Performance of Steel Moment Resistant Frame Whit Friction Pendulum System Under Static Nonlinear Analysis

Sh.E. Esmailzadeh Toloui
Department of Civil Engineering,University of Shomal, Amol, Iran.

J.V. Vaseghi Amiri
Professor Assistant, Department of Civil Engineering, Babol University of Technology, Iran
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Ch.K. Karimi
Department of Civil Engineering, Azad University –Tehran Central Branch,Iran.

SUMMARY:
Recently, in several countries the application of base isolation technology has already been proven as the effective and economically viable method to enhance the capability of structures in seismic mitigation. Seismic isolation can be an effective tool for the earthquake resistant design of bridges that can be used in both new construction and retrofit. The Friction Pendulum System (FPS) is a seismic isolation bearing, with a mechanism based on its concave geometry and surface friction properties. The supported structure is administered into a pendulum motion as the housing plate simultaneously glides on the concave dish and dissipates hysteretic energy via friction.

In this paper , studies the effect of increase of period and increase of friction coefficient of seismic base isolator of friction pendulum system (FPS) type on seismic response of steel moment resisting frames. For this purpose, frames with 3, 5 and 7 stories have been modeled in both state with fixed base and isolated base, along with different period and different friction coefficient of (FPS) under effect of spectrum earthquake IBC2006 code in SAP2000 software. The superstructure is idealized as linear shear type flexible building. The points of performance of this structures have with nonlinear static analysis (push over).

Keywords: Friction pendulum system, Performance, Nonlinear static analyses,

1. INTRODUCTION

Recently, in several countries the application of base isolation technology has already been proven as the effective and economically viable method to enhance the capability of structures in seismic mitigation.

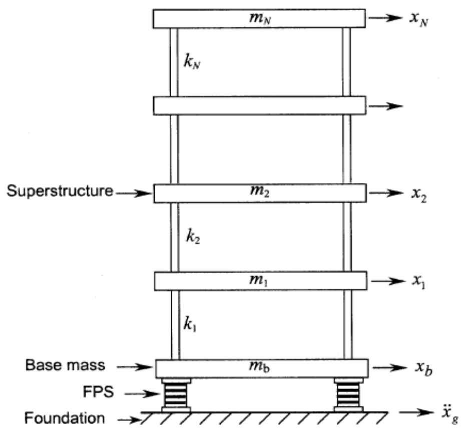
The friction pendulum system (FPS), proposed by Zayas in 1987 [1] includes an articulated slider and one concave sliding surface. Comprehensive experimental and numerical studies presented by many investigators have proved that the FPS isolator is an effective device for isolating seismic transmitted energy. However, earthquakes with long predominant periods often produce significant displacement responses in the isolators of base-isolated structures.

Seismic isolation can be an effective tool for the earthquake resistant design of structure that can be used in both new construction and retrofit. The Friction Pendulum System (FPS) is a seismic isolation bearing, with a mechanism based on its concave geometry and surface friction properties. The supported structure is administered into a pendulum motion as the housing plate simultaneously glides on the concave dish and dissipates hysteretic energy via friction.

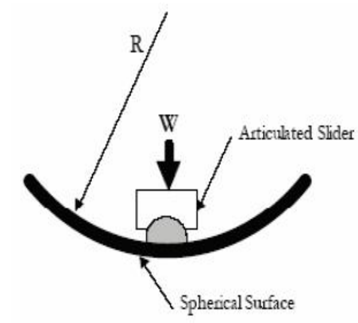
Characteristics of the FPS pertaining to durability under severe environmental conditions, reduced height, and insensitivity to the frequency content of the ground motions, make it a viable option for structure seismic isolation.

2. MODELING OF FRICTION PENDULUM SYSTEM

The design process for an isolation system will generally begin with preliminary design using parameters from a previous project or from data from manufacture to estimate the possible maximum displacement of system and maximum values of various controlling quantities.



