International Journal of Trend in Research and Development, Volume 7(5), ISSN: 2394-9333
www.ijtrd.com

Seismic Retrofitting by Base Isolation and Analysing Through ETABS

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Abstract: Base isolation is regarded as a promising solution of earthquake resistant design, which results in significantly low floor accelerations, and inters storey drifts. This ensures the safety of structural as well as non structural elements, thereby keeping the building operational even after a severe earthquake. The effectiveness of a base isolation system is governed by the bilinear characteristics offered by the isolators.

The present work attempts to study the effectiveness of base isolation using friction pendulum bearings (FPB) over conventional construction, using a hypothetical case study of identical conventional and isolated buildings constructed in the most seismically active region in India (Zone V). It is seen that the base isolated building exhibits excellent performance compared to the conventional ductile building. The modeling procedure for both fixed base and base isolated building in ETABS software is carried out for a regular (G+8) storied MRF building. Linear analysis using Time History Analysis (THA) for the records of Kobe earthquake, 1995 and Nonlinear analysis using Incremental Dynamic Analysis (IDA) was carried out. For IDA, incremental intensities of 0.2g, 0.4g, 0.6g, 0.8g, 1.0g and 1.2g for the previously considered Kobe earthquake were taken as input.

The results of various parameters such as the variation in maximum storey displacement, maximum storey drift, lateral loads to stories, storey overturning and torsional moments and storey shear of both the buildings are studied. Using base isolation system for a (G+8) storied frame, it was found that the base isolation technique although enhanced the original performance of the building, would not be better suited for structures more than 10 storey which may exhibit time periods around 1s. It was observed that the variation in maximum storey displacement in isolated model is very low while compared with fixed base model, with the isolated frame exhibiting higher displacements. However, the interstorey displacements and drift were comparatively reduced leading to a safe design. It was also observed that storey overturning moment & storey shear exhibit a similar trend in base isolated building. The radius of proposed FPB are calculated using a suggested by Naeim, 1999 and comments were made on the overall feasibility of the proposed isolation system.

I. INTRODUCTION

In conventional medium rise buildings, the fundamental frequency of vibration is in the range of frequencies with maximum earthquake energy content. Thus, the building acts unintentionally as an amplifier for the ground accelerations, thereby increasing the accelerations at each floor level up to the top. This increases the stresses in the frame members, and result in high values of inter- story drifts, which leads either to damage or to loss of functionality of the various service components mounted on different floor levels. The ground accelerations expected in an event of an earthquake have a great deal of uncertainty in their assessment. Moreover, since the magnitudes of the forces in event of earthquake are very large, the use of more popular design in elastic range of material behavior results in very large member sections which are uneconomical and impractical. Earthquake resistant design may be realized in two different approaches as explained in the following sections.

A. Conventional Earthquake Resistant Design-

The regions where the inelastic behavior is permitted are detailed with special provisions so that they get the necessary ductility capacity for the hysteretic energy dissipation. However, the inter-story drifts essential for the hysteresis, produces strains in the non- structural components like masonry in-fills, doorways and false ceilings, causing their damage or even collapse. Moreover, the structural components lose their strength capacity because of the repeated hysteretic cycles.

B. Non-conventional Earthquake Resistant Design

The demand force acting on the structure in an event of an earthquake is directly proportional to the spectral acceleration of the structure which is related to the time period and damping of the structure. This relationship is represented by a response spectrum. The response spectra obtained for hard soil according to IS:1893(Part-1)- 2002. Following are two methods in non-conventional earthquake resistant design which realize the reduction in earthquake demand forces.

- Passive Energy Dissipation Devices: Installation of these devices in the structural system increases the overall damping of the structure thereby reducing the spectral accelerations and displacements.
- Seismic Retrofitting by Base Isolation: In this method, a time period shift to a range of 2 to 3 sec is realized by introducing flexible mounts near the ground level into the structural system. The aim is to unlink or decouple the superstructure and the foundation from the horizontal components of earthquake ground motion, because of which the building can float over the isolators in event of an earthquake.

Seismic Retrofitting by Base Isolation

The earthquake resistant structures can be categorized into rigid structures and flexible structures. In rigid structures, the control methods that are applied to withstand extreme loads are basically reducing the inter-story displacement with the help of diagonal bracing, the installation of shear walls and the use of composite materials. In flexible structures, such as base-isolated buildings, the key control approach is to reduce the excitation input with the use of dampers and isolators.

Basic Elements of a Base Isolation

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

Structural System - This system comprises of the structural components of the superstructure as well as the foundation. 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.

