Seismic Response of Silo Supporting Structure Isolated with Triple Friction Pendulum System under Near-Fault Ground Motions

[1]Akash Thummar, [2]V. R. Panchal

[1]Post graduate Student (Structural Engineering), M. S. Patel Department of Civil Engineering, Chandubhai S. Patel Institute and Technology, Charotar University of Science and Technology, Changa, Gujarat, India

[2]Professor and Head, M. S. Patel Department of Civil Engineering, Chandubhai S. Patel Institute of Technology, Charotar University of Science and Technology, Changa, Gujarat, India

thummarakash100@gmail.com[1]

vijaypanchal.cv@charusat.ac.in[2]

Abstract: Silos are generally used for storing the grains, cement and any solid, liquid and powder material. In present time, Silos are considered as a special structure. The main purpose of this study is to investigate dynamic response of silo isolated with Triple Friction Pendulum System (TFPS) and Friction Pendulum System (FPS). A 4940 tonnes capacity silo, which is located in a seismic area with ground acceleration $a_g = 0.2g$ and Spectrum Period T_C = 1.0 sec. The supporting structure has an octagonal shape. TFPS and FPS are provided between superstructure and supporting structure. The dynamic analysis of silo has been carried out under near fault earthquake ground motion by using the software SAP2000. The results show that silo isolated with TFPS decreases the effect of seismic response as compared to silo isolated with FPS.

Keywords – Seismic Response, Isolation System, Time History Analysis, Triple friction pendulum system, Friction pendulum system.

I. INTRODUCTION

Earthquake is one of the dominant natural hazards on the earth and has affected numerous cities and villages of almost every continent. Such ground motions cause significant damage to the various man-made structures. Numbers of earthquake occurs all over the world every year. Thus, it is compulsory to design structures that are earthquake resistant.

Earthquake is the natural shaking of the ground and is not a regular phenomenon. This shaking causes a destructive effect on the structure. To design the structure for earthquake loading, dynamic analysis is required.

Now-a-days the structures are made tall and big with different shapes and sizes. Mainly silos, storage tanks, water tanks, etc. are important structures and they have broad use in industries and other activities. Seismic protection is an important requirement which save the structures from damaging effect of earthquakes. Seismic design of structures using base isolation technique is a large area of research and development [1].

Base isolation systems are the most successful and widely accepted methods for reducing structural vibration. Various base isolation systems namely Elastomeric Bearing, Frictional Bearing and Roller Bearing have been developed to study effectiveness of base isolation system. Sliding type isolator works on principle of friction. Sliding type isolators includes Friction Pendulum System (FPS), Variable Frequency Pendulum Isolator (VFPI), Triple Friction Pendulum System (TFPS), etc. In this study, TFPS and FPS isolation systems are used.

II. PROPERTIES OF SILO

Silo used to store lime stone powder is considered in this analysis. Line diagram of silo structure is shown in Figure 1. The silo contains a storage cell with a volume of 3800 m^3 and a centrically braced support structure, with "X" and inverted "V" shape diagonals [2]. The model of the silo structure is shown in Figure 2.

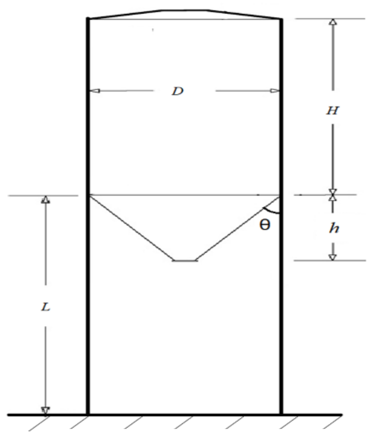


Figure 1 Line diagram of silo structure

2.1 Silo Structure details

- Cylindrical storage cell diameter D = 15.30 m
- Height of silo H = 15.80 m
- Funnel height h = 12.25 m and angle of θ = 60°
- Height of support structure L = 30 m
- Support structure column = 8 numbers at an angle of 45°
- Rectangular hollow section is used for bracing

- Rolled profile section is used for making beams
- HEA and TUBO sections are as per Euro steel table.

