

Seismic Analysis of Fixed Base and Base Isolated Building Using Lead Rubber Bearing

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Abstract- During the last few decades world has witnessed several devastating earthquakes, results in the loss of property of life thus putting a great moral responsibility on structural engineers to build the structure in such a way that they can withstand during the most severe earthquakes. Traditionally the structures were designed by increasing the stiffness of the structure or to make the structure flexible enough to reduce the impact of forces induced on the structure during earthquake which results in increase of peak floor acceleration or increase in inter storey drift values of the structure respectively and hence makes it difficult in insuring the safety of the structure and its non structural components.

Various studies have been performed in the past few years to minimize the damages caused by earthquake forces/ vibrations to the structure as well as non structural components of a RCC structure. The outcome of these studies is the use of various types of passive, active and hybrid control systems in which the base isolation is one of the passive control system by using lead rubber bearing isolators, friction pendulum, tuned mass dampers, tuned liquid dampers and elastomeric isolators. The concept of base isolators is to increase the flexibility of the structure at the base in both the orthogonal horizontal directions.

The intent of this paper is to study the effectiveness of the lead rubber isolator for G+15 storey RCC framed structure. The structure is analyzed in ETABS software using Bhuj earthquake data for two cases; one is for rigid jointed framed RCC structure and second is by the introduction of lead rubber bearing (LRB) isolators under the most seismically active region in India i.e. in zone V resting on loose soil (type III). The effectiveness of an isolator is demonstrated by comparing the storey drift, lateral displacement of the structure, base shear, acceleration and maximum bending moment of the fixed base structure to the isolated base structure.

Non-Linear time history analysis method is used to study the results.

Index Terms- Active control system, Base isolation, Hybrid control system, Lead rubber bearing, Peak floor acceleration, Time history analysis.

I. INTRODUCTION

Huge dynamic forces acts on a structure during an occurrence of earthquake, cyclones, blasts and storms however the most unpredictable and critical amongst these are the earthquakes in a high seismic zone for low to medium rise buildings. Earthquake occurs due to the movement of tectonic plates or volcanic activity below the surface of earth as a result of which huge vibrations are induced at the earth's surface. The earthquake force is much greater than the fundamental frequency of vibration which means that the structure behaves as an amplifier and when these vibrations are transmitted to the building the acceleration experienced at floor is much higher at top of building as compared to the bottom stories and huge inter storey drift is experienced between the floors makes the building non operational post earthquake. However there are certain buildings like emergency centers, fire stations, police stations, communication centers and hospitals needs to be operational post earthquake. In conventional design method the inter storey drift is reduced by increasing the stiffness of the structure which may rise in the peak floor acceleration hence make them difficult in insuring the safety of the structure.

Various studies have been performed to make the structure earthquake resistant, in a most economical way. The most common amongst them is the base isolation of the structure. As the name suggests itself that the structure is isolated from its base so that the earthquake vibrations should not get transferred to the structure. The fundamental principle of base isolation is to decouple the structure from the

earthquake induced ground motions by rectifying the response of the structures so that the ground can move without transmitting the forces to the structure. The base isolator must be strong enough so that it can with stand the vertical load of the structure during its life and increase the flexibility of the structure at the base in the two orthogonal horizontal directions without causing damage to the structure.

Lead rubber bearing (LRB) isolator is one of the most common and widely used base isolation technique used now a days. LRB consists of a cylindrical lead core surrounded by alternate layers of laminated rubber and steel shim plates. Steel plates are also provided at both ends of the isolator. The lead core provides damping to the isolator which helps in reducing the amplitude of vibration, rubber provides the flexibility of the building and the steel shim plates acts as a reinforcement in the load carrying capacity of the isolator thus the structure is flexible in both orthogonal horizontal directions and stiff enough to withstand under the vertical loads of the structure. Fig.1 shows a typical LRB isolator.