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.

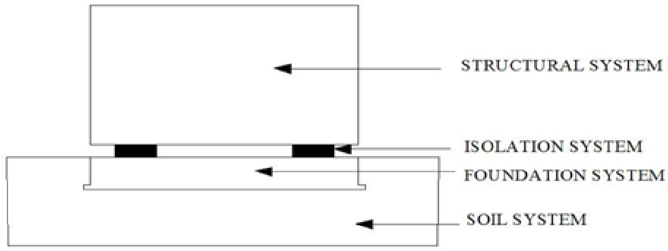


Fig. 1. Components of a Base Isolated Structure (Som and Singh, 2017)

Base Isolator (Friction Pendulum System)

The concept of sliding bearings is also combined with the concept of a pendulum type response, obtaining a conceptually interesting seismic isolation system known as a friction pendulum system. The slider is faced with a bearing material which when in contact with the polished chrome surface, results in a maximum sliding friction coefficient of the order of 0.1 or less at high velocity of sliding and a minimum friction coefficient of the order of 0.05 or less for very low velocities of sliding. The dependency of coefficient of friction on velocity is a characteristic of Teflon-type materials (Kelly J M, 1996).

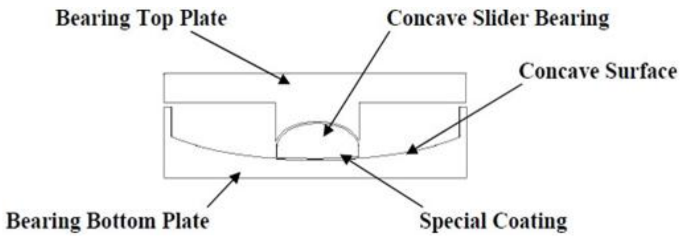


Fig. 2 - Cross - Section of Friction Pendulum Bearing (Kravchuk, 2008)

II. MODELLING BY ETABS

ETABS is a sophisticated, yet easy to use, special purpose analysis and design program developed specifically for building systems. ETABS features an intuitive and powerful graphical interface coupled with unmatched modelling, analytical, and design procedures, all integrated using a common database. Although quick and easy for simple structures, ETABS can also handle the largest and most complex building models, including a wide range of nonlinear behaviours, making it the tool of choice for structural engineers in the building industry Seismic Analysis Procedure as per IS:1893 (Part-1)-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. This re-examination and continuous effort has resulted in several revisions of Indian Standard: 1893 (1962, 1966, 1970, 1975, 1984 and 2002) code of practice on "Criteria for earthquake resistant design of structures" by the Bureau of Indian Standards (BIS), New Delhi.

Design Lateral Force-

This analysis is carried out by either equivalent lateral force procedure or dynamic analysis procedure given in the clause 7.8 of IS:1893(Part-1)-2002.

- Equivalent Lateral Force Method-

The total design lateral force or design base shear along any principal direction is given in terms of design horizontal seismic coefficient and seismic weight of the structure. Design horizontal seismic coefficient depends on the zone factor of the site, importance of the structure, response reduction factor of the lateral load resisting elements and the fundamental period of the structure. The procedure generally used for the equivalent static analysis is explained below:

i) Determination of fundamental natural period (Ta) of the buildings

$T_a = 0.075h^{0.75}$ Moment resisting RC frame building without brick infill wall

$T_a = 0.085h^{0.75}$ Moment resisting steel frame building without brick infill walls

$Ta = 0.009h/\sqrt{d}$ All other buildings including moment resisting RC frame Building with brick infill walls.
Where,

h- is the height of building in m.
d- is the base dimension of building at plinth level in m, along the considered direction of lateral force.

ii) Determination of base shear (V_B) of the building

$$V_B = A_h \times W$$

Where,

$$Ah = \frac{Z\ I\ Sa}{2\ R\ g}$$

'Ah' is the design horizontal seismic coefficient, which depends on the seismic zone factor (Z), importance factor (I), response reduction factor (R) and the average response acceleration coefficients (Sa/g). Sa/g in turn depends on the nature of foundation soil (rock, medium or soft soil sites), natural period and the damping of the structure.

iii) Distribution of design base shear

The design base shear VB thus obtained shall be distributed along the height of the building as per the following expression:

$$Wihi^2 Qi = \frac{V_{Bn}}{\sum_{I=1} Wihi^2}$$

Where, Qi is the design lateral force, Wi is the seismic weight, hi is the height of the ith floor measured from base and n is the number of stories in the building.

