Comparative Study of Sliding Isolation System for Low Frequency Ground Motion

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SUMMARY:

Base isolation is one of the passive systems of energy dissipation. Several base isolation systems have been proposed in published literature. However most of these isolation devices have proved to be of limited effectiveness under low frequency ground motions. Effectiveness of various sliding isolation systems, such as Pure Friction (PF), Friction Pendulum System (FPS), Variable Frequency Pendulum Isolator (VFPI), Conical Friction Pendulum Isolator (CFPI), for low frequency ground motions are studied in this paper. Also an attempt has been made to improve the effectiveness of sliding isolation system during low frequency ground motion by varying the coefficient of friction at predefined distance from centre of isolator. The behavior of five storey lumped mass structure isolated using PF, FPS, VFPI, CFPI subjected to low frequency ground motions has been numerically examined. Comparative study has been carried out to determine most effective sliding isolation system for low frequency ground motion.

Keywords: Base isolation, VFPI, Low frequency ground motions, Passive control.

1. INTRODUCTION

Base isolation has emerged as an effective technique in minimizing the earthquake forces. In this technique, a flexible layer (or isolator) is placed between the structure and its foundation such that relative deformations are permitted at this level. Due to flexibility of the isolator layer, the time period of motion of the isolator is relatively long; as a result the use of isolator shifts the fundamental period of the structure away from the predominant periods of ground excitation. Extensive review of base isolation systems and its applicability is available in literature (Buckle and Mayes 1990, Kelly 1993, Naeim and Kelly 1993).

Practical isolation devices typically also include energy dissipating mechanism so as to reduce deformations at the isolator level. For example friction type base isolators like Pure-Friction System (horizontal sliding surface) have been found to be very effective in reducing structural response (Mostaghel et al. 1983). The performance of friction isolators is relatively insensitive to variations in the frequency content and amplitude of the input excitation, making performance of sliding isolators very robust. Pure-Friction (PF) system may experience large sliding and residual displacements, which are often difficult to incorporate in structural design.

An effective mechanism to provide restoring force by gravity has been utilised in Friction Pendulum System (FPS) (Zayas et al. 1987). In this system, the sliding surface takes a concave spherical shape so that the sliding and re-centring mechanisms are integrated in one unit. One main disadvantage is that FPS isolators can be effectively designed for a specific level (amplitude and frequency characteristics) of ground excitation (Sinha and Pranesh 1998). Typically FPS has a constant long isolation period and may come in resonance with a low frequency ground motion.

To overcome the difficulty of constant period of isolator and to take the advantage of restoring force mechanism Pranesh (2000) proposed an isolator called as Variable Frequency Pendulum Isolator (VFPI). In this isolator the geometry of VFPI is non spherical (Pranesh M. and Sinha R. 2000, Malu and Murnal 2010). The geometry of VFPI overrules the limitations of both PF and FPS, while retains the advantages. The geometry of VFPI is derived from elliptical shape. It consists of a series of continuously transforming elliptical surfaces with increasing major axis. This geometry of VFPI is chosen to achieve a progressive period shift at different response levels. The VFPI retains the advantages of both PF and FPS, due to amplitude dependent time period and softening mechanism of isolator restoring force. VFPI is relatively flatter than FPS, which results in smaller vertical displacement for similar sliding displacements. Flatter sliding surface will result in the generation of smaller overturning forces in the structure. The most important properties of this system are: (1) its time period of oscillation depends on sliding displacement, and (2) its restoring force has a bounded value and exhibits softening behaviour for large displacements. (Pranesh and Sinha 2000)

To overcome the limitations of FPS under near source ground motion Lyan-Yawn Lu et. al. (2004) proposed a new isolator called Conical Frequency Pendulum Isolator (CFPI). The sliding surface of CFPI is identical to FPS (with a constant radius R) when the isolator displacement is within a threshold value, say d_b. Once the displacement of CFPI exceeds d_b, the sliding surface becomes an inclined plane tangent to the spherical surface. As a result CFPI is same as FPS for $x < d_b$. The value of d_b is taken as $0.1R$ for CFPI.

