DESIGN OF BASE ISOLATORS FOR A 5-STOREYED BUILDING WITH ISOLATOR'S ANALYSIS IN ABAQUS®

A PROJECT

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

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

Under the supervision of

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MAY 2015

DECLARATION

I hereby declare that the research work presented in this Project entitled "*Design of Base Isolators for a 5-storeyed Building with Isolator's Analysis in ABAQUS*®" submitted for the award of the degree of Master of Technology in Structural Engineering to the Department of Civil Engineering, Jaypee University of Information and Technology Waknaghat, is original and my own account of research. This research work is independent and its main content work has not previously been submitted for degree at any university in India or Abroad.

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CERTIFICATE

This is to certify that the work which is being presented in the project title "DESIGN OF BASE ISOLATORS FOR A 5-STOREYED BUILDING WITH ISOLATOR'S ANALYSIS IN ABAQUS®" in partial fulfillment of the requirements for the award of the degree of Master of Technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by Amit Thakur during a period from August 2014 to May 2015 under the supervision of **Mr. Anil Dhiman** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

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

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ABSTRACT

In recent years considerable attention has been paid to research and development of structural control devices with particular emphasis on mitigation of wind and seismic response of buildings.

vibration-control measures i.e passive, active, semi-active and hybrid vibration control methods have been developed in past few years . Passive vibration control helps to keep the building essentially elastic during large earthquakes and its fundamental frequency is lower than both its fixed base frequency and the frequencies of ground motion. Base isolation is a passive vibration control system and helps to reduce the seismic forces at a large scale.

Forced vibration analysis was carried out on the framed structure by the use of computer program ABAQUS 6.13 and validating the same experimentally. The isolation system reduces the interstorey drift in the superstructure by a factor of at least two and sometimes by a factor of at least five. Acceleration responses are also reduced in the structure by an amount of although the amount of reduction depends upon the force deflection characteristic of the isolators. Better performance of isolated structure with respect to the fixed base structure is also observed in floor displacements, base shear floor acceleration relative to the ground(less acceleration imparted on each floor and their magnitude is approximately same in each floor), roof displacement. Introduction of horizontal flexibility at the base helps in proper energy dissipation at the base level and reducing the seismic forces in the super structure which are considered during design. For Comparison Building is designed with fixed base and with base isolator , and storey drift , displacement , velocity and acceleration are compared for both the structures . Then Manual Designing of the Isolator is done and analysis of that isolator is done in ABAQUS Software.

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CHAPTER

1

INTRODUCTION

1.1 Background

For seismic design of building structures, the traditional method, *i.e*., strengthening the stiffness, strength, and ductility of the structures, has been in common use for a long time. Therefore, the dimensions of structural members and the consumption of material are expected to be increased, which leads to higher cost of the buildings as well as larger seismic responses due to larger stiffness of the structures. Thus, the efficiency of the traditional method is constrained. To overcome these disadvantages associated with the traditional method, many vibration-control measures, called structural control, have been studied and remarkable advances in this respect have been made over recent years. Structural Control is a diverse field of study. Structural Control is the one of the areas of current research aims to reduce structural vibrations during loading such as earthquakes and strong winds.

In terms of different vibration absorption methods, structural control can be classified into active control, passive control, hybrid control, semi-active control and so on. The passive control is more studied and applied to the existing buildings than the others. Base isolation is a passive vibration control system that does not require any external power source for its operation and utilizes the motion of the structure to develop the control forces. Performance of base isolated buildings in different parts of the world during earthquakes in the recent past established that the base isolation technology is a viable alternative to conventional earthquake-resistant design of medium-rise buildings. The application of this technology may keep the building to remain essentially elastic and thus ensure safety during large earthquakes. Since a base-isolated structure has fundamental frequency lower than both its fixed base frequency and the dominant frequencies of ground motion, the first mode of vibration of isolated structure involves deformation only in the isolation system whereas superstructure remains almost rigid. In this way, the isolation becomes an attractive approach where protection of expensive sensitive equipments and internal non-structural components is needed. It was of interest to check the difference between the responses of a fixed-base building frame and the isolated-base building frame under seismic loading. This was the primary motivation of the present study.

1.2 Importance of Present Study

Civil Engineers are still unable to rigorously predict even in a probabilistic way the loads which structures may have to withstand during their useful life. All structures are subjected to vibration. Recent destructive earthquakes in California and Japan have shown how vulnerable our structures and societies remain to natural phenomena. The enormous losses inflicted by such catastrophes have motivated ever more stringent requirements on the performance of structural systems, in an effort to reduce the cost of repair and disruption. The cost and performance requirements for both buildings and equipment have motivated advances in the field of Structural Control, which deals with methodologies for the protection of high performance structural systems. The vibration isolator is a device that is designed to effectively isolate such structures from harmful vibrations.

1.3 Vibration Control

- ☐ Vibration control is the mechanism to mitigate vibrations by reducing the mechanical interaction between the vibration source and the structure, equipment etc. to be protected.

- ☐ Structural control relies on stiffness (i.e. energy storage) and damping (i.e. energy absorption/dissipation) devices in a structure to control its response to undesirable excitations caused by winds and moderate earthquakes. This control has, in most cases, been achieved passively by means of bracing systems and shear walls, which do not require any additional external energy input. More recently, we have seen the emergence of more modem passive structural control systems. The tuned mass damper and base isolation systems are examples of such relatively modern passive systems.

1.4 Base Isolation of Structures

1.4.1 Concept of base isolation

Base isolation system isolation of superstructure from the foundation is known as base isolation. It is one of the most popular means of protecting a structure against earthquake forces. It is a collection of structural elements which detach a superstructure from its substructure resting on a shaking ground thus protecting a building structure. It is meant to enable a 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. Contrary to popular belief base isolation does not make a building earthquake proof.

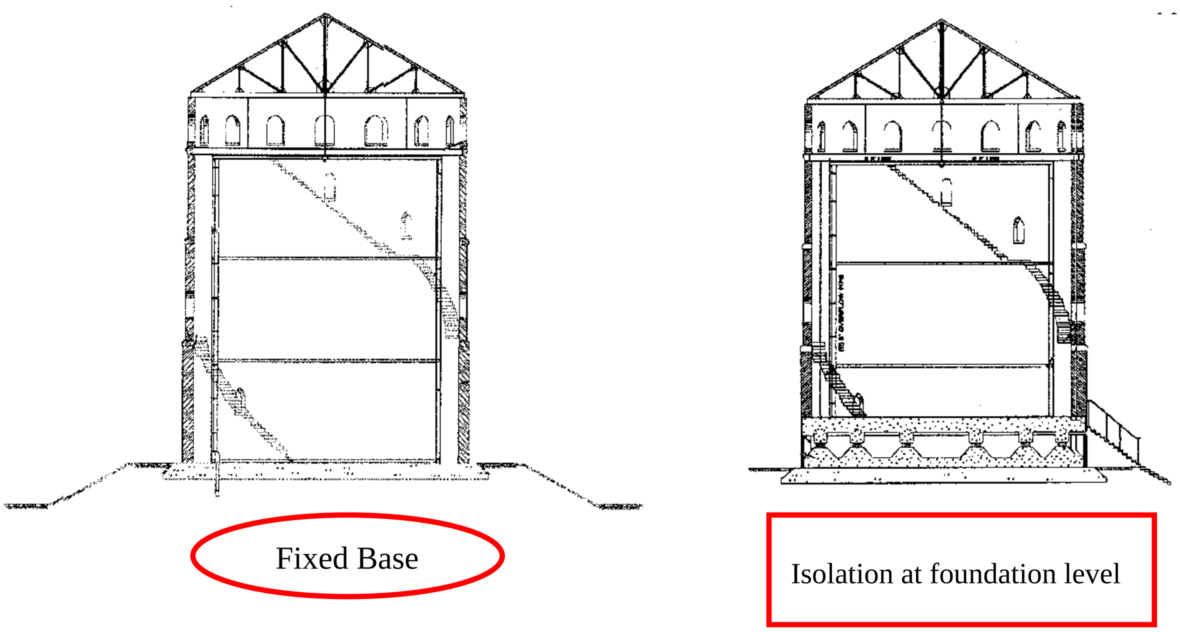


Fig. 1.1 (Isolation at foundation Level)

Seismic base isolation of structures such as multi-storey buildings, nuclear reactors, bridges, and liquid storage tanks are designed to preserve structural integrity and to prevent injury to the occupants and damage to the contents by reducing the earthquake-induced forces and deformations in the super-structure. This is a type of passive vibration control. The performance of these systems depends on two main characteristics

(1) The capacity of shifting the system fundamental frequency to a lower value, which is well remote from the frequency band of most common earthquake ground motions.
(2) The energy dissipation of the isolator.

1.5 Types of Base Isolation Systems

1.5.1 Lead rubber bearing is a type of base isolation employing a heavy damping. Heavy damping mechanism incorporated in vibration control technologies and, particularly, in base isolation devices, is often considered a valuable source of suppressing vibrations thus enhancing a building's seismic performance.

Fig. 1.2 Lead Rubber Bearing

1.5.2 Tuned mass Damper

It is a huge concrete block mounted in skyscrapers or other structures and moved in opposition to the resonance frequency oscillations of the structures by means of some sort of spring mechanism. It is used in structures to reduce the amplitude of mechanical vibrations.

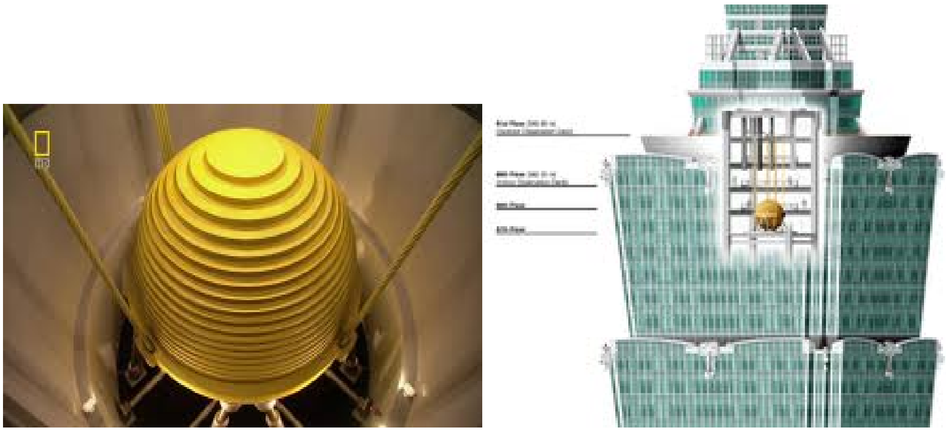


Fig. 1.3 Tuned Mass Damper

1.5.3 Simple roller bearing is a base isolation device which is intended for protection of various building and non-building structures against potentially damaging lateral impacts of strong earthquakes. This metallic bearing support may be adapted, with certain precautions, as a seismic isolator to skyscrapers and buildings on soft ground.The primary function of the bearing is to reduce the friction and resistance that occurs while moving an object.

Fig 1.4 Simple Roller Bearing

1.6 Base Isolators

The isolators work in a similar way to car suspension, which allows a car to travel over rough ground without the occupants of the car getting thrown around.

Types of Isolators

- Elastomeric bearing
- Sliding Bearing

1.6.1 Elastomeric bearing

An elastomeric bearing consists of alternating layers of rubber and steel shims bonded together.The steel shims perform the function of preventing the rubber layers from bulging.Elastomeric bearings use either natural rubber or synthetic rubber (such as neoprene).These are much more flexible under lateral loads.Examples are Foothill Community Law and Justice Center, Rancho Cucamonga, CA.

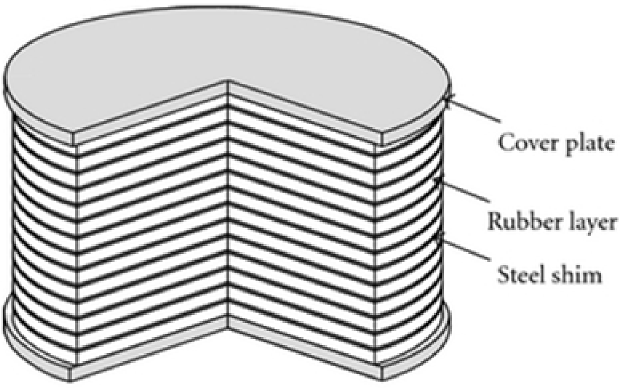


Fig 1.5 Elastomeric bearing

1.6.2 Spherical sliding base isolators

- The structure is supported by bearing pads that have curved surface and low friction .
- During an earthquake, the building is free to slide on the bearings.

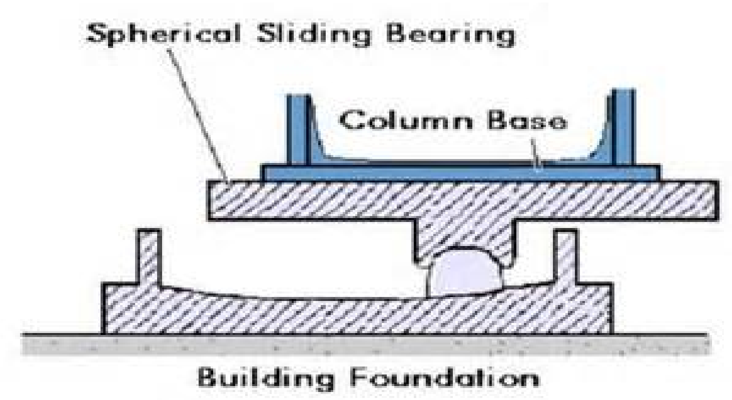


Fig1.6 Spherical Sliding Bearing

1.6.3 Advantages of ase Isolators

- Isolates building from ground motion
- lesser seismic loads, hence less damage to buildings
- minimal repair of superstructure
- Building can remain serviceable throughout construction.
- Does not provide major intrusion upon existing superstructure

1.6.4 Disadvantages of base isolators

- Expensive technique
- Cannot be applied partially to structures unlike other retrofitting
- Challenging to implement in an efficient manner
- Not suitable for buildings rested on soft soil
- Inefficient for high rise buildings

1.7 Classification of bearing

Classification of bearing is done on the basis of degree of freedom and material used for the manufacturing of bearings.

Classification on the basis of material used

1. Steel
2. Rubber (elastomer)
3. Poly Tetra Fluoro Ethylene (PTFE)
4. Combination of any two

Table 1.1 Classification on the basis of degree of freedom

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

1.7.1 Reinforced elastomeric bearing

As we see different types of bearing and most common material in all of them is steel, which has its biggest demerit of corrosion and need high level of maintenance.So, to eliminate these problems, engineers had to look for next alternative which will be cheaper, require less maintenance and free from environmental effect. This search results into a new material which has been found to satisfy all these requirements known as elastomer.

An elastomeric bearing can accommodate both rotation and translation through deformation of elastomer. Few benefits of elastomeric bearing over other types of bearings are -

1. Easy to install,
2. Initial cost as well as maintenance cost is lesser compared to other bearings,
3. Environment resistant, as they do not freeze, corrodes and deteriorates,
4. It can permits movements of the structure in all direction, depending upon the direction of applied load, and
5. Elastomer has anti-vibration properties so it behaves as a shock absorber too.

An elastomer is a member of class of polymeric substance, which is obtained after vulcanization of rubber and possessing the ability to regain shape almost completely after large deformation. However, a normal rubber is brittle at low temperature and sticky at high temperature. Vulcanization results in cross linking of rubber molecule which makes the rubber stronger and give the property to regain the shape after large deformation. But one of major drawback of vulcanization is that it can’t be recycled.

As elastomer do not obey Hooke’s law, and the simple theory of mechanics characterizing the behavior of rubber is not the same as used for conventional material. So, most of the codal provisions for design, fabrication, installation and maintenance of elastomeric bearings are based on extensive experimental studies. Types of Elastomeric Bearing -

1. Plain elastomeric bearing,
2. Steel reinforced elastomeric bearing, and
3. Fiber reinforced elastomeric bearing.

Plain elastomeric bearing is made up of only elastomers and have a tendency to bulge under heavy loading. To overcome this bulging steel laminates are inserted along with the elastomer layer. These steel laminates separating the layer of elastomer were encased within the elastomeric material, this helps the elastomer to behave an individual pad while vertical loads is acting, while horizontal strain on each layer is additive. In fiber reinforced bearing, fiber glass is used for reinforcement in the place of steel laminates.

1.8 Response of the building under Earthquake

1.8.1 Building frequency and period

The magnitude of Building response mainly accelerations depends primarily upon the frequencies of input ground motions and Buildings natural frequency. When these are equal or nearly equal to one another, the buildings response reaches a peak level. In some cases, this dynamic amplification level can increase the building acceleration to a value two times or more that of ground acceleration at the base of the building. Generally buildings with higher natural frequency and a short natural period tend to suffer higher accelerations and smaller displacement. Buildings with lower natural frequency and a long natural period tend to suffer lower accelerations and larger displacement. When the frequency content of the ground motion is around the building’s natural frequency, it is said that the building and the ground motion are in resonance with one another. Resonance tend to increase or amplify the building response by which buildings suffer the greatest damage from ground motion at a frequency close to its own natural frequency.

1.8.2 Building stiffness

Taller the building, longer the natural period and the building is more flexible than shorter building.

1.8.3 Ductility

Ductility is the ability to undergo distortion or deformation without complete breakage or failure. In order to be earthquake resistant the building will possess enough ductility to withstand the size and type of earthquake it is likely to experience during its lifetime.

1.8.4 Damping

All buildings possess some intrinsic damping. Damping is due to internal friction and adsorption of energy by buildings structural and non- structural components. Earthquake resistant design and construction employ added damping devices like shock absorbers to supplement artificially the intrinsic damping of a building.

