Seismic Performance of Sliding Type Isolation with Variable Friction

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Abstract

The seismic response of shear type multi storey building isolated with variable friction pendulum system (VFPS) is investigated under horizontal component of near fault ground motion motions and artificial accelarogram. The VFPS, an advanced sliding type isolator, is proposed as an alternative for FPS. The governing equation of motion of building isolated with VFPS are derived and solved in the incremental form by using Newmark's (step-by-step) Beta method assuming linear variation of acceleration of the VFPS over small time interval, as the force-deformation behaviour of the VFPS is non-linear. To verify the effectiveness of VFPS, seismic performance of friction pendulum system (FPS) is compared with the same building isolated by FPS.
Keyword- Base Isolation, Variable Friction Pendulum System, Near Fault Ground Motions, Friction Pendulum System, and Friction Coefficient

I. INTRODUCTION

In today's performance based context, an effective way of protecting structure is to mitigate the seismic demand on the system itself. For this base isolation is very effective method. In the base isolation system a flexible layer is provided between the structure and its base. Due to the flexibility of the isolation layer, the time period of the base isolator is relatively long; so the isolator time period controls the fundamental period of the isolated structure. This base isolation device also include an energy dissipating mechanism so as to reduce deformation at the isolator level. For example, friction type base isolator uses a sliding surface for both isolation and energy dissipation, and has been found to be very effective in reducing structural responses. This feature is the most important benefit of the friction-type isolators as compared to elastomeric bearings.

Among various friction type isolators, the friction pendulum system (FPS) is found to be most attractive due to its ease in installation and simple mechanism of restoring force by gravity action. The FPS has been adopted as a very effective device for the protection and retrofitting of existing structures. However, the FPS designed for a particular intensity of excitation may not give very satisfactory performance during earthquakes with much higher intensity. To overcome these variable friction pendulum system (VFPS) is proposed for near fault earthquake ground motions in this study. The seismic response of a multi-storey building isolated with VFPS has been investigated under near-fault ground motions and artificial accelarogram. The specific objectives of the present may be summarised as : (1) To study the behaviour of VFPS isolated system relative to the FPS, (2) To propose necessary modification in VFPS to enhance its performance, (3) To carry out non-linear time history analyses (NLTHAs) using a customized computer program to study effectiveness of VFPS under wide range of earthquake ground motion.

II. DESCRIPTION OF VFPS

The VFPS, an advanced friction base isolator, is very similar to FPS in regard of details and operation. The main difference between FPS and VFPS is that the friction coefficient of FPS is considered to be constant whereas the friction coefficient of VFPS is varied in the form of concentric rings, such variation in coefficient of friction in VFPS can be achieved by gradually varying the roughness of spherical surface. Variable friction pendulum device consists of a fixed base-plate overlaid by a sheet of stainless steel material with areas with different friction co efficient and a slider composed by a steel plate and a sliding pad of low friction material (see figure 1). In variable friction pendulum device the sliding surfaces are characterized by a radius of curvature. The slider is free to move with respect to the base-plate surface, treated specially to form a number of bands arranged as a series of concentric rings (see figure 1). Each ring is characterized by different frictional properties.