The study of structures subjected to low frequency ground motions has a special significance due to the nature of such ground motions. The low frequency ground motions have a long period ranging between 1sec to 2sec. Due to this long period nature of low frequency ground motions, most isolators may have time period in the same range and hence may amplify the ground motion significantly. In fact under such ground motion conventional fixed base structure may behave better than an isolated building. However due to variable frequency nature of VFPI, it is likely to perform under such ground motions as well. In the present paper the performance of various isolators for aseismic design of multi-storied shear structure subjected to low frequency ground motions has been investigated. Comparative study of performance has been carried out and most suitable isolator for low frequency ground motions has been suggested in present paper. For further improvement of the performance of isolator variable coefficient of friction, at predefined point, is accomplished and comparative study is carried for variable coefficient of friction also.

2. SLIDING ISOLATOR GEOMETRY:

2.1 Friction Pendulum System (FPS)

The Friction Pendulum System has a spherical sliding surface. Due to spherical geometry the frequency of FPS is almost constant and is approximately equal to $\sqrt{g / R}$, where R is the radius of curvature of the sliding surface (Zayas et al. 1990).

2.2 Conical Friction Pendulum Isolator (CFPI)

The sliding surface of CFPI is basically derived from spherical surface of FPS (Lyan-Ywan Lu 2004). The surface is identical to FPS up to d_b, after that it becomes tangent to the spherical surface.
$\omega_b(x) = 0$ for $x > d_b$. This implies that the isolation system possesses no predominant frequency when the isolation displacement exceeds d_b. For CFPI, the restoring force becomes a constant after d_b.

2.3 Variable Frequency Pendulum Isolator (VFPI)

Sliding surface based on the expression of an ellipse has been used as the basis for developing sliding surface of VFPI (Pranesh 2000). The ellipse have a and b as its semi-major and semi-minor axes. To get the desired variation of the frequency the semi-major axis is expressed as a variable in getting the geometry of VFPI. The semi-major axis can be expressed as,

$$a = x + d \qquad (2.1)$$

The frequency of VFPI changes as sliding surface and at any sliding displacement *x*, the frequency of VFPI is given as,

$$\omega_b^2(x) = \frac{\omega_I^2}{(1+r)^2\sqrt{1+2r}} \tag{2.2}$$

where, $\omega_I^2 = gb/d^2$ is the initial frequency (at zero sliding) and

$r = x\,\mathrm{sgn}(x)/d$ is a non-dimensional parameter.

In the above equations, parameters *b* and *d* completely define the isolator characteristics. It can be observed that the ratio b/d^2 governs the initial frequency of the isolator. Similarly, the value of $1/d$ determines the rate of variation of isolator frequency, and this factor has been defined as *frequency variation factor* (FVF). It can also be observed from Eqn. 2.2 that the rate of decrease of isolator frequency is directly proportional to FVF for given initial frequency. As a result VFPI becomes softened systems for larger isolator displacement. (Pranesh and Sinha 2000, Pranesh and Malu 2007)

For the comparison purpose the parameters of various isolators are chosen such that the three isolators have the same initial stiffness and same initial period as tabulated in Table 1. Figure 1 shows the comparison between geometry of various isolators chosen in this study.

Table 1. Parameter values for various isolators for T_i = 2s

Isolator Type	FPS	VFPI	CFPI
Parameter value	R = 1 m	d = 0.3 m b = 0.09 m	R = 1 m d_b = 0.1R = 0.1 m

