

## Seismic Analysis of Fixed Based and Base Isolated Building Structures

Ms. Minal Ashok Somwanshi<sup>†</sup> and Mrs. Rina N. Pantawane<sup>†</sup>

<sup>†</sup>Asst. Professor, Department of Civil Engineering, Jawaharlal Darda Institute of Engineering and Technology, Yavatmal, Maharashtra, India

Accepted 22 July 2015, Available online 28 July 2015, Vol.3 (July/Aug 2015 issue)

### Abstract

*Non-structural components are sensitive to large ground motion which produces floor accelerations, velocities, and displacements. During an earthquake, the building produces this motion, resulting in peak floor accelerations higher than the peak ground acceleration. Thus earthquake ground motion can cause significant or severe structural damages. The use of base isolation is the best method to reduce interstorey drift and floor accelerations. A new type of base-isolation system is developed here for a multi-storey reinforced concrete building. This work deals with modeling and analysis of 13-storey rigid jointed plane frame for two cases. First case is fixed base and second case is base isolated. Modeling and analysis is done using E-TABS software for Bhuj earthquake ground motion records. Maximum vertical reaction is obtained from analysis in E-TABS software. Using this vertical reaction and total mass of structure lead rubber bearings are designed manually. Time-history analysis is carried out in order to evaluate floor response, accelerations and displacements during a ground motion. This paper intends to demonstrate how an isolation system can be efficient, evaluating its effectiveness for the building in terms of maximum shear force, maximum bending moment, base shear, storey drift and storey displacement reductions.*

**Keywords:** Base isolation, lead-rubber bearing, time-history analysis, reinforced concrete building, storey acceleration, floor displacement, storey drift, base shear.

### 1. Introduction

Conventional seismic design attempts to make buildings that do not collapse under strong earthquake shaking, but may sustain damage to non-structural elements and to some structural members in the building. Non-structural components may consist of furniture, equipment, partitions, curtain wall systems, piping, electrical equipment and many other items. There are mainly three main categories: architectural components, mechanical and electrical equipments, and building contents. This may render the building non-functional after the earthquake, which may be problematic in some structures, like hospitals, which need to remain functional during the earthquake. Non-structural components are sensitive to large floor accelerations, velocities, and displacements. When a building is subjected to an earthquake ground motion, the building induces motion, resulting in floor accelerations higher than the ground acceleration. Hence, it is present need and also a duty of civil engineers to innovate earthquake resisting design approach to reduce such type of structural damages. Special techniques are required to design buildings such that they remain practically undamaged even in a severe earthquake. There are two basic technologies used to protect buildings from damaging earthquake effects. These are base isolation devices and seismic dampers. The

idea behind base isolation is to detach (isolate) the building from the ground in such a way that earthquake motions are not transmitted up through the building, or at least greatly reduced. Seismic dampers are special devices introduced in the building to absorb the energy provided by the ground motion to the building (much like the way shock absorbers in motor vehicles absorb the impacts due to undulations of the road).

#### 1.1 Base Isolation

The concept of base isolation is explained through an example building resting on frictionless rollers. When the ground shakes, the rollers freely roll, but the building above does not move. Thus, no force is transferred to the building due to shaking of the ground; simply, the building does not experience the earthquake. Now, if the same building is rested on flexible pads that offer resistance against lateral movements, then some effect of the ground shaking will be transferred to the building above. If the flexible pads are properly chosen, the forces induced by ground shaking can be a few times smaller than that experienced by the building built directly on ground, namely a fixed base building. The flexible pads are called base-isolators, whereas the structures protected by means of these devices are called base-isolated buildings. The main feature of the base isolation

technology is that it introduces flexibility in the structure. As a result, a robust medium-rise masonry or reinforced concrete building becomes extremely flexible. The isolators are often designed to absorb energy and thus add damping to the system. This helps in further reducing the seismic response of the building. Several commercial brands of base isolators are available in the market, and many of them look like large rubber pads, although there are other types that are based on sliding of one part of the building relative to the other. A careful study is required to identify the most suitable type of device for a particular building. Also, base isolation is not suitable for all buildings. Most suitable buildings for base-isolation are low to medium-rise buildings rested on hard soil underneath. High-rise buildings or buildings rested on soft soil are not suitable for base isolation.

### 1.2 Objective

This paper deals with a new type of base isolation application. The work includes design of 13-storey reinforced concrete symmetric and Asymmetrical building in accordance with IS 1893:2002 provisions; one with fixed base and other is base isolated. By analyzing the fixed base buildings, we get maximum reactions under each column. For these maximum values lead-rubber bearings (LRBs) are designed manually in order to isolate the superstructure from substructure. Time history analysis is carried out by taking Bhuj earthquake ground motion records. The objectives of this work are as follows:

- 1) To carry out modeling and analysis of fixed base and base isolated buildings by using E-TABS software and study the effects of earthquake ground motions on these models.
- 2) To design and study the effectiveness of lead rubber bearing used as base isolation system.
- 3) To carry out comparison between fixed base and base isolated building on the basis of their dynamic properties like maximum shear force, maximum bending moment, base shear, storey drift and storey acceleration.
- 4) To study the behavior of symmetric and asymmetric building under strong earthquake ground motion.

In this manner it could be possible to decide the effectiveness of this base isolation system, giving advices for future possible applications.

### 1.3 Review of Literature

Many methods have been proposed for achieving the optimum performance of structures subjected to earthquake excitation. The use of lead rubber bearing isolators for absorbing energy is the best technique. Many papers have been published related with base isolation

technique as an earthquake resistant device. Some of them are discussed below.

**Radmila B. Salic et al<sup>1</sup>** In this paper the authors have demonstrated the effect of dynamic response of the seven-story residential building under the earthquake ground motions. Mode shapes, natural frequencies and damping ratios of the existing fixed-base building are obtained by ARTeMIS (Ambient Response Testing and Modal Identification Software). The fixed base model represents the dynamic behavior of the structure and seismic isolated model representing the dynamic behavior of the structure isolated by lead rubber bearing seismic isolation system. Dynamic analysis of both models has been performed by ETABS (Nonlinear version 9.0.4). The finite element model was chosen to satisfy the needs of this analysis. The Dynamic responses of fixed base and seismic isolated models have been calculated for four types of real earthquake time histories of different frequency characteristics whose value is determined based on the detailed site response analysis. The authors have showed that increase of natural period of structure increases flexibility of the same structure. In seismic isolated model, base shear force is highly reduced. Increased flexibility of the system led to increase of the total displacements due to the elasticity of the existing isolation. Implementation of the isolation system resulted into the reduction of the interstorey drifts. Analysis of seismic isolated model has shown significant reduction of the storey accelerations.