Design of FPB isolators

Friction Pendulum Bearings work on the same principle as a simple pendulum. When activated during an earthquake, the articulated slider moves along the concave surface causing the structure to move in small simple harmonic motions, as illustrated in Figure. Similar to a simple pendulum, the bearings increase the structures natural period by causing the building to slide along the concave inner surface of the bearing (Kelly,J.M.,1996)

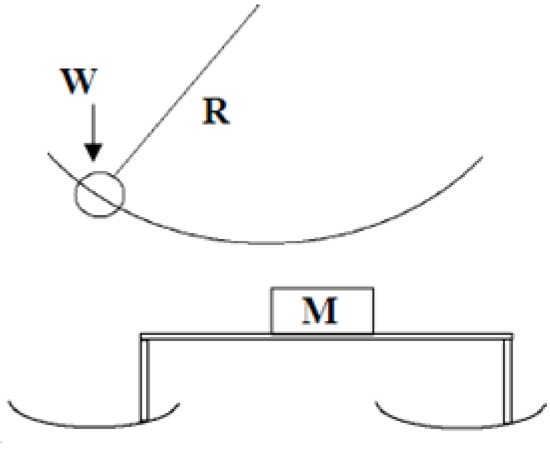


Fig. 3 - Concept of Sliding Friction Pendulum

Design Steps For Friction Pendulum Bearing

STEP 1: Radius of friction pendulum is given by

$$R = g \times \left(\frac{T}{2\pi}\right)^2$$

STEP 2: Damping provided to system given by

$$\beta = \left(\frac{2}{\pi}\right) \times \left(\frac{\mu}{\mu + \frac{D}{R}}\right)$$

STEP 3: Horizontal stiffness for isolator given by

$$K_H = \frac{W}{R}$$

STEP 4: Effective stiffness for isolator given by

$$K_{eff} = \left(\frac{W}{R}\right) + \left(\mu \times \frac{W}{R}\right)$$

STEP 5: Vertical displacement of structure given by

$$\Delta_V = \frac{1}{2} \times \left(\frac{D^2}{R}\right)$$

Here, W stands for the effective weight and is calculated as mass source in ETABS (Dead load + 0.5 x Live load). This is in accordance to the provision laid down in IS:1893(Part-1)-2002. Based on the input values of time period (taken as 2.5s), the value of radius is calculated on the basis of the above formula (Naeim,1999) as 0.95m. Effective Spring stiffness was found to be as 1081 kN/m in the U2 and U3 directions. Direction U1 was kept fixed. The loading obtained in terms of Dead and Live loads is used in the calculation of horizontal stiffness effective stiffness. Damping is taken as 0.25.

III. ANALYSIS

Incremental Dynamic Analysis was carried out using the records of KJM000 and KJM090 stations which recorded the ground motions of Kobe earthquake of 1995 in the X and Y directions respectively. These records were scaled to various intensities ranging from 0.2g to 1.2g in an increment of 0.2g.

The general formula for scale factor is given as:

$$\text{Scale Factor} = \frac{\text{PGA of Target Spectrum}}{\text{PGA of Considered Earthquake}}$$

where, PGA stands for PGA acceleration and Target Spectrum is the Response Spectrum of Zone V as per IS:1893(Part-1)-2002.

The following scale factors were thus calculated:

Table 1: Scaling of Selected Ground Motion for IDA

PGA for Zone V	PGA of Kobe	Normalized Scale Factor	Records for IDA	
			Intensities	Modified Scale Factor
0.36 g i.e. 3.531 m/s^2	0.717 g i.e. 7.033 m/s^2	0.5021	0.2 g	0.2789
			0.4 g	0.5578
			0.6 g	0.8368
			0.8 g	1.1157
			1.0 g	1.3954
			1.2 g	1.6736

IV. RESULTS

A. Modal Time Period

The time period of base isolated building is observed to be around four 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.

B. Maximum Story Drift-

Story drift is calculated as displacement at top story minus displacement at bottom story divided by height of story. The significant characteristic of base isolation system enabled the superstructure to have a rigid movement and as a result, shows the relative story 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 inter-story drift in case of isolated buildings provides better earthquake resistance to adjacent floors.

C. Maximum Story Displacement

The variation in maximum displacement of stories in base isolated model is very low while compared with fixed base model. It is observed that although the total maximum displacement is higher in case of isolated building, the inter-story displacement is comparatively lower. This reduced displacement will enable the columns to behave more effectively in the event of an earthquake and prevent buckling failures.