Table 1 Section detail

Members	Sections
Column	HEA 500
Beam	HEA 300
Bracing	TUBO 100 X 100 X 10

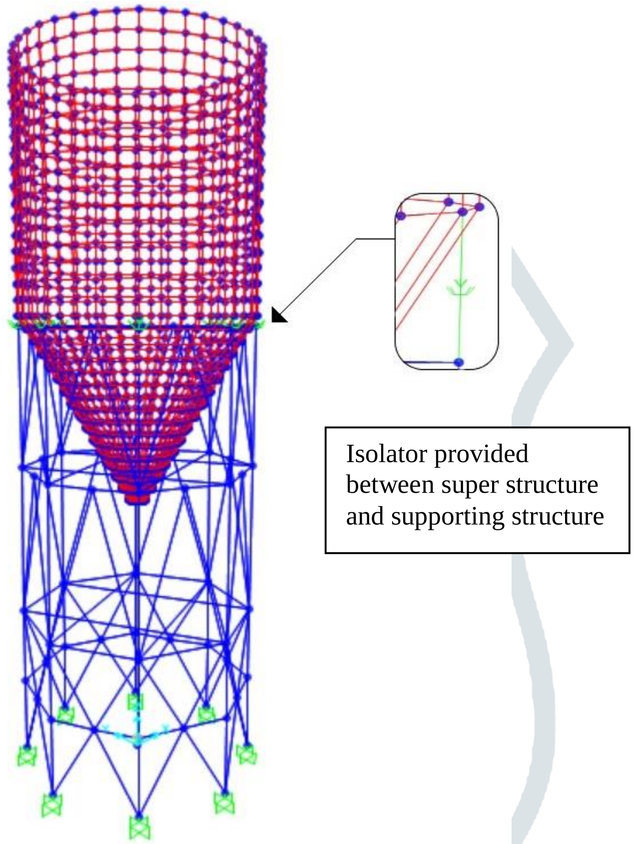


Figure 2 Isolated silo model in SAP2000

2.2 Time period of silo structure

After the model analysis was completed, it is observed that the first two modes of vibration are correlated modes having their fundamental vibration periods T_1 = 0.8149 sec. and T_2 = 0.7960 sec.

III. DETAILS OF FRICTION BEARINGS

For this study work, silo is modelled in SAP2000 as shown in Figure 2. Non-linear time history analysis is carried out using six near fault earthquake ground motions. Geometrical properties of isolator for modelling of FPS and TFPS are given below [3-5].

3.1 Friction Pendulum Bearing (FPS)

The Friction Pendulum bearing consists of a base-plate with an articulated slider and a spherical concave dish and the shear force-horizontal deformation behaviour is illustrated in Figure 3. Under the horizontal motion, the spherical concave dish displaces horizontally relative to the articulated slider and base-plate as shown in Figure 4.

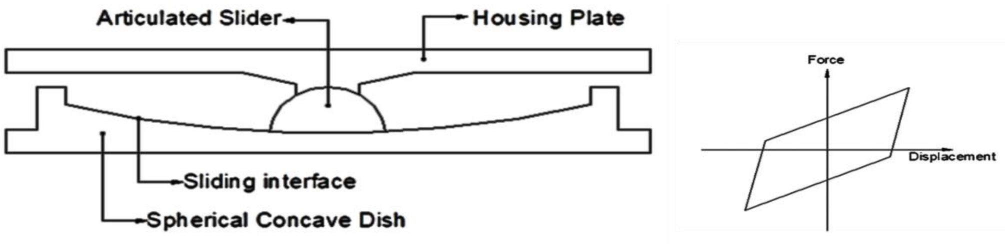
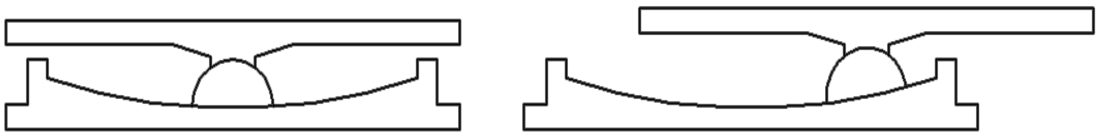


Figure 3 Schematic diagram and Hysteresis loop of FPS [6]



(a) (b)

Figure 4 Possible position of FPS [6]

3.2 Properties of Friction Pendulum Bearing (FPS)

Table 2 FPS Details

Radius of curvature of sliding surface R_{eff}	0.30 m
Displacement capacity D	1 m
Friction coefficient μ	0.05

Table 3 Linear Properties and Non-Linear Properties of FPS

Linear Properties	Elastic stiffness K_{eff1} (kN/m)	20490.34
Non-Linear Properties	Effective stiffness K_{eff2} (kN/m)	605775
	Friction coefficient, slow & fast μ	0.05
	Rate parameter	1
	Net pendulum Radius (m)	0.3

3.3 Triple Friction Pendulum Bearing (TFPS)

The Triple Pendulum bearing is modern sliding system containing better seismic performance with three sliders as the rigid slider, articulated slider and plate as shown in Figure 5. As the ground motions become stronger, the bearing displacements increase as shown in Figure 6.

