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SEISMIC EFFECTS ON MEDIUM RISE STRUCTURES ISOLATED WITH FRICTION PENDULUM BEARINGS

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ABSTRACT

In the present work, friction pendulum bearings (FPB) are added to a hypothetical open ground storied regular building and its performance is compared to that to a fixed base building. The finite element model of the structure was placed in Zone V as per IS:1893(Part-1)-2002 so as to obtain its performance in terms of story drift, top story displacement, overturning moments and storey shear. Linear Time History Analysis (LTHA) was carried out on the modeled structures and it was observed that although the base isolated model exhibited greater displacements, the interstory displacements and drift were comparatively low which will result in less buckling of columns and hence to a safer design. It was also observed that values of overturning moment & storey shear were reduced in the case of base isolated building by a large extent. Finally comments were made on the overall feasibility of the proposed isolation system.

KEYWORDS: *Base Isolation, FPB, Earthquakescaling, Seismic strengthening, THA.*

1. INTRODUCTION

Seismic design of structures has been one of the most important and interesting issue in thelast century. So far several major earthquakes have been experienced, all of which have caused damage to life and property. There goes a saying, "Earthquakes never kills people, but poorly constructed structures do." As such there has been an increasing awareness among structural engineers regarding the seismic safety of structures.

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 over conventional seismic construction, using a case study of identical conventional and isolated building constructed for experimental purposes in Guwahati, a seismically active region in India lying in Zone V. The comparison of analytical results with the records for an actually recorded low intensity earthquake (Kobe, 1995) is done by carrying out a time history analysis.

The concept of base isolation for equipments is well known and the procedures for the same are well established. However its application in building structures is rather challenging. To study the behavior of isolated buildings as compared to conventional fixed base buildings under actual earthquake scenario, two identical G+8 buildings have been modeled in ETABS. One of the buildings has a conventional fixed base foundation while the other was made to rest over a series of FPB isolators. The main objectives of this study are - (i) to review the literature, covering various types of base isolation systems and the behavior of isolated structures, (ii) to study the various analytical methods, and validate them using the available records, (iii) to develop a simplified model of the base isolated structure and compare its results with 3D analysis in ETABS and also with the available records, and (iv) to study the comparative behavior of identical conventional and isolated buildings for high and moderate intensity earthquakes.

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Fig. 1 - Concept of Sliding Friction Pendulum

Design steps for friction pendulum bearing (Naeim, 1999)-

STEP 1: Radius of friction pendulum is given by- $R = g \times \left(\frac{T}{2\pi}\right)^2$

STEP2: 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**.

2. MATERIALS AND METHODS

The following assumptions were made for modeling the structures in ETABS-

- 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 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.

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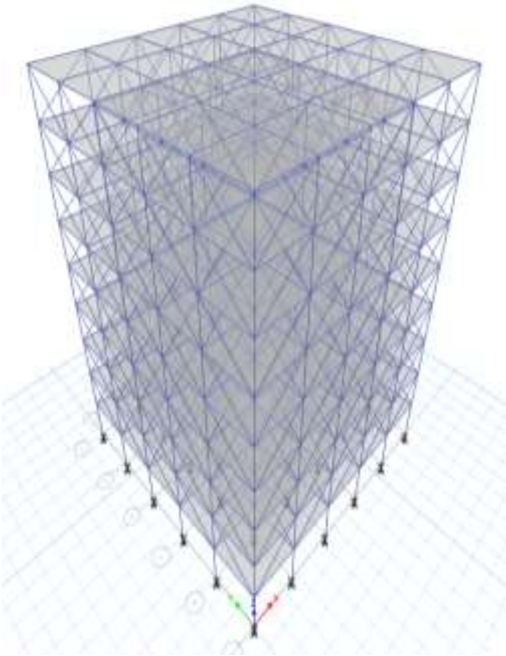

Fig. 2 - Perspective view of the generated model

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	Grade of concrete & steel			M30 & Fe415
9	Beam Size			0.30 m x 0.50 m
10	Column Size			0.30 m x 0.70 m
11	Slab Thickness			0.150 m
12	Wall Thickness			0. 230 m
13	Assumed Strut Size (For Wall Modeling)			230mm x 300mm
14	Loads Applied	DL	Dead Load	Calculated as per Self Weight
			Floor Finish	1 kN/m^2
		LL	Live Load	3 kN/m^2
		EQX	Seismic Load	Calculated as per IS:1893-2002
15	Mass Source (as per IS:1893-2002)			DL + (0.5 x LL)

