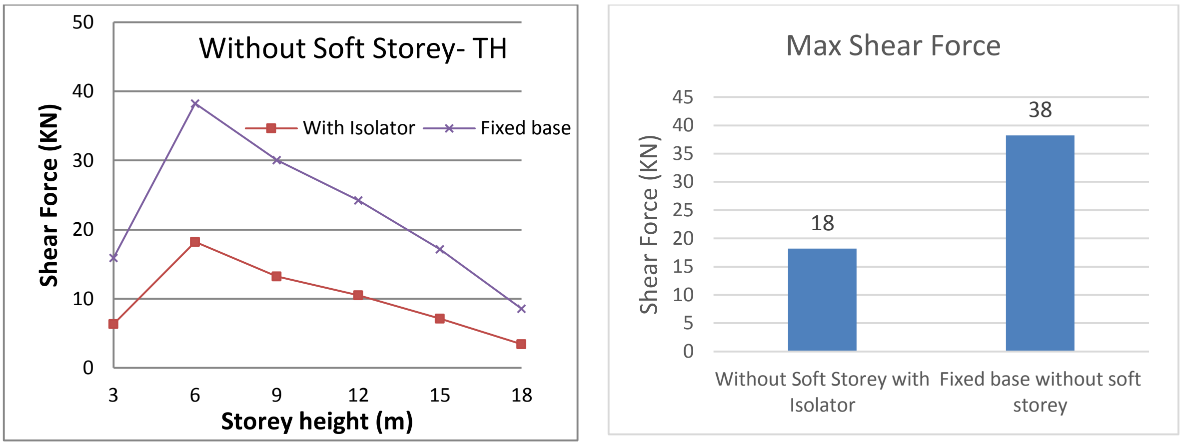


Figure 4.51: Interior Column Shear for without **Soft Storey** buildings for assign Time History

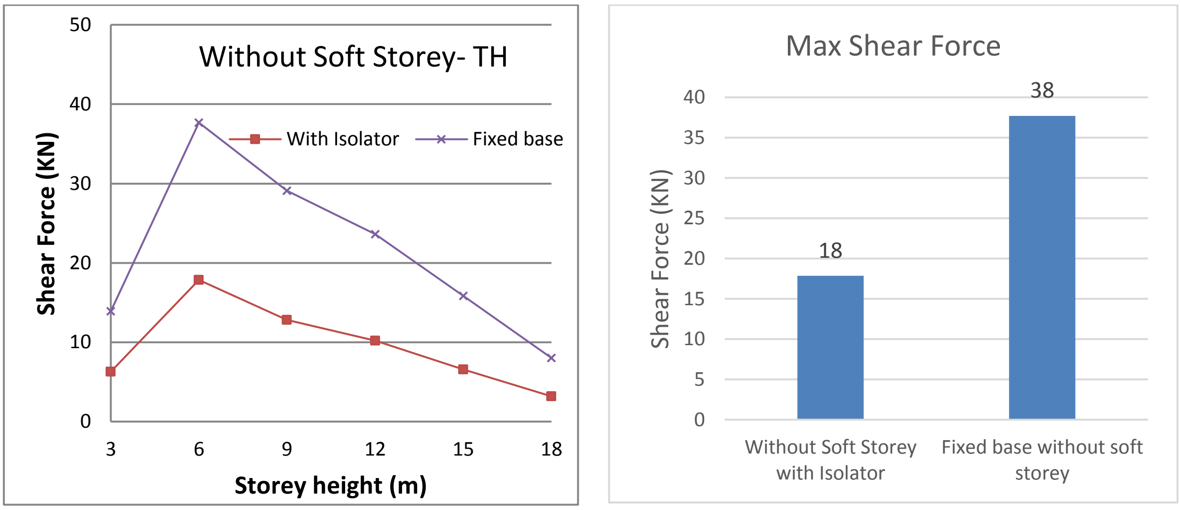


Figure 4.52: Exterior middle Column Shear for without **Soft Storey** buildings for assign Time History

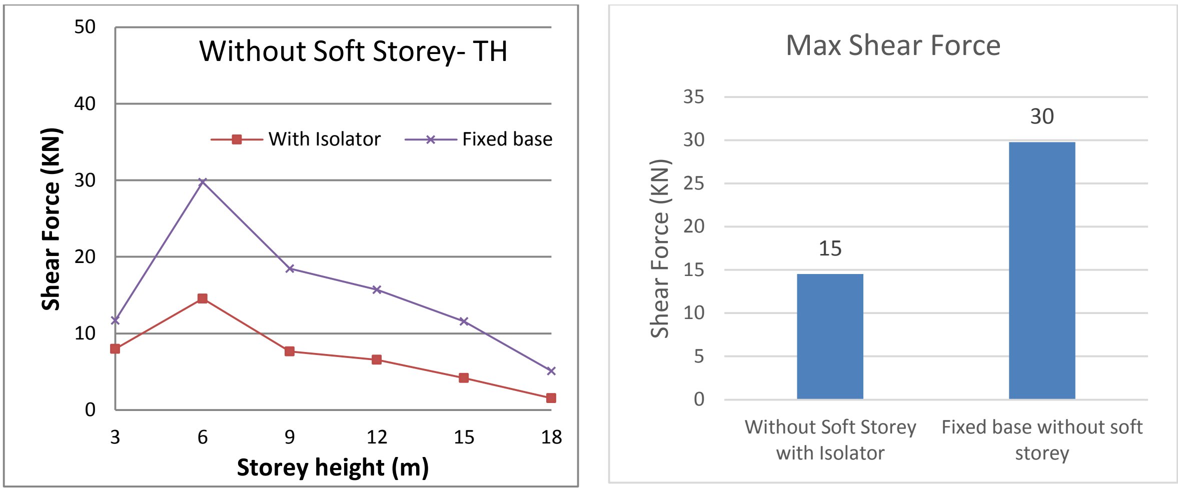


Figure 4.53: Corner Column Shear for without **Soft Storey** buildings for assign Time History

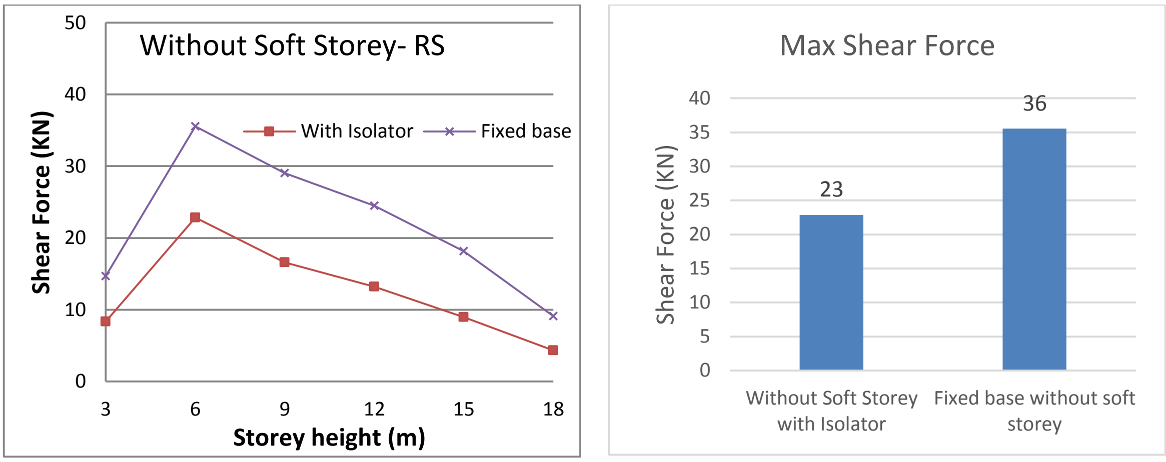


Figure 4.54: Interior Column Shear for without **Soft Storey** buildings for assign Response Spectrum

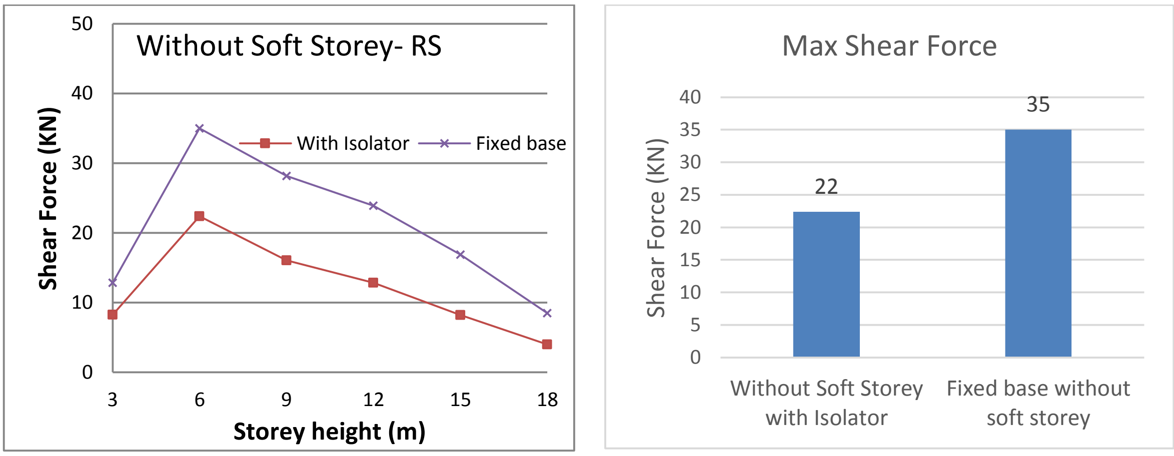


Figure 4.55: Exterior middle Column Shear for without **Soft Storey** buildings for assign Response Spectrum

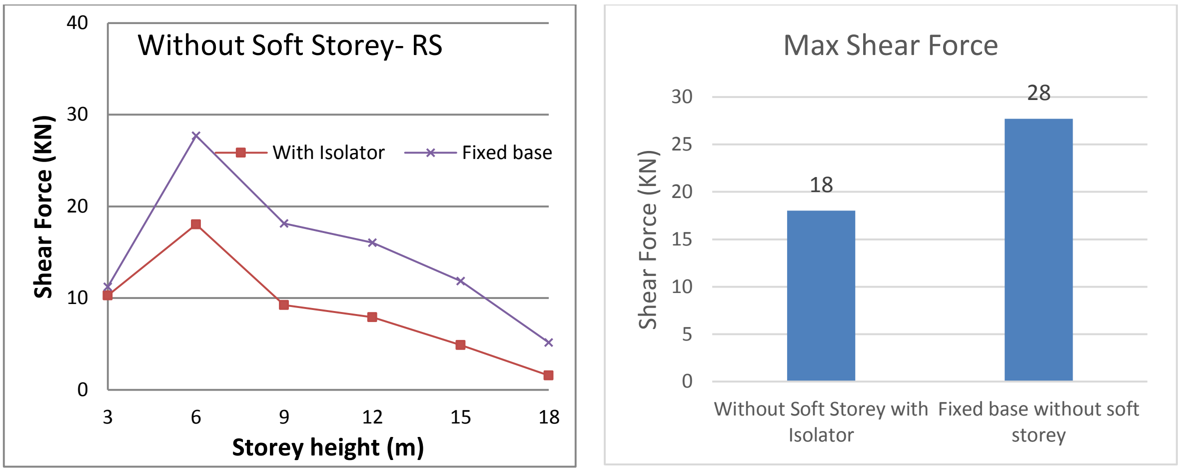


Figure 4.56: Corner Column Shear for without **Soft Storey** buildings for assign Response Spectrum

4.8.5 Column Shear-Time History Vs Response Spectrum

In time history and response analysis, column shear variation found in four different kinds of buildings and it is found that column shear value found higher in response spectrum analysis for both corner, exterior middle and interior column (Figures 4.57 to 4.68).

It is found that, in soft storey isolated building, column shear is maximum at 1st storey (bottom storey, up to 3m height). Column shear found higher in response spectrum analysis compared to time history (Figures 4.57 to 4.59). Where maximum column shear value in response spectrum analysis is almost 1.5 times higher compared to time history analysis.

In soft storey fixed base building, column shear is maximum at soft storey location. Column shear found higher in time history analysis compared to response spectrum (Figure 4.60 to 4.62). Where maximum column shear value in time history analysis is 1.2 times higher compared to response spectrum analysis. Here it seen the soft story fixed base building response spectrum effect is less than time history.

In without soft storey isolated building, column shear is maximum in 1st storey location. Column shear found higher in response spectrum analysis compared to time history (Figures 4.63 to 4.65). where maximum column shear value in time history analysis is 1.2 times higher compared to response spectrum analysis.

In without soft storey fixed base building, column shear is maximum at 1st storey and shear is higher compared to other storey. Column shear found higher in time history analysis compared to response spectrum (Figures 4.66 to 4.68). Where maximum column shear value in time history analysis is 1.2 times higher compared to response spectrum analysis.

So in four types of buildings we found the soft storey effect and isolator effect for column shear variation for both time history and response spectrum analysis.

Column Shear-Time History Vs Response Spectrum

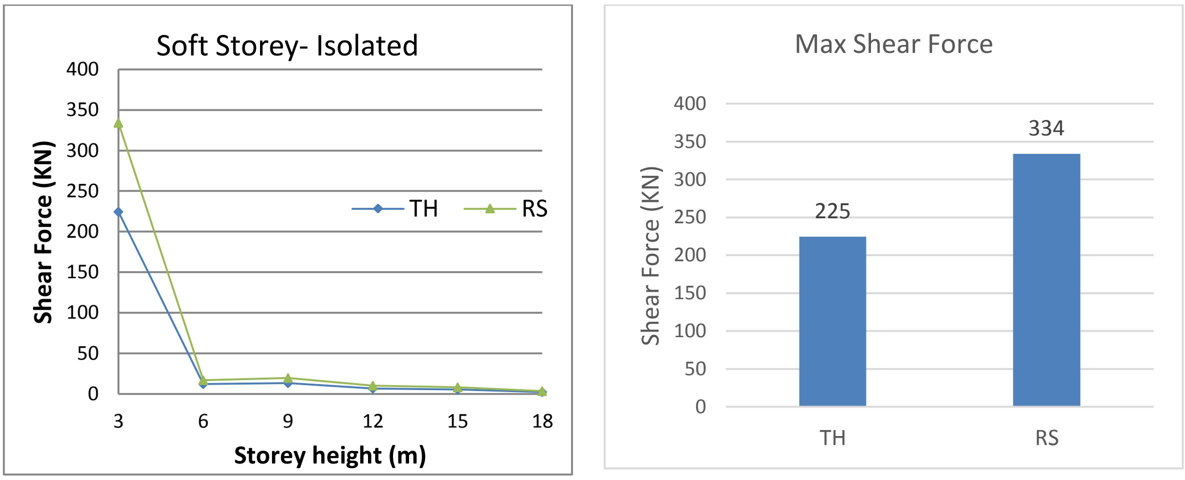


Figure 4.57: Interior Column Shear (TH Vs RS) for **Soft Storey Isolated** building

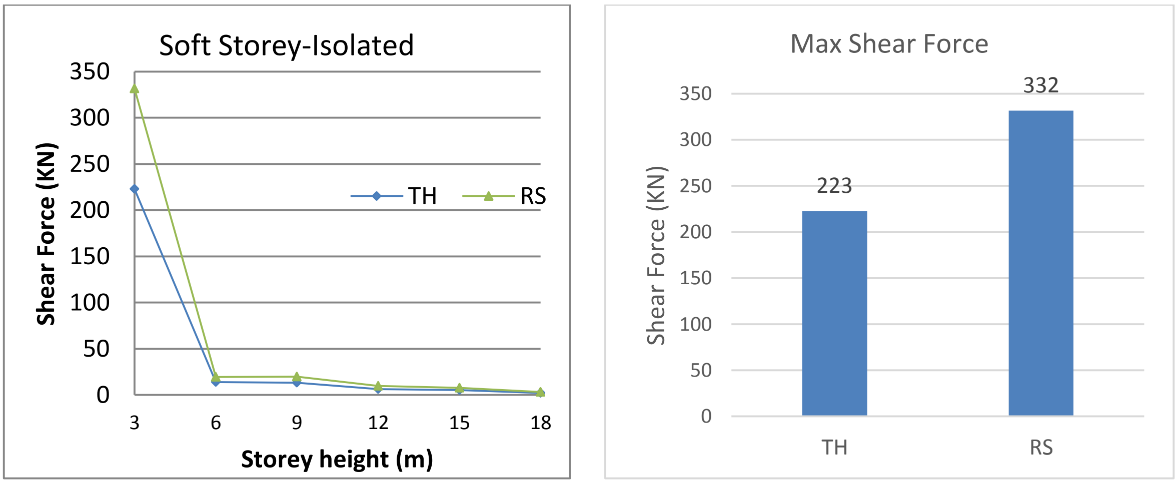


Figure 4.58: Exterior middle Column Shear (TH Vs RS) for **Soft Storey Isolated** building

