MAJOR PROJECT REPORT

ON

COMPARATIVE STUDY OF BASE ISOLATED & FIXED BASE RC FRAME STRUCTURE

A Dissertation submitted in partial fulfillment of the requirement for the Award of degree of

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

Submitted by:

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(2K15/STE/18)

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July 2017

CANDIDATE'S DECLARATION

I hereby declare that the project work entitled **"Comparative Study of Base Isolated & Fixed Base RC Frame Structure"** submitted to Department of Civil Engineering, DTU is a record of an original work done by **Shivam Agrawal** under the guidance of **Dr. Nirendra Dev**, Professor, Department of Civil Engineering, DTU, and this project work has not performed the basis for the award of any Degree or diploma/fellowship and similar project, if any.

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CERTIFICATE

This is to certify that the project entitled **"Comparative Study of Base Isolated & Fixed Base RC Frame Structure"** submitted by **Shivam Agarwal,** in partial fulfillment of the requirements for award of the degree of **MASTER OF TECHNOLOGY (STRUCTURAL ENGINEERING)** to Delhi Technical University is the record of student's own work and was carried out under my supervision.

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.   (**Shivam Agrawal)**

ABSTRACT

Earthquake can cause significant or severe structural damages. To protect the structure from severe damages, different kind of structural design techniques are used such as providing shear wall, bracing in building, use of base isolation device and dampers etc. In present study we are going to use base isolation technique. These techniques reduce the seismic forces by providing the high lateral flexibility, which in turn increase the time period of vibration of structure & reduce the base shear. The research and development works of different types of base isolation technique are ongoing intensively.

This study presents a brief history of isolation techniques and preliminary design of high damping rubber bearing and lead rubber bearing isolator with the help of provisions provided in uniform building code (UBC -1997). In this study, modeling and analysis of G+6 story fixed base and base isolated structure is carried out using E-TABS software in order to evaluate floor response, displacement, drift, time period of structure during earthquake. This study intends to demonstrate how an isolation system can be efficient for earthquake resistant design of building.

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1. INTRODUCTION

1.1 Background

An earthquake is the perceptible shaking of the earth surface, resulting from the sudden release of energy in the Earth's crust that creates seismic waves which resulted in the shaking of ground (Earthquake).

Earthquakes can be strong enough cause injuries and death of many people and cause severe damages to man-made structure such as buildings, dams, bridges, roads etc. Every year thousands of people are rendered homeless, displaced, injured and even die all over the world due to earthquakes. An earthquake is a current problem of great political and social relevance and a challenge to the structural engineers.

In the past building structures have been designed without any consideration of the seismic effects. The knowledge about the earthquake, their behavior and their effects on structure grew with time and seismic resistant design procedures have been started to be followed the analysis and design of structures. Basic requirement for safety of building from earthquake is to design such building that can resist effect of ground motion and would not collapse during the strong earthquake but may sustain some non-structural damage. In recent times, due to advancement in technologies many new systems have been developed to reduce the impact of earthquake forces on structure. Such systems are shear wall, bracings, base isolation, seismic dampers etc. In this study we will explore the concept of base isolation. The basic idea behind the base isolation is to decouple the superstructure from ground in such a way that earthquake motions will not be transfer to the superstructure or at least greatly reduce the seismic force transmitted to building or superstructure. Base isolation system provides high lateral flexibility which increases the time period of structure. As the time period of structure increases story acceleration of structure gets decrease which insures the reduction in base shear and story shear.

Figure 1.1: Base isolation in Christchurch Art Gallery, Christchurch, New Zealand

Figure 1.2: Base Isolation in Bhuj Hospital, Gujarat

1.2 Objective

This study includes design of G+6 story fixed base and base isolated building in accordance with IS 1893:2002 provisions. After analyzing fixed base building, we get maximum reaction under each column. From this reaction, we manually design the base isolation device. After that we analyze the building with base isolation and compare the result obtained for base shear, story drift, story displacement, time period from fixed base building. The objectives of study are as follows:

- Study of types of base isolators
- Modeling & analysis of building for fixed base.
- Modeling & analysis of building using base isolation device.
- Compare the result obtained.

2 LITERATURE REVIEW

2.1 Introduction

In this chapter we have given brief history and basic principle of base isolation. We have also discussed about the classification and type of base isolation system.

2.2 Overview

The purpose of earthquake prevention of buildings is to provide the structural safety and comfort by controlling the internal forces and displacement within the particular limits. The common method for protecting the structures against the destructive effects of earthquakes is to damp the seismic energy for limiting the seismic energy by the structural elements, thus providing the resistance against the earthquake. In spite of using this method for a certain level of protection, the structure could be damaged for real sometimes. Another method for protection of the structures against the earthquake is to isolate the building from the ground and/or to install seismic energy dissipating elements at the appropriate places of the building. With this method, better protection could be provided, by designing correctly against the earthquake and therefore significant structural damage level could be minimized.

2.3 Classification of Seismic Isolation Systems

All response control systems are classified in accordance to their operation principles as active, passive and hybrid systems.

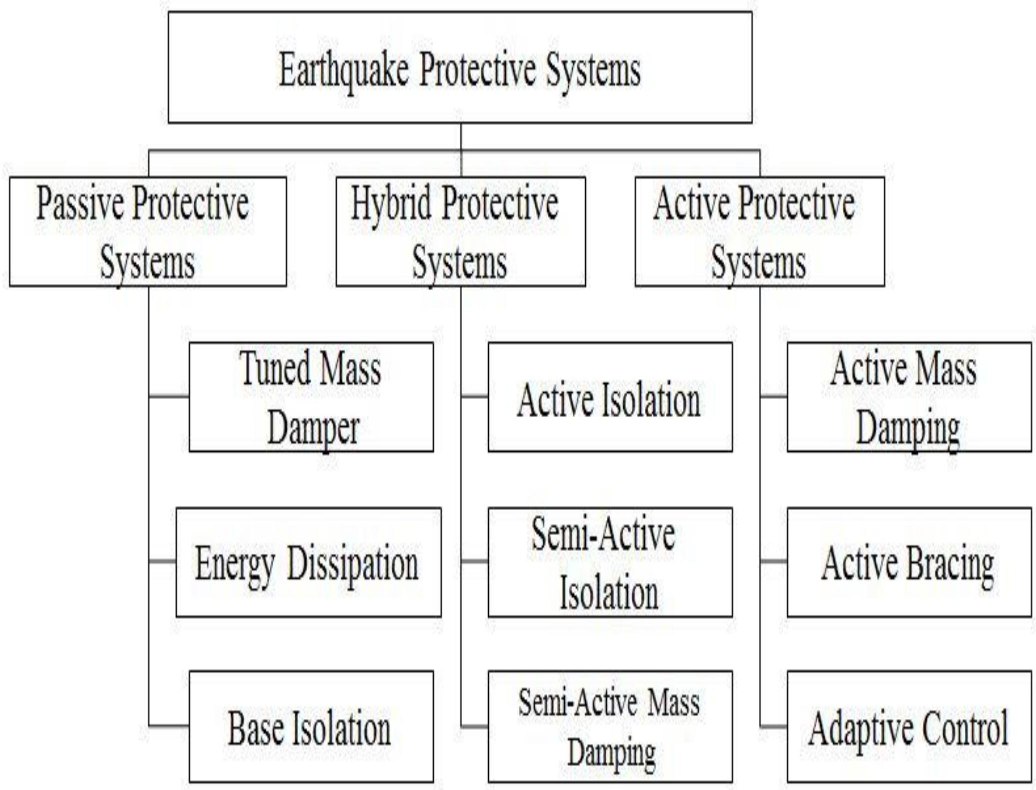

Figure 2.1: Earthquake resistant systems

2.3.1 Active Control Systems

The operation mechanism of active control systems is based on providing a continuous energy from outside. That is why the cost of setting up these systems is high. The system can control the acceleration, displacement or velocity of the structure. Active control systems are composed of electronic devices such as computers, actuators and starters. The design of active control systems is independent from the intensity of the ground motion (TORUNBALCI, 2004).

2.3.2 Passive Control Systems

Passive control systems operate without utilization of any external energy source. Therefore, the cost of this system's setting up is less in comparison with active systems. These systems can control the displacement up to a certain limit. In the passive control systems, the protection systems are designed in accordance to protection level required for earthquakes of certain magnitude. These systems are composed of dampers, isolators and other devices that can easily be found and applied. Passive control systems, which more effective in practical sense, have many types. The utilization of all these systems is based on materials that absorb energy at the certain level, either individually or jointly (TORUNBALCI, 2004)

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2.3.3 Hybrid Control Systems

Hybrid systems are systems implying the combined use of passive and active control systems. For example, a base isolated structure is equipped with actuators, which actively control the enhancement of its performance.

2.4 Base Isolation Systems

It is a system that may be defined as a flexible or sliding interface positioned between a structure and its foundation, for the purpose of decoupling the horizontal motions of the ground from the horizontal motions of the structure, thereby reducing earthquake damage to the structure and its contents. Base isolation system absorbs and deflects the energy released from the earthquake before it is transferred to the structure.

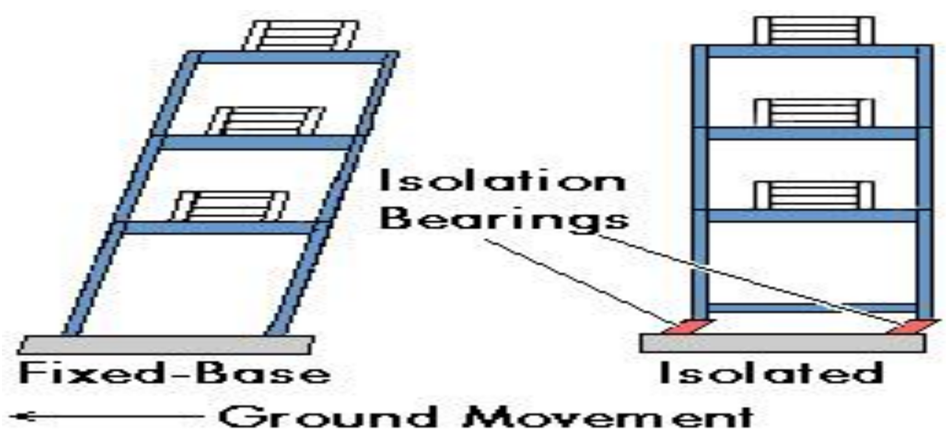

Figure 2.2: Pictorial representation of effect of ground motion on fixed & base isolated building

The term isolation refers to reduced interaction between structure and the ground. Since the seismic isolation system is located under the structure, it is referred as 'Base isolation’. Base isolation is a passive control system meaning thereby that it does not require any external force or energy for its activation. The base isolators used in this system mitigate the effect of an earthquake by decoupling the components of the buildings from direct contact with the ground essentially isolating the structure from potentially dangerous ground motions. The base-isolation techniques prove to be very effective for the seismic protection of new framed buildings as well as for the seismic retrofitting of existing ones.

