

# ANALYSIS OF THE BASE ISOLATED BUILDING (LEAD PLUG BEARING) IN ETABS

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**Abstract** - The present work attempts to study the effectiveness of base isolation using lead rubber bearings (LRB) over conventional construction, using a case study of identical conventional and isolated building constructed in the most seismically active region in India (Zone V). Base isolator is a device which decouples a super structure from its substructure resting on a shaking ground thus protecting structural and non-structural components. This project deals with design, modeling and analysis of G+6 rigid jointed plane symmetrical RCC frames for two cases. First case is fixed base and second case is base isolated (LRB). Building displacement and acceleration are compared for that both cases. For analysis ETABS software is used and for designing of isolator 1893:2002 (part 1) and Design of seismic isolated structures (F.Naeim and J.M. Kelly) is used by me.

**Keywords:** Base isolation, lead-rubber bearing, response spectrum analysis, storey acceleration, floor displacement, storey drift, base shear.

## 1. INTRODUCTION

Base isolation of structures is one of the most desired means to protect it against earthquake forces. The term base isolation have two word first is 'base' its meaning is a part that supports from underneath or perform as a foundation of a structure, and second is 'isolation' its meaning of the state of being disparate. The effective reduction of inter storey drift in the floor of base isolation system can ensure the lowest damage to facilities and also human safety.

The concept of base isolation technique had been suggested in last few decades and the available technologies and the knowledge of base isolation system are getting mature and well established. Seismic isolation systems are more effective when applied to high stiffness, low-rise buildings, owing to their abilities to alter the characteristic of the building from rigid to flexible. An increasing number of structures to be isolated reflect the fact that base isolation system is gradually becoming accepted as a proven technology in earthquake hazard mitigation. Lead-plug bearings are made up of low-damping elastomers and lead cores with diameters between 15% to 33% of the bonded diameter of the bearing. Laminated-rubber bearings supplies the

required displacements for seismic isolation. By combining laminated-rubber bearings with a lead-plug insert, which provides hysteretic energy dissipation, the damping required for a successful seismic isolation system can be incorporated in a single compact component. The maximum shear strain range for lead-plug bearings varies as a function of manufacturer but is generally between 125% and 200%. LRB isolators have cylindrical rubber bearings, which are reinforced with steel shims. Shims and rubber is placed as alternate layers. Steel plates are also provided at the two ends of the isolator. The steel shims boost the load carrying capacity, thus the structure is stiff under vertical loads and flexible under horizontal loads.

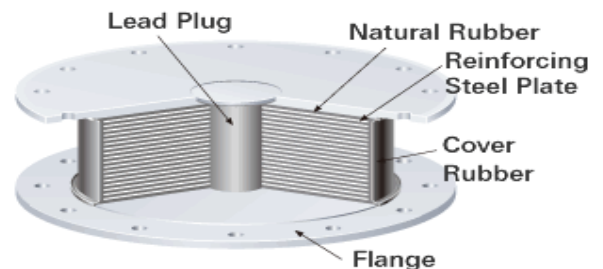


Fig - 1: Lead rubber bearing

The fundamental principal of base isolation system is to rectify the response of the structure so that the ground can move below the structure without transferring these motions into the superstructure. In an ideal system for the supple this separation would be total. But In the existing world there is a need to have some contact between the superstructure and sub structure.

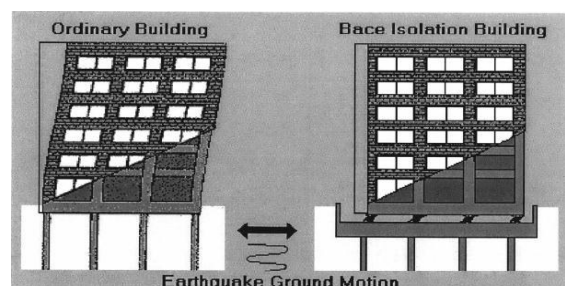


Fig -2: Behaviour of structure without and with isolator incorporation

### 1.1 Basic elements of base isolator

The base isolated structure consists of several components as represented in Fig. A brief introduction of component system are presented as follows

**1. Isolation system-** The various isolators, which reduce the time period shift of the structure to a period, range of 2 to 3 sec, with the isolation system. In base isolation structure only isolation system show non linear behavior, while structure and soil system are shows linear behavior.