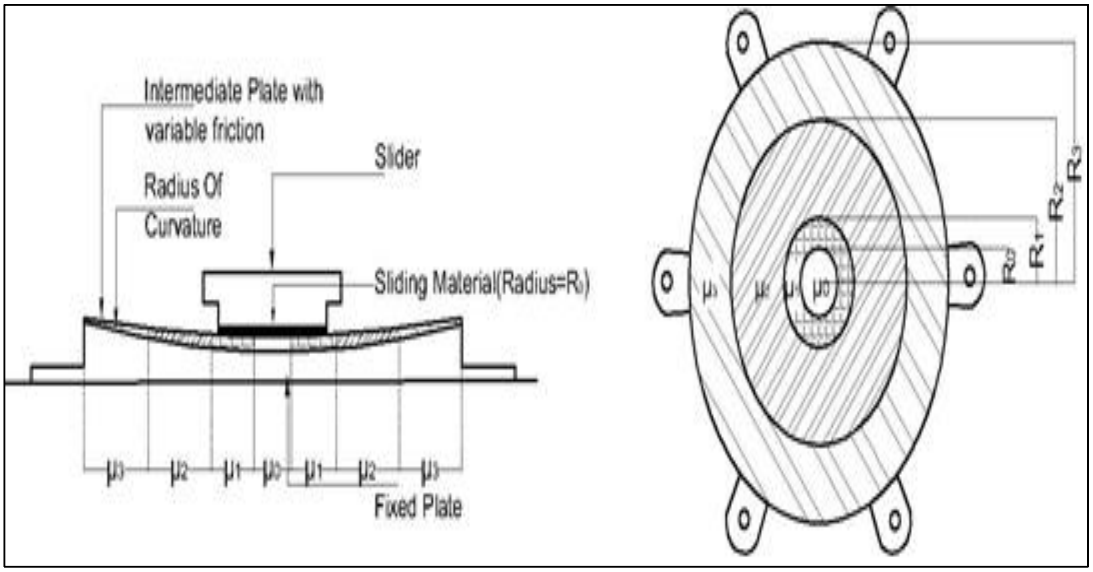

Fig. 1: Cross section of VFPS and Arial view of VFPS

III. MULTI STOREY BUILDING ISOLATED WITH VFPS

Figure 2 shows the structural system under consideration which is an idealized multi-storey shear type building isolated with VFPS. The isolator is installed between the base mass and foundation of the structure. The mathematical modeling of VFPS is also shown in Figure 2. The various assumptions made for the structural system consideration are:

1) The structure is excited by a single horizontal component of near-fault earthquake ground motion only and the effect of vertical component of earthquake acceleration is neglected.
2) The restoring force provided by the VFPS is considered as linear.
3) No overturning or tilting will occur in the superstructure.
4) Force-deformation behavior of the superstructure is considered to be linear with viscous damping.
5) Mass and stiffness of each story is considered as unit.

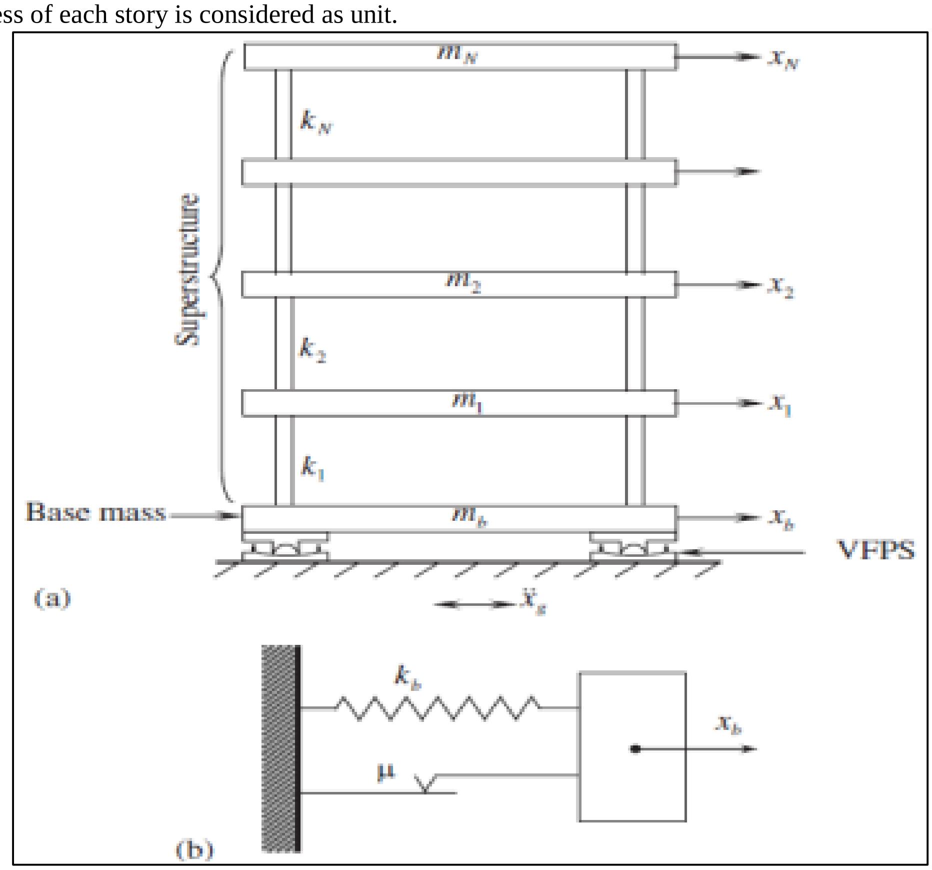

Fig. 2: Modeling of the multi-storey building and the VFPS

IV. GOVERNING EQUATION OF MOTION

The governing equations of motion for the N- storey superstructure model are expressed in the matrix form as,