(a) Flexible superstructure with FPS



(b) Components of the Friction Pendulum System (FPS)

Figure 2.1 . Model of *N*-story base-isolated building and components of the FPS

If the load on an FPS isolator is W, the horizontal displacement is D, and the friction coefficient is μ , than the resisting force F is given by:

$$F = \frac{W}{R} D + \mu W (sgn D^{\cdot}) \tag{2.1}$$

Where R is the radius of curvature of the dish. The first term is the restoring force due to rise of mass, providing a horizontal stiffness:

$$K_H = \frac{W}{R} \tag{2.2}$$

Which produce an isolated structure period T given by :

$$T = 2\pi \sqrt{\frac{R}{g}} \tag{2.3}$$

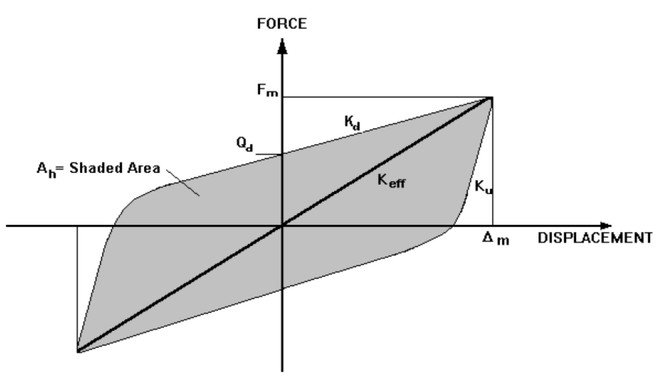


Figure 2.2 Idealized hysteresis loop of FPS

Which is independent of the carried mass. The second term is the friction force between the slider and the concave surface. The coefficient of friction μ depends on pressure P and sliding velocity $\dot{D}$ a typical hysteresis loop for FPS system is shown in Figure 2.2 . The very liner nature of restoring force, the high stiffness before sliding occurs, and the energy dissipation due to the sliding friction are clear from this figure the equivalent (peak –to-peak) stiffness is given by [4]:

$$k_{eff} = \frac{W}{R} + \frac{\mu W}{D} \tag{2.4}$$

The damping produced by friction at the sliding surface can be estimated by the code formula:

$$\beta_{eff} = \frac{Area\ of\ \text{hysteresis}\ loop}{4\,\pi\, k_{eff}\, D^2} \tag{2.5}$$

The area of the hysteresis loop is 4μwD; thus:

$$\beta = \frac{4\,\mu\, W\, d}{2\pi\left[\left(\frac{W}{R}\right)D+\mu\, W\right]d} = \frac{2}{\pi}\frac{\mu}{\frac{D}{R}+\mu} \tag{2.6}$$

4. STORY DRIFT

Part of results of the story drift in 3, 5, and 7 story isolated frames with FPS base isolators under Ex loading in periods of 1.6, 2, 2.4, and 3 second with friction coefficient of 0.05, 0.1, and 0.15 have been shown in Figures 4.1 to 4.3.

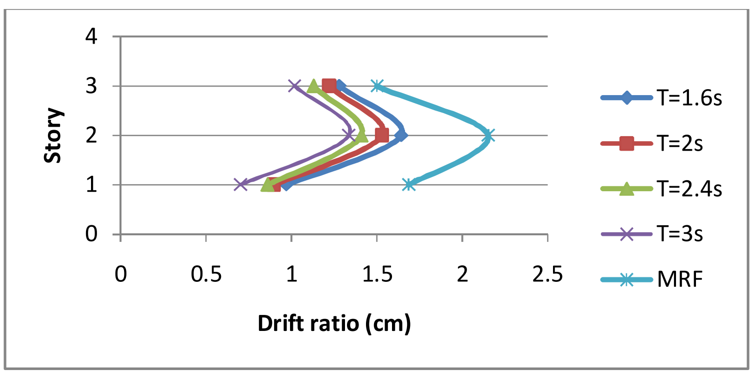


Figure 4.1. Story drift in 3 story isolated frame (μ=0.05), and fixed support frame

