MAT JOURNALS

Journal of Structural and Transportation Studies
Volume 2 Issue 2

SEISMIC ASSESSMENT AND ANALYSIS OF BASE ISOLATED BUILDING

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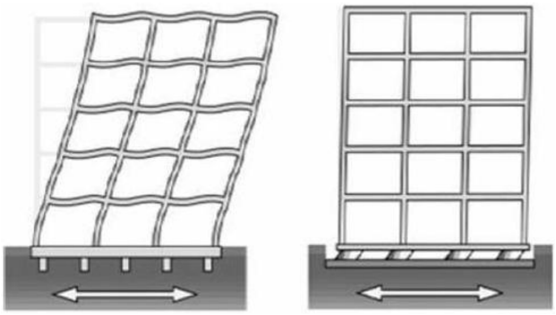
Abstract

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 modelled in the most seismically active region in India (Zone V). The modeling procedure for both fixed base and base isolated building in finite element software, is carried out for a (G+8) storied building. The dimensions of LRB are calculated using a MATLAB code which is also cross-checked through a Visual Basic (VB) script. The results of key parameters including the variation in storey displacement, storey drift, storey shear, and overturning moment of isolated building is evaluated. Using base isolation system at the base of a (G+8) storied building, it is found that the building was better protected, leading to the hypothesis that base isolation is an ideal technique for structures more than 6-7 storeys. It was found that the maximum displacement of base isolated model is very. Also, the storey overturning moment & storey shear are also found to be reduced in the case of base isolated building.

***Keywords**: Base Isolation, Lead Rubber Bearings, LRB, Earthquakes, Seismic strengthening*

INTRODUCTION

Buildings built according to codal provisions and specifications are expected to get damaged in the event of a strong earthquake, but not loose its integrity and collapse. This conventional approach towards seismic design is called Earthquake design philosophy and is generally applicable for all ordinary structures. However it is unacceptable for critical structures such as hospitals, fire stations, and telecommunications centers because these are the responders in case of an emergency and must remain fully operational even in the event of a strong earthquake. The concept of isolating the base of a building from the ground was originally suggested by William Robinson in the early 70s which led to the invention of Lead Rubber bearing (LRB). In the last few decades, enhancement in available technologies and knowledge of base isolation system has led to the born of a mature and well established seismic isolation industry. Isolation systems work best when applied to low-rise and medium-rise buildings with high initial stiffness. An ever increasing number of base isolated structures around the work reflects the fact that use of base isolation systems is gradually becoming the top choice of engineers to counteract the seismic effects on the structure. It is now a proven technology in earthquake hazard mitigation.



(a) (b)

Fig.1 *- Behavior of structure (a) without isolator and (b) with isolator incorporation*

Base isolation provides protection to the superstructure by uncoupling it from the foundation, thereby reducing the negative effects of earthquake ground motion. After investigating these buildings that experienced the Kobe earthquake in 1995 in Japan, the performance of base-isolated buildings, subjected to a large scale earthquake has proven to be excellent as predicted. Hence, engineers have devoted time and research to this topic and the isolation system technologies have been well developed and established in terms of theory, design and construction phases.

An ingenious breakthrough in earthquake engineering called "Base Isolation" has revolutionized the way buildings are engineered in earthquake prone areas. A number of buildings have been constructed throughout the world which uses the concept of base isolation for their seismic safety. The performance of these buildings during actual earthquakes has proved the effectiveness of base isolation technique. Contrary to the conventional earthquake resistant design, loose contents and non-structural components like masonry infills have been protected in real earthquakes thereby keeping the buildings functional after the earthquake. The base isolated structure consists of several component systems as represented in Fig. 1.3. A brief introduction of these component systems are presented as follows:

Isolation System - The various isolators, which facilitate the time period shift of the structure to a period range of 2 to 3 sec, form the isolation system. Extensive experimental studies have revealed bilinear force deformation behaviour for various types of isolators, details of which have been provided in Chapter 2. In base isolated structure, localized non-linearity is observed in the isolation system, while the structural and the soil system are usually assumed to behave linearly.