SN	Specifications	Size
16	Load Combination for Static Analysis	1.2 DL + 1.2 LL + 1.2 EQX

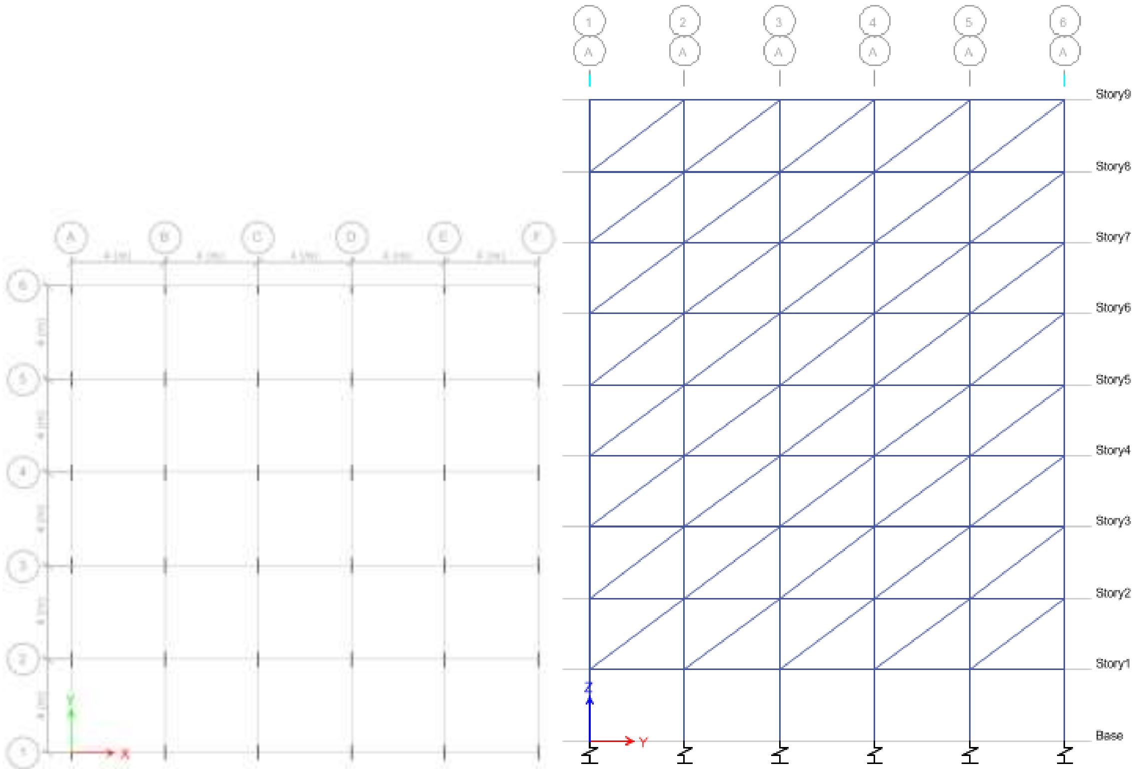

Fig. 3 - Plan and Elevation of the models

The modeling of masonry infill wall in the building is done by equivalent diagonal strut method as given in FEMA-273. The thickness and material properties of diagonal strut are similar to that of infill wall. According to FEMA-273, width of diagonal strut is given by-

$$a = 0.175\left(\lambda_1 h_{col}\right)^{-0.4} r_{\inf}$$

where,

$$\lambda_1 = \left[\frac{E_{me} t_{\inf} \sin 2\theta}{4E_{fe} I_{col} h_{\inf}}\right]^{1/4}$$

and, h_{col} = Column height between center lines of beams (in.),
h_{inf} = Height of infill panes (in.),
E_{fe} = Expected Modulus of Elasticity of Frame material (psi),
E_{me} = Expected Modulus of Elasticity of Infill material (psi),
I_{col} = Moment of inertia of column (in.^{4}),
L_{inf} = Length of infill panel (in.),
r_{inf} = Diagonal length of infill panel (in.),
t_{inf} = Thickness of infill panel and equivalent strut (in.),
θ = Angle whose tangent is the infill height to length aspect ratio (rad),
λ_1 = Coefficient used to determine the equivalent width of infill strut

Time-history analysis provides for linear or nonlinear evaluation of dynamic structural response under loading which may vary according to the specified time function. The biggest advantage of this method is that the Response

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spectrum analysis is limited to linear assumptions on the system's response whereas it is possible to include material or geometrical nonlinearities in time domain analysis. Considering the above, LTHA was best suited for the present study.

