

# Comparative Study of Base Isolated & Fixed Base RC Frame Structure

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## ARTICLE DETAILS

### Article History

Published Online: 10 November 2018

### Keywords

Earthquake, damage, structure, E-TABS

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## 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. 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

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. At the Earth's surface, earthquakes can be identified in the forms of shaking of ground. When the epicenter of a large earthquake is located offshore, the seabed may be displaced sufficiently to cause a tsunami. Earthquakes can also cause landslides, and occasionally volcanic activity. Earthquake be defined as any seismic event, either natural or manmade that generates seismic waves. —Earthquakes are caused mostly by rupture of geological faults, but also by other events such as volcanic activity, landslides, mine blasts, and nuclear tests. An earthquake's point of initial rupture is called its focus or hypocenter. The epicenter is the point at ground level directly above the hypocenter (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. The main use of isolation system is to reduce the displacements, base reactions and member forces in structure (S.D.Darshale and N.L.Shelke.,2016).

Dynamic linear analysis has been performed by using response spectrum method. The different results were obtained with the different condition of terrain and zone. As with the introduction of the isolator, the fundamental natural time period of structure increases but base shear reduces. Enter story drift of building also increase. As due to different terrain condition results were going to change as base isolator make the building as rigid building with the higher time period (Sekar and Kadappan.,2015). Sometimes the effect of the earthquake is severe that the passive nature of rubber is not able to sustain the energy arises due to seismic activity. Hence smart base isolation with adoptive and controllable properties was developed with varied stiffness and damping properties of the isolator.(Y. Li and J. Li., 2014).

Many researchers has been worked on base isolation system that it is become acceptable as a whole in engineering field. However so many types of isolation systems are being invented but amongst them few has become accepted thoroughly.(Monika Jain, S. S. Sanghai.,2017)

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. When soil structure interaction was neglected an undammed vibration was considered, critical harmonic excitation occurs after which the behavior of structure and isolator was unbounded. The results obtained depended on damping of the isolator .The resonant response of isolator and superstructure has been increased when SSI was taken into account. (J. Enrique Luco., 2014).

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. Two main type of commonly used bearings are Rubber bearings and friction bearings. Both the rubber isolators and frictional isolators are divided into sub-types of isolators based on the material and the functions. Usability of isolator will be depends on its flexibility and the amount of energy it can dissipate. Hence the isolator should be a single unit that should effective to lengthen the natural time period of structure also should reduce the response of structure (Mostaghel N *et al.*,1983)

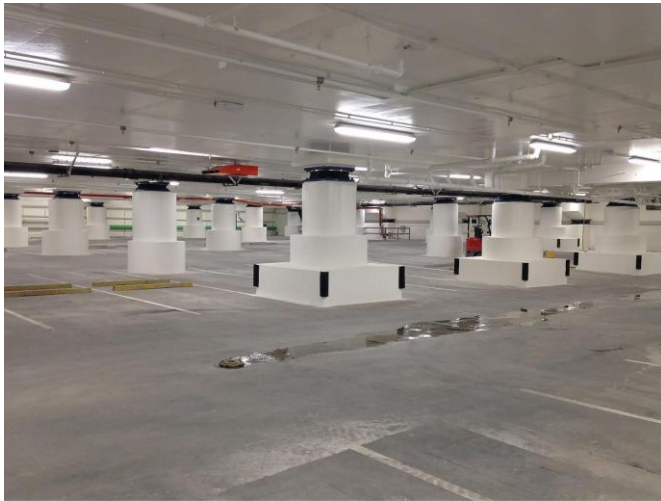


Figure 1.1: Base isolation in Christchurch Art Gallery, Christchurch, New Zealand