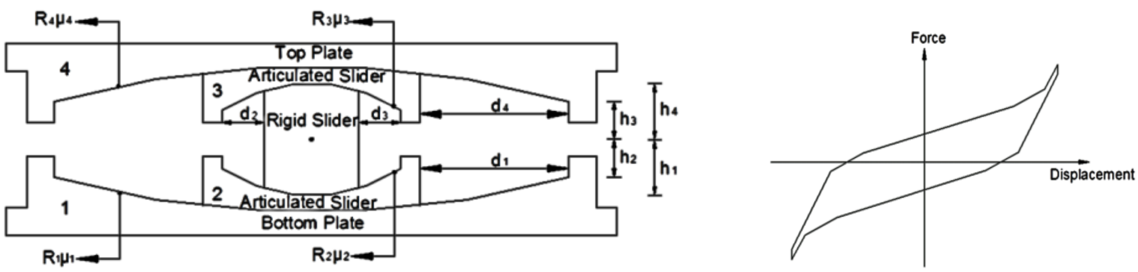


Figure 5 Schematic diagram and Hysteresis loop of TFPS [6]

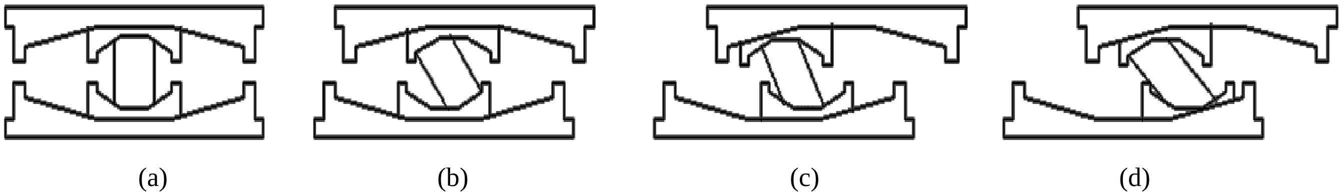


Figure 6 Possible position of TFPS [6]

3.4 Properties of Triple Friction Pendulum Bearing (TFPS)

Table 4 TFPS Details

Radius of curvature of sliding surface	$R_{eff\,1} = R_{eff\,4}$	0.1727 m
	$R_{eff\,2} = R_{eff\,3}$	0.0280 m
Displacement capacity of slider	$d_1 = d_4$	0.4302 m
	$d_2 = d_3$	0.0698 m
Friction coefficient	$\mu_2 = \mu_3$	0.015
	μ_1	0.035
	μ_4	0.07

Table 5 Linear Properties and Non-Linear Properties of TFPS

Parameters		TFPS			
		Outer Top	Outer Bottom	Inner Top	Inner Bottom
Linear Properties	Elastic stiffness K_{eff1} (kN/m)	17819.56	17819.56	17819.56	17819.56
Non-Linear Properties	Effective stiffness K_{eff2} (kN/m)	848085	424042.5	181732.5	181732.5
	Friction coefficient slow & fast μ	0.070	0.035	0.015	0.015
	Rate parameter	1	1	1	1
	Radius of sliding surface (m)	0.1727	0.1727	0.028	0.028
	Stop distance (m)	0.4302	0.4302	0.0698	0.0698

Table 6 Properties of the FPS and TFPS having the same effective time period and design displacement

Isolator	T_{eff} (s)	D (m)	R_{eff1}	R_{eff2}	R_{eff3}	R_{eff4}	μ_1	μ_2	μ_3	μ_4
FPS	1	1	0.30	-	-	-	0.05	-	-	-
TFPS	1	1	0.1727	0.028	0.028	0.1727	0.035	0.015	0.015	0.070

IV. Time History Data, Hysteresis Behaviour of FPS and TFPS and Comparison of Base Shear

The six different near-fault ground motions are used for the analysis. Table 7 shows the peak ground displacement (PGD), peak ground velocity (PGV) and peak ground acceleration (PGA) data for the different earthquake ground motions.