**V. Kilaret et al<sup>2</sup>** In this paper four-storey RCC building is designed according to Euro Code 8 for seismic analysis and dynamic performance evaluation. Different sets of base isolation devices are studied for investigation. First case is the use of simple rubber bearing and second one is the use of lead rubber bearing as a base isolation system. For the investigation of each system a soft, normal and hard rubber stiffness with different damping values were used. Non-linear pushover analysis was performed with the recent version of computer analysis software SAP 2000. From this study it is concluded that the stiffer isolators with higher damping gives smaller target base displacements as compared to softer one with lower damping. It can also be seen that the relative displacement of the superstructure are smaller if the softer isolators are used. The smallest relative displacement can be expected with the use of softer isolators with higher damping. If the used isolators are too stiff it cannot protect the superstructure.

**A. B. M. Saiful Islam et al<sup>3</sup>** In this paper a soft storey building is analyzed for seismic loading by creating a building model having lot of open spaces. The soft storey creates the major weak point in earthquake which means that during the event when soft storey collapses, it can make the whole building down. It causes very severe structural damage and building becomes unusable.

This research includes the placement of two types of isolators, first is lead rubber bearing (LRB) and second one is high damping lead rubber bearing (HDRB). Each storey is provided by isolators and its consequences were studied for different damping values. Finally the study reveals that use of isolators is most beneficial tool to protect soft storey buildings under strong earthquake ground motions. Provision of lead rubber bearing is more efficient than high damping rubber bearing because as time period increases in high damping rubber bearing, acceleration also increases which is undesirable to protect building during earthquake. This condition is exactly reverse in case of lead rubber bearing. It has been also shown the response of base isolated building and arrangement of bearing in the building. As damping provides sufficient resistance to structure against service loading, various damping values are taken into account for this investigation. This study also deals with the main requirement for installation of isolators. Finally, it has concluded that the flexibility, damping and resistance to service loads are the main parameters which affects for practical isolation system to be incorporated in building structures. Additional requirements such as durability, cost, ease of installation and specific project requirements influences device selection; but all practical systems should contain these essential elements.

**Di Sarno, et al**<sup>4</sup> has presented the structural analysis of the complex irregular multi-storey RC frame used for the hospital building. It was carried out by means of modal analysis with response spectrum. The structure exhibits large mass eccentricity due to its irregularity in shape. The building is provided by circular shape high damping rubber bearing as per required diameter in accordance with Euro Code 8 to act as a base isolation system. The main objective of this study is to improve the earthquake resistant design approach by studying the properties like horizontal flexibility to increase structural period and reduce the transfer of seismic energy to the superstructure; second property is the energy dissipation (due to relatively high viscous damping) to reduce lateral displacements; and last one is the provision of sufficient stiffness at small displacements to provide adequate rigidity to the structure. This case study reveals that base isolation is an effective strategy to improve the seismic performance for relatively flexible framed structures at serviceability point of view. It also concluded that the relatively high horizontal flexibility of the superstructure apparently reduces the beneficial effects of the base isolation system. It is demonstrated that although the base-isolated and the fixed base construction may undergo the same maximum accelerations the structural and non-structural damage are prevented in the frame resting on rubber devices. Savings of about 40% were estimated for percentage of steel reinforcement to be used for the columns and beams of the base isolated frame.

A review of the Japanese seismic design and construction practices adopted after the 1995 Kobe earthquake has been presented by **Masayoshi Nakashima Praween Chusilp**<sup>5</sup> in their paper. In Kobe earthquake, the ground shaking in some regions was significantly larger than that considered in the Japan seismic design code. It leads to substantial evolution in Japanese design and construction practices. Here, two limit-states design (life safety and damage limitation) are demonstrated with the two levels (the structure should remain elastic in small to moderate earthquakes called level 1) and (sustain some yielding and plastification in some structural members in a large earthquake called level 2 design) stipulated in the 1981, Japan seismic design code, but are distinguished because of two new features. Finally it has concluded that the Japanese seismic design code is to be revised towards more performance- based engineering.

**Juan C. Ramallo, et al**<sup>6</sup> In this paper authors have investigated the effects of using controllable semiactive dampers, such as magnetorheological fluid dampers, in a base isolation system. A two degree of freedom model of a base isolated building is used. The fundamental concept is to isolate a structure from ground, especially in the frequency range where the building is most affected. The goal is to reduction in interstorey drifts and floor accelerations to limit damage to the structure and its contents in a cost-effective manner. This paper investigates the improvements that may be achieved by replacing supplemental linear viscous damping devices in base isolation with semiactive dampers. A linear, two degree of freedom (2DOF), lumped mass model of a base-isolated building is used as the test bed for this study. The system model is used in this test is a single degree-of freedom model that has mass and fundamental modal frequency and damping ratio. In this study passive linear viscous damper, active damper and semiactive damper have been used. Generalized semiactive as well as magnetorheological fluid dampers was used in seismic protection system. Authors have concluded that the semiactive damper was able to accomplish nearly as much as the fully active damper. With the semiactive damper, the peak base drifts were decreased as compared to the optimal passive linear damper. This study suggests that semiactive dampers, such as magnetorheological fluid dampers, show significant promise for use in base isolation applications with greatly reduced power requirements as compared to the active systems.