D. Story Shear

In ETABS software, Story shear is reported in the global coordinate system. The forces are reported at the top of the story, just above the story level, just below the story level itself, and at the bottom of the story. Story 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 half story shear. This result in the reduction of inertia forces.

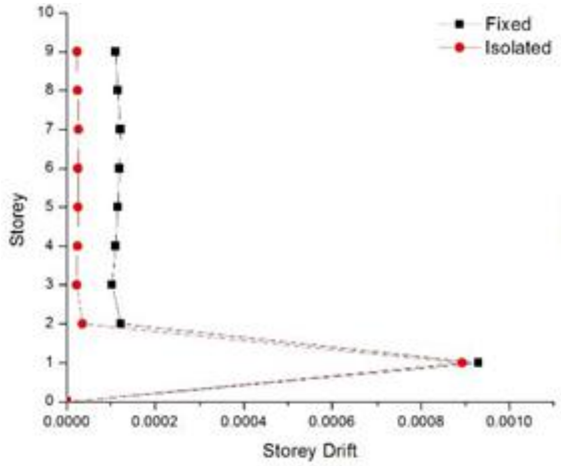
E. Story Overturning Moment

Story overturning moment is negligibly affected or base isolated building. It is thus safe to say that there is evidently no or negligible difference in the values of moments even after using FPB base isolation system for a (G+8) storied building.

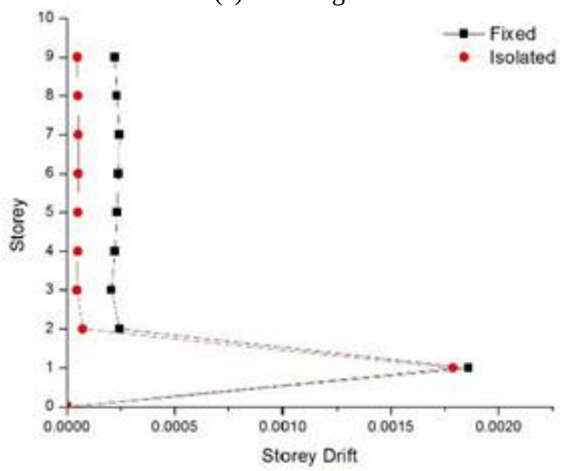
F. Torsional Moment

It is evident that the values of torsional moments are greatly reduced (by almost 75%) in case of base isolated buildings leading us to believe that FPB is an effective solution for providing earthquake resistance characteristic to the structure.