The base isolations systems in general, consists of a bearings allowing the horizontal movement, a damper controlling the displacements and members providing rigidity under lateral loads. Bearings member has behaviour rigid enough to transfer loads vertically and horizontally flexible. This behaviour changes the period of base isolation system along with the superstructure, thus the whole structure and helps to decrease inertia forces. The decrease in inertia forces when compared with traditionally designed buildings depends on the dynamic characteristics of the building in traditional buildings, the shape of response spectra curve in buildings with seismic isolation. The additional ductility to change the first mode period causes big displacements in the superstructure when compared to seismic isolation system (TORUNBALCI, 2004). As a result of this damage and use problems may arise. Displacements can be decreased through increasing energy dumping capacity of the base isolation system. Earthquake-resistant technology enables the building to counteract the earthquake load by making its strength and resilience great enough to resist shakings. Although it can protect the building safely, it is ac-companied by a risk that the furniture inside could fall or drop. Seismic Isolation system turns destructive seismic shakings into slower and softer ones preventing possible damage. This structure can evade the tremors, taking them in stride and safeguarding the building, human lives and property.

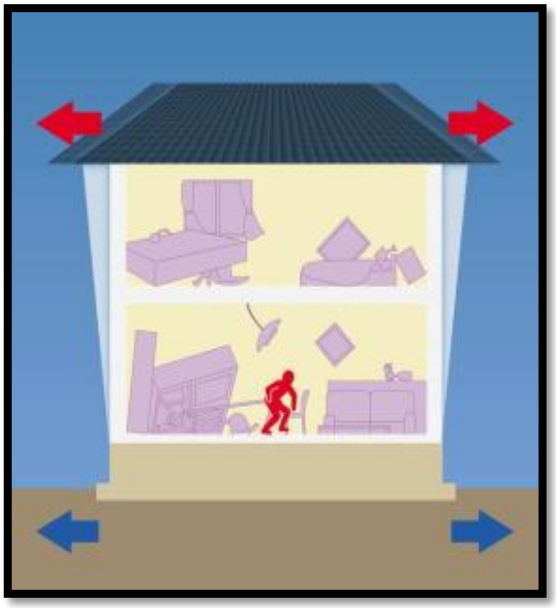

Figure 2.3: Earthquake Resistant House

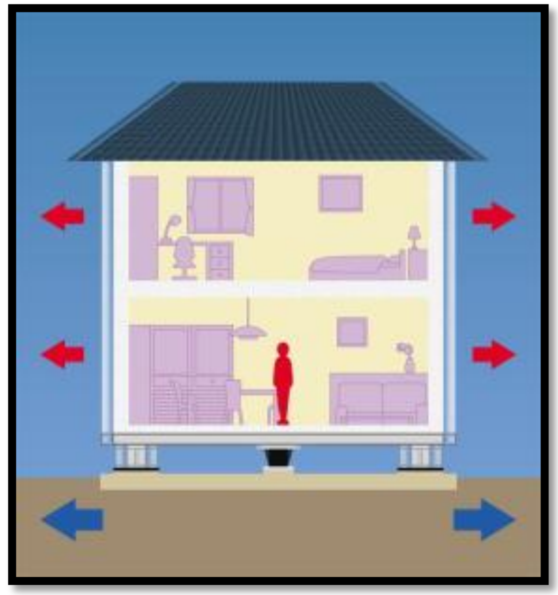

Figure 2.4: Base Isolated House

2.5 Principle of Base Isolation

The fundamental principle of base isolation is to modify the response of the building so that the ground can move below the building without transmitting these motions into the building. A building that is perfectly rigid will have a zero period. When the ground moves the acceleration induced in the structure will be equal to the ground acceleration and there will be zero relative displacement between the structure and the ground. The structure and ground move by same amount. A building that is perfectly flexible will have an infinite period. For this type of structure, when the ground beneath the structure moves there will be zero acceleration induced in the structure and the relative displacement between the structure and ground will be equal to the ground displacement So in flexible structures the structure will not move, the ground will.

2.6 Type of Base Isolation Systems

In seismic isolation, the fundamental purpose is to reduce substantially the ground motion forces and energy transmission. Installing isolating layers with a considerable horizontal flexibility is a good way to achieve that aim. Base isolation is classified under two categories. They are elastomeric bearings and sliding type bearings.

Sliding System

1. Resilient friction system

2. Friction pendulum system

Elastomeric Bearing

1. Natural rubber bearing

2. Low damping rubber bearings

3. Lead plug bearings

4. High damping rubber bearing

2.6.1 Sliding System

- Uses sliding elements between the foundation and base of the structure.
- The sliding displacements are controlled by high-tension springs or laminated rubber bearings, or by making the sliding surface curved.
- These mechanisms provide a restoring force to return the structure to its equilibrium position.

2.6.1.1 Friction pendulum bearing

The Friction pendulum system (FPS) is a sliding isolation system wherein the weight of the structure is supported on spherical sliding surfaces that slide relative to each other when the ground motion exceeds a threshold level.

Friction pendulum bearing are made from two horizontal steel plates that can slide over each other because of their shape and an additional articulated slider. They are designed to be very stiff and strong for vertical load , so that they can carry the weight of the building.

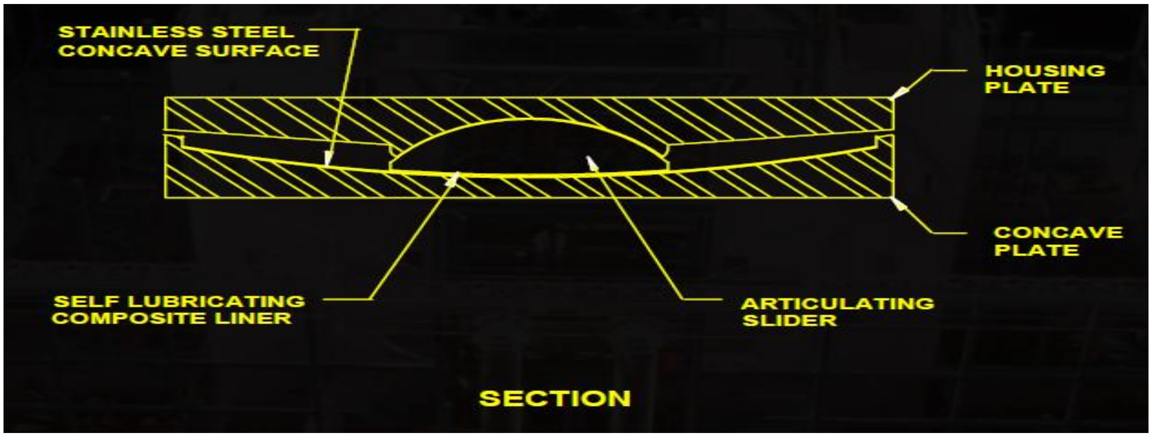

Figure 2.5: Friction Pendulum Bearing

2.6.2 Elastomeric Isolators

- These are formed of thin horizontal layers of natural or synthetic rubber bonded between steel plates.
- The steel plates prevent the rubber layers from bulging and so the bearing is able to support higher vertical loads with only small deformations.
- Plain elastomeric bearings provide flexibility but no significant damping and will move under service loads.

2.6.2.1 Low Damping Natural or Synthetic Rubber Bearings

- Elastomeric bearings use either natural rubber or synthetic rubber (such as neoprene), which have little inherent damping.
- For isolation they are generally used with special elastomer compounds (high damping rubber bearings) or in combination with other devices (lead rubber bearings).

2.6.2.2 Lead Rubber Bearings

- A lead-rubber bearing is formed of a lead plug force-fitted into a pre-formed hole in an elastomeric bearing.
- The lead core provides rigidity under service loads and energy dissipation under high lateral loads.

- The entire bearing is encased in cover rubber to provide environmental protection.
- When subjected to low lateral loads (such as minor earthquake) the lead rubber bearing is stiff both laterally and vertically.

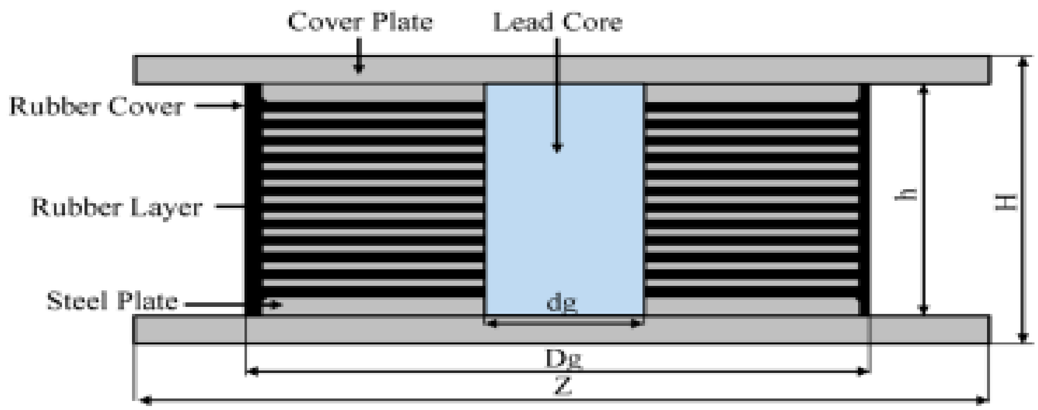

Figure 2.6: Lead Rubber Bearing

2.7 Application of Base Isolation

Seismic isolation is a relatively recent and evolving technology. It has been in increased use since the 1980s, and has been well evaluated and reviewed internationally.

- 1st application in New Zealand in 1974
- 1st US application in 1984
- 1st Japanese application in 1985
- 1st Indian application in 2001

Traditionally, the application of the system is seen in larger buildings and bridges. Additionally, engineers have made an effort to apply the system at a lower cost in residential areas. Base isolation techniques have been utilized worldwide for retrofitting historical structures and monuments to reduce any possible destruction. Also on a smaller scale, museums have started to use the system to ensure the security of artifacts. Base Isolators need not be placed only at foundation level to resist earthquake ground motions. They can even be placed at any floor level to isolate vibrations of machine also.