1.8.5Methodology

a) A thorough literature review to understand the seismic evaluation of building structure, application of time-history analysis and Modal analysis.

b) Modal analysis of a Benchmark Problem was carried out to validate the accuracy of steps involved in ABAQUS 6.13 software package. And building design has been done on STAAD Pro to find out the load on the column ends, so as to manually design the isolator.

CHAPTER

2

LITERATURE REVIEW

2.1 Introduction - Thus the modal analysis of framed Structure is of great technicalimportance for understanding the behavior of the framed Structure under applied dynamic loading. The study of response analysis methodology (Experimental or Analytical) of a base isolated framed structure with a fixed base otherwise similar framed structure is essential to conclude the effectiveness of base isolation using rubber bearing.

"Earthquake resistance structures" generally mean the structures which resist the earthquake and save and maintain their functions. The key points for their design includes select good ground for the site, make them light, make them strong, make them ductile, shift the natural period of the structures from the predominant period of earthquake motion, heighten the damping capacity.

Izumi Masanory studied on the remained literature, the first base isolated structure was proposed by Kawai in 1981 after the Nobi Earthquake (M=8.0) on journal of Architecture and building Science. His structure has rollers at its foundation mat of logs put on several steps by lengthwise and crosswise manually. After the San Francisco Earthquake (M=7.8) an English doctor J.A. Calantarients patented a construction by putting a talc between the foundations in 1909. The first base isolated systems actually constructed in the world are the Fudo Bank Buildings in Himeji and Simonoseki, Japan designed by R. Oka. After the world War-II, the U.S took a leading part of Earthquake Engineering.

GarevskiA*etal***.** The primary school "Pestalozzi" in Skopje, built in 1969, is the first building in theworld for which natural rubber isolators were used for its protection against strong earthquakes. The first base isolated building in the United States is the Foothill Communities of Law And Justice Centre completed in 1985 having four stories high with a full basement and sub-basement for isolation system which consists of 98 isolators of multilayered natural rubber bearings reinforced with steel plates. The Superstructure of the building has a Structural Steel frame stiffened by braced frames in some Bays. In India, base isolation technique was first demonstrated after the 1993 Killari (Maharashtra) Earthquake [EERI, 1999]. Two single storey buildings (one school building and another shopping complex building) in newly relocated Killari town were built with rubber base isolators resting on hard ground. Both were brick masonry buildings with concrete roof. After the 2001 Bhuj (Gujarat) earthquake, the four-storeyBhuj Hospital building was built with base isolation technique . The Base isolation system has been introduced in some books of dynamic Engineering and the number of scholars has been increasing in the world. Constantinou *et al.* described in this paper an analytical model and an algorithm to analyze multiple buildings on a common isolation system and the results are used to demonstrate the importance of analyzing the combined system as against analyzing individual buildings.

Jain and Thakkar explored the idea of superstructure stiffening is to enhance the effectiveness of base isolation for 10 to 20 storeys range of buildings. The superstructure stiffening may result in reduced fixed base period and such buildings, if base isolated may develop smaller seismic response.

Jangid and Kulkarni made a comparison in this study of the seismic response of a multi-storeybase-isolated building by idealizing the superstructure as rigid and flexible. The top floor acceleration and bearing displacement of the system are plotted for different system parameters and compared with the corresponding response under rigid superstructure conditions to study the influence of superstructure flexibility.

Naharajaiah and Sun carried out a study aimed to evaluate the seismic response of base isolated USC Hospital Building and Fire Command Control Building in Los Angles during the 1994 Northridge earthquake. Hang*et al.*presented theearthquake responses of the multifunctional vibration-absorption RC mega frame structures decrease significantly in comparison with the normal megaframestructures,namely 60-80 per cent decrease of the earthquake responses of the major frames and 70-90 per cent decrease of the ones of the minor frames.

Mazza and Vulcanocompared different base-isolation techniques, in order to evaluate their effects on the structural response and applicability limits under near-fault earthquakes. Palazzo and Pettidescribed rational methodology to evaluatebehaviour factors for base isolated structures (BIS) code. The method used in this study is to directly derive q-factors by the nonlinear response analysis of 2 d.f. isolated models subject to strong seismic excitations artificially generated according to EC8 design spectra.

Dutta and Jangid investigated the reliability against the first passage failure of base-isolated and fixed base steel buildings frames due to earthquake ground motion and found base isolated structures are more reliable than fixed base frame. Mei[13] applied Classical theories in modelling in-plane vibrations in planar frame structures. Analytical solution has been obtained using a wave vibration approach. The propagation, reflection, and transmission matrices, as well as the matrix relations between the injected waves and externally applied forces and moments are obtained using classical vibration theories.

The theory of the buckling isolation bearings is an outgrowth of work by Haringx in 1947 on the mechanical characteristics of helical steel springs and rubber rods used for vibration mountings. This work was published in a series of reports, the third of which (Haringx 1948)covers the stability of solid rubber rods. The Haringx theorywas later applied by Gent (1964) to the problem of the stability of multilayered rubber compression springs, and this application forms the basis for the theory of buckling in elastomeric isolators.

The First analysis was done using an energy approach by Rocard 1937 further developments were made by Gent and Lindley 1959 and Gent and Meinecke 1970. The ``pressure solution" approach developed by Kelly 1997 is a simplified version of these earlier analyses. In this method, the elastomer is assumed to be strictly incompressible. The normal stress components are approximated by the pressure. Each individual elastomeric layer in the bearing deforms according to two kinematic assumptions horizontal planes remain planar; and points on a vertical line lie on a parabola after loading. In this paper, the extensional flexibility of the fiber reinforcement is incorporated into the ``pressure solution" method to analyze the bending stiffness of the fiber-reinforced circular isolators. The bending stiffness formula of the fiber-reinforced circular isolators is derived. The influence of fiber flexibility on the mechanical properties of the fiber-reinforced isolators is studied.

Recent years have seen a number of catastrophic structural failures due to severe, impulsive, seismic events. Some researchers e.g., Hall et al. 1995; Heaton et al. 1995 have raised concerns as to the efficacy of seismic isolation during such events. Based on observations from the January 17, 1994 Northridge earthquake, these researchers suggested that base-isolated buildings are vulnerable to strong impulsive ground motions generated at near-source locations. Moreover, recent revisions to the Uniform Building Code ICBO 1997 have made the requirements for base-isolation systems more stringent compared to the previous versions ICBO 1994; Kelly 1999, potentially rendering the additional complexity and cost of base-isolated structures less economically justified Kelly 1999b. The code-mandated accommodation of larger base displacements and the requirement to consider a stronger Maximum Capable Earthquake has suggested the need for supplemental damping devices Asher et al. 1996!.

The addition of damping, however, may also increase the internal motion of the superstructure as well as increase absolute accelerations, thus defeating many of the gains base isolation is intended to provide Inaudi and Kelly 1993; Kelly 1999. To understand the impact of excessive damping, it is important to consider the ever increasing necessity of protecting nonstructural components and highly sensitive equipment such as are found in hospitals, communication centers, and computer facilities. The performance of this equipment can be easily disrupted by moderate acceleration levels and even permanently damaged by higher excitations Inaudi and Kelly 1993a!. Consequently, mitigating damage to the contents of a structure has become a key objective in base isolation design. For example, the 1994 Northridge earth-quake ``caused extensive destruction of building interiors. Be-cause of the intense shaking and heavy damage to other building elements, sprinkler piping was frequently severed and systems were rendered useless on a much wider scale than has been seen in other earthquakes.

The HDR bearing not only supports the structure by the restricting the bulge of the rubber layers with the reinforced steel plates, but also reduces the inertia force of the structure by extending the natural period and absorbs the earthquake energy by its hysteretic damping Skinner et al. (1993). Hence, accurate modeling of the high damping rubber bearings requires the coupled modeling of the slight compressibility, the kinematic nonlinearity, and the material nonlinearity. In the case of laminated rubber bearings with carbon filled rubber natural rubber bearings!, which shows small damping, Seki et al.1987.

Takayamaet al. (1990) Billings (1993), and Matsuda (1999) developed the two- or three-dimensional finite element models of the bearings with hyperelasticity, and investigated the internal stress or strain state under the large deformation. In this research, the hysteretic behaviors of the rubber component were not taken into account. Ali and Abdel- Ghaffar 1995! presented the analysis of lead ± rubber bearings with the finite-element method, in which the rubber component was modeled as hyper elasticity, and its energy absorbing behavior was not considered. Salomon et al. (1999). proposed a constitutive model of HDRs, where the hysteretic behaviors of the rubber component were modeled by viscoelastic and plastic constitutive models, and, then, developed the three-dimensional finite-element model of the bearing with that constitutive model. However, in this research, the accuracy of the proposed constitutive model was not presented and, in addition, the validity of the finite-element model was shown only qualitatively in comparison with the public experimental results of the bearings. Matsuda ~2001! also developed a three-dimensional finite element model of high damping rubber bearings, in which the behaviors of the HDR were approximated by the viscoelastic damage model Simo (1987); Simo and Hughes (1997). The simulations in this research indicated that only the viscosity was not enough to reproduce the large hysteretic energy loss of HDRs.

Since few accurate constitutive models of HDRs have existed so far, behaviors of the rubber materials including HDRs have usually been approximated by hyper elasticity, or hyperplastic-based viscoelasticity. Therefore, the finite-element methods developed in the previous research premise to use hyperplastic-based constitutive models Duffett and Reddy 1983; Simo and Taylor 1991; Gandala 1992; Watanabe and Hisada 1996!, and the constitutive models described with the values in the current configuration cannot apply directly to them. In the formulation by Sussman and Bathe ~1987!, which is consistent with the constitutive models in terms of the current configuration, numerical computation is unstable in some cases.

Unlike building frames that resist lateral forces primarily in one direction, the peak deformation in any direction due to simultaneous application of two horizontal components of excitation controls the design of the isolation system. Further-more, isolator nonlinearity causes bidirectional interaction consistent with the assumption of a circular interaction surface, as shown by extensive testing of both high-damping and lead-rubber bridge bearings ~Huang 2002!. Analytical models that included this interaction usually estimated the measured response of a rigid block shaken by various ground motions more accurately than those that neglected it Huang 2002!. Biaxial excitation and bidirectional yield-interaction should be considered to achieve a realistic estimate of deformations and forces for design, something lacking in the current International Building Code IBC procedure ICC 2000!.

2.2 Objectives of the Present Work

The main aim of this project to make a suitable isolator on ABAQUS and to find out whether the isolator is safe for the building. The building is designed in STAAD pro where load of the building at the end of the one column is taken and Isolator is manually designed to find out its dimensions . Then the model is generated in ABAQUS according to the manual design and efficiency of the isolator is calculated whether the designed isolator is safe for the building or not.

CHAPTER

3

ANALYSIS OF 5-STOREYED BUILDING IN STAAD PRO

3.1 Problem Definition

In this section, a five-storeyed RCC building is modeled in STAAD.pro (a) with its based fixed to the ground and (b) with its base isolated from the ground. This building example is taken from S K Duggal (2013) Design of Earthquake resistant building. The supports are modeled as springs with stiffnesses equivalent to isolator stiffnesses as designed by the guidelines of UBC in Design of Isolated Seismic Structures by Farzad Naeim and J M Kelly (2002). Figure 3.1 shows isometric view of the building considered, Its properties are:

Number of storeys = 5
Storey height = 18m
Number of bays in X-direction = 4
Number of bays in Y-direction = 5
Size of beams = .3 ×.6 m
Size of columns = .3 × .6 m
Slab thickness = .1 m
Concrete Grade = M25
Steel reinforcement grade = Fe 415
Seismic zone of site = Seismic Zone 4 (Delhi)

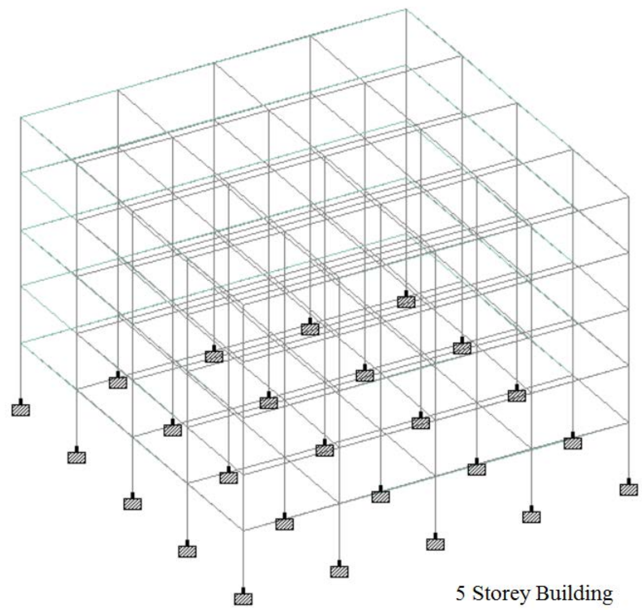
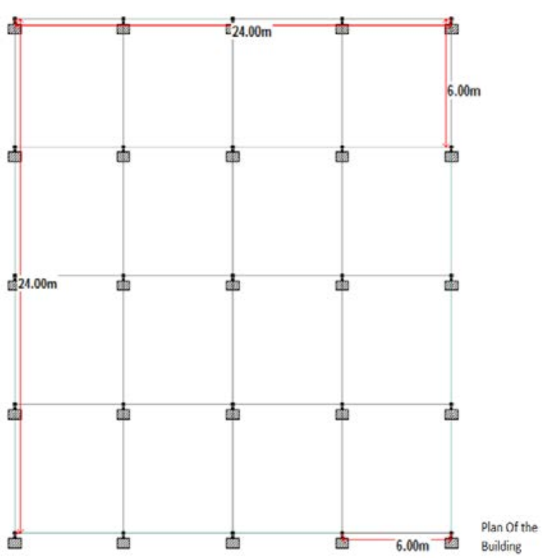
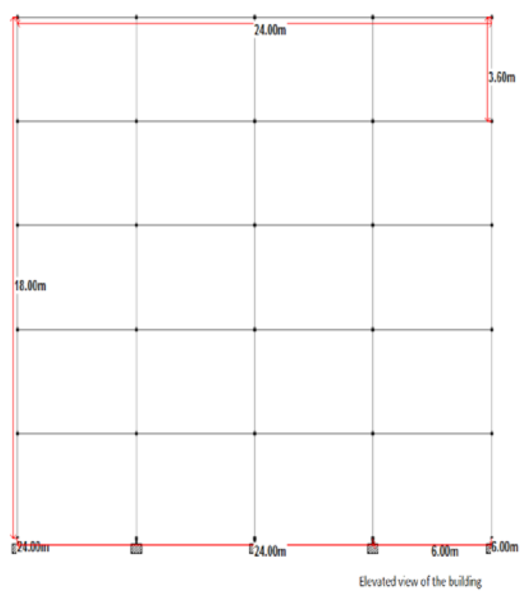


Fig.3.1 Isometric view of the building





Plan

Elevation

Time history analysis to find out the response of the building during an earthquake for 20 sec.

The following results are obtained from the analysis.

On the roof at different nodes of the building,the time Displacement graph in X, Y, Z Direction.

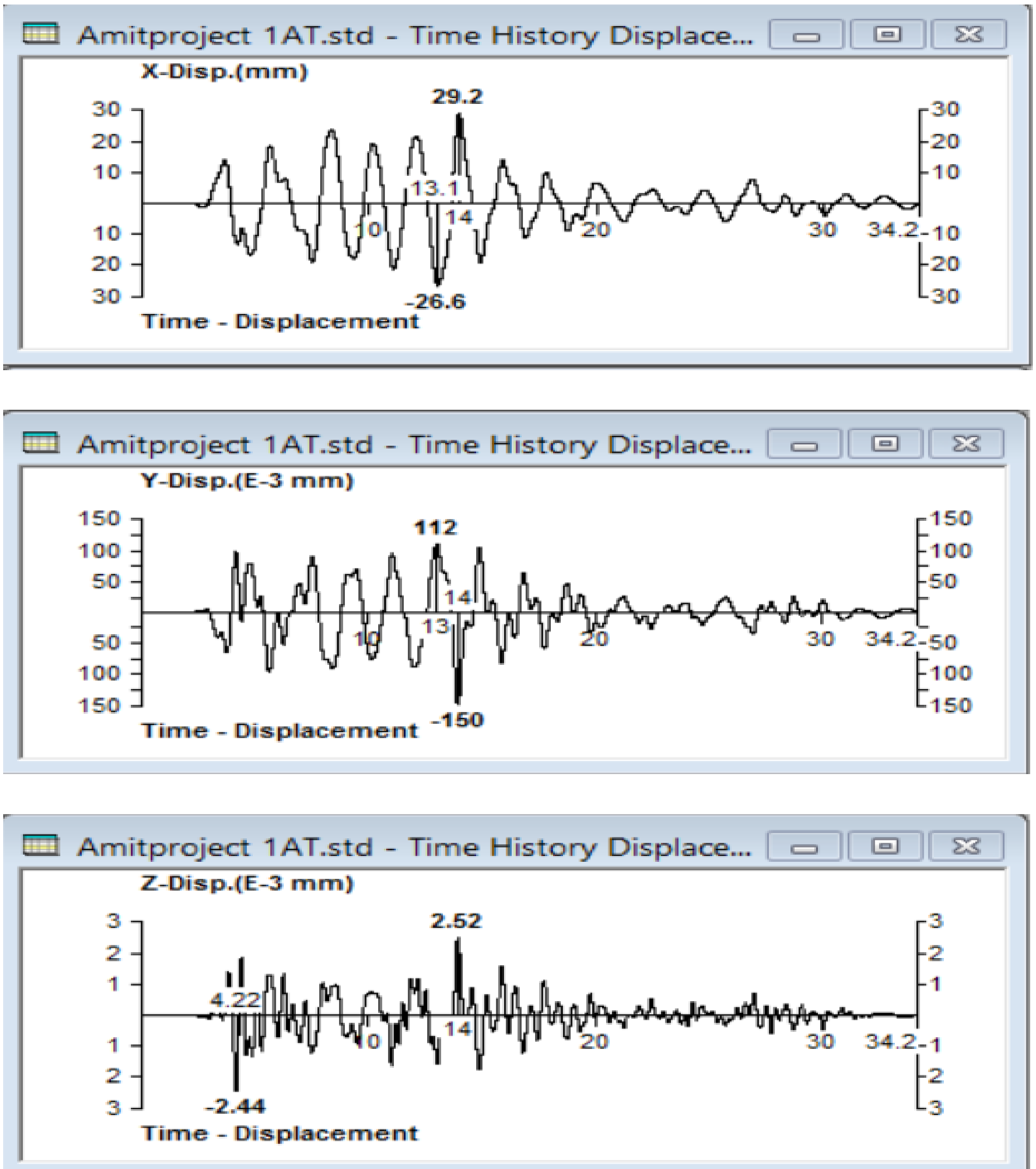


Fig. 3.2 Time displacement graphs at Roof Node (Fixed base)

These graphs show the displacement on the roof during an earthquake, in X-direction displacement is 29.2 mm at 14 secs, in Y-direction the displacement is 112 mm at 13 secs and in Z-direction the displacement is 2.52 mm at 14 secs.