**J. C. Ramallo1, et al**<sup>7</sup> have presented an innovative base isolation strategy and shows how it can effectively protect the structures against extreme earthquakes without sacrificing performance during the more frequent, moderate seismic events. This innovative concept includes base isolation system with semiactive or controllable passive dampers for seismic response mitigation. In this method the structure is modeled as a single degree-of-freedom system representing the

fundamental mode. When the isolation layer is added, the augmented model is a two degree-of-freedom system. Test has been shown experimentally that the linear behavior of low-damping rubber bearings can extend to shear strains above 100%. Lead-rubber bearings are considered as the baseline against which the smart damping strategies are compared. The rubber isolation in these two systems is identical. The various ground excitations are used for modal excitation. A family of controllers that decreases base drift and absolute accelerations (compared to the LRB) is obtained for a controllable smart damper. The base isolation system, comprised of low-damping elastomeric bearings, and controllable semiactive dampers, was shown to have superior performance compared to several passive base isolation designs using lead-rubber bearings.

**AbdolrahimJalaliet al**<sup>8</sup> has presented comparative study of seismic base-isolation of multi-story buildings and fixed base building. Nonlinear time-history analysis of created models was conducted by using ETABS (8.5.0). Fundamental periods, modal participation factors and base-shears were studied for all of the model buildings. Base-isolation generally falls into the passive category of structural control, while it can be active or passive. In this investigation the effects of superstructure characteristics on isolation performance, nonlinear time-history analyzed by Ritz vectors are conducted using ETABS 8.5.0. Comparing base-isolated building with fixed base building, the efficiency of isolation is examined. It has shown the results for fixed-base and base-isolated building. For first mode period in base-isolated building is 2.3 times longer than that of fixed-base building. Modal participation factor of the fundamental structural mode of base-isolated building is 0.4 times lesser than that of fixed-base building. Finally conclusion was made that superstructure characteristics have a considerable effect on isolation performance. By using proper characteristics of superstructure, base-isolation performance can be improved. The characteristics of superstructure have different effects on isolation performance in low-rise buildings, medium-rise buildings and high-rise buildings. In low-rise buildings, simple base-isolation has good performance and there is no need to modify the superstructure characteristics. Indeed, these modifications cannot have positive effect on isolation performance. In medium-rise buildings, it can reach better isolation by assigning additional base-mass and increasing the damping of superstructure. In high-rise buildings, stiffening superstructure and increasing the damping will cause an effective base-isolation.

**Pan Wen et al**<sup>9</sup> have presented the design of base isolation structure. Two step design method for base isolation structure was put forward. In the first step, the estimation of isolation layer, and only a few basic data of structure was required. In the second step, detail design along with the step-by-step time history analysis was adopted for determination of superstructure, foundation

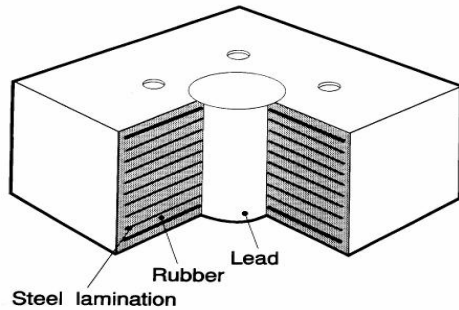
and base isolation device. Computer software based on above method with user-friendly interface, pre-processor and post-processor was developed for practical engineering design of superstructure and foundation. The main content of base isolation structure design consists of two parts: the first is design of base isolation device, and the second is design of structural elements above the isolation layer. The study reveals that in first stage design method, base isolation device lengthen the natural period of structure, in which the dynamic characteristic of the structure has been changed to achieve the aim of reducing the earthquake effect on superstructure. After the first step, base isolation device has tentatively selected based on the total horizontal stiffness of isolation layer. In the second step design method for seismic isolation structure is used to calculate earthquake resistant capacity of base isolation structure and optimize arrangement and parameters of base isolation device. It has been concluded that the computation result of two step design method is simple and practical, and its concept is clear and easy for further expansion and application. The method is advantageous to enhance design quality and reduce design period. The simplified method is suitable for multi-storey isolation structure. With the increase of the layer number, influence of higher modes increased. The method is not adapted for high-rise isolation structure.

**Pradeep Kumar T. V. et al**<sup>10</sup> has shown force-deformation behavior of isolation bearings. In this paper the isolation bearing consists of an isolator which increases the natural period of the structure away from the high-energy periods of the earthquake and a damper to absorb energy in order to reduce the seismic force. The most common isolation bearing used was the lead-rubber bearing. It has been observed that lead-rubber bearings have little strain-rate dependence for a wide frequency range which contains typical earthquake frequencies. Authors have designed the isolated bearing. The isolation bearings are modeled by a bilinear model based on the three parameters: initial stiffness, lower stiffness, and characteristic strength. It has given new relationship to find out the yield displacement and yield force for an equivalent bilinear isolation bearing system. Compared to the conventional method the newly derived equations give accurate results and are less time consuming. The graphical representation of the new relationship shown in the paper is useful for bearing design.

## 2. Lead Rubber Bearing

A variety of isolation devices including elastomeric bearings (with and without lead core), frictional/sliding bearings and roller bearings have been developed and used practically for a seismic design of buildings during the last 25 years. Among the various base isolation systems, the lead-rubber bearings (LRB) had been used extensively. It consists of alternate layers of rubber and

steel plates with one or more lead plugs (Figure 2.1) that are inserted into the holes. The lead core deforms in shear providing the bilinear response (i.e. adds hysteretic damping in the isolated structure) and also provides the initial rigidity against minor earthquakes and strong winds. The steel plates in the elastomeric bearing gives large plastic deformations. So, an elastomeric bearing was then replaced by lead plug and was tested.



**Fig.1** Section of Lead Rubber Bearing (Courtesy:Salic R. B.,et al<sup>1</sup>)

The lead-rubber bearings represent an economic solution for the seismic isolation problems because it combines the functions of vertical support, of rigidity at service load levels, and of horizontal flexibility at earthquake load.

Lead yields at low stress, around 10MPa, and behaves like an elastic-plastic solid. Lead is also “hot-worked” when plastically deformed at ambient temperature and the mechanical properties of the lead are being continuously restored by the simultaneous interrelated processes of recovery, recrystallization and grain growth. As a matter of fact, deforming lead at 20°C is like deforming steel at temperatures higher than 400°C. Lead has good fatigue properties during cycling at plastic strains. The hole for the lead-plug can be machined through the bearing after manufacture, or the hole can be made in the steel plates and rubber sheets before they are joined together. The lead, in any case, must fit tightly in the elastomeric bearing and this is achieved by making the lead plug a little larger (1%) than the hole and forcing it into it. In this way, when the bearing is deformed horizontally, the lead insert is forced by the interlocking steel plates to deform in shear throughout its whole volume. The yield force of the lead insert can be easily determined from the yield stress of the lead in the bearing.