2.8 Advantages of Base isolation

- Reduced the seismic demand of structure, thereby reducing the cost of structure.
- Lesser displacements during an earthquake.
- Improves safety of Structures
- Reduced the damages caused during an earthquake. This helps in maintaining the performance of structure after event.
- Enhances the performance of structure under seismic loads.
- Preservation of property

2.9 Basic Terminologies

- **Design Displacement** "is the design-basis earthquake lateral displacement, excluding additional displacement due to actual and accidental torsion, required for design of the isolation system" (Uniform Building Code, 1997).
- **Design Basis Earthquake** "is the earthquake which can reasonably be expected to occur at least once during the design life of structure" (Uniform Building Code, 1997). DBE or Design Basis earthquake (DBE) defines the peak horizontal accelerations with 10% probability of exceedance in 50 years
- **Effective Damping** "is the value of equivalent viscous damping corresponding to energy dissipated during cyclic response of the isolation system" (Uniform Building Code, 1997).
- **Effective Stiffness** "is the value of the lateral force in the isolation system, or an element thereof, divided by the corresponding lateral displacement" (Uniform Building Code, 1997).
- **Isolation Interface** "is the boundary between the upper portion of the structure, which is isolated, and the lower portion of the structure, which moves rigidly with the ground".
- **Isolation System** "is the collection of structural elements that includes all individual isolator units, all structural elements that transfer force between elements of the isolation system, and all connections to other structural elements.

The isolation system also includes the wind-restraint system if such a system is used to meet the design requirements of this section" (Uniform Building Code, 1997).

- **Maximum Capable Earthquake** "defines the peak horizontal accelerations with 2% probability of exceedance in 50 years" (Uniform Building Code, 1997).
- **Maximum Displacement** "is the maximum capable earthquake lateral displacement, excluding additional displacement due to actual and accidental torsion, required for design of the isolation system" (Uniform Building Code, 1997).
- **Total Design Displacement** "is the design-basis earthquake lateral displacement, including additional displacement due to actual and accidental torsion, required for design of the isolation system, or an element thereof" (Uniform Building Code, 1997).
- **Effective period at the design displacement** "the effective period of the isolated structure at the design displacement, T_D, corresponds to DBE" (Uniform Building Code, 1997):
- **Effective period at the design displacement** "the effective period of the isolated structure at the design displacement, T_D, corresponds to DBE" (Uniform Building Code, 1997):
- **Drift Limits. "**The maximum inter-story drift ratio of the structure above the isolation system shall not exceed 0.010/RI" (Uniform Building Code, 1997)

3 METHDOLOGY

3.1 Introduction

In this chapter we have discussed some code provisions for design of base isolation and there preliminary design procedure. The uniform building code (UBC-97) code will be used in this chapter.

3.2 Design Method

Earlier version of UBC code preferred statically lateral response method of design which is based on single mode of vibration. In this method design forces were computed from the forces in isolator at design displacement which makes the whole analysis process simple.

Now a day's use of dynamic analysis has been increased & incentives have been inserted in code to encourage the use of dynamic analysis. It is necessary to perform static analysis for all isolation system as it establishes the minimum level for design displacement and forces. Static analysis is useful for both preliminary design and for review of design by dynamic analysis process. Dynamic analysis is required in many cases and is carried out by response spectrum analysis or time history analysis.

3.2.1 Static analysis

The static lateral response procedure may be used for design of a seismic-isolated structure, if they fulfill the criteria given below (Naeim & Kelly, 1999):

1. The structure should be located at least 10 kilometers from all active faults.
2. The height of the structure above the base isolation is equal to or less than or 19.8 m.
3. The effective period of the isolated structure, T_M, is equal to or less than 3.0 seconds.

4. The effective period of the isolated structure, T_D is greater than three times the fixed-base period of the structure.
5. The structure should be of regular configuration above the base isolation.

3.3 Static Lateral Response Procedure

Following terms and equations are used in analysis of seismic isolation design of building using UBC-97 code.

- **Design displacement**:

$$D_D = \frac{g}{4\pi^2}\frac{C_{vd} * T_D}{B_d} \quad (3.1)$$

- **Effective period at the design displacement:**

$$T_D = 2\pi\sqrt{\frac{W}{g * k_d}} \quad (3.2)$$

- **Maximum displacement** :

$$D_M = \frac{g}{4\pi^2}\frac{C_{vm} * T_D}{B_d} \quad (3.3)$$

- **Effective period at the maximum displacement:**

$$T_M = 2\pi\sqrt{\frac{W}{g * k_m}} \quad (3.4)$$

3.4 Isolator Design Procedures

Basic design procedures for high damping rubber isolators (HDR) and lead-rubber isolators (LRB) are given in this chapter. Base isolation device are made by the alternate layer of rubber and steel plates in circular or rectangular shapes. For lead rubber bearing a led plug is inserted in high damping rubber isolator.

3.4.1 Elastomeric Isolators

Shape factor is one of the most important parameter in design of elastomeric bearings, which is defined as

$$S = \frac{\varphi}{4t} \quad \ldots\ldots \quad (3.5)$$

Φ = Diameter of rubber bearing

t = single rubber layer thickness

Value of S is preferred b/w 10 to 20.

The horizontal stiffness of a single isolator is given by

$$K_H = \frac{GA}{t_r} \quad \ldots\ldots \quad (3.6)$$

K_H = Effective stiffness of isolation system in the horizontal direction under consideration, at a design displacement.

G = Shear modulus of the rubber

A = X-sectional area of the rubber

t_r = Overall rubber layer thickness.

Overall rubber layer thickness is given by:

$$t_r = \frac{D}{\gamma} \quad \ldots\ldots \quad (3.7)$$

The vertical stiffness of a rubber bearing is given by

$$K_v = \frac{E_c A_s}{t_r} \quad \ldots\ldots \quad (3.8)$$

Where,

E_c = Compression modulus of the rubber-steel composite

A_s = Area of a steel shim plate.

For a circular pad without any holes in the center

$$E_c = 6GS^2 \quad \text{…………. (3.9)}$$

For bearings with very large shape factors the compressibility of rubber affects the value of Ec. In such cases a more accurate estimate of E_c may be obtained from

$$E_c = \frac{6GS^2K}{6GS^2 + K} \quad \text{…………... (3.10)}$$

K = Bulk modulus of rubber

Generally, value of K varies from 1000 MPa to 2500 MPa.The value of 2000 MPa is used in our study.

3.4.2 Lead-Rubber Isolators (LRB)

The lead-rubber bearings is a nonlinear system which may be very effectively idealized in terms of a bilinear force—deflection curve with constant values throughout many cycles of loading (Figure 3.1).

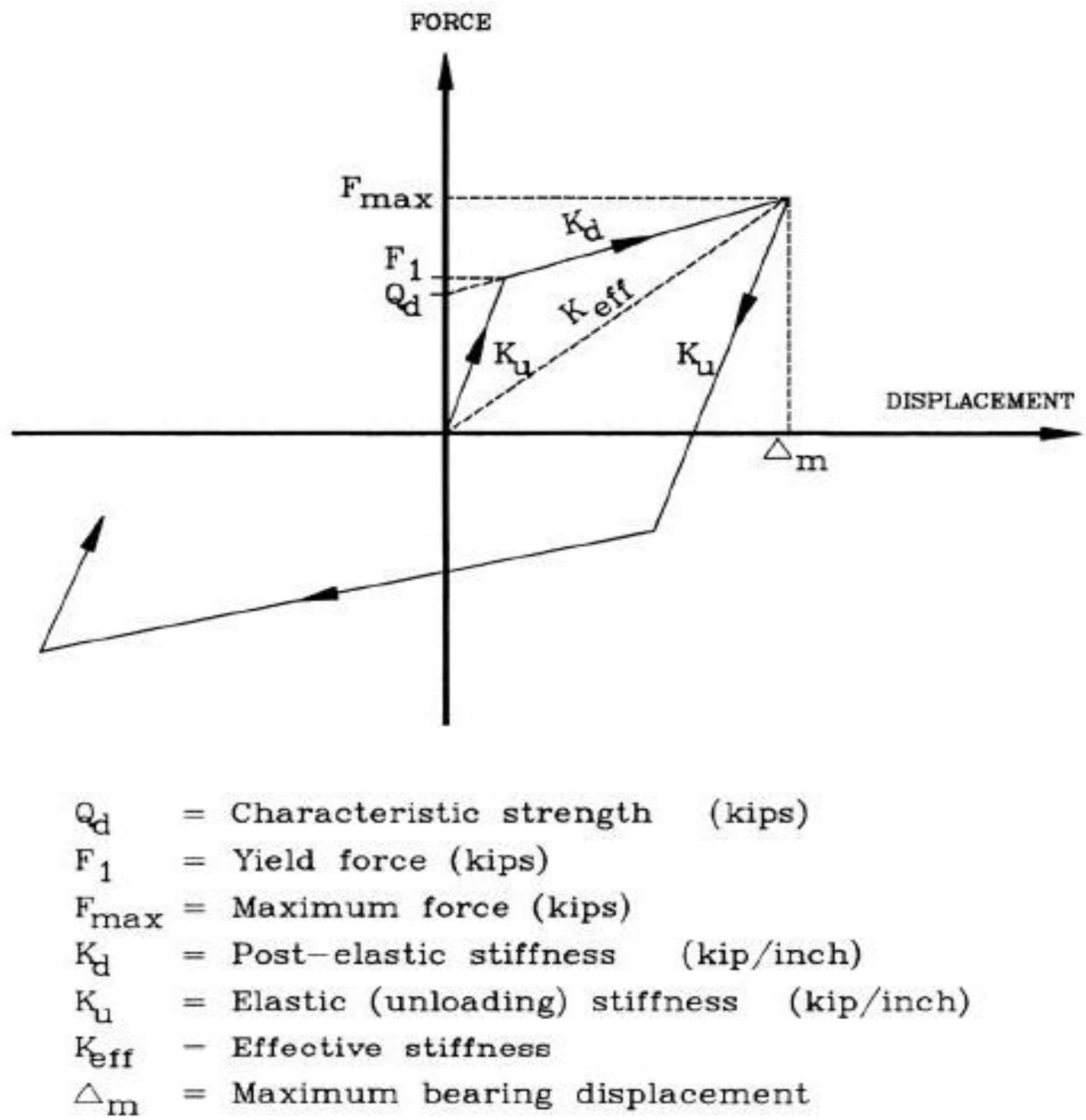

Figure 3.1: Graph of hysteresis loop

The yield stress of lead is taken as 11 MPa.

D_y = yield displacement

$$K_{eff} = K_d + \frac{Q_d}{D} \qquad D \geq D_y \text{ .... (3.11)}$$

$$T = 2\pi\sqrt{\frac{W}{g * k_{eff}}} \text{ .... (3.12)}$$

For lead-rubber isolators K_u is taken as $10K_u$.

