American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-03, Issue-11, pp-30-37
www.ajer.org

Research Paper Open Access

Earthquake Response Mitigation of RC Building Using Friction Pendulum System

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ABSTRACT : *Earthquake hazard mitigation is very sensitive issue now a day's therefore researchers are struggling for optimum solution since last few decades. Base isolation technique is one of the effective techniques which give better results seismic hazard mitigation under earthquake excitation particularly in building structures, bridges and water tanks etc. Base isolation reduces not only the effects of earthquake acceleration to be transmitted to the structures, but also protects the content of building while simultaneous supporting the mass of structure. This study proposed a realistic ten storey RC building which is model as shear type lumped mass having single degrees-of-freedom at each floor level. This building is isolated by Friction Pendulum System of sliding base isolated type and excited under unidirectional ground motion due to four realistic earthquakes namely, Imperial Valley, 1940, Loma Prieta, 1989, Kobe, 1995 and Northridge, 1994. The governing equation of motion for the building solved using Newmarks method whereas isolation system is modelled by Wen's model. The effectiveness of proposed isolation system and building response has been evaluated by coding in MATLAB 8.2 computing software. Further, effectiveness of isolation system is also studied in terms of peak responses of building. The results obtained from the study underscored that Friction Pendulum System works effectively in limiting the building responses during excitation due to earthquakes.*

KEYWORDS : *Earthquake Response, Base isolation, Friction Pendulum System, Mitigation*

I. INTRODUCTION

Earthquake is natural and unpredictable phenomena, which has tremendous destructive energy in the form of ground shaking during an earthquake leads to enormous amounts of energy released. This release of energy can cause by sudden dislocation of segments of crust, volcanic eruptions. In the process of dislocations of crust segments, however, leads to the most destructive earthquakes may cause significant life hazard therefore, past disastrous earthquakes underlined the need of seismic hazard mitigation. Structural vibrations produced due to earthquake can be controlled by various means that is, increasing strength, stiffness and ductility. The researchers are considerably involved in developing seismic resistance through various techniques as conventional and Non-conventional technique. The non-conventional technique in which controlling devices are added based on which control system is employed that is, active, passive or combined. Further, passive control system in which base isolation system is one of the most popular technique and works with the concept of reducing fundamental frequency of structural vibration to a value lower than the seismic energy containing frequency. During earthquake, flexible device get momentum as a result building gets decoupled from the ground motion leads to avoid certain devastating hazard.

In relevant to above study, many past researchers have established their research findings but few of them are outlined and reviewed as Jangid and Datta [1] (1995) presented an updated review on behaviour of various base isolated systems applied to the buildings subjected to seismic excitation. The study includes literatures on theoretical aspects, parametric behaviour of base isolation building and experimental studies to verify some theoretical findings. P. Bhaskar Rao and R. S. Jangid [2] (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 analysed to investigate the performance of sliding system and concluded that sliding base isolation found very effective in controlling seismic response. Matsagar and Jangid [4] (2004) performed the computational study on structural responses and bearing displacement for the various isolation systems during impact upon adjacent structures. From the study, it is observed that increase in the building flexibility causes to increase in superstructure acceleration and decreases in bearing displacement marginally. S. M. Dumne *et al* [5] (2012) studied the effectiveness of semiactive hybrid control involving base isolation for seismic performance of connected dissimilar buildings. The effective analysis in terms of peak responses have been evaluated by taking numerical example of realistic coupled RC buildings subjected to unidirectional earthquake excitation. From the numerical study, it is observed that semiactive hybrid control involving sliding base isolation not only effective in controlling the seismic responses but also avoids the damages due to pounding. 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 Friction Pendulum base isolation system in terms of peak response reduction and (iii) comparative study of peak responses of base isolated and non-isolated building.

