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Analysis of friction pendulum bearing isolated structure

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Abstract - *Friction pendulum bearings (FPBs) are a type of base isolation technique which essentially detaches structures from the ground to help stabilize the building from the unstable ground motion. FPBs allow superstructures to rest atop two concave surfaces with a ball bearing as a buffer between the two surfaces. During an earthquake the bearings shift against the direction of earthquake, hence by keeping the building stable. This system can be implemented in a vast array of structures, from buildings to bridges and even oil rigs in the middle of the ocean. Implementation of FPBs can help preserve structures for decades, which creates a feeling of security within the inhabitants. Throughout this paper, various structural aspects of building isolated with friction pendulum bearing system such as building deflection , inter story drift and overturning moment were studied. The study was done using the software, E-tabs 2015, by conducting nonlinear time history analysis on the structure. A comparative study was also conducted based on these aspects for single, double and triple concave friction pendulum bearing system and it was found that triple pendulum bearing isolator was superior among the three.*

Key Words:*Base isolation, Earthquake, Friction pendulum system, Friction coefficient, Optimum position*, etc

1.INTRODUCTION

The purpose of this paper is to study the performance of friction pendulum devices during their service life. These bearings are characterized by the capability to undergo large displacements despite their compact size and high re-centering capacity. These properties make this device superior among other commonly used isolation devices such as lead-rubber bearings or spring type isolation systems. In these supports the friction produced during sliding of the surfaces exclusively dissipates the seismic motion while the seismic isolation is obtained by the shifting of the natural period of the superstructure.

The recent seismic events occurred in the regions with high seismic hazard like in Utharakhand (India, 2015) and Japan (2011), have shown that despite the efforts made to reduce and prevent economic losses, casualties and injuries, earthquakes continue to be a huge plague in the world. For mitigating the seismic hazard many seismic construction designs and technologies have been developed over the years and particularly attention has been given to the effects of earthquake in the most vulnerable buildings like multi-storied buildings, bridges, hospitals, data centers, etc.

Many protection systems have been developed and utilized in many applications all over the world, and the seismic isolation has become a relevant and important way to improve the seismic response in the design of new buildings and in the retrofitting of existing ones. Seismic isolation devices are applied between the superstructure and the foundation of the building to decouple the structures from the ground earthquake motion. The Friction Pendulum System (FPS) is a base isolation system that has been won place in the world market. These types of structures are not familiar in India.

In relevant to this study, many past researchers have established their research findings but few of them are outlined and reviewed as Zuhair Abd Hacheem and Israa Khudhair AL-Shimmari [1] (2010) studied the finite element analysis of friction pendulum system (FPS) of a multi-story building and without base isolation subjected to two real different earthquakes (el Centro & Loma prieta) using engineering program (ETABS nonlinear version 9.5) and concluded that drift, displacement and base shear in isolated systems is much smaller in comparison with the classical fixed-base systems. Nikolay Kravchuk, Ryan Colquhoun, and Ali Porbaha California [2]. (2008) developed a base isolation system to physically demonstrate the concept of friction pendulum in the laboratory for earthquake engineering education. The responses of a single degree of freedom system with and without base isolation were studied and compared for free and forced vibrations using the accelerometers attached to the top of the model structures and the system showed a significant improvement in dynamic response of the model structure by reducing the lateral acceleration and increasing the damping of the system. Yu. N. Drozdov, V. A. Nadein, and V. N. Puchkov [3] (2001) studied the performance of sliding systems under near-fault motions and found that friction coefficient of various sliding isolation systems is typically dependent on relative velocity at the sliding interface. The response of building system is analyzed to investigate the performance of sliding system and concluded that sliding base isolation found very effective in controlling seismic response. Fanel Scheaua(2012)[4] conducted a theoretical study on single friction pendulum bearing system and double friction pendulum system, and their applications and concluded that, the friction systems perform very well under a variety of severe earthquake loadings and are quite effective in reducing the large levels of the superstructure's acceleration without inducing large base displacements, comparative study of different base isolation systems has shown that the response of sliding system does not vary with the frequency content of earthquake ground motion. Friction dampers have high potential and low cost and they can be utilized in both energy dissipation and re-centering. M. Malekzadeh And T. Taghikhany[5](2010) studied the seismic behavior of structures isolated by DCFP bearings is compared with the response of the same buildings using the fps bearing. A series of nonlinear dynamic analyses were carried out under ensembles of ground motions at three different hazard levels. The result supports the advantages of dcfp isolation systems and dcfp acts as an adaptive isolation system, since stiffness and damping vary in proportion to the level of input ground motion, and can control peak acceleration and inter story drift together. The specific objectives of study are (i) determination of seismic response of building with and without base isolation system (ii) study the seismic performance of various types of Friction Pendulum base isolation systems (single, double and triple) in terms of building displacement, inter story drift and overturning moment.