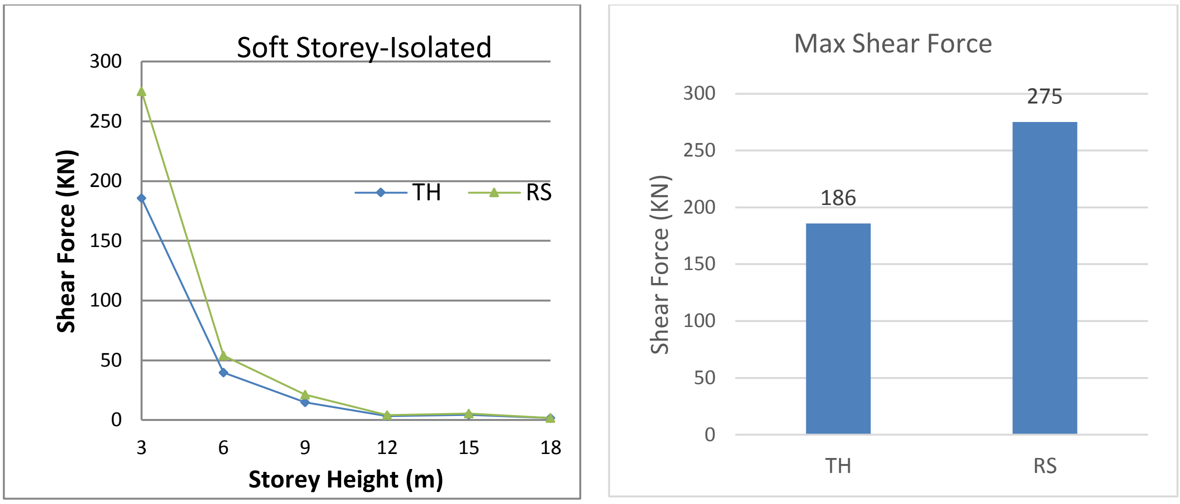


Figure 4.59: Corner Column Shear (TH Vs RS) for **Soft Storey Isolated** building

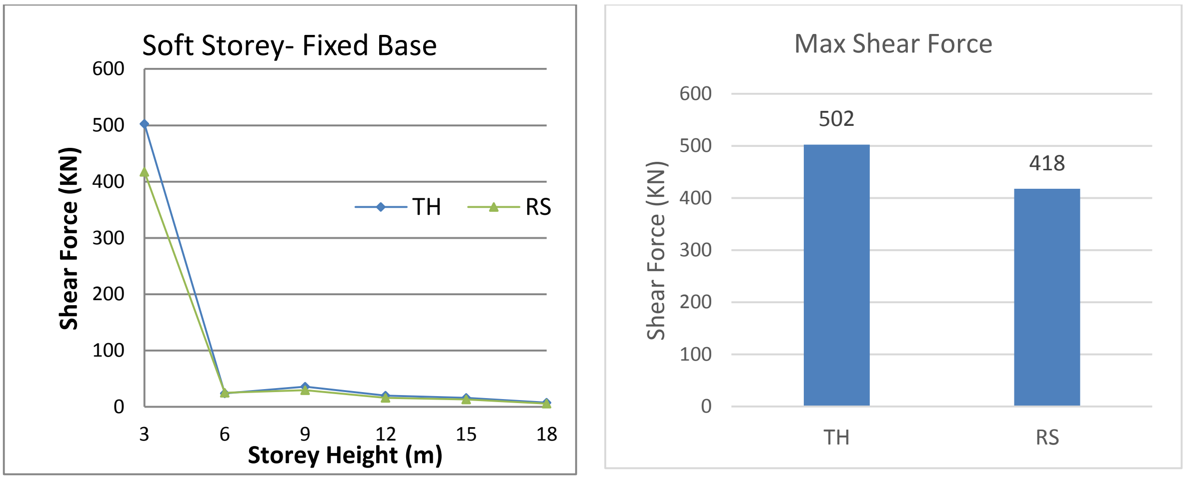


Figure 4.60: Interior Column Shear (TH Vs RS) for **Soft Storey Fixed base** building

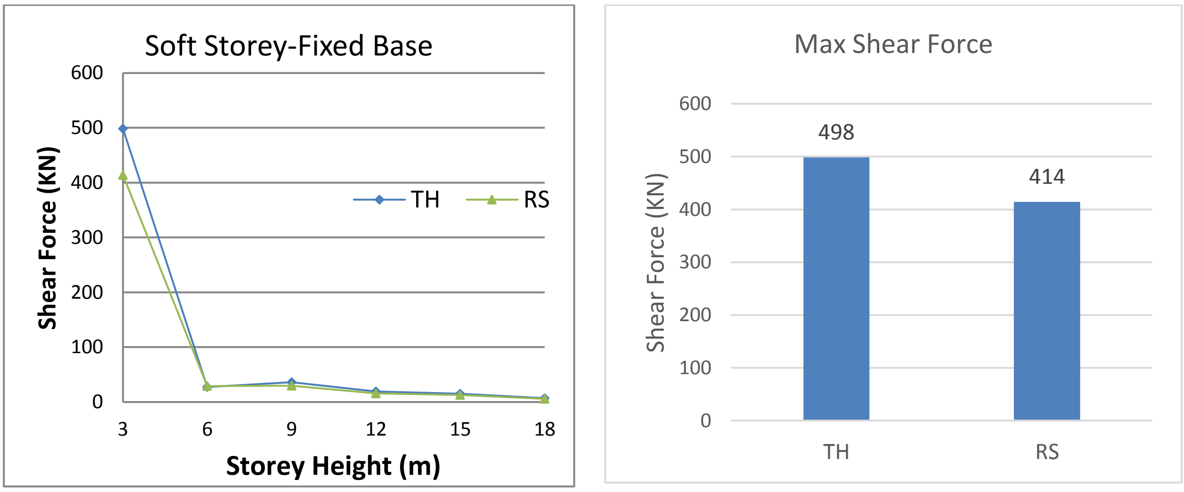


Figure 4.61: Exterior middle Column Shear (TH Vs RS) for **Soft Storey Fixed base** building

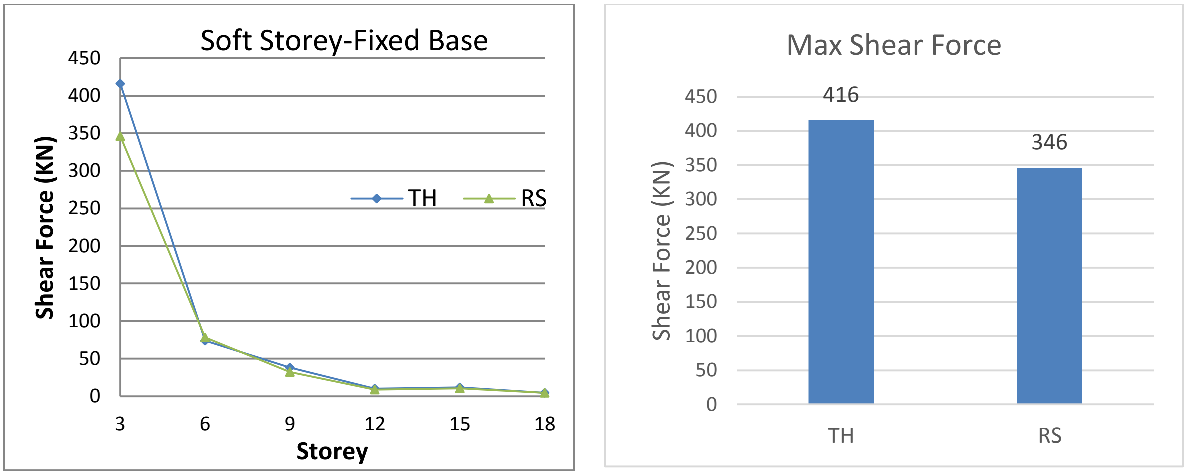


Figure 4.62: Corner Column Shear (TH Vs RS) for **Soft Storey Fixed base** building

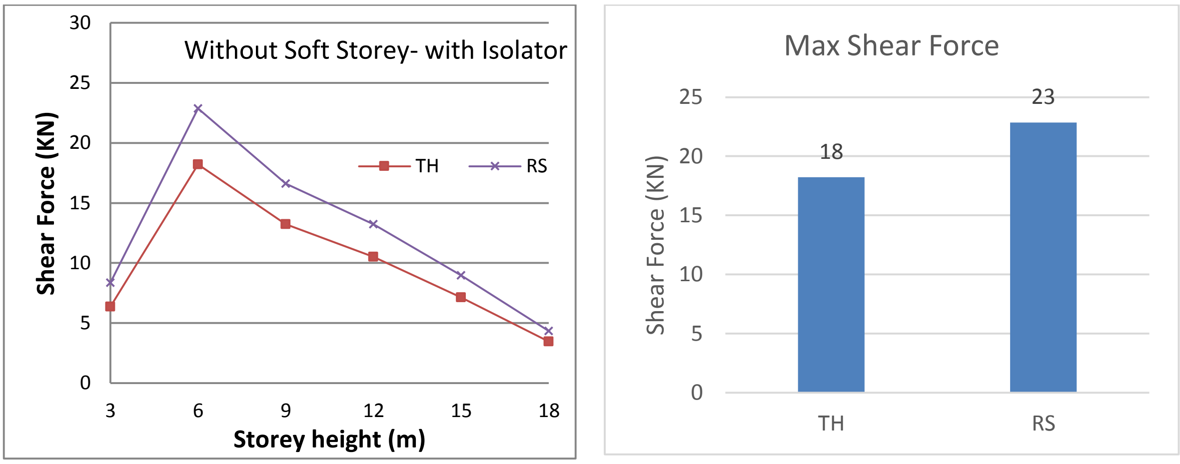


Figure 4.63: Interior Column Shear (TH Vs RS) for **without Soft Storey Isolated** building

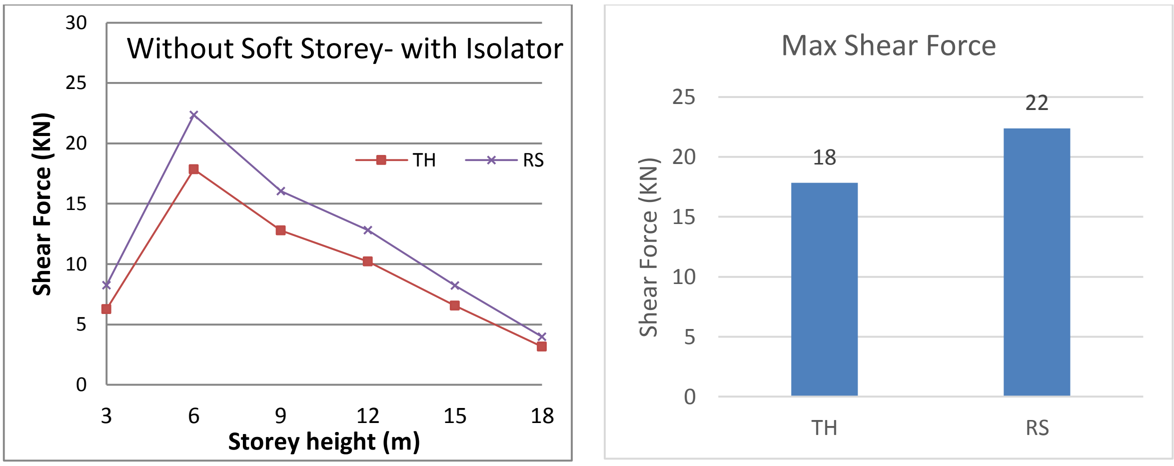


Figure 4.64: Exterior middle Column Shear (TH Vs RS) for **without Soft Storey Isolated** building

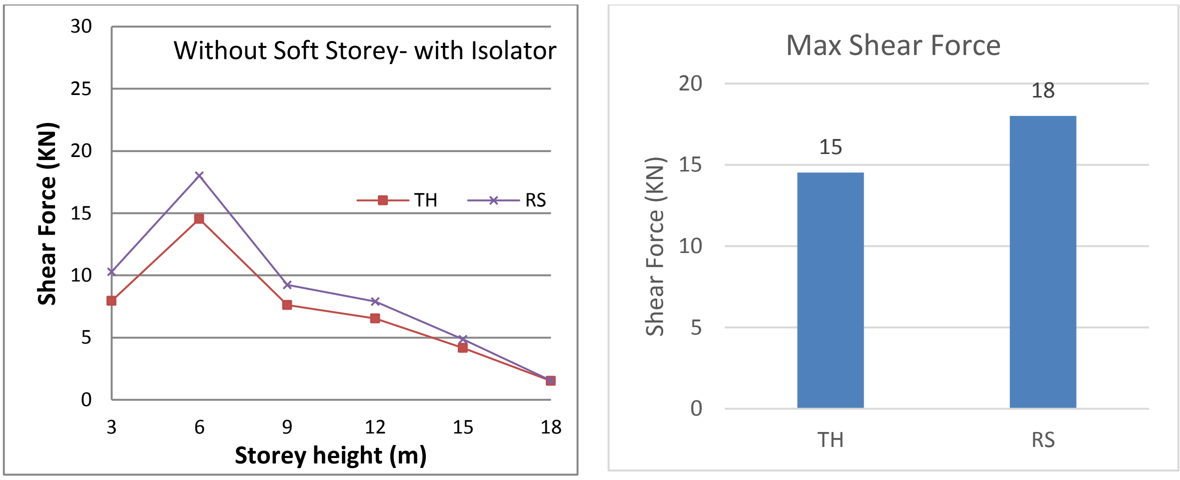


Figure 4.65: Corner Column Shear (TH Vs RS) for without **Soft Storey Isolated** building

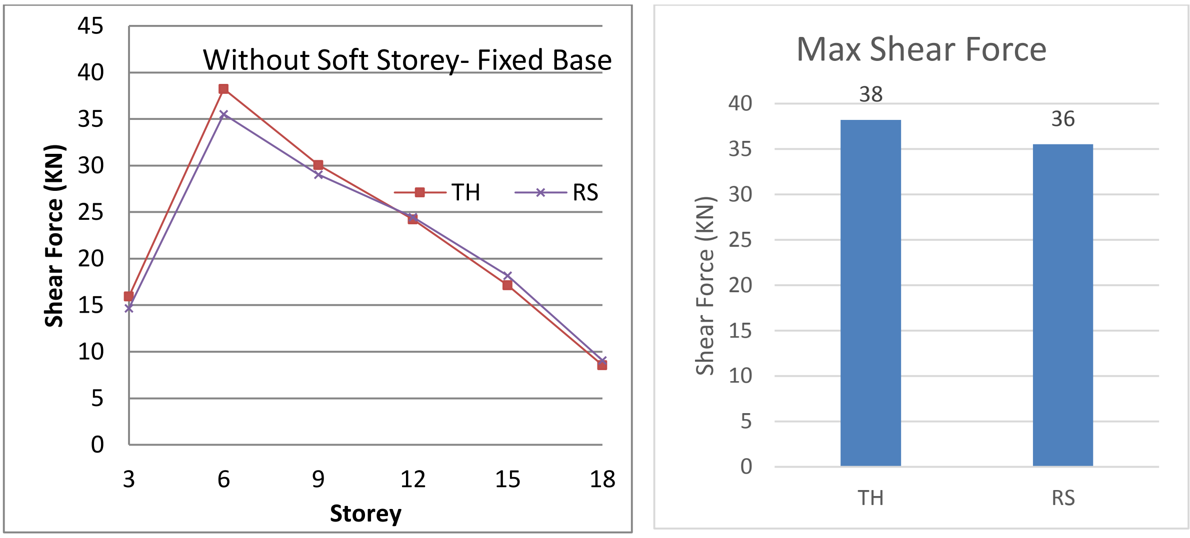


Figure 4.66: Interior Column Shear (TH Vs RS) for **without Soft Storey Fixed base** building