**2. Structural system-** This system consist of structural component of superstructure as well as foundation. The inter storey drift for isolated structure is very low so, that the super structure can conveniently be assume to behave like linear elastic manner.

**3. Soil system-** The sub soil system exhibits their own stiffness and damping properties which may or may not affect the response of the structure which is situated upon it. This influence of the interaction between the soil and structure becomes significant in case of loose subsoil strata.

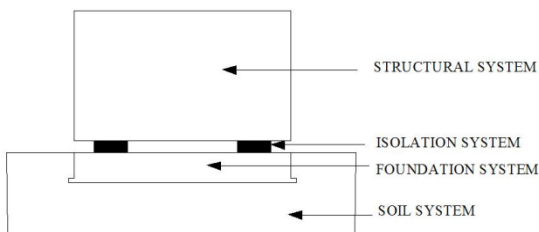


Figure-3: Components of a Base Isolated Structure

Base isolated buildings in India - New Bhuj Hospital, Bhuj City, Gujarat. 186 lead embedded rubber blocks and 96 Teflon Slider are used.

### 2. ANALYSIS AND DESIGN

Among all methods available for analysis we use response spectrum method. This method is the linear dynamic analysis method. In this method the peak responses of a structure during an earthquake is obtained directly from the earthquake responses. The maximum response is plotted against the un damped natural period and for various damping values, and can be expressed in terms of maximum relative velocity or maximum relative displacement. (Duggal S K, 2010). A Response Spectrum is a curve plotted in between response of a single degree freedom and oscillator of varying period to a specific earthquake motion. It plots a graph between acceleration, Velocity or displacement response. By assuming damping, spectra may be

generated in the structure. Code specifies the response based on soil type and Zone factor.

### 2.1 PROBLEM STATEMENT

G+6 storied buildings are modeled using conventional beams, columns & slabs. These buildings were given square geometry with plan dimensions of 12m x 12m. They are loaded with Dead, Live and Seismic Forces (according to IS:1893(Part-1)-2002). These models are then analyzed using response spectrum method for earthquake zone V of India (Zone Factor = 0.36). The details of the modeled building are listed below. Modal damping of 5% is considered with OMRF (Response Reduction Factor, R=3) and Importance Factor (I) =1. The performance of the models is recorded through ETABS to present a brief idea about the role of base isolation in protecting the structure against earthquake hazards.

The following assumptions were made before the start of the modeling procedure so as to maintain similar conditions for both the models:

1. Only the main block of the building is considered. The staircases are not considered in the design procedure.
2. The building is to be used for residential purposes, so we mainly focus on the response of the frame configuration.
3. At ground floor, slabs are not provided and the floor is resting directly on the ground.
4. The beams are resting centrally on the columns so as to avoid the conditions of eccentricity. This is achieved automatically in ETABS.
5. For all structural elements, M30 & Fe 415 are used.
6. The footings are not designed. Supports are assigned in the form of either fixed supports (for fixed base building) or link supports (for base isolated building).
7. Seismic loads are considered in the horizontal direction only (X & Y) and the loads in vertical direction (Z) are assumed to be insignificant.

### 2.2 DESIGN PROCEDURE FOR LEAD RUBBER BEARING

1. This maximum vertical reaction of fixed base building is 1500 KN for internal column and 1000 KN for external column is considered as supporting weight of LRBs.
2. Target period (2.5 seconds ) and the effective damping  $\beta$ .  $\beta$  is assumed to be 5% for reinforced concrete structure according to IS 1893:2002 §7.8.2.1.