Table 7 Near-Fault Earthquake Ground Data

Earthquake	Recording station	PGA (*g*)	PGV (m/s)	PGD (m)
Imperial Valley,1979	El Centro Array #5	0.37	0.98	0.765
Imperial Valley, 1979	El Centro Array #7	0.46	1.13	0.491
Northridge, 1994	Newhall	0.72	1.19	0.381
Landers, 1992	Lucerne Valley	0.71	1.36	2.3
Northridge, 1994	Rinaldi	0.89	1.75	0.391
Northridge, 1994	Sylmar	0.73	1.22	0.311

4.1 Hysteresis loop of silo isolated with FPS and TFPS under near fault ground motion.

4.1.1 Hysteresis behavior of FPS under near fault ground motion

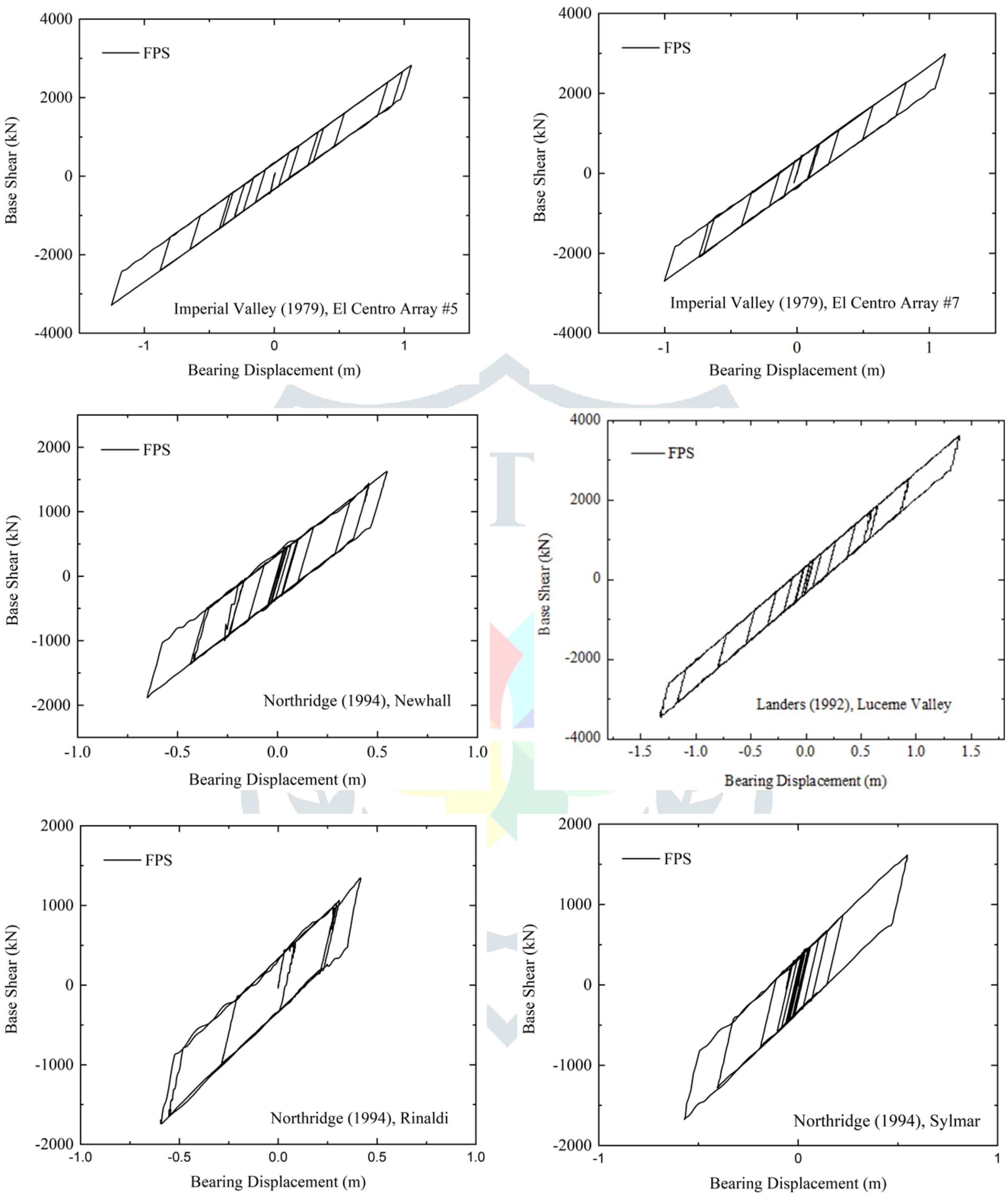


Figure 7 Hysteresis loop of silo isolated with FPS under near fault ground motion

Figure 7 show the Hysteresis behaviour of FPS. These figures represent the results of base shear and bearing displacement at six different near-fault ground motions.

