SEISMIC ANALYSIS OF MULTISTOREY RC BUILDINGS WITH BASE ISOLATION SYSTEM

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Abstract: An earthquake is a natural disaster which causes damages to the structures and responsible for loss of life. Earthquake refers to shaking of ground and is unpredictable. It is not possible to prevent the earthquake and thus attempts have been made to resist the earthquake forces acting on the structures. Base isolation is one of the effective method of resisting earthquake forces. They consist of rubber bearings which are sandwiched between superstructure and its foundation. These rubber bearings absorb earthquake energy thus resulting in energy dissipation.

In this thesis work, an attempt is made to study the behavior of structures with and without base isolation system. Lead Rubber Bearings (LRBs) are used as an isolation system. Four models of plan 20m x 20m with different heights are modelled and analysed in ETABS 2016 software. Response spectrum method is carried out for the analysis of models. The models are analysed for two different zones of India. I.e. Zone II (low seismic risk) and Zone V (severe seismic risk) as per IS 1893:2002 (Part 1). From the analysis of fixed base models, maximum axial reaction is obtained and LRBs are designed manually as per Design of Seismic Isolated Structures by James M Kelly and Farzad Naeim.

The parameters such as storey displacements, storey drifts and mode periods are compared between fixed base and isolated base models. It is found that, storey drifts are reduced in the building with isolated base. Storey displacements and mode periods are increased due to increase in the flexibility of isolated base building. Hence it is found that the use of base isolation system reduces the earthquake forces transferring to the superstructure.

Key words: **Base Isolation, Lead Rubber Bearings (LRBs), Response spectrum method, Storey displacements, Storey drifts, Mode periods.**

1. INTRODUCTION

1.1 General

An Earthquake refers to the shaking of earth's surface. Earthquake is a wave like motion which is generated by the stresses resulting in sudden energy release in earth's crust. Most of the buildings are susceptible to the earthquake. Both structural as well as non-structural components of the buildings are affected by an earthquake. The earthquake occurs without any warning and affects greatly the buildings which are situated in earthquake prone areas. It is very difficult to avoid the buildings from being damaged during earthquake. However, necessary care should be taken during the design of buildings in order to reduce the effect of an earthquake. The extent of damage mainly depends on the magnitude and intensity of earthquake. Also various structural properties such as irregularities in the buildings, presence of soft storey, foundation type etc.

The buildings near the epicenter are most likely to damage first since the intensity of an earthquake will be greater at that region compared to the buildings situated away from the epicenter. These earthquakes not only damage the structures but also lead to loss of life. Due to the damage of structures and loss of life by an earthquake, many attempts have been made in order to prevent the earthquake effect on the structures by the means of developing Earthquake Resisting Systems. Since the buildings are subjected to both linear and non-linear dynamic actions, various forces are developed at the base of structure. Thus, by providing proper systems the effect of an earthquake on the structures can be reduced to some extent.

1.2 Base Isolation

Base isolation is a technique of reducing the effect of earthquake forces on the structures. As the name indicates it refers to the separation of base of the superstructure from the substructure which is resting on shaking ground. i.e., Decoupling of the superstructure from its substructure. The base isolation concept had be discussed in last few decades and is well adopted in the present situation. The base isolation technique is mainly intended to reduce the earthquake forces that act on the structure. This can be achieved by providing suitable supporting systems between the superstructure and its foundation.

These supporting systems reduces the inter storey drift by absorbing the earthquake energy resulting in least damage of structure and also increases the human safety. Through the base isolation, flexibility can be introduced in the structure thus making the RC building or masonry building extremely flexible. Base isolation is effective and suitable only for low rise and medium rise buildings situated on hard soil.

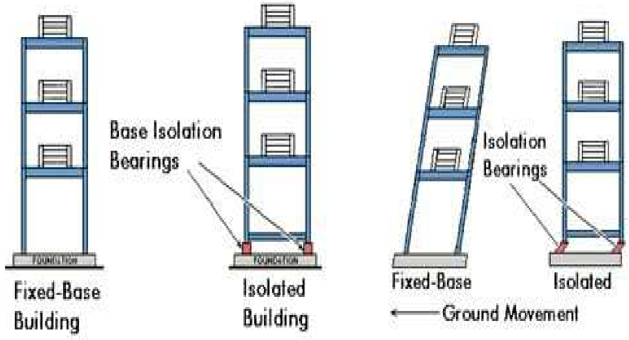

Fig. 1 Behavior of Fixed base and Base Isolated Building

1.3 Types of Base Isolation Systems

1. Elastomeric bearing systems
2. Sliding system
3. Dampers

Elastomeric bearing systems are further classified as:

1. Natural Rubber Bearings
2. Lead Rubber Bearings (LRBs)
3. High Damping Rubber Bearings (HDRBs)

In this project, Lead Rubber Bearing is used for base isolation.