3. Spectral acceleration from the response spectrum graph in relation with the period  $T = 1$  sec is found to be 0.56 and damping factor for 0.05( $\beta$ ) is 1 from table 3, IS 1893:2002.

4. Bearing stiffness: -

(a) For rubber bearing

$$K_H = \left[ \frac{2\pi}{T_{eff}} \right]^2 \times \frac{W_i}{g} = 631.65 \text{ KN/m}$$

Similarly,

$$K_H^I = \left[ \frac{2\pi}{2.5} \right]^2 \times \frac{1500}{g} = 947.48 \text{ KN/m.}$$

5. First estimation of design displacement:

$$D_{bd} = \frac{g \times c_v \times T_{eff}}{4\pi^2 \times B} = \frac{9.81 \times 0.56 \times 2.5}{4 \times \pi^2 \times 1} = 0.347 \text{ m}$$

Assume total rubber thickness  $t_r = 200$  mm with shear modulus 0.4MPa for external column and 1.0 MPa for internal column.

$$K_H^E = \frac{G_I \times A}{t_r} = 631.65 \text{ KN/m}$$

$$\text{so, } A = \frac{t_r \times K_H^I}{G_I} = \frac{0.2 \times 631.65 \times 10^3}{0.4 \times 10^6} = 0.3158 \text{ m}^2$$

Hence, diameter of rubber bearing

$$\phi = \sqrt{\frac{4 \times A}{\pi}} = 0.634 \text{ m}$$

Take,  $\phi = 600$  mm. So,  $A = 0.283 \text{ m}^2$

6. Actual bearing stiffness

$$K_H^E = \frac{G_I \times I}{T_r} = \frac{0.4 \times 0.28}{0.2} = 0.566 \text{ MN/m}$$

$$K_H^I = \frac{G_E \times I}{T_r} = \frac{1 \times 0.283}{0.2} = 1.415 \text{ MN/m}$$

7. Composite stiffness

$$K_H = 12 \times K_H^E + 4 \times K_H^I = 12.452 \text{ MN}$$

Therefore,

$$\omega^2 = \frac{12.452 \times 10^6}{634.2 \times 10^3} = 7.61$$

So,  $\omega = 2.75$  rad/sec and  $T = \frac{2\pi}{\omega} = 2.2$  sec

$$\text{So, } D_D = \frac{9.81 \times 0.56 \times 2.27}{4\pi^2 \times 1} = 0.315 \text{ m}$$

8. Allowance for torsion

$$D_T = \left[ D \left( 1 + Y \frac{12e}{b^2 + d^2} \right) \right] =$$

Here,

1.  $b =$  dimension of shorter side = 12
2.  $y =$  half of longer dimension =  $\frac{d}{2} = \frac{12}{2} = 6$
3.  $d =$  dimension of longer side = 12

4.  $e = 0.05$  times of longer direction =  $0.05 \times 12 = 0.6$

So,

$$0.315 \left[ 1 + 6 \times \frac{12 \times 0.6}{12^2 + 12^2} \right] = 0.362 \text{ m}$$

$$\begin{aligned} \text{Torsional stiffness } (K_\theta) &= 0.566 \times 10^6 [4 \times (6^2 + 6^2) + 8 \times (2^2 + 6^2) + 1.415 \times 10^6 \times (4 \times 2^2 + 2^2)] \\ &= 389.403 \times 10^6 \text{ Nm} \end{aligned}$$

Additional displacement

$$\theta_y = \frac{K_H}{K_Q} \times D \times e \times Y = 0.036 \text{ m}$$

9. Elastic base shear

$$V_s = \frac{K_H \times D_D}{R_W} = 2.18 \times 10^6 \text{ N}$$

10. Bearing details

Assume vertical frequency  $f_v = 10$  Hz

$$\begin{aligned} \text{Then, } 6S^2 &= \frac{FV^2}{F^2 H} \\ \frac{1}{\sqrt{6}} \times \frac{F_V}{F_H} &= \frac{1}{\sqrt{6}} \times \frac{10}{1/2.27} = 9.26 \end{aligned}$$