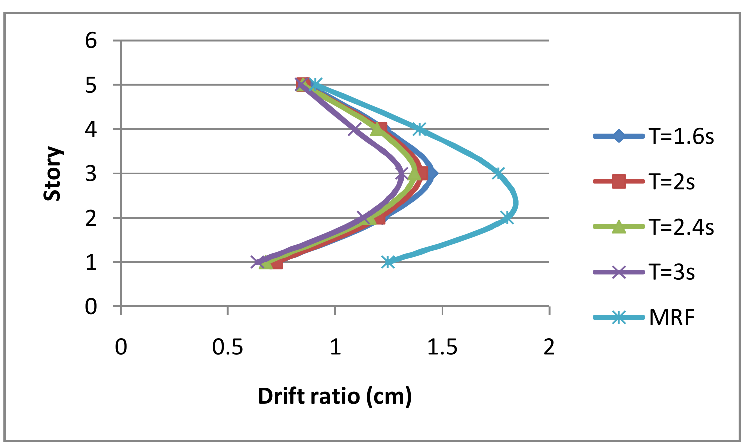


Figure 4.2. Story drift in 5 story isolated frame (μ=0.1), and fixed support frame

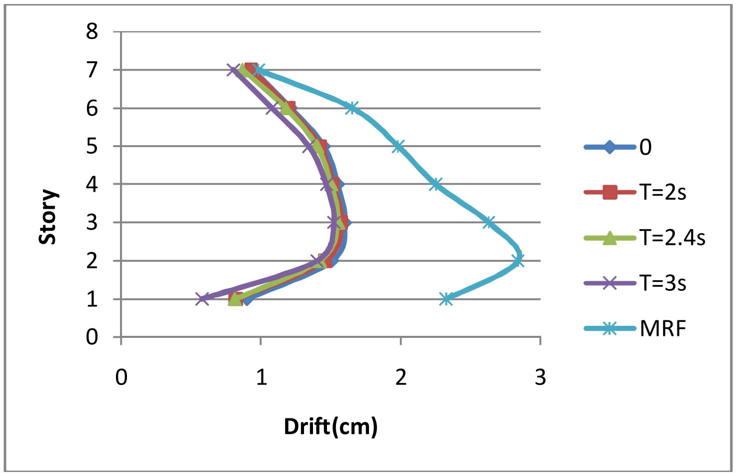


Figure 4.3. Story drift in 7 story isolated frame (μ=0.15), and fixed support frame

As shown in the Figures, story drift in the performance point of structure in the isolated frames become considerably less and its distribution in the height structure are more uniform than steel frames with fixed support. Another important point is the reduction of story drift in isolated frames by increasing the period of designing of the base isolators.

According to these diagrams, it can be concluded that in all the isolated frames with the period of 3 second, the minimum drift are created in stories of these frames. The impact of increasing the friction coefficient of base isolator surface on story drift in the optimum period of 3 second in the performance point of these frames have been shown in Figure 4.4.

These diagrams have been drawn in order to determine the appropriate amount of the friction coefficient of base isolator surface of FPS in the designed, suitable period. Studying the results of these diagrams shows that in period of 3 second in the performance point of structure, the minimum story drift occurs in frames which its friction coefficient of base isolator surface is equal to μ=0.05.

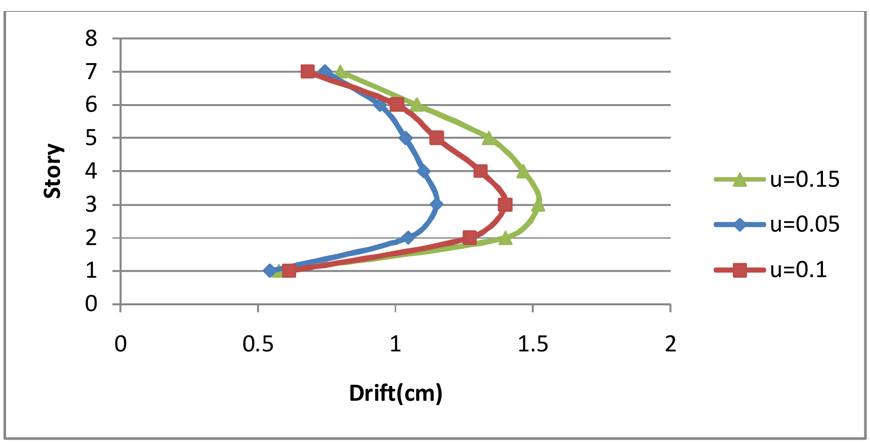


Figure 4.4. Story drift in 7 story isolated frame (T=3s)