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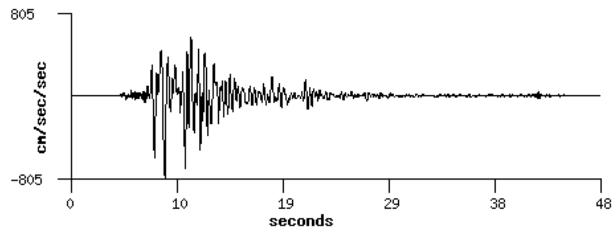

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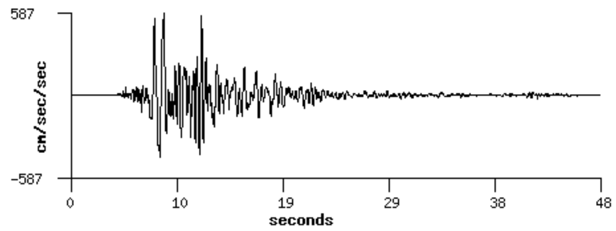

Fig. 4 - Ground motion Records of Kobe, Japan (16 Jan, 1995)used for LTHA
Station - KJMA (Hypocentral Distance = 25.6 km)PGA (cm/s^2): -805.45 (in X direction)
(http://www.strongmotioncenter.org/vdc/scripts/plot.plx?stn=4039&evt=1098)

The following parameters were considered to present a comparison between the models:

- Modal Time Period
- Maximum Storey Drift
- Maximum Storey Displacement
- Storey Shear
- Overturning Moment
- Torsional Moment

These records were scaled to match the target spectrum of Zone V. The general formula for scale factor is given below:

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

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

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Impact Factor: 5.164
CODEN: IJESS7

Table 2 - Scaling of Selected Ground Motion for IDA

PGA for Zone V	PGA of Kobe	Normalized Scale Factor
0.36 g i.e. 3.531 m/s^2	0.717 g i.e. 7.033 m/s^2	0.5021

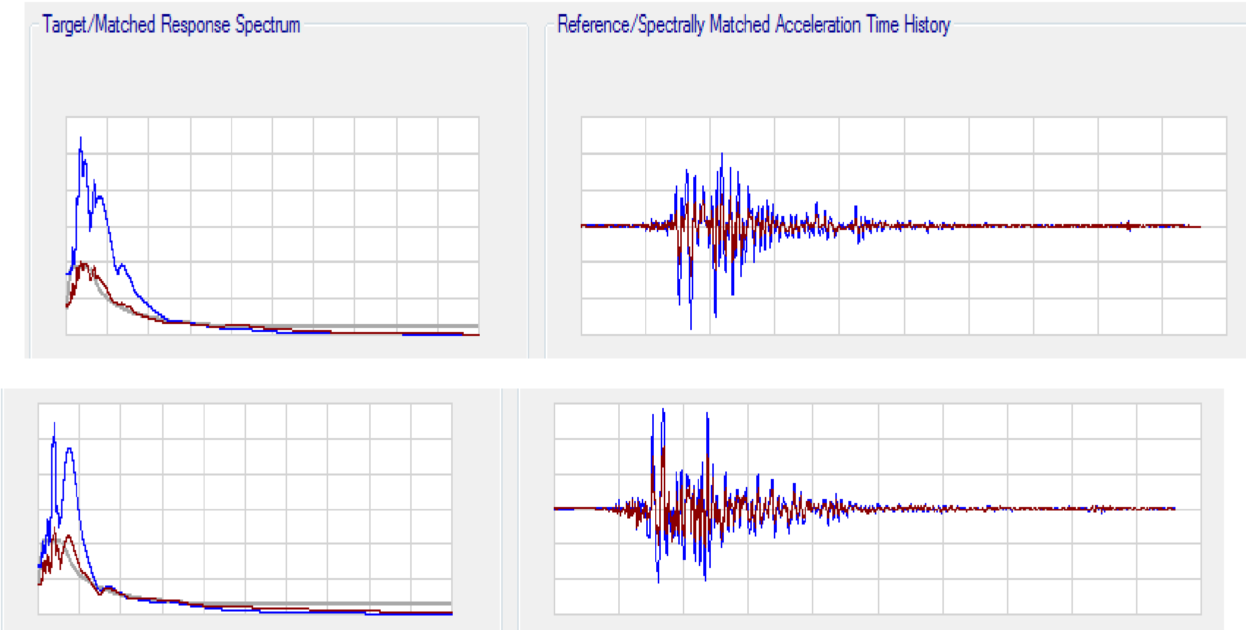

Fig. 5 - Spectral Matching of Selected Earthquake Motion in X & Y directions (in g units)(Records used - Target Spectrum is defined as Response Spectrum for Zone V and Time History records of Kobe, 1995 earthquake along X and Y directions are defined as ground motions recorded at KJM000 and KJM090 stations)