To calculate the vertical frequency and the buckling load for bearing, we use small strain shear modulus for each rubber such as 20%. So,

$$\begin{aligned} G_{0.2}^E &= 0.7 \text{ MPa and } G_{0.2}^I = 1.4 \text{ MPa} \\ E_C &= \frac{6GS^2K}{6GS^2 + K} \quad \text{where } K = 2000 \text{ MPa} \\ E_C^E &= 347 \times 10^6 \text{ N/m}^2 \\ E_C^I &= 592 \times 10^6 \text{ N/m}^2 \end{aligned}$$

Composite stiffness of isolator

$$\begin{aligned} K_H &= \frac{A \times (12 \times 347 \times 10^6 + 4 \times 592 \times 10^6)}{T_r} \\ &= 9242 \times \frac{10^6 \text{ N}}{\text{m}} \\ \omega^2 &= \frac{9242 \times 10^6}{1634.2 \times 10^3} \text{ N/m} \end{aligned}$$

So,  $\omega = 75.20$  and  $f = 11.96$  Hz

Therefore,

$$S = \frac{\phi}{4T} = T = \frac{\phi}{45} = \frac{600}{4 \times 10} = 15 \text{ mm.}$$

$Nt = 200$  mm. So,  $N = 13.33$  layers

Take,  $N = 12$ , Than  $T = 16.7$  mm

$$\begin{aligned} S &= \frac{600}{4 \times 16.7} = 9, \\ F_V &= \frac{9(11.96)}{10} = 10.77 \text{ Hz} \end{aligned}$$

Assume, Thickness of end plates 25 mm and steel plates 2 mm.

Total height (H) = 2 × 25 + 200 + 11 × 2 = 272 mm.

With cover of 5 mm, Diameter of steel plates = 590mm.

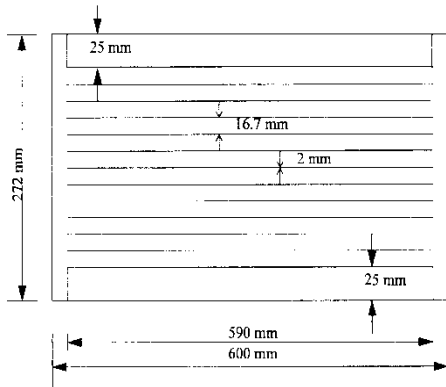


Fig - 4: Detail design of isolator

(B) For lead plug bearing

12. Design displacement

$$D_D = \frac{9.81}{4\pi^2} \times \frac{CV.T}{B}$$

$$= \frac{9.81}{4\pi^2} \times \frac{0.56 \times 2.5}{1} = 0.347 \text{ m}$$

13. The required stiffness to provide a period of 2.5 sec

$$K_H = 1634.2 \times 10^3 \times \left(\frac{2\pi}{2.5}\right)^2$$

$$= 10.322 \times 10^6 \text{ N/m}$$

14. The global energy dissipated per cycle

$$W_D = 2\pi K_{eff} \cdot D^2 \times \beta_{eff}$$

$$2\pi(10.1) \times (0.347)^2 \times 0.05$$

$$= 0.382 \times 10^6 \text{ Nm}$$

The relationship of these quantities to the two lead plug bearing parameters Q and  $K_r$  is

$$K_{eff} = K_r + \frac{Q}{D}$$

And,  $W_D = 4Q(D - D_Y)$

Where,  $D_Y = \frac{Q}{K_1 - K_2}$

And as an approximate rule of thumb, we take  $K_1 = 10K_2$ . If we neglect  $D_Y$ , we have a first approximation for Q