Lead Rubber Bearings (LRBs):

Lead rubber bearings are similar to natural rubber bearings but they are provided with centrally placed cylindrical lead plug. These LRBs provides greater vertical stiffness and damping properties compared to natural rubber bearings. LRBs are widely used compared to other base isolation systems.

They consist of rubber layers and steel plates in alternative manner with lead plug placed centrally. Lead plug may be one or more. These alternative layers are mounted in between the thick steel plates. The lead plug resists the earthquake forces by energy dissipation. These lead plugs undergo shear deformation providing bilinear response. The steel plates provides vertical stiffness and vertical load capacity. Rubber layers provide horizontal flexibility to the system. The thick steel plates on which isolator are mounted is used to connect superstructure and foundation. Under the greater seismic loads, lead undergoes plastic deformation which results in greater bearing displacement. The lead plug also encounters the deformation as rubber but however it produces heat or kinetic energy is dissipated in the form of heat. Thus the energy transfer to the building is reduced due to hysteretic conduct of plug. By this way, LRBs provides desirable hysteretic damping characteristics that improve the structural response.

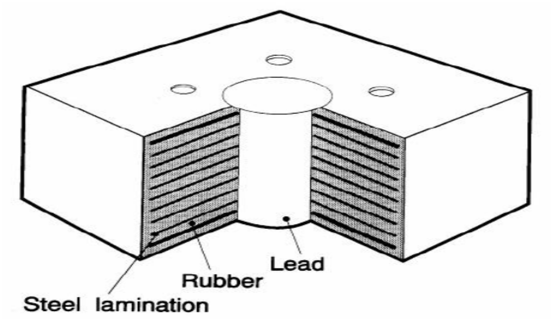

Fig. 2 Lead Rubber Bearing

2. OBJECTIVES

- To make a comparative study of fixed base and isolated base multistory RC buildings.
- The buildings are modelled and analyzed in ETABS 2016 as per IS 1893:2002(part 1)**[4]** codal provisions.
- To provide Lead rubber bearings (LRBs) as an isolation system. LRBs are manually designed by considering the maximum axial reaction which can be obtained by analyzing the structure with fixed base.
- To carry out Dynamic analysis and the results between fixed base and isolated base building are compared.
- The results are obtained in terms of storey displacement, storey drift and mode period.

3. METHODOLOGY AND ANALYSIS

3.1 Plan Details

The RC buildings of plan 20m x 20m with different heights having Special Moment Resisting Frame (SMRF) with each grid spacing of 5m in both directions are modelled and analysed. The software ETABS 2016 is used for modelling and analysis of the building. The buildings are analysed for zone II (Low seismic effect) and zone V (Severe seismic effect).

3.2 Model Details

1. Type of structure: Special Moment resisting frame
2. Storey height: 3m
3. Concrete Grade: M20
4. Steel Grade: Fe415
5. Column size: 450 x 450 mm
6. Beam Size: 230 x 350 mm
7. Slab thickness: 125 mm
8. Walls: Exterior – 230 mm
   Interior – 150 mm
9. Live loads: Typical floor - 3 kN/m^2
   Roof - 1.5 kN/m^2
10. Floor Finish: Typical floor - 1 kN/m^2
    Roof - 0.5 kN/m^2
11. Zonefactor (Z): Zone V – 0.36
    Zone II - 0.1
12. Importance factor (I): 1
13. Response reduction (R): 5
14. Soil type: III (Soft)

3.3 Models Description

- **Model 1 (M1):** A 5 storey RC building of plan 20m x 20m is analysed with fixed base and isolated base for zone II and zone V.
- **Model 2 (M2):** Modelling and analysis of10 storey RC building of plan 20m x 20m with fixed base and isolated base for zone II and zone V.
- **Model 3 (M3):** Analysis of15 storey RC building of plan 20m x 20m for zone II and zone V.
- **Model 4 (M4):** A 20 storey RC building with same plan dimensions is analysed for zone II and zone V.