1.1 Friction pendulum bearing system

Seismic design of structures is attained by developing a capacity of resistance and deformability of the structure greater than the demand, which is produced due to the ground motion. When an earthquake strikes, a vibration is induced on the structure. A seismic event is manifested by the vibrations induced by the movement of the ground and which in turn produces an inertial force on the structure equal to the product of its masses for accelerations in magnitude and opposite in direction. It is important to increase the resistance of the structure with changes in the intensity of the earthquake to avoid structural damages during a seismic event.

Friction pendulum bearings (FPBs) are a modern sliding based earthquake damage-preventing system and it is been slowly evolving and gaining importance in the last decade. The first official model was designed by Victor Zayas in 1985, and FBS has become a superior safety-assuring system for modern world. Today, FPBs are available in different configurations, including single, double, and triple concave FPB systems. It consists of a bearing bottom plate coated with a sliding material (Teflon), an articulated slider and a bearing top plate. FPB's are provided over the pile cap or column head upon which the superstructure rests. Thereby detaching the superstructure from the substructure and filtering out the earthquake forces affecting the super structure. With the implementation of the FPB's, factors such as base shear, joint acceleration, story drift and displacement of the structure during an earthquake are lowered and hence building is to be designed only for wind and gravity loads. Hence reducing the size of the structural members, resulting in an economic construction.

When an earthquake hits, the top concave surface slides along the bearing positioned at the center. The structure which is resting atop this top plate also moves along till the seismic activity halts, then the bearing returns to its original position, i.e. center of the concave surface. During this process, the excessive seismic energy is dissipated; thereby preventing the future damages and the structure remains in the same vertical axis throughout the seismic event.

There are two stages in the performance of an FPB, a static and a dynamic phase, distinguished by the friction in the sliding interphase. When the lateral forces acting on the structure is below the frictional resistance offered, FBP's acts as a rigid connection transferring the total force between the superstructure and the substructure. But when the excitation force is greater than the static frictional force, the system gets activated. The supported structure moves similar to a simple pendulum, thereby dissipating he hysteretic earthquake force by friction.

Today three types of FPBs are available: single, double, and triple concave friction pendulum isolator. Each of them is evolved over the former and is more effective I n comparison. The design of TFPB's are more complex on comparison with the first FPB system, single friction pendulum bearing. The major difference among the three lies in the number of sliding surfaces. The single concave FPB has only one concave surface, which is on the bottom plate. The top plate has a flat surface with a cavity to accommodate the articulated slider. The double concave FPB differs from the single in terms of the bottom bearing plate which is concave and hence the bearing is not restricted to a single plate . Finally, the triple concave FPB is the same as the double, however with another pair of sliding plates between the outer surfaces and the bearing, making four sliding surfaces. The difference between each three lies in the effectiveness and the designs but their functions do not. Triple concave FPB structures have much higher bearing displacement capacities among the three FPBs, concluding it as the most advanced among the three.

