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A STUDY ON RESPONSE OF BASE ISOLATED STRUCTURE UNDER NEAR-FAULT GROUND MOTION

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Abstract — *This dissertation evaluates the seismic performance of a G+4 storey reinforced concrete building equipped with Triple Friction Pendulum Bearings (TFPB) under near-fault ground excitations characterized by forward-directivity and fling-step pulses, and compares it with far-field records. A validated nonlinear model in SAP2000 (Fast Nonlinear Time History Analysis) is used to simulate 15 earthquake records consist of five far-field, five near-fault with forward directivity and five near-fault with fling step. Results show that TFPB effectively extends the fundamental period and significantly reduces base shear and roof accelerations relative to a fixed-base system, with broad-stable hysteresis loops indicating high energy dissipation. Near-fault pulses impose notable larger displacement demands, peak isolator displacements and top-story drifts increase, with the most critical demands observed for long-period, high-velocity pulses. While isolation controls force demands, serviceability checks for isolator displacement capacity and top-floor drift govern design in near-fault cases. The study confirms TFPB's suitability for low-to mid-rise buildings in high seismicity, highlights the need for pulse-aware selection of radii and friction properties, and recommends displacement-capacity verification and performance-based criteria for near-fault applications.*

Keywords- *Base isolation, Triple friction pendulum isolator, Seismic Performance, Far-field ground motion, Near-fault ground motion, SAP2000.*

I. INTRODUCTION

An Earthquake is the shaking of upper crust of the earth, much energy of the earth's core is release suddenly in the form of horizontal and vertical seismic waves. The seismic activity of a specific area refers to that earthquake frequency, time period and size. Major seismic activity or shaking is occurs due to movement of tectonic plates of earth, which is result of huge energy release at specific center of earth's core. An intense slippage or rupture towards fault line results in abrupt release of elastic energy stored in rocks that are subjected to huge strain. Seismic isolation and energy dissipating systems are developed by duration to prevent/reduce damage to structure and offer more time for escape in the major earthquakes.

In recent years, Seismic base isolation has gained widespread attention as a leading solution for earthquake resistant structure design. Their rising popularity can be credited to a combination of effective structural performance, better energy dissipation. Earthquake generates dangerous ground acceleration frequency with large amount of energy hits at base of Structure, which acts as complex seismic excitation force. In minor seismic activities, the non-structural elements are damaged; still the building is remains useful, but due to serviceability problems the structure becomes useless.

Base isolation is One of the best adaptive solution for earthquake engineering, which is decouples the superstructure from its foundation. . It is the most effective energy dissipation systems available for reducing sudden collapse in hazardous seismic forces. The natural vibration time period of the structure is significantly increases due to much lower excitation frequency. Due to these, the risk of resonance becomes normalized. Due to base isolation availability, superstructure behaves relatively very stiff and acts as a rigid body. The general classification of base isolation system is elastomeric and sliding bearings. . The lead rubber bearing and high damping rubber bearings are common examples of elastomeric bearings. And the flat plate bearing, concave pendulum bearings is main type of sliding bearings system.

The mickle estimable and impressive discovery for seismic isolation is concave pendulum bearing system. Because of restoring force and energy, this system is exhibits delicate operation under hazardous earth tremor and it's credible for reduction of storey accelerations. The construction of this devices consists various arrangements of spherical concave friction plates and rigid internal slider. Single friction pendulum system (FPS), double friction pendulum system and most adaptive triple friction pendulum system is a type of concave friction pendulum systems. As name suggest, three friction pendulum mechanisms are evolves to control seismic response of considered structure.

The base isolation extends the fundamental vibration period of structure, and thus decreases pseudo-acceleration for the considered design spectrum. The primary reason for expediency of base isolation is extension in first mode period. The natural fundamental modal time period of structure is increases with height of the structure and therefore taller structures have larger time period which is sufficient to attract low earthquake forces without isolation. Hence, the credibility of base isolation is limited to low and medium-rise buildings which has low natural time period. The basic and important concept of seismic base isolation is to minimize the response to ground motions by, decreasing stiffness, addition in natural time period and provision to increase energy dissipation by damping improvement.

II. ANALYSIS OF CONSIDERED FIVE STOREY STRUCTURE

This study is deal with the analysis of G+4 storey symmetric regular RC frame building. A building is considered for most mechanism of ground motions to compare structural response parameters with each ground motions applied. Figure 2.1 shows geometry and 3D shape of each sections of structure considered for study.