## 2.2 Modeling and Analysis

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

- Fixed based building.
- Base isolated building

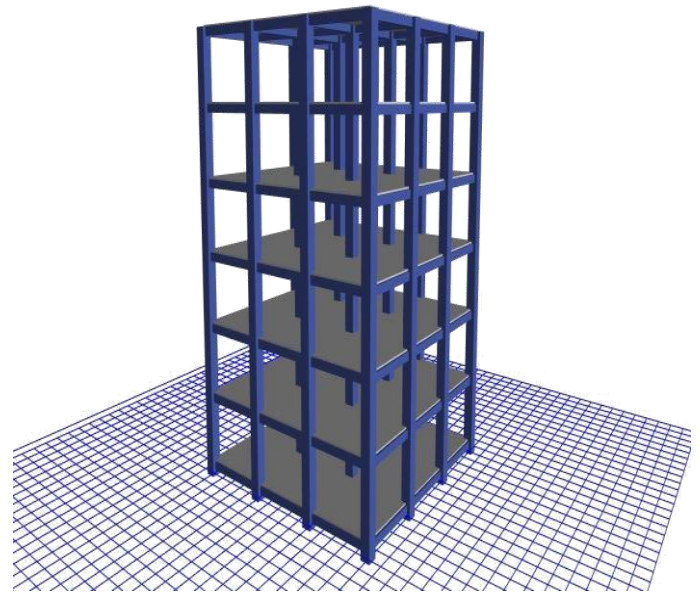


Figure 1.2: 3D view of model

### 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. Methodology

### 2.1 Design Of Base Isolation

The High Damping Rubber Bearing and Lead Rubber Bearing Isolation device based on Uniform Building Code-1997 has been designed.

#### 2.1.1 Design Procedure Using UBC-97

The following are the preliminary design procedures

##### 2.1.1.1 Establish all dynamics parameters

The bearing loads are as follows:

- Four at 1556.2625 KN
- Eight at 2276.076 KN
- Four at 3212.3279 KN

##### 2.1.1.2 High-Damping Rubber Isolators

High damping rubber was designed for load of 2276.076 KN.

##### 2.1.1.3 Lead-Rubber Isolators

The same target period of 2.5 seconds is maintained and shear modulus was taken.

## 2.3 Structural Specifications

### 2.3.1 Member Properties

Table 2.1: 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   |

### 2.3.2 Material Properties

Table 2.2: Summary for material properties

|                          |          |
|--------------------------|----------|
| Grade of concrete        | M30      |
| Grade of steel           | Fe= 415  |
| Density of brick Masonry | 20 KN/m3 |

### 2.3.3 Load Intensities

Table 2.3: Summary of load parameters

|              |  |
|--------------|--|
| Dead Load    | As per IS 875 (Part 1)-1987                                      |
| Live Load    | Roof: 1.5 KN/m <sup>2</sup><br>Other floors: 3 kN/m <sup>2</sup> |
| Floor Finish | 1 KN/m <sup>3</sup>  |
| Earth load   | As per IS 1893 ( Part 1)- 2002                                   |

**2.3.4 Load Combinations**

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

|     |        |     |        |
|-----|--------|-----|--------|
| 1.  | Comb1  | 2.  | Comb2  |
| 3.  | Comb3  | 4.  | Comb4  |
| 5.  | Comb5  | 6.  | Comb6  |
| 7.  | Comb7  | 8.  | Comb8  |
| 9.  | Comb9  | 10. | Comb10 |
| 11. | Comb11 | 12. | Comb12 |
| 13. | Comb13 |     |        |

Note: DL- Dead Load LL- Live Load

- Earthquake load in X direction
- Earthquake load in X direction

**2.3.5 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 2.4: Summary of Earthquake parameters

| CODE USED                 | IS1893 (Part 1)-2002 |
|---------------------------|----------------------|
| Earth quake zone          | V                    |
| Zone Factor               | Z=0.36               |
| Importance factor         | I=1.0                |
| Response reduction factor | R=5                  |

**3. Result Analysis**

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

Results obtained from software are specified below:

**3.1 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.

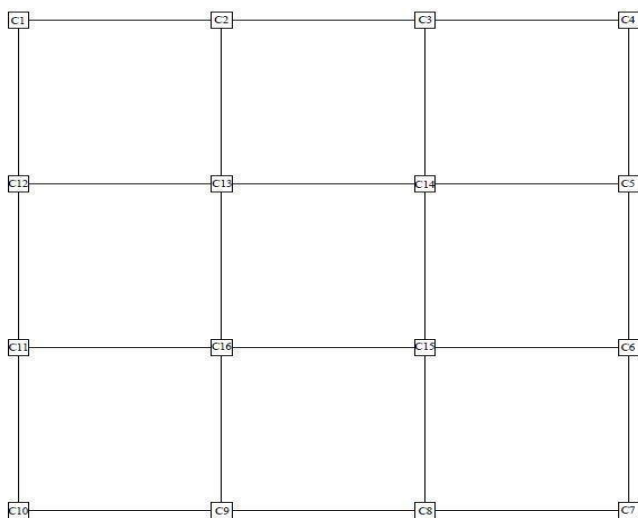


Figure 3.1: Plan view of model with column numbering

Table 3.1: Maximum vertical reaction on column base

| Load combinations<br>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              |

**3.2 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 3.2: Base shear for fixed base & base isolated structure

| Load Combination | Base Shear (KN) |             |
|------------------|-----------------|-------------|
|                  | X- direction    | Y-direction |
| Structure        |                 |             |
| Fixed Base       | 1604.6573       | 0           |
| Base Isolated    | 743.9874        | 0           |

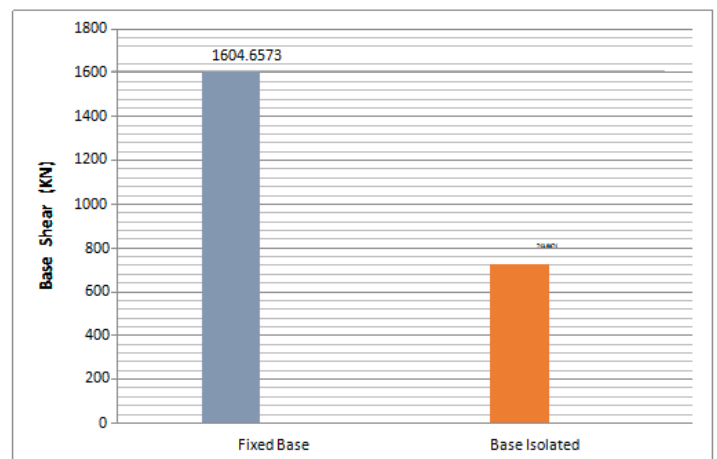


Figure 3.2: Base shear bar chart

**Table 3.3: Story shear due to Earthquake forces in X direction**

| Load Combination |          |   |   |  |  |
|------------------|----------|---|---|--|--|
| 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 3.4: Story shear due to Earthquake forces in Y direction**

| Load Combination |          |   |   |  |  |
|------------------|----------|---|---|--|--|
| 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                                       |