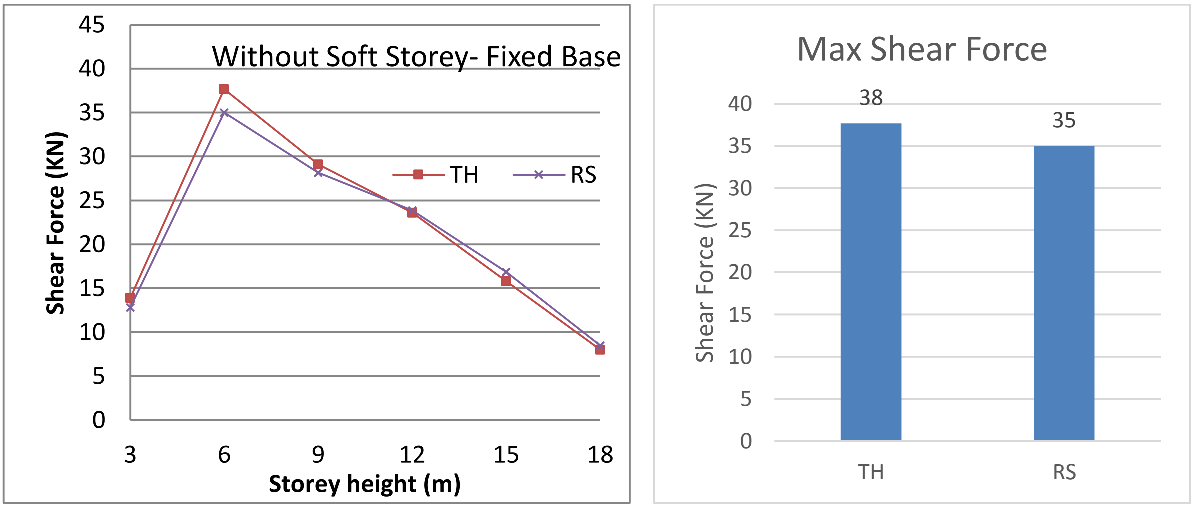


Figure 4.67: Exterior middle Column Shear (TH Vs RS) for **without Soft Storey Fixed base** building

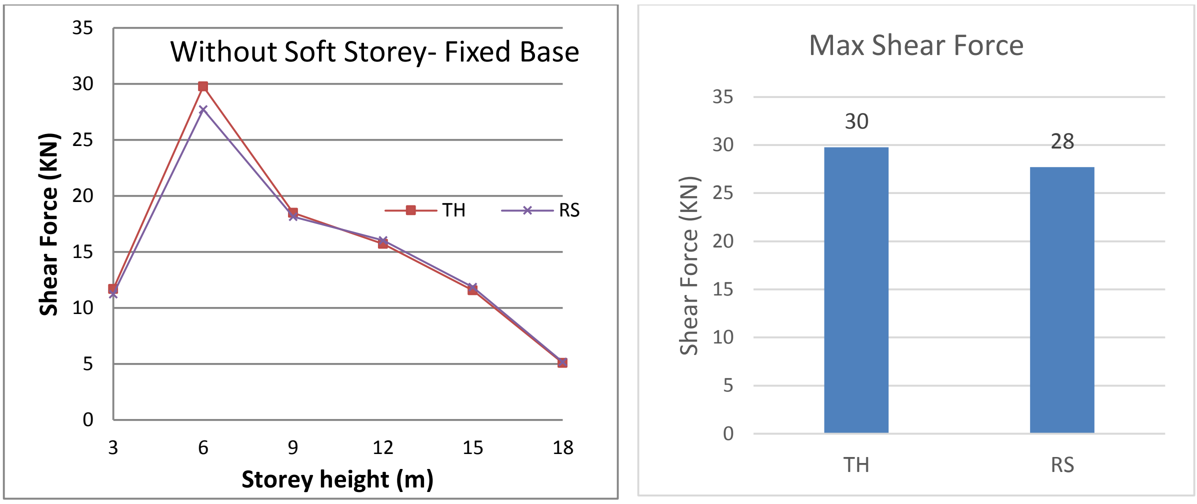


Figure 4.68: Corner Column Shear (TH Vs RS) for **without Soft Storey Fixed base** building

4.9 Base Shear

Base shear coefficients (Figure 4.69) at time history is 26% lower than the response spectrum base shear value. Base shear is higher in non-isolated building than isolated building.

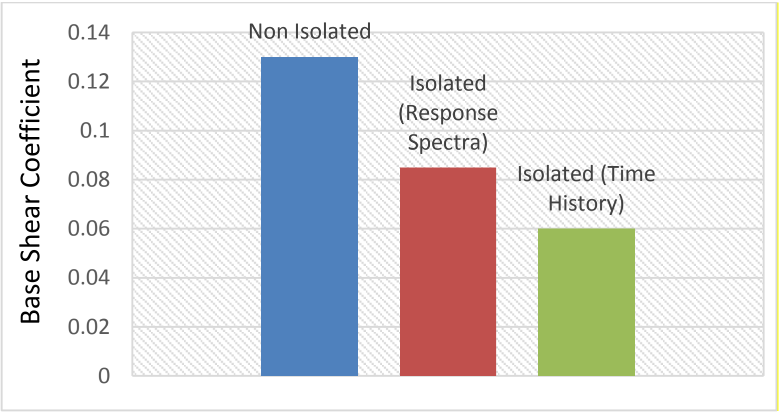


Figure 4.69. Base Shear Coefficients for LRB, T_i=1.5 Seconds

4.10 Displacement

In Storey level fixed base building displacement is higher than Isolated Building. Displacement is high in soft storey location (Figures 4.70 and 4.72). Top displacement of isolated building increases but the relative maximum displacement of a building reduces in a larger amount (generally 35%-70% range). Fixed base soft storey displacement is higher than fixed base without soft storey.

Using Isolator displacement value can be reduced 45% for fixed base soft storey building and 41% for fixed base without soft storey building (Figures 4.71 to 72)

The displacement from the time history analysis plotted in Figure 4.73 is about 38% lower than the displacement from response spectrum analysis. Figure 4.73 suggests that results are relatively insensitive to the period of the structure above the isolators.

The mean time history results show that the design procedure generally provided a conservative estimate of isolation system performance except for the elastic isolation system, where the design procedure under-estimated displacements and shear forces, especially for short period isolation systems.

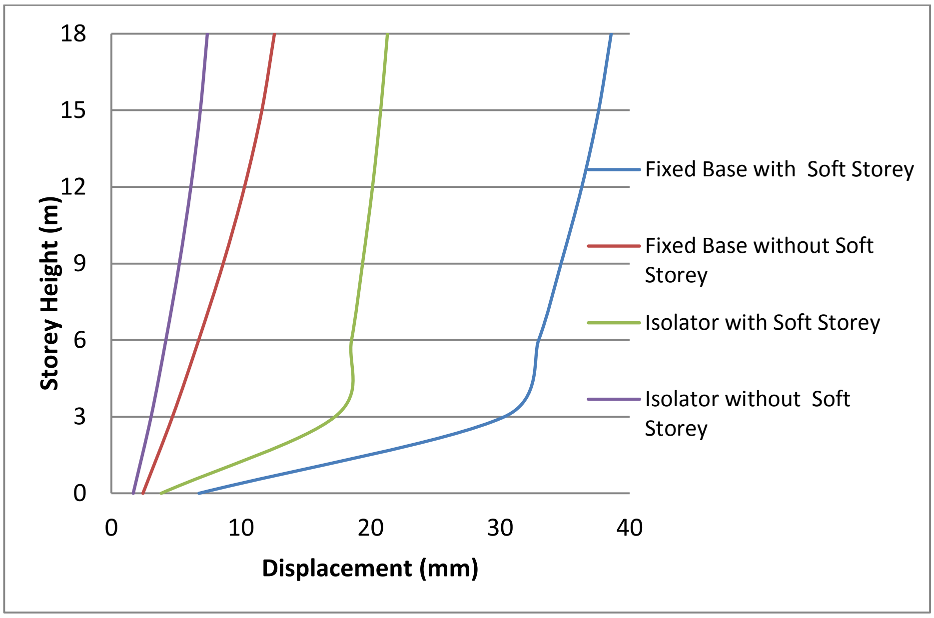


Figure 4.70 Displacement Vs Storey level for the assigned Time History

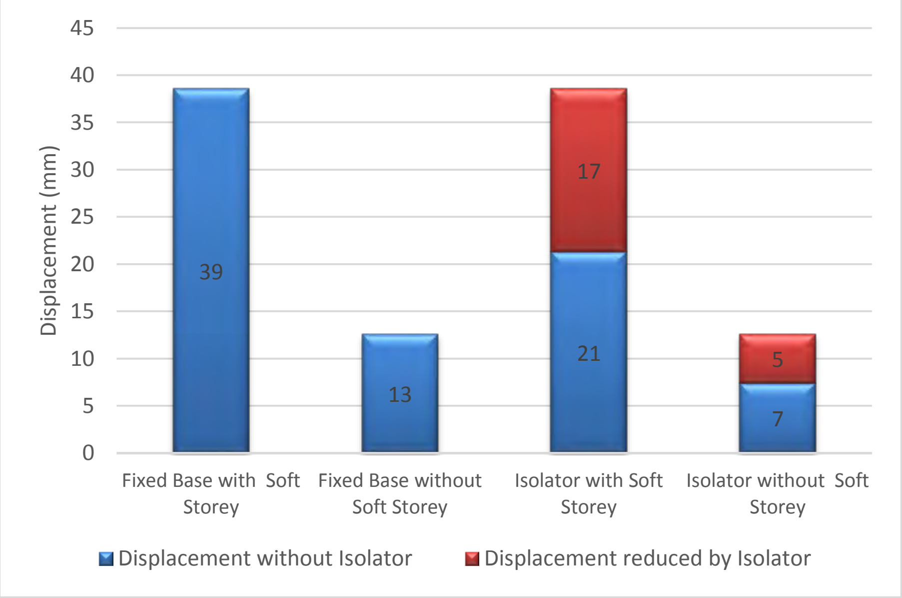


Figure 4.71 Displacement reduced by using Isolator

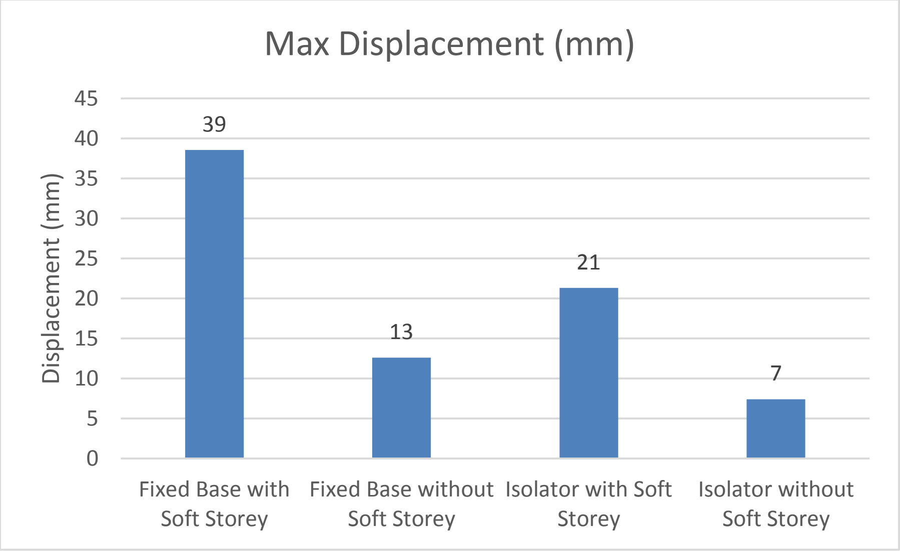


Figure 4.72 Max Displacement for the assigned Time History

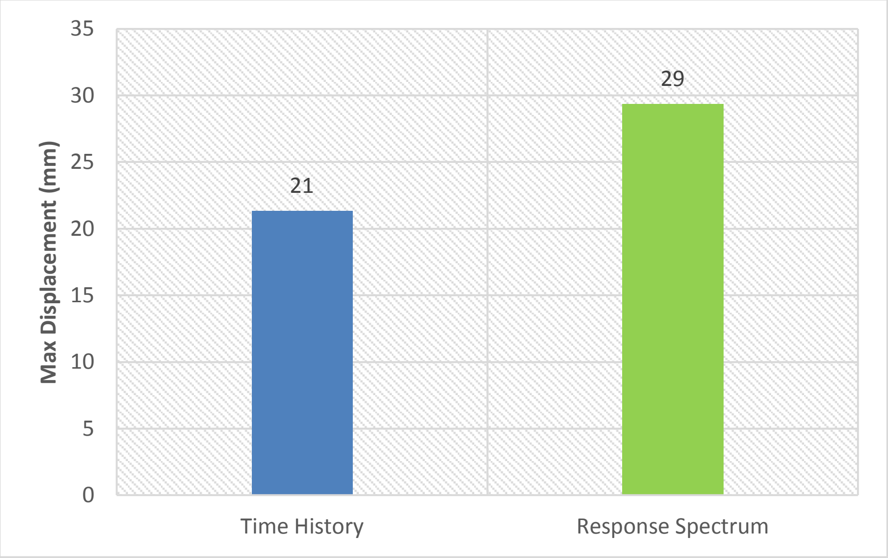


Figure 4.73 Max Displacement for Time History Vs Response Spectrum

4.11 Storey Drift

In time period response spectra analysis, it is found that maximum storey drift (Figures 4.74 and 4.75) found soft storey location. If we compared with mentioned four kinds of building, storey drift is found maximum in fixed base soft storey building 43% higher than isolated soft storey building. The upper stories move as single block as there is presence of infill masonry which makes it stiffer. Hence displacement is more in soft storey as we found storey drift is maximum in first storey location i.e soft storey location.

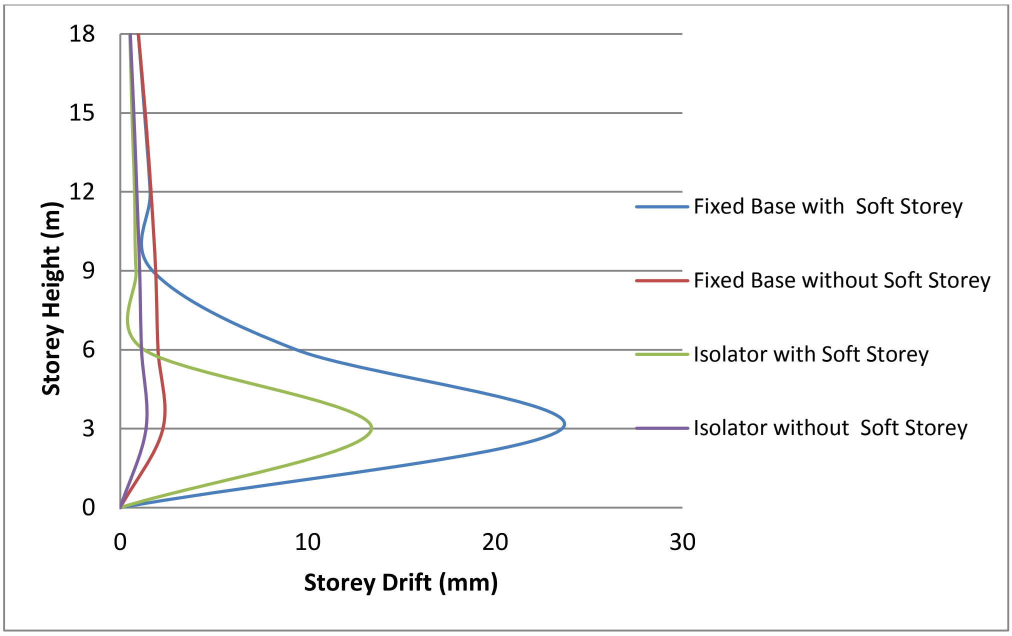


Figure 4.74: Storey drifts for four kinds of building

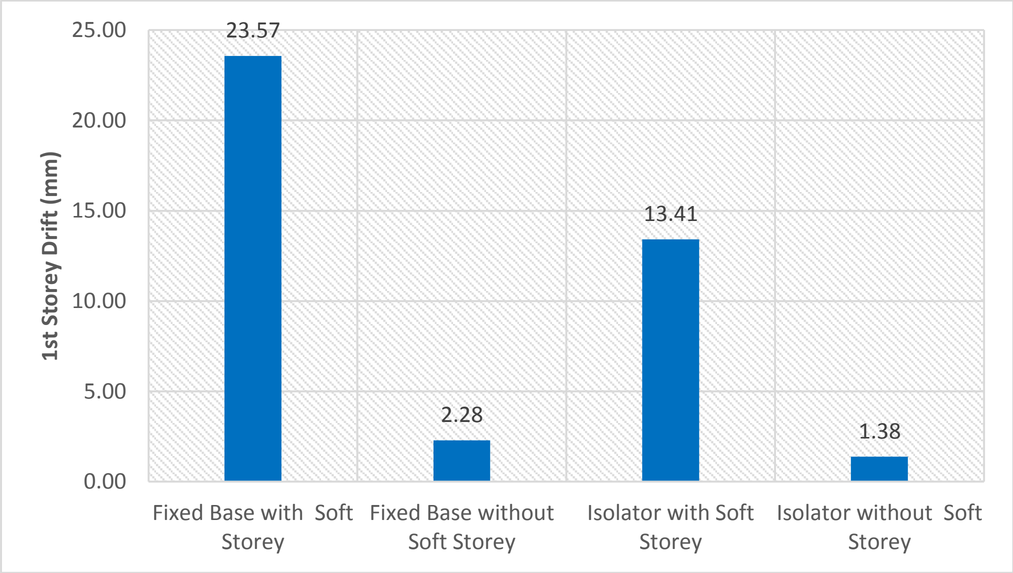


Figure 4.75: First storey drift for four kinds of building

4.12 Accelerations

In time period response spectra analysis, it is found that acceleration is higher in fixed base soft storey building in X direction (Figures 4.76, 4.77). Acceleration is higher in soft storey building compared to the in filled building. Max Acceleration is 74% higher in fixed base soft storey building compared with isolated soft storey building and Max Acceleration is 27% higher in the fixed base in filled building compared with Isolated in filled building.