II. PROBLEM IDENTIFICATION

A realistic ten storey RC building isolated with Friction pendulum system (FPS) and assuming strata at the foundation level is hard which is excited by unidirectional ground motion due to earthquake. The details of design parameters are, plan dimension 20m X 30 m, grade of concrete M20, size of column 300 X 300 mm, beam size 300 X 450 mm, slab thickness 135 mm, structural damping equal to 5% and thickness of infill wall is 230 mm. The plan and elevation of proposed building model are shown in figure 1.

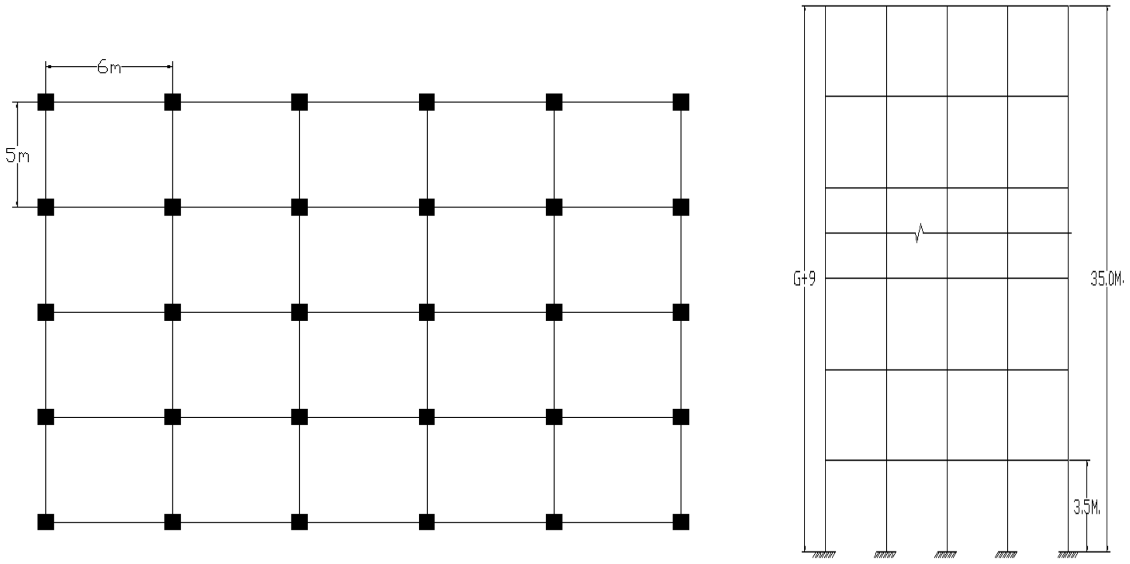


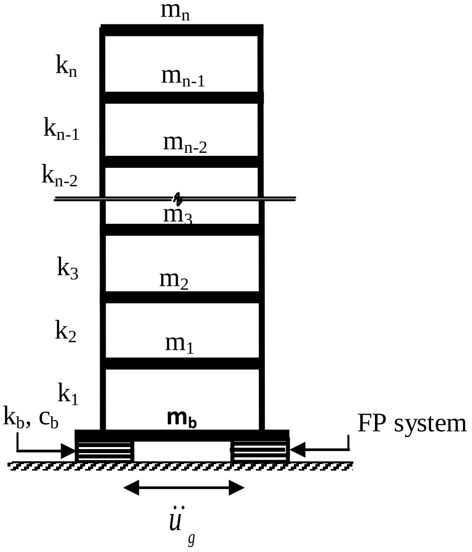
Fig. 1 Plan and Elevation of the proposed building model

III. STRUCTURAL MODEL OF BUILDING

The building model is idealized as a linear shear type lumped mass with single lateral degrees of freedom at each floor levels including isolation floor. The structural building model is assumed to remain in linear elastic state, therefore, does not yield during excitation. The numerical study has been performed corresponding to unidirectional excitation due to four real earthquakes. During this study, it is assumed that spatial variation of ground motion and also effect due to soil structure interaction is neglected. The governing equations of motion for multi degrees-of-freedom building with isolated base are expressed in matrix form as