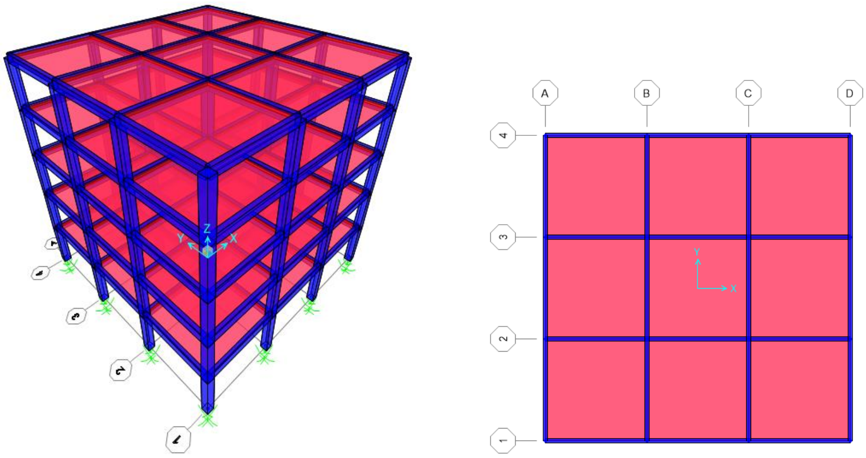


Figure 1. Geometry and Plan view of building structure considered

Table 1. Structural properties of building considered

Description	Dimensions (m)
Column	0.45 X 0.45
Beam	0.23 X 0.50
Slab	0.20
Storey height or floor height	3.0
No. of floor	G + 4
Grid size	15.0 X 15.0
Bay size	5.0 X 5.0
Grade of concrete	M30
Grade of steel	Fe415
Floor finish load	1.5 KN/m^2
Live load	4.0 KN/m^2

The triple friction pendulum isolator is located between base of column and fixed ground. Axial load of column is transferred through TFP isolator to footing and then ground.

III. PROPERTIES OF MODELLING TFP ISOLATOR AND GROUND MOTION CONSIDERED

Table 2. Geometric properties of TFP isolator

Property	R_1=R_4	R_2=R_3	h_1=h_4	H_2=h_3	d_1=d_4	d_1=d_4	R_{1eff}=R_{4eff}	R_{2eff}=R_{3eff}
Value (m)	3.556	0.647	0.161	0.121	0.566	0.081	3.395	0.526

Table 3. Details of considered earthquake ground motions

No.	Year	Earthquake	Magnitude, M_w	Station	PGA (g)
Far-field ground motion					
1	1940	Imperial valley, FF1	6.95	EL Centro	0.313
2	1989	Loma prieta, FF2	6.9	Capitola	0.420
3	1987	Superstition Hill, FF3	6.7	EL Centro	0.512
4	1994	Northridge, FF4	6.7	Canoga park	0.477
5	1994	Northridge, FF5	6.7	Saticoy station	0.529
Near-fault with directivity focusing					
1	1994	Northridge, FN1	6.7	Newhall	0.720
2	1994	Northridge, FN2	6.7	Rinaldi	0.890
3	1992	Landers, FN3	7.3	Lucerne valley	0.710
4	1979	Imperial valley, FN4	6.4	EL Centro array 5	0.370
5	1979	Imperial Valley, FN5	6.4	EL Centro array 7	0.460
Near-fault with fling step effect					
1	1999	Chi Chi, FL1	7.6	TCU129	0.610
2	1999	Kocaeli, FL2	7.4	YPT	0.230
3	1999	Chi Chi, FL3	7.6	TCU074	0.590
4	1999	Chi Chi, FL4	7.6	TCU052	0.440
5	1999	Chi Chi, FL5	7.6	TCU068	0.500

IV. RESPNOSE OF CONSIDERED STRUCTURE

The seismic analysis of considered G+4 storey building is carried out by fast nonlinear time history analysis in SAP2000 software. The all below displayed results are obtained from the analysis of single model with distinct fifteen ground motion records in SAP2000 software.

A. Modal time period

The natural modal time periods for initial 3 modes are shown in figure 4.4. In which, comparison structure. It seems that huge reduction in TFPB isolated building compared to fixed base, due to reduction in base shear and displacement capacity of triple friction pendulum isolator.