4.1.2 Hysteresis behavior of TFPS under near fault ground motion

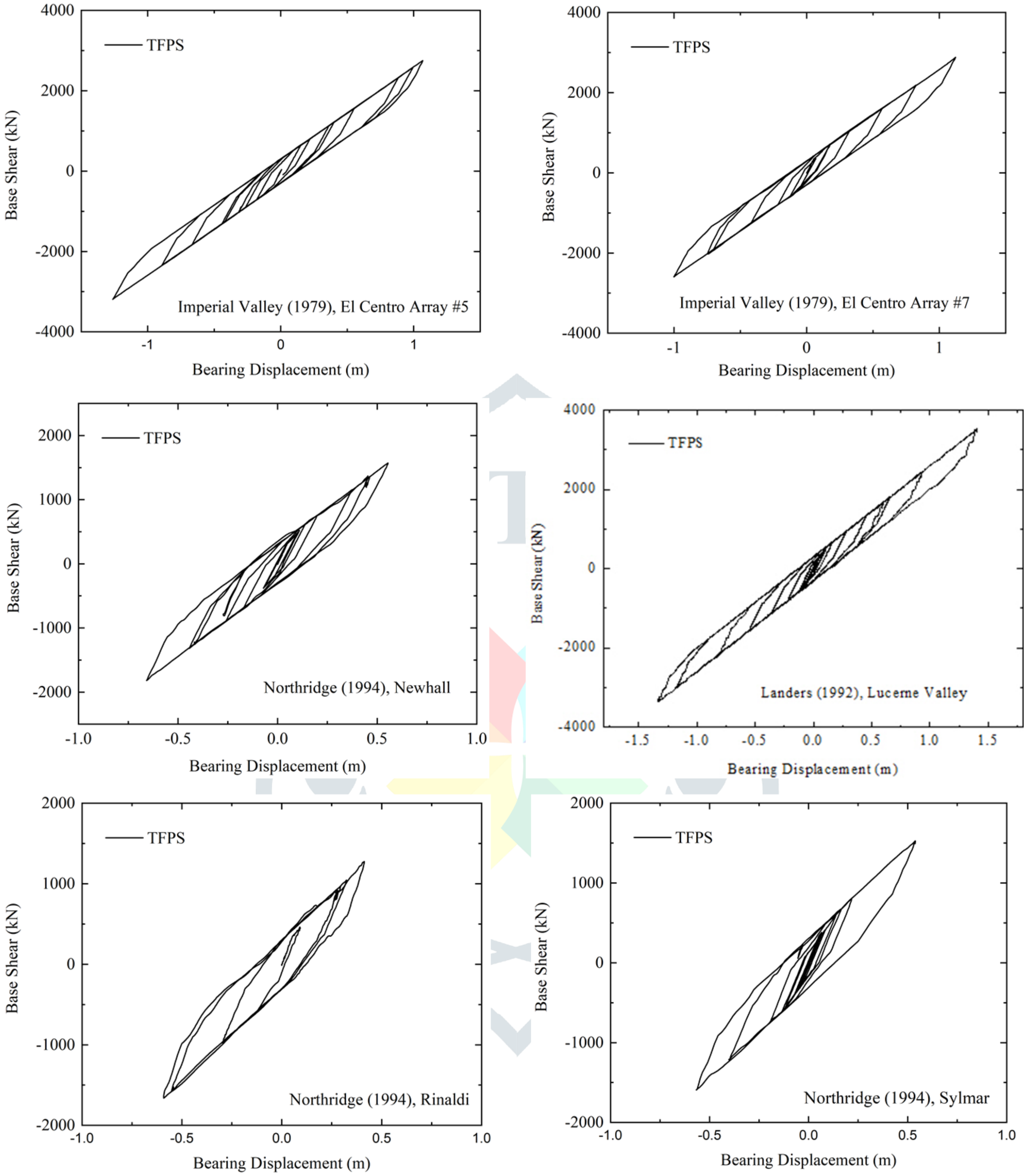


Figure 8 Hysteresis loop of silo isolated with TFPS under near fault ground motion

Figure 8 show the Hysteresis behaviour of TFPS. These figures represent the results of base shear and bearing displacement at six different near-fault ground motions.