The velocity-time graphs at a node on the roof are shown in Fig. 3.3.

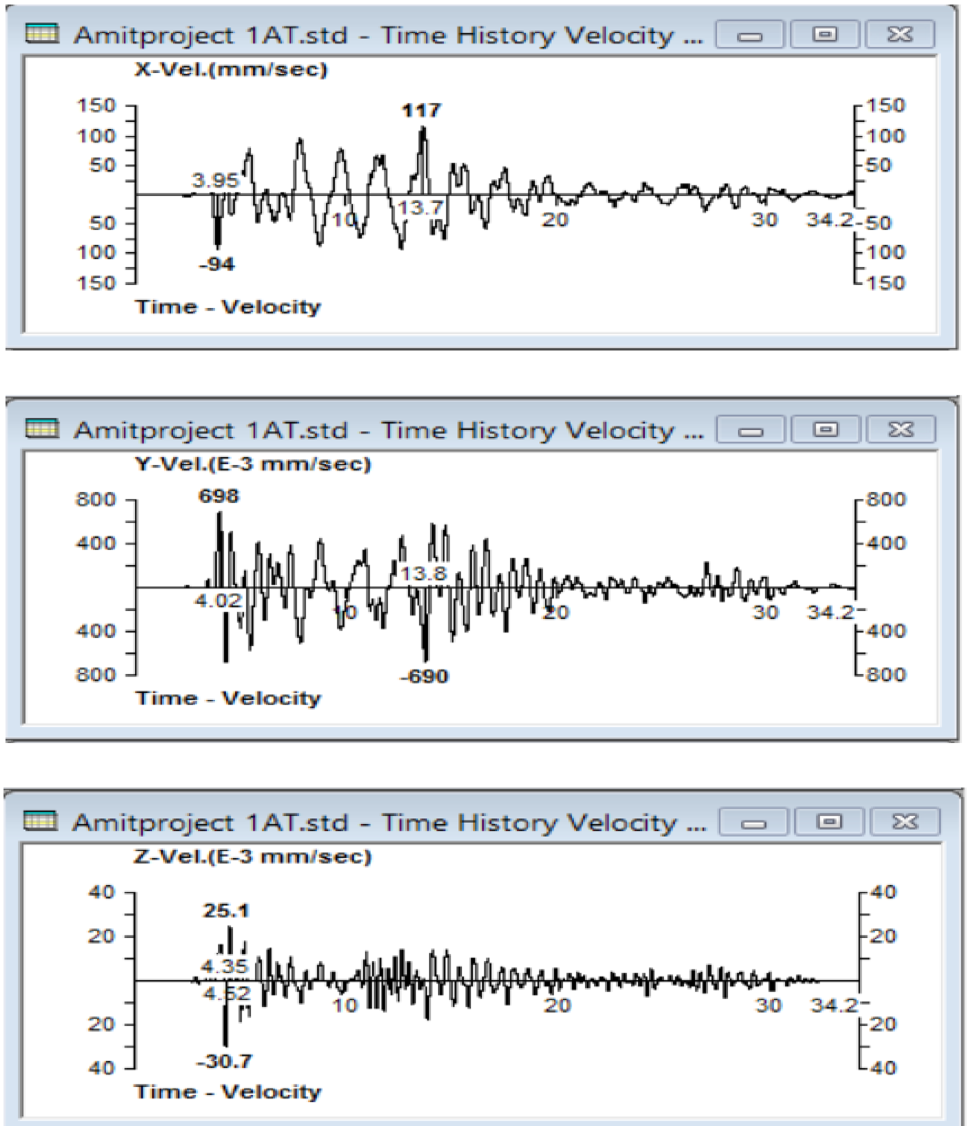


Fig. 3.3 Time velocity Graph at roof node (Fixed base)

The above figures show the velocity of nodes in building at roof, in X direction the maximum velocity is 117 mm/sec at 13.7 secs, in Y direction the 698 mm/ sec at 4.02 secs and in Z-direction The velocity is 25.1 mm/ sec at 4.35secs.

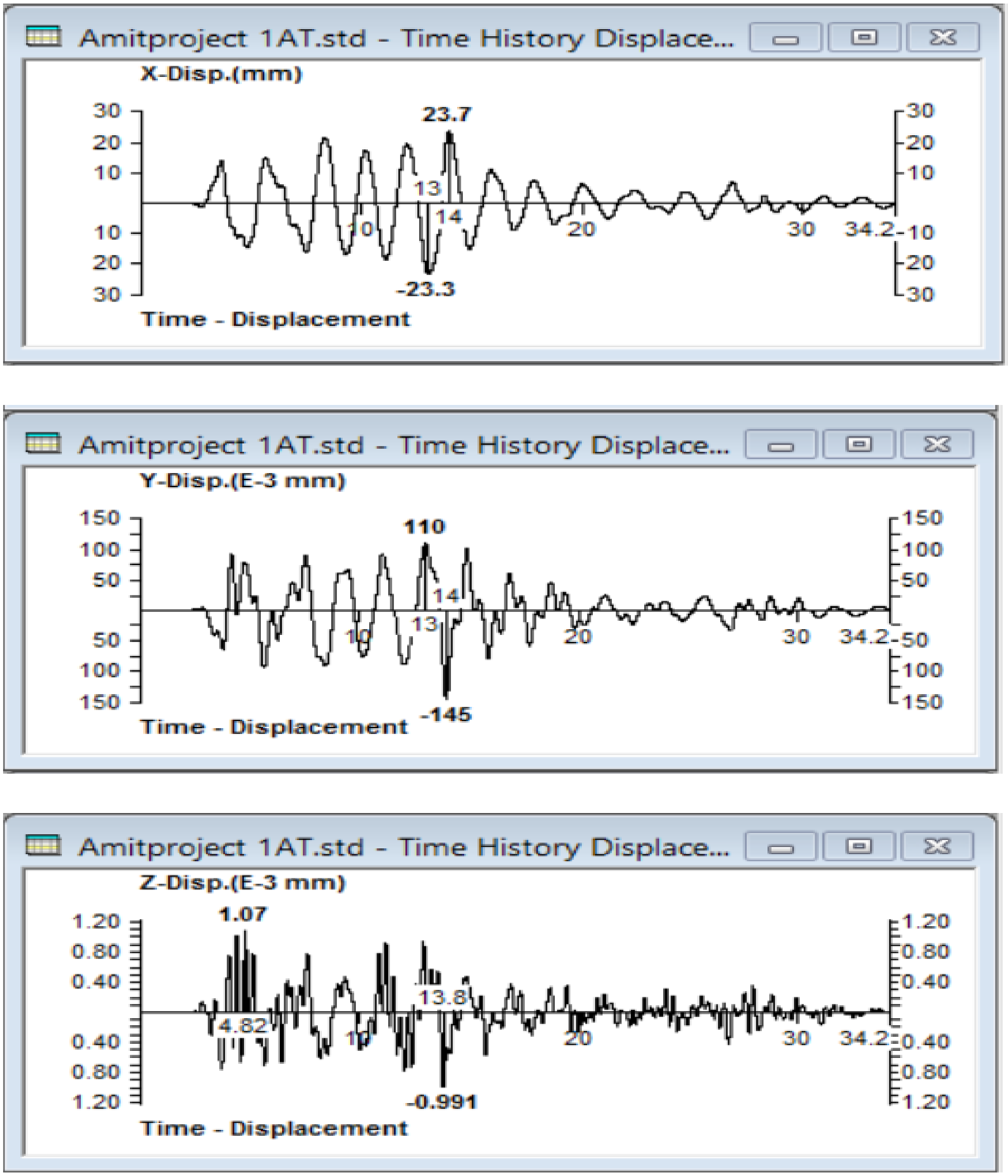
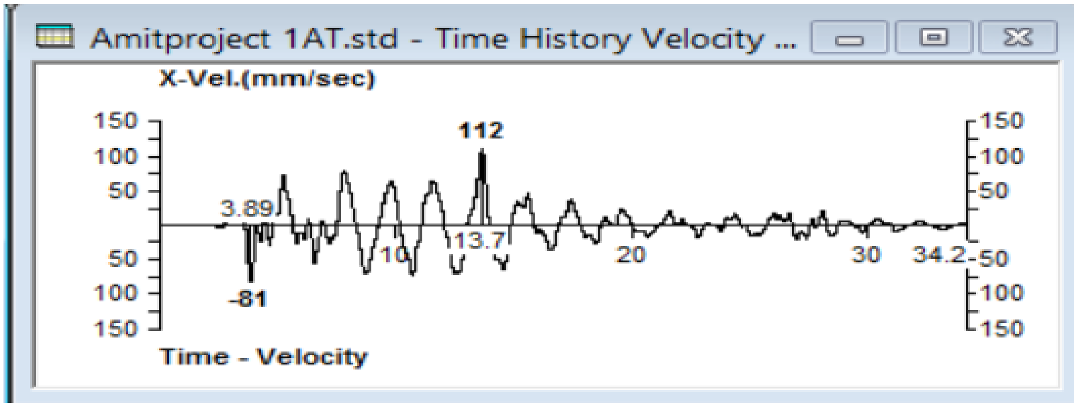
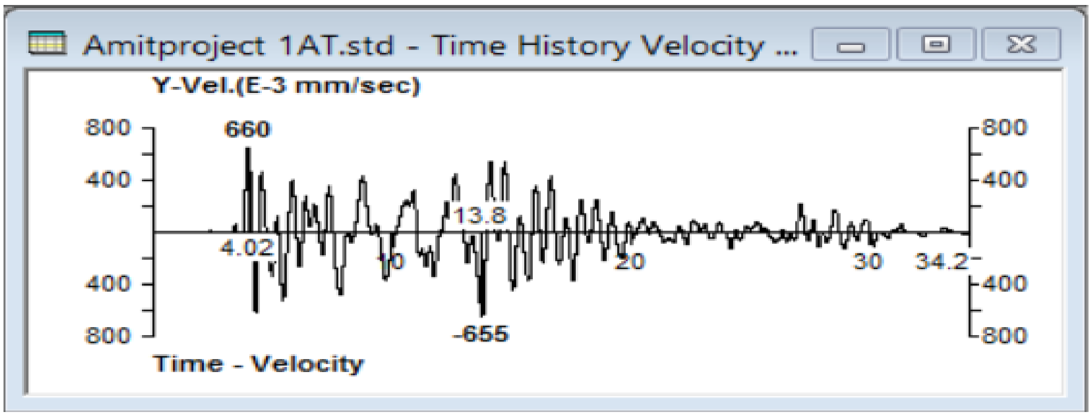


Fig. 3.4 Time displacement Graph for floor node (fixed base)

Figure 3.4 shows the displacement-time history of few chosen nodes in the structure in the three directions. In the Y-direction, the maximum displacement is 23.7 mm at 14 secs, in X-direction the displacement is 110 mm at 13 secs and in Z direction the displacement is 1.07 mm in secs





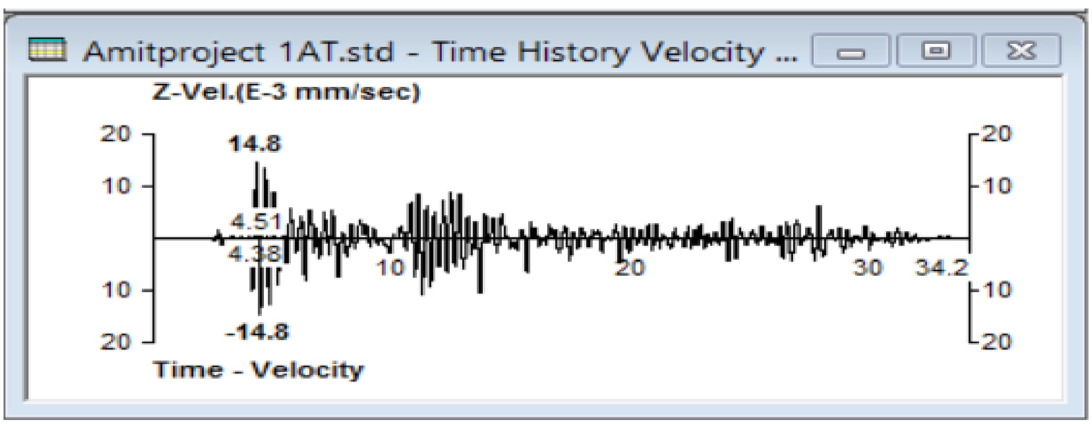
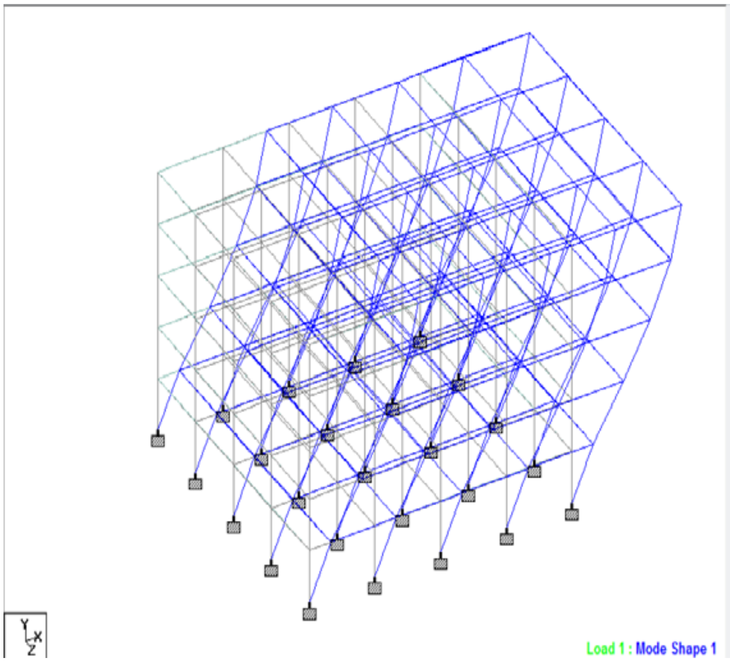


Fig 3.5 Time Velocity graph for floor node (Fixed Base)

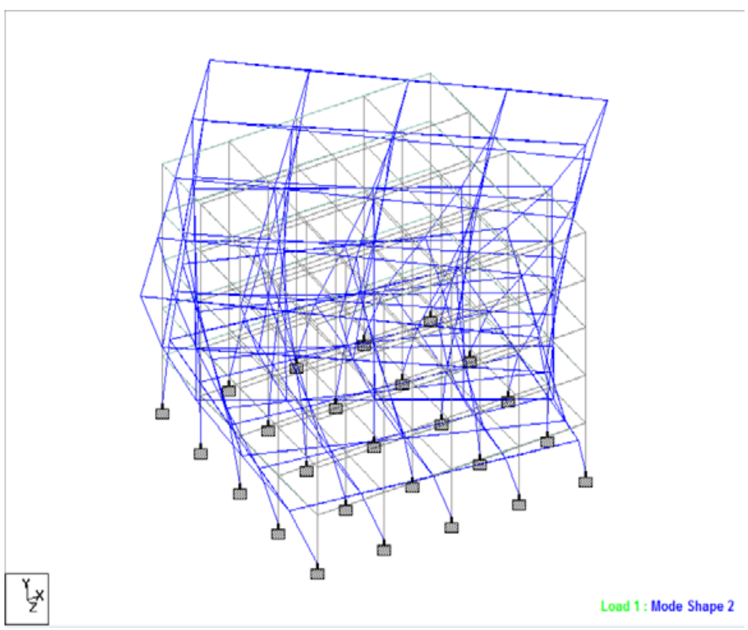
It can be seen that in X direction, the velocity is 112mm/s in 13.7 s, in Y direction the velocity is 660mm/s in 4.02 s and in Z direction the velocity is 4.51 mm/s in 14.8s.