Structural System - This system comprises of the structural components of the superstructure as well as the foundation[1-5]. The inter-storey drifts as observed in isolated structures are so low, that the superstructure can conveniently be assumed to behave in a linear elastic manner[6-10].

Soil System - The subsoil stratum exhibits their own stiffness and damping properties which may or may not affect the response of the structures they bear. This influence of the interaction between the soil and the structural system becomes significant in case of loose subsoil strata.

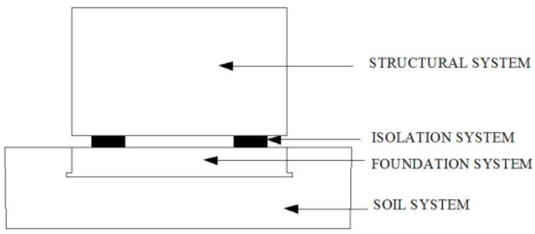


***Fig. 2** - Components of a Base Isolated Structure*

Lead-plug bearings are constructed with low-damping elastomers and lead cores with diameters ranging 15% to 33% of the bonded diameter of the bearing. Laminated-rubber bearings are able to supply the required displacements for seismic isolation. By combining them 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. Thus, one device is able to support the structure vertically, to provide the horizontal flexibility together with the restoring force, and to provide the required hysteretic damping. The maximum shear strain range for lead-plug bearings varies as a function of manufacturer but is generally between 125% and 200%.

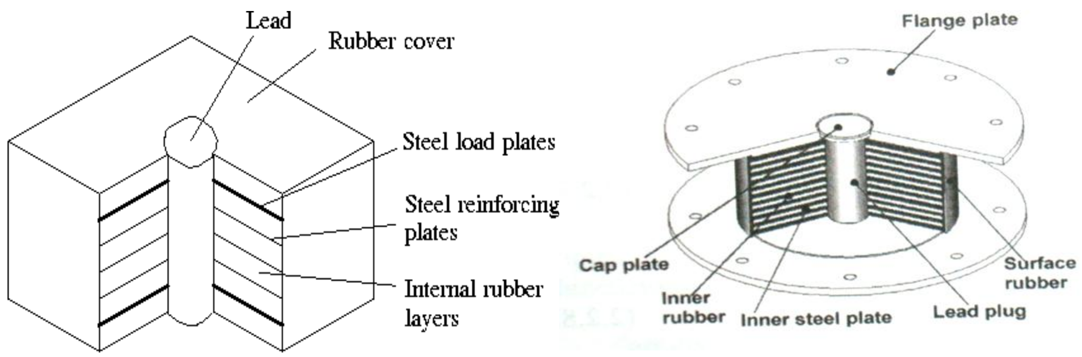


***Fig. 3** - Lead rubber bearing*

Objectives of this study

- To review the literature, covering various types of base isolation systems and the behaviour of isolated structures.
- To develop a simplified building model of a fixed base and a base isolated structure and compare their results with 3D analysis in ETABS and also with the available records.
- To study the comparative behaviour of identical conventional and isolated (G+8) storied buildings for high intensity earthquakes and comment on the feasibility of using base isolation for highly seismic areas.

The use of LRB is shown in this study. It implies that the isolators remain in the initial stiffness range for the recorded intensities. Thus the comparison of the analysis with the records is limited for behaviour of isolators in initial stiffness range. The comparison of post yield behaviour cannot be done with the available records. In order to study the post yield behaviour, the present study relies on 3-D analysis in ETABS, and an attempt is made to compare the analytical results with the conventional building analysis.