3.4 ETABS Models

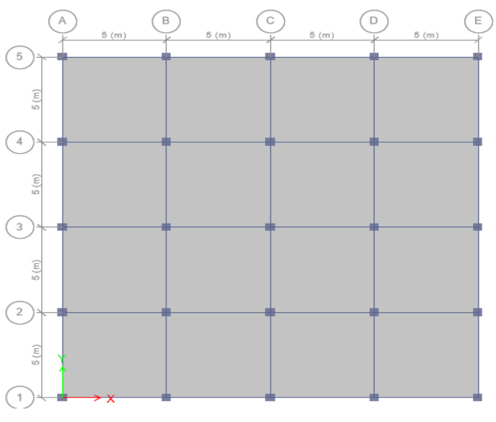

Fig. 3 Typical Building Plan

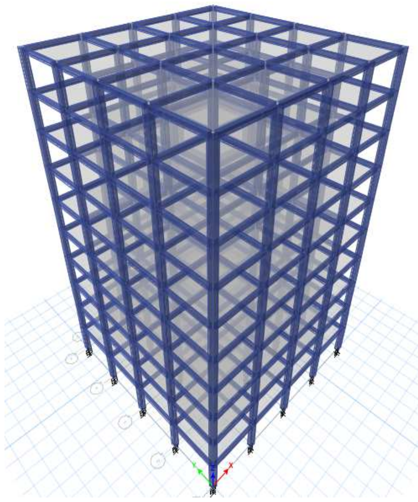

Fig. 4Isometric view of Model

3.5 Design of Lead Rubber Bearing

The design of Lead Rubber Bearing is carried out according to **"Design of Seismic Isolated Structures" [6]** by James M. Kelly and Farzad Naeim and **Uniform Building Code (UBC) 1997 [7]**.

1. **Design displacement (Dd):**
   Assume design period Td = 2.5 seconds, g = 9.81
   $Dd = [\frac{g}{4\pi^2}]*[\frac{C_v T_d}{B_d}]$ Cv – seismic coefficient, Bd – damping coefficient

2. **Effective stiffness (K_{eff}):**
   $K_{eff} = \left[\frac{W}{g}\right] * [\frac{2\pi}{T_d}]^2$

3. **Energy dissipated per cycle (W_D):**
   $W_D = 2*K_{eff}*Dd^2*\beta$ Effective damping, β = 5%

4. **Force at zero displacement (F_o):**
   $F_o = \frac{W_D}{4Dd}$

5. **Stiffness in rubber (K_r):**
   $K_r = K_{eff} - \frac{F_o}{4Dd}$

   [$\frac{F_o}{4Dd}$ = Lead core stiffness of LRB]

6. **Total LRB thickness (t_r):**
   $t_r = \frac{Dd}{\gamma}$ Max shear strain of rubber, γ = 1.5

7. **Diameter and area of lead core:**
   Lead core diameter, $D_{pb} = \sqrt{\frac{4Fo}{\pi\sigma_{pb}}}$ Yield stress in lead, σ_{pb} = 11pa

   Lead core area, $A_{pb} = \frac{\pi}{4}*D_{pb}*D_{pb}$

8. **Area of bearing (A_{lrb}):**
   $A_{lrb} = \frac{Keff * tr}{G}$ G = Rubber shear modulus (varies 0.4 to 1.1Mpa)
   Taking G = 0.8Mpa
   Diameter of bearing, $D_{lrb} = \sqrt{\frac{4Alrb}{\pi}}$

9. Shape factor (S_i):

$$S_i = \left[\frac{1}{2.4}\right] * \left[\frac{f_v}{f_h}\right]$$

f_h = Horizontal frequency

f_v = Vertical frequency

WKT, $S = \left[\frac{D_{lrb}}{4t}\right]$ where t is singlerubber layer thickness

Therefore, Number of rubber layers, $N = \frac{t_r}{t}$

10. Total height of LRB (H):

$$H = (N*t) + (N-1)\, t_s + 2t_{ap}$$

Where, N = Number of rubber layers

t = Single rubber layer thickness

t_s = Steel lamination thickness (0.003m)

t_{ap} = Laminated end plate thickness (0.04m)

11. Bearing Horizontal Stiffness (K_H):

$$K_H = \frac{G*Alrb}{tr}$$

Taking shear modulus, G = 1Mpa

12. Compression Modulus(E_c):

$$E_c = 6GS_i^2 * \left[1 - \frac{6GS_i^2}{K}\right]$$

K = compression modulus of rubber = 2000Mpa

13. Total Vertical Stiffness (K_V):

$$K_v = \frac{E_C*Alrb}{tr}$$

Table 1 Lead Rubber Bearing properties of 10 storey Model

1) Effective stiffness (K_{eff})	1773.44 kN/m
2) Bearing horizontal stiffness (K_h)	2215.24 kN/m
3) Vertical stiffness (K_v)	930403.58 kN/m
4) Yield force (F)	46.65 KN
5) Stiffness ratio	0.1
6) Damping	0.05

4. RESULTS AND DISCUSSIONS

In this section, the results of all the models for only zone V have been discussed. The following three parameters of Fixed Base (FB) and Isolated Base (IB) buildings obtained from response spectrum analysis are compared.