5. BACE SHEAR

According to the values presented in Tables 5.1 to 5.2, it can be found that the shear force value transferred to the structure is reduced by increasing of the designed period of base isolator. It means that in the period of 3 second, the minimum shear force value is transferred to the structure. This indicates the fact that by increasing the displacement of base isolator, the shear force value transferred to the structure is considerably reduced. So with transition of the suitable period for designing of base isolators, the shear force value transferred to the structure can be largely reduced, and it can be seen the better performance of these systems.

Table 5.1. Value of transferred shear to structure in performance point for 3 story isolated frame

Isolation type	Target Displacement(cm)	FPS Displacement(cm)	Total Base Shear (ton)	FPS shear (ton)	Base Shear in Frame (ton)
FPS3-1.6-0.05	27.8	17.97	138.23	88.31	49.92
FPS3-2.0-0.05	32.7	23.22	118.19	84.65	33.54
FPS3-2.4-0.05	37.59	28.51	103.26	79.64	23.62
FPS3-3.0-0.05	44.7	35.27	84.45	64.81	19.64
FPS3-1.6-0.10	27.8	17.67	158.84	97.49	61.35
FPS3-2.0-0.10	32.7	22.5	135.34	90.23	45.11
FPS3-2.4-0.10	37.59	26.84	117.52	84.22	33.3
FPS3-3.0-0.10	44.7	33.67	101.26	78.86	22.4
FPS3-1.6-0.15	27.8	17.5	177.511	109.46	68.05
FPS3-2.0-0.15	32.7	22.445	155.28	106.113	49.16
FPS3-2.4-0.15	37.59	26.39	139.17	104.27	34.9
FPS3-3.0-0.15	44.7	33.03	123.67	96.63	27.04

Table 5.2. value of transferred shear to structure in performance point for 5 story isolated frame

Isolation type	Target Displacement(cm)	FPS Displacement(cm)	Total Base Shear (ton)	FPS shear (ton)	Base Shear in Frame (ton)
FPS5-1.6-0.05	29.65	17.89	202.41	113.09	89.32
FPS5-2.0-0.05	34.55	22.76	162.76	107.89	54.87
FPS5-2.4-0.05	39.47	27.996	145.92	105.92	40.00
FPS5-3.0-0.05	46.68	34.13	123.74	94.53	29.21
FPS5-1.6-0.10	29.65	17.85	250.57	141.00	109.57
FPS5-2.0-0.10	34.55	22.47	193.97	122.55	71.42
FPS5-2.4-0.10	39.47	27.47	168.37	121.35	47.02
FPS5-3.0-0.10	46.68	34.01	154.23	120.15	34.08
FPS5-1.6-0.15	29.65	16.50	270.80	150.67	120.13
FPS5-2.0-0.15	34.55	22.055	244.80	149.87	94.93
FPS5-2.4-0.15	39.47	27.09	225.67	148.70	76.97
FPS5-3.0-0.15	46.68	33.40	174.66	137.12	37.544

6. THE RANGE AND LOCATION OF PLASTIC HINGES IN STRUCTURES

After studying the status of the hinges formed in the performance point relating to each of the 3, 5, and 7 story isolated frames in the periods of 1.6, 2.4 and 3 with the friction factor of 0.05, 0.1, and 0.15 under loading Ex, the following results are obtained which have been shown in Tables 6.1 and 6.2. The numbers mentioned in these Tables show the hinges formed in the different performance levels at frames' members.