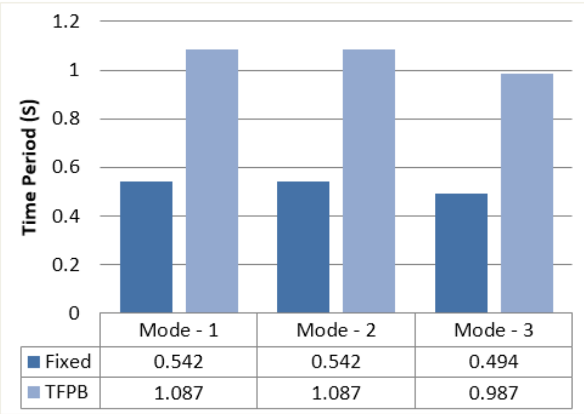
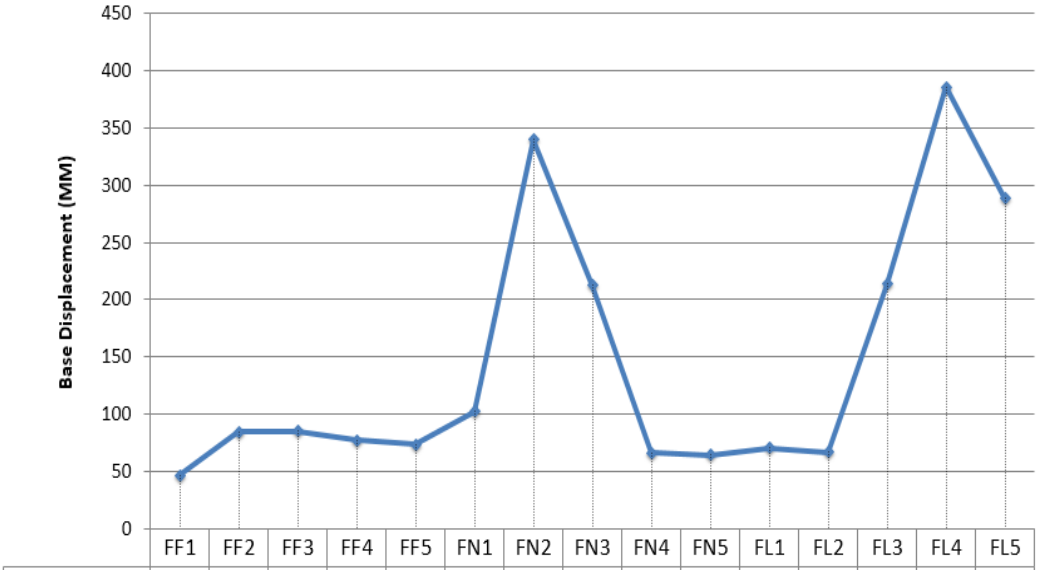


Figure 2. Modal time period of fixed and TFPB isolated building

B. Base displacement

The TFP bearing has effectively reduced base shear and overall stiffness of building. The graphical presentation shows the peak base displacement at end node of column of considered five storey building.

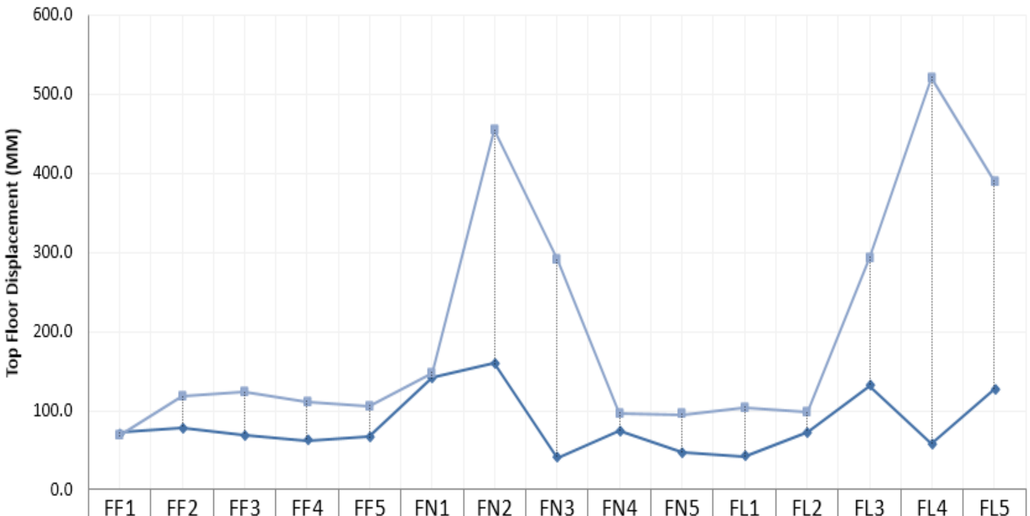


	FF1	FF2	FF3	FF4	FF5	FN1	FN2	FN3	FN4	FN5	FL1	FL2	FL3	FL4	FL5
Base disp.(mm)	46.6	84.5	85	77	73.2	102.2	340.2	212.6	65.9	64.5	70.3	67	213.5	386	288.3

Figure 3. Peak Base displacement of TFPB isolated building

C. Top floor displacement

In TFP bearing isolated structure, the top floor displacement is significantly increased for near-fault ground motions compared to far-field. Specially Northridge 1994, FN2 and Chi Chi earthquakes 1999, FL4 are responses huge parameters compared to fixed base.