2. MODELING AND ANALYSIS

Modeling and numerical analysis were conducted using the software ETABS Nonlinear version 2015. 25 stories real building was modeled and the properties as described in table 1. were assigned to the structure. The floors and roof were modelled as rigid diaphragms in order to effectively constrain the displacements of all the points making up each floor, the lateral loads are distributed based on the relative stiffness of the resisting elements. To account for the dead weight of the residential Building, the weights exterior walls were calculated and converted into masses. The masses were assigned to the diaphragms as additional area mass. Live loads were also assigned

Table -1: Building description

Particulars	Steel Structure	
Total height of the building	75.3 m	
Height of each story	3m	
Size of beam	Story 1-8	ISMB 550
	Story 8-16	ISMB 450
	Story 16-25	ISMB 350
Size of column	Story 1-8	ISMB 600
	Story 8-16	ISMB 500
	Story 16-25	ISMB 400
Thickness of slab	86mm	
Seismic zone	V	
Soil type	Alluvial	
Response reduction factor (R)	5.0	
Importance factor (I)	1.0	
Seismic zone factor (Z)	0.36	
Grade of concrete	M25	
Grade of reinforcing steel	Fe415	
Grade of structural steel	Fe350	
Density of concrete	25KN/m2	
Diaphragm	Rigid	

The period for the fixed base is identified. Then the calculated friction pendulum bearing properties described in table 1,2and 3 are given as link/ support properties in the software and the base-isolation time history analysis were performed.

Table -2: Link properties of single pendulum isolator

DOF	Trans. Stiffness		Frictional Coefficient		Rate parameter	Radius
	Linear	Non linear				
	kN/m	kN/m	Slow	Fast	sec/mm	m
U1	1094548	1094548				
U2	4378.19	109454	0.02	0.04	0.05	.97
U3	4378.19	109454	0.02	0.04	0.05	.97

Table -2: Link properties of double pendulum isolator

DOF	Trans. Stiffness		Frictional Coefficient		Rate parameter	Radius
	Linear	Non linear				
	kN/m	kN/m	Slow	Fast	sec/mm	m
U1	1133097	1133097				
U2	4532.3	113309	0.02	0.04	0.05	1.907
U3	4532.3	113309	0.02	0.04	0.05	1.907

Table -3: Link properties of triple pendulum isolator

Property	Inner slider	Outer slider
Element height (mm)	45.7	71.2
Elastic stiffness (kN/m)	21234.25	84937
Effective stiffness (kN/m)	8538.95	4856.31
Friction coefficient-fast	0.010	0.040
Friction coefficient-slow	0.005	0.020
Radius (mm)	460	970
Rate parameter (sec/mm)	0.050	0.124