In time period response spectra analysis, it is found that Acceleration is higher in fixed base soft storey building in Y direction (Figures 4.78, 4.79). Acceleration is higher in soft storey building compared to the in filled building. Maximum acceleration is 97% higher in fixed base soft storey building compared with isolated soft storey building and Max acceleration is 95% higher in the fixed base in filled building compared with Isolated in filled building

In level of joint it is found that acceleration is higher in fixed base soft storey building and acceleration is higher in soft storey building compared to the in filled building (Figure 4.80). Max Acceleration is 1.5 to 3 times higher in fixed base soft storey building levels compared with isolated soft storey building levels and Max acceleration is 1.5 to 2.5 times higher in the fixed base in filled building levels compared with Isolated in filled building levels.

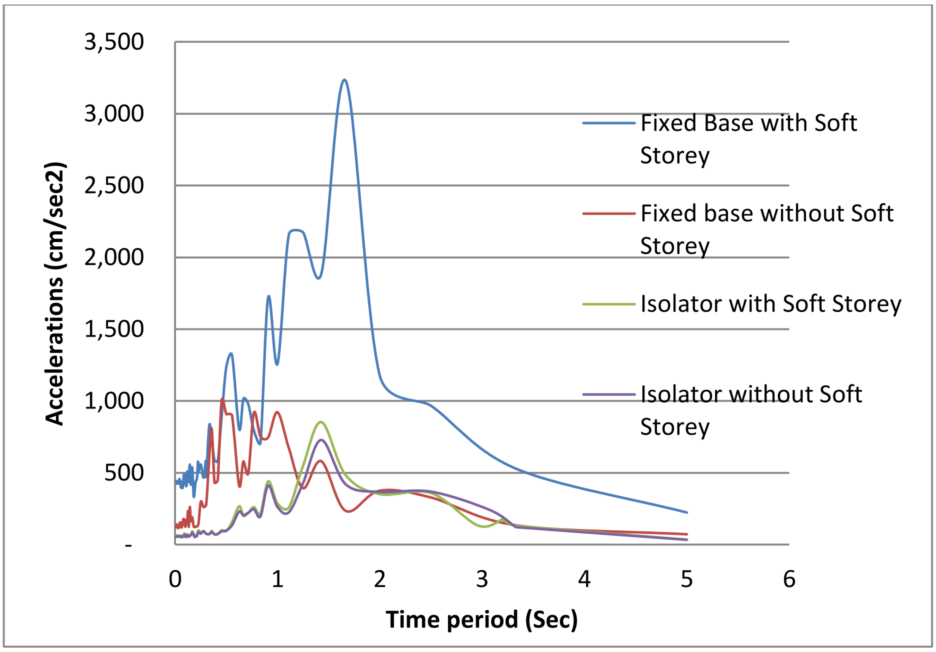


Figure 4.76: Acceleration Vs Time Period Response Spectra for the assigned Time History

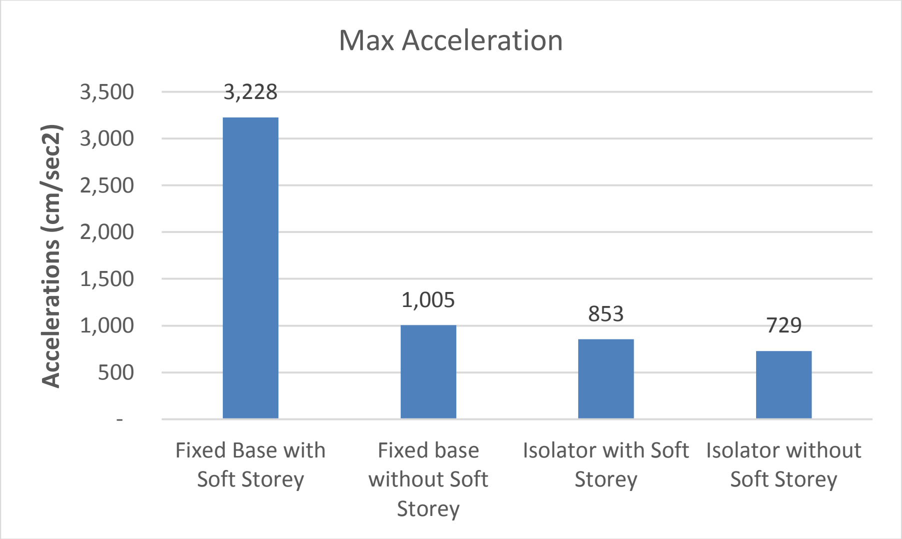


Figure 4.77: Maximum Acceleration in X direction for four different kinds of buildings

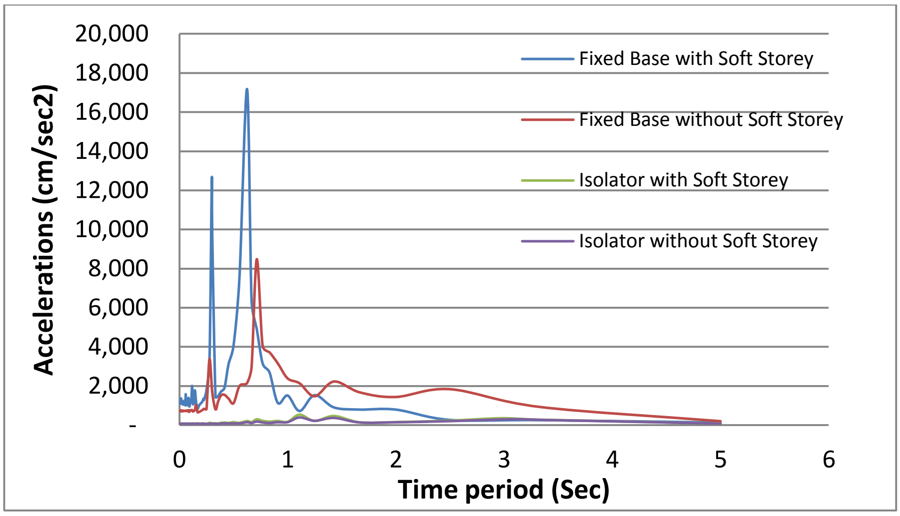


Figure 4.78: Acceleration Vs Time Period RS in Y direction for the assigned Time History

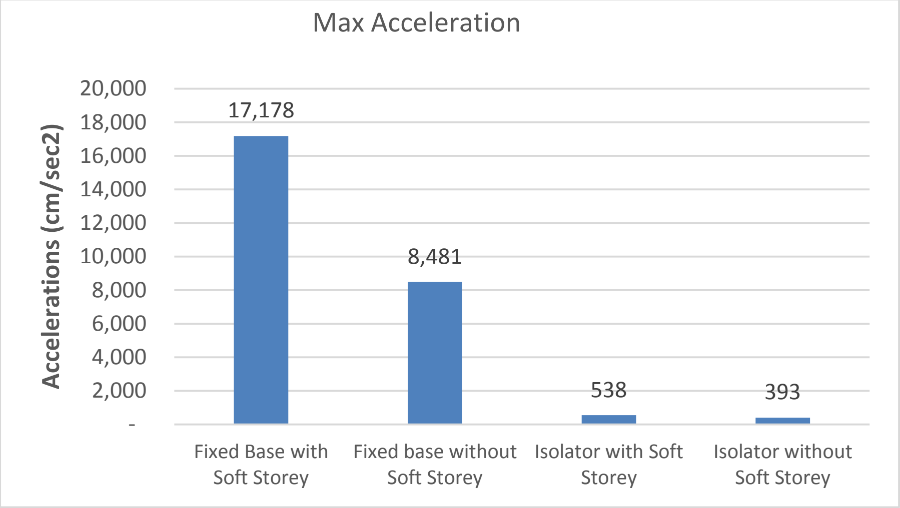


Figure 4.79: Maximum Acceleration in Y direction for four different kinds of buildings

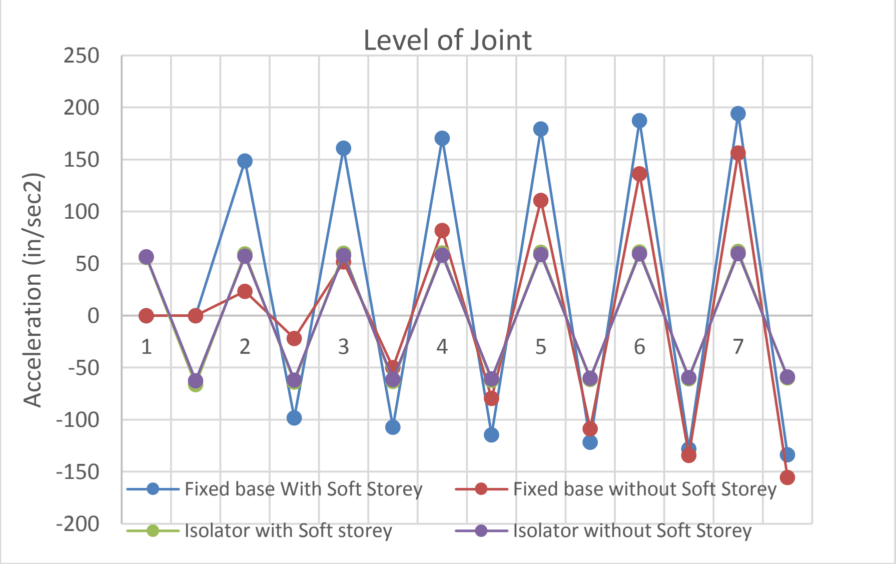


Figure 4.80 Acceleration at Storey Joints level for the assigned Time History

4.13 Conclusions

In building structures, soft storey subjects a major weak point in earthquake, and may cause severe change in structural behavior which may render the structure totally unusable. In this revise, effect of incorporation of isolator on the seismic behavior of buildings subjected to the appropriate earthquake for Dhaka has been evaluated. The values of structural parameters reduce in a drastic amount while using isolator. Apart from this, incorporation of Lead Rubber Bearing is beneficial than fixed base building. Of course the suitability of isolation system may vary as per time period, damping and specific design constraint. It is also shown that the amount of masonry infill is very vital for soft storey buildings.

In this study, isolated and fixed base building are incorporated for investigation. Isolation devices variation for building different column can also be adopted to justify the structural behavior. It should be pointed out that this investigation was based on soft to medium soil at free-field excitations in accordance with the site specific bilateral EQ data.

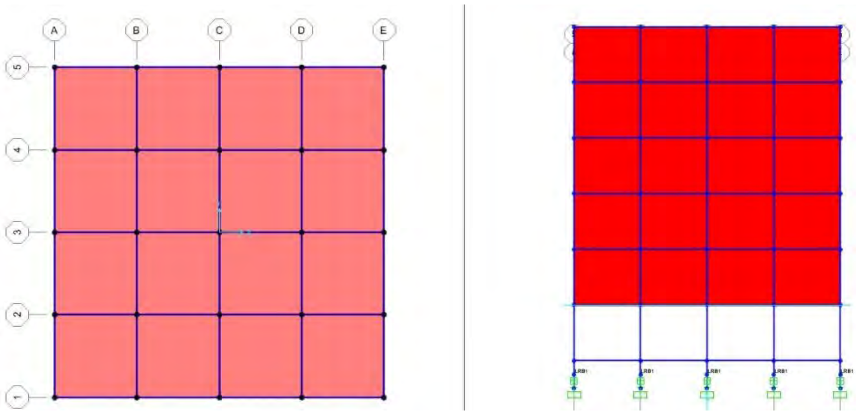
In this analysis we found that fixed base building shows its maximum displacement compared to other building and by using isolator we can reduce 45% of the building displacement value. Storey drift and building acceleration also found maximum in soft storey fixed base building which can also be reduce by using isolator. So there is soft storey. Infill and isolator effect for building from which we can decide the best and safe building to construct.

Chapter 5

PARAMETRIC STUDY OF A PROTOTYPE BUILDING WITH & WITHOUT ISOLATOR

5.1 General

For this study a prototype building of plan size 4@3.66m span at both directions has been chosen for 6 storeys with soft bottom storey (Figure 5.1) along with varying percentage of infill. Isolated building also analyzed for different varying isolator properties and compared with fixed base building. And then taking the same plan the building has also been analyzed for 3, 4 and 5 storey's to all the buildings dynamic analysis which is shown subsequently. For all the buildings dynamic analysis for both response spectrum and time history analysis has been performed same as previous chapter.



Plan Elevation

Figure 5.1. Plan and Elevation of modeled BI Building with Soft Bottom Story

5.2 Isolator system variation

Here isolation system was defined with effective periods of 2.0 seconds, which covers the usual range of isolation system period. Table 5.1 lists the variations considered in the evaluation and the hysteresis parameters used for modeling.

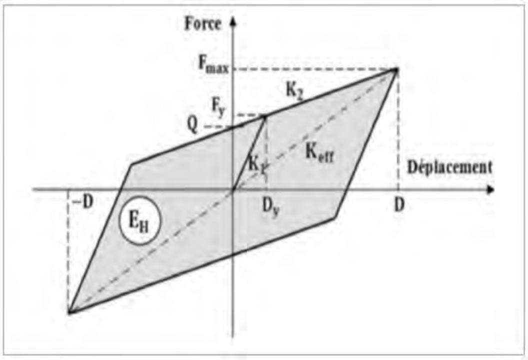


Table 5.1: Isolation variation

System	**Characteristic Strength (Q_d)**	**Period of Isolator (Sec)**	**Initial Stiffness, K_1**	**Post-yield Stiffness, K_2**	**Yield Force F_y**
Title			**(KN/mm)**	**(KN/mm)**	**(KN)**
LRB1	0.05	2	12.20158	1.11331	328
LRB2	0.075	2	13.20158	1.20455	450
LRB3	0.10	2	14.20158	1.29580	550
LRB4	0.15	2	15.20158	1.38704	650
LRB5	0.20	2	16.20158	1.47828	750

5.3 Observation and Results

After parametric study for 100% masonry infill with Soft Bottom Storey Building below result have found.

5.3.1 Maximum Moment with Isolator properties variation

For Initial Stiffness (K_1) variations:

Isolator properties plays a vital rule for moment variations. In this parametric study we have maximum moment from corner column of the isolated soft storey building and we found that maximum moment decrease with increasing initial stiffness (K_1) value.