3. RESULTS AND DISCUSSION

a) Modal Time Period (in seconds)-

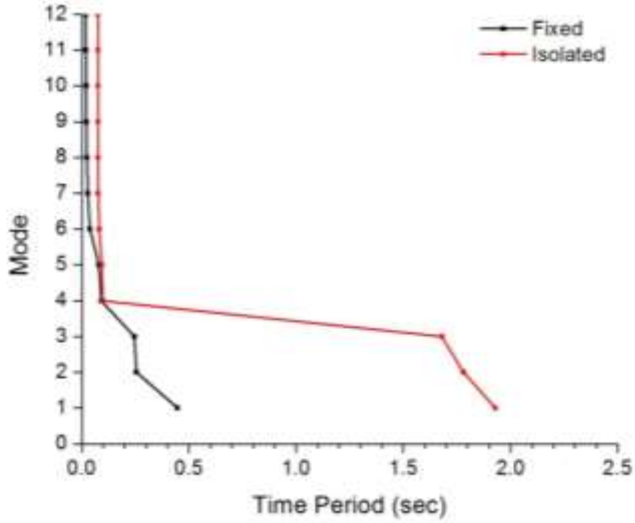

Fig. 6 - Model period for G+8 Building

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CODEN: IJESS7

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 Storey Drift-

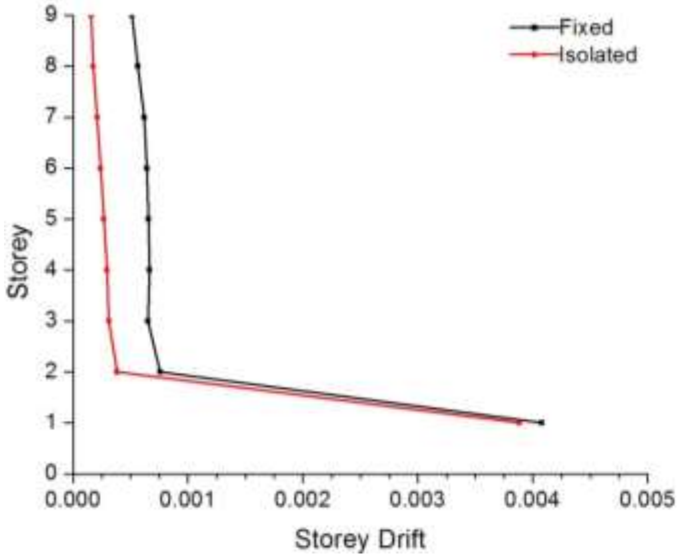

Fig. 7 - Storey Drift along X direction

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.

c) Maximum Storey Displacement (in cm)-

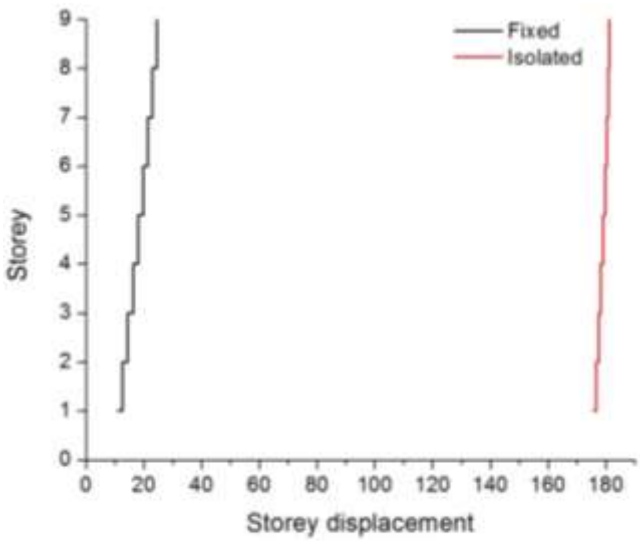

Fig. 8 - Storey Displacements along X direction

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CODEN: IJESS7

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-storey displacement is comparatively lower leading to a more steep graph. This reduced displacement will enable the columns to behave more effectively in the event of an earthquake and prevent buckling failures.