**2.1 Design of Lead Rubber Bearing for Symmetrical Building**

The calculation of lead rubber bearing is carried out as follows:

1. The first step is to decide the minimum rubber bearing diameter depending on vertical reaction. This maximum vertical reaction obtained from analysis

result of fixed base building which is found to be 1609kN is considered as supporting weight LRBs.

2. Second step is to set the target period  $T_{eff}$  (2 seconds appears to be the desired one) and the effective damping  $\beta$  is assumed to be 5% for reinforced concrete structure according to IS 1893:2002<sup>11</sup> §7.8.2.1.
3. In third step, the spectral acceleration  $S_a$  from the response spectrum graph in relation with the desired period is found to be 0.728.
4. In next step design displacement is calculated:

$$d_{bd} = \left(\frac{T_{eff}}{2\pi}\right) S_a$$

$$= \left(\frac{2}{2\pi}\right) \times 0.728$$

$$= 0.2318 \text{ m.}$$

Where,  
 $S_a = 0.728$ , spectral acceleration  
 $T_{eff}$  = Target period  
 $d_{bd}$  = Design displacement of isolator

5. The required stiffness to provide a  $T_{eff}$  period is the effective stiffness:

$$K_{eff} = \left(\frac{2\pi}{T_{eff}}\right)^2 \frac{W_i}{g}$$

$$= \left(\frac{2\pi}{2}\right)^2 \frac{1609}{9.81}$$

$$= 1618.7 \text{ kN/m}$$

Where,  
 $T_{eff}$  = Effective fundamental period of the superstructure corresponding to horizontal translation, the superstructure assumed as a rigid body  
 $W_i$  = The weight on the isolator i.e. maximum vertical reaction  
 $K_{eff}$  = Effective stiffness of the isolation system in the principal horizontal direction under consideration, at a displacement equal to the design displacement  $d_{bd}$

6.  $E_D$  = Dissipated energy per cycle at the design displacement ( $d_{bd}$ )

$$E_D = 2K_{eff}d_{bd}^2\beta$$

$$= 2 \times 1618.7 \times 0.2318^2 \times 0.05$$

$$= 27.35 \text{ kNm}$$

Where,  
 $\beta$  = Effective damping

7.  $F_0$  = Force at zero displacement under cyclic loading

$$F_0 = \frac{E_D}{4d_{bd}} = \frac{27.35}{4 \times 0.2318} = 29.48 \text{ kN}$$

8.  $K_{pb}$  = Stiffness of lead core of lead-rubber bearing

$$K_{pb} = \frac{F_0}{d_{bd}} = \frac{29.48}{0.2318} = 127.17 \text{ kN/m}$$

9.  $K_r$  = Stiffness of rubber in LRB

$$K_r = K_{eff} - K_{pb} = 1618.7 - 127.17 = 1491.53 \text{ kN/m}$$

10.  $t_r$  = Total thickness of LRB

$$t_r = \frac{d_{bd}}{\gamma} = \frac{0.2318}{1.5} = 0.1545 \text{ m.}$$

11.  $D_{bearing}$  = Diameter of lead rubber bearing

$$= \sqrt{\frac{K_r t_r}{400\pi}} = \sqrt{\frac{1491.53 \times 0.1545}{400\pi}} = 0.4282 \text{ m}$$

Where,

$D_{bearing}$  = Diameter of lead-rubber bearing

$t_r$  = Total lead-rubber bearing thickness

12. Total loaded area ( $A_L$ ) calculation

- $D_{pb}$  = Diameter of lead core of LRB

$$D_{pb} = \sqrt{\frac{4f_0}{\pi \sigma_{pb}}} = \sqrt{\frac{4 \times 29.76}{\pi \times 11000}} = 0.0578 \text{ m.}$$

Where,

$\sigma_{pb}$  = Total yield stress in lead, it is assumed to be

11 pa

- Area of lead core in LRB

$$A_{pb} = \frac{\pi}{4} \times (D_{pb})^2 = \frac{\pi}{4} \times 0.0578^2 = 0.002706 \text{ m}^2$$

- $D_{ff}$  = Diameter of force free section  
=  $D_{bearing} - 2 t_r$

$$= 0.4282 - 2 \times 0.01$$

$$= 0.4082 \text{ m.}$$

- $A_{ff}$  = force free area

$$= \frac{\pi}{4} (D_{ff})^2 = \frac{\pi}{4} \times 0.4082^2 = 0.13 \text{ m}^2$$

- $A_L$  = Total loaded area

= Force free area – Area of lead core

$$= 0.13 - 0.002706 = 0.128 \text{ m}^2$$

13. Circumference of force free section

$$C_f = \pi \times t \times D_{ff} = \pi \times 0.01 \times 0.4082 = 0.01280 \text{ m}$$

14.  $S_i$  = Shape factor

$$= \frac{\text{loaded area}}{\text{circumference of force free section}}$$

$$= \frac{A_L}{C_f} = \frac{0.128}{0.0128} = 10$$

15. H = Total height of LRB

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

$$N = \frac{0.2}{t} = \frac{0.2}{0.01} = 20$$

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

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

Where,

N = No. of rubber layer

t = Single rubber layer thickness (0.01)

$t_s$  = Thickness of steel lamination (0.003)

$t_{ap}$  = Laminated anchor plate thickness (0.04) m.

16. Bearing horizontal stiffness ( $K_b$ )

$$K_b = \frac{G A_r}{H} = \frac{1000 \times 0.128}{0.337} = 380 \text{ kN/m}$$

Where,

G = shear modulus (varying from 0.4 to 1.1 Mpa)

Adopting 1 Mpa

$A_r$  = rubber layer area

$$= 0.128 \text{ m}^2$$

H = Height of LRB = 0.337 m.