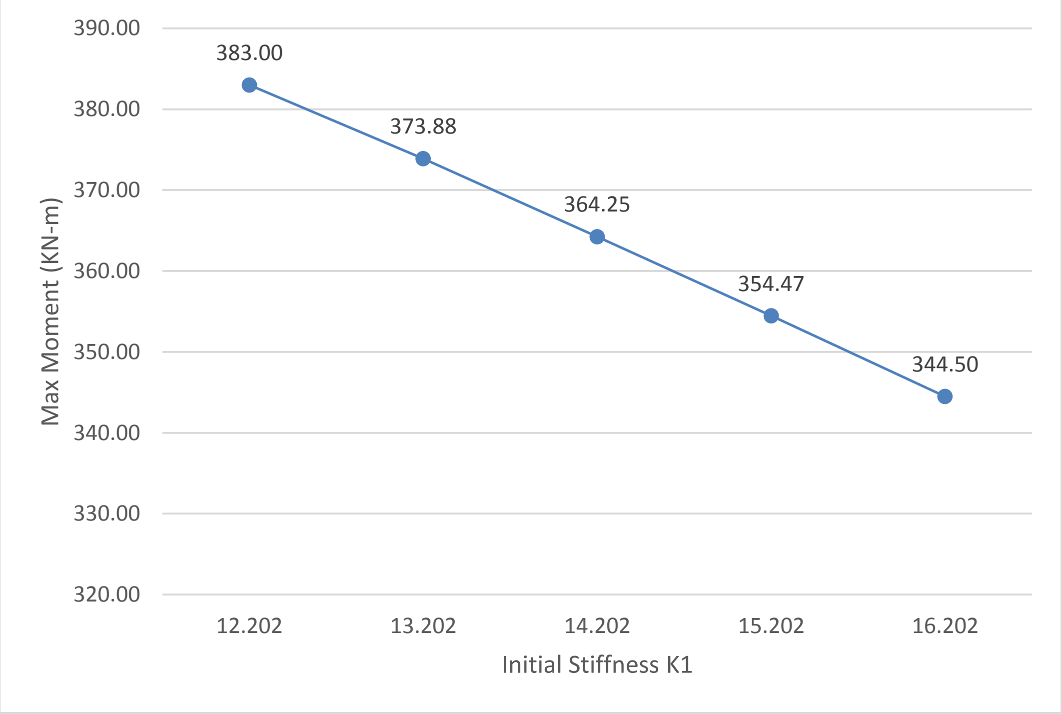


Figure 5.2: Moment variation with initial Stiffness (K_1) variation

For post yield Stiffness (K_2) variations:

Maximum moment showing different variation with increasing post yield stiffness (K_2).

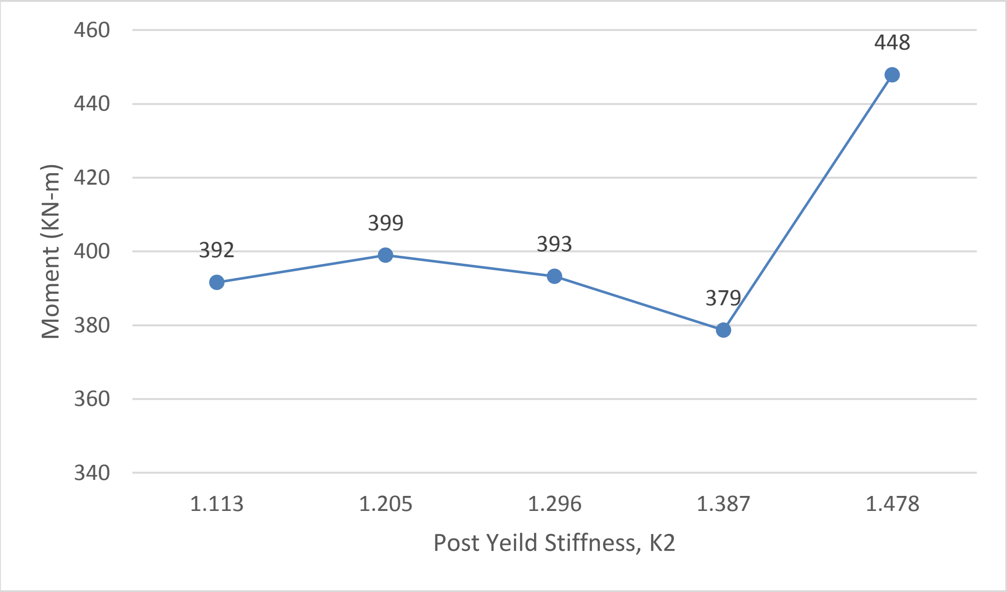


Figure 5.3: Moment variation with post yield Stiffness (K_2) variation

For Yield force (F_y) variations:

It is also observed that maximum moment increased with increasing yield force (F_y).

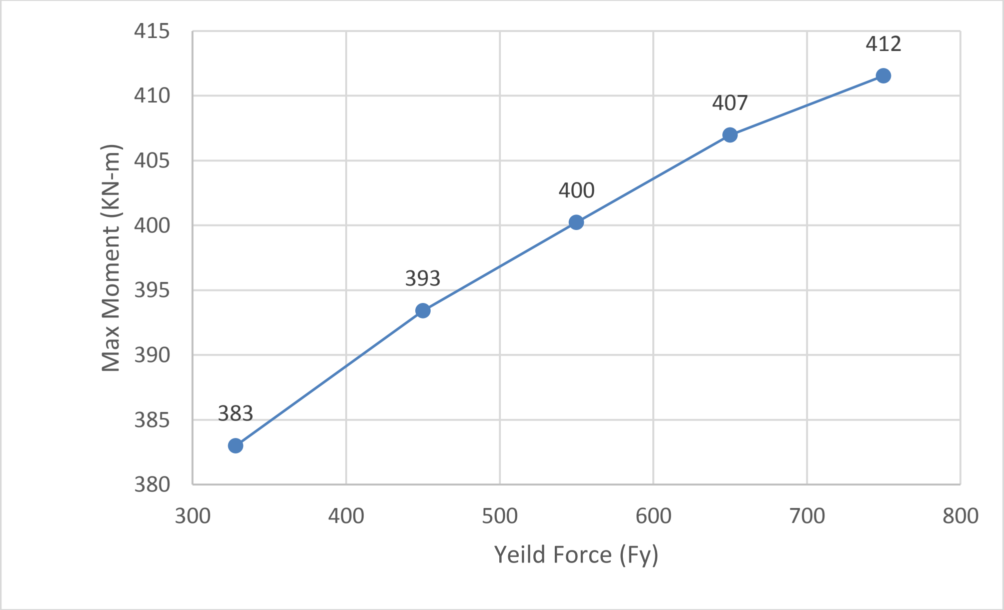


Figure 5.4: Moment changes with isolator properties (F_y) variation

5.3.2 Peak Shear with Isolator properties variation

Isolator properties also plays a vital rule for column shear variations. In this parametric study we found that peak shear decrease with increasing initial stiffness (K_1) and peak shear showing different variation with increasing post yield stiffness (K_2). It is also observed that peak shear increased with increasing yield force (F_y). (Figures 5.5 to 5.7)

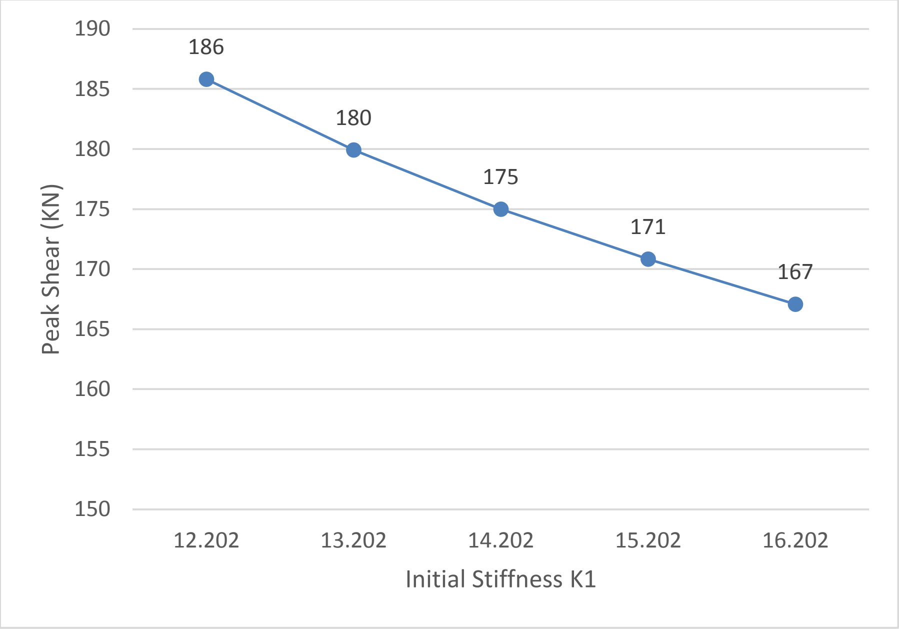


Figure 5.5: Peak shear variation with initial stiffness (K_1) variation

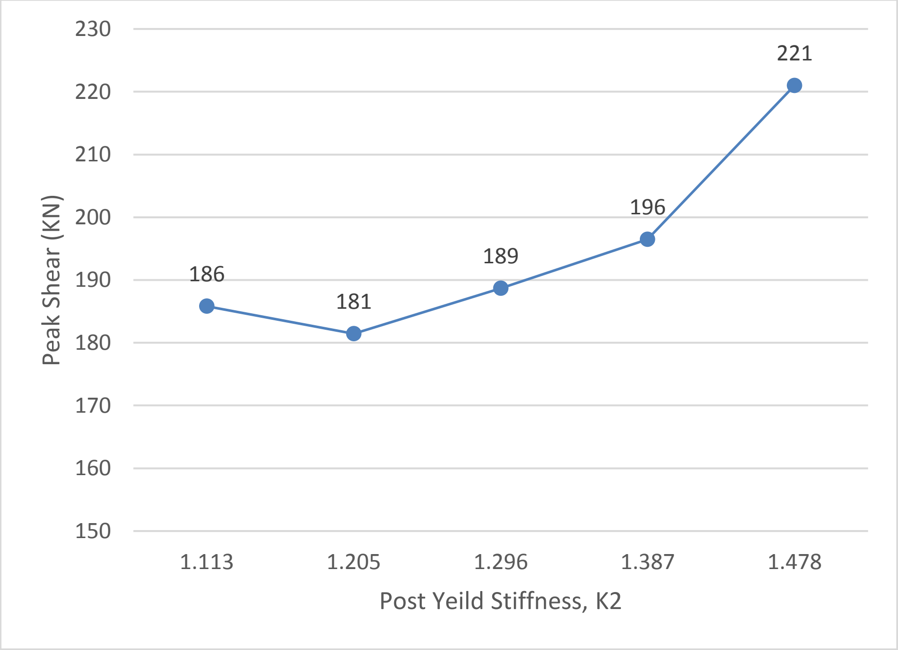


Figure 5.6: Peak shear variation with post yield stiffness (K_2) variation

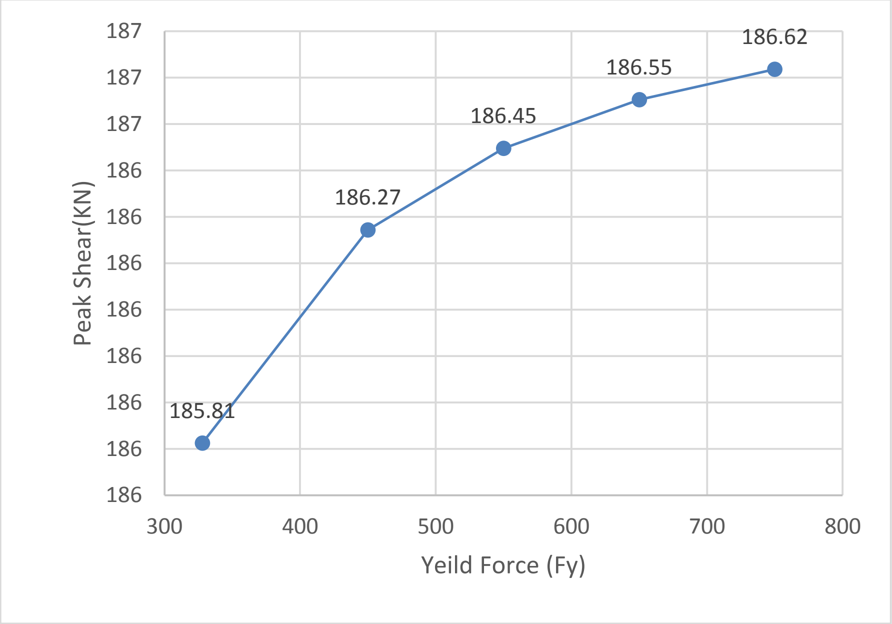


Figure 5.7: Peak Shear changes with isolator properties (F_y) variation

5.3.3 Max Displacement with Isolator properties variation

Isolator properties values variation gives maximum displacement variation in time history analysis. In this parametric study we found that maximum displacement decrease with increasing initial stiffness (K_1) and maximum displacement showing different variation with increasing post yield stiffness (K_2). It is also observed that maximum displacement increased with increasing yield force (F_y).

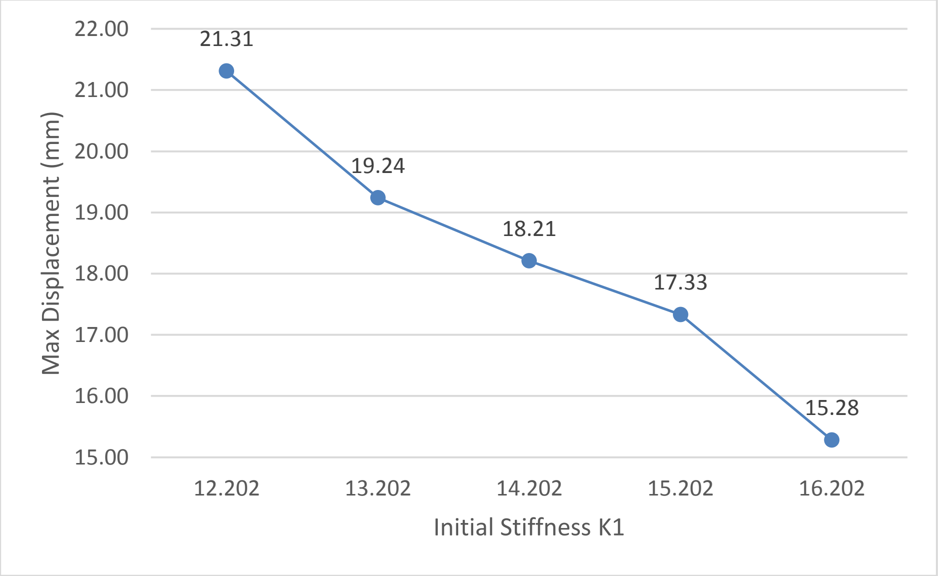


Figure 5.8: Maximum displacement variation with initial stiffness (K_1) variation

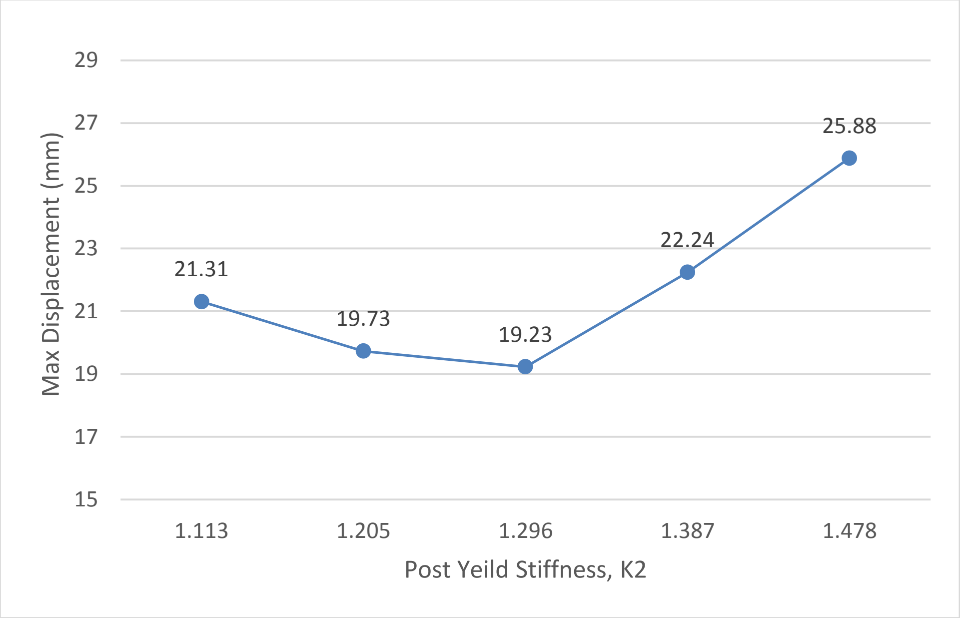


Figure 5.9: Maximum displacement variation with post yield stiffness (K_2) variation