4.2 Variation of Base Shear of Non-isolated silo and silo isolated with FPS and TFPS under near-fault ground motion.

4.2.1 Comparision of Base Shear with FPS and Non-isolated silo

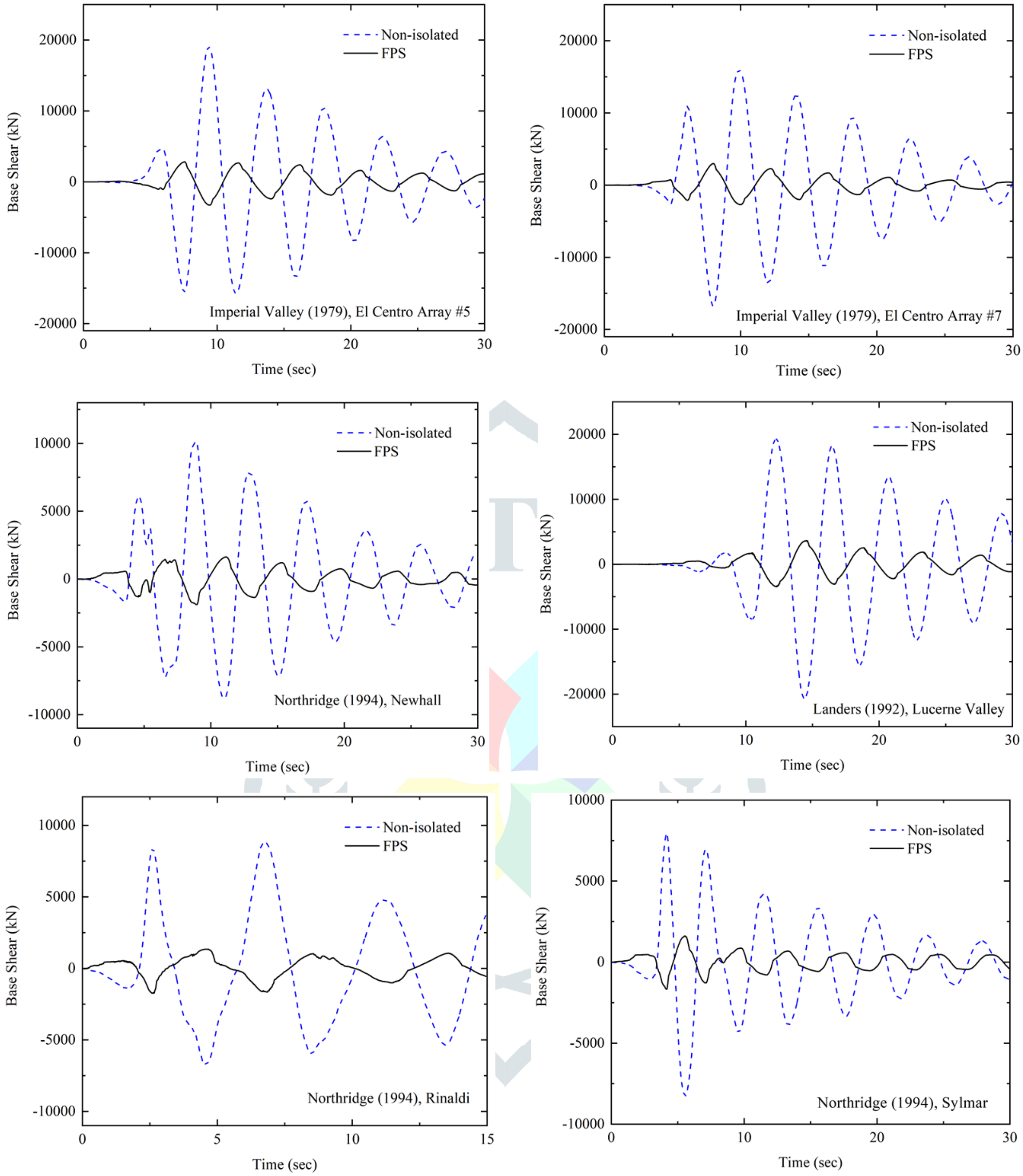


Figure 9 Comparison of Base Shear for Non-isolated silo and silo isolated with FPS

Figures 9 shows the comparison of Base shear of silo isolated with FPS and Non-isolated silo. These figures represent the results of Base shear at different near-fault ground motions.