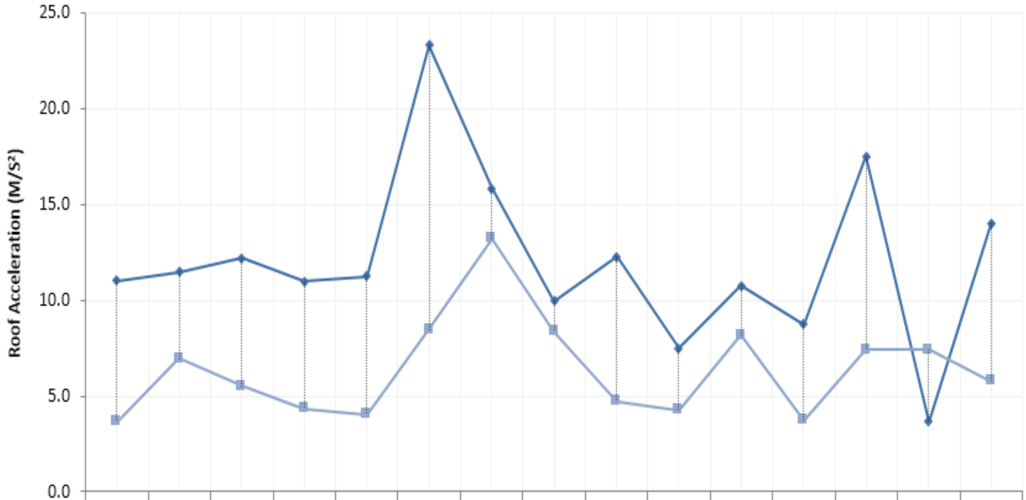


	FF1	FF2	FF3	FF4	FF5	FN1	FN2	FN3	FN4	FN5	FL1	FL2	FL3	FL4	FL5
Fixed	72.2	78.4	69.3	62.5	66.7	141.7	160.0	40.8	74.5	47.5	42.5	73.0	131.8	57.9	127.5
TFPB	68.7	117.9	123.4	111.3	105.6	147.6	454.5	291.1	96.5	95.3	104.0	97.4	293.3	521.4	390.0

Figure 4. Peak top floor displacement of fixed base and TFPB isolated building

D. Roof acceleration

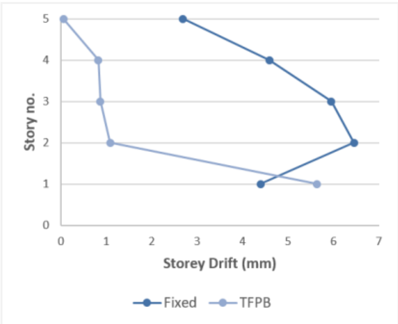
Methods for computation of seismic response acceleration are divided in two ways one is overall floor acceleration or average floor acceleration and second is roof acceleration for better results in seismic reflection of considered structure. The maximum roof acceleration for base isolated building is seems in 1994 Northridge (FN2) earthquake is 13.2 M/s2, due to high peak ground acceleration (PGA). As shown in graphical representation only for 1999 Chi Chi earthquake (FL4) roof acceleration is went more than fixed base building.



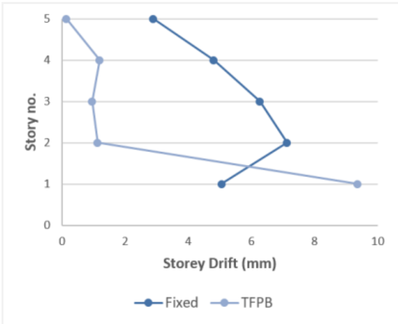
	FF1	FF2	FF3	FF4	FF5	FN1	FN2	FN3	FN4	FN5	FL1	FL2	FL3	FL4	FL5
Fixed	11.0	11.5	12.2	11.0	11.3	23.3	15.8	10.0	12.3	7.5	10.8	8.8	17.5	3.7	14.0
TFPB	3.7	7.0	5.5	4.4	4.0	8.5	13.2	8.4	4.7	4.3	8.2	3.7	7.4	7.4	5.8