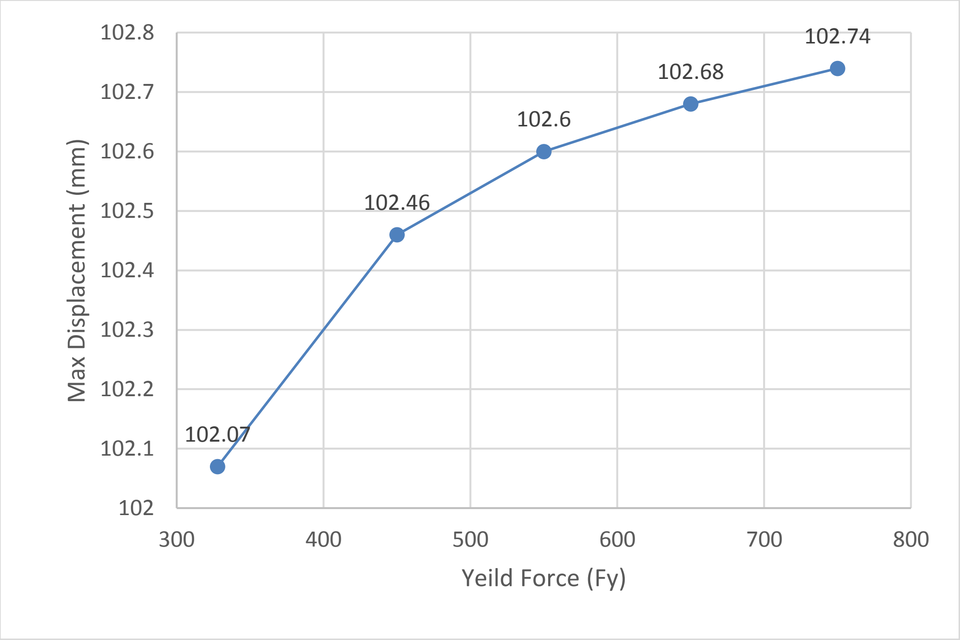
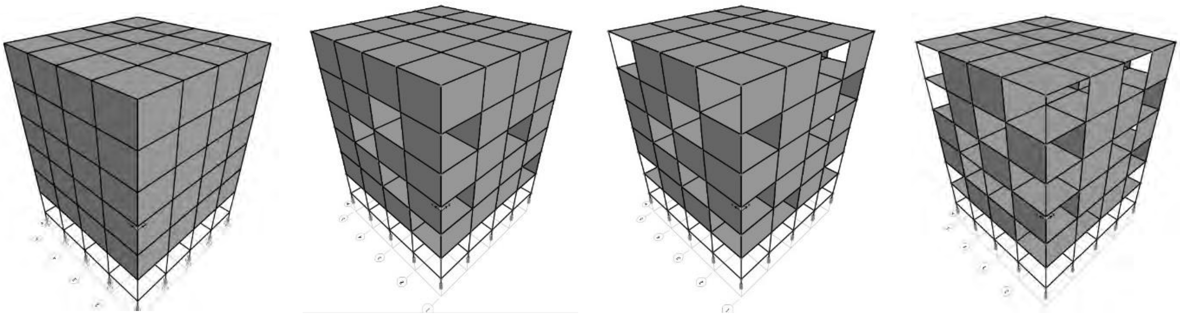


Figure 5.10: Maximum displacement changes with isolator properties (F_y) variation

5.3.4 Effect of infill variation

The percentage of infill in the soft storey structure changes the behavior of different parameters. In this study, values for 83%, 67%, and 50% masonry infill were compared with 100% infill, as shown in Figures. 5.12-5.13 for column moments.



100% infill 83% infill 67% infill 50% infill

Figure 5.11: % of infill variation in soft storey building

It has been revealed that there is radical reduction of column moments for BI building when the masonry infill amount is decreased than cent percent. This amount comes to around 7% value of the column moment at 100% infill. With increasing infill percentages, the column moment also increases which is true for both FB abs BI building. However, for the fixed structural case, 100% infill shows less column moment than lower infill percentage responses as the moment pattern is different for the fixed base case than isolated base. (Figures. 5.12, 5.13)

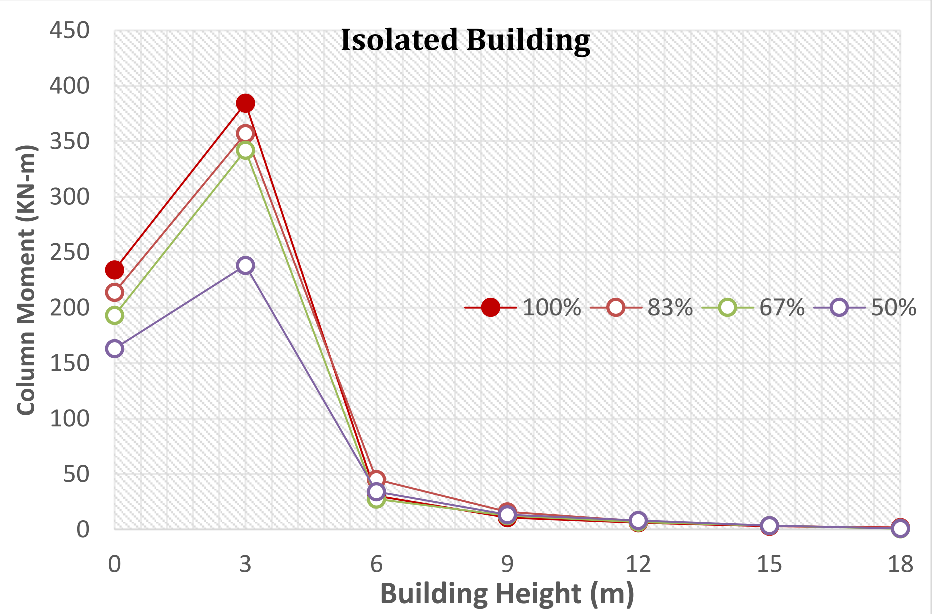


Figure 5.12 Interior Column Moment (KN-m) varying infill (**Isolated building**)

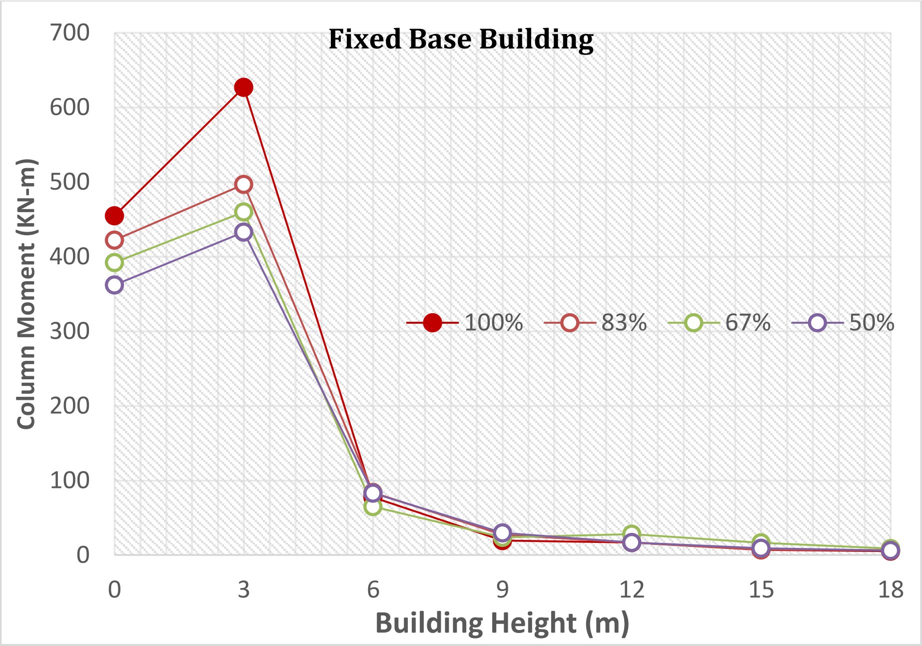
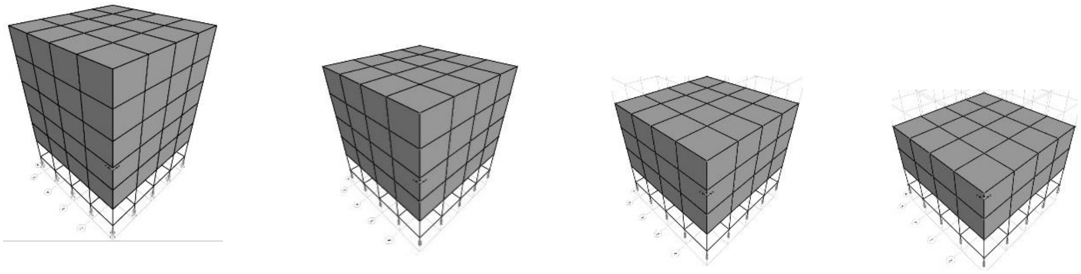


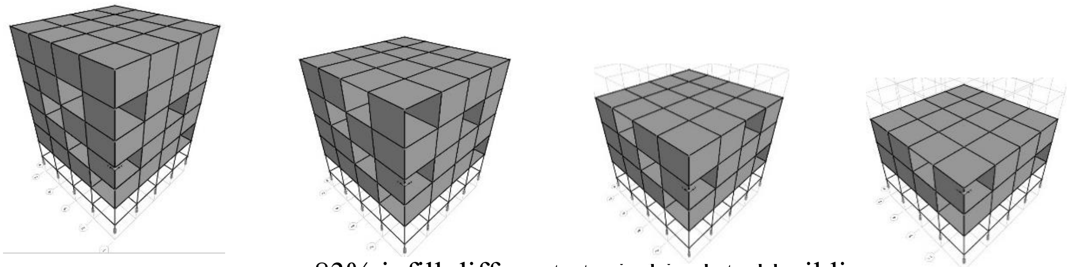
Figure 5.13 Interior Column Moment (KN-m) varying infill (**Fixed Base building**)

5.3.5 Effect of masonry infill variation on structural parameters

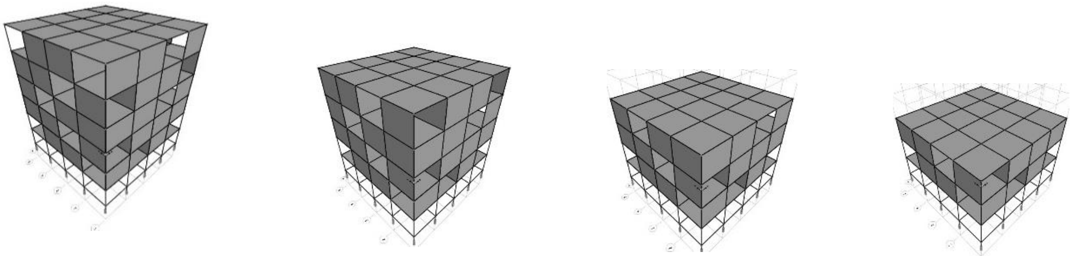
For this investigation taking the same plan the soft storey building has been analyzed for 3, 4, 5 and 6 storey's are chosen to ease the effective comparison for 100%, 83%, 67% and 50% infill for isolated building (Figures 5.14 to 5.15). The results described are the governing result through time history analysis. In soft storey position at 3m height exterior corner column moment is high for all buildings (Figures 5.16 to 5.19).



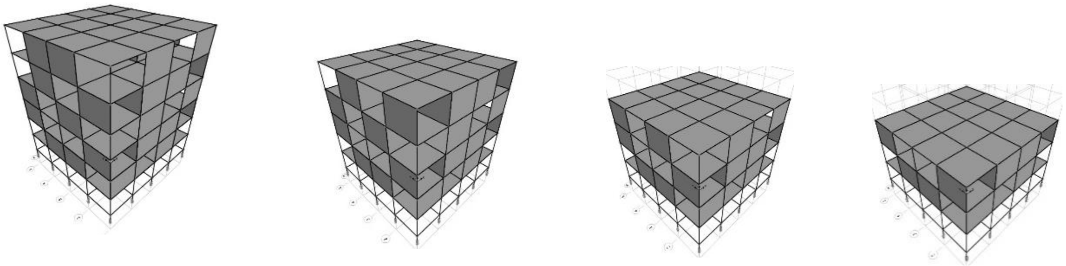
100% infill different storied isolated building



83% infill different storied isolated building



67% infill different storied isolated building



50% infill different storied isolated building

Figure 5.14: % of infill variation in different storied soft storey building

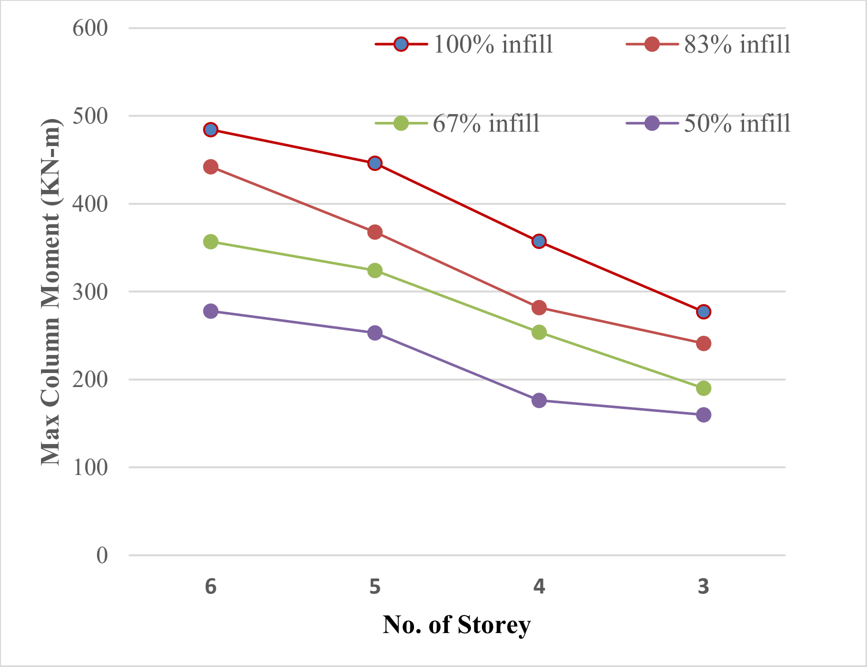


Figure 5.15: Exterior corner Column Max Moment for % infill for different storied isolated soft storey building.