$$Q = \frac{W_D}{4(D - D_Y)} = \frac{W_D}{4D} = 0.25 \times 10^6 \text{ N}$$

$$\text{So, } K_2 = K_{eff} - \frac{Q}{D} = 9.6 \times 10^6 \text{ N/m}$$

$$\text{And, } D_Y = \frac{Q}{K_1 - K_2} = \frac{Q}{9K_2} = 0.00289 \text{ m}$$

$$\approx 0.003 \text{ m}$$

Correcting the first estimation of Q for  $D_Y$  gives

$$Q = \frac{W_D}{4(D - D_Y)} = 0.277 \times 10^6 \text{ N}$$

$$A_{pb} = \frac{Q}{F_y} = 0.0277 \text{ m}^2$$

Provided lead plug around 0.6 m in diameter, lead plugs of diameter 100-150 mm are appropriate, so we provide 100 mm. the area of 100 mm diameter plug is 0079 m<sup>2</sup>.

Total rubber stiffness( $K_r$ )

$$K_r = K_H - \frac{Q}{D_D} = 9.5 \times 10^6 \text{ N}$$

Stiffness of the plain elastomeric bearing

$$K_r = \frac{0.4}{0.240} \times 0.283 = 0.472 \times 10^6 \text{ N/m}$$

And,

$$K_{eff} = 16 \times K_r + \frac{W_D}{D_D} = 8.33 \times 10^6 \text{ N/m}$$

$$W_D = 4 \times Q(D_D - D_Y) = 0.381 \times 10^6 \text{ N/m}$$

15. Vertical stiffness of LRB

Vertical stiffness of rubber bearing is given by

$$K_V = \frac{A \times E_C}{T_r}$$

$$E_C = 6GS^2$$

$$E_C^E = 6G^E S^2 = 240 \times 10^6 \text{ N}$$

$$E_C^I = 6G^I S^2 = 600 \times 10^6 \text{ N}$$

Composite compression modulus

$$E_C = 12 \times E_C^E + 4 \times E_C^I = 5280 \times 10^6 \text{ N}$$

$$\text{Now, } K_V = \frac{0.283 \times 5280 \times 10^6}{0.2}$$

$$= 7471.2 \times 10^6 \text{ N}$$

From above calculation summary of lead rubber bearing design for symmetric building is as shown in Table

Table 1 :- Lead rubber bearing parameters

Items	Design Values
Diameter of rubber(m)	0.600
Thickness of rubber layer (m)	0.200
Thickness of one rubber layer (m)	0.167
Diameter of lead (m)	0.100
No. of layers	12
Height of isolator (m)	0.272
Thickness of steel plate (m)	0.003
Thickness of cover plate (m)	0.025
Diameter of steel (m)	0.590

### 3. MODELLING

#### 3.1. Description of Models

- Model 1 = Fixed Base
- Model 2 = Base isolated (LRB)

#### 3.2. Building details

- Structure = RCC (OMRF)
- Structure Type = Plan Regular Structure
- Plan Diameter = 12mx12m
- Height of Building = 21m (G+6)
- Height of each Storey = 3m
- In X-direction = 3 bay of 4m length
- In Y-direction = 3 bay of 4m length

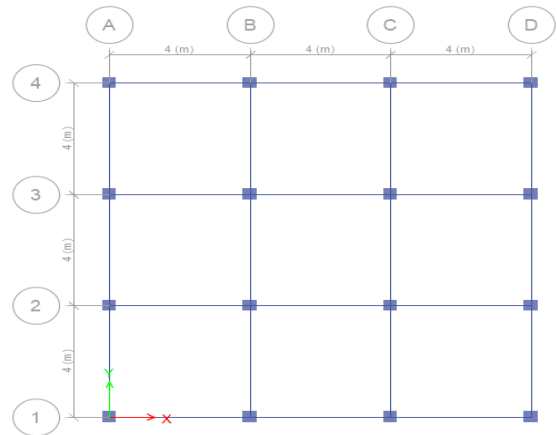


Fig - 5 : Plan

#### 3.3 Material Properties

- Grade of concrete = M30
- Grade of steel = Fe415
- Density of concrete = 25KN/m<sup>3</sup>
- Density of brick infill wall = 19.2KN/m<sup>3</sup>