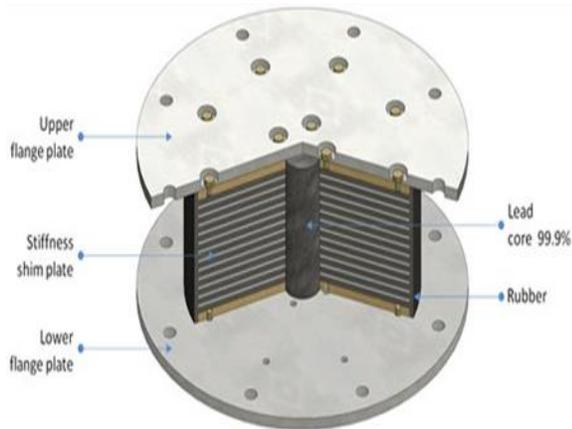


Fig.1 Lead rubber bearing schematic

II. MODELLING

The building is G+15 storey Reinforce Concrete Frame. It is square in plan, with dimensions 5x5 m. Storey height is 3.0 m and therefore the total height of the building is 32 m. Spacing between columns is 5 m in both directions. All the column sections are 750 x 750 mm in dimension and all the beam sections are 350 x 500 mm in dimension. The floor system is the same at all floors with 160mm thin shell. Fig. 2 shows the floor framing arrangement. The building input parameters are shown in table I.

Table I Input Parameters for Modelling

Parameters of Building	Description/Values
Type of frame	Special moment
Number of storeys	G+15
Length of building in X	15
Length of building in Y	15
Height of building (m)	45
Height of each storey	3
Grade of Beam and Slab	M25
Grade of column	M30
Reinforcement Grade	Fe 415
Support type	Fixed and Base

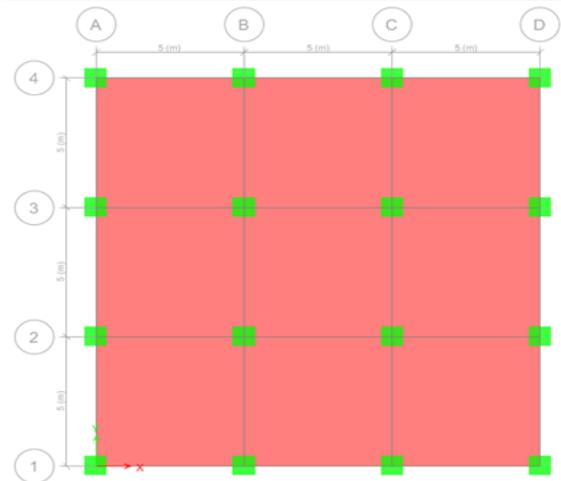


Fig.2 Floor Framing Plan

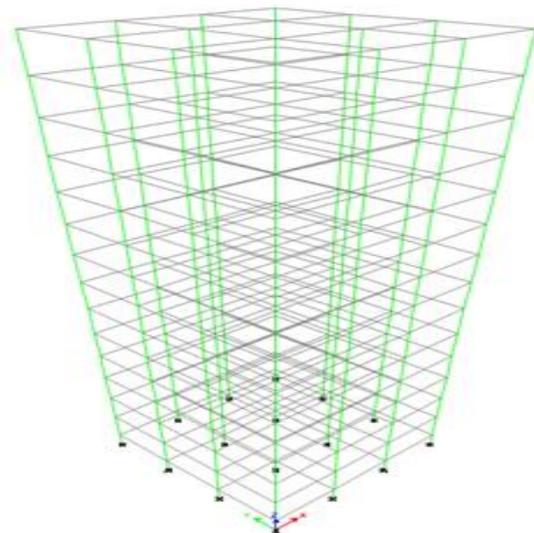


Fig.3 Fixed Base 3-D View

A. Section Properties

The section sizes and thickness of slab is shown in table II.