The first three mode shapes of the building are given in Fig. 3.6.,

Mode Shape 1



Mode Shape 2



Mode Shape 3

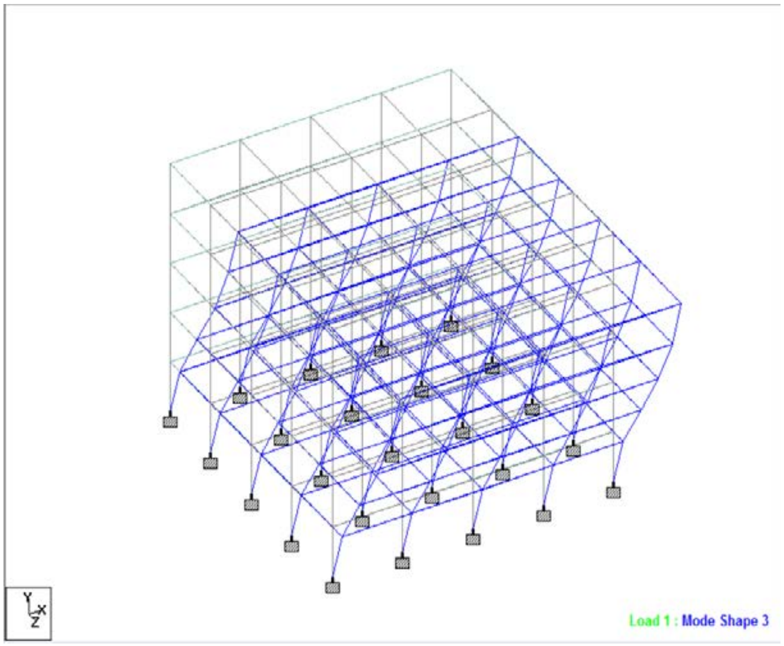


Fig 3.6 Mode Shapes (Fixed Base)

These mode shapes tells us the response of the building at different frequencies.

CHAPTER

4

DESIGN OF THE BASE ISOLATORS

4.1

The building example is taken from S K Duggal (2013) for the paper. The building is a 5-storeyed one,lying in seismic zone IV (as it is situated in Delhi). The building is an OMRF. Using UBC (uniform building code 1997), Chapter 16 requirements, the parameters associated with location are Z= 0.4, S=S_c, N_d = 1.

Starting with the assumption of target period of 2.5 sec, and a target maximum shear strain of 1.5, it should be noted that it would be possible to use only a single bearing design for this project, since the building is small. Therefore,

G_a = 0.4 MPa

G_b =1.0 MPa

Bearing Stiffnesses

Type A

$K_h^a = 95 \times 1000 \times (2\pi /2.5)^2 = 599464$ N/m

Type B

$K_h^b = 190 \times 1000 \times (2\pi /2.5)^2 = 1198928$ N/m

First Estimate of design displacement D_d

$D_d = \frac{g}{4\pi 2} \frac{Cvd\ Td}{Bd}$

Assume composite damping

$B_d = 1.2$ (From UBC 97, TableA-16 C)

$C_{vd} = 0.56$ (Table 16R)

$D_d = \frac{9.81\times 0.56\times 2.5}{4\pi\ 2\ (1.2)} = 0.289\text{m}$

Take $t_r = 200$ mm

$K_h^a = G_a\ A/\ t_r = 0.599$ MN/m

$A = K_h^a \times t_r\ /\ Ga$

$= 0.316\ m^2$

$\phi = 0.634$ m

$\phi = 600$ mm and $A = 0.283\ m^2$

Actual Bearing Stiffness

$K_h^b = 1.0 \times 0.283/\ 0.200 = 1415$ KN/m

Composite Stiffness

$K_H = 12\times 566 + 3\times 1415 = 11040$ KN/m

Therefore

$(\text{Actual frequency})^2 = 11040 \times 10^3 \times 1/\ 1600 \times 10^3 = 6.90\ \text{sec}^2$

$T = \sqrt{6.90} = 2.62$ sec

Composite Damping

From the code

$\beta = W_d/2\pi\ K_hD^2$

$\beta = 2\pi\ K_D{}^AD^2\ \beta_A + 2\pi\ K_h{}^BD^2\ \beta_B\ /\ 2\pi K_d\ D^2$

$= K_H{}^A\ \beta_A + K_H{}^B\ \beta_B\ /\ k_D$

$\beta = 12\times\ 0.566\times 0.08\ + 3\times 1.415\times 0.15\ /11.04 \quad = 0.107$

$B_D = 1.2 + (0.7/10)\times 0.3 = 1.22$

Using this period and damping factor, the design displacement becomes,

$D_D = 9.81\times 0.56\times 2.39/\ 4\pi^2\ 1.22$

$= 0.272$ m

Now Rotational stiffness or torsional stiffness

It s given by

$K_\Theta = \sum_{i=1}^{n} Kh2\ (x_i{}^2 + y_i{}^2)$

$= 0.566\ [\ 4\times (10^2 + 20^2) + 4\times(10^2+10^2) + 2\times 20^2 + 2\times 10^2] + 1.415\ (2\times 10^2)$

$= 0.565\ (2000+800+200+800) + 1.415\times 200$

$= 2433000$ kN/m

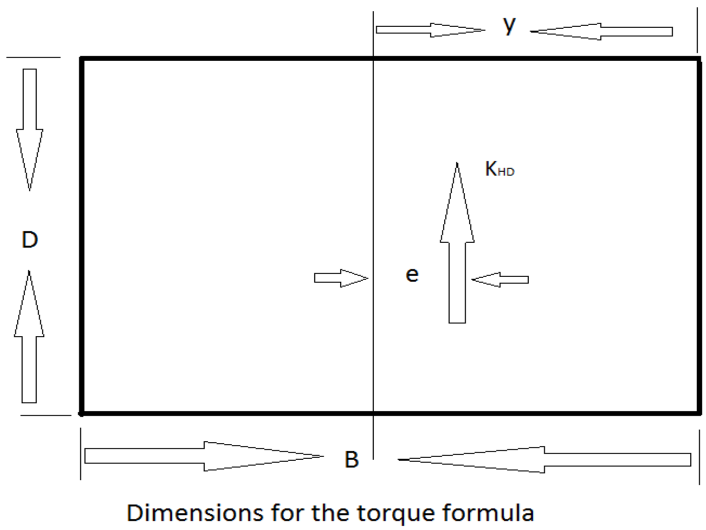


Fig 4.1 Dimensions for torque formula

Applied Torque is given as

$M = (K_H D)_e$

Therefore additional displacement = θ_y

$= K_H\, K_e y / K_\Theta$

$= 11.04\ (0.274)\ (2)\ (20) / 2433 \times 10^3$

$= 0.04$ m

$D_T = 0.272 + 0.05 = 0.322$ m

Thus $\Upsilon_{max} = 1.6$ – larger than targeted but acceptable

Code mandatory minimum allowance for torsion 1.1D = 0.300m, so take $D_T = 0.322$m

Bearing Detail

Select vertical frequency F_v=10 hz, then $6S^2 = f_v^2 / f_h^2$ means

S= shape factor which is given by below formula

$S = 1/\sqrt{6}\ f_v / f_h$

$S = 1/\sqrt{6}\ (10/1/2.39) = 10$

Take k = 2000 N/mm

$E_c = E_c{}' K / E_c{}' + K$

K = bulk modulus of elasticity

$E_ç{}'$ = compression modulus

$E_ç{}' = 6GS^2$

$E_c = 6GS^2K / 6GS^2 + K$

$E_c{}^A = 6GS^2\ K / 6GS^2 + K$

$= 6\ (0.7)\ (100)\ (2000) / 420 + 2000$

$= 347 \times 10^3\ KN/m^2$

$E_c{}^B = 8.4 \times 100 \times 2000 / 2840$

$= 592 \times 10^3\ KN/m^2$

Composite $K_H = (12 \times 347 + 3 \times 592)(0.283)$

$= 8405 \times 10^3\ KN/m$

Therefore any S in the range 5-6 is adequate

S= ǿ /4t

T = ǿ /4S

= 600 /4×6

= 600/24 = 25mm

nt = 200

$n \times 25 = 200$

$n = 200/25 = 8$

Take n=8, then t= 25mm and this allow us to complete the design of bearing, the end plates are 30mm thick and the shimes are 2mm each. The total height is'

$h = 60 + 200 + 2\times7 = 274mm$

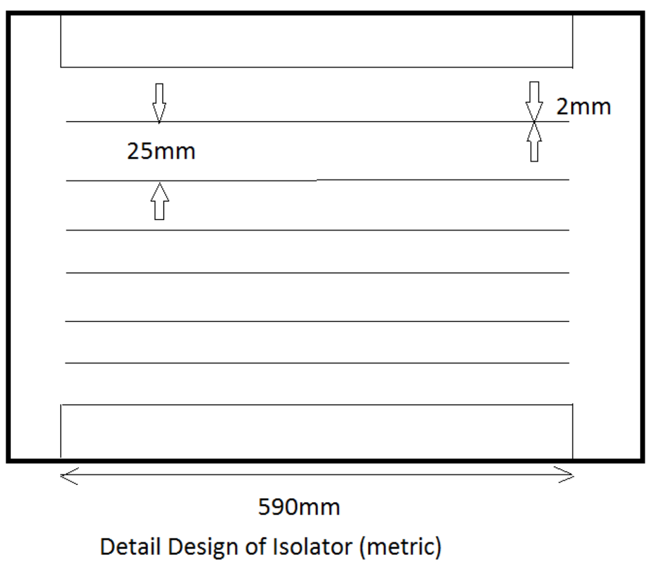


Fig. 4.2 Sectional view of the designed isolator.

Now the building is designed in STAAD pro using the properties of isolator attached at the base of the building instead of fixed, to find out the response of the building by Time history Analysis . In next chapter we will Design the building using isolator at the base.

CHAPTER

5

ANALYSIS OF BASE ISOLATED 5-STOREYED BUILDING

In this chapter, the same building is analysed in STAAD.pro with fixed supportd converted to spring supports with stiffnesses equivalent to isolators designed in the previous chapter.

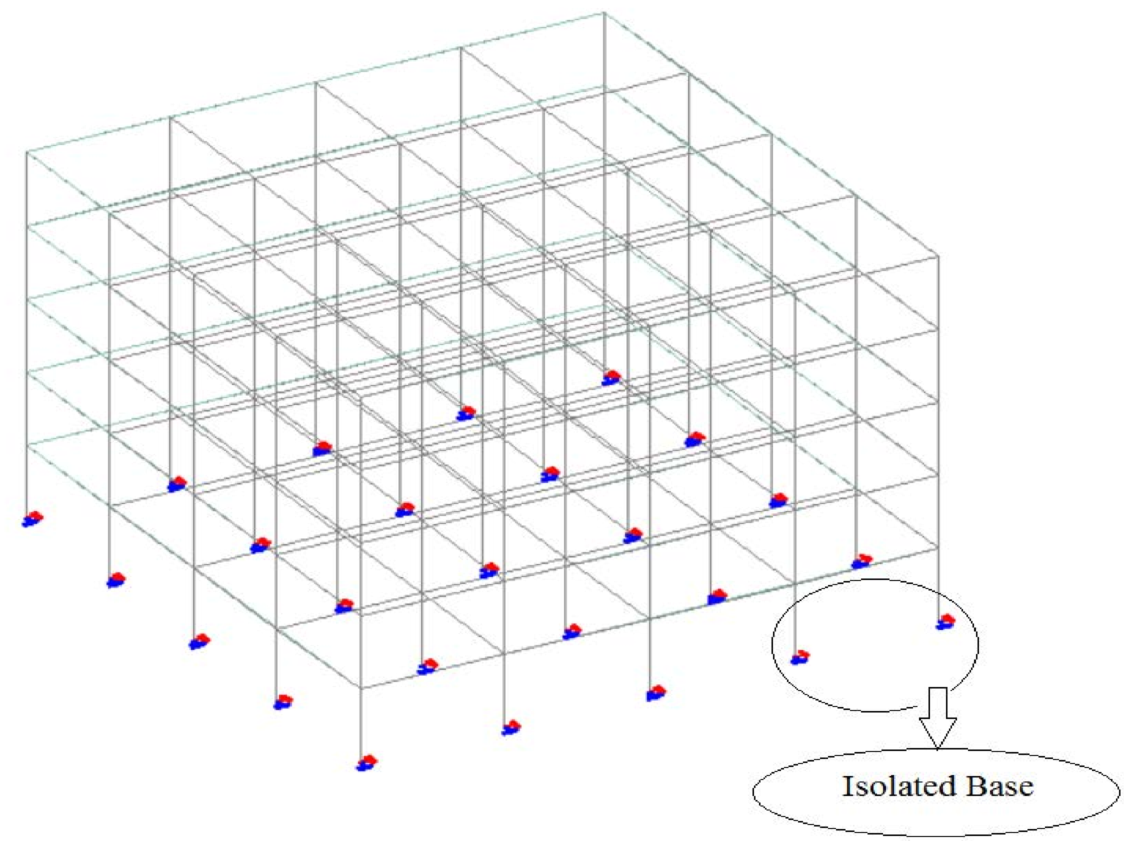


Fig 5.1 Building base attached with base Isolator

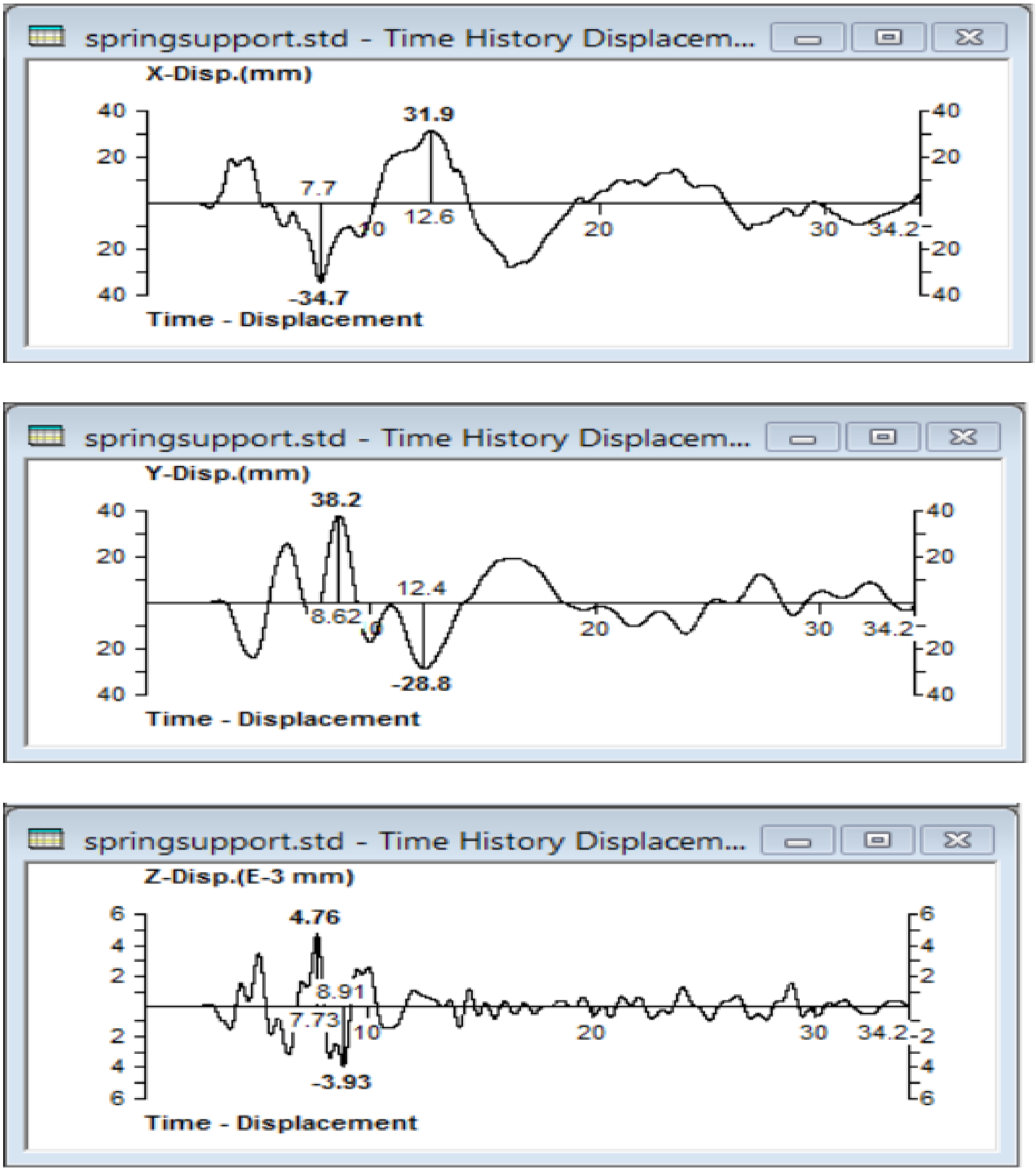


Fig 5.2 Time Displacement Graphs at roof node (Base Isolated)

The above graphs show the displacement at the node on the roof of the building for given period of time.

In X direction the displacement is 31.9 mm in 12.6 secs, in Y direction the displacement is 38.2mm in 8.62 secs and in Z direction the displacement at that node is4.76mm in.7.73secs.

Time Velocity-time graph For the node at the roof.