In order to identified vulnerable points in structure and show appropriate solution, first it must be acted relative to identifying the vulnerable component and their behavior against to earthquake. So base on the nonlinear behavior of structure, display of formation of plastic hinges in structure and their location along with the behavior stage for some of the frame have been shown in the following figures As shown in the Figures 6.1 and 6.2. the location of formation all the hinges are in isolated frames in the performance point of structure in beams and it has not been formed any hinges in columns. But at steel moment frame with fixed support, in addition plastic hinges formed in beam, as significant percentage of plastic hinges formed in column, that range of this hinges are out from CP.

Table 6.1. The range of hinges formed in the performance level for 5 story isolated frames and fixed support

Isolation Type	Building Performance Levels							
	AtoB	BtoIO	IOtoLS	LStoCP	CPtoC	CtoD	DtoE	BeyondE	Total
FPS5-1.6-0.05	87	11	0	0	0	0	0	0	98
FPS5-2.0-0.05	92	6	0	0	0	0	0	0	98
FPS5-2.4-0.05	93	5	0	0	0	0	0	0	98
FPS5-3.0-0.05	93	5	0	0	0	0	0	0	98
FPS5-1.6-0.10	85	13	0	0	0	0	0	0	98
FPS5-2.0-0.10	88	10	0	0	0	0	0	0	98
FPS5-2.4-0.10	88	10	0	0	0	0	0	0	98
FPS5-3.0-0.10	90	8	0	0	0	0	0	0	98
FPS5-1.6-0.15	85	13	0	0	0	0	0	0	98
FPS5-2.0-0.15	85	13	0	0	0	0	0	0	98
FPS5-2.4-0.15	86	12	0	0	0	0	0	0	98
FPS5-3.0-0.15	88	10	0	0	0	0	0	0	98
Fixed Base	57	16	13	0	0	4	0	0	90

Table 6.2. The range of hinges formed in the performance level for 7 story isolated frames and fixed support

Isolation Type	Building Performance Levels							
	AtoB	BtoIO	IOtoLS	LStoCP	CPtoC	CtoD	DtoE	BeyondE	Total
FPS7-1.6-0.05	117	17	0	0	0	0	0	0	134
FPS7-2.0-0.05	119	15	0	0	0	0	0	0	134
FPS7-2.4-0.05	121	13	0	0	0	0	0	0	134
FPS7-3.0-0.05	123	11	0	0	0	0	0	0	134
FPS7-1.6-0.10	114	20	0	0	0	0	0	0	134
FPS7-2.0-0.10	119	15	0	0	0	0	0	0	134
FPS7-2.4-0.10	122	12	0	0	0	0	0	0	134
FPS7-3.0-0.10	122	12	0	0	0	0	0	0	134
FPS7-1.6-0.15	115	19	0	0	0	0	0	0	134
FPS7-2.0-0.15	116	18	0	0	0	0	0	0	134
FPS7-2.4-0.15	118	16	0	0	0	0	0	0	134

Continuation of Table 6.2. The range of hinges formed in the performance level for 7 story isolated frames and fixed support

Isolation Type	Building Performance Levels								
	AtoB	BtoIO	IOtoLS	LStoCP	CPtoC	CtoD	DtoE	BeyondE	Total
FPS7-3.0-0.15	120	14	0	0	0	0	0	0	134
Fixed Base	89	9	20	0	0	8	0	0	126