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = -[M]\{r\}\ddot{u}_g + [B_p]\{f_b\} \qquad (1)$$

where, $[M]$, $[C]$, and $[K]$ are the mass, damping and stiffness matrices of building respectively, $\{u\}=\{u_b, u_1, u_2, u_3 \ldots\ldots u_n\}$, $\{\dot{u}\}$ and $\{\ddot{u}\}$ are the vectors of relative floor displacement, velocity and acceleration response respectively, $\ddot{u}_g$ is the ground acceleration due to earthquake, $\{r\}$ is the vector of influence coefficient



having all elements equal to one, [B_p] is the bearing location vector, {f_b} is the vector of bearing force and (u_b) is the bearing displacement.

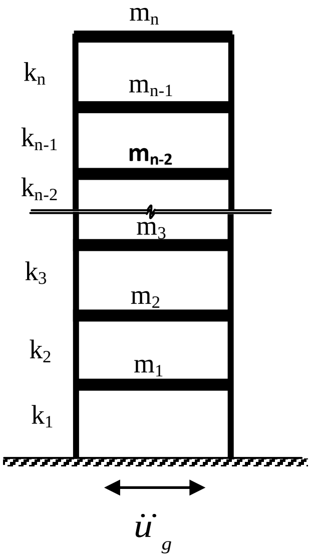
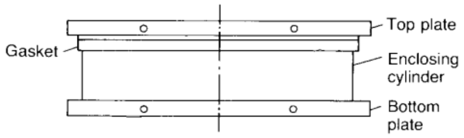


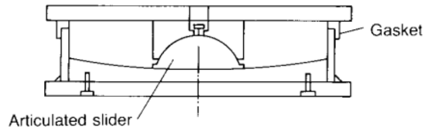
Fig. 2 Structural model of building with and without FP System

The classical stiffness and damping matrix may not be suitable since superstructure and substructure have significant difference in stiffness and damping so non-classical type of matrices are to be constructed. Under which, it is constructed by first evaluating the classical stiffness and damping matrix for building without isolation then stiffness and damping matrix for building with base isolation is superimposed by assembling matrix due to superstructure and substructure.

Computation of bearing force : The Friction- Pendulum system is based on well-known engineering principle of pendulum motion having combine action of sliding and restoring force by geometry. The cross section and schematic diagram is shown in figure 3. This system is equipped with re-centring force provided by gravitational action, which is achieved by means of an articulated slider moves on spherical concave chrome surface. When the slider is in contact with polished chrome surface then there will be maximum coefficient of friction in the order of 0.1 or less and may be minimum of 0.05 or less corresponding to low velocity of slider.



FPS Isolator elevation



FPS Isolator section

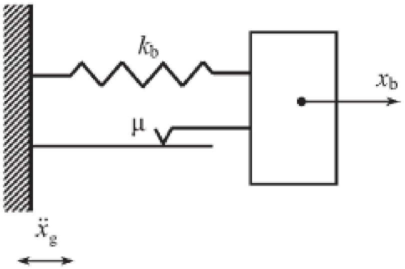


Fig. 3 Cross-section and schematic diagram of FPS system

In this system, the structure is supported on spherical shaped bearings and load is applied through a small area covered by high strength composite materials. The residual displacement after an earthquake is reduced due to self centring action. The friction pendulum system (FPS) provides isolation effects through the parallel action of friction and restoring spring. The bearing force yielded by FPS is given by,

$$f_b = k_b u_b + f_r \qquad (2)$$

Where, k_b is the stiffness of bearing provided through inward gravity action, u_b is the bearing displacement, f_r is the friction force generated at the interface of isolation system and its modelling is described as friction force is modelled by two approaches referred as, conventional model and hysteretic model. In the study, hysteretic model is considered to compute the frictional force in which hysteretic displacement (Z) is evaluated using Wen's equation. The frictional force mobilized at the interface of system is