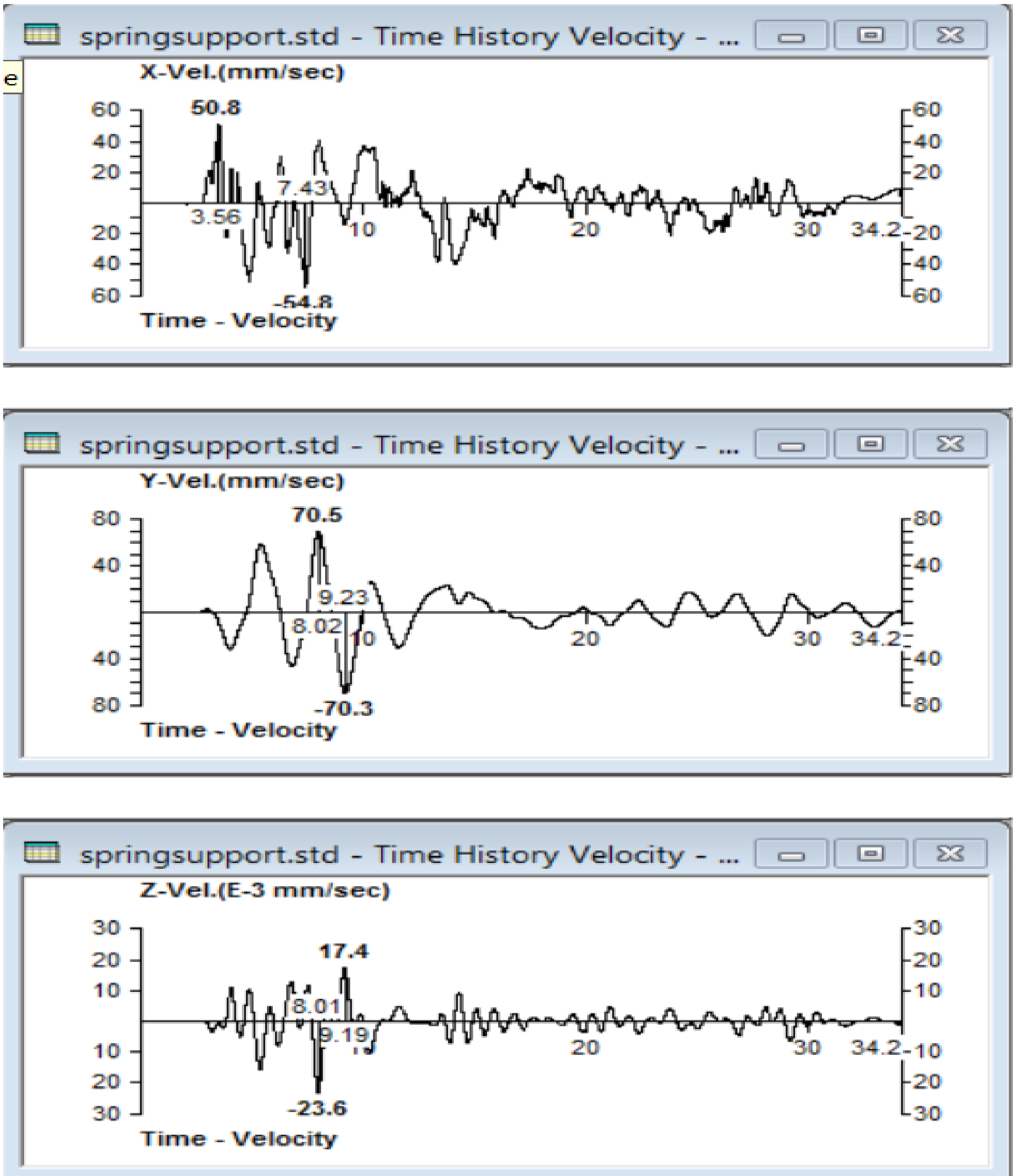


Fig 5.3 Time velocity Graph for roof node (Base Isolated)

The above graphs show the velocity of the building at node chosen in the roof.

In X direction, the maximum velocity is 50.8mm/sec at 3.56 sec, in Y direction, the maximum velocity is 70.5 mm/sec at 9.19 sec and in Z direction the maximum velocity is 17.4mm/sec at 9.19secs.

Now the below readings are taken for the floor,

The time displacement graph for node at the floor of the building,

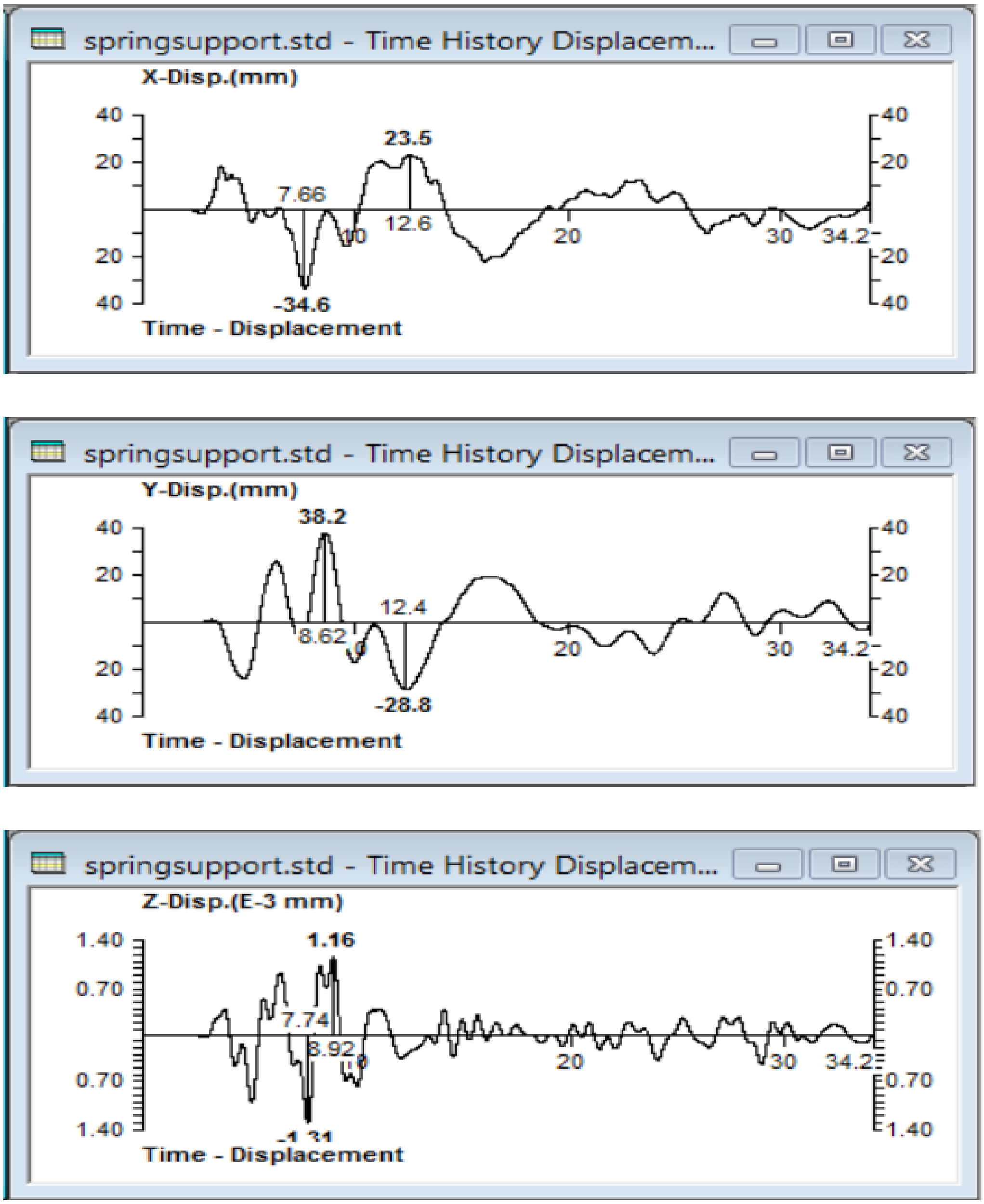
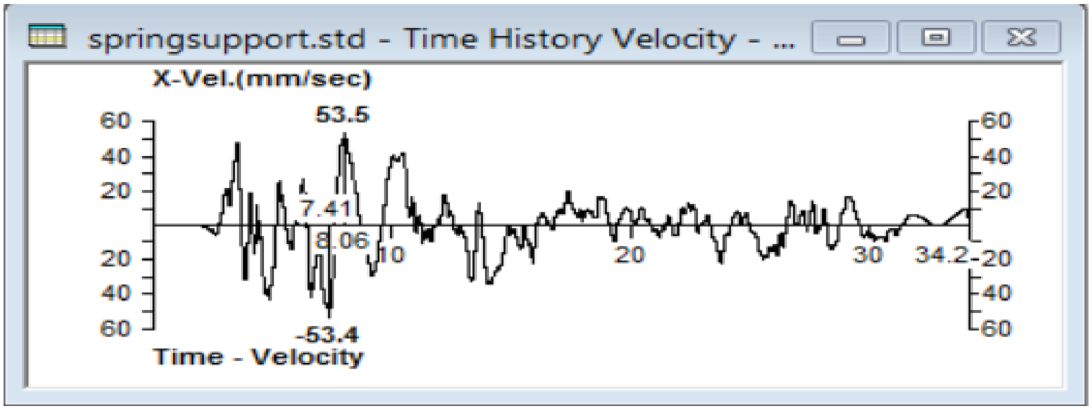
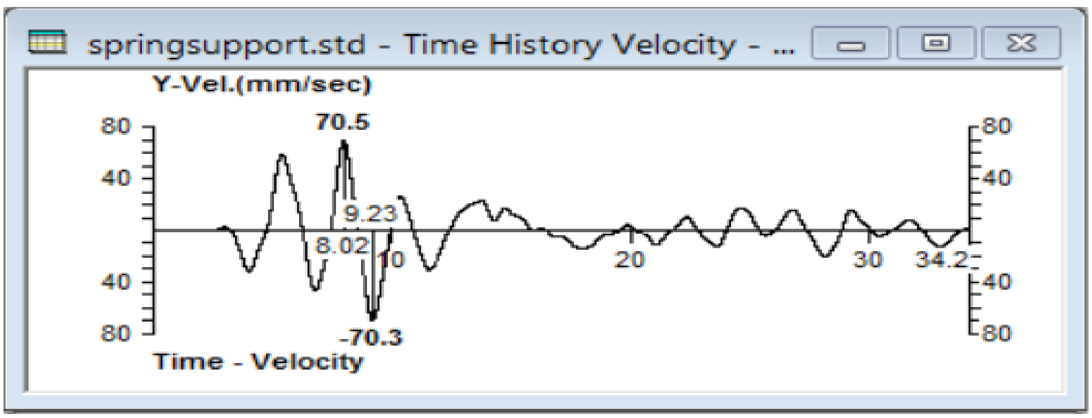


Fig 5.4 Time displacement Graph For Floor node (Base Isolated)





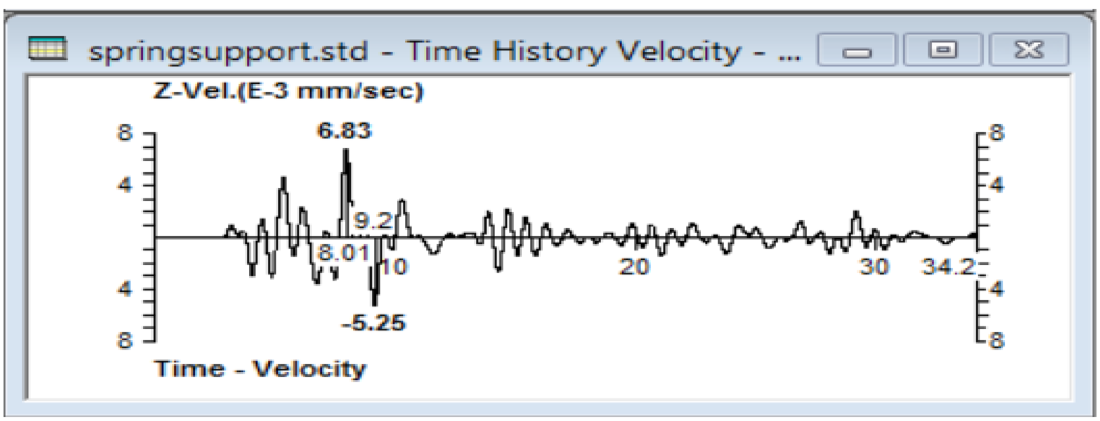


Fig 5.5 Time Velocity graph For floor node (Base isolated)

Table 5.1 Displacement, Velocity, Acceleration Data at single node in Building

Displacement Data				
	Roof	Floor 4	Floor 3	Floor 2
Fixed base (mm)	152	145	127	95.1
Base Isolated (mm)	38.2	28.8	19.2	18
Velocity Data				
	Roof	Floor 4	Floor 3	Floor 2
Fixed base (mm/s)	698	660	550	375
Base Isolated (mm/s)	70.5	68.9	65.1	60.9
Acceleration Data				
	Roof	Floor 4	Floor 3	Floor 2
Fixed base (m/s^2)	107	34.8	90.4	29.5
Base Isolated (m/s^2)	9.44	8.25	5.8	3.52

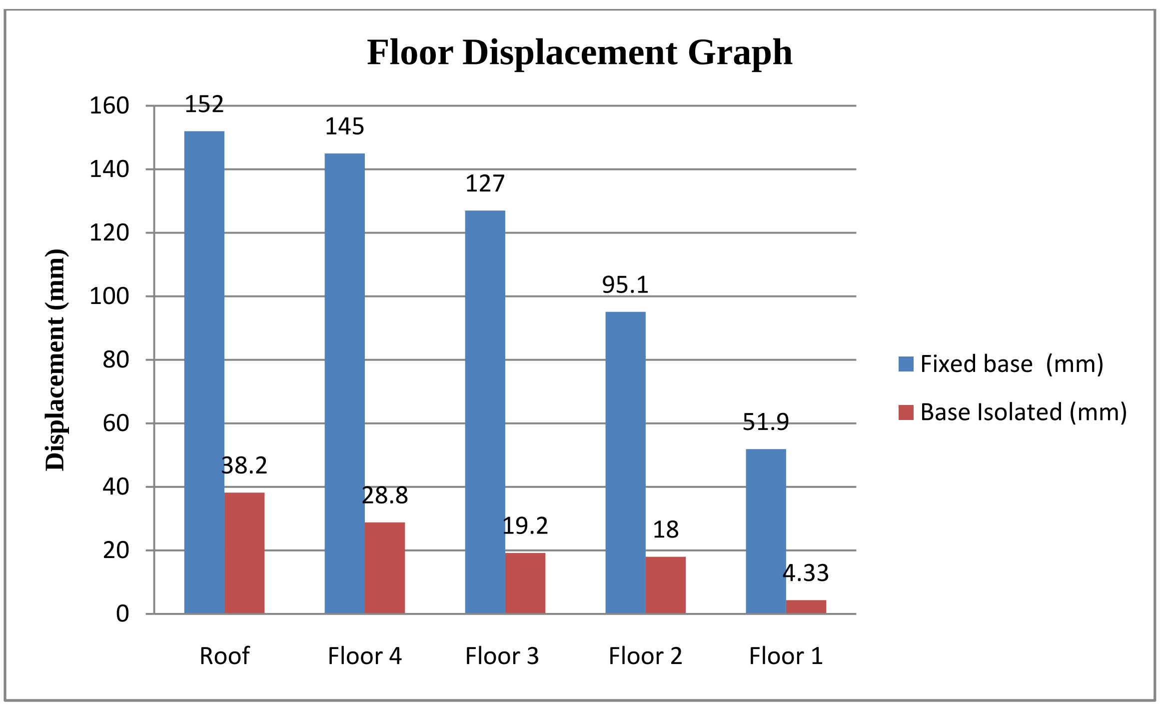


Fig 5.6 Displacement graph (Fixed Base v/s Base Isolated)

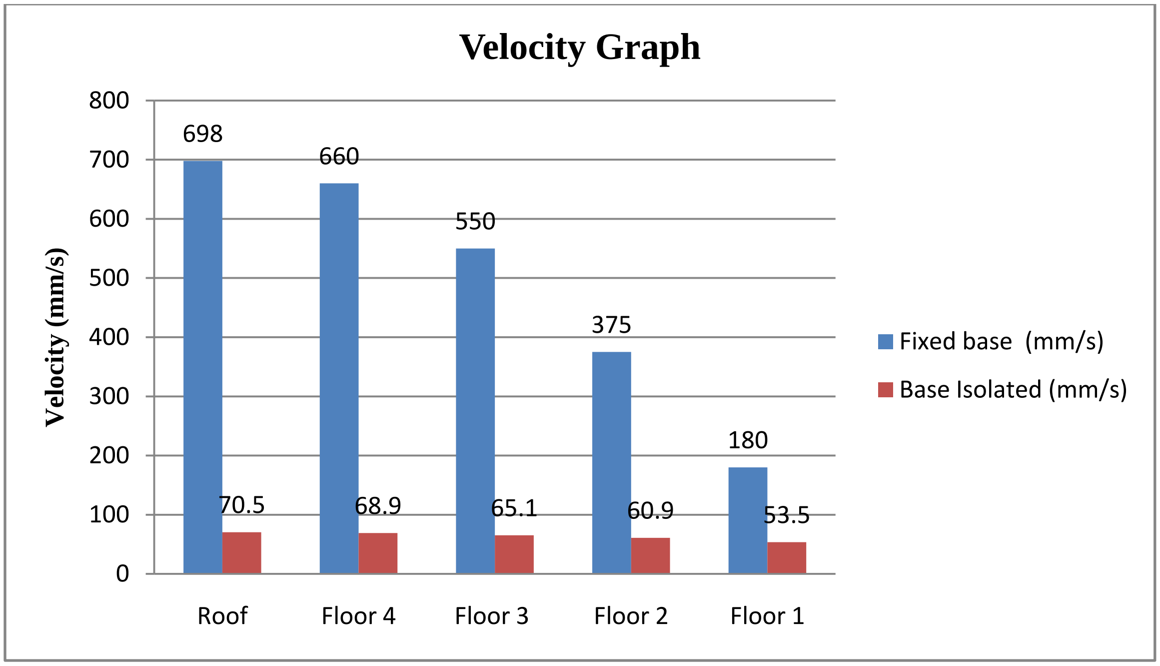


Fig 5.7 Floor-wise Velocity graph (Fixed Base v/s Base Isolated)