4.2.2 Comparision of Base Shear of silo isolated with TFPS and Non-isolated silo

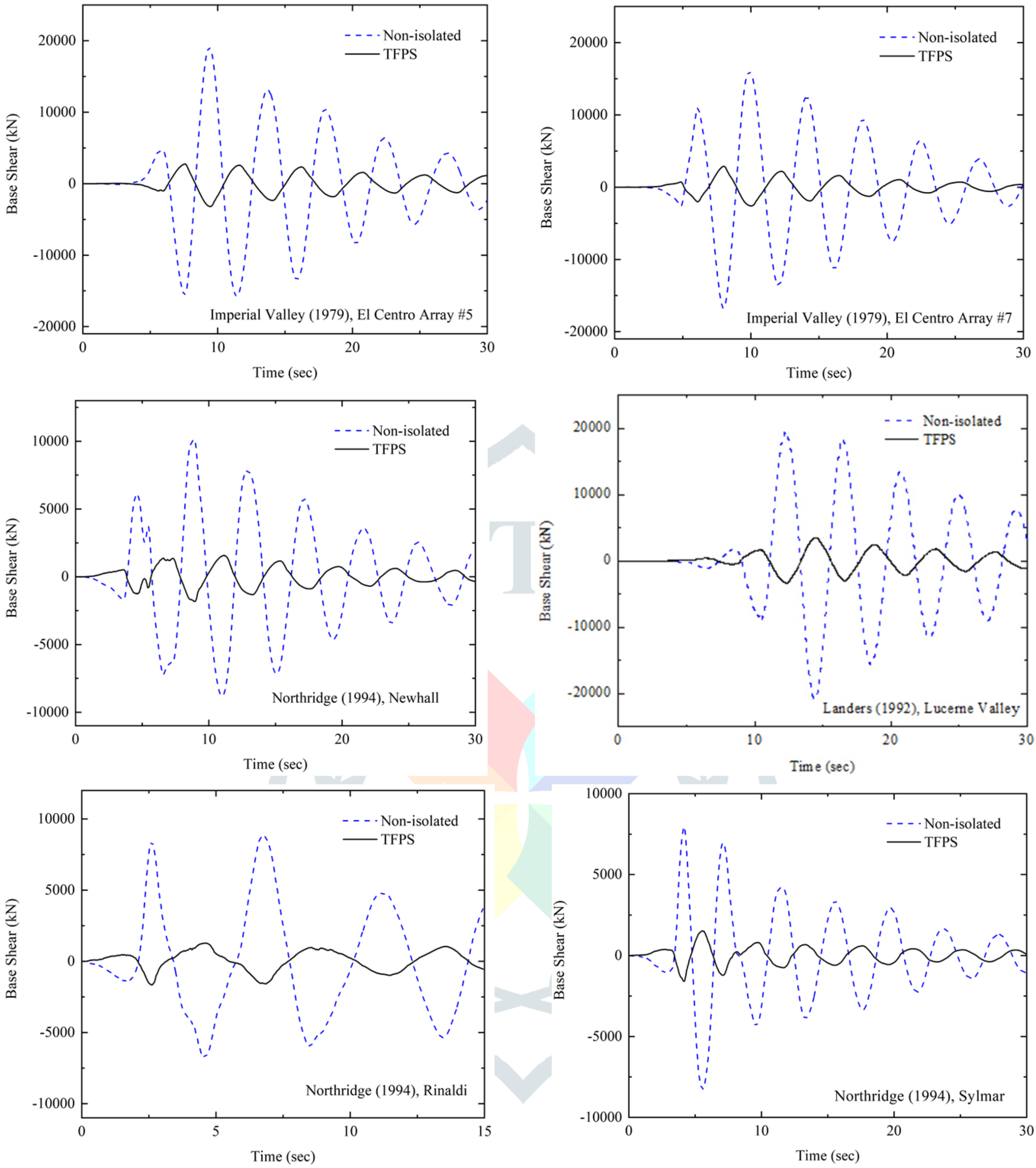


Figure 10 Comparison of Base Shear for Non-isolated silo and silo isolated with TFPS

Figures 10 shows the comparison of Base shear of silo isolated with TFPS and Non-isolated silo. These figures represent the results of Base shear at different near-fault ground motions.

V. ANALYSIS RESULTS

Table 8 Comparison of Base shear between Non isolated and silo isolated with FPS & TFPS

BASE SHEAR (kN)			
	Non isolated	TFPS	FPS
1979 Imperial Valley, California (Array #5)	19025.80	3193.42	3289.38
1979 Imperial Valley, California (Array #7)	16779.95	2883.48	2988.31
1994 Northridge, California (Newhall)	10167.66	1818.72	1881.65
1992 Landers, California (Lucerne Valley)	20728.46	3359.41	3622.17
1994 Northridge, California (Rinaldi)	8826.49	1661.13	1741.27
1994 Northridge, California (Sylmar)	8262.52	1593.56	1676.37