Dissipated energy per cycle at design displacement is given by the formula:

$$W_D = 2\pi K_{eff} {D_D}^2 \beta \text{ .... } (3.13)$$

Area of hysteresis loop is given by the formula below:

$$W_D = 4Q_d(D_D - D_y) \text{ .... } (3.14)$$

4 DESIGN OF BASE ISOLATION

4.1 Introduction

In this chapter, we have designed the High Damping Rubber Bearing and Lead Rubber Bearing Isolation device based on Uniform Building Code-1997.

4.2 Design Procedure Using UBC-97

The following are the preliminary design procedures:

4.2.1 Establish all dynamics parameters

- We are assuming our structure is in New Delhi. In accordance with UBC-97, New Delhi is classified as Seismic Zone 3.
- Next, we find out the seismic zone factor Z. For New Delhi, $Z = 0.3$ (UBC-97, Table 16-I).
- Next, we establish the soil profile type. For our project we have taken the soil condition as stiff soil profile, which is classified as soil profile type S_d.
- Next, we establish the seismic source type. For our project we have taken the seismic source type, which is "capable of producing large-magnitude earthquakes ($M > 7.0$) and has a high rate of seismic activity". This is classified as type A source. (UBC-97, Table 16-U).
- Next, we establish near source factor N_a and N_v. Owing to the closest earthquake source was over 15km, we define the near source factor N_a and $N_v = 1.0$. (UBC-97, Table 16-S and 16-T).
- Next, we measure MCE response coefficientM_m. The coefficient M_m is intended to estimate MCE based on the DBE shaking characteristics. $Z * N_v = 0.3 * 1.0 = 0.3$, $M_m = 1.50$ (UBC-97, Table A-16-D).
- Determine Seismic Coefficients: C_{ad} , C_{vd} defined separately corresponding to the soil profile type and seismic zone. (Table 16-Q, 16-R, and A-16-F, A-16-G). $C_{ad} = 0.36$, $C_{vd} = 0.54$,
  $C_{vm} = 1.6 * M_m * Z * N_v = 1.6 * 1.5 * 0.3 * 1 = 0.72$

$C_{am} = 1.1 * M_m * Z * N_a = 1.1 * 1.5 * 0.3 * 1 = 0.495$

- Determine structural system reduction factor R_I, which can be obtained from the basic structure system. R_I is equal to 2.0 in our case(moment resisting system) (UBC-97, Table A-16-E).
- For design purposes 15% damping is assumed, therefore damping coefficient $B_d = B_m = 1.35$
- Select a desired isolated period of vibration T_d – an isolated period b/w 2.0 to 3.0 sec is desirable.

The bearing loads are as follows:

Four at 1556.2625 KN

Eight at 2276.076 KN

Four at 3212.3279 KN

4.2.2 High-Damping Rubber Isolators

High damping rubber is designed for load of 2276.076 KN. We take shear modulus $G = 1.0$ MPa and bulk modulus $K = 2000$ MPa for high damping rubber. Target Period is taken as $T_d = 2.5$ sec.

$$K_H = \left(\frac{2\pi}{Td}\right)^2 \frac{W}{g} = \left(\frac{2\pi}{2.5}\right)^2 * \frac{2276.076}{9.81} = 1465.540 \text{ KN/m}$$

$T_d =$ Effective fundamental period of superstructure corresponding to horizontal translation

$W =$ the weight on the isolator (i.e. maximum vertical reaction)

The design displacement is obtained from Eq. (3.1)

$$D_D = \frac{g}{4\pi^2} \frac{C_{vd} * T_D}{B_d}$$

$$B_D = 1.35 , C_{vd} = 0.54 , T_D = 2.5 \text{ sec}$$

$$D_D = \frac{9.81}{4\pi^2} * \frac{0.54 * 2.5}{1.35} = 0.248 \text{ m}$$

$$\text{Take, } D_D = 0.250 \text{ m}$$

Generally, we take the design displacement at 150% shear strain. From Eq. (3.7), we can calculate the total rubber thickness required

$$\gamma = \frac{D_D}{t_r}$$

$$t_r = \frac{0.25}{1.5} = 0.170 \text{ m}$$

Take thickness of rubber bearing

$$t_r = 180 \text{ mm}$$

Now we calculate the cross-sectional area and the required diameter of the bearing from Eq. (3.7)

$$G = 1.0 \text{ MPa}$$

$$A = \frac{KH*tr}{G} = 0.264 \text{ m}^2$$

Diameter of rubber bearing $(\emptyset)$

$$\emptyset = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4*0.264}{\pi}} = 0.58 \text{ m}$$

Use, $\emptyset = 0.60 \text{ m}$

Now we re-calculate A, K_H and T_D based on this bearing diameter

$$A = \frac{\pi\emptyset^2}{4} = \frac{\pi * 0.6^2}{4} = 0.283\text{m}^2$$

$$K_H = 1465.540 * \frac{0.283}{0.264} = 1571.01 \text{ KN/m}$$

$$T_D = 2.5 * \sqrt{\frac{1465.540}{1571.01}} = 2.41 \text{ sec}$$

Select shape factor of $S = 10$,

From Eq. (3.5)

$$t = \frac{\emptyset}{4s} = \frac{0.6}{4 * 10} = 15 \text{ mm}$$

$$n = \text{no. of rubber layer} = \frac{0.180}{0.015} = 12$$

Take 2 mm thick steel shim plates and 25mm top and bottom end plates, the total height of the bearing is

$$H = 180 + (12 - 1) * 2 + 2 * 25 = 252 \text{ mm}$$

$$K = 2000\text{Mpa}$$

From Eq. (3.10)

$$E_c = \frac{6GS^2K}{6GS^2 + K} = \frac{6*1*10^2*2000}{6*1*10^2+2000} = 461.54 \text{ MPa}$$

From Eq. (3.8)

$$K_V = \frac{Ec * A}{t_r} = \frac{461.54 * 10^6 * 0.283}{0.18} = 725643.44 \text{ KN/m}$$

Table 4-1: HDRB isolator input parameters for E-TAB Software

Eff. Vertical Stiffness, K_V	725643.44 KN/m
Eff. Horizontal Stiffness, K_H	1571.01 KN/m
Effective damping ratio,β	15 %
Shear Modulus, G	1.0 MPa

4.2.3 Lead-Rubber Isolators

The same target period of 2.5 seconds is maintained and shear modulus of $G = 0.8$ MPa is taken.

Design displacement is calculated below,

$$D_D = \frac{g}{4\pi^2}\frac{C_{vd} * T_D}{B_d}$$

$$B_D = 1.35\ , C_{vd} = 0.54\ , T_D = 2.5\ \text{sec}$$

$$D_D = 0.250\ \text{m}$$

$$K_H = \left(\frac{2\pi}{Td}\right)^2 \frac{W}{g} = \left(\frac{2\pi}{2.5}\right)^2 * \frac{3212.4}{9.81} = 2068.381\ \text{KN/m}$$

The energy dissipated per cycle is from Eq. (3.14)

$$W_D = 2\pi K_{eff} {D_D}^2 \beta$$

$$= 2\pi * 2068.381 * 0.25^2 * 0.15 = 121.84\ \text{KN.m}$$

From Eq. (3.15)

$W_D = 4Q_d(D_D - D_y)$, ignore D_y due to its small size.

$$Q_d \cong \frac{W_D}{4D_D} = \frac{121.84}{4 * 0.250} = 121.84\ \text{KN}$$

Now, we can estimate K_d from Eq. (3.12)

$$K_d = K_H - \frac{Q_d}{D_D} = 2068.381 - \frac{121.84}{0.25} = 1581.02\ \text{KN/m}$$

and since

$D_y = \frac{Q_d}{K_u - K_d}$, and $K_u \approx 10K_d$, then

$$D_y \cong \frac{Q_d}{9K_d} = \frac{121.84}{9 * 1581.02} = 0.0085\ \text{m}$$

A_{pb}= X-sectional area of the lead plug

Yield stress for lead $F_y{}^{pb} = 11$ MPa

$$A_{pb} = \frac{Q_d}{F_y{}^{pb}} = \frac{121.84 * 1000}{11} = 11076.36 \text{ mm}^2$$

$$\emptyset_{pb} = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4*11076.36}{\pi}} = 118.75 \text{ mm}$$

Take, $\emptyset_{pb} = 120$ mm

So area of lead plug provided is

$$A = \frac{\pi \emptyset_{pb}{}^2}{4} = \frac{\pi * 120^2}{4} = 11309.73 \text{ mm}^2$$

Now, $Q_d = \frac{11309.73*11}{1000} = 124.407$ KN

The stiffness provided by lead plug (K_{pb})is

$$K_{pb} = \frac{Q_d}{D} = \frac{124.407}{0.25} = 497.628 \text{ KN/m}$$

$$K_{rubber} = K_H - \frac{Q_d}{D_D} = 2068.381 - \frac{124.407}{0.25} = 1570.753 \text{ KN/m}$$

Take, $t_r = 180$ mm , $G = 0.8$ MPa

$$A_{rubber} = \frac{K_{rubber} * t_r}{G} = \frac{1570.753 * 180}{0.8} = 353419.425 \text{ mm}^2$$

$$A_{rubber} = \frac{\pi \emptyset^2}{4} - \frac{\pi \emptyset_{pb}{}^2}{4}$$

$\emptyset = 680$ mm

Shape factor,

$$S = \frac{\emptyset}{4t} = \frac{680}{4 * 15} = 11.33$$

Using 2 mm thick steel shim plates and 25mm top and bottom end plates, the total height of the bearing is

$$H = 180 + (12 - 1) * 2 + 2 * 25 = 252 \text{ mm}$$

$$K = 2000\text{Mpa}$$

$$E_c = \frac{6GS^2K}{6GS^2 + K} = \frac{6*0.8*11.33^2*2000}{6*0.8*11.33^2+2000} = 471.04 \text{ MPa}$$

$$K_V = \frac{Ec * A}{t_r} = \frac{353419.425 * 471.04}{180} = 924859.366 \text{ KN/m}$$

Table 4-2: LRB isolator input parameters for E-TAB software

Eff. Vertical Stiffness, K_V	924859.366 KN/m
Eff. Horizontal Stiffness, K_H	2068.381 KN/m
Pre Yield Stiffness, K_u	15707.53 KN/m
Effective damping ratio,β	15 %
Post Yield Stiffness Ratio, $\frac{K_d}{K_u}$	0.1
Yield Force of Lead Plug, Q_d	1571.01 KN
Shear Modulus, G	0.8 MPa

5 Modeling and Analysis

5.1 Introduction

This study includes modeling and analysis of the structure using standard ETABS software version 2015. Vertical reaction of ground story column is calculated by service loads.