$$f_r = f_s \text{ x } z \qquad (3)$$

Where, f_s is the limiting frictional force and expressed by

$$f_s = \mu M_t g. \qquad (4)$$

where, M_t is the total mass of building including mass of isolation floor, g is the gravitational acceleration, μ is the friction coefficient of sliding system that depends on the instantaneous velocity of base floor and expressed by the equation. The friction coefficient (μ) of sliding system with Teflon-steel bearing can be modelled by using an equation is described below

$$\mu = \mu_{max} - (\Delta\mu)exp(-a|\, v_b\, |) \qquad (5)$$

where, μ_{max} is the maximum friction coefficient at large velocity of sliding (after levelling off), μ_{min} is the minimum friction coefficient at small velocity of sliding, Δμ is the difference of maximum and minimum friction coefficient respectively at large and small velocity at the interface of system, and its value is assumed to be independent of relative velocity (Δμ=0) at the sliding interface which leads to coulomb-friction idealization, a is the calibration constant for a given bearing pressure and interface condition is taken as 20 sec/m and z is the hysteretic displacement evaluated by Wen's model, satisfying the nonlinear first order differential equation as

$$q\dot{z}_b = -\beta\, |v_b|z_b|\, z_b|^{n-1} - \tau\, v_b|z_b|^n + Av_b \qquad (6)$$

where, q is the yield displacement of bearing, β and τ are the strengthening coefficients of lead plug that control the shape and size of hysteresis loop, n and A are the integer constant that controls the smoothness of transition from elastic to plastic state. The parameters of wen's model are so selected so as to provide a rigid- plastic shape that is, β= 0.5, τ= 0.5, n= 2, Q= 25mm and A= 1. The parameter of isolation system, namely stiffness (k_b) and damping (c_b) are so selected to provide desired value of isolation period (T_b) and damping ratio (ξ_b) respectively as $T_b = 2\pi\sqrt{\dfrac{M_t}{\alpha_b k_b}}$ and $\xi_b = \dfrac{c_b}{2M_t\omega_b}$ where, M_t is the total mass of building including isolation floor, respectively, k_b and c_b are the stiffness and damping of isolation system respectively, and ω_b is the natural frequency of bearing

IV. SOLUTION PROCEDURE

The governing equation of motion for multi-storeyed building involving sliding base isolation is solved numerically by Newmark's step by step method assuming linear variation in acceleration over a small time interval (Δt). The time interval is kept very small to achieve stability of Newmark's integration method. The algorithm developed for governing equation of motion of building and bearing used is simulated through MATLAB® version 8.2 computing software. Further, graphs from results are drawn using Origin 8.0 software.

Earthquake	Recording station	Component	PGA(g)
Imperial Valley, 1940	El-Centro	N00E	0.348
Loma Prieta, 1989	Los Gatos Presentation Centre	N00E	0.570
Northridge, 1994	Japan Meteorological Agency	N00E	0.834
Kobe, 1995	Sylmer Converter Station	N00E	0.843

Table 1 Details of earthquake ground motions

V. NUMERICAL STUDY

A structural model of lumped mass system having 5% of critical damping with ten storey's of RC framed building in which each floor mass as 674.05 tonne and stiffness is of 5.17E+06 kN/m, respectively, which gives fundamental period of fixed base building is equal to 0.48 seconds. The mass of isolation floor is taken as 10% in excess of floor mass of superstructure floor. The parameters of friction pendulum system considered are as T_b=3 sec and μ_{max}=0.05. The response parameters of interest are, top floor displacement (u_f), acceleration (a_f), story drift (u_r), normalized bearing force (F_b/W), bearing displacement (u_b), normalized base shear (B_{sy}), Here bearing force (F_b), storey shear (S_{sy}) and Base shear (B_{sy}) are normalized by total weight of building (W). The building is subjected to unidirectional excitation for which four real earthquake ground motions are considered and details are given in table 1.