MODELLING & ANALYSIS

(G+8) storied buildings are modeled using conventional beams, columns & slabs. These buildings were given square geometry with plan dimensions of 20m x 20m. They are loaded with Dead, Live and Seismic Forces (according to IS:1893(Part-1)-2002). These models are then analyzed using response spectrum

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

- Only the main block of the building is considered. The staircases are not considered in the design procedure.
- The building is to be used for residential purposes, and only exterior walls are provided so as to focus mainly on the response of the frame configuration.
- At ground floor, slabs are not provided and the floor is resting directly on the ground.
- The beams are resting centrally on the columns so as to avoid the conditions of eccentricity. This is achieved automatically in ETABS.
- For all structural elements, M30 & Fe 415 are used.
- 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).
- Seismic loads are considered in the horizontal direction only (X & Y) and the loads in vertical direction (Z) are assumed to be insignificant.
- Sizes of the members are as follows: (All dimensions are in mm)

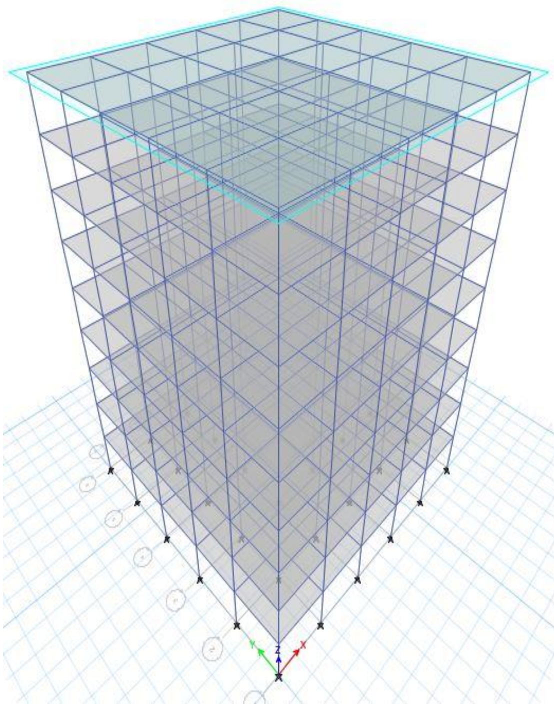

Fig. 4 *- Perspective view of the generated model*

Table 1 *- Member Properties & Specifications for the various Models*

SN	Specifications		Size
1	Plan dimensions		20 m x 20 m (X*Y)
2	Floor to floor height		3 m (Z)
3	Total height of Building (G+8)		27 m
4	Type of Structure		OMRF
5	Soil Type (as per IS:1893(Part-1)-2002)		Medium
6	Response Reduction Factor		3
7	Importance Factor		1
8	Seismic Zone Factor		0.36 (Zone V)
9	Grade of concrete & steel		M30 & Fe415
10	Beam Size		0.23 m x 0.48 m
11	Column Size		0.30 m x 0.70 m
12	Slab Thickness		0.150 m
13	Wall Thickness		0. 230 m
14	Load Combination		1.2 DL + 1.2 LL + 1.2 EQX
15	Loads Applied	Dead Load	Calculated as per Self Weight
		Floor Finish	1 kN/m^2
		Live Load	3 kN/m^2
		Seismic Load	Calculated as per IS:1893-2002

Exact seismic analysis of the structure is highly complex and to tackle this complexity, numbers of researches have been done with an aim to counter the complex dynamic effect of seismic induced forces in structures, for the design of earthquake resistant structures in a refined and easy manner. The isolation system or elastomeric bearings (and bridge bearings) are designed on the basis of bilinear model based on the parameters: K_e, K_2, and Q etc., as shown in Fig.4.3 (Naeim F, 1999). Isolation bearings will have high initial stiffness, K_e and after yielding they will have lower stiffness, K_2 (Kelly J M, 1996).

The initial stiffness, K_e is estimated from a hysteresis loop from elastomeric bearing tests or as a multiple of K_2 for lead–plug bearings.

The characteristic strength, Q is estimated from the hysteresis loops for elastomeric bearings. For lead–plug bearings, Q is given by the yield stress of the lead and the area of cross section of the lead core. The hysteretic damping of this bearing is due to the plastic deformation of the lead core.