17. Total bearing vertical stiffness

$$K_v = \frac{G S_i^2 A_r k}{(6 G S_i^2 + k) H} = \frac{6 \times 1000 \times 10^2 \times 0.128 \times 2000 \times 10^3}{(6 \times 1000 \times 10^2 + 2000 \times 10^3) \times 0.337}$$

$$= 175.302 \text{ MN/m.}$$

Where,

$S_i$  = Shape factor = 10

k = rubber compression modulus = 2000 MPa

From above calculation summary of lead rubber bearing design for symmetric building is as shown in Table 1

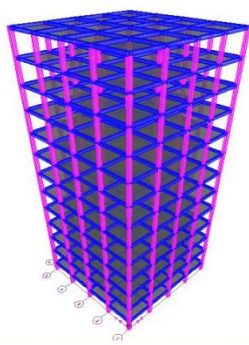
**Table 1** Summary of LRB parameters for Symmetric Building

1. Required Stiffness ( $K_{eff}$ )	1618.7 kN/m
2. Bearing horizontal stiffness ( $K_b$ )	380 kN/m
3. Vertical stiffness ( $K_v$ )	175.302 MN/m
4. Yield force (F)	29.76839 kN
5. Stiffness ratio	0.1
6. Damping	0.05

### 2.3 Modeling and Analysis of Base Isolated Symmetrical Building Model

The main objective of work is to reduce dynamic properties of structure by providing Base Isolation. Thus from above design of Lead Rubber Bearing data a Base Isolated symmetric building model is created and

analyzed by using E-TABS software. The assumed preliminary data required for analysis of frame is shown in Table 1. The three dimensional view of created model of base isolated symmetrical building is as shown in Figure 2 and The analysis of Base Isolated Symmetric Building model gives following results as shown in Table 2.



**Fig.2** Model of Base Isolated Symmetric Building

**Table 2** Analysis result of Base Isolated symmetricalBuilding

Sr. No.	Building Parameter	Result
1.	Maximum Shear Force	26.78 kN
2.	Maximum Bending Moment	43.785 kN-m
3.	Storey Drift	0.001642 m (at storey 4 for load comb.3)
4.	Storey Acceleration	0.4135 m/s <sup>2</sup>
5.	Base Shear	2.105 kN (X- Direction)
		1.771 kN (Y-Direction)
6.	Storey Displacement	0.0516 m.

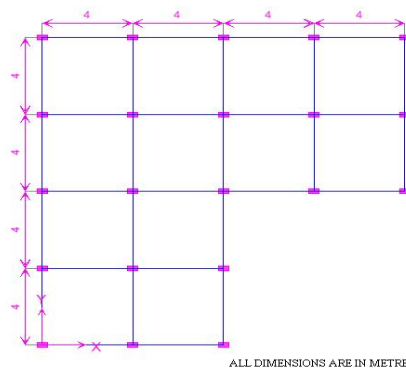
**2.4 Modeling and Analysis of Fixed Base Asymmetrical Building Model**

The main aim of this project work is to study the dynamic behavior of structures of different shape and symmetry, during strong earthquake ground motions. For this asymmetrical building is modeled and analyzed under Bhuj earthquake ground motion records. Assumed Preliminary Data Required for Analysis of Asymmetrical Fixed Base Multi-Storey Building is as shown in Table 3

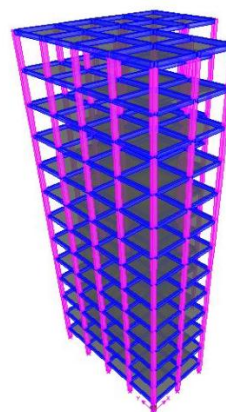
**Table 3** Assumed Preliminary Data Required for Analysis of Asymmetrical Fixed Base Building

1	Type of structure	Multi-storey rigid jointed plane frame (Special RC moment resisting frame)
2	Seismic zone	V
3	Zone Factor	0.36
4	Number of storey	G+13
5	Floor Height	3.2 m
6	base floor height	2 m

7	Infill wall	230 mm thick outer wall; 115 mm inner wall
8	Impose load	4 kN/m <sup>2</sup>
9	Materials	Concrete (M25) and Reinforcement Fe415
10	Size of column	250 mm x 450 mm ; 21 in no.
11	Size of beam	250mm x 350 mm
12	Depth of slab	120 mm
13	Specific weight of RCC	25 kN/m <sup>3</sup>
14	Specific weight of infill	20 kN/m <sup>3</sup>
15	Type of soil	Rock
16	Response spectra	As per IS 1893 (part 1):2002
17	Time history	Compatible to IS 1893 (Part 1): 2002 spectra at rocky site for 5% damping for Bhuj earthquake ground motion record.
18	Load Combinations	As per IS 1893:2002
		1) 1.7(DL + LL)
		2) 1.7(DL + EL)
3) 1.3(DL + LL + EL)		
19	Response Reduction Factor (R)	5
20	Importance factor( I)	1



**Fig. 3** Plan of Fixed Base Asymmetrical Building



**Fig.4** Three Dimensional view of Fixed BaseAsymmetrical Building



**Table 4** Analysis result of Fixed Base Asymmetrical Building

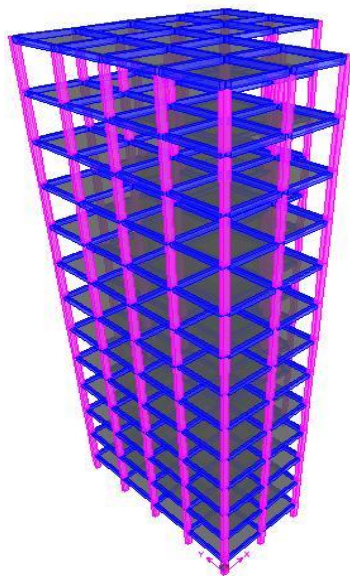
Sr. No.	Building Parameter	Result
1.	Maximum Shear Force	43.6 Kn
2.	Maximum Bending Moment	69.756 kN-m
3.	Maximum Vertical Reaction	29694.02 kN
4.	Maximum Storey Drift	0.55 m
5.	Maximum Storey Acceleration	0.98 m/s <sup>2</sup>
6.	Base Shear	2.521 kN ( X-Direction) 1.595 kN (Y-Direction)
7.	Maximum Lateral Displacement	0.082 m

**2.5 Design of Lead Rubber Bearing for Asymmetrical Building**

Lead Rubber Bearing design for asymmetrical building follows same procedure as carried out for symmetric building. The summary of designed parameters of lead rubber bearing for fixed base asymmetric building is calculated in accordance with section 2.3. The summary of this is as shown in Table 5

**2.6 Modeling and Analysis of Asymmetrical Base Isolated Building**

The procedure adopted for the modeling and analysis of base isolated symmetrical building is used for modeling and analysis of asymmetrical base isolated building. The assumed preliminary data required for analysis of asymmetrical base isolated building as shown in Table 5. The created model of asymmetrical base isolated building in E-TABS is as shown in fig.5.