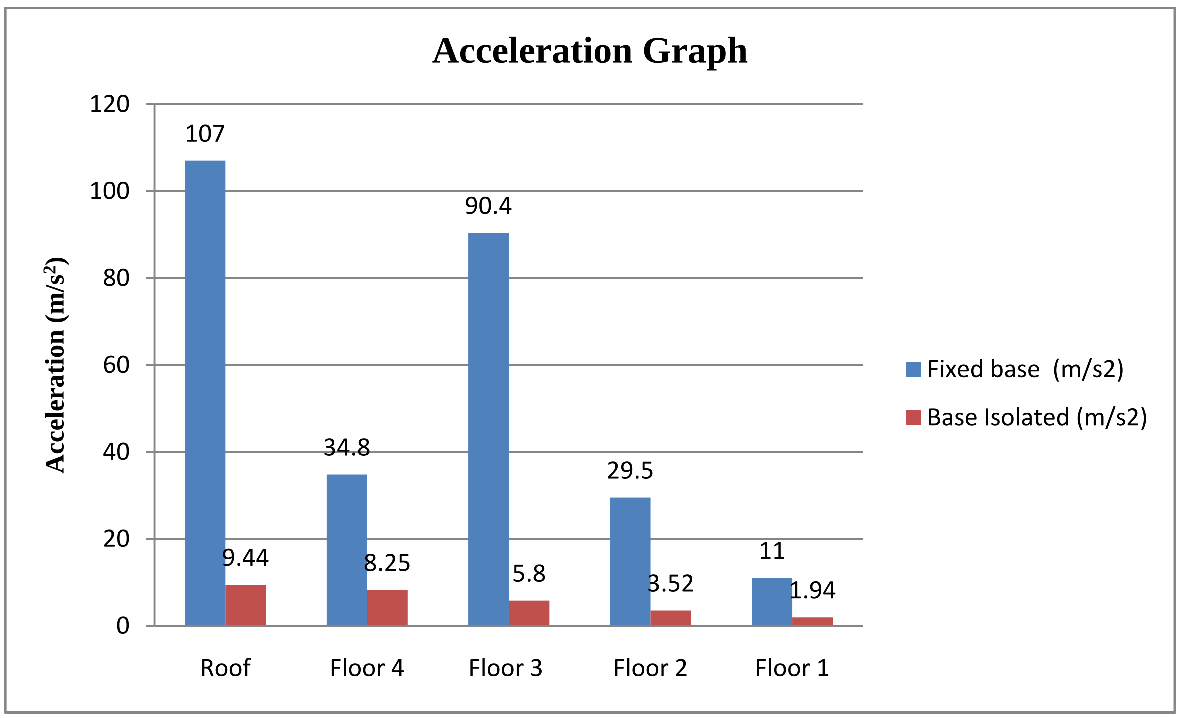
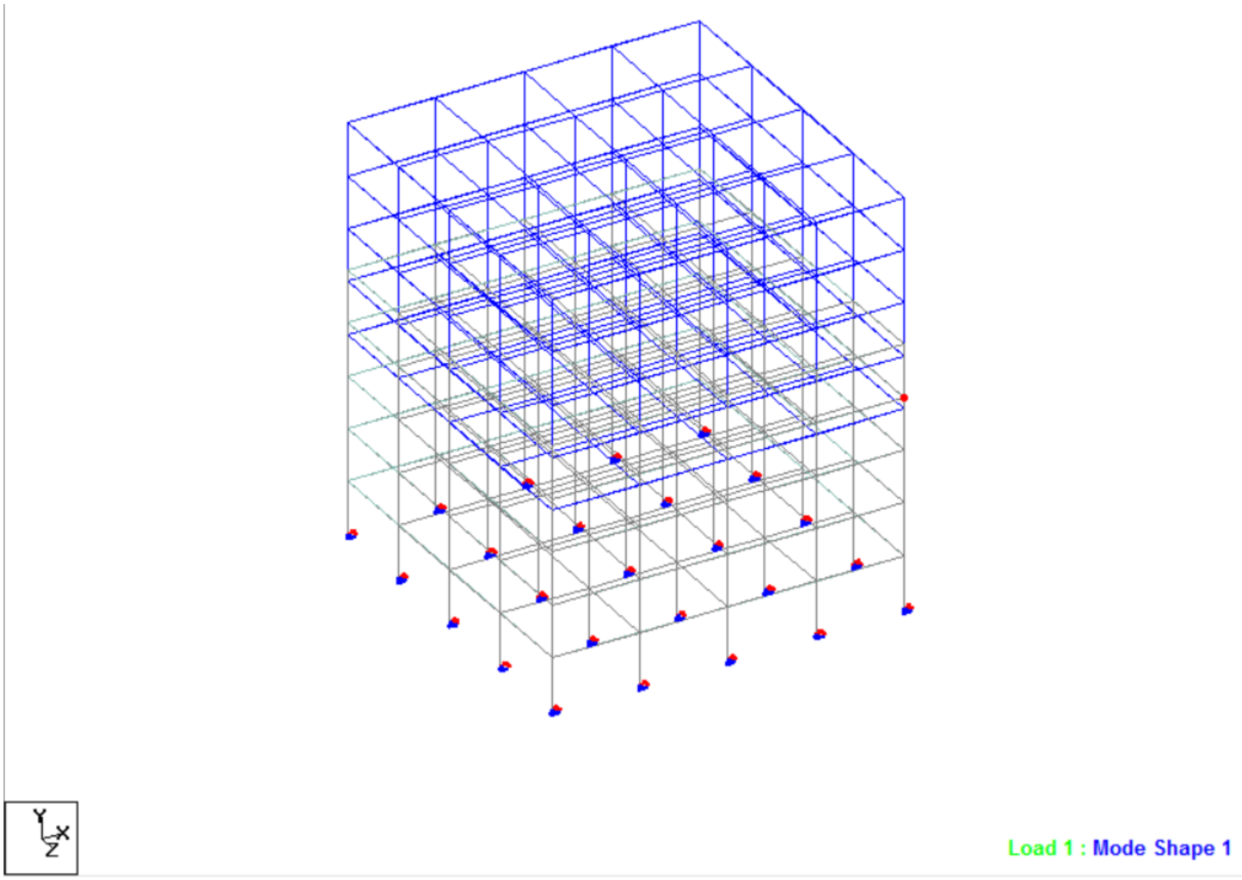


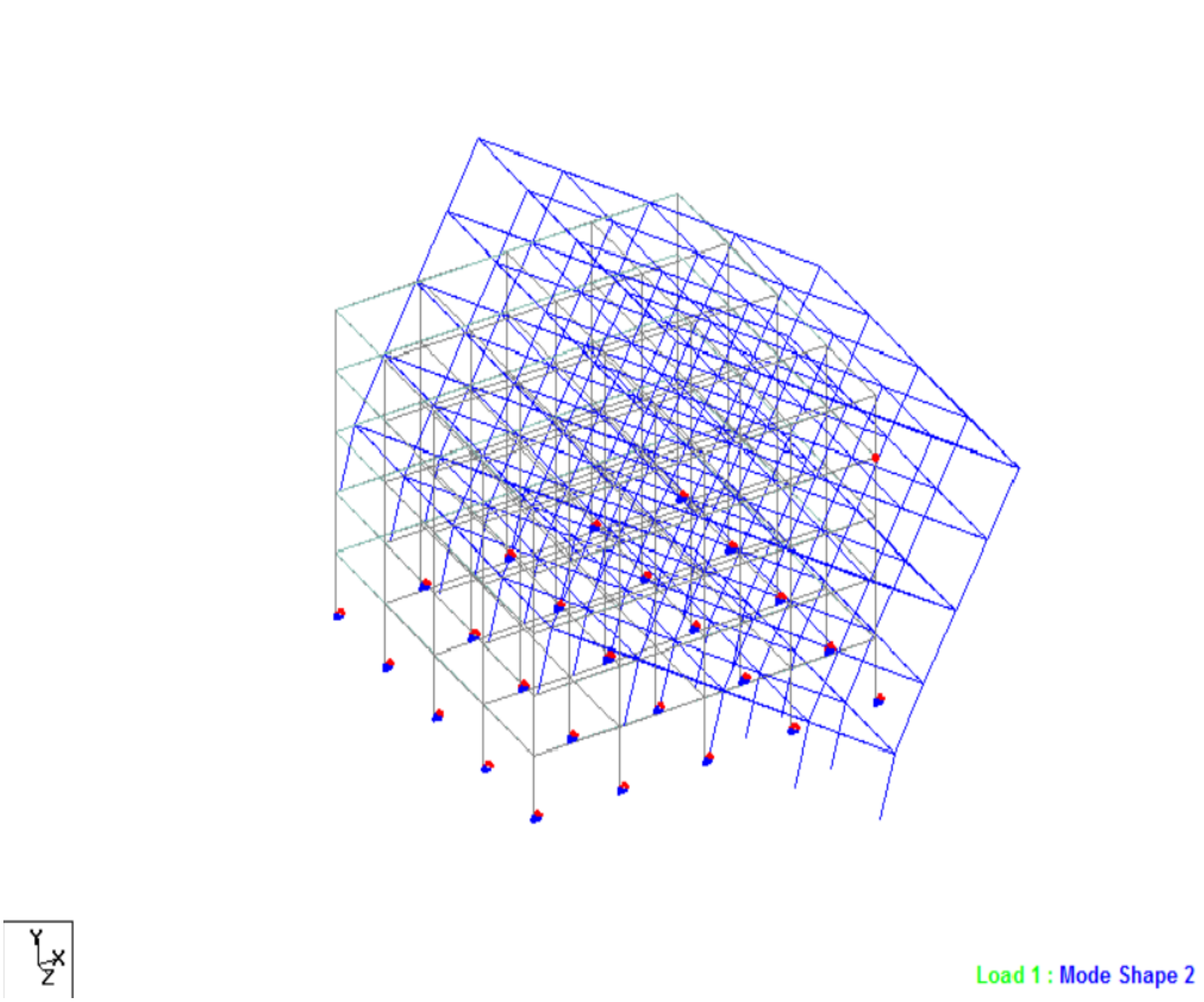
Fig 5.8 Acceleration graph (Fixed Base v/s Base Isolated)

5.1 First Three Mode Shapes of the Base Isolated Building

Mode Shape 1



Mode Shape 2



Mode shape 3

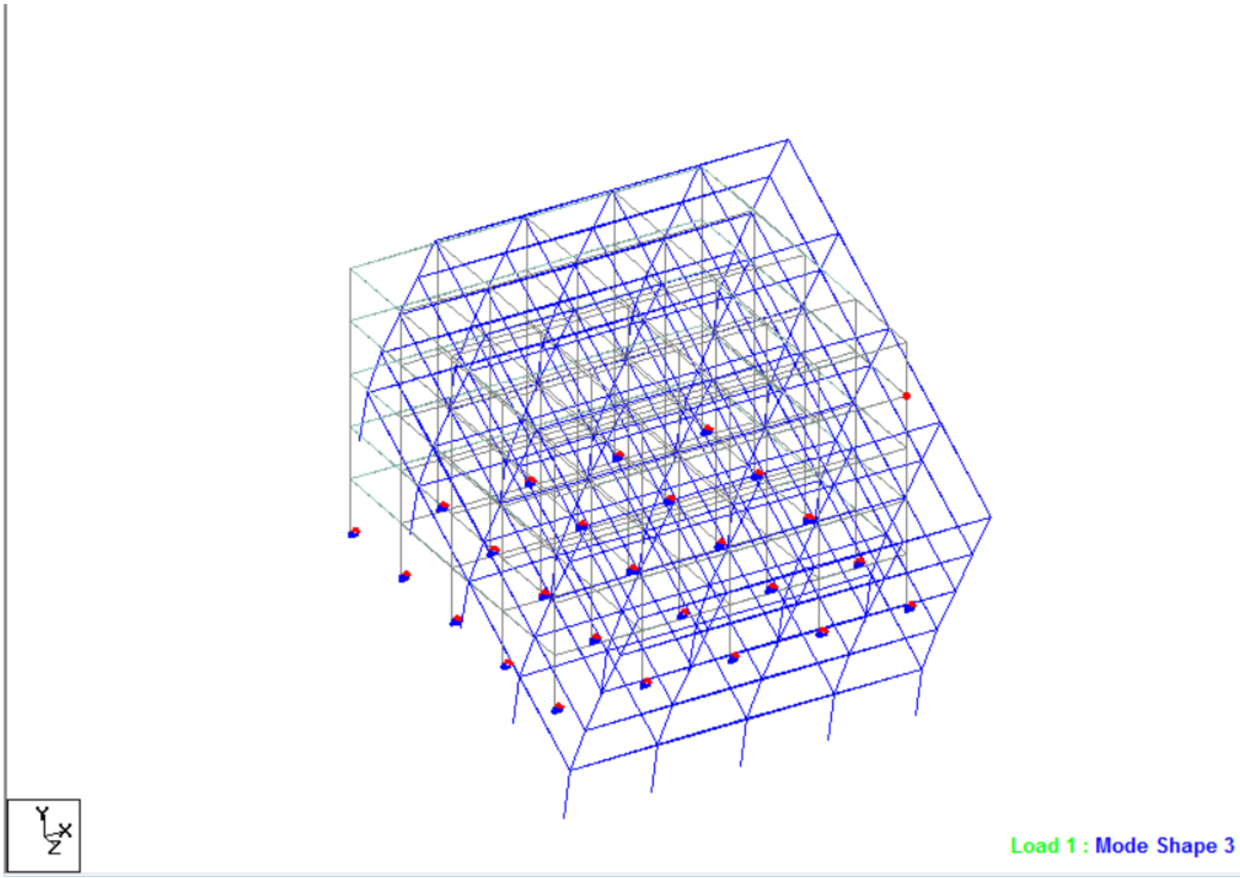


Fig 5.9 Mode shapes of the Base Isolated Building

Table 5.2 Storey Drift Fixed v/s Base Isolated

Storey	Storey drift for fixed base (mm)	Storey Drift for Base Isolated (mm)
0	0	0
0-1	25.985	5.476
1-2	28.929	12.624

2-3	31.751	18.296
3-4	33.58	21.624
4-5	34.556	25.932

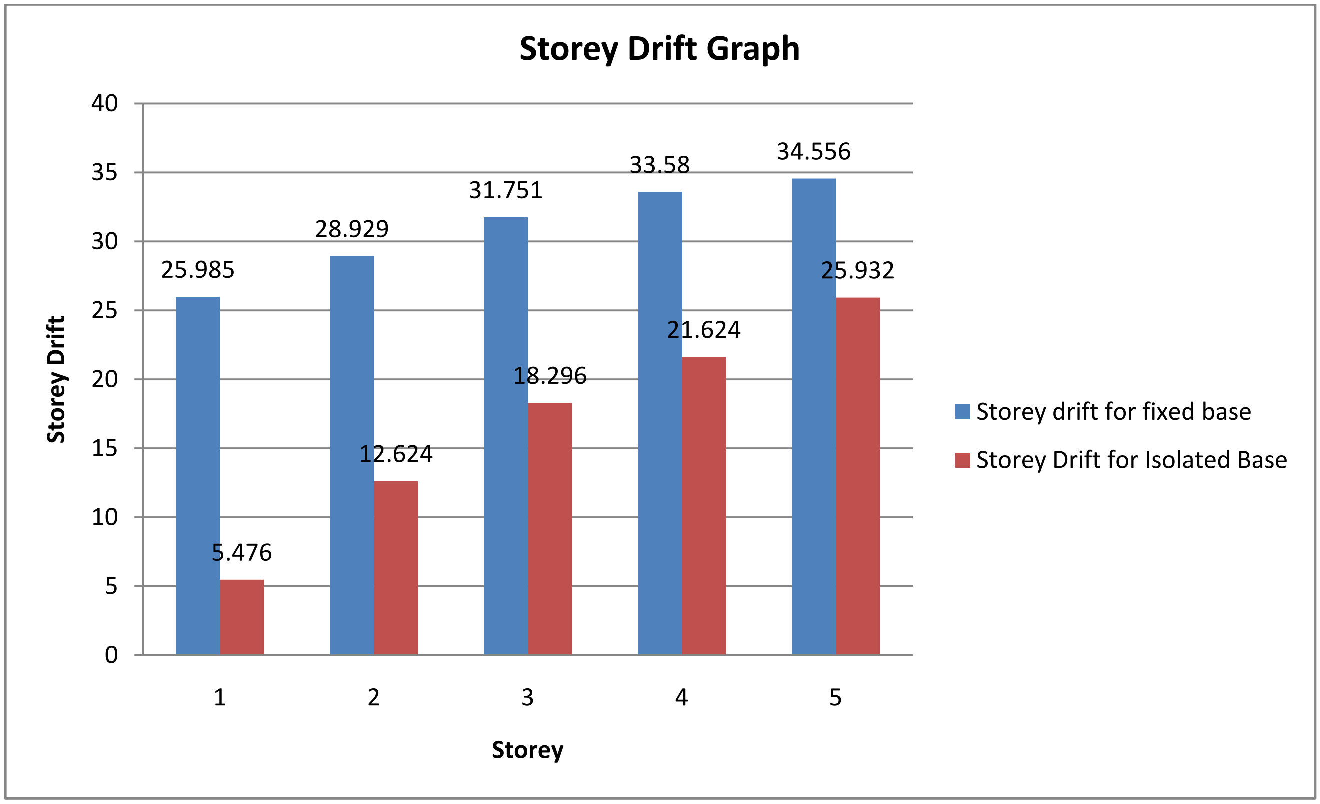


Fig. 5.10 Storey drift graph between Isolated and fixed base

5.2 Period Shift Effect

The spring-like isolation bearings with considerable lateral flexibility help in reducing the earthquake forces by changing the structure's fundamental period to avoid resonance with the predominant frequency contents of earthquakes. Whereas the sliding-type isolation bearings filter out earthquake forces via the discontinuous sliding interfaces, between which the forces transmitted to the superstructure are limited by the maximum friction forces regardless of earthquake intensity. That can be shown from the graph shown below.