Figure 5. Roof acceleration of fixed base and TFPB isolated building

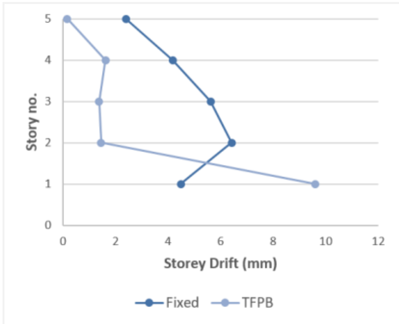
E. Storey drift



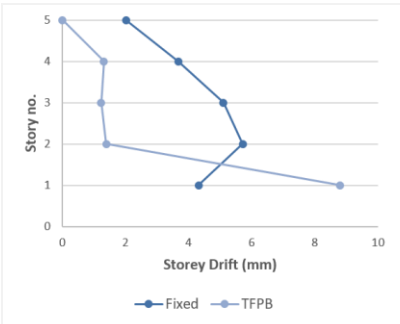
FF1



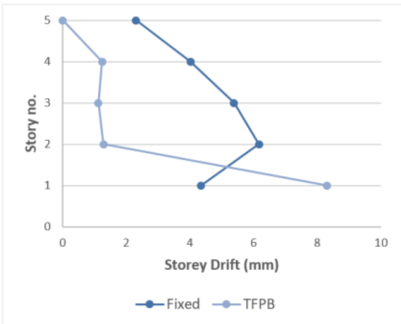
FF2



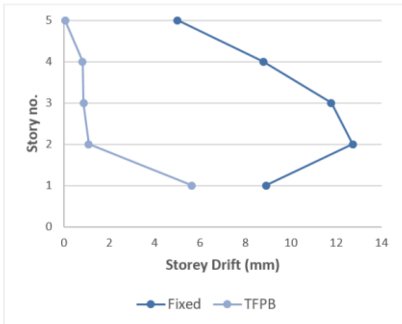
FF3



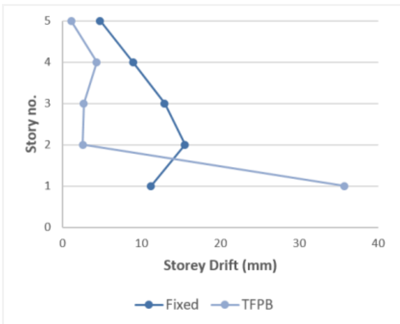
FF4



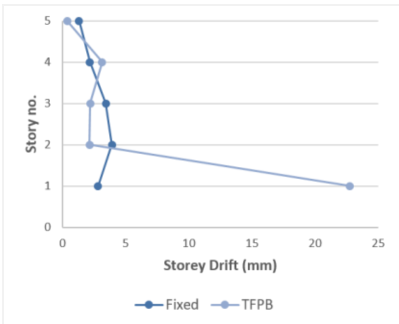
FF5



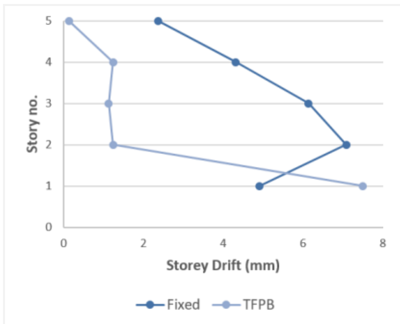
FN1



FN2



FN3



FN4

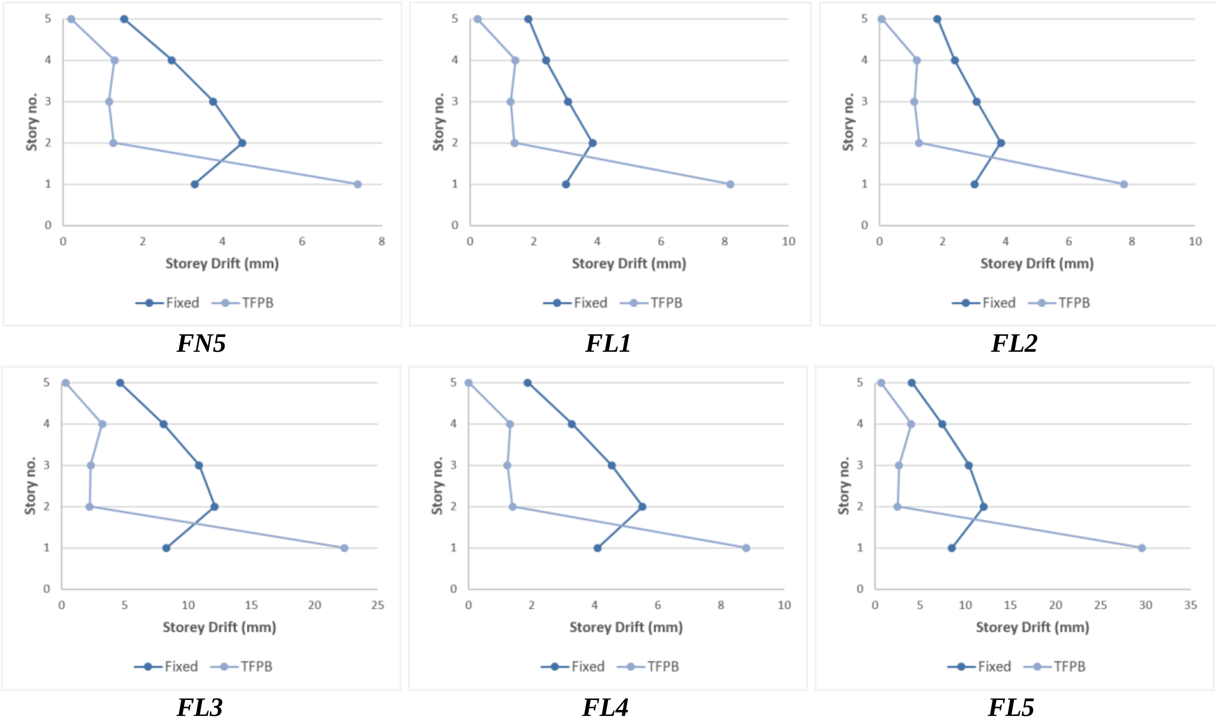


Figure 6. storey drift diagram comparison with all graound motions

The individual graphs presents comparison of storey drift between fixed base and triple friction pendulum bearing base isolated building structure.