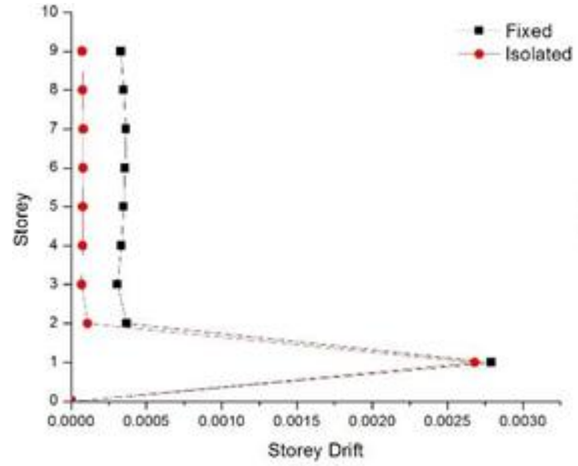
G. Storey Drift from IDA



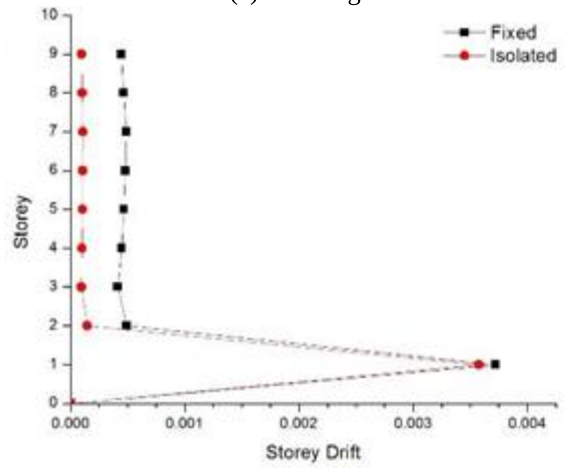
(a) X - 0.2 g



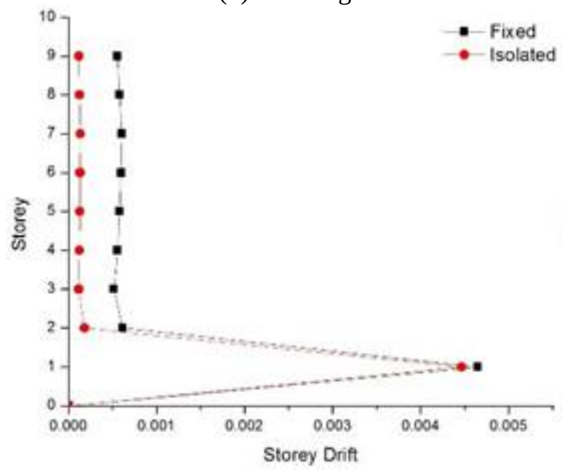
(b) X - 0.4 g



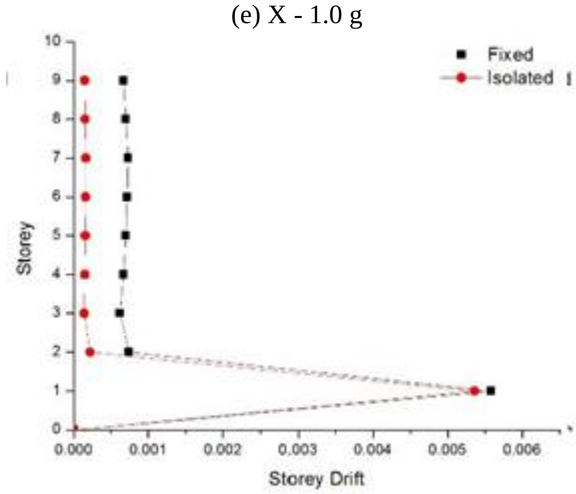
(c) X - 0.6 g



(d) X - 0.8 g

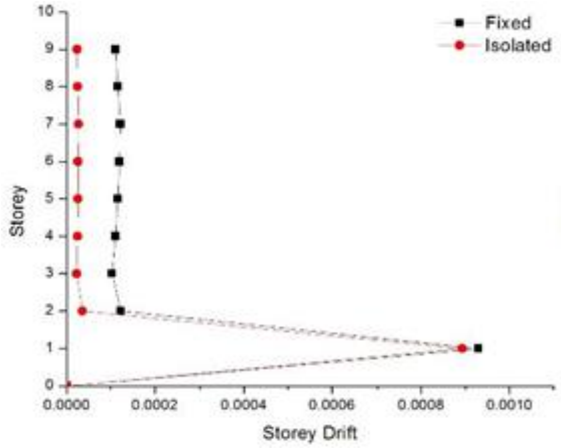


(e) X - 1.0 g

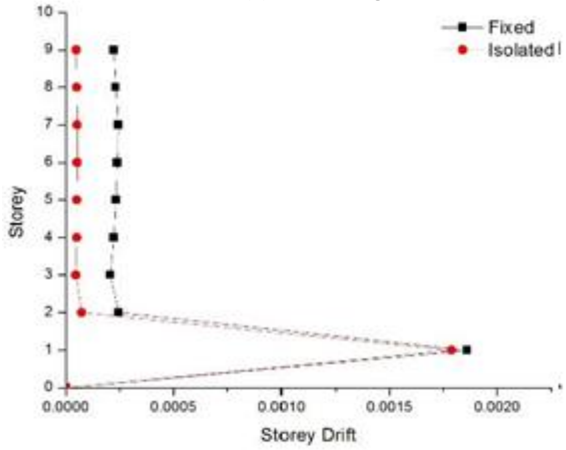


(f) X - 1.2 g

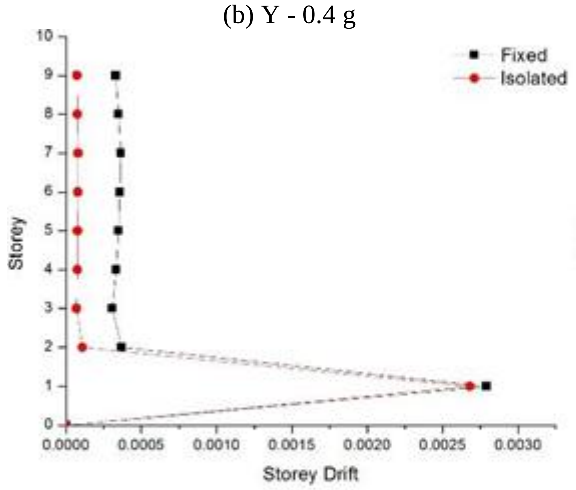
Fig. 4 (a) to (f) - Storey Drift along X direction for the records of KJM000 station