Table II Section Details

S.No.	Type of Section	Size (mm)
1	Beam	350 x 500
2	Column	750 x 750
3	Slab	160

B. Loads and Load Combination

The load values and load combinations used in the analysis of building are shown in table III below:

Table III Loads and Load Combinations

S.No	Load Type	Value
1	Dead Load (DL)	Self weight of
2	Live Load (LL)	5kN/m ²
3	Floor Finish (FF)	1 kN/m ²
4	Load	As per IS 1893: 2002

C. Seismic Data

The assumed preliminary seismic data used for the analysis of building is shown in table IV below:

Table IV Seismic Data

S.No.	Type	Description
1	Soil type	III (soft)
2	Seismic Zone	V
3	Seismic Zone Factor	0.36
4	Response reduction	5.0
5	Importance Factor	1.0
6	Damping of structure	5%

III. ANALYSIS OF FIXED BASE BUILDING

Initially the building was analyzed as fixed base building by providing the fixed supports at the end of columns in ETABS by assuming that the primary lateral load resisting system consists of a moment resisting RCC frame. For fixed base building the fundamental time period, total vertical load (DL+LL), base shear, maximum lateral displacement, storey drift and acceleration values were obtained.

The fundamental time period of fixed base building was 1.75seconds and the vertical load in the interior column (as expected in case of symmetrical building) was 8687 kN for which the isolator properties have been worked out.

IV. BASE ISOLATOR DESIGN

Initially, Total load of the structure, W = 8687 kN. The fixed base time period of the frame is, T = 1.75 s. Assuming a time period separation of 3, the fundamental time period of the frame is 5.25 s. Assuming a damping of 10% for the isolator, the response spectrum provides a value of

$$\frac{S_a}{g} = 0.32 \text{ for } T = 5.25 \text{ s}$$

A. Maximum Design Displacement of the Isolator

$$S_d = \frac{S_d T_b}{4} = \frac{0.32 \times 0.36 \times 9.81 \times 5.25}{4 \times \pi^2}$$

$$S_d = 0.15 \text{ m}$$

B. Effective Stiffness of the Isolator

$$K_{eff} = \frac{4W\pi^2}{gT_b^2} = \frac{8687 \times 4 \times \pi^2}{9.81 \times 5.25^2}$$

$$K_{eff} = 1268.36 \text{ kN/m}$$

C. Energy Dissipation Per Cycle

$$Q_D = \frac{W_D}{4S_d} = \frac{\pi}{2} \times K_{eff} \times \zeta_{eff} \times S_d$$