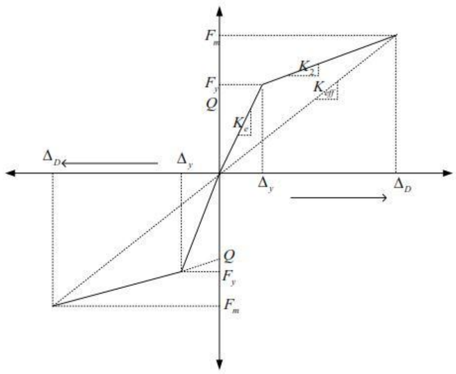

Fig. 5 *- Typical bilinear displacement curve for LRB isolator (Naeim F, 1999)*

Here, K_{eff}, K_2 and K_e are effective stiffness, post yield stiffness and the elastic stiffness of the isolator respectively,
Q is the characteristic strength,
Δ_y, Δ_d are the yield and design displacements respectively, and
F_y, F_m are the forces corresponding to yield and design displacement respectively.

For laminated lead rubber bearings as an approximation, we take $K_e \approx 10K_2$. (Govardhan et al, 2011). From the above equations, it is clear that the K_2, Q and Δ_y are interdependent on each other. The values of the K_2, Q and Δ_y can be accurately calculated only by iteration. Therefore equations are proposed to evaluate their values directly.

Table 2 *- Summary of design of circular LRB isolators*

Items	Values
Design period	2.5
No. of isolator	36
Load / isolator	1648
K_{eff} / isolator	1061
K_1 / isolator	8110
K_2 / isolator	811
Q / isolator	131
Rotation of K_2 / K_1	0.1

***Table 3** - Geometric Properties of circular LRB isolators (The properties of LRB are found using MATLAB code and cross-checked using a & VB scripts)*

Items	Specifications
Diameter of rubber(m)	0.390
Thickness of rubber layer (m)	0.070
Thickness of one rubber layer (m)	0.010
Diameter of lead (m)	0.090
No. of layers	7
Height of isolator (m)	0.140
Thickness of steel plate (m)	0.003
Thickness of cover plate (m)	0.025
Diameter of steel (m)	0.390

In this study, RSA is adopted for the analysis of prepared models. Models are represented by IB and FB as shown earlier. In order to perform the seismic analysis of a structure at any location, the actual records of time history are needed. But it is not practically possible to prepare such records for all the areas and hence in many cases, these records are unavailable. In such cases, response spectrum analysis is carried out. This method involves the calculation of only the maximum or peak values of member forces and displacements in each of the considered mode using prescribed design spectra. This spectra is the average of several past earthquakes and can be used as an effective method of employing earthquake ground motions.

As per IS:1893(Part-1)-2002, the response spectra shown above is recommended for design of structures subjected to seismic forces. The spectra is shown for all four seismic zones in India as per IS:1893(Part-1)-2002. A response spectrum is basically a plot of the peak steady-state response in terms of displacement, velocity or acceleration, for of a series of varying natural frequencies. The main limitation of RSA if that they are universally acceptable only for linear systems. For nonlinear analysis, Time-History Analysis is adopted.

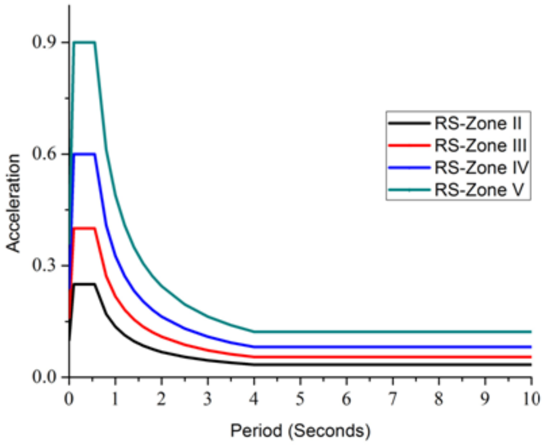

***Fig. 6** - Response Spectra for different Seismic Zones as per IS:1893(Part-1)-2002*

The behavior of all the framing systems is taken as a basic study on the modeled structure. The lateral drift/deflection ratio is checked against the clause 7.11.1 of IS:1893(Part-1)-2002 i.e. under transient seismic loads. For asserting the simplest yet reliable method for analysis, the combined action of DL, LL & EQ forces are considered (i.e. 1.2 DL + 1.2 LL + 1.2 EQX). The structure with different framing system has been modeled using ETABS software with the above mentioned load conditions and combinations.