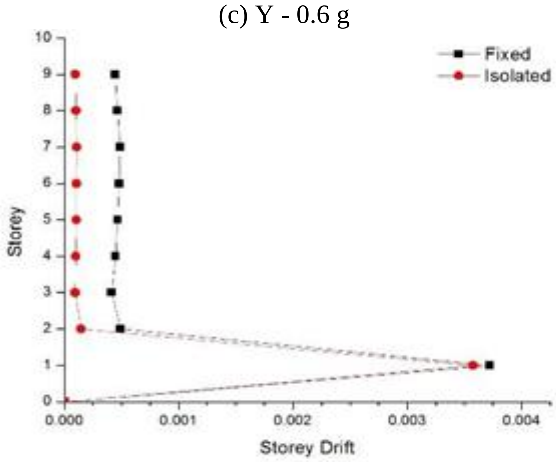
(a) Y - 0.2 g



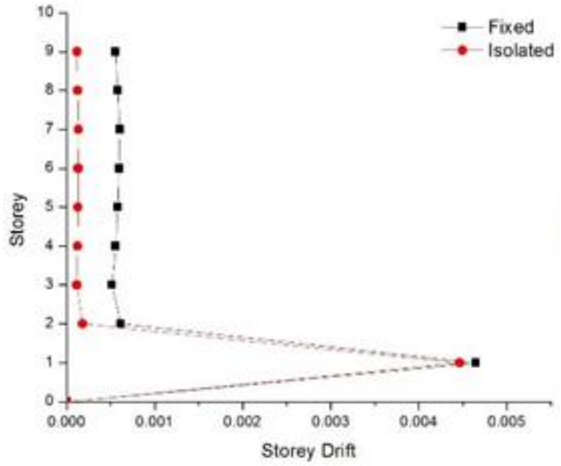
(b) Y - 0.4 g



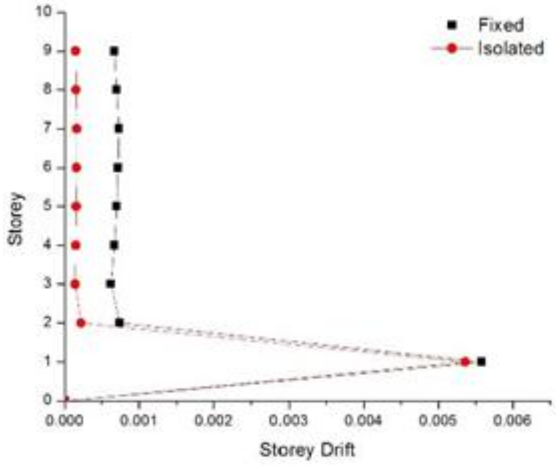
(c) Y - 0.6 g



(d) Y - 0.8 g



(e) Y - 1.0 g



(f) Y - 1.2 g

Fig. 5 (a) to (f) - Story Drift along Y direction for the records of KJM090 station

In all the above figures of Fig. 5.8 and 5.9, it is evident that the story drift is reduced in the case of base isolated buildings which will lead to a lower inter story drift ratio. As per Clause 7.11.1 of IS:1893(Part-1)-2002, the maximum story drift for any particular floor is given by 0.004 Hi where Hi is the floor height in meters. After cross checking the results of IDA, it was found that the considered building is not failing for even a high intensity of 1.2 g which suggests that although it was designed only to withstand 0.36 g (nominal acceleration for Zone V), it is able to withstand even heavy accelerations of 1.2 g.

SUMMARY & CONCLUSION

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) story buildings. Friction pendulum bearing was adopted for analysis purposes and the time history records of Kobe earthquake of Japan (1995) were used. From the above Fig. 4. (a)-(f) and 5 (a) to (f), 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 friction pendulum isolators of 0.95 m radius exhibited a much lower fundamental frequency than that of a building with fixed base. Also, this frequency is much lower than 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. The effect of infill walls was also observed in reducing the lateral deformations of higher stories.

Since this approach of providing active control is still evolving, the codes lay down conservative design requirements and strict testing and acceptance procedures for isolators. Also, it was noticed that the structures whose period lies around 1.0s require additional lateral resistance, which can be provided using other passive and semi active control strategies such as dampers and braces. This suggested that isolation is an effective earthquake resistant technique for low and medium rise structures.

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