$$= \frac{\pi}{2} \times 1268.36 \times 0.1 \times 0.15$$

$$Q_D = 29.89 \text{ kNm}$$

D. Post Yield Stiffness of the Isolator

$$K_d = K_{eff} - \frac{Q_D}{S_d} = 1268.36 - \frac{29.89}{0.15}$$

$$K_d = 1069.1 \text{ kN/m}$$

E. Yield Displacement

$$D_y = \frac{Q_D}{9 K_d} = \frac{29.89}{9 \times 1069.1}$$

$$D_y = 0.003 \text{ m}$$

F. Yield Force

$$F_y = K_u \times D_y$$

$$K_u = 10 K_d$$

$$F_y = 10 \times 1069.1 \times 0.003$$

$$F_y = 32.07 \text{ kN}$$

G. Maximum Force

$$F_m = Q_D + K_d S_d$$

$$F_m = 29.89 + 1069.1 \times 0.15$$

$$F_m = 190.26 \text{ kN}$$

$$K_u = \frac{F_y}{D_y}$$

$$K_u = \frac{32.07}{0.003}$$

$$K_u = 10690 \text{ kN/m}$$

H. Check for K_{eff}

$$K_{eff} = \frac{F_m}{S_d}$$

$$K_{eff} = \frac{190.26}{0.15}$$

$$K_{eff} = 1268.4 \text{ kN/m}$$

I. Force At Zero Displacement Under Cyclic Loading

$$F_0 = \frac{Q_D}{4S_d}$$

$$F_0 = \frac{29.89}{4 \times 0.15}$$

$$F_0 = 49.82 \text{ kN}$$

J. Stiffness of Lead Core of Lead Rubber Bearing

$$K_{pb} = \frac{F_0}{S_d}$$

$$K_{pb} = \frac{49.82}{0.15}$$

$$K_{pb} = 332.13 \text{ kN}$$

K. Stiffness of Rubber in Lead Rubber Bearing

$$K_r = K_{eff} - K_{pb}$$

$$K_r = 1268.36 - 332.13$$

$$K_r = 936.23 \text{ kN/m}$$

L. Total Thickness of Lead Rubber Bearing

$$t_r = \frac{S_d}{Y}$$

$$t_r = \frac{0.15}{0.5}$$

$$t_r = 0.3 \text{ m}$$

Where Y is the design shear strain which is 0.5 (as per T.K. Dutta).

M. Diameter of Bearing

$$D_{bearing} = \sqrt{\frac{t_r K_r}{400 \pi}}$$

$$D_{bearing} = \sqrt{\frac{936.23 \times 0.3}{400 \pi}}$$

$$D_{bearing} = 0.47 \text{ m}$$

N. Diameter of Lead Core of Lead Rubber Bearing

$$D_{pb} = \sqrt{\frac{4F_0}{\pi \sigma_{pb}}}$$

$$D_{pb} = \sqrt{\frac{4 \times 49.82}{\pi \times 11000}}$$

$$D_{pb} = 0.076 \text{ m}$$

Where σ_{pb} is the total yield stress in lead and it is assumed to be 11 MPa.

O. Area of Lead Core of Lead Rubber Bearing

$$A_{pb} = \pi (D_{pb}^2)/4$$

$$A_{pb} = 0.785 \times (0.076)^2$$

$$A_{pb} = 4.534 \times 10^{-3} \text{ m}^2$$

P. Diameter of Force Free Section

$$D_{ff} = D_{bearing} - 2t$$

$$D_{ff} = 0.47 - 2 \times 0.01$$

$$D_{ff} = 0.45 \text{ m}$$

Where t is the single layer thickness which is 0.01 m

Q. Force Free Area

$$A_{ff} = \pi (D_{ff}^2)/4$$

$$A_{ff} = 0.785 \times (0.45)^2$$

$$A_{ff} = 0.159 \text{ m}^2$$

R. Total Loaded Area

$$A_L = \text{Force free area} - \text{Area of lead core}$$

$$A_L = 0.159 - 4.534 \times 10^{-3}$$

$$A_L = 0.154 \text{ m}^2$$

S. Circumference of Force Free Area

$$C_f = \pi t D_{ff}$$

$$C_f = \pi \times 0.01 \times 0.45$$

$$C_f = 0.014 \text{ m}$$

T. Shape Factor

$$S_i = \frac{\text{Load Area}}{\text{Circumference of force free area}}$$

$$S_i = \frac{0.154}{0.014}$$

$$S_i = 11$$

U. Total Height of Lear Rubber Bearing

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

$$N = \frac{0.2}{t}$$

$$N = \frac{0.2}{0.01}$$

$$N = 20$$

$$H = (20 \times 0.01) + (20-1) \times 0.003 + 2 \times 0.04$$

$$H = 0.337 \text{ m}$$

Where,

N is the number of rubber layer

t is the single layer thickness which is 0.01 m

t_s is the thickness of steel lamination which is 0.003m

t_{ap} is the laminated anchor plate thickness which is 0.04 m

V. Bearing Horizontal Stiffness

$$K_b = \frac{G A_r}{H}$$

$$K_b = \frac{1000 \times 0.154}{0.337}$$

$$K_b = 456.97 \text{ kN/m}$$

Where G is the shear modulus which is varying from 0.4 MPa to 1.1 Mpa, however the value of G considered for the design of bearing is 1.0 Mpa