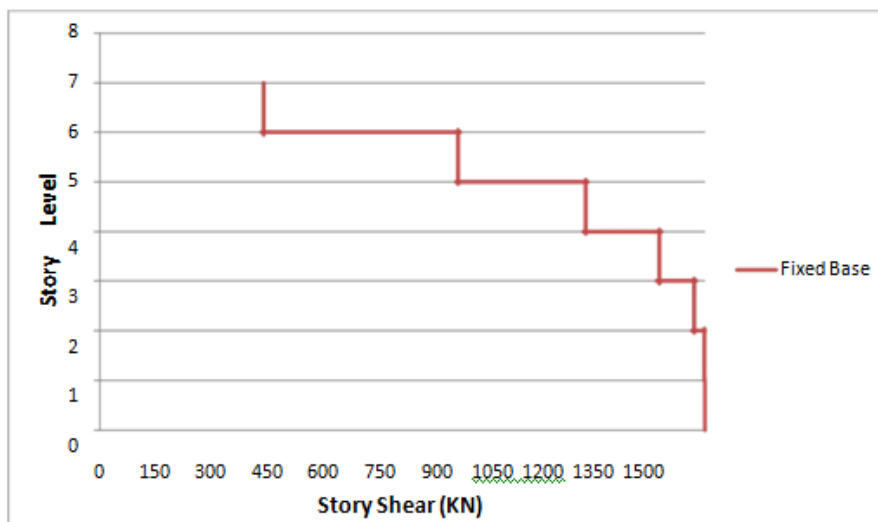


Figure 3.3: Graphical representation of story shear for fixed base structure

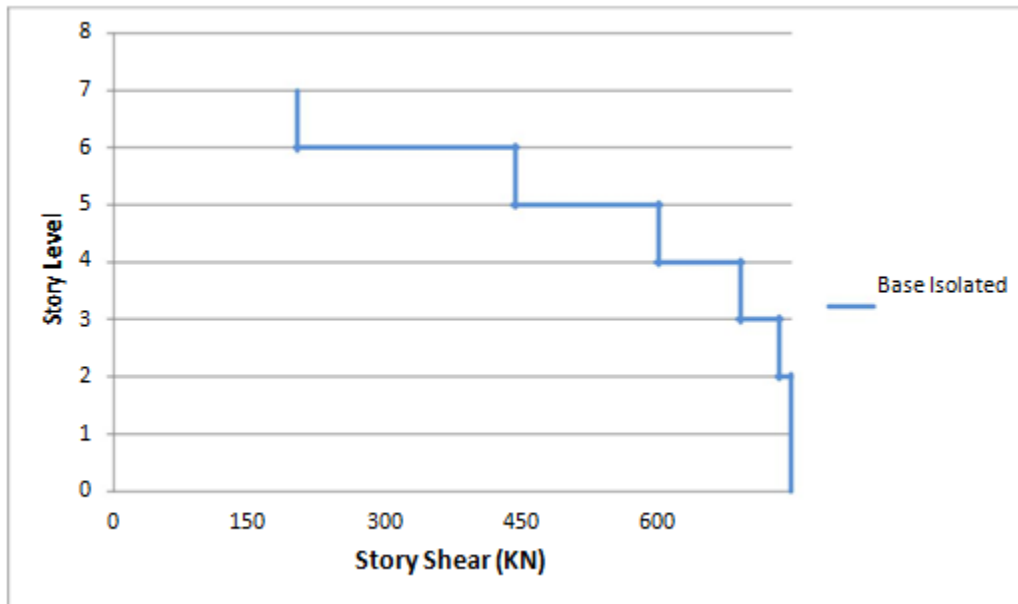


Figure 3.4: Graphical representation of story shear for base isolated structure

### 3.3 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 3.5: 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 3.6: Story Displacement due to Earthquake forces in Y direction

| Load Combination |               |  |  |   |   |        |
|------------------|---------------|--|--|---|---|--------|
| 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 |