Models considered for analysis

1. Fixed based building.

2. Base isolated building

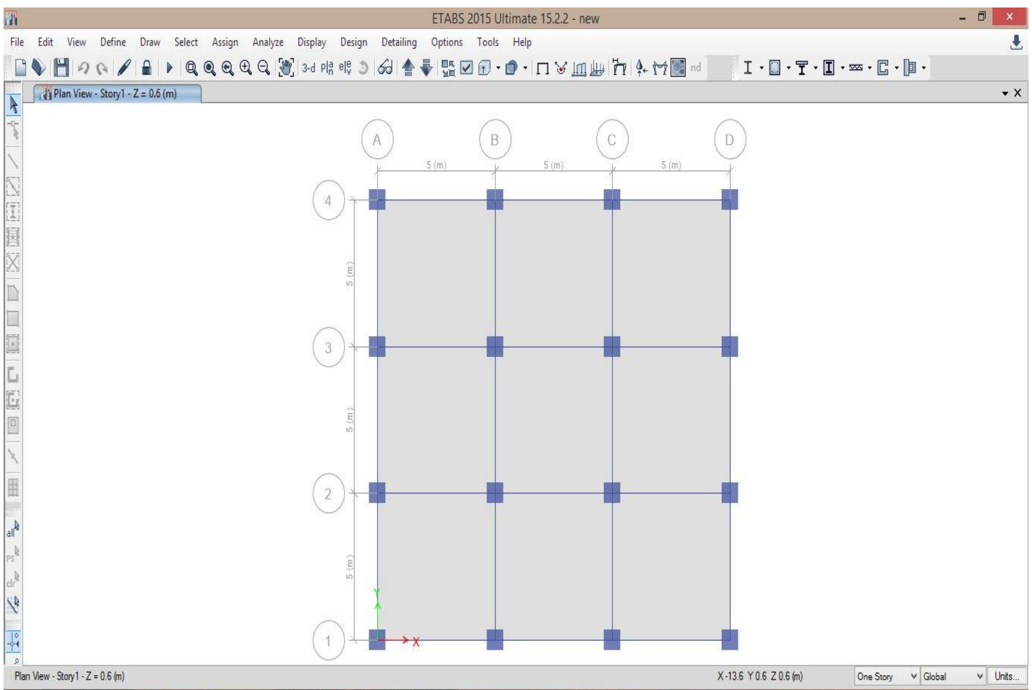

Figure 5.1: Plan view of model

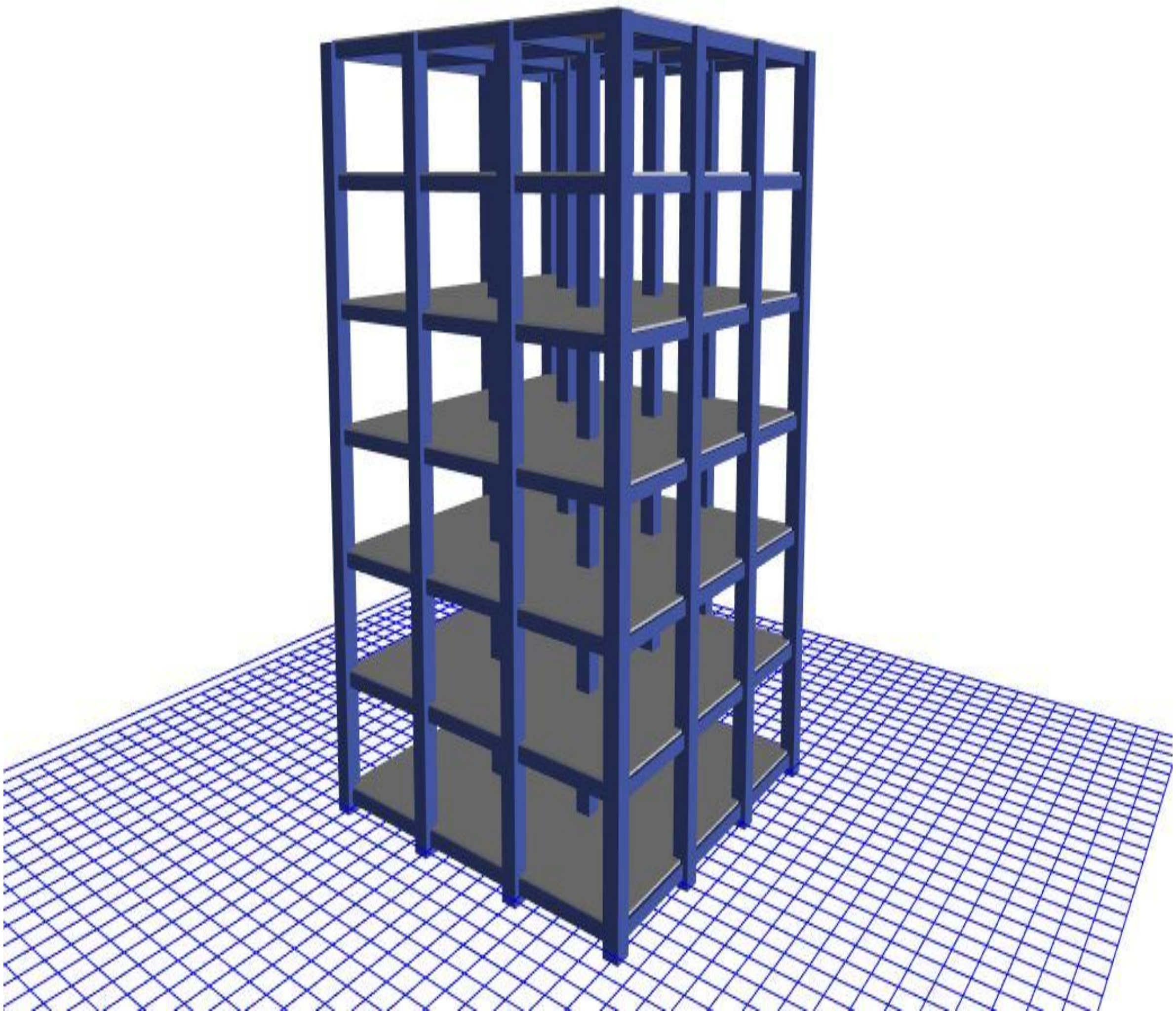

Figure 5.2: 3D view of model

5.1.1 Structural Specifications

5.1.2 Member Properties

Table 5-1: Summary for member properties

No of story	G+6
Spacing of frames in X	5.0m
Spacing of frames in Y	5.0m
Size of beam	250 x 350mm
Size of column	700 x 700mm
Story height	3.0 m
Height of Building	18.6 m
Thickness of slab	150mm
Thickness of wall	230 mm thick outer walls, 115 mm thick inner wall
Height of parapet wall	1.0 m

5.1.3 Material Properties

Table 5-2: Summary for material properties

Grade of Concrete	M30
Grade of Steel	Fe 415
Density of Brick masonry	20 KN/m3

5.1.4 Load Intensities

Table 5-3: Summary of load parameters

Dead load	As per IS 875 (Part 1)-1987
Live load	Roof: 1.5 kN/m^2 Other Floors: 3 kN/m^2
Floor Finish	1 kN/m^2
Earthquake load	As per IS 1893 (part 1)-2002

5.1.5 Load Combinations

As per IS 1893 (part 1)-2002, following load combinations for Limit State has been used:

1. Comb1 1.5(DL + LL)
2. Comb2 1.2(DL + LL + Ex)
3. Comb3 1.2(DL + LL − Ex)
4. Comb4 1.2 (DL + LL + Ey)
5. Comb5 1.2(DL + LL − Ey)
6. Comb6 1.5(DL + Ex)
7. Comb7 1.5(DL − Ex)
8. Comb8 1.5(DL + Ey)
9. Comb9 1.5(DL − Ey)
10. Comb10 (0.9DL + 1.5Ex)
11. Comb11 (0.9DL − 1.5Ex)
12. Comb12 (0.9DL + 1.5Ey)
13. Comb13 (0.9DL − 1.5Ey)

Note:

DL- Dead Load

LL- Live Load

Ex - Earthquake load in X direction

Ey - Earthquake load in X direction

5.1.6 Earthquake Parameters

Earthquake parameters specified below are taken from IS 1893 (part-1)-2002 and used for static analysis (Equivalent lateral load procedure) of model for earthquake loading.

Table 5-4: Summary of Earthquake parameters

Code used	IS 1893 (part 1)-2002
Earth quake zone	V
Zone factor	Z =0.36
Importance factor	I =1.0
Response reduction factor	R =5

5.2 Analysis Result

Analysis is done in E-TAB 2015 software which is based on finite element method.

Results obtained from software are specified below:

5.2.1 Base Reaction

Maximum vertical reactions on the base of the columns which is used in the calculation of effective stiffness of rubber bearing are specified below.

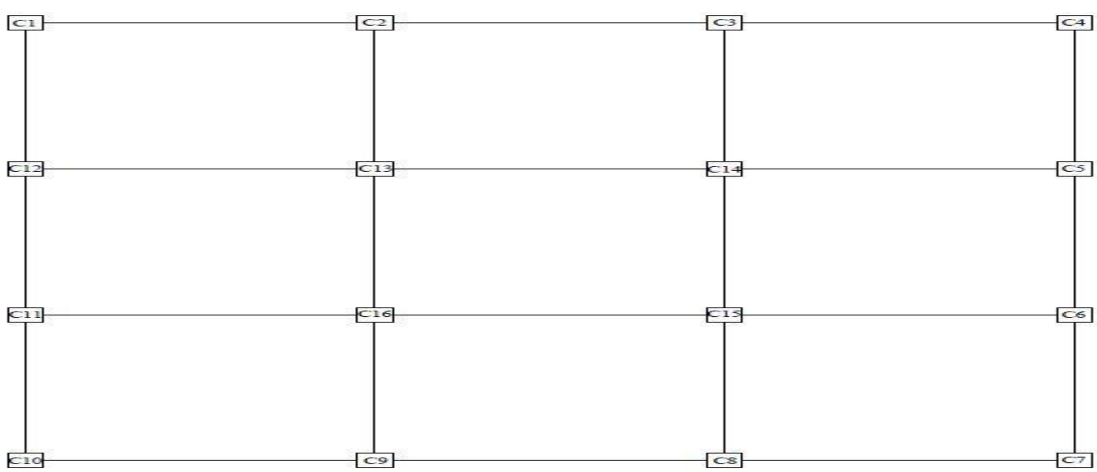

Figure 5.3: Plan view of model with column numbering

Table 5-5: Maximum vertical reaction on column base

Load Combination Comb1 1.5(DL+LL)	
Column No.	Vertical Reaction (KN)
C1	1556.2625
C2	2276.076
C3	2276.076
C4	1556.2625
C5	2276.076
C6	2276.076
C7	1556.2625
C8	2276.076
C9	2276.076
C10	1556.2625
C11	2276.076
C12	2276.076
C13	3212.3279
C14	3212.3279
C15	3212.3279
C16	3212.3279

5.2.2 STORY FORCES AND BASE SHEAR

Base Shear and story forces are obtained from static analysis for G+6 story building models in both X and Y directions are listed in both tabular and graphical form below.