d) Storey Shear (in kN)-

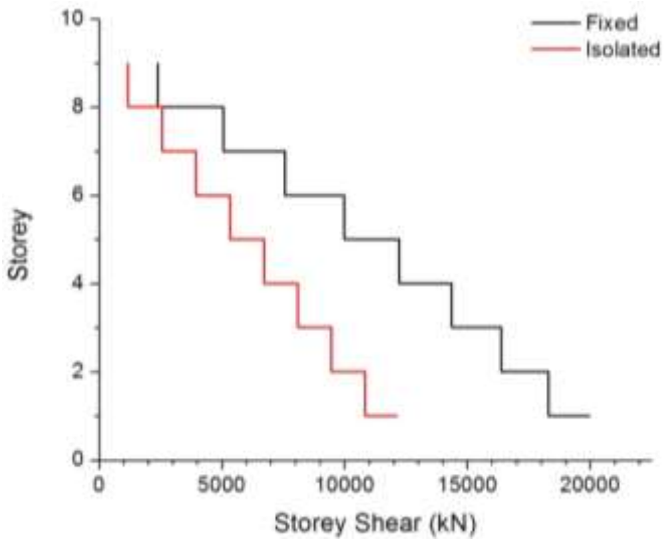

Fig. 9 - Storey Shear at different floors

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. 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 half storey shear. This results in the reduction of inertia forces.

e) Storey Overturning Moment (in kNm)-

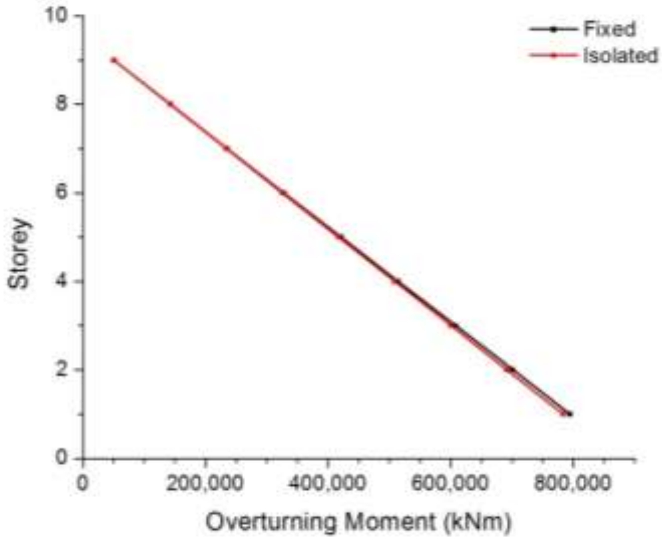

Fig. 10 - Storey Overturning Moments

Storey 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 (in kNm)-

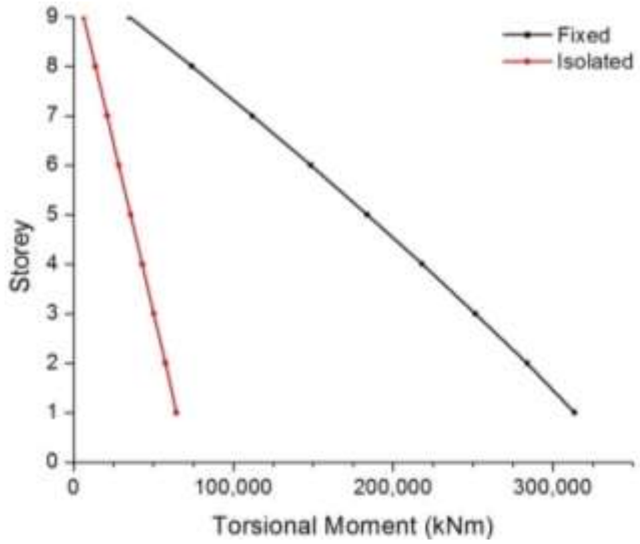

Fig. 11 - Torsional Moments

It is evident from the above figure 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.
be

4. CONCLUSION

It is clear to all that the seismic hazard has to be carefully evaluated before the construction of important and high-rise structures. The present study was carried out for a hypotheticalG+8 storey building. Two models of the same were prepared with one being fixed base and the other being base isolated using FPB.LTHA was carried out and the records of Kobe earthquake of Japan (1995) were used. The radius of the proposed FPB was calculated by the method suggested by Naeim, 1999 and was found to be 0.95m. The building supported on FPB exhibited a much higher time period and its frequency was found to be much lower than the predominant frequencies of ground motion. The effect of infill walls was clearly evident as they proved to be quite effective in reducing the lateral deformations of higher stories. However the absence of lateral struts in the ground floor suggested a behavior mechanism similar to that of soft storey structures. 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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