#### 3.4 Section Properties

- Beam size = 300mmx450mm
- Outer Column = 400mmx400mm
- Slab Thickness = 150mm
- Wall Thickness = 230mm

#### 3.5. Load Consideration

##### 3.5.1. Gravity Load:

- Dead load = Column, Beam, Slab
- Live load = 3KN/m<sup>2</sup>
- Floor Finish = 1KN/m<sup>2</sup>

##### 3.5.2. Lateral Load of Response Spectrum Analysis:

- Soil Profile type = Medium
- Seismic Zone Factor = Zone 5
- Response Reduction Factor = 5.0
- Importance Factor = 1.0
- Damping = 5.0

#### 3.6. Characteristics of Lead Rubber Bearing -

Isolators are provided above every footing at 0.272m above base level. Properties of LRB are mentioned below:

- Vertical stiffness (linear) = 771200KN/m
- Horizontal stiffness (linear) = 1103.7KN/m
- Horizontal stiffness (Nonlinear) = 11037 KN/m

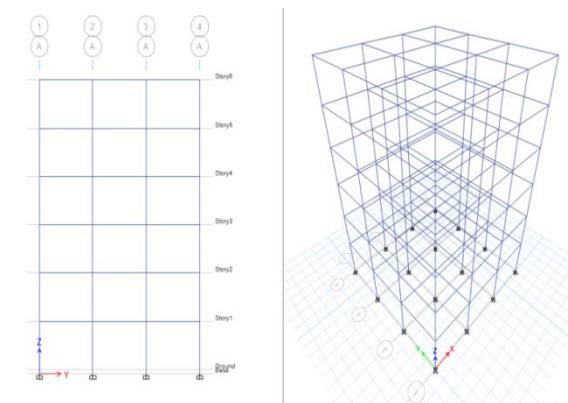


Fig - 6: Fixed base

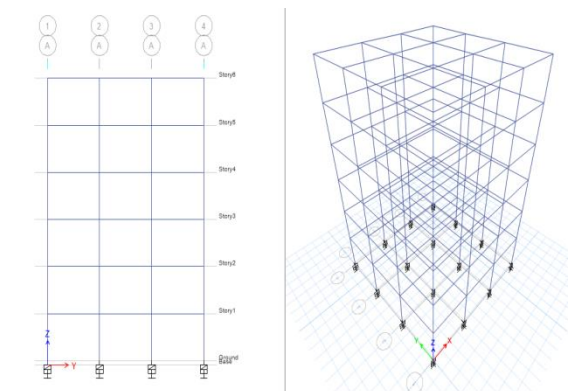


Fig 7- Base isolated building

### 4. RESULT

#### 4.1. Storey displacement

Table 2 - Storey displacement of different storey

Storey	Fixed base building (mm)	Base isolated building (mm)
Storey 6	289.83	530.08
Storey 5	269.96	522.166



Storey 4	234.86	507.65
Storey 3	186.33	486.25
Storey 2	126.494	457.88
Storey 1	58.998	417.67
Base	0	335.55

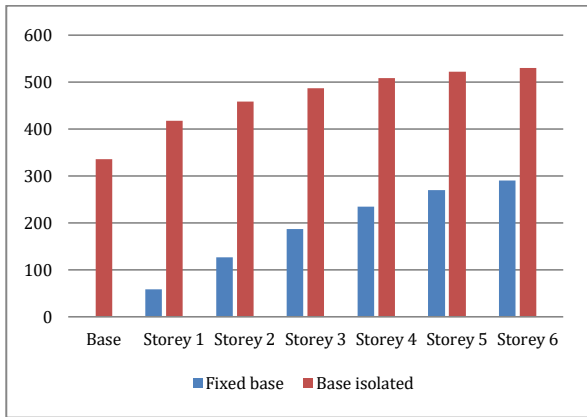


Fig -8: Displacement of different storey

The variation in maximum displacement of stories in base isolated model is very low while compared with fixed base model.