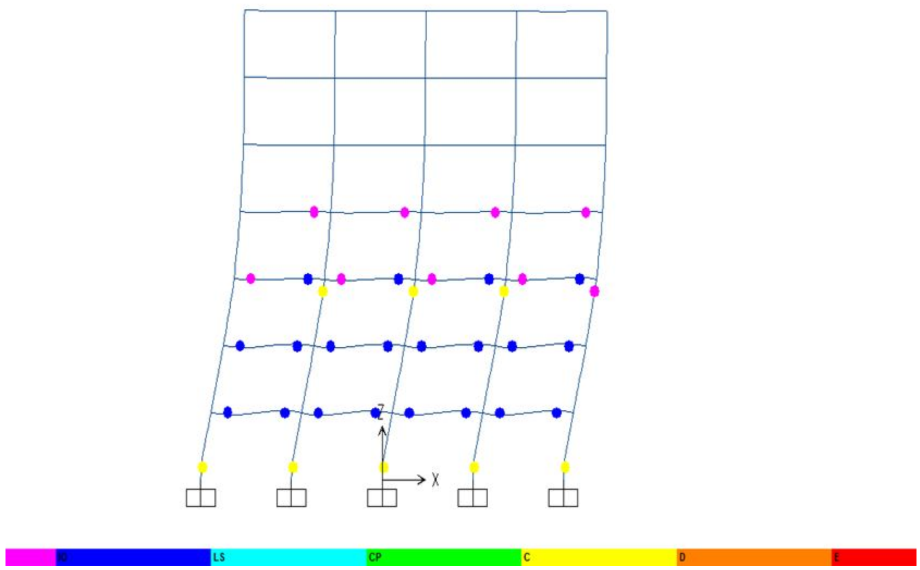


Figure 6.1. The location and range of hinges formed in 7 story isolated frame T=3s , μ=0.05

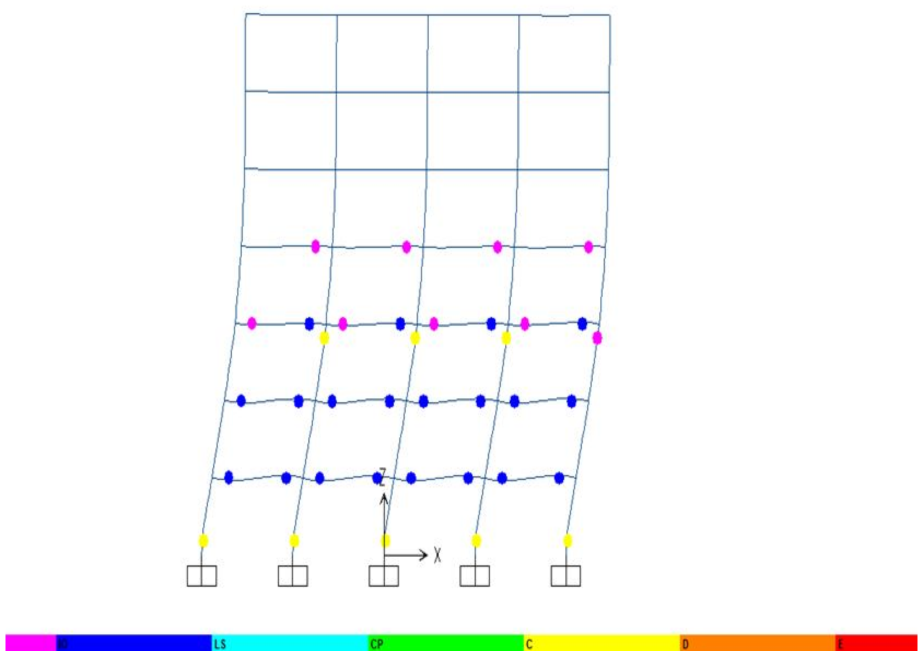


Figure 6.2. The location and range of hinges formed in 7 story with fixed support

7. CONCLUSION

in isolated frame with FPS, the number of hinges formed in the performance point of structure in compared to steel moment frame with fixed support become less considerably, and the range of all the hinges formed are IO.

Story drift in isolated frame are less than frame with fixed support considerably and, its distribution in stories are more uniform.

By increasing the designed period of isolators can be reduced the shear force value transferred to structure.

For 3, 5 and 7 story frame in which its isolators are designed for the period of 1.6, 2, 2.4 and 3 second, the minimum number of plastic hinges are formed in the frames at the period of T=3s and also story drift are less than the other designed periods. So the period of T=3s can be mentioned as appropriate period for determining the better performance in designing of this kinds of isolators.

Investigating on the performance of isolated steel frames that are designed for the friction coefficient of 0.05, 0.1 and 0.15 shows that in the friction coefficient for FPS, the minimum number of plastic hinges and story drift has occurred. So it can be used this kind of the friction coefficient as appropriate one for achieving ideal performance in designing and building this kind of isolators.

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