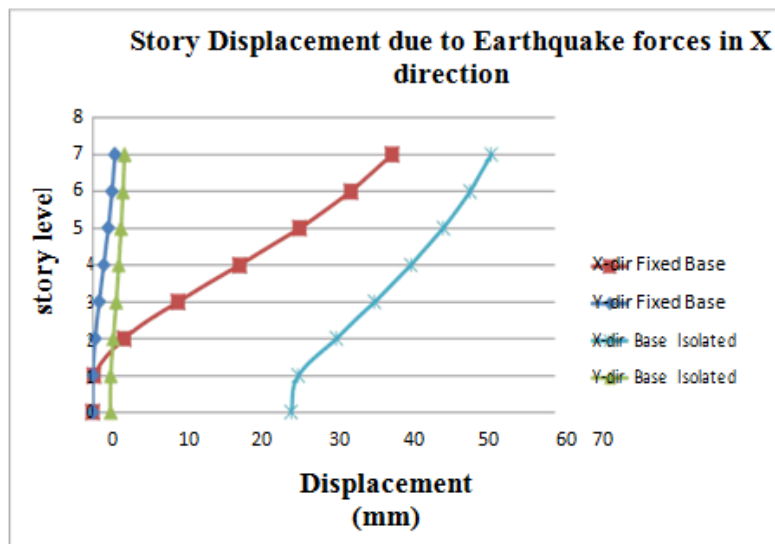


Figure 3.5: Story Displacement due to Earthquake forces in X direction

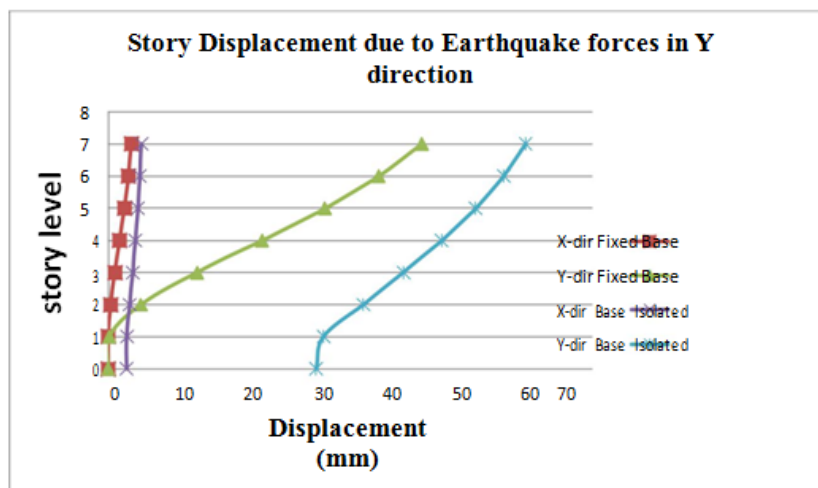


Figure 3.6: Story Displacement due to Earthquake forces in Y direction

### 3.4 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 3.7: Story Drift due to Earthquake forces in X direction

| Load Combination | 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 3.8: Story Drift due to Earthquake forces in Y direction**

| Load Combination |               |  |  |   |   |
|------------------|---------------|--|--|---|---|
| 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   |