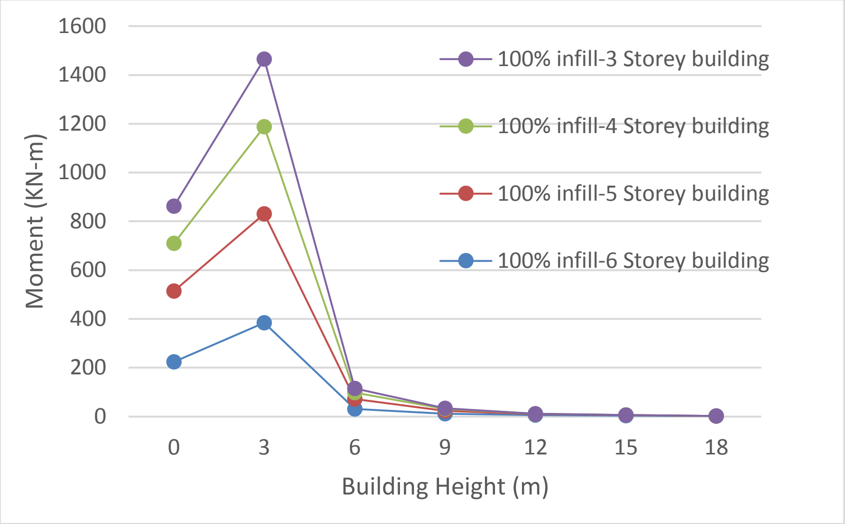


Figure 5.16: Exterior corner Column Moment for 100% infill for different storied building

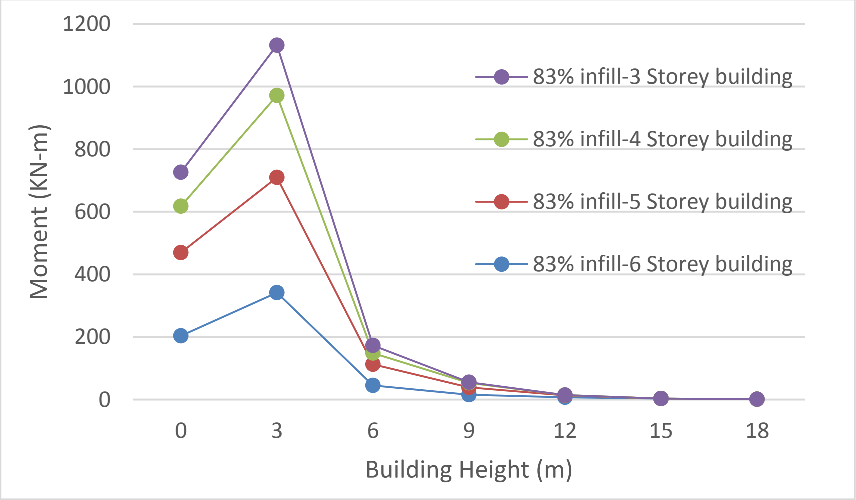


Figure 5.17: Exterior corner Column Moment for 83% infill for different storied building

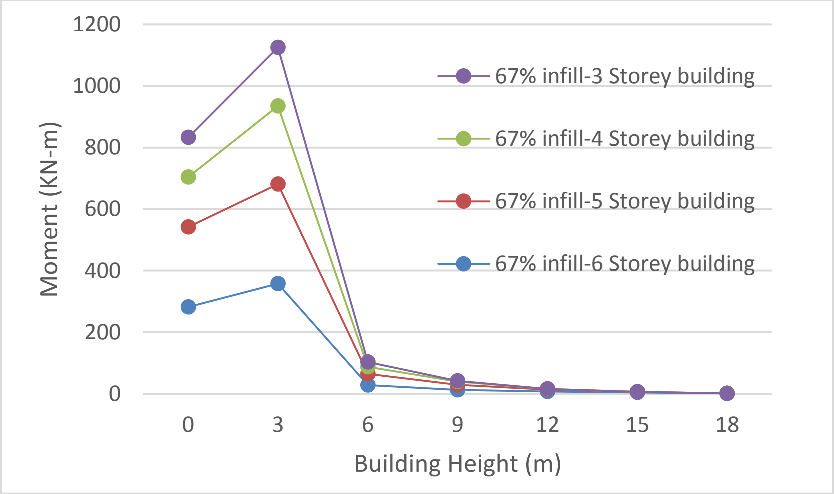


Figure 5.18: Exterior corner Column Moment for 67% infill for different storied building

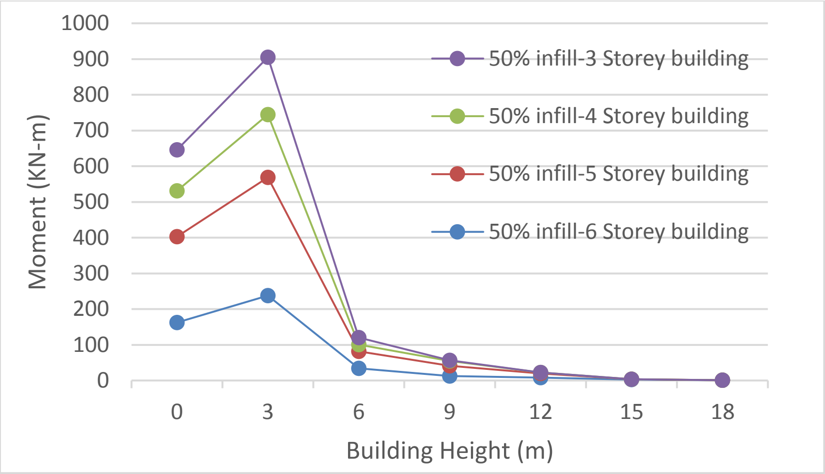


Figure 5.19: Exterior corner Column Moment for 50% infill different storied building

For 83% masonry infill 1st storey displacement is higher than other storey are shown from Figure 5.20. Displacement decreases after 1st storey and it's given the nominal value in the top storey.

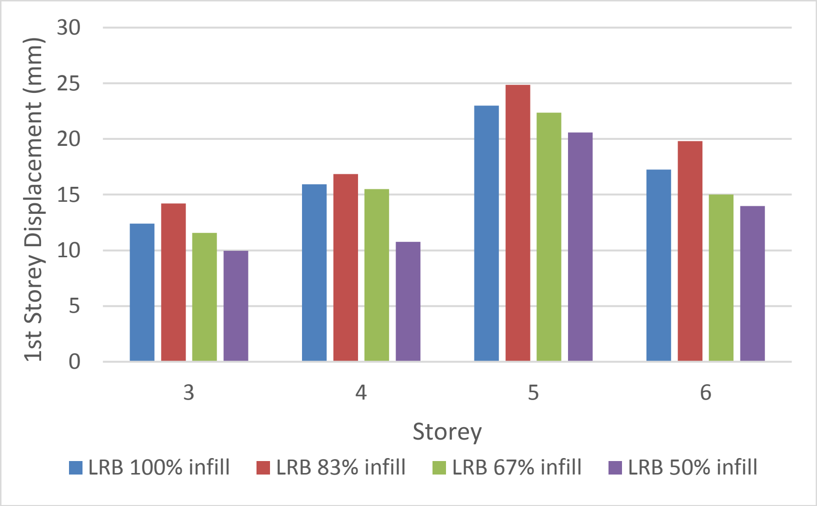


Figure 5.20: 1st storey displacement for 6, 5, 4 and 3 storey building in different infill

5.4 Conclusions

In this parametric study we found the soft storey and isolator effect for column moment, column shear, displacement, storey drift and acceleration changing the isolator properties and also found the variation of the moment, shear and storey displacement varying the % of infill for different storied building.

Where we found that isolator properties change the column moment, shear and relative displacement as well.

Chapter 6

COST ANALYSIS OF SEISMIC BASE ISOLATED SYSTEM

6.1 General

The question to Engineers for a building considering isolation system is Cost. There are both direct and indirect costs and cost savings related with the system. Though the installation of the isolation system adds to first cost than a non-isolated system, the use of Isolators reduces the reinforcement requirement of a building and ultimately reduces the total cost. So the use of isolators not only enhances the safety but also makes the structure more economic. The intent of this chapter is to analyze the cost and compare the cost savings while using the isolation system against the cases without using isolator.

6.2 Different Costs associated in Building Design and Construction

6.2.1 Engineering Design and Documentation Cost

An isolated structure requires lots of extra engineering efforts to analysis, design and documentation. The extra cost associated with this depends on the project i.e. Size and extent of the project. The following things are required to consider,

- Analysis effort is usually the largest added engineering cost. Analysis types and costs depend on the building type and location. Few isolated structures can be analyzed using the equivalent static load method so at least a response spectrum analysis is required. Some structures require a time history analysis. Even a non-isolated building is required to analyze in the same way, as an isolated structure analysis requires.
- Detailing of the isolator connections is an added cost. The large displacements cause secondary moments (P- Δ effect), which involve significant design effort.
- Extra site supervision may be needed for installation, which requires added cost.

6.2.2 Cost of Isolators

There is a wide range of cost of isolators. For most types, the cost is influenced mostly by the maximum displacement and to a lesser extent by the loads that they support. For a given level of seismic load, displacement is proportional to the isolated period and the greater extent of isolation, the greater the cost. The cost per device can range from $200 to $1200 or more (US dollars, year 2017). The total cost of isolation system depends on the efficiency of the isolator layout. Generally, the higher the load supported per isolator the higher the efficiency.

6.2.3 Cost of Structural Changes

The cost of changes to the structural configuration is potentially the largest component of the first cost and is a function of the building layout. A building with a basement can be isolated below the ground floor level with little added cost. A building that would have a slab on grade will require a suspended floor. The difference in cost between a suspended floor and a slab on grade add significantly to the construction cost.

Other cost may arise for the portion of the structure below the isolator plane. For example, if the isolators are on the top of the basement wall, below ground floor, they will apply out of plane loads to the basement walls, pilasters or buttresses may be needed to resist these loads.

Obviously, the costs of structural changes to accommodate isolation are very project specific. They generally range from 0% to a high of perhaps 20% of structural cost, although the extreme is unlikely. The most commonly added cost will be in the range of 1 % to 3%.

6.3 Different Types of Cost Savings associated with Isolation

6.3.1 Savings in Structural System Costs

The philosophy of seismic isolation is to reduce earthquake forces on the structural system and it follows that a system designed for lower forces will cost less. The extent of force reduction depends on, the structure, the level of seismicity and the extent of isolation. Generally, the earthquake force reduces by a factor of at least 3 and may be reduced by a factor of 8 or more for ideal situations.

6.3.2 Reduced Damage Costs

The isolated building will suffer less damage than a non-isolated building. This is because of the lower levels of ductility design into the isolated building. The reduced costs may be even more dramatic in the non-structural system. This arises from the reductions in floor accelerations and in structural drifts.

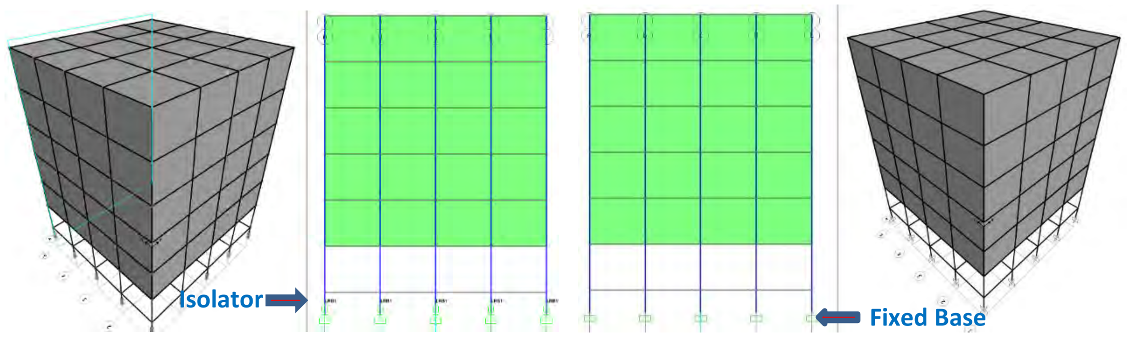
It is difficult to quantify reduced damage costs because life cycle analysis is not usually performed for most structures. As performance based Design becomes more widespread it is possible that this may occur. In the meantime, there are some tools available to assess the reduced costs of damage.

There are two components of damage in earthquakes:

- *Drift related damage:* Imposed deformations from drift will damage the primary structure and also non-structural components such as cladding, windows, partitions etc.
- Accelerations, Inertia forces from floor accelerations will damage components such as ceilings and contents.

For non-isolated buildings, it is difficult to control both of these causes of damage. A building can be designed stiffer to reduce drifts and reduce damage costs from this cause but the floor accelerations tend to be higher in stiffer buildings and so acceleration-related damage will increase.

6.4 Cost Analysis of the Building for which Isolator was designed



The following data (Table 6.1, 6.2, 6.3) was obtained for the building designed in the previous chapter. The table gives a detail comparison between the reinforcement requirement of an isolated and non-isolated building of a single Corner Column-C1 (4 nos.), Exterior middle column C2 (12 nos), interior column C3 (9 nos.) without changing the Column Dimension. Table 6.4, 6.5, 6.6 gives the same comparison with changing the column Dimension. Table 6.7, 6.8, 6.9 and Table 6.10 give a detail comparison between the reinforcement requirements of the Beams (B1, B2, B3 and Grade Beam GB respectively) of a single frame.

Table 6.1 Reinforcement requirement of Column C_1

Story Details	Story Height	Non- Isolated Building				Isolated Building			
	(ft)	Column Size (in^2)	Volume of 4 nos. of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for 4 Column (in^3)	Column Size (in^2)	Volume of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for 4 Column (in^3)
Base	5	15x22	79200	6.094	1462.56	15x22	79200	4.23	1015.20
GF	10	12x18	103680	4.591	2203.68	12x18	103680	3.822	1834.56
F-1	10	12x18	103680	4.591	2203.68	12x18	103680	3.822	1834.56
F-2	10	12x18	103680	3.483	1671.84	12x18	103680	2.731	1310.88
F-3	10	12x18	103680	3.483	1671.48	12x18	103680	2.731	1310.88
F-4	10	12x18	103680	2.543	1220.64	12x18	103680	1.882	903.36
F-5	10	12x18	103680	2.543	1220.64	12x18	103680	1.882	903.36
	∑=				**11654.88**			∑=	**9112.8**

Table 6.2 Reinforcement requirement of Column C_2

Story Details	Story Height	Non- Isolated Building				Isolated Building			
	(ft)	Column Size (in^2)	Volume of 12 nos of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for **12 Column** (in^3)	Column Size (in^2)	Volume of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for **12 Column** (in^3)
Base	5	15X20	216000	6.206	4468.32	15X20	216000	4.818	3468.96
GF	10	12x20	345600	4.906	7064.64	12x20	345600	3.91	5630.40
F-1	10	12x20	345600	4.906	7064.64	12x20	345600	3.91	5630.40
F-2	10	12x20	345600	4.187	6029.28	12x20	345600	3.15	4536
F-3	10	12x20	345600	4.187	6029.28	12x20	345600	3.15	4536
F-4	10	12x20	345600	2.831	4076.64	12x20	345600	2.08	2995.2
F-5	10	12x20	345600	2.831	4076.64	12x20	345600	2.08	2995.2
				∑=	38809.44			∑=	29792.16

Table 6.3 Reinforcement requirement of Column C_3

Story Details	Story Height (ft)	Non- Isolated Building				Isolated Building			
		Column Size (in^2)	Volume of 9 nos of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for **9 column** (in^3)	Column Size (in^2)	Volume of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for **9 column** (in^3)
Base	5	15X22	178200	6.375	3442.5	15X22	178200	4.95	2673
GF	10	15x20	324000	5.32	5745.60	15x20	324000	4.25	4590
F-1	10	15x20	324000	5.32	5745.60	15x20	324000	4.25	4590
F-2	10	15x20	324000	4.52	4881.6	15x20	324000	3.61	3898.8
F-3	10	15x20	324000	4.52	4881.6	15x20	324000	3.61	3898.8
F-4	10	15x20	324000	3.25	3510	15x20	324000	2.25	2430
F-5	10	15x20	324000	3.25	3510	15x20	324000	2.25	2430
				∑=	31716.9			∑=	24510.6

Table 6.4 Reinforcement comparison of Column C_1 reducing Column Size

Story Details	Story Height (ft)	Non- Isolated Building				Isolated Building			
		Column Size (in^2)	Volume of 4 nos. of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for 4 Column (in^3)	Column Size (in^2)	Volume of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for 4 Column (in^3)
Base	5	15x22	79200	6.094	1462.56	15x20	72000	4.04	969.60
GF	10	12x18	103680	4.591	2203.68	10x18	86400	3.69	1771.2
F-1	10	12x18	103680	4.591	2203.68	10x18	86400	3.69	1771.2
F-2	10	12x18	103680	3.483	1671.84	10x18	86400	2.51	1204.8
F-3	10	12x18	103680	3.483	1671.48	10x18	86400	2.51	1204.8
F-4	10	12x18	103680	2.543	1220.64	10x18	86400	1.72	825.60
F-5	10	12x18	103680	2.543	1220.64	10x18	86400	1.72	825.60
				∑=	**11654.88**			∑=	**8576.4**