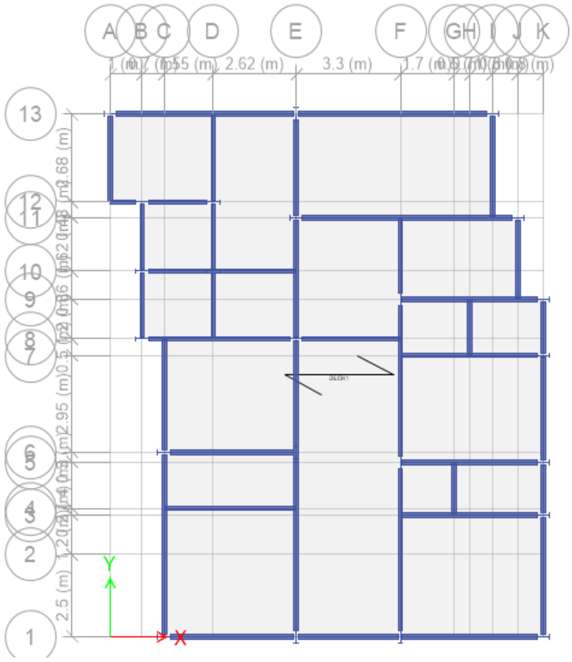

Fig -1: Plan of the proposed building

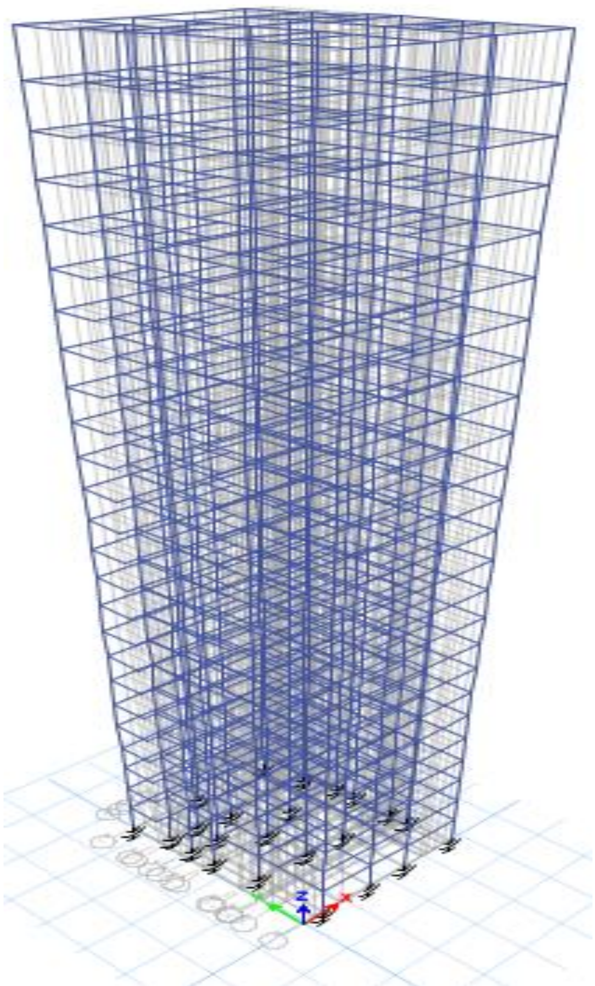

Fig -2: 3D view of the proposed building

The response of the structure with the isolator wass determined. The plan and ETABS models of the building considered for the analysis are shown in Figure 1and 2. The response of the aforementioned systems subjected to a strong earthquake were studied. El Centro earthquake having 500 increment and 0.02 time step was considered for the study

3. RESULTS AND DISCUSSIONS

After conducting the time history analysis on single, double and triple pendulum isolated structures and bare frame, following results were obtained