The comparison of peak responses of isolated building and fixed base building under all considered ground motions are shown in table 2 along with percentage reduction of peak responses are written in parenthesis with respect to the peak responses of fixed base building. It is noted that reduction in floor displacement, acceleration and base shear are in the range of 80-90% for the building under four different earthquakes which implies that base isolation mechanism underscored the most effective technique in mitigating the building responses.

Table 2 Comparison of peak responses of building under various earthquakes (T_b=3s, μ_b = 0.05)

Earthquake	Peak responses	Uncontrol	FPS control
Imperial Valley, 1940	u_f	5.7589	0.6637 (88.47)
	a_r	1.0817	0.1978 (81.71)
	B_{sy}/W	0.7086	0.0949 (86.60)
	u_b	---	6.147
Loma Prieta, 1989	u_f	14.6720	1.5673 (89.89)
	a_f	2.3784	0.3084 (87.03)
	B_{sy}/W	1.8605	0.2394 (87.13)
	u_b	---	31.576
Northridge, 1994	u_f	15.6566	1.4365 (90.82)
	a_f	2.7142	0.2913 (89.26)
	B_{sy}/W	1.8246	0.2072 (88.64)
	u_b	---	20.108
Kobe, 1995	u_f	16.3702	1.1392 (93.04)
	a_r	2.8304	0.2889 (89.79)
	B_{sy}/W	1.9778	0.1408 (92.88)
	u_b	---	12.307

Note: Value in parenthesis represents the percentage reduction in response.

The fig. 4 shows time varying response of proposed building and is observed that value of displacement response is lesser in all three earthquakes except Loma Prieta Earthquake. Further, fig. 5 and 6 reflects that top floor acceleration response and base respectively of building are reduced effectively due to presence of base isolation which clarify the effectiveness of friction pendulum system. Fig. 7 shows peak displacement response at each floor of building and is observed that initial peak displacement of upper floor of building reduced considerably except in case of Loma Prieta earthquake. From the fig. 8 one can comment that peak acceleration found to have large variation in lower floor acceleration and upper floor acceleration. Fig. 9 shows storey drift of building floor and it is noted that FPS is more effective in reducing storey drift except under Loma Prieta earthquake. Fig. 10 indicate that peak story shear response of building floors and observed that FPS is effective in reducing storey shear at each floor. From the fig. 11, one can conclude that various energy loops of bearing force-displacement reflects that smooth functioning of FPS bearing under all four considered earthquakes.

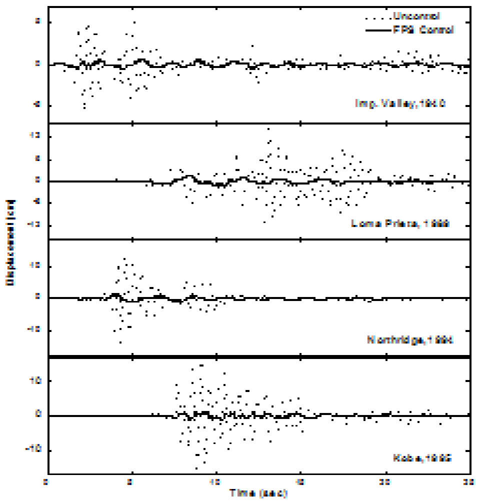


Fig. 4 Time varying displacement response of top floor
(T_b= 3s, μ_b=0.05)