W. Total Vertical Bearing

$$K_v = \frac{6 G S_l^2 A_r K}{(6 G S_l^2 + K)H}$$

$$K_v = \frac{6 \times 1000 \times 11^2 \times 0.154 \times 2000 \times 1000}{(6 \times 1000 \times 11^2 + 2000 \times 1000) 0.337}$$

$$K_v = 243.406 \times 10^3 \text{ kN/m}$$

From the above calculation, the summary of lead rubber bearing design is as shown in Table V below:

Table V: Summary of LRB Parameters

Effective Stiffness (<i>K_{eff}</i>)	1268.4 kN/m
Bearing Horizontal Stiffness (<i>K_b</i>)	456.97 kN/m
Vertical Stiffness (<i>K_v</i>)	243.406 kN/m
Yield Force (<i>F_y</i>)	32.07 kN
Stiffness Ratio	0.1
Damping	0.05

V. ANALYSIS OF BASE ISOLATED BUILDING

ETABS software was used for the analysis of building which facilitates the modeling of base isolator. At first the fixed supports are removed from the model and then the rubber isolators are provided in the form of links. The properties of links are provided in the calculation of LRB and the summary of the parameters used to define the links are tabulated in table V above.

V. RESULTS

A. Shift in Time Period

Base isolation shifts the fundamental period of the structure from the dominant period of earthquake. It generally shifts the fundamental time period of the structure more than 2 seconds. The severe accelerations of an earthquake are avoided due to period shift by isolation. From table 6, the shift in the time period is shown for successive three modes.

Table VI: Time Period Response of Fixed Base and Base Isolated Building

Mode	Fixed Base Time Period	Isolated Base Time Period
1	1.75	3.94
2	1.75	3.94
3	1.48	3.15

B. Base Shear Response of Fixed and Isolated Base Building

The maximum base shear in column of fixed base and base isolated buildings are shown in figure 4.

From figure 4, it is observed that the base shear in column is reduced in base isolated building as compared to fixed base building by 42.1%.

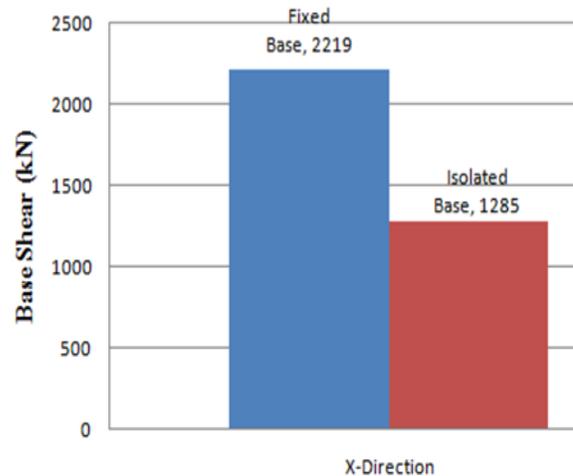


Fig.4 Base Shear

C. Maximum Bending Moment

Maximum bending moment of fixed base building and base isolated building is shown in figure 5.

From figure 5, it is observed that the maximum bending moment is reduced in base isolated building as compared to the fixed base building by 55%.



Fig.5 Maximum Bending Moment at Base

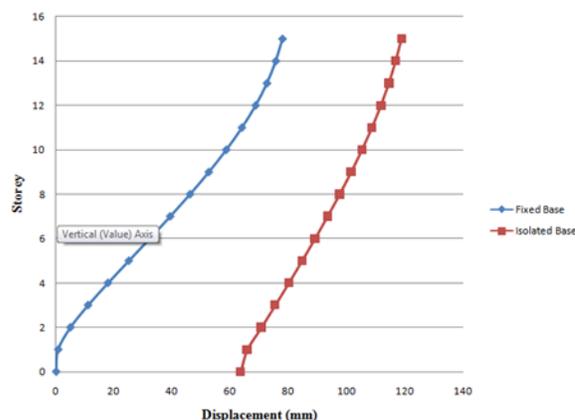


Fig.7 Lateral Displacement

D. Storey Drift

From figure 6, it is observed that the values the drift value of base isolated building is more as compared to the fixed base building, however, the relative storey drift values for storey second above are very less as compared to the fixed base building.