3.1. Base shear

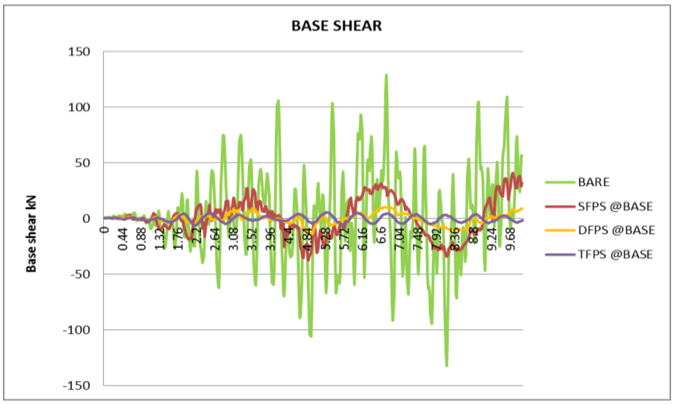

Chart -1: Plot of base shear for different isolators

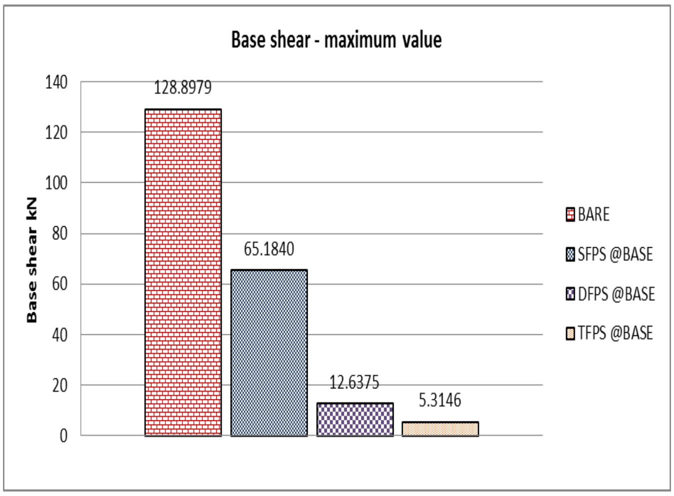

Chart -2: Maximum values of Base shear

From non-linear dynamic time history analysis, the introduction of single, double and triple pendulum bearings results in about 49%, 90% and 95% reduction in maximum base shear respectively

3.2. Story displacement

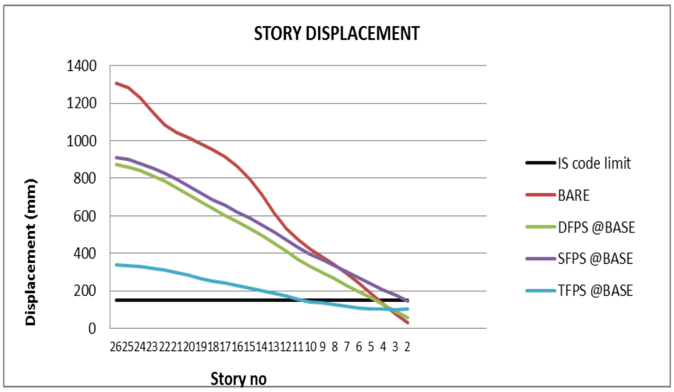

Chart -3: Plot of story displacement for different isolators.

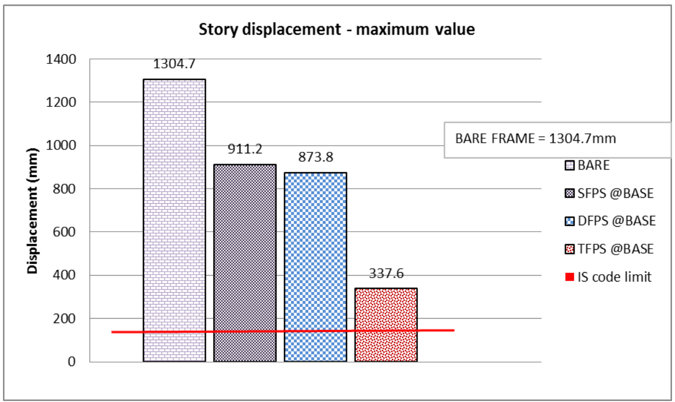

Chart -4: Maximum values of story displacement.

From non-linear dynamic time history analysis, the introduction of single, double and triple pendulum bearings results in about 30%,33% and 74% of maximum story displacement reduction respectively. But it may be noted that the obtained values are greater than that of the limiting value described in IS 1893-2002 i.e. 0.002 times of height of building

3.3. Story drift

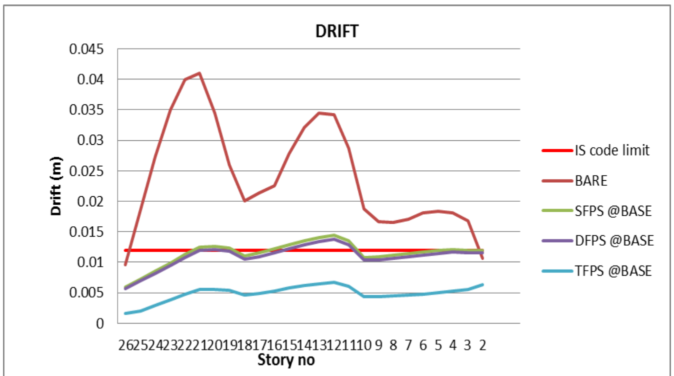

Chart -5: Plot of story drift for different isolators.