**Fig.5** Model of Base Isolated building in E-TABS

**Table 5** Summary of Lead Rubber Bearing parameters for Asymmetric Building

1. Required Stiffness (K <sub>eff</sub> )	29874.43 kN/m
2. Bearing horizontal stiffness (K <sub>b</sub> )	27528.1 kN/m
3. Vertical stiffness (K <sub>v</sub> )	1020.15 MN/m
4. Yield force (F <sub>0</sub> )	549.3742kN
5. Stiffness ratio	0.1
6. Damping	0.05 (%)

The Time History and Response Spectrum analysis of base isolated asymmetrical building model gives results as shown in Table 6

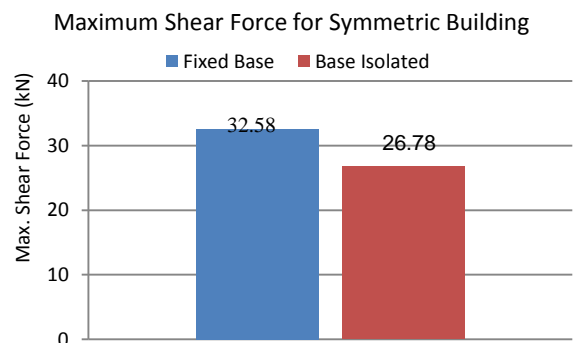
**Table 6** Analysis result of Base Isolated Asymmetrical Building

Sr.	Building Parameter	Result
1	Maximum Shear Force	42.31 kN
2	Maximum Bending	68.405 kN-m
3	Maximum Storey Drift	0.44 m
4	Maximum Storey	0.85 m/s <sup>2</sup>
5	Base Shear	2.028kN ( X-Direction) 1.38kN (Y-Direction)
6	Maximum Lateral	0.0848 m

**3. Observation and Result**

**3.1 Maximum Shear Force**

Maximum shear force in column of fixed base and base isolated symmetric building and fixed base and base isolated asymmetric building are shown in Figure 6, and 7. From Figure 6, it is observed that for symmetric building with maximum shear force in base isolated buildings are decreased by 17.8% in comparison to fixed base building model. Similarly, Figure 7 shows that for maximum shear force in base isolated buildings in asymmetric model is decreased by 3% in comparison to fixed base building model.



**Fig. 6** Maximum Shear force in Symmetric Building



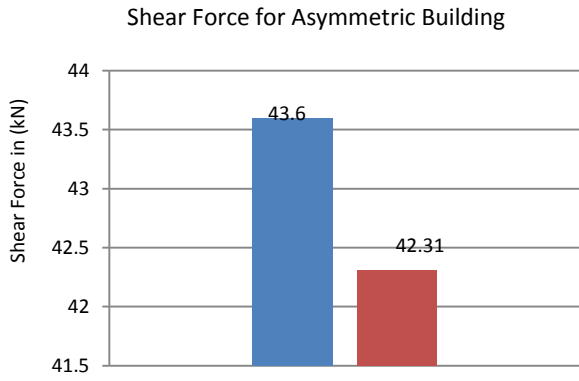


Fig. 7 Maximum Shear force in Asymmetric Building

3.2 Maximum Bending Moment

Maximum Bending Moment in column of fixed base and base isolated symmetric building and fixed base and base isolated asymmetric building are shown in Figure8, and 9. From Figure 8, it is observed that for symmetric building with maximum Bending Moment in base isolated buildings are decreased by 16.11% in comparison to fixed base building model. Similarly, Figure 9 shows that for maximum Bending Moment in base isolated buildings in asymmetric model is decreased by 2% in comparison to fixed base building model.

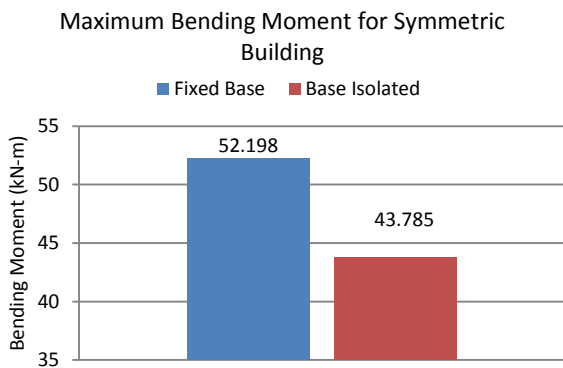


Fig.8 Maximum Bending Moment in SymmetricBuilding

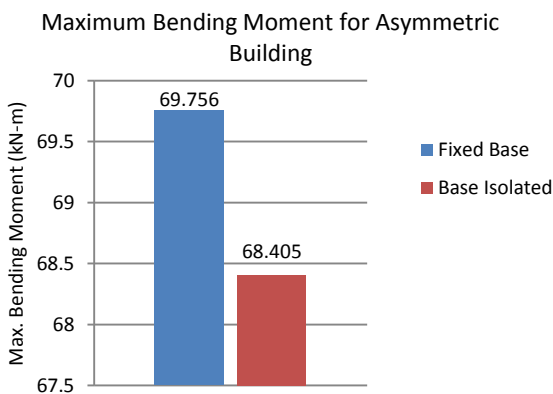


Fig.9 Maximum Bending Moment in AsymmetricBuilding

3.3 Base Shear

Maximum Base shear in fixed base and base isolated symmetric building and fixed base and base isolated asymmetric building are shown in Figure 10, and 11. From Figure 10, it is observed that for symmetric building with maximum amplitude value in base isolated building is decreased by 35.63% in X-direction while 34.77% in Y-direction in comparison to fixed base building model. Similarly, Figure 11 shows that for maximum Base Shear in base isolated buildings in asymmetric model is decreased by 19.5% in X- direction while 13.5% in Y-direction in comparison to fixed base building model.