Table 5-6: Base shear for fixed base & base isolated structure

Load Combination	Comb7 (1.5DL − 1.5Ex)	
Structure	Base Shear (KN)	
	X- direction	Y-direction
Fixed Base	1604.6573	0
Base Isolated	743.9874	0

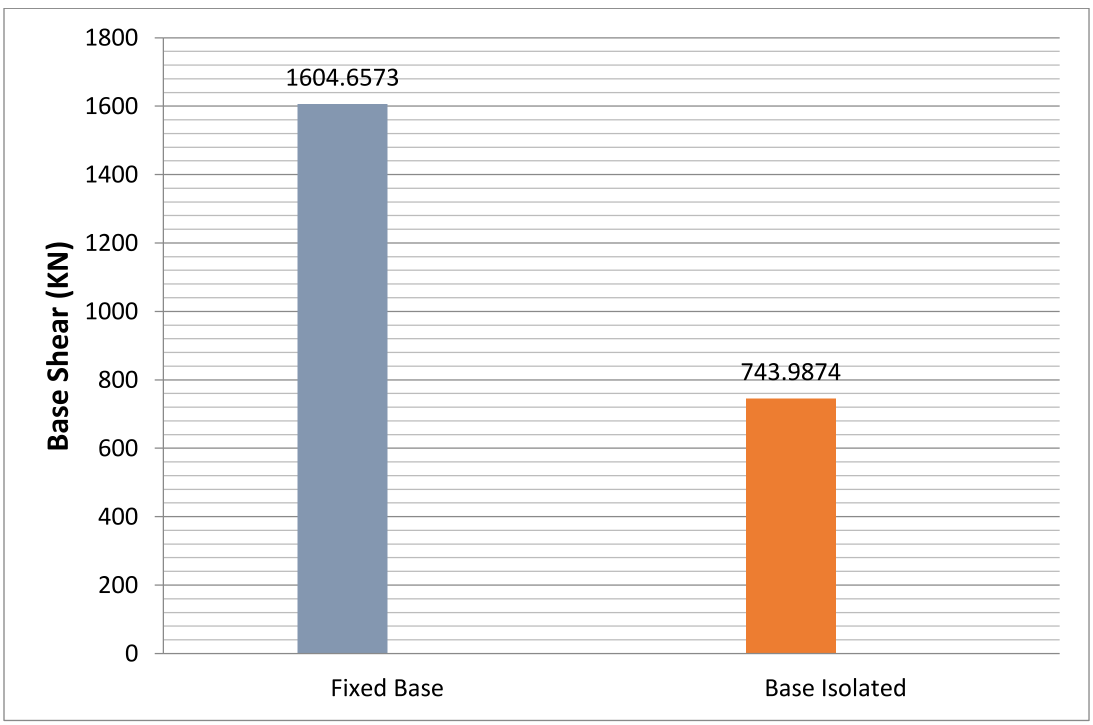

Figure 5.4: Base shear bar chart

Table 5-7: Story shear due to Earthquake forces in X direction

Load Combination	Comb7 (1.5DL − 1.5Ex)					
Story No.	Location	Story Shear for Fixed Base Model X dir (KN)	Story Shear for Fixed Base Model Y dir (KN)	Story Shear for Base Isolated Model X dir (KN)	Story Shear for Base Isolated Model Y dir (KN)
7	Top	434.0378	0	201.2384	0
	Bottom	434.0378	0	201.2384	0
6	Top	950.9389	0	440.8957	0
	Bottom	950.9389	0	440.8957	0
5	Top	1288.1481	0	597.2402	0
	Bottom	1288.1481	0	597.2402	0
4	Top	1483.8976	0	687.9981	0
	Bottom	1483.8976	0	687.9981	0
3	Top	1576.4199	0	730.8953	0
	Bottom	1576.4199	0	730.8953	0
2	Top	1603.9471	0	743.6581	0
	Bottom	1603.9471	0	743.6581	0
1	Top	1604.6573	0	743.9874	0
	Bottom	1604.6573	0	743.9874	0

Table 5-8: Story shear due to Earthquake forces in Y direction

Load Combination	Comb9 1.5(DL − Ey)				
Story No.	Location	Story Shear for Fixed Base Model X dir (KN)	Story Shear for Fixed Base Model Y dir (KN)	Story Shear for Base Isolated Model X dir (KN)	Story Shear for Base Isolated Model Y dir (KN)
Story 7	Top	0	434.0378	0	201.2384
	Bottom	0	434.0378	0	201.2384
Story 6	Top	0	950.9389	0	440.8957
	Bottom	0	950.9389	0	440.8957
Story 5	Top	0	1288.1481	0	597.2402
	Bottom	0	1288.1481	0	597.2402
Story 4	Top	0	1483.8976	0	687.9981
	Bottom	0	1483.8976	0	687.9981
Story 3	Top	0	1576.4199	0	730.8953
	Bottom	0	1576.4199	0	730.8953
Story 2	Top	0	1603.9471	0	743.6581
	Bottom	0	1603.9471	0	743.6581
Story 1	Top	0	1604.6573	0	743.9874
	Bottom	0	1604.6573	0	743.9874

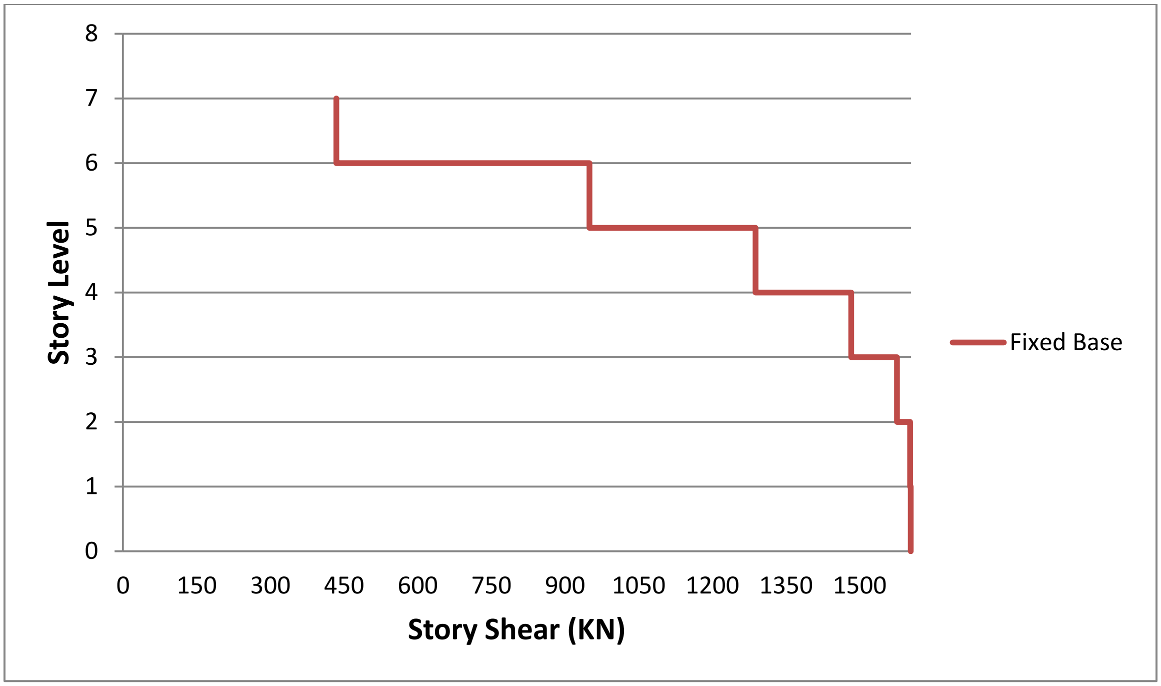

Figure 5.5: Graphical representation of story shear for fixed base structure

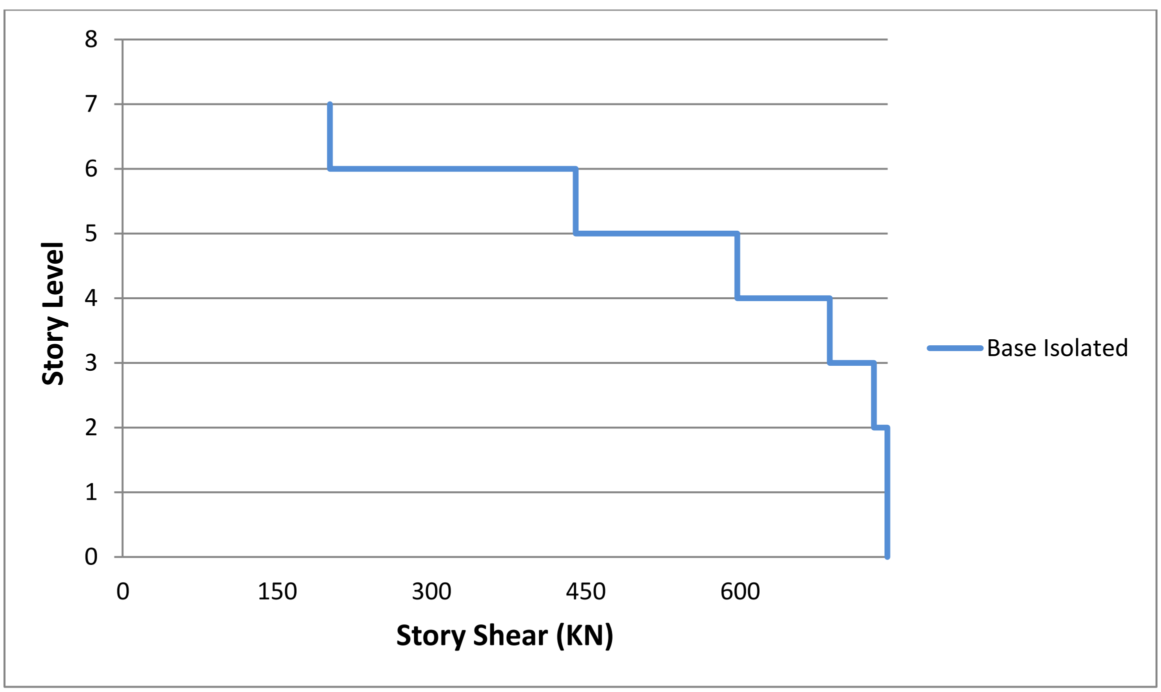

Figure 5.6: Graphical representation of story shear for base isolated structure

5.2.3 STORY DISPLACEMENT

Maximum story displacement which are obtained from static analysis for both fixed base and base isolated G+6 story building models are listed in both tabular and graphical form below:

Table 5-9: Story Displacement due to Earthquake forces in X direction

Load Combination	Comb7 (1.5DL-1.5Ex)				
Story No.	Elevation (m)	Story Displacement for Fixed Base Model X dir (mm)	Story Displacement for Fixed Base Model Y dir (mm)	Story Displacement for Base Isolated Model X dir (mm)	Story Displacement for Base Isolated Model Y dir (mm)
Story 7	18.6	45.344	3.355	60.383	4.794
Story 6	15.6	39.121	2.907	57.171	4.572
Story 5	12.6	31.338	2.341	53.117	4.289
Story 4	9.6	22.268	1.674	48.22	3.941
Story 3	6.6	12.883	0.975	42.708	3.546
Story 2	3.6	4.732	0.361	36.896	3.126
Story 1	0.6	0.171	0.013	31.14	2.704
Base	0	0	0	30.075	2.686

Table 5-10 : Story Displacement due to Earthquake forces in Y direction

Load Combination	Comb9 1.5(DL − Ey)				
Story No.	Elevation (m)	Story Displacement for Fixed Base Model X dir (mm)	Story Displacement for Fixed Base Model Y dir (mm)	Story Displacement for Base Isolated Model X dir (mm)	Story Displacement for Base Isolated Model Y dir (mm)
Story 7	18.6	3.355	45.344	4.794	60.383
Story 6	15.6	2.907	39.121	4.572	57.171
Story 5	12.6	2.341	31.338	4.289	53.117
Story 4	9.6	1.674	22.268	3.941	48.22
Story 3	6.6	0.975	12.883	3.546	42.708
Story 2	3.6	0.361	4.732	3.126	36.896
Story 1	0.6	0.013	0.171	2.704	31.14
Base	0	0	0	2.686	30.075

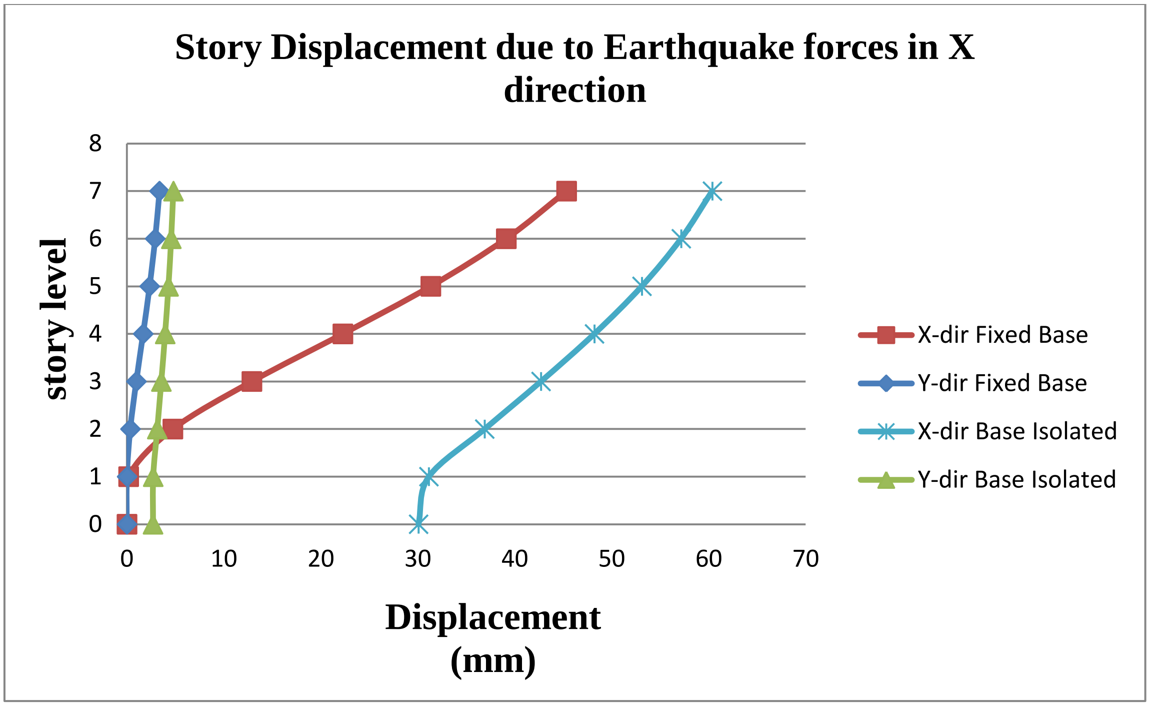

Figure 5.7: Story Displacement due to Earthquake forces in X direction

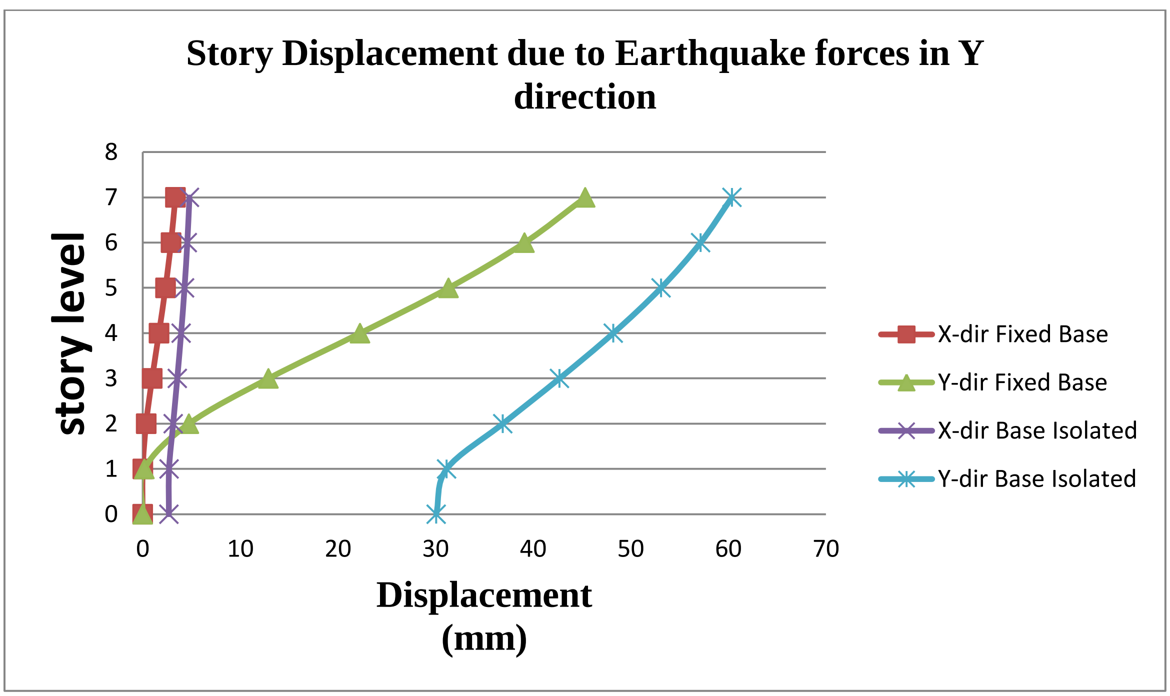

Figure 5.8: Story Displacement due to Earthquake forces in Y direction

5.2.4 STORY DRIFT

Story drift is lateral displacement of one level of multistory building relative to level below, normalized by story height. Maximum story drift which are obtained from static analysis for both fixed base and base isolated G+6 story building models are listed in both tabular and graphical form below:

Table 5-11: Story Drift due to Earthquake forces in X direction

Load Combination	Comb7 (1.5DL − 1.5Ex)				
Story No.	Elevation (m)	Story Drift for Fixed Base Model X dir	Story Drift for Fixed Base Model Y dir	Story Drift for Base Isolated Model X dir	Story Drift for Base Isolated Model Y dir
Story 7	18.6	0.002074	0.000149	0.001071	0.000074
Story 6	15.6	0.002594	0.000189	0.001351	0.000095
Story 5	12.6	0.003023	0.000222	0.001632	0.000116
Story 4	9.6	0.003128	0.000233	0.001837	0.000132
Story 3	6.6	0.002717	0.000205	0.001937	0.00014
Story 2	3.6	0.00152	0.000116	0.001919	0.000141
Story 1	0.6	0.000285	0.000022	0.001984	0.00025
Base	0	0	0	0	0

Table 5-12: Story Drift due to Earthquake forces in Y direction

Load Combination	Comb9 1.5(DL − Ey)				
Story No.	Elevation (m)	Story Drift for Fixed Base Model X dir	Story Drift for Fixed Base Model Y dir	Story Drift for Base Isolated Model X dir	Story Drift for Base Isolated Model Y dir
Story 7	18.6	0.000149	0.002074	0.000074	0.001071
Story 6	15.6	0.000189	0.002594	0.000095	0.001351
Story 5	12.6	0.000222	0.003023	0.000116	0.001632
Story 4	9.6	0.000233	0.003128	0.000132	0.001837
Story 3	6.6	0.000205	0.002717	0.00014	0.001937
Story 2	3.6	0.000116	0.00152	0.000141	0.001919
Story 1	0.6	0.000022	0.000285	0.00025	0.001984
Base	0	0	0	0	0