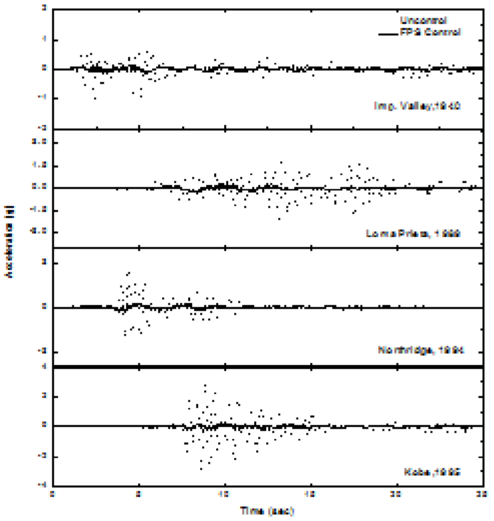


Fig. 5 Time varying acceleration response of top floor
(T_b= 3s, μ_b=0.05)

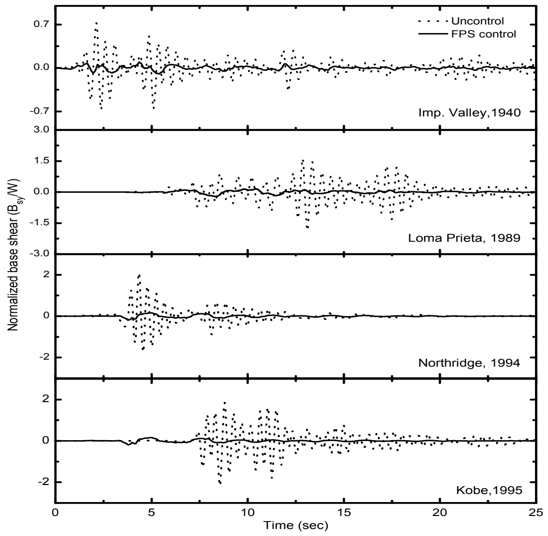


Fig.6 Time varying base shear response of building
(T_b= 3s, μ_b=0.05)

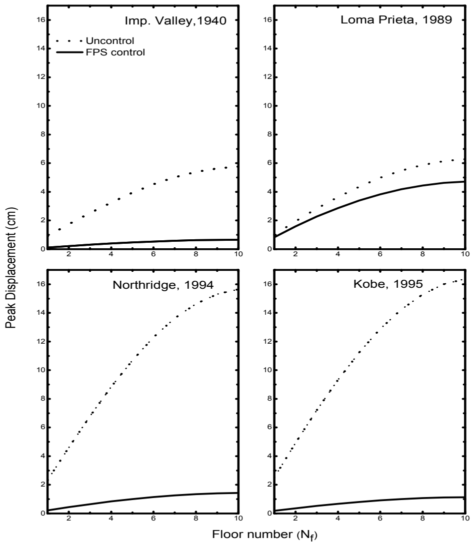


Fig. 7 Peak displacement response of building floors
(T_b= 3s, μ_b=0.05)

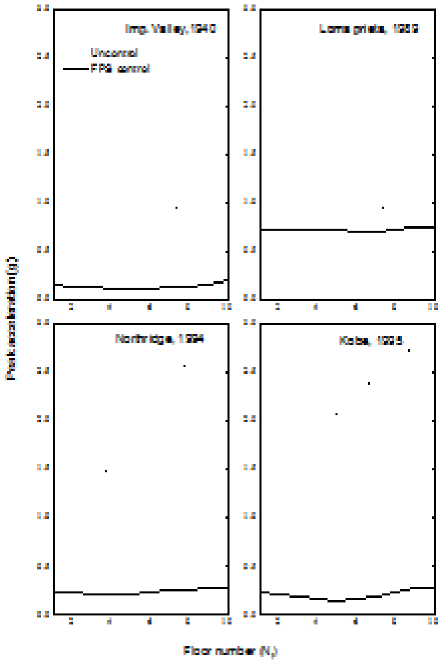


Fig. 8 Peak acceleration responses of building floors $(T_b = 3s,\ \mu_b = 0.05)$