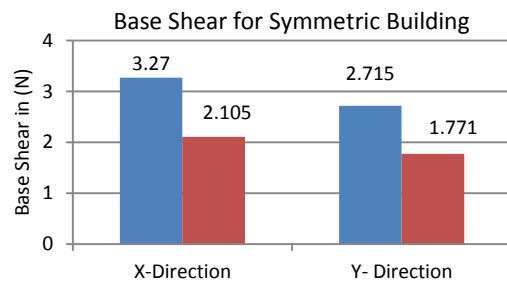


Fig.10Base Shear in Symmetric Building

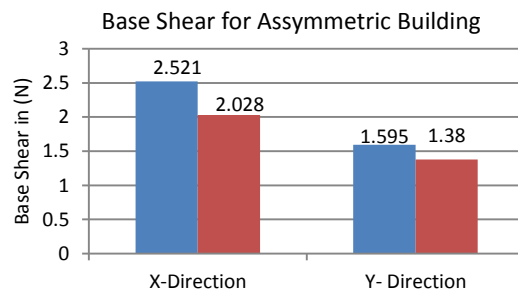


Fig.11 Base Shear in Asymmetric Building

3.4 Storey Acceleration

The floor level Vsstorey acceleration graph of fixed and base isolated building for symmetric and fixed base and base isolated asymmetric building with X and Y Directions are as shown in Figure 12, 13. From Figure 12, it is observed that storey acceleration in base isolated building model decreases by 33% and by 6% in Asymmetric building model in X- Direction for 13-storey in comparison with of fixed base building for same storey level. There is large difference in storey acceleration for fixed base building model from bottom to top storey. In base isolated model the storey accelerations are nearly same from bottom to top storey.

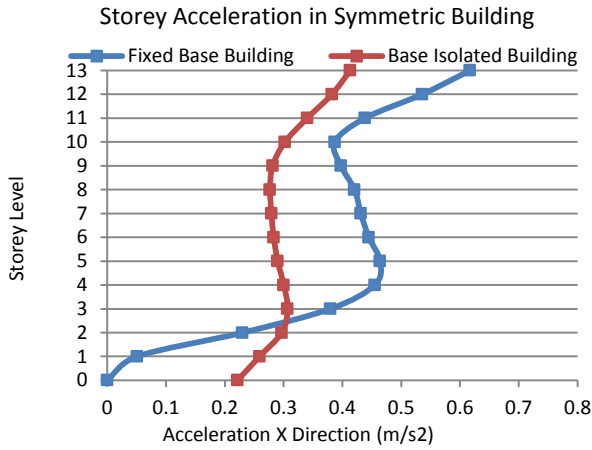


Fig.12 Storey Acceleration in Symmetric Building

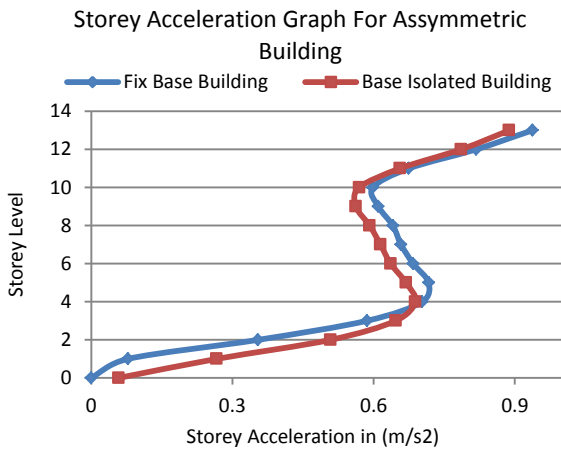


Fig.13 Storey Acceleration in Asymmetric Building

3.5 Storey Drifts

The floor level Vsstorey drifts graph models of fixed and base isolated building for symmetric building and fixed base and base isolated asymmetric building are as shown in Figure 14 and 15. From Figure 14 and 15, it is observed that the base isolated building storey drifts are significantly reduced in comparison with the corresponding fixed base models.

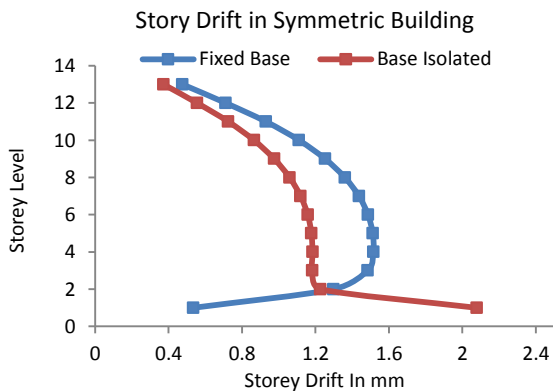


Fig. 14 Story Drift in Symmetric Building

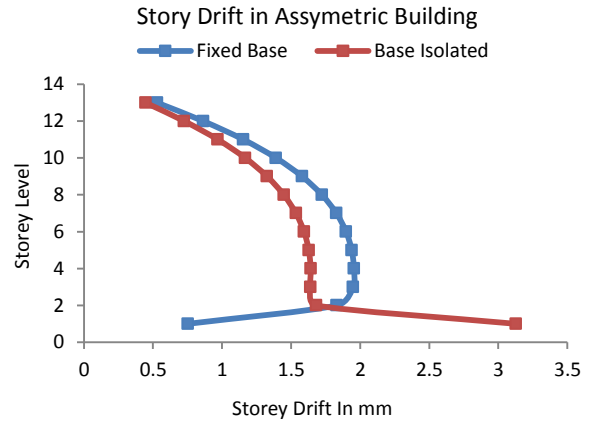


Fig. 15 Story Drift in Asymmetric Building

3.6 Lateral Displacement

The floor level Vs lateral displacements graph of models of fixed and base isolated symmetric building for and fixed base and base isolated asymmetric building are as shown in Figure 16 and 17 respectively. From Figure 16 and 17, it is observed that in base isolated building the lateral displacements are observed more as compared to fixed base building.