Table 6.5 Reinforcement comparison of Column C_2 reducing Column Size

Story Details	Story Height (ft)	Non- Isolated Building				Isolated Building			
		Column Size (in^2)	Volume of 12 nos of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for **12 Column** (in^3)	Column Size (in^2)	Volume of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for **12 Column** (in^3)
Base	6	15X20	216000	6.206	4468.32	12X20	172800	4.69	3376.8
GF	10	12x20	345600	4.906	7064.64	10x20	288000	3.68	5299.2
F-1	10	12x20	345600	4.906	7064.64	10x20	288000	3.68	5299.2
F-2	10	12x20	345600	4.187	6029.28	10x20	288000	3.03	4363.2
F-3	10	12x20	345600	4.187	6029.28	10x20	288000	3.03	4363.2
F-4	10	12x20	345600	2.831	4076.64	10x20	288000	1.97	2836.8
F-5	10	12x20	345600	2.831	4076.64	10x20	288000	1.97	2836.8
				∑=	**38809.44**			∑=	**28375.2**

Table 6.6 Reinforcement comparison of Column C_3 reducing Column Size

Story Details	Story Height (ft)	Non- Isolated Building				Isolated Building			
		Column Size (in^2)	Volume of 9 nos of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for **9 column** (in^3)	Column Size (in^2)	Volume of Column (in^3)	Reinforcement Required (in^2)	Total Volume of Reinforcement for **9 column** (in^3)
Base	6	15X22	178200	6.375	3442.5	12X22	142560	4.78	5162.4
GF	10	15x20	324000	5.32	5745.60	12x20	259200	4.08	4406.4
F-1	10	15x20	324000	5.32	5745.60	12x20	259200	4.08	4406.4
F-2	10	15x20	324000	4.52	4881.6	12x20	259200	3.53	3812.4
F-3	10	15x20	324000	4.52	4881.6	12x20	259200	3.53	3812.4
F-4	10	15x20	324000	3.25	3510	12x20	259200	2.13	2300.4
F-5	10	15x20	324000	3.25	3510	12x20	259200	2.13	2300.4
				∑=	**31716.9**			∑=	**26200.80**

Table 6.7 Reinforcement requirement of Floor Beam (F-1 to 5)

Story Details	Length (ft)	Non- Isolated Building				Isolated Building			
		Beam Size (in^2)	Volume of 40 nos. of Beam (in^3)	Reinforcement Required (By Volume) (in^3)		Beam Size (in^2)	Volume of 40 nos. of Beam (in^3)	Reinforcement Required (By Volume) (in^3)	
				-ve	+ve			-ve	+ve
F-1	12	10X12	691200	25698	23688	10X12	691200	5790	3660
F-2	12	10X12	691200	26172	24162	10X12	691200	5772	3660
F-3	12	10X12	691200	25902	23910	10X12	691200	5604	3648
F-4	12	10X12	691200	22524	19854	10X12	691200	4944	3228
F-5	12	10X12	691200	16388	14040	10X12	691200	4056	2658
				∑=116684	∑=105654			∑=26166	∑=16854

Table 6.8 Reinforcement requirement of Grade Beam GB

Story Details	Length (ft)	Non- Isolated Building				Isolated Building			
		Beam Size (in^2)	Volume of **40** nos. of Beam (in^3)	Reinforcement Required (By Volume) (in^3)		Column Size (in^2)	Volume of **40** nos. of Beam (in^3)	Reinforcement Required (By Volume) (in^3)	
				-ve	+ve			-ve	+ve
GF	12	12X15	1036800	26143	23771	12X15	1036800	5887	4993
				∑=26143	∑=23771			∑=5887	∑=4993

6.4.1 Cost Analysis of Column

The ten-story building, which was designed for base isolation, has 25 columns and in the process of analysis and design it was assumed that the columns were of FB= 10X12, GB= 12X15 size. Table 6.1, 6.2, 6.3 gives the total amount i.e. volume of reinforcement required for a single column (both isolated and non-isolated) from Base to Top. In Table 6.9 that volume of reinforcement is converted to weight of reinforcement by assuming unit weight of steel 490 lb/ft3. From the current market price of 60- grade steel, we have assumed price of steel as 90,000 Taka/ton including installation for the cost analysis. In the Building there are 4 columns C1, 12 columns C2, 9 columns C3 members in total six story. Table 6.9 gives the cost of reinforcement for individual single Column. So in the computation of total cost of reinforcement for those Columns got the Column reinforcement difference between isolated and non-isolated building (Figure 6.1)

Table 6.9 Cost Calculation of individual single Column (GF to Top Floor)

Column	Non- Isolated Building		Isolated Building	
	Weight of Reinforcement (Kg)	Cost (Taka)	Weight of Reinforcement (Kg)	Cost (Taka)
C1	1502.23	135201	1105.44	99490
C2	5002.26	450203	3657.36	329162
C3	4088.09	367928	3377.10	303939
Total	10592.58	953332	8140	732591

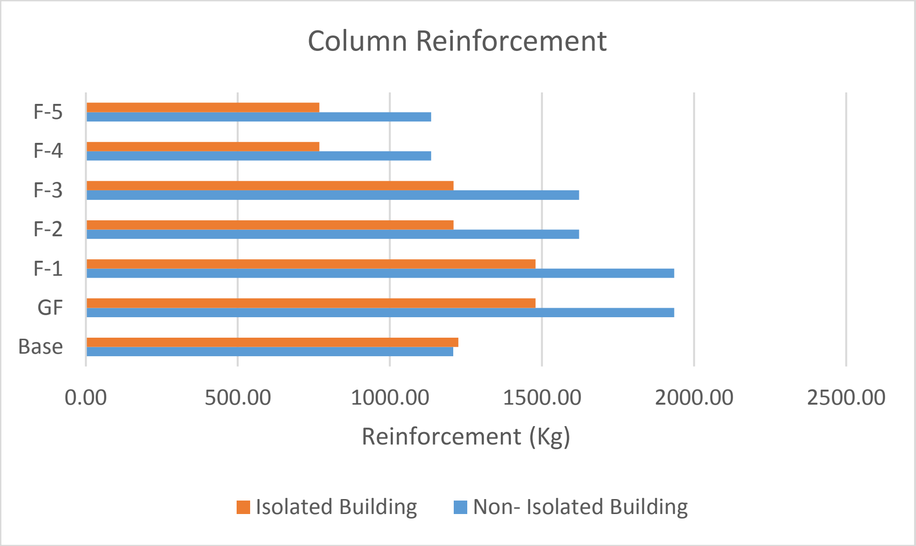


Figure 6.1: Column reinforcement different between isolated & non-isolated building

6.4.2 Cost Analysis of Beam

The six-story building, which was designed for base isolation, has two types of Beams (GB & FB). Table 6.7, 6.8 gives the total amount i.e. volume of reinforcement required for those beams (both isolated and non-isolated) from F-1 to Top. In Table 6.10 that volume of reinforcement is converted to weight of reinforcement by assuming unit weight of steel 490 lb/ft3. From the current market price of 60-grade steel, we have assumed price of steel as 90,000 Taka/ton for the cost analysis. Beams reinforcement difference between isolated and non-isolated building shown in (Figure 6.2)

Table 6.10 Cost Calculation of Beam (GF to Top Floor)

Beam	Non- Isolated Building		Isolated Building	
	Weight of Reinforcement (Kg)	Cost (Taka)	Weight of Reinforcement (Kg)	Cost (Taka)
GB	6,434	579,060	1,402	126,212
FB	28,658	2,579,205	5,545	499,050
Total	35,092	3,158,265	6,947	625,262

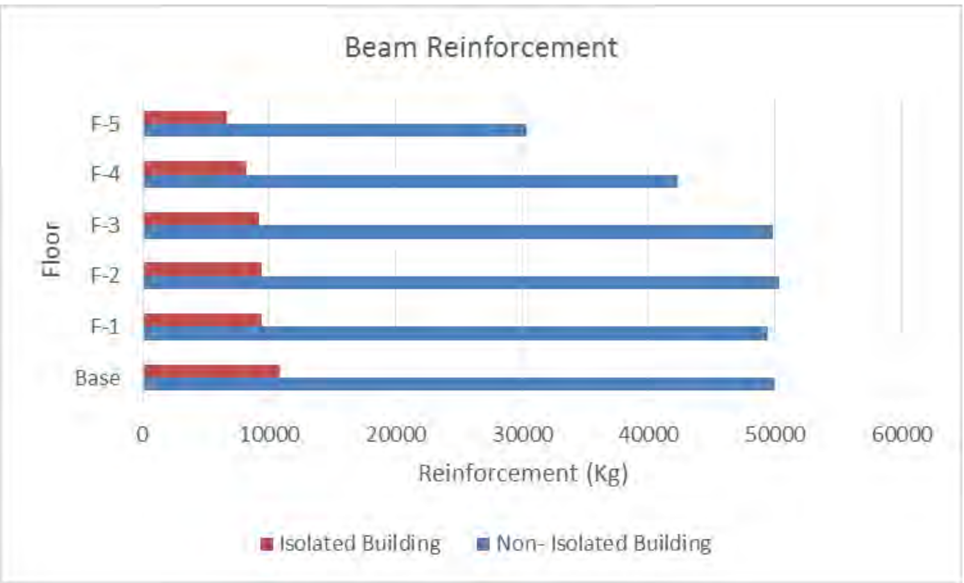


Figure 6.2: Beam reinforcement different between isolated & non-isolated building

6.4.3 Cost Savings through reducing reinforcement

As mentioned in the previous two sections (6.4.1 and 6.4.2), the costs obtained from Table 6.9 and Table 6.10 was multiplied by the factors told above. Table 6.11 gives the total cost savings by using isolators in the building.

Table 6.11 Cost savings through reducing reinforcement by using isolators in the building.

Structural Element	Non- Isolated Building	Isolated Building	Savings (Taka)
	Total cost (Taka)	Total cost (Taka)	
Column	953,332	732,591	220,741
Beam	3,158,265	625,262	2,533,003
Sum Total	**4,111,597**	**1,357,853**	**2,753,744**

6.5 Cost Analysis of Isolator

Isolator cost depends on the layer thickness, no. of layers, diameter of isolator etc. The values of different components are analyzed result for the taken 6 story building. Cost per Isolator has been collected from inter net. Table 6.12 shows cost of total 25 Isolators in the Building.

Table 6.12 Isolator costing in the building

Diameter of Isolator (in)	Layer Thickness (in)	No. of Layers	Allowable Displacement (in)	Cost per Isolator (Tk.)	No. of Isolators	Cost for Isolators (Tk.)
13.5	0.25	15	1.64	104,000	25	**2,600,000**

6.6 Net Cost Savings in the Isolated Building

Though reinforcement savings of Beams and Columns decreases the building cost in isolated system, Isolator adds a countable amount of cost. Here for the sample 6 story building, cost savings excluding the Isolator costs are mentioned in Table 6.13.

Table 6.13 Net Cost Savings in the Isolated Building

No. of Story	Savings from Beams and Columns	No. of Isolators	Cost per Isolator(Dollar)	Cost per Isolator(Tk.)	Isolator Costs(Tk.)	Net Savings (Tk.)
6	2,753,744	25	1,300	104,000	2,600,000	**153,744**

6.7 Some other means of Cost Savings

Though the cost of isolators is highly site specific and displacement related, yet the cost savings of our current Building compensates the minimum cost of isolators used. Further cost reduction is achievable if the following steps are followed.

- By changing the dimension of Beam and Column along with reinforcement
- By readjusting the footing size and footing reinforcement
- By using different Column sections in different panels (Exterior, Interior, and Comer) rather than using same column sections for all Columns
- By changing the stiffness and Damping parameters of Isolator

6.8 Recommendations

After cost study for both isolated and no isolated building, we can decide that isolated building can save money and can achieve safety from earth quake if we can properly design the isolator & isolated building as well. So to construct a building using isolator is the best option for safety and cost savings at least 3% to 4% from the total building cost.

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY

7.1 General

This paper discusses the design considerations for the base-isolated demonstration building, the design and testing of the bearings and the cost-effectiveness of the isolation system. The seismic performance of the base-isolated building is discussed in chapter 2. It is expected that this newly developed isolation system, designed specifically for low-axial pressure applications, can be adopted for the earthquake protection of a variety of smaller public buildings such as housing, schools, and hospitals in developing countries.

7.2 Drawback

Though the cost of isolators is highly site specific and displacement related, yet the cost savings of building compensates the minimum cost of isolators. The design technique of base isolator of this research can be used effectively for any other buildings but the output results of different relationship obtained here is limited to 6- storey Residential Building. Based on the entire study, with known factors further analysis are suggested for improving safety climate in Building construction not only Dhaka but also globally and to generalize the gaining for all high-rise structures, steps that can be implemented conforming economic and efficient constraints will be suggested.

7.3 Conclusions

From the analysis performed in this work, it can be seen that base isolation is an effective way of reducing moment and shear that concentrates in a soft storey column. Using the parameters appropriate for Dhaka region and those of Lead Rubber Bearing isolator, it has been found that incorporation of base isolation reduces the column moment up to 39% whereas, column shear is reduced by 55%. Hence, LRB isolators may be used as effecting way of reducing risk in a soft storey building.

After an extensive and systemic study, the following conclusions applicable only for this building:

- The design technique of base isolator used in chapter 3 can be used effectively for any other buildings.
- The installation of isolator in building considerably increases the time period of building, which means it reduces the possibility of resonance of the structure. So installation of isolator provides the greater safety of the building by reducing the severity of damage for both structures and human lives considerably.
- Top displacement of an isolated building increases but the relative maximum displacement of a building reduces in a larger amount (generally 35%-70% range) by the use of isolator.
- Using Isolator displacement value can be reduced 45% for fixed base soft storey building and 41% for fixed base without soft storey building.
- Storey drift is found maximum in fixed base soft storey building. The upper stories move as single block as there is presence of infill masonry which makes it stiffer. Hence displacement is more in soft storey as we found storey drift is maximum in first storey location i.e soft storey location and using isolator in fixed base soft storey building storey drift can be reduce 43%.
- From these analysis it can be seen that in non-isolated soft storey building, maximum column moment is 39% higher than that of isolated soft storey building. Again, non-isolated without soft storey building maximum column moment is 41% higher than isolated without soft storey building. Favorable effect of using base isolation is evident from these results that it reduce column moment 39% in soft storey building and 41% in fixed base building respectively.
- Distribution of interior column shear with storey height for four different buildings with corresponding peak shear at soft storey level. As can be seen, in non-isolated soft storey building maximum column shear is 55% higher than isolated soft storey building and non-isolated without soft storey building maximum column shear is 52% higher than isolated without soft storey building. So, Column Shear also can be reduce 55% in soft storey building and 52% in infill building by using isolator.
- Acceleration is higher in soft storey building compared to the in filled building. Max Acceleration is 74% higher in fixed base soft storey building compared with isolated

soft storey building and Max Acceleration is 27% higher in the fixed base in filled building compared with Isolated in filled building.

- In parametric study we found that Isolator properties also plays a vital rule for column shear variations. We found that peak shear, moment and displacement decrease with increasing initial stiffness (K_1) and peak shear, moment and displacement showing different variation with increasing post yield stiffness (K_2). It is also observed that peak shear, moment and displacement increased with increasing yield force (F_y).
- In parametric study we found that moment values changes with different properties of isolator. So by this analysis we can use accurate isolator to adjust the column moment for the building as well.
- From % of infill variation for different storied building (i.e. 3, 4 5, 6 and so on) we can adjust column moment and displacement by this study. For 83% masonry infill 1st storey displacement is higher than other storey. Displacement decreases after 1st storey and it's given the nominal value in the top storey.
- The cost saving in isolated building increases largely with the increase in no. of stories. So to construct a building using isolator is the best option for safety and cost savings at least 3% to 4% from the total building cost.

7.4 Recommendations for Future Study

- As the output of the thesis is restricted to 6 Story Building further analysis work is encouraged for a generalized data of all High-rise Building.
- Extensive study is required on the cost of rubber isolation i.e. there must be some established relationships between increase in rubber layers and cost, increase/decrease in damping and cost, increase in bearing diameter and costs
- Can be study using different types isolator compared to LRB
- Building cost estimation using isolator can be more details for all structural member.
- Shear wall effect can be established in this analysis.

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