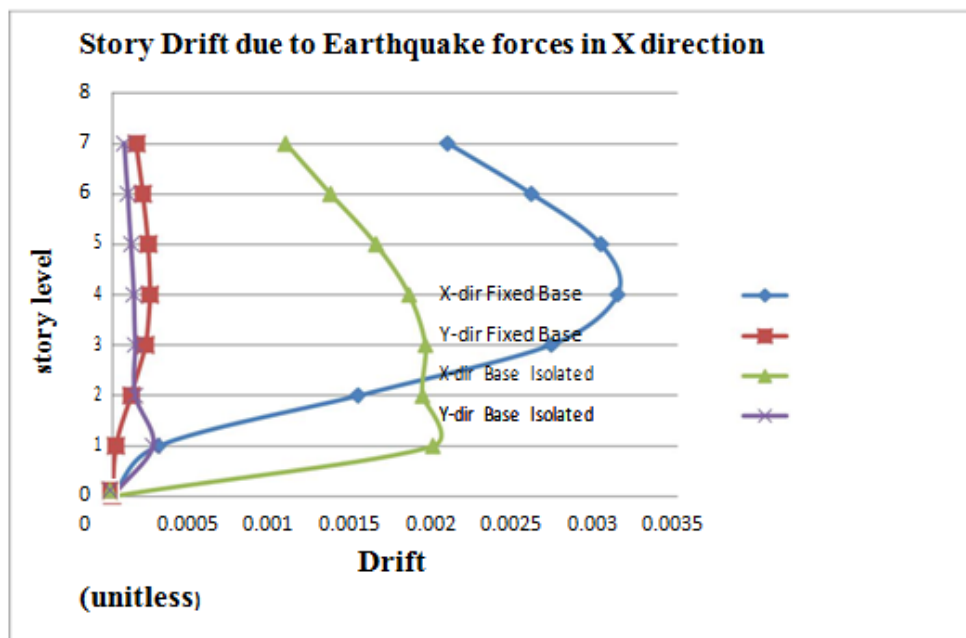


Figure 3.7: Story Drift due to Earthquake forces in X direction

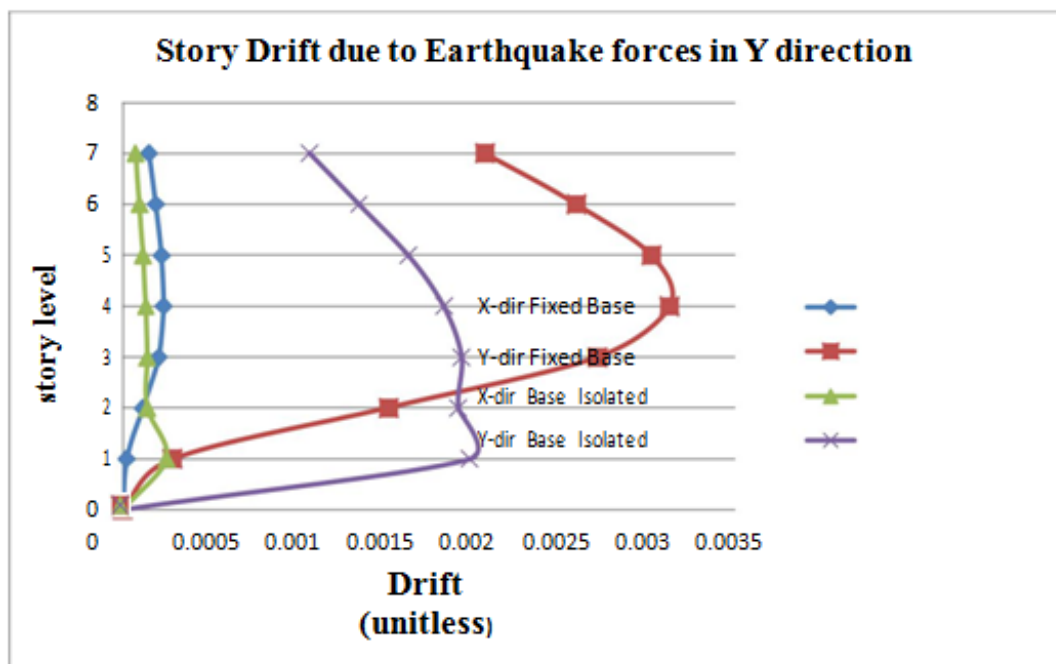


Figure 3.8: Story Drift due to Earthquake forces in Y direction

### 3.5 Modal Period

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

**Table 3.9: 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                                     |

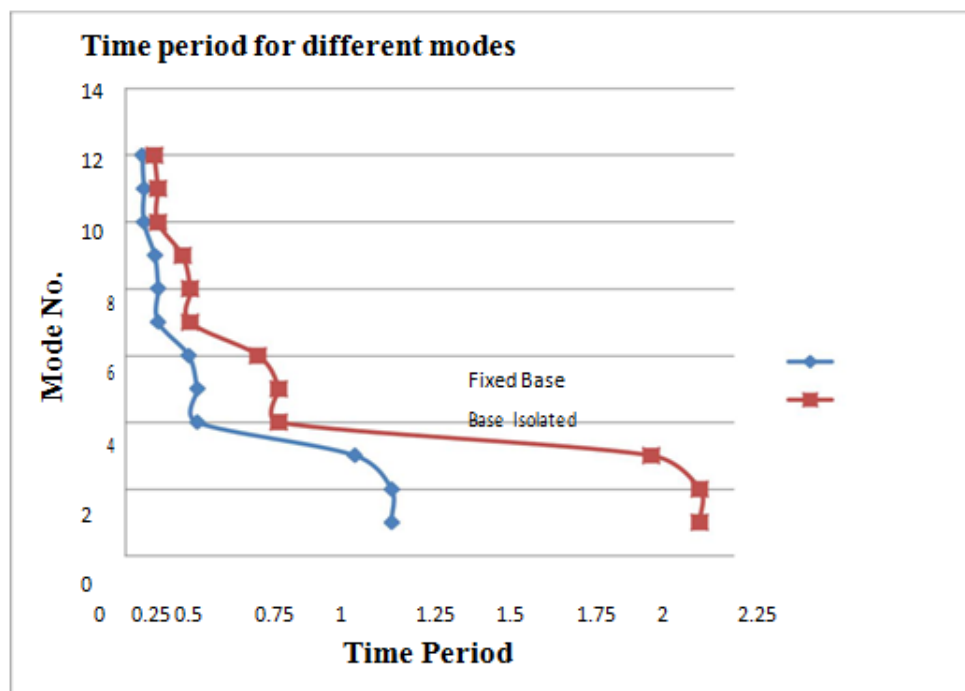


Figure 3.9: Time period for different modes

### 4. 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.

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