F. Base shear

The comparison of base shear for each time history indicates effectiveness of TFP bearing isolator in each type of seismic ground accelerations and variable striking mechanisms.

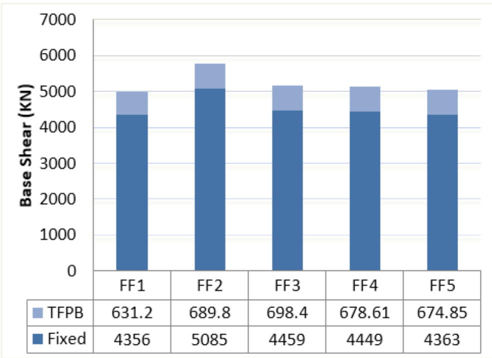


Figure 7. Base shear for far-field ground motions

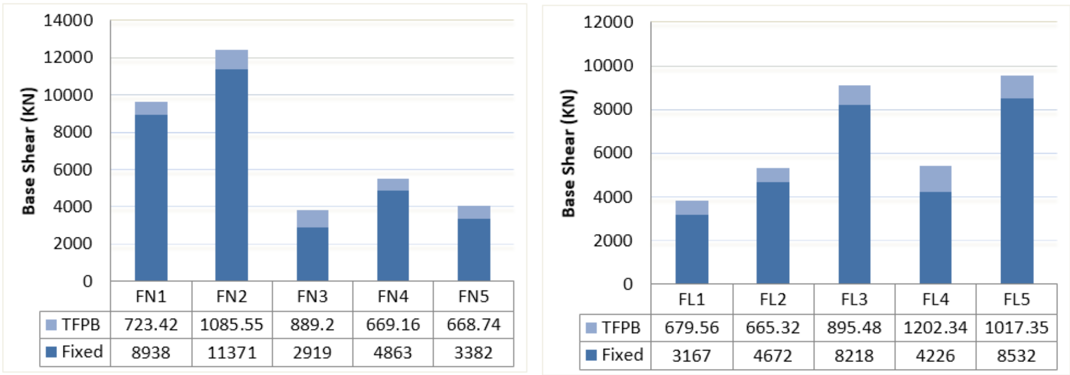
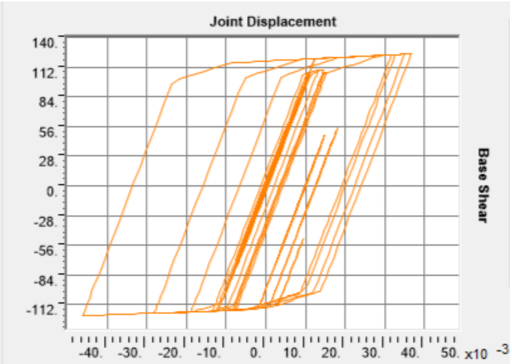


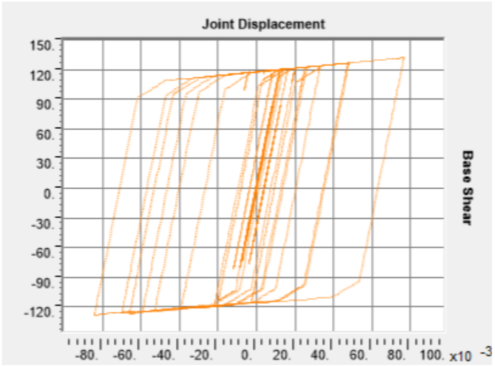
Figure 8. Base shear for near-fault ground motions

G. Force-displacement behavior

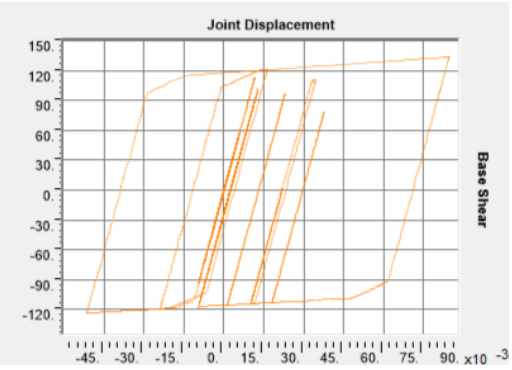
The plotted area of hysteresis loop determines the amount of dissipated energy by TFP bearing for considered building structure during the each earthquake ground motions.