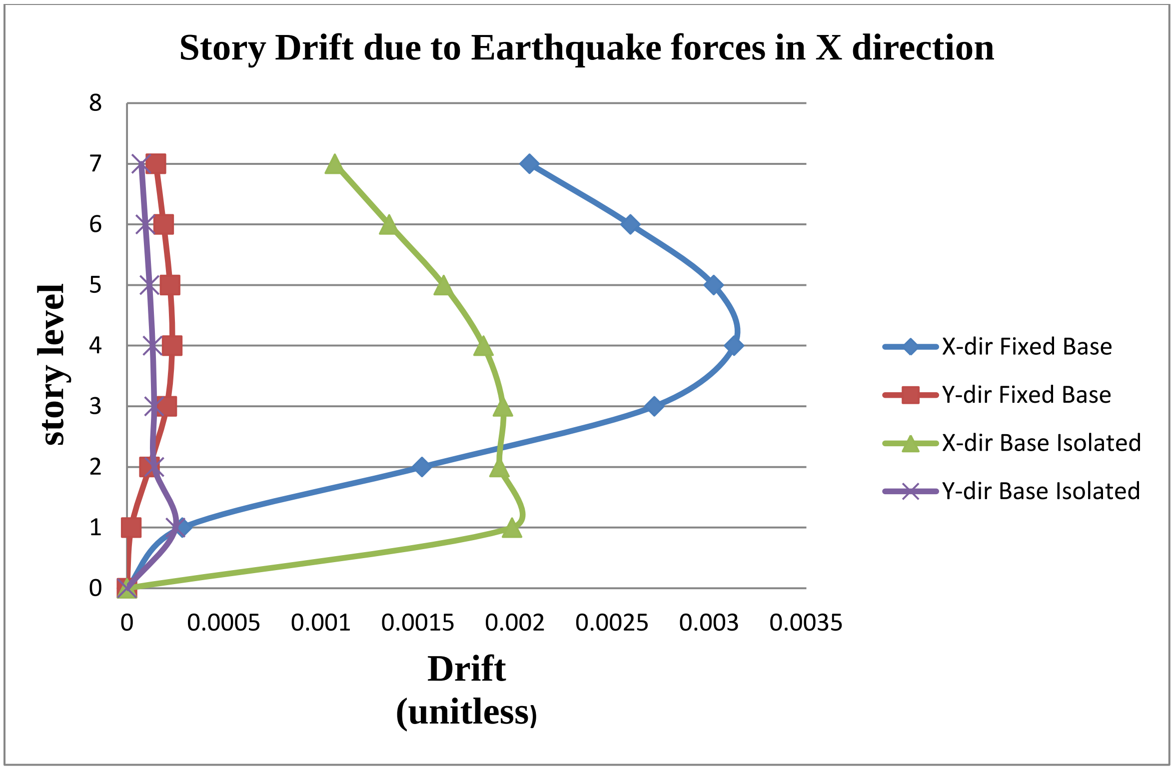

Figure 5.9: Story Drift due to Earthquake forces in X direction

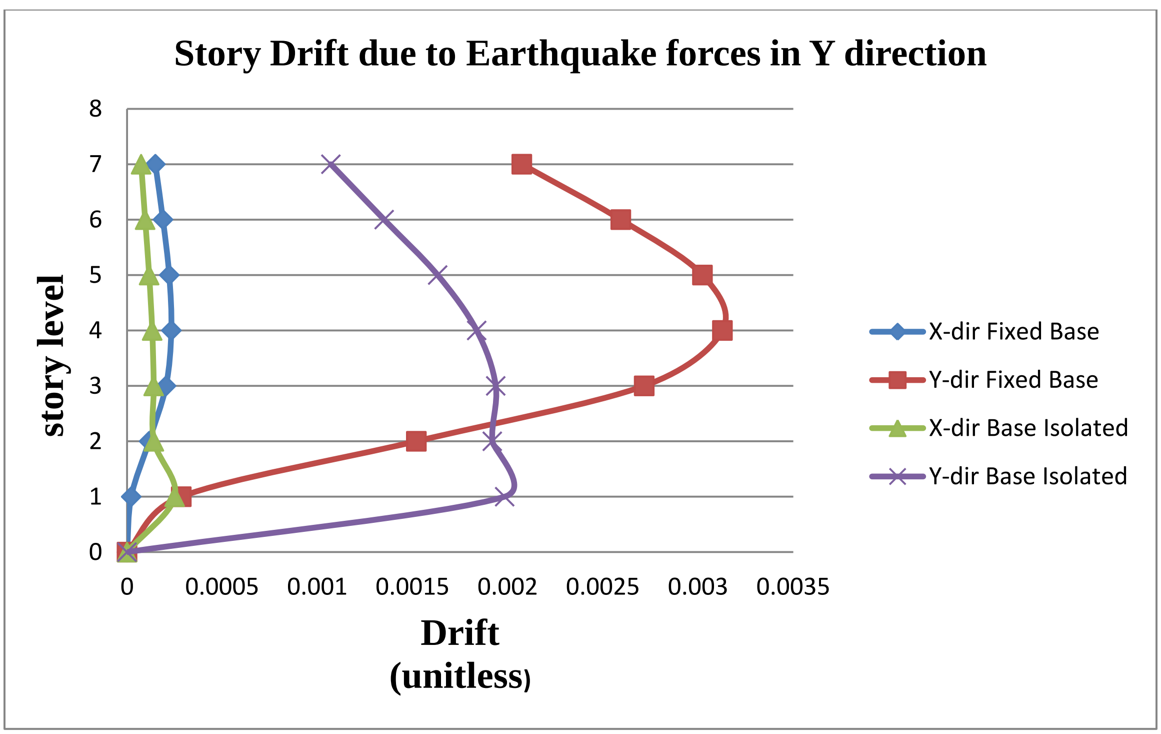

Figure 5.10: Story Drift due to Earthquake forces in Y direction

5.2.5 MODAL PERIOD

Time period for each mode for both fixed base and base isolated model are given below:

Table 5-13: Time period for different modes

Mode No.	Time period for Fixed Base Model (sec)	Time period for Base Isolated Model (sec)
1	0.984	2.123
2	0.984	2.123
3	0.848	1.944
4	0.265	0.566
5	0.265	0.566
6	0.233	0.489
7	0.12	0.239
8	0.12	0.239
9	0.108	0.21
10	0.068	0.119
11	0.068	0.119
12	0.062	0.107

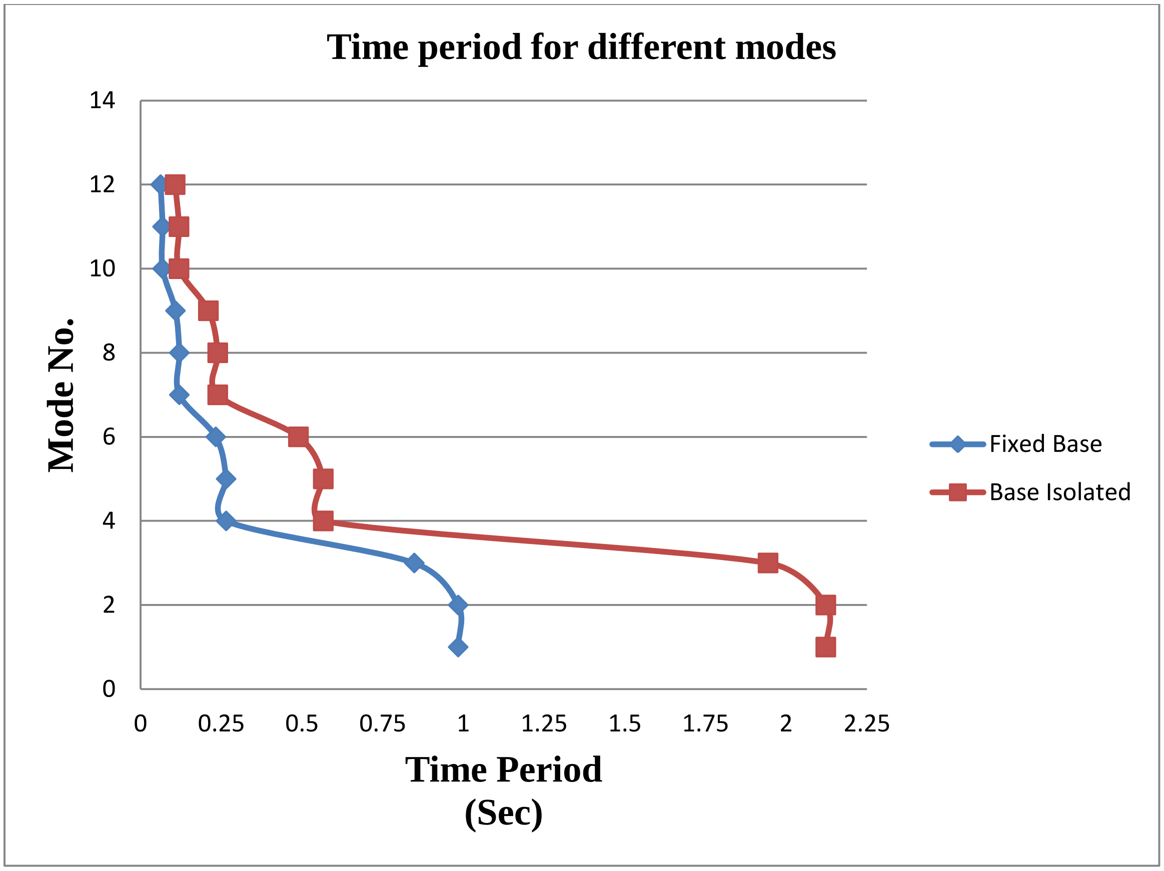

Figure 5.11: Time period for different modes

6 CONCLUSION & FUTURE SCOPE

6.1 Conclusion

The objective of present study was to analyze a fixed base and base isolated building to assess the seismic behavior of structure in high seismic zone. In this study High Damping Rubber Bearing and Lead Rubber Bearing has been designed. Following observations are made after analyzing G+ 6 story building in seismic zone V using ETABS software.

- The base shear gets reduced by 46.5%, when base isolation is provided as compare to fixed based building. The base isolated building is having high efficiency in decreasing the base shear compare to fixed based building.
- Story drift gets reduced by 50% to 60% in both X & Y directions by using base isolation devices over the fixed based structure.
- The story displacement is more in both directions in case of base isolated structure. The lateral story displacement for base isolated building is always more than the lateral displacement of fixed base building. The increase in the lateral displacement in the ground floor is always be more than the increase in the high floor for base isolated building.
- Time period of the base isolated structure is also increases as compared to fixed base structure due to increase in lateral flexibility of structure by the base isolation system.
- This study shows that "the building gives better performance by the use of isolators at the base of the building as compared to fixed based building at higher seismic prone area".

6.2 Future Scope

This study deals with the analysis of fixed base and base isolated structure having G+ 6 story in high seismic zone. “The Base isolation system has been considered as a technology to protect and ensure safety of human lives against large-scale earthquakes. However, with higher vision to prevent economic damages and ensure security for the future, authors strongly believe that base isolation is the technology that will realize the seismic protection concept for the next generation” (Fumiaki, Toru , Norikatsu , & Hiroyuki , 2000).

In this study we have only talked about base isolation device for earthquake resistant design. Base isolation is used for only low rise to mid-rise building. Future study can be done in case of use of base isolation device in high rise building and to explore different earthquake resistant system that can be used for high rise building.

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