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = -[M]\{r\}(\ddot{x}_g + \ddot{x}_b)$$

Where, [M], [C] and [K] are the mass, damping and stiffness matrix of the fixed base structure respectively of the size n, $\{x\} = \{x_1, x_2, \ldots, x_n\}^T$ is the lateral floor displacement vector relative to the isolator, $\{r\} = \{1,1,1, \ldots, 1\}^T$ is the influence coefficient vector, $\ddot{x}_b$ is the acceleration of isolator relative to ground, $\ddot{x}_g$ is the earthquake ground acceleration.
The governing equations of motion for the isolator is written as,

$$m_b x_b + F_b - c_1\dot{x} - k_1 x_1 = -m_b \ddot{x}_g$$

Where, m_b is the total mass of the bearing and base, F_b is the restoring force in isolator k_1 and c_1 is the stiffness and damping of first storey of the superstructure.
The restoring force of the isolator is expressed as,

$$F_b = k_b x_b + F_x$$

Where F_x is the frictional force in the VFPS, $k_b = W/R$ is the stiffness of the VFPS and R is the radius of curvature of spherical surface of VFPS.
The stiffness, kb; of the VFPS is designed so as to provide the specific value of the isolation period, Tb; expressed as:

$$Tb = 2\pi\ M/K_b$$

The governing equations of motion of the base-isolated structure cannot be solved using the classical modal superposition technique due to non-linear force–deformation behaviour of the VFPS. As a result, the governing equations of motion are solved in the incremental form using Newmark's beta method (step-by-step method) assuming linear variation of acceleration over small time interval.

V. NUMERICAL STUDY

Here in present study, earthquake response of five storey shear type building isolated with VFPS is examined when subjected to unilateral component of near fault ground motions and artificial accelarogram. The behavior of VFPS isolated at the base of foundation is investigated. The formation of VFPS isolator is mainly to provide two main parameters one of which is fundamental time period and second one is friction coefficient (μ). For this study time period Tb for VFPS is taken as 2.5 sec and friction coefficient for VFPS is taken as 0.055, 0.081, 0.074 and 0.066 from inner ring to outer ring. In these study peak responses of building isolated by VFPS and FPS is carried out under the effect of near fault earthquake ground motions and artificial accelarogram and Some characteristics of these earthquake are given in table 1. Performance of VFPS and FPS evaluated using customized computer program and peak values of isolator displacement and base shear is described in Table 2.

Near-fault earthquake ground motions	*Recording station*	*Duration (sec)*	*PGA (g)*
October 15, 1979 Imperial Valley California(EQ1)	*El Centro Array #5*	*39.420 (1971/0.02)*	*0.37*
October 15, 1979 Imperial Valley California(EQ2)	*El Centro Array #7*	*36.900 (1845/0.02)*	*0.46*
January 17, 1994 Northridge California(EQ3)	*Sylmar*	*60.000 (3000/0.02)*	*0.73*
Artificial Accelarogram 1(AA1)	-	-	-
Artificial Accelarogram 2(AA2)	-	-	-
Artificial Accelarogram 3(AA3)	-	-	-

Table 1: some characteristics of normal component of Near-fault ground motions used in this study

EQ NAME	*DISPLACEMENT*		*BASE SHEAR*	
	VFPS	*FPS*	*VFPS*	*FPS*
EQ1	*0.3810*	*0.4470*	*0.3207*	*0.3443*
EQ2	*0.3944*	*0.4443*	*0.3279*	*0.3411*
EQ3	*0.5481*	*0.6698*	*0.4139*	*0.4898*
AE1	*0.3315*	*0.3912*	*0.2875*	*0.3068*
AE2	*0.2865*	*0.3415*	*0.2655*	*0.2749*
AE3	*0.3338*	*0.3946*	*0.2889*	*0.3090*

Table 2: Peak values for VFPS and FPS system

Fig 3 and Fig 4 shows the peak values of isolator displacement and base shear under different near fault ground motions and artificial accelarogram for structure isolated with VFPS and FPS.