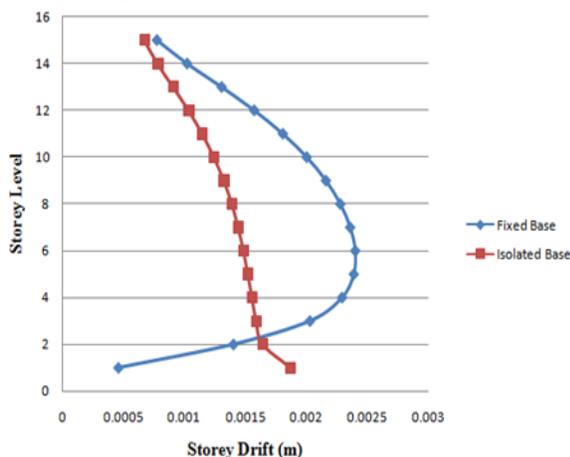


Fig.6 Storey Drift

E. Lateral Displacement

The lateral displacement values of different storeys of fixed base building and base isolated building is shown in figure 7.

From figure 7, it is observed that the values the displacement value of base isolated building is more at first storey as compared to the fixed base building, however, the relative storey displacement values for storey second above are very less as compared to the fixed base building. This shows that the upper storeys will experience less displacement in case of buildings having base isolation rather than in fixed base buildings.

F. Floor Acceleration

The floor acceleration values of different storeys of fixed base building and base isolated building is shown in figure 8.

From figure 8, it is observed that in case of isolated base buildings the acceleration at each floor is less as compared to the fixed base buildings with respect to ground. The magnitude of acceleration imparted at each floor is approximately equal which signifies the rigidity of the superstructure above the isolator and the entire superstructure.

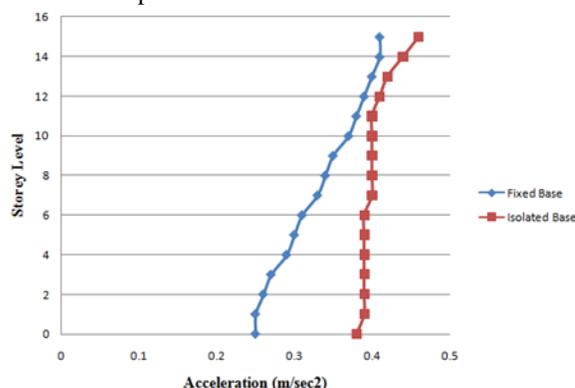


Fig.8 Floor Acceleration

VI. CONCLUSION

From the analysis of both fixed base building and the base isolated building after providing LRB isolators the following conclusions are made:

- It is observed that there is an increase in time period for base isolated buildings with LRB isolators as compared to fixed base buildings.
- The time period of fixed base building shifts from 1.75 seconds to 3.94 seconds in base isolated building with LRB isolator.

- A huge amount of reduction is observed in base shear values from 2219kN in case of fixed base building to 1285kN in case of base isolated building with LRB isolator.
- The reduction in maximum bending moment is observed in base isolated building with LRB isolator as compared to fixed base building.
- It is also observed that the storey drift is more at first storey level in base isolated building with LRB isolator as compared to fixed base building.
- The inter storey drift between the floors are very less in base isolated building with LRB isolator as compared to fixed base building.
- The acceleration at the base of isolated building with LRB isolator is more as compared to fixed base building. However, the relative acceleration value between the floors is almost negligible in base isolated building with LRB isolator as compared to fixed base buildings.

From the results it is concluded that after providing LRB isolator as base isolator the seismic response of the building is reduced and the performance of building during an earthquake is improved which makes it more suitable for facilities which are most needed post earthquake and also for the retrofitting of important structures.

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