RESULTS & DISCUSSIONS

Modal Time Period (in seconds)-

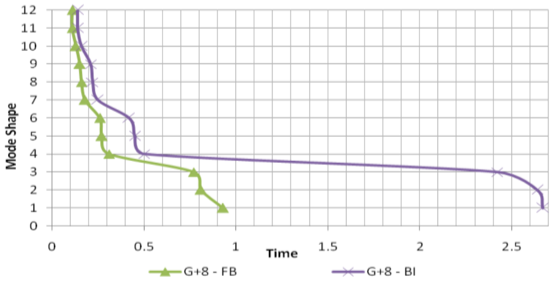

Fig. 7 *- Model period for G+8 Building*

The time period of base isolated building is observed to be around three times that of fixed base building. This increase in modal time causes the structure to jump out of the heavy spectral damage range as explained in the figure below. Thus, isolated structures are subjected to lower degrees of floor acceleration and base shear leaving them comparatively safer as compared to fixed base buildings.

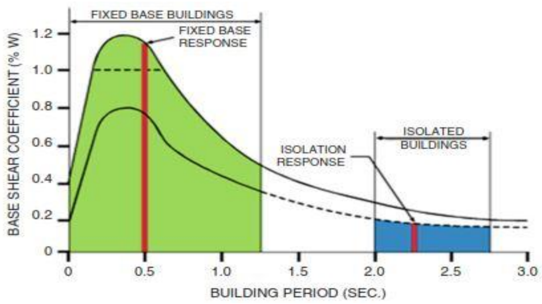

Fig. 8*- Period Shift with seismic isolation (Morgan T A, 2015)*

Maximum Storey Drift-

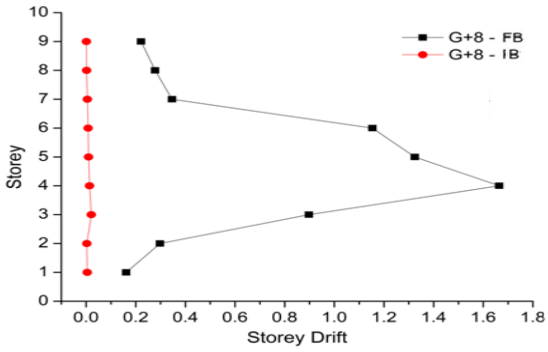

Fig. 9 *- Storey Drift along X direction*

Storey drift is calculated as displacement at top storey minus displacement at bottom storey divided by height of storey. The significant characteristic of base isolation system enabled the superstructure to have a rigid movement and as a result, shows the relative storey drift of structural element decreased. Consequently the internal forces of beams and columns will be also be reduced. It is observed that the story drift for fixed base building is much more than that of base isolated building. This reduction in interstorey drift in case of isolated buildings provides better earthquake resistance to adjacent floors.

Maximum Storey Displacement (in cm)-

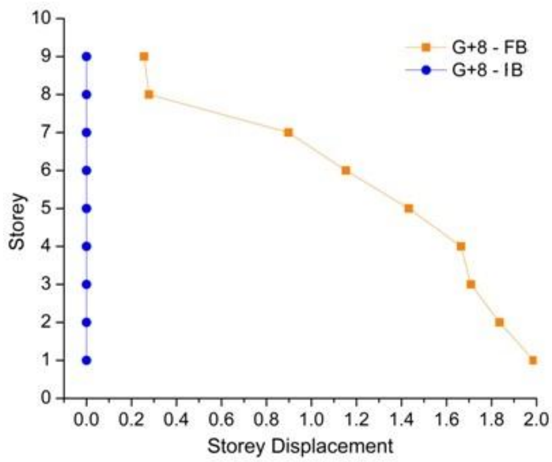

Fig. 10 *- Storey Displacements along X direction*

The variation in maximum displacement of stories in base isolated model is very low while compared with fixed base model. It is observed that when increasing the number of stories this variation of maximum displacement of stories will be somehow considerable.