### 4.2. Storey Drift

Table 3- Storey drift of different storey

Storey	Fixed base building (mm)	Base isolated building (mm)
Storey 6	19.87	7.91
Storey 5	35.10	14.526
Storey 4	48.53	21.39
Storey 3	59.83	28.37
Storey 2	67.49	40.21
Storey 1	58.998	82.12

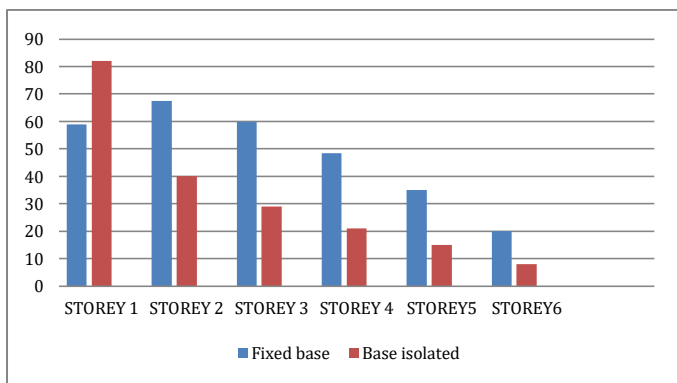


Fig -9: Storey drift at different floors (mm)

In figure it is observed that In base isolated model story drift in x-x direction at story 6 reduced by 60% when compared to fixed base model.

### 4.3. Storey Shear

Table 4 - Storey shear of different stories

Storey	Fixed base building (KN)	Base isolated building (KN)
Storey 6	2766.66	989
Storey 5	5387.59	2095
Storey 4	7210.47	3087.61
Storey 3	8635.43	3983.64
Storey 2	9902.01	4830.26
Storey 1	10663.02	5646.91

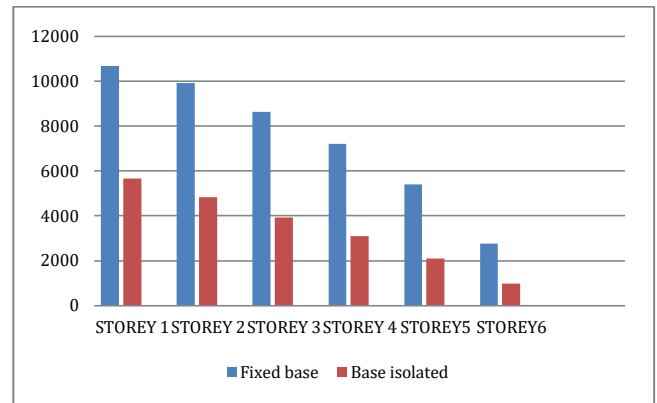


Fig -10 : Storey shear at different floors (KN)

From fig 10, The base isolated model story shears in x-x direction at top story reduced by 47% when compared with fixed base model.

### 5. CONCLUSION

Fixed base model base isolated model by providing lead rubber bearing these two models were analyzed by response spectrum analysis from these building models following conclusions can be made.

- Story shear reduced after the lead rubber bearing (LRB) is provided as base isolation system which reduces the seismic effect on building.
- Base shear is also reduced after providing LRB which makes structure stable during earthquake.
- Story drift are reduced in higher stories which makes structure safe against earthquake.
- Modal displacements are increased in every story after providing LRB which is important to make a structure flexible during earthquake.
- Natural periods are increased which reduces earthquake forces on the shaking.

Finally it is concluded that after LRB is provided as base isolation system it increases the structures stability against earthquake and reduces reinforcement hence make structure economical.

## 6. REFERENCES

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