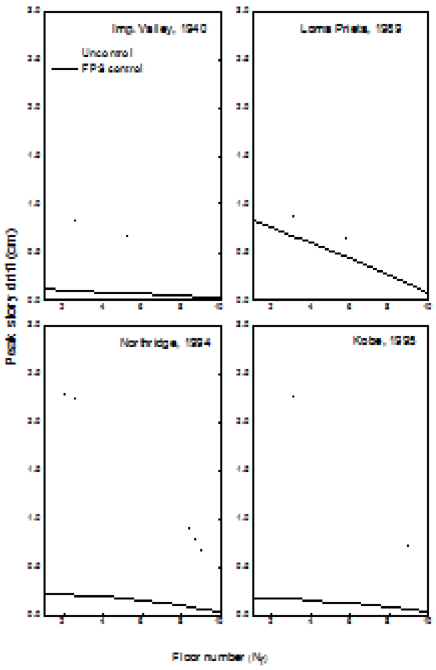


Fig. 9 Peak story drift response of building floors $(T_b = 3s,\ \mu_b = 0.05)$

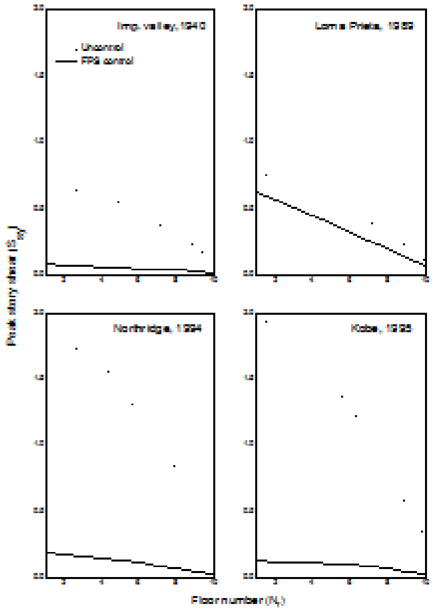


Fig. 10 Peak story shear response of building floors $(T_b = 3s,\ \mu_b = 0.05)$

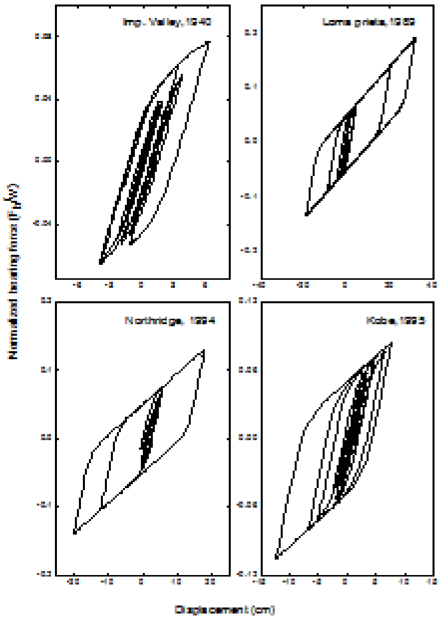


Fig. 11 Force-displacement behaviour of FP System for various earthquakes $(T_b = 3s,\ \mu_b = 0.05)$

VI. CONCLUSIONS

In this study, effectiveness of the proposed FPS control in terms of peak responses of building has been examined through MATLAB® version 8.2 using ten storied RC framed building. The proposed building model is excited to unidirectional excitation for which four real earthquake ground motions are taken. The numerical results are outlined and following precise conclusions are drawn

[1] The seismic responses of building isolated with Friction Pendulum system perform effectively in reducing the responses during earthquake.
[2] The mitigation of peak responses of building under FPS is about 85% in respect of fixed base building responses which reflects the well functioning of bearing used.
[3] The performance of FPS bearing in controlling peak responses that is, displacement, acceleration, and base shear is lesser under Loma Prieta earthquake as compared to other earthquakes considered.
[4] The energy loop from the bearing force-displacement shows that FPS bearing reflects enough seismic energy input during earthquakes.

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