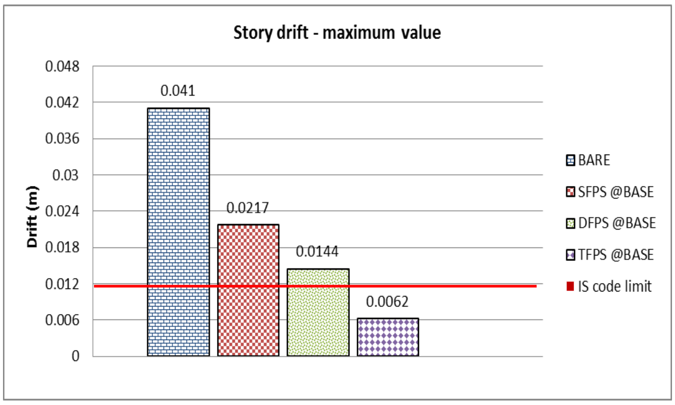

Chart -6: Maximum values of story drift.

From non-linear dynamic time history analysis, the introduction of single, double and triple pendulum bearings results in about 64%, 47% and 84% reduction in maximum story drift respectively. But it may be noted that the among the obtained result only the maximum value drift in double and triple pendulum bearing isolated structures are smaller than that of the limiting value described in IS 1893-2002 i.e. 0.004 times of height of story.

3.4. Story overturning moment

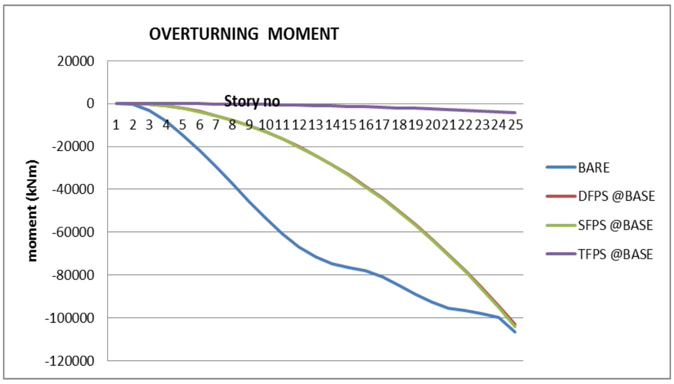

Chart -7: Plot of story overturning moment for different isolators.

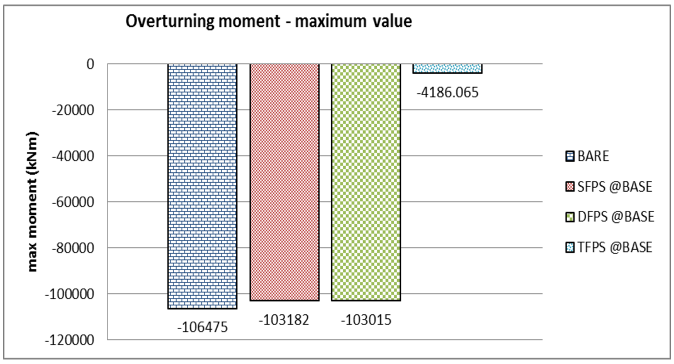

Chart -8: Maximum values of story overturning moment.

4. CONCLUSIONS

This paper assessed the overall behavior of friction pendulum isolates building under lateral earthquake loads from which the following conclusions can be drawn based on the above results.

- The restoring forces developed on double and triple friction pendulum bearings were 1.22 and 11.04 times that of single friction pendulum bearing respectively.
- For building with base isolation, the base shear, drift, displacement and overturning moment values are considerably reduced due to the higher time period resulting in lower acceleration acting on the structures.
- Numerical study was conducted on a 25 storied real structure considering fixed base and isolated base with single, double and triple pendulum isolators. The triple pendulum isolator was found superior among the three in terms of story drift, displacement, moment and base shear. But none of the above structures confirmed to the safety limit described in IS 1893-2002, in terms of drift and displacement together.
- To make the proposed structure stable, floor isolation along with the base isolation using FPS have to be provided at suitable heights

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