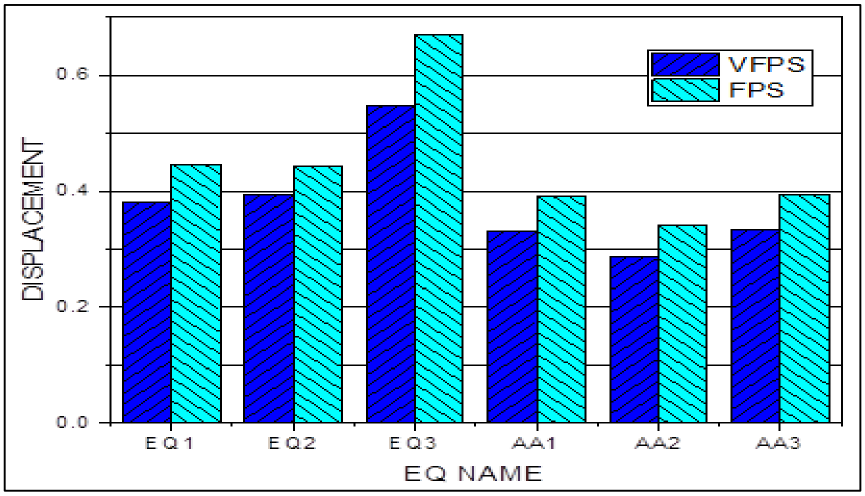

Fig. 3: Peak values of displacement of VFPS and VFPS under various earthquakes

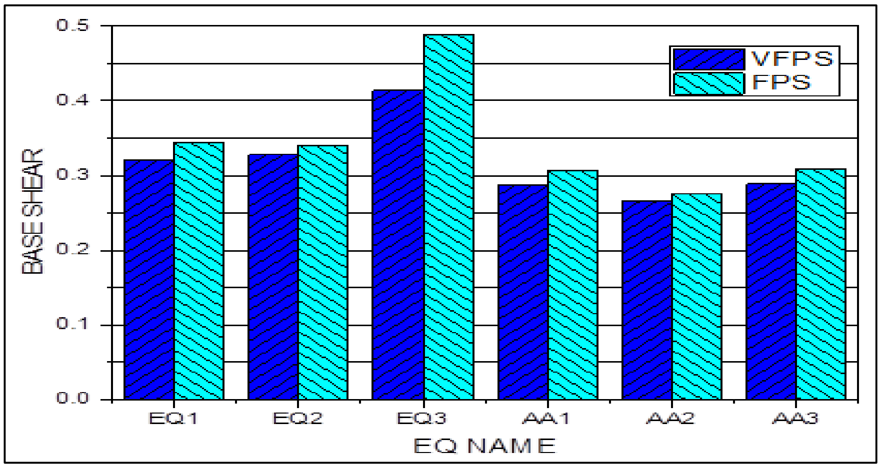

Fig. 4: Peak values of base shear of VFPS and FPS under various earthquakes

Fig 5 shows the displacement and base shear responses for building isolated with VFPS and FPS under effect of El Centro array #5. Peak value of base shear for VFPS and FPS is 0.3207 and 0.3443 respectively. Peak value of displacement for VFPS and FPS is 0.3810 and 0.4470 respectively.