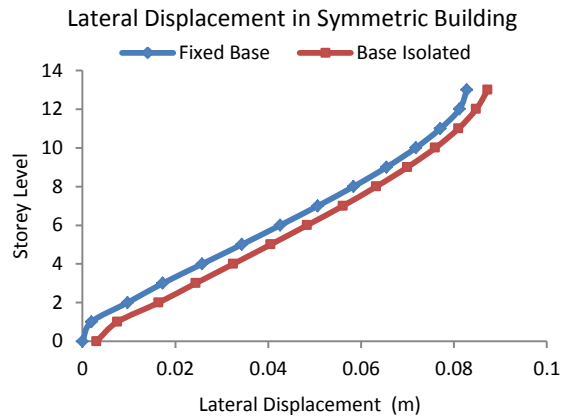


Fig. 16 Lateral Displacement in Symmetric Building

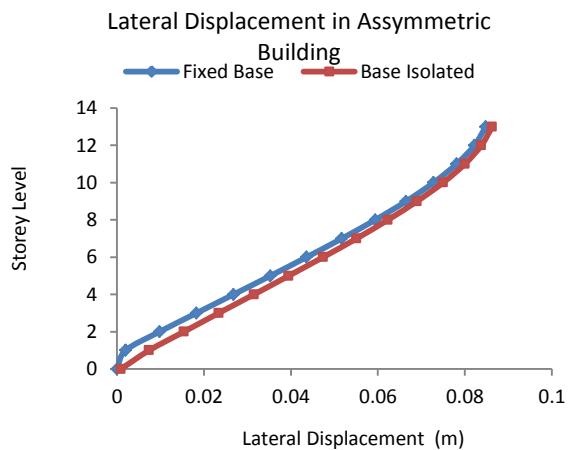


Fig. 17 Lateral Displacement in Asymmetric Building

## Conclusion

From analytical results, it is observed that base isolation technique is very significant in order to reduce the seismic response of both symmetric as well as asymmetric models as compared to fixed base building and control the damages in building during strong ground shaking. By comparing the dynamic properties of buildings following conclusions are made:

1. It has been observed that maximum shear force, bending moment, storey acceleration, base shear decreases; whereas increase in lateral displacements were observed for bottom storey then gradually decreases for top storey of base isolated building as compared with fixed base building model.

2. From analytical study, it is observed that for both models of symmetric as well as asymmetric, fixed base building have zero displacement at base of building whereas, base isolated building models shows appreciable amount of lateral displacements at base. Also it has been observed that as floor height increases, lateral displacements increases drastically in fixed base building as compare to base isolated building. Due to this reduction in lateral displacement during earthquake damages of structural as well as non structural is minimized.

3. At base more storey drift was observed for base isolated model as compared to model of fixed base building. As storey height increases, the storey drifts in base isolated building model drastically decreases as compared to model of fixed base building.

4. It is observed that for fixed base building have zero storey acceleration at base of building whereas, in case of base isolated building model appreciable amount of storey acceleration has been found out at base. Also it has been observed that as floor height increases, storey acceleration increases drastically in fixed base building as compared to base isolated building where it is almost constant.

5. From the study of symmetric and asymmetric building models it can be concluded that shear force, bending moment, storey drift and acceleration has not changed appreciably in asymmetrical building as compared to symmetric building model. Therefore it is concluded that symmetrical building with base isolation remains strong enough during earthquake as compared to asymmetric buildings.

6. In both of the models fixed base and base isolated there is reduction in bending moment. Thus it will require less reinforcement. Therefore cost is reduced considerably.

Finally it is concluded that base isolation system is significantly effective to protect the structures against moderate as well as strong earthquake ground motion.

## References

- [1] Salic R. B., Garevski M. A. And Milutinovic Z. V., "Response of Lead-Rubber Bearing isolated Structure," The 14<sup>th</sup> World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.
- [2] Kilar V. And Koren D., "Usage Of Simplified N2 Method For Analysis Of Base Isolated Structures," The 14<sup>th</sup> World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.
- [3] Saiful Islam A. B. M., Jameel M., Ahmad S.I. And Jumaat M. Z., "Study On Corollary of Seismic Base Isolation System On Buildings With Soft Storey," International Journal of the Physical Sciences Vol. 6(11), pp. 2654-2661, 4 June, 2011 ISSN1992-1950 ©2011 Academic Journals.
- [4] Di Sarno, L., Cosenza, E. and Pecce, M.R., "Application Of Base Isolation To A Large Hospital In Naples, Italy," 10<sup>th</sup> World Conference on Seismic Isolation, Energy Dissipation and active Vibrations Control of Structures, Istanbul, Turkey, May 27-30, 2007.
- [5] Nakashima M., Chusilp P., "A Partial View of Japanese Post-Kobe Seismic Design and Construction Practices", Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto 611-0011, Japan.
- [6] Ramallo J. C., Johnson E. A., Spencer B.F., Jr., and Sain M.K., "Semiactive Building Base Isolation", The 1999 American Control Conference, San Diego, California, June 2-4, 1999.
- [7] Ramallo J. C.; Johnson E. A., A. M. Asce; and B. F. Spencer Jr., M.Asce, "Smart Base Isolation Systems", 10.1061/ASCE/0733-9399/2002/128:10/1088.
- [8] A. Jalali and P. Narjabadifam, "Optimum Modal Characteristics for Multi-Story Buildings Isolated with Lead rubber bearings", 4th International Conference on Earthquake Engineering, Taipei, Taiwan, October 12-13, 2006, Paper No. 187.
- [9] Wen P. And Baifeng S., "Two Step Design Method For Base Isolation Structures", The 14<sup>th</sup> World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.
- [10] Pradeep Kumar T. V. And D. K. Paul, "Force-Deformation Behavior of Isolation Bearings", 10.1061/ASCE/1084-0702/2007/12:4/527.
- [11] Indian Standard Criteria for Earthquake Resistant Design Structure 1839-2002
- [12] Shrikhande M. and Agrawal P., "Earthquake Resistant Design structure", Tata McGra Hill Publication, 10th Edition 2004.
- [13] Duggle S.K., "Earthquake Resistant Design Structure", Tata McGra Hill Publication, 10th Edition 2004.
- [14] Zanaica L., "Design of Storey-Isolation System in Multi-Storey Building" MEEES programmed, May, 2007.