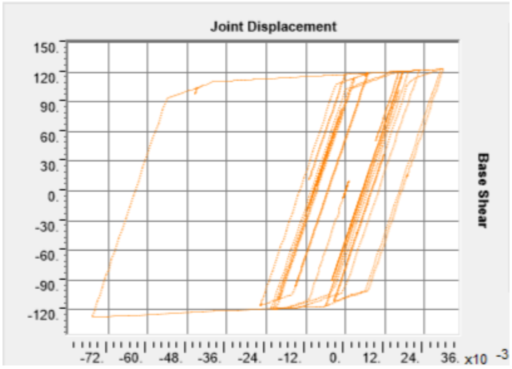
FF1



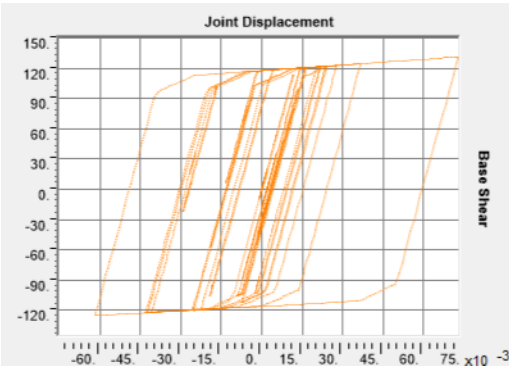
FF2



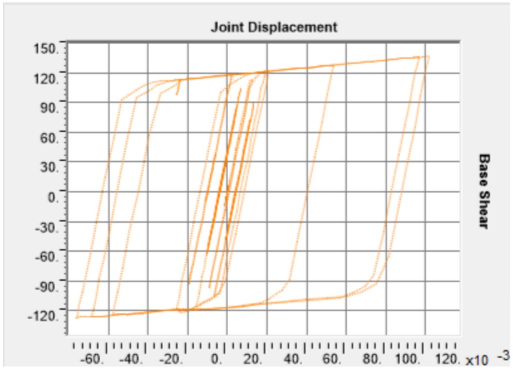
FF3



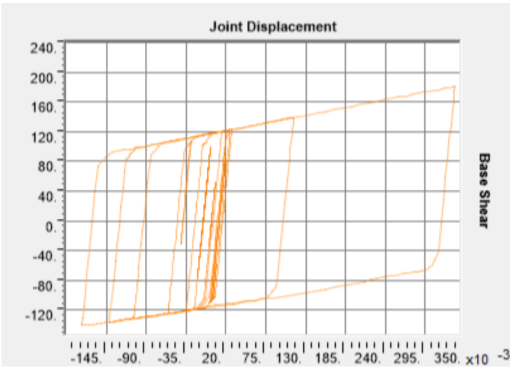
FF4



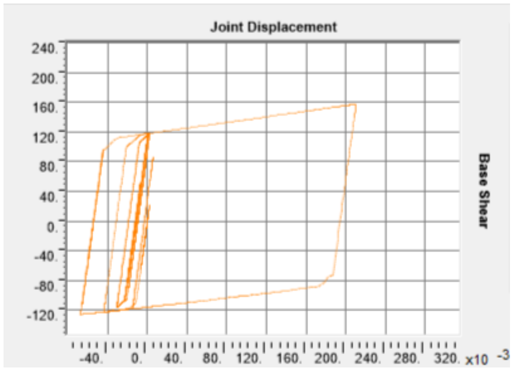
FF5



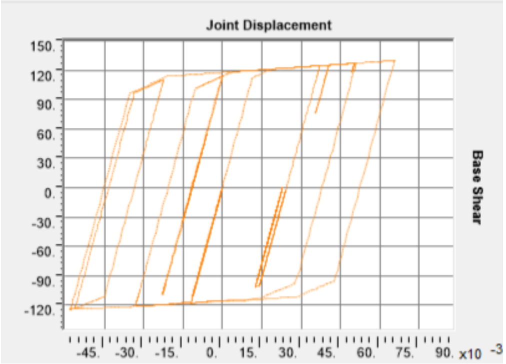
FN1



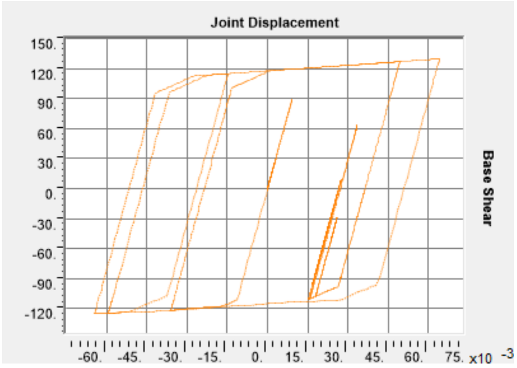
FN2



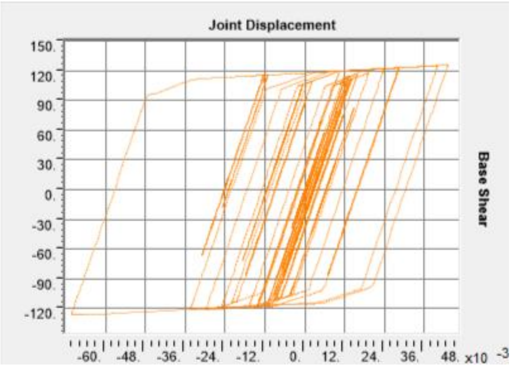
FN3



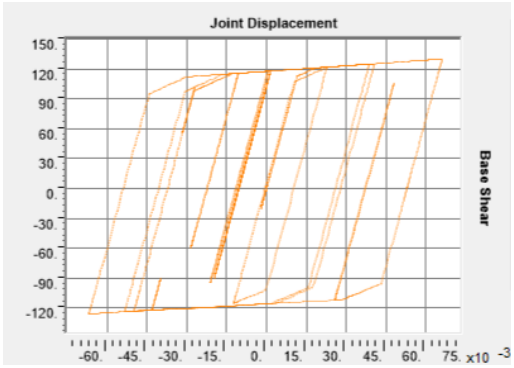
FN4



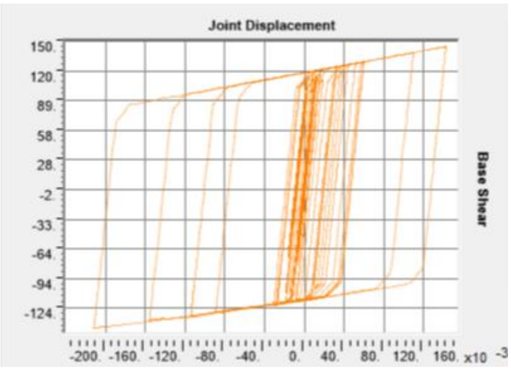
FN5



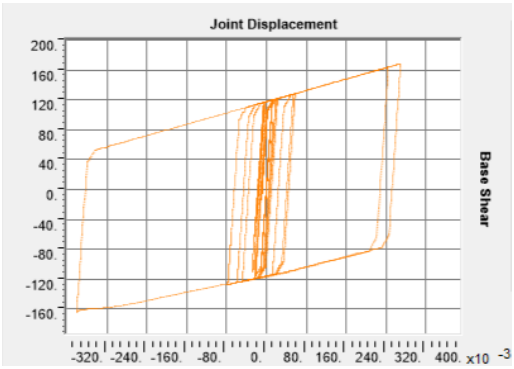
FL1



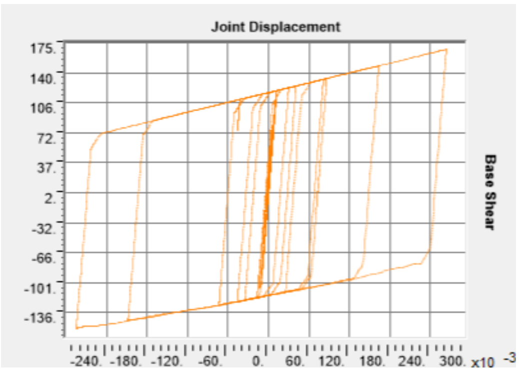
FL2



FL3



FL4



FL5

Figure 9. Force-Displacement behavior for far-field & near-fault ground motions

V. CONCLUSION

The Triple Friction Pendulum Bearing (TFPB) system significantly improved the seismic performance of the G+4 storey RC building compared to the fixed-base structure. On the basis of presented results, the conclusions derived from the study are mentioned below,

a) Base isolation increased the fundamental time period of the structure, which helped to reduce the transmission of earthquake forces to the superstructure.
b) The TFPB-isolated building showed considerable reduction in base shear and roof acceleration under both far-field and near-fault earthquake motions.
c) Near-fault ground motions produced much higher displacement demands than far-field records due to the presence of pulse-type effects such as forward directivity and fling-step behavior.
d) The maximum isolator displacement and top-floor displacement were observed during Chi-Chi earthquake-FL4 and Northridge earthquake records-FN2, indicating the critical influence of long-period velocity pulses.
e) Although TFPB effectively controlled structural forces, higher storey drift and displacement responses were noticed under severe near-fault excitations.
f) The hysteresis loops obtained from nonlinear time-history analysis confirmed stable energy dissipation characteristics of the Triple Friction Pendulum Bearing system.
g) Fast Nonlinear Analysis (FNA) in SAP2000 was found effective for capturing nonlinear seismic response with acceptable computational efficiency.
h) This study confirms that, TFPB is more suitable for low-to-medium rise buildings located in high seismic zones where near-fault earthquake effects are significant.

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