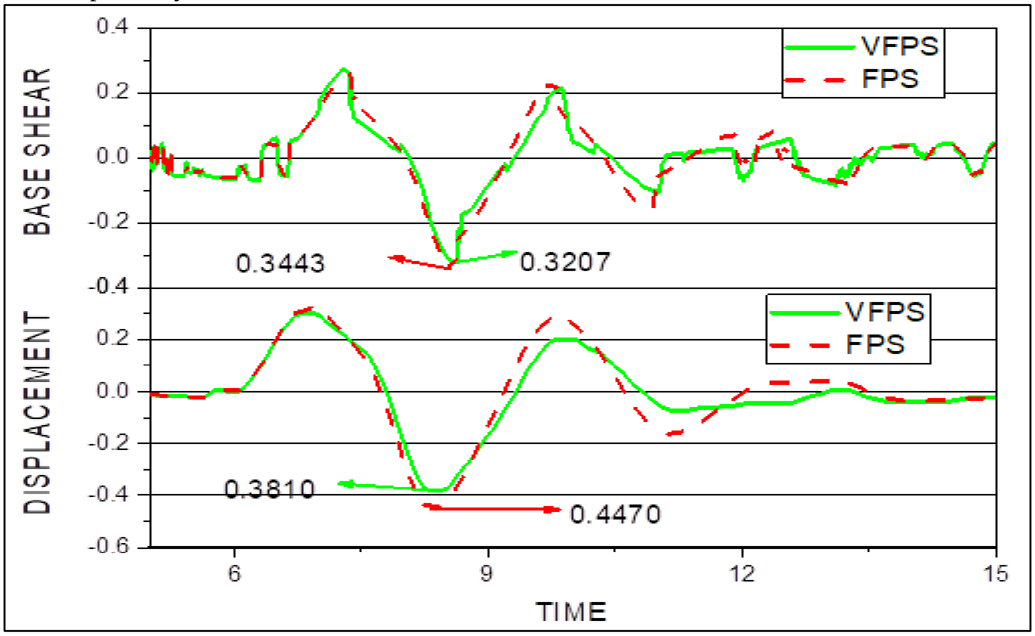

Fig. 5: Base shear and displacement under El Centro array #5

Fig 6 shows the displacement and base shear responses for building isolated with VFPS and FPS under effect of Sylmar earthquake. Peak value of base shear for VFPS and FPS is 0.4139 and 0.4898 respectively. Peak value of displacement for VFPS and FPS is 0.5481 and 0.6698 respectively.

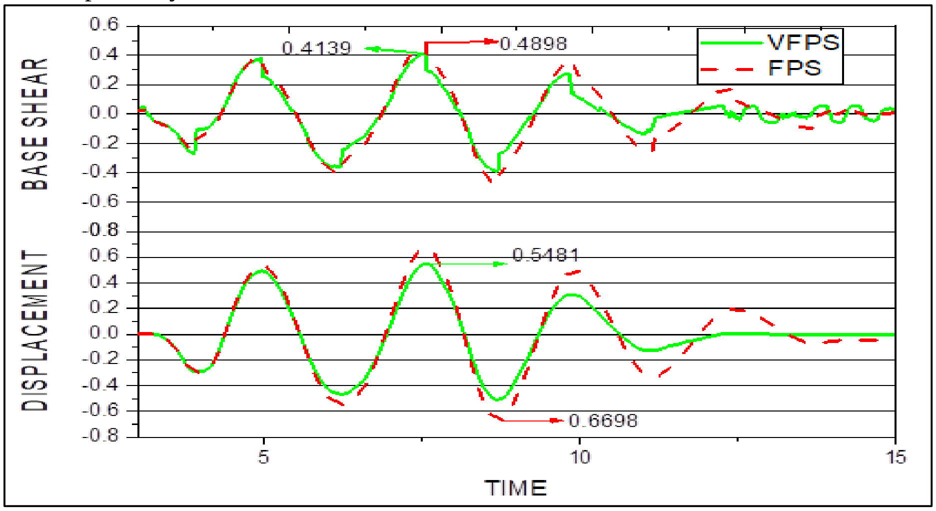

Fig. 6: Base shear and displacement under Sylmar

Fig 7 is the hysteresis loop for building isolated by VFPS and FPS respectively under the effect of El Centro array #5 Earthquakes.