Table 9 Comparison of Displacement between TFPS and FPS

DISPLACEMENT (m)		
	TFPS	FPS
1979 Imperial Valley, California (Array #5)	1.263	1.253
1979 Imperial Valley, California (Array #7)	1.123	1.120
1994 Northridge, California (Newhall)	0.659	0.653
1992 Landers, California (Lucerne Valley)	1.404	1.393
1994 Northridge, California (Rinaldi)	0.591	0.595
1994 Northridge, California (Sylmar)	0.566	0.570

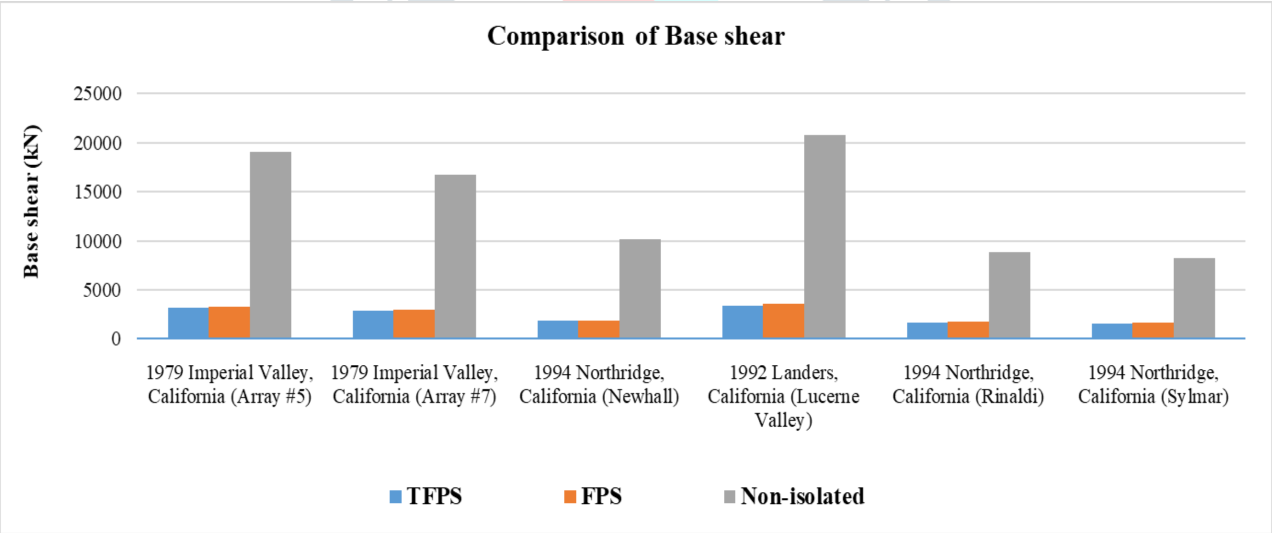


Figure 11 Comparison of Base Shear for Non-isolated and silo isolated with FPS and TFPS

VI. CONCLUSIONS

In this study, the isolators are designed for equal effective displacement capacity and effective time period. The dynamic response of silo structure isolated with TFPS and FPS is investigated under different near fault ground motions. Isolated silo structure is analyzed using SAP2000. From the study following conclusions are observed.

1) Bearing displacement is approximately same in both TFPS and FPS isolator.
2) After installation of TFPS, base shear is reduced as compared to the FPS.
3) TFPS is effective as compared to FPS in base isolation of silo as base shear is reduced in case of TFPS as compared to FPS.

VII. REFERENCES

[1] Kanyilmaz A. and Castiglioni C. A. (2017), “Reducing the seismic vulnerability of existing elevated silos by means of base isolation devices”, *Engineering Structures*, Vol. 143, pp. 477-497.

[2] Bitca D. V., Ursu E., Ione P. (2015), “Seismic base isolators for a silo supporting structure”, Mathematical Modelling in Civil Engineering, Vol. 11, pp.1-9.

[3] Sarlis A. A. S., Constatinou M. C., “Modeling Triple Friction Pendulum Isolators in Program SAP2000”, Report, June 27, 2010.

[4] Kitayama S., Constatinou M. C., “Evaluation of Triple Friction Pendulum Isolator Element in Program SAP2000”, Report, August 27, 2015.

[5] Sodha A. H., Soni D. P., Desai M. K., Kumar S. (2017), “Behaviour of Quintuple Friction Pendulum System under Near-Fault Earthquake”, *Journal of Earthquake and Tsunami*, Vol. 12, pp. 1-17.

[6] Parekh S., Kumar M., Panchal V. R. (2016), “Seismic Response of Cable Stayed Bridge Isolated with Triple Friction Pendulum System”, *International Journal of Innovative Research in Science and Engineering*, Vol. 2, pp. 202-215.