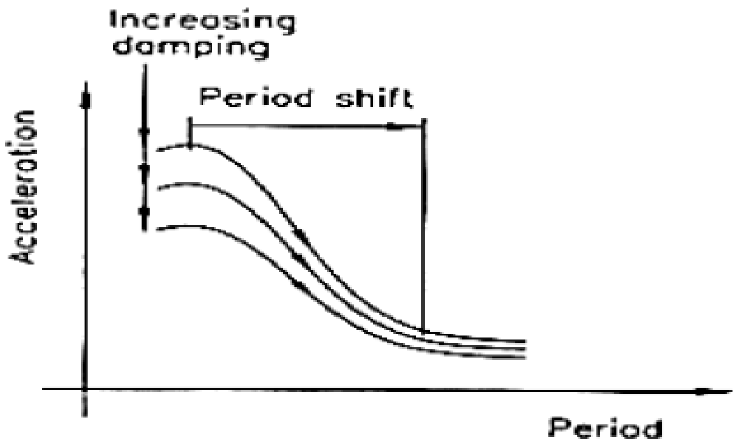


Fig 5.11 Period shift graph (by Weng, Yen-Po)

Table 5.3 Isolation Effectiveness

Mode Shape	Time period for fixed base (s) (A)	S_a/g (acceleration Coefficient) (B)	Time period For Base Isolated (s) (C)	S_a/g (Acceleration coefficient) (D)	Isolation Effectiveness (B-D)/B ×100
1	1.74128	0.623	10.84419	0.11	82.34%
2	1.5351	0.68	6.0666	0.2	70.58%
3	0.6247	1.58	3.26547	0.39	75.31%
4	0.53214	1.65	2.35738	0.48	70.90%
5	0.45208	2.12	2.22129	0.5	76.41%
6	0.40674	2.2	1.22618	0.89	59.54%
7	0.40037	2.21	0.87664	1.18	46.60%
8	0.35277	2.39	0.80679	1.16	51.46%
9	0.34134	2.4	0.80289	1.14	52.5%
10	0.29916	2.42	0.74227	1.09	54.95%
11	0.29427	2.45	0.6819	1.02	58.36%

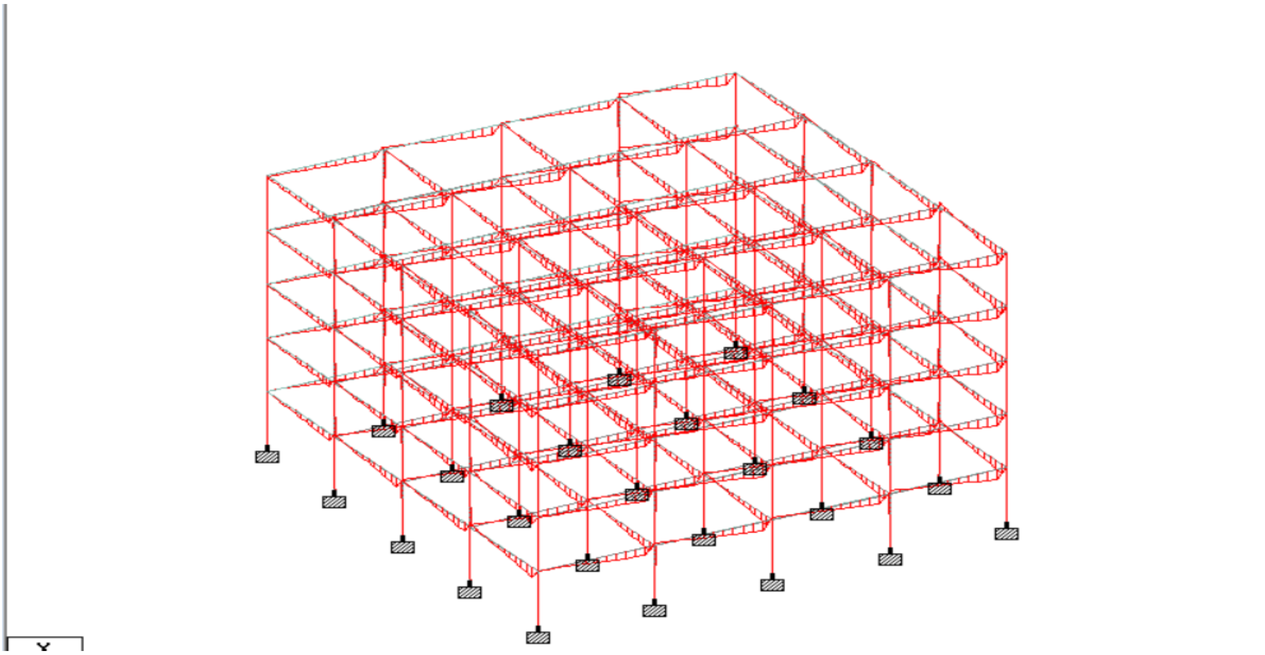


Fig. 5.12 Shear force diagram of the frame.

Amitproject 1AT.std - Beam Force Detail:

All / Max Axial Forces / Max Bending Moments / Max Shear Forces

Beam	L/C	Dist m	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
		0.900	155.351	-0.078	-10.876	-0.001	9.677	-0.07
		1.800	155.351	-0.078	-10.876	-0.001	-0.111	-0.00
		2.700	155.351	-0.078	-10.876	-0.001	-9.899	0.06
		3.600	155.351	-0.078	-10.876	-0.001	-19.687	0.13
	4 COMBINATI	0.000	331.046	18.705	-14.292	0.135	25.498	34.85
		0.900	327.229	7.877	-14.286	0.135	12.659	17.78
		1.800	323.412	-2.952	-14.279	0.135	-0.180	0.70
		2.700	319.595	-13.780	-14.273	0.135	-13.018	-16.36
		3.600	315.778	18.705	-14.292	0.135	-25.922	44.56
	5 COMBINATI	0.000	20.343	18.861	7.459	0.136	-13.433	35.15
		0.900	16.527	8.033	7.465	0.136	-6.695	17.93
		1.800	12.710	-2.796	7.472	0.136	0.042	0.72

Fig 5.13 Maximum Shear Force From analysis of 5 storey building in STAAD.pro

CHAPTER

6

STABILITY ANALYSIS OF ISOLATOR USING ABAQUS®

6.1 Material parameters of laminated rubber bearing

Rubbers are usually considered as almost incompressible material including nonlinear geometric effects. The mechanical rubber behavior is modeled by a homogeneous, isotropic and hyperelastic model and it is usually described in terms of a strain energy potential, U, which defines the strain energy stored in the material per unit of reference volume in the initial configuration as a function of the strain at that point in the material.

6.2 Hyperelasticity

Hyperelasticity is a time independent behavior of rubbers and foams subjected to large strains. Hyperelastic constitutive laws are used to model materials that respond elastically when subjected to very large strains. They account both for nonlinear material behavior and large shape changes. The main applications of the theory are (i) To model the rubbery behavior of a polymeric material, and (ii) to model polymeric foams that can be subjected to large reversible shape changes (e.g. a sponge).A material is said to be hyperelastic if components of stress tensor σ_{ij} can be derived from a scalar function of strain tensor.

6.3 Assigning material properties and dimensions

The values of the Neo-Hookean coefficients and material properties of the laminated elastomeric bearing and steel shims used in ABAQUS are shown in Table 5.1. The steel material of the top and bottom plates and the shims was assumed to be mild steel.

Table 6.1 Material properties for all the circular bearings

Material	Properties	Explanation
Rubber	C_{10}= 0.37 MPa D_1= 1×10^{-5}MPa G = 0.73 MPa	Neo-Hookean (Finite element modeling) Shear modulus (theoretical approach)
Steel shims	E = 210MPa υ = 0.3 Yield Stress = 210MPa	Young's modulus Poisson's ratio Von-Mises yield criterion

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Table 6.2 Material properties for all rectangular bearings

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Material	Properties	Explanation
Rubber	C_{10}= 0.506 MPa D_1= 1×10^{-5}MPa G = 1.012 MPa	Neo-Hookean (Finite element modeling) Shear modulus (theoretical approach)
Steel shims	E = 210MPa υ = 0.3 Yield Stress = 210MPa	Young's modulus Poisson's ratio VonMises yield criterion

6.4 Model Problem and Analysis in ABAQUS

6.4.1 Problem statement For Isolator 1

An isolator model (Isolator-1) has been taken for illustration which is elastomeric bearing. This is created using ABAQUS for the calculation of stiffness, obtain the force-deformation curve and stability assessment for the same.

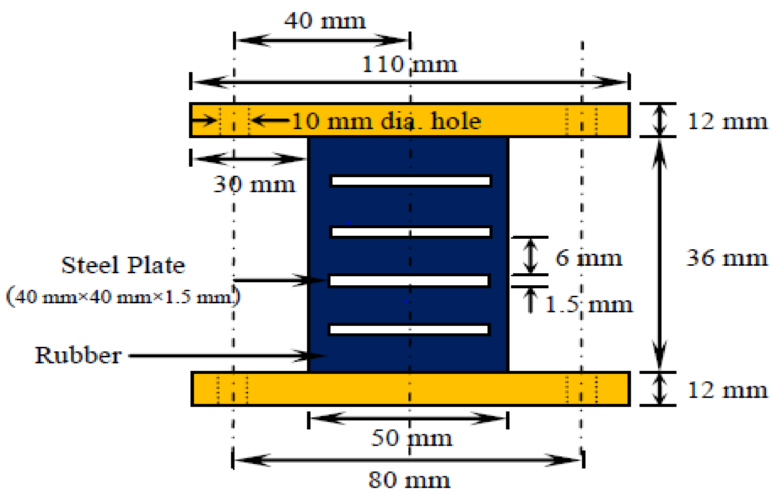

Figure 6.1 Dimensions of rectangular bearing

6.4.2 Solution

Size of the elastomer is 50 mm × 50 mm × 6 mm including the side cover. To make the modelling simplified the side covers of the bearing are eliminated in FE modeling of the rectangular bearing. Hence, the size of the elastomers of the bearing is taken as 40 mm × 40 mm × 6 mm. The size of steel laminate is 40 mm × 40 mm × 1.5 mm. The size of top and bottom steel plate is taken as 100 mm × 100 mm × 12 mm, for modelling, this is because the elastomer dimensions are also reduced.

6.4.3 Modeling of parts

The starting coordinates defined for the rectangular shape are (-0.020,-0.020) and the end coordinate is defined as (0.020, 0.020), the dimensions are in (m) unit for length and N is the unit for force during modelling.

6.4.4 Parts

1. Assign the coordinates for the plan dimensions and then extrude equal to thickness of the rubber, steel or plates in the features.
2. Define the inner and outer surface, which will be used to define the constrained and in assembly.
3. Section assignment as the solid, homogeneous for all model.

6.4.5 Material definition

Stel is defined as an elastic material in which density and elastic modulus is defined. Rubber is defined as the hyperelastic material and the material constant are set for Neo-Hookean model. Neo-Hookean model defines the strain energy potential *U* as (ABAQUS Documentation for Hyperelastic material models)

$$U = C_{10}(I_1 - 3) + \frac{(J^{el} - 1)^2}{D_1} \tag{1}$$

$$C_{10} = \frac{G}{2}, D_1 = \frac{2}{k} \tag{2}$$

$$I_1 = \bar{\lambda}_1^{\,2} + \bar{\lambda}_2^{\,2} + \bar{\lambda}_3^{\,2} \tag{3}$$

$$\bar{\lambda}_i = J^{-\frac{1}{3}} \lambda_i \tag{4}$$

where, C_{10} and D_1 are the material parameters, I_1 is the first deviatoric straininvariants, $J^{el}$is the elastic volume ratio, J is the total volume ratio, λ_i are the principal stretches, and $\bar{\lambda}_i$ is deviatoric stretches. For hyperelastic material the Poisson's ratio and K/G are related as

$$\mu = \frac{(3K/G) - 2}{(6K/G) + 2} \tag{5}$$

Value of the shear modulus (G) provided by the manufacturer is 9.75 kg/cm^2. However shear modulus generally lies in the range of 8 - 12 kg/cm^2 (Maalek, et al., 2007). In the current modelling$G$ is taken as 1.13 MPa with around 12% (to keep G in the range of 8 - 12 kg/cm^2) increase in the value of G to match the results obtained from experimental hysteresis loop. Bulk modulus (K) is assumed as 2000 MPa for elastomers as per Warn and Whittaker, 2006.

The material constants are taken as per the assumed value or the value obtained from the experimental investigations. For stiffness calculation of the rectangular bearings, cyclic loading was applied during experimental method and its force-deformation behavior is plotted. Stiffness and damping of the bearing is calculated from the experimentally obtained force-deformation behavior. Rayleigh damping in the form of mass proportional damping and stiffness proportional damping, is used for FE modeling of the bearing. The classical damping equation is expressed as

$$c = a_0 m + a_1 k \tag{6}$$

where, a_0 or α and a_1 or β are respectively the mass and stiffness proportional factors. In ABAQUS modeling the stiffness proportional factor (a_1 orβ) is considered as 10%. The damping factor can be changed to get the results which will be in best agreement with the experimental investigation.

For the current study the values of stiffness proportional constant (a_1 orβ) is assigned as 10% and mass proportional constant (a_0 or α) is assigned as zero.

6.4.6 Meshing

Elastomer layer is divided into 10 parts along the edge and in two parts along the thickness. The steel shim is divided into 10 parts along the edges and remains a single element along its thickness. The top and bottom steel cover plates are divided into 15 elements along the edges and in two parts along the thickness. Rectangular bearing contain 4517 nodes and 2424 elements.

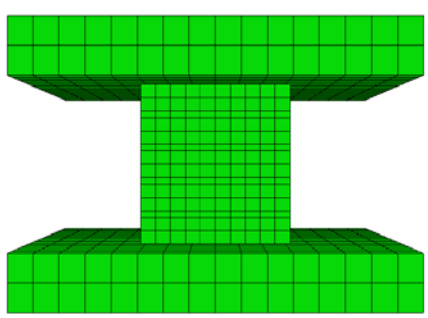

Figure 6.2 Meshing of rectangular bearing

6.5 ASSEMBLY

6.5.1 Instance

Instances are selected one by one and they are arranged by translating the instances one over another. The bottom plate is selected as the first instance and set as dependent (mesh on part), after that the elastomer layer is selected as instance and also set asdependent (mesh on part), on the screen both the plate and elastomers are presented. Next, the elastomer layer is selected for the instance translation and translated from the coordinates (0, 0, 0) to (0, 0, 0.012), because the thickness of steel plate is as 12 mm. same is done for the all instances one by one.

6.5.2 Features

Two reference points are set (RF -1, RF -2), which will be used to tie the nodes and also for applying the loads.

6.5.3 Sets

All nodes of bottom and top are selected and two sets are formed one for top nodes and other for bottom nodes. Reference point is also set as one of set as reference point set.

6.5.4 Constraints

All the layers of elastomer are to be tied together for the analysis, for this the steel shims are selected as Mater surfaces and elastomer layers are selected as slave surface for each interaction between steel and elastomer. Rigid body constrain is defined for the bottom nodes and tied with the bottom reference point similarly is done for the top nodes.

6.6 STEPS

6.6.1 Initial step

The boundary conditions are defined in the initial step and are propagated for the next step.

6.6.2 Dynamic/ Implicit step

This step is used for the stiffness calculations, time period is defined according the amplitude defined for the shear force for total number of cycles. Increments is defined as automatic and specify the minimum and maximum size of increments.

The axial compressive load is defined in the pressure form on the top surface of cove steel plate. Next load is defined for the shear force which is set to its maximum value (CF1) and the amplitude is defined so that the cycling loading is applied.

6.6.3 Static/RIKS step

This step is used for the stability analysis of the bearing. In the stopping criteria for analysis is defined with the maximum displacement (0.004 m, equal to width of bearing) in the X direction (D.O.F =1) at the top reference point. Increments are set as per the requirements.

Loads is defined CF1 equal to shear force (1kN) which will provides the lateral deformation in X direction and axial compressive load is defined CF3 equal to the critical load obtained from the buckling analysis for the same model.

6.6.4 Job

Job is defined for the analysis of stiffness and stability analysis.

6.6.5 Visualization

6.6.6 Stiffness

CF1 Shear force, U1 Displacement is obtained for each axial loads and plotted.