Storey Shear (in kN)-

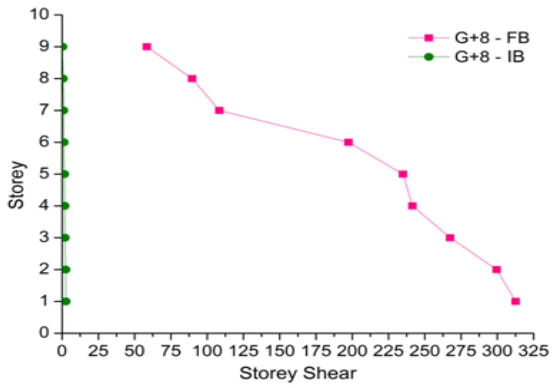

Fig. 11 *- Storey Shear at different floors*

In ETABS software, Storey shear is reported in the global coordinate system. The forces are reported at the top of the storey, just above the storey level, just below the storey level itself, and at the bottom of the storey[11-18]. Storey shear is also reduced in base isolated building, resulting in making the superstructure above the isolation plane as rigid and stiffer. Compared to fixed base buildings, these buildings were subjected to almost negligible storey shear. Also, due to decrease in lateral loads to stories, the accelerations of the stories are reduced. This results in the reduction of inertia forces.

Storey Overturning Moment (in kNm)-

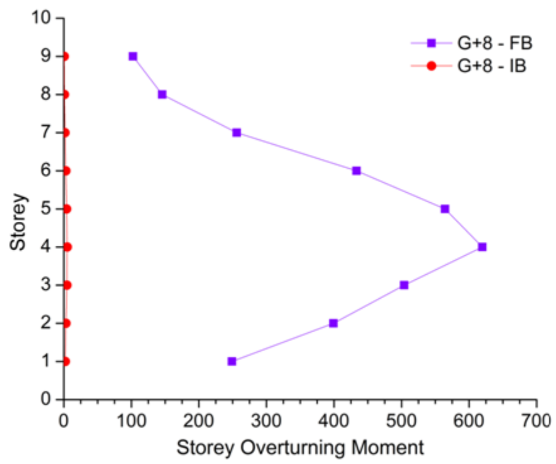

Fig. 12 *- Storey Overturning Moments*

Similar to storey shear, Storey overturning moment is also reduced in base isolated building, resulting in making the superstructure stiffer. It is thus safe to say that using base isolation system for a (G+8) storied building, is an effective technique to make the structure earthquake resistant.

CONCLUSIONS

It is clear to all that the seismic hazard has to be carefully evaluated before the construction of important and high-rise structures. Structural response is reduced due to the increased damping in isolation system for the structure. The isolators are often designed to absorb energy and thus add damping to the system. The present study has been concentrated on a typical square plan for the (G+8) storey buildings. From the above graphs, it is evident that base isolated buildings (IB) are clearly behaving in a more effective manner by reducing the structural response as compared to fixed base building. The building supported on isolators experienced a higher time period as opposed to the fixed base building. Also, the fundamental frequency of the isolated building was much lower than that of the predominant frequencies of ground motion. As a result, the high energy in ground motion at these higher frequencies does not get transmitted to the building framework vibrating in higher modes. Since this approach is still evolving, the codes lay down conservative design requirements and strict testing and acceptance procedures for isolators.

Scope for Future works

- ✓ It is necessary to analyze the cost of using these base isolation strategies too as economy and efficiency, both are the primary concerns of a structural designer or engineer.

- ✓ This work can be further extended by analyzing multiple isolation systems for different buildings such as OMRF, SMRF, ordinary steel frames, and braced steel frames.
- ✓ Also, since the present study addressed a medium rise building of (G+8) storey, further analysis for low rises and high rises can be carried out.
- ✓ Finally, using record of actual major earthquakes that occurred in the past, time history analysis of these models can be carried out to predict their behaviour more accurately.

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