1. Storey Displacements
2. Storey Drifts
3. Mode Periods

4.1 Storey Displacements

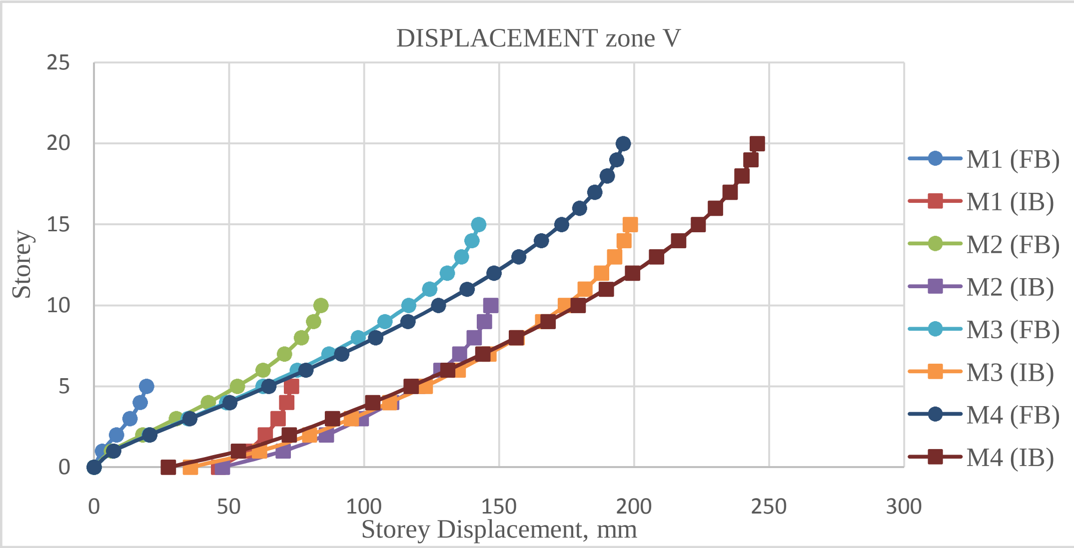

Fig. 5 Storey Displacements of all models for zone V

Discussions:

- From the analysis results of all the models, the maximum displacement occurs in the top storey. The variation in the displacements of all models for zone V is shown in the figure 5.
- In model M1 of 5 storey, the storey displacement for an isolated base is increased by 73.3% compared to fixed base.
- In model M2 of 10 storey, the storey displacement for an isolated base is increased by 42.8% compared to fixed base.
- In model M3 of 15 storey, the storey displacement for an isolated base is increased by 28.2% compared to fixed base.
- In model M4 of 20 storey, the storey displacement for an isolated base is increased by 20.2% compared to fixed base.

4.2 Storey Drifts

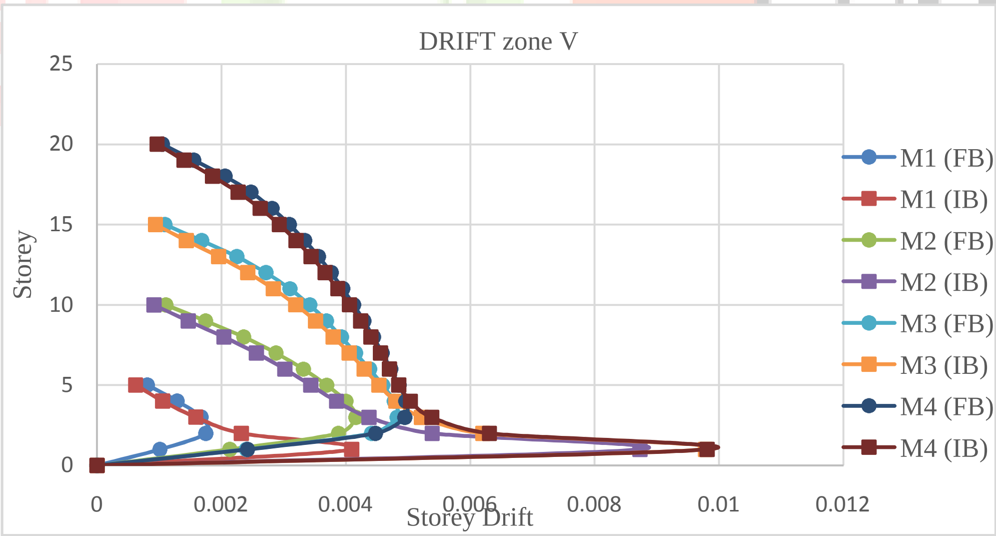

Fig. 6 Storey Drifts of all models for zone V

Discussions:

- The variation in the storey drifts of all models for zone V is shown in the figure 6.
- From the graph it is seen that, the storey drifts are maximum between storey 3 and storey 4 for fixed base and it keeps decreasing for the higher stories.
- Similarly, the drifts are maximum at storey 1 for isolated base and it keeps decreasing for the higher stories.
- In M1, The storey drift at storey 5 is reduced by 23.3% for an isolated base.
- In M2, The storey drift at storey 10 is reduced by 17.2% for an isolated base.

- In M3, The storey drift at storey 15 is reduced by 13.7% for an isolated base.
- In M4, The storey drift at storey 20 is reduced by 8.2% for an isolated base.

4.3 Mode Periods

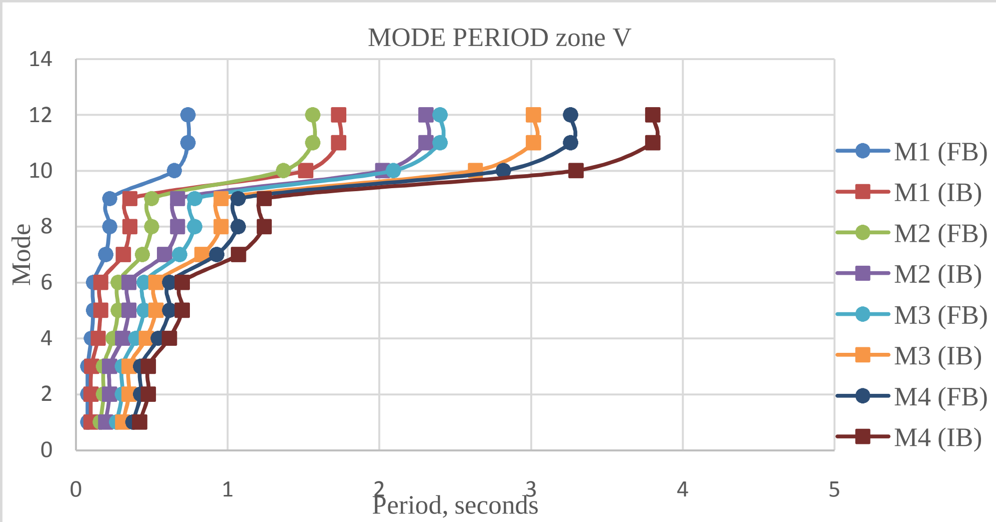

Fig. 7 Mode Period of all models for zone V

Discussions:

- The variation in the mode periods for all the models for zone V is shown in the figure 7.
- 12 different modes were considered for each model and maximum period occurs for mode 12.
- The mode period for an isolated base is increased from 0.738 to 1.732 seconds for model M1.
- The mode period for an isolated base is increased from 1.561 to 2.301 seconds for model M2.
- The mode period for an isolated base is increased from 2.401 to 3.016 seconds for model M3.
- The mode period for an isolated base is increased from 3.261 to 3.803 seconds for model M4.

5. CONCLUSIONS

- The displacement in the base isolated buildings has been increased as compared to fixed base. The displacement at the base of fixed base building is zero while the displacement at the base of isolated building has some displacement due to elasticity of isolators. The displacement of buildings in zone V is more compared to zone II since zone V has higher seismic effects.
- The displacements of all the models for zone II is reduced nearly 72% compared to displacements of all models for zone V.
- The storey drift in the base isolated buildings has been reduced compared to fixed base building. The storey drift in the storey 1 is higher for base isolated buildings due to higher seismic forces at the base and it keeps decreasing for the higher storeys. Storey drifts are maximum at zone V compared to zone II.
- The storey drifts for zone II is also reduced nearly upto 72% compared to zone V.
- The time period of base isolated building has been increased due to flexibility. As the height of the building increases, the time period also increases. 12 different modes were considered and mode 12 has highest time period.
- By the use of base isolation system, the structures can be protected against minor as well as major earthquakes to some extent. It is one of the very effective method to provide safety against earthquakes.

6. REFERENCES

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