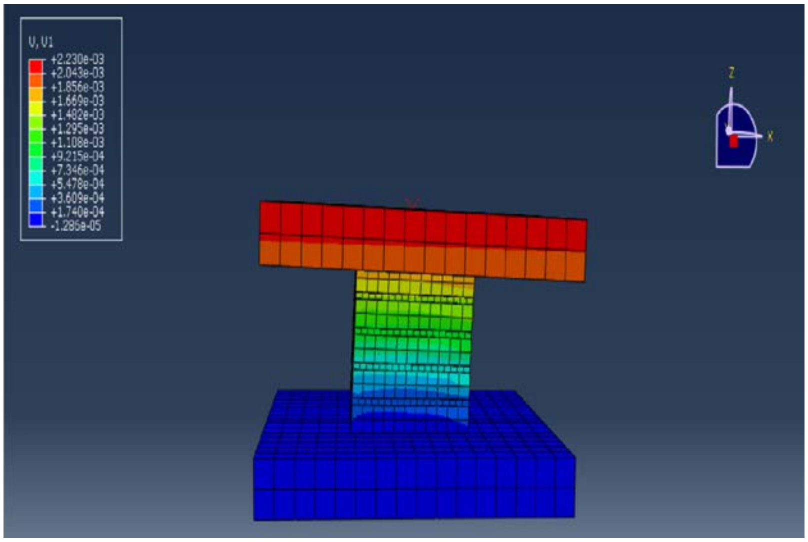

Fig 6.3 Model generated from ABAQUS (Isolator 1)

Table 6.3 Sear Force v/s Displacement data

Shear Force	Displacement
0	0
35	0.530324

70	1.18879
105	1.84767
140	2.50594
175	3.16342
140	2.76493
105	2.10804
70	1.449
35	0.789606
0	0.130044
-35	-0.529487
-70	-1.18879
-105	-1.84767
-140	-2.50594
-175	-3.16342
-140	-2.76493
-105	-2.10804
-70	-1.449
-35	-0.789606
0	-0.130044
31.5	0.46406

6.5	1.12288
101.5	1.7818
136.5	2.44014
171.5	3.09771
143.5	2.82967
108.5	2.17391
73.5	1.51493
38.5	0.855557
3.5	0.196002
-31.5	-0.463541
-66.5	-1.12287
-101.5	-1.7818
-136.5	-2.44014
-171.5	-3.09771
-143.5	-2.82967
-108.5	-2.17391
-73.5	-1.51493
-38.5	-0.855557
-3.5	-0.196002
28	0.398459

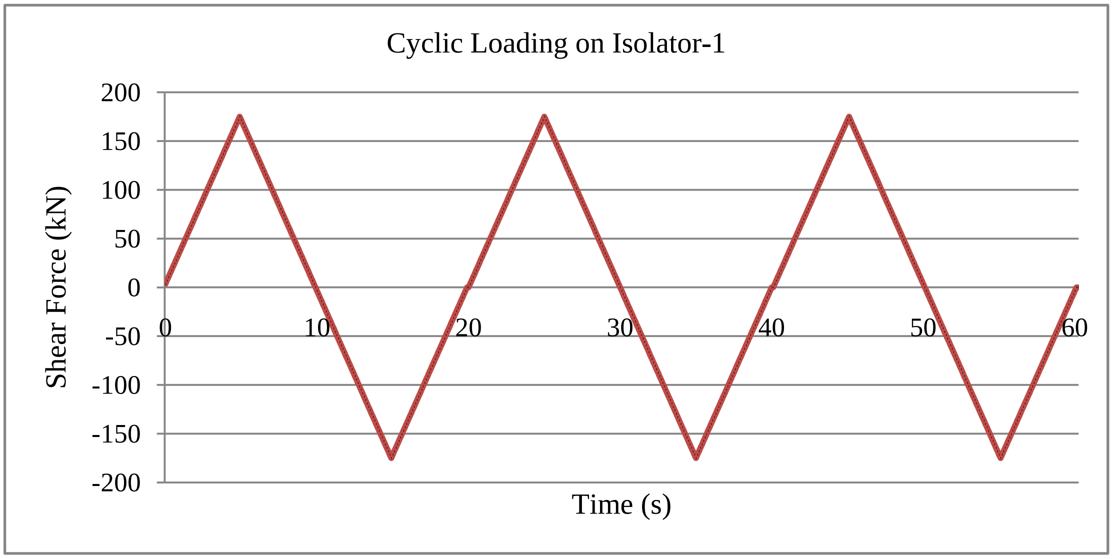

Fig 6.4 Cyclic loading graph for Isolator 1

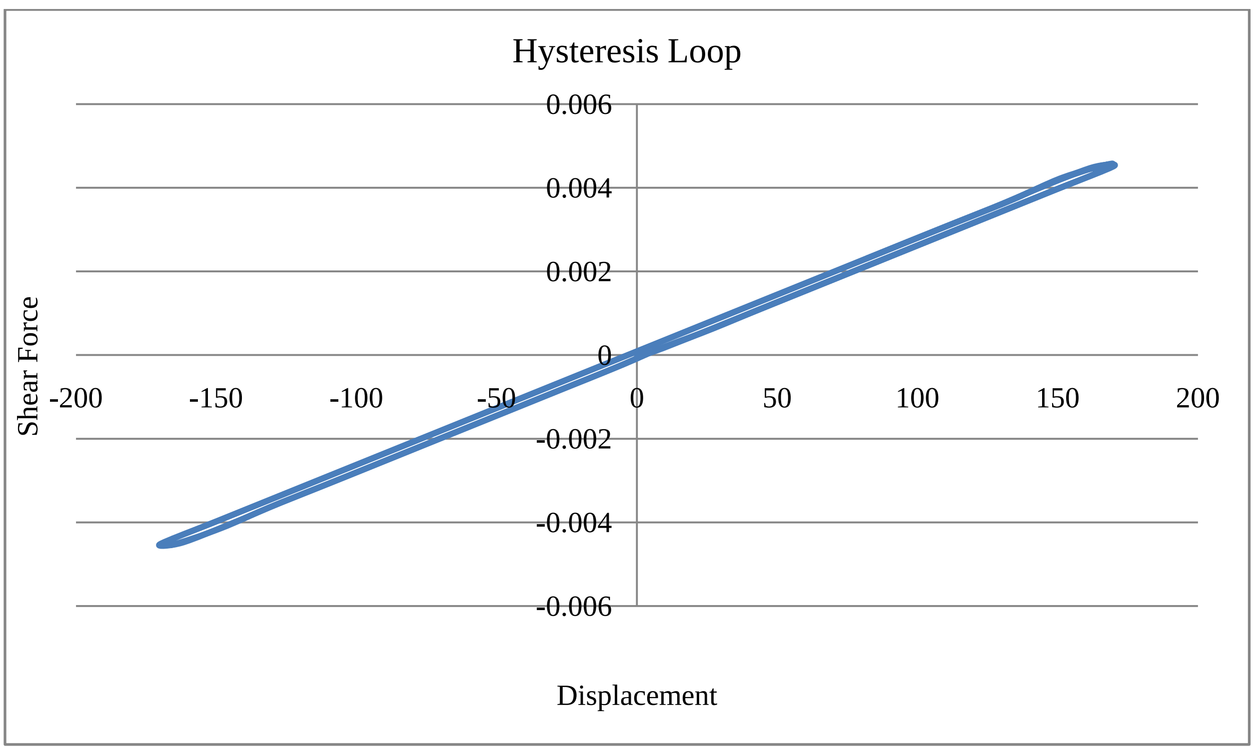

Fig 6.5 Hysteresis Loop Graph from Isolator 1

From Fig. 6.5, it can be seen that the hysteresis loop formed is very small and the energy displaced is very less. As the for maximum shear force was 175 kN/m, the displacement in Isolator came out to be 4.26 mm, hence the energy dissipated per loading cycle by this isolator can be obtained by computing the area enclosed in the hysteresis loop.

Following the similar procedure, the isolator (Isolator-2) designed for the 5-storey building has been modeled in ABAQUS. The dimensions and other properties of the isolator has been taken from the manual design results obtained in the previous chapter. The energy dissipation and its response to cyclic loading is investigated in ABAQUS. This facilitates checking the safety of the designed isolator for the building.

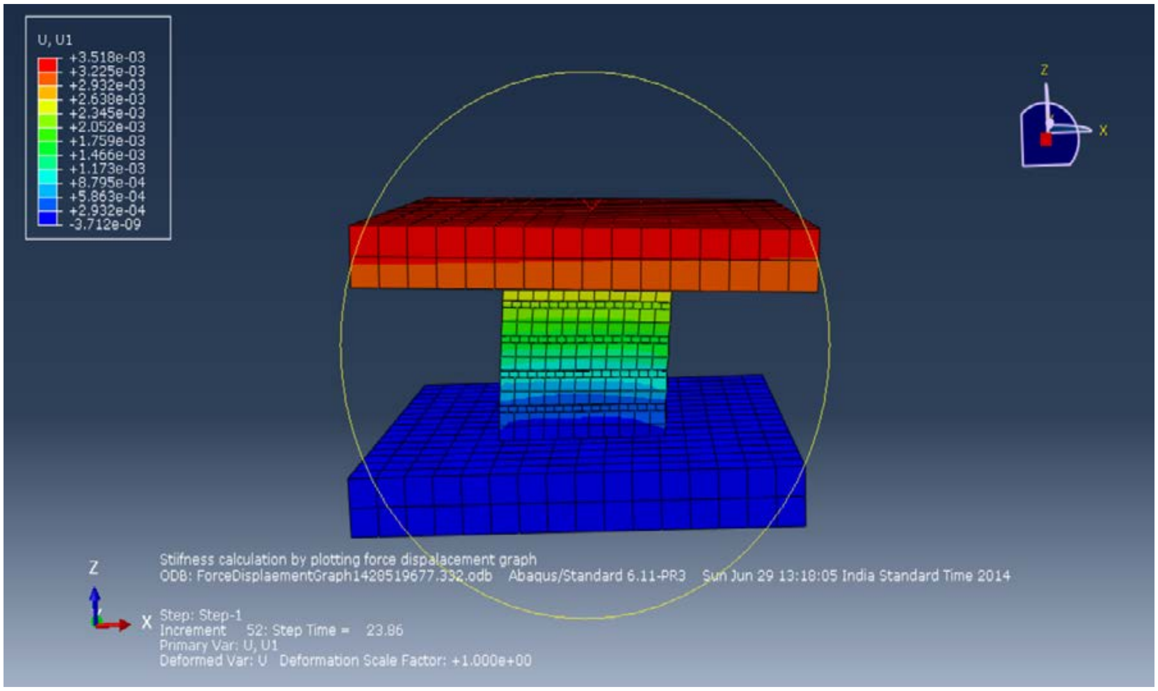

Fig. 6.6 Model generated in ABAQUS (Isolator 2)

TABLE-6.4 Shear force at various time points obtained from ABAQUS model

Shear Force (kN)	Time (s)
0	0
6.62	0.1
13.24	0.2

19.86	0.3
26.48	0.4
33.1	0.5
39.72	0.6
46.34	0.7
52.96	0.8
59.58	0.9
66.2	1
72.82	1.1
79.44	1.2
86.06	1.3
92.68	1.4
99.3	1.5
105.92	1.6
112.54	1.7
119.16	1.8
125.78	1.9
132.4	2
139.02	2.1
145.64	2.2
152.26	2.3
158.88	2.4
165.5	2.5
172.12	2.6
178.74	2.7
185.36	2.8
191.98	2.9
198.6	3
205.22	3.1
211.84	3.2

218.46	3.3
225.08	3.4
231.7	3.5
238.32	3.6
244.94	3.7
251.56	3.8
258.18	3.9
264.8	4
271.42	4.1
278.04	4.2
284.66	4.3
291.28	4.4
297.9	4.5
304.52	4.6
311.14	4.7
317.76	4.8
324.38	4.9
331	5
324.38	5.1
317.76	5.2
311.14	5.3
304.52	5.4
297.9	5.5
291.28	5.6
284.66	5.7
278.04	5.8

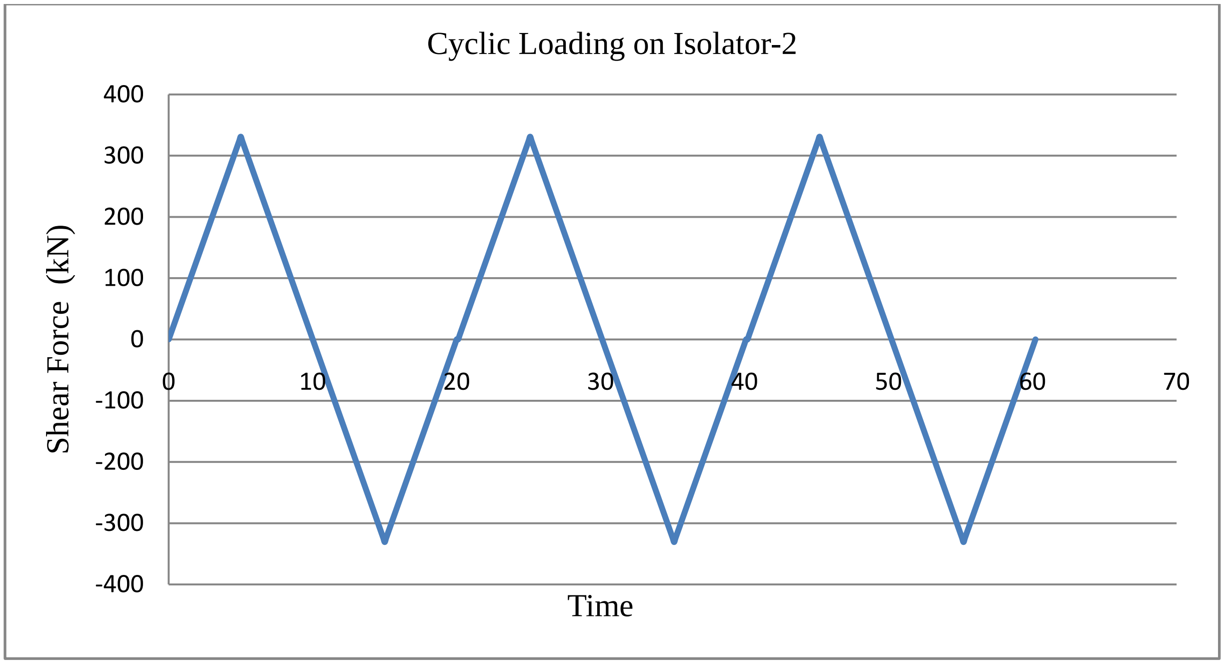

Fig 6.7 Cyclic loading graph from (Isolator 2)

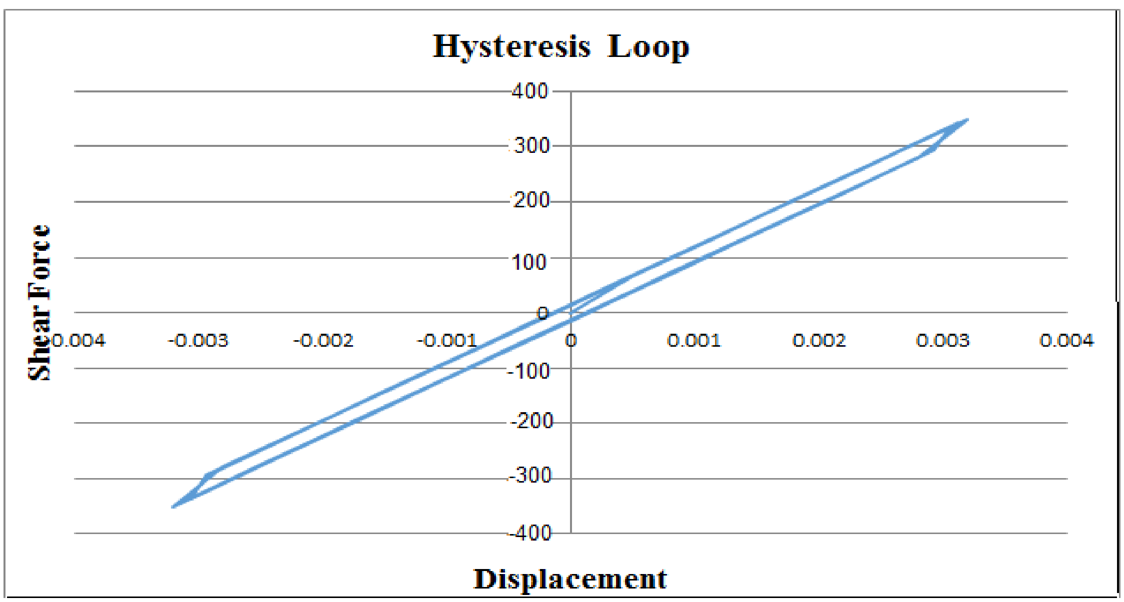

Fig 6.8 Hysteresis loop Graph (Isolator 2)

6.7 Energy Dissipated by Isolator

Energy Dissipated from Isolator 1:

$= 2 [½ × 175 × 4.26 – 1/2×152 × 4.02]$

$= 2 [372.75 -305.52]$

$= 2 ×67.23$

= 134.46 Joules/cycle

Energy Dissipated from Isolator 2:

$= 2 [½ × 331 × 3.16 – ½ × 290 × 2.75]$

$=2 [522.98 – 398.75]$

$=2 × 124.46$

= 248.46 Joules/cycle

CHAPTER

7

CONCLUSIONS

In the present work, a 5-storeyed RC framed building have been analysed with fixed base and base isolation. Its performance was studied for both the cases using response spectrum method. The isolators have been designed as per Uniform Building Code. The isolator modeling has been in ABAQUS and lateral forces generated in the building have been applied to judge its performance in terms of displacement and energy dissipated. From the work carried out in this dissertation, the following conclusions are drawn.

1. Base isolation shifts the time period of vibration of the structure significantly thereby reducing the effect of earthquake acceleration to as high extent as 83%, as revealed from isolation effectiveness measured in terms of percentage reduction in acceleration coefficient. Especially for first five modes it is more than 70%.

2. Displacement and velocity responses are also observed to be reducing by a large degree after base isolation is implemented.

3. Storey drift is also reduced by a factor ranging from 5 to 1.5, highest being towards the ground storey. This alleviates shear forces and bending moments in the columns thereby reducing the demand on the structure.

4. Performance of the isolator model in the ABAQUS® is seen to be satisfactory and within limits in terms of its lateral displacement, when loaded with maximum shear force that any column of the building considered can receive.

5. The energy dissipated per cycle (EDC) by each isolator is about 250 Joules, which is a measure of its damping. The equivalent damping obtained is 10.7% which is within the acceptable range of 10 – 20% for isolation devices.

SCOPE FOR FURTHER WORK

The following may be considered for possible extension to the work presented herein.

1. Optimum design of isolators by limiting their dimensions and number and thickness of steel shims.
2. Redesigning the building with reduced demands after base isolation, for economy.
3. Carrying out stability analysis of isolators during high intensity earthquake motions taking into account their rotations and shear strain in plastic region.

CHAPTER

8

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