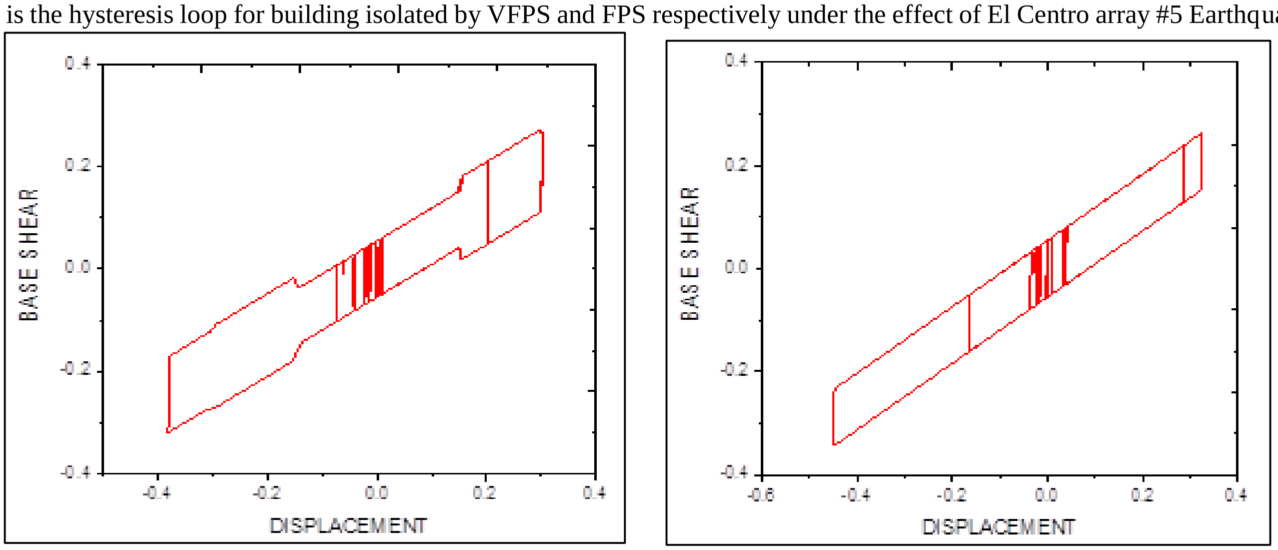

Fig. 7: Hysteresis loop for El Centro array #5 for VFPS and FPS

Fig 8 is the hysteresis loop for building isolated by VFPS and FPS respectively under the effect of Sylmar earthquake.

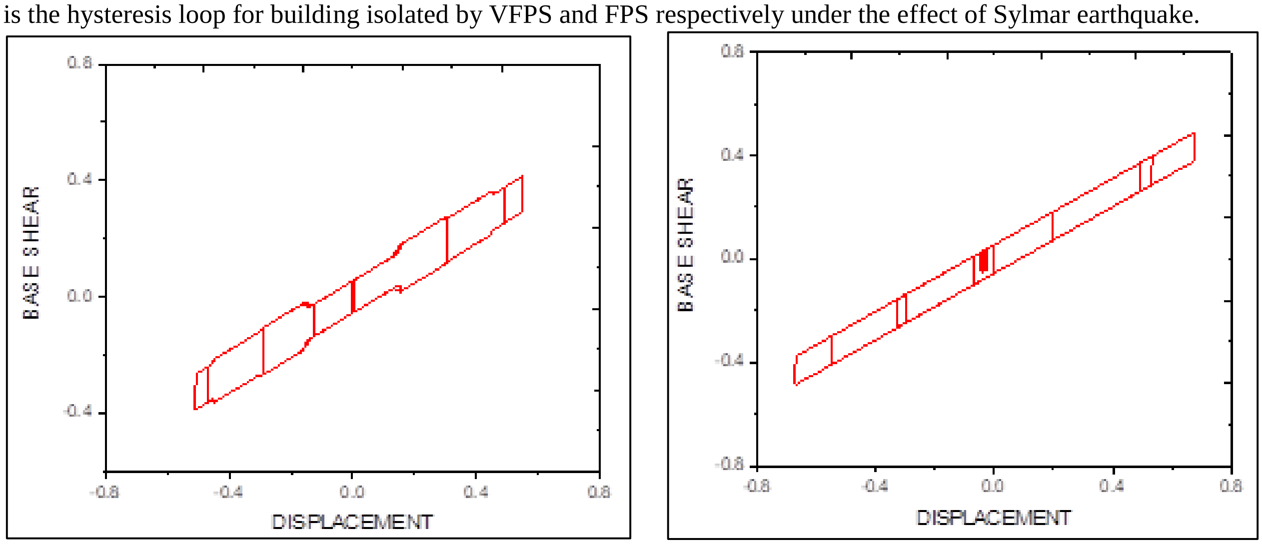

Fig. 8: Hysteresis loop for Sylmar for VFPS and FPS

VI. Conclusions

The earthquake response of shear type multi storey building isolated by VFPS at the base is examined when subjected to unilateral component of near fault ground motions and artificial accelarogram. The response of the system is obtained using standard numerical technique by neglecting the effects of overturning of superstructure, nonlinearity in the restoring force of friction isolators and the vertical acceleration of ground motion. The comparison of the seismic response of building isolated with VFPS and FPS is made in order to verify the effectiveness of VFPS. From the trends of the Numerical results of the present study, the following conclusions may be drawn:

1) With the installation of VFPS in building, the base shear and the isolator displacement during near fault ground motions can be controlled within desirable range.
2) VFPS can dissipate more energy than FPS; hence VFPS can be used for base isolation as well as energy dissipative device.
3) VFPS can potentially be used to achieve high seismic performance under near fault ground motion.
4) The VFPI acts as an isolator combined with the effective energy dissipation and restoring mechanism for all of the coefficients of friction.

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