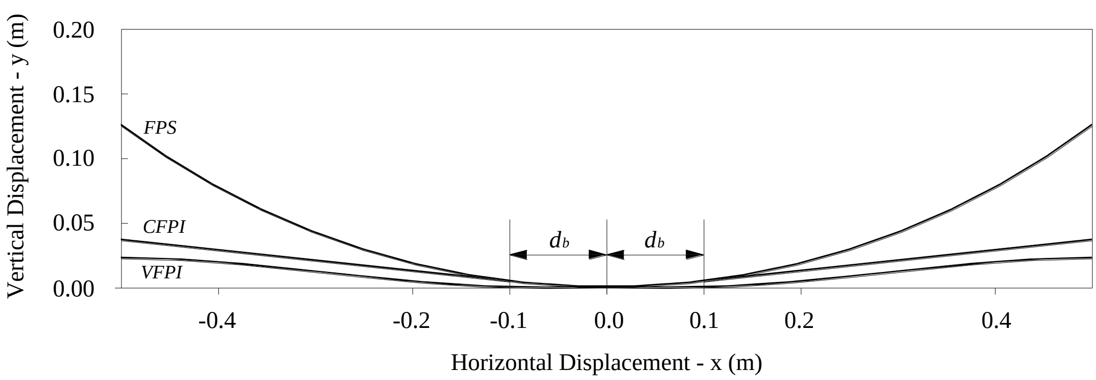

Figure 1. Geometry of various isolators

3. MATHEMATICAL FORMULATION

Consider an N-storey shear structure isolated by sliding type isolator. The motion of the structure can be in either of two phases: non-sliding phase and sliding phase. In non-sliding phase, the structure behaves like a conventional fixed base structure since there is no relative motion at the isolator level. When the frictional force at the sliding surface is overcome, there is relative motion at the sliding surface, and the structure enters sliding phase. The total motion consists of a series of alternating non-sliding and sliding phases.

In non-sliding phase the structure behaves as a fixed-base structure, since there is no relative motion between the ground and base mass. The equations of motion in this phase are:

$$\mathbf{M}_0\ddot{\mathbf{x}}_0 + \mathbf{C}_0\dot{\mathbf{x}}_0 + \mathbf{K}_0\mathbf{x}_0 = -\mathbf{M}_0\mathbf{r}_0\ddot{x}_g \tag{3.1}$$

and

$$x_b = \text{constant}; \ \dot{x}_b = \ddot{x}_b = 0 \tag{3.2}$$

The structure is classically damped in this phase and hence Eqn. 3.1 can be readily solved by usual modal analysis procedures (Clough and Penziene 1993).

When the structure is subjected to base excitation, it will remain in non-sliding phase unless the frictional resistance at the sliding surface is overcome. Therefore the condition for the beginning of sliding phase can be written as

$$\left| \left\{ \sum_{i=1}^{N} m_i(\ddot{x}_i + \ddot{x}_g) + m_b\ddot{x}_g \right\} + m_t\omega^2{}_b(x)x_b \right| \geq m_t\mu g \tag{3.3}$$

$\mu = \mu_1$ or μ_2, is the coefficient of friction at respective isolator position.

Once the inequality Eqn. 3.3 is satisfied the structure enters sliding phase and the degree of freedom (DOF) corresponding to the base mass also experiences motion. The equations of motion are now given by,

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{C}\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} = -\mathbf{M}\mathbf{r}\ddot{x}_g - \mathbf{r}\mu_f \tag{3.4}$$

where, **M**, **C**, **K** are the modified mass, damping and stiffness matrices of order N+1, **r** is the modified influence coefficient vector and μ_f is the frictional force as given below.

$$\mathbf{M} = \begin{bmatrix} \mathbf{M_0} & \mathbf{M_0 r_0} \\ [\mathbf{M_0 r}]^{\mathrm{T}} & m_t \end{bmatrix}, \quad \mathbf{C} = \begin{bmatrix} \mathbf{C_0} & \mathbf{0} \\ \mathbf{0} & 0 \end{bmatrix}, \tag{3.5}$$

$$\mathbf{K} = \begin{bmatrix} \mathbf{K_0} & \mathbf{0} \\ \mathbf{0} & k_b \end{bmatrix}, \quad \mathbf{x} = \begin{Bmatrix} \mathbf{x_0} \\ x_b \end{Bmatrix}, \quad \mathbf{r} = \begin{bmatrix} \mathbf{0} \\ 1 \end{bmatrix} \text{ and } \mu_f = m_t g \mu \,\mathrm{sgn}(\dot{x}_b)$$

$\mu = \mu_1$ or μ_2, is the coefficient of friction at respective isolator position.

Eqn. 3.5 can be solved numerically. But for large size problems the computational effort is large and the analysis does not provide proper insight into the behaviour of the structure. In view of this and the non-classical nature of damping, complex modal analysis is used in the present investigations.

The direction of sliding depends on the signum function that in turn depends on the forces acting on the structure at the end of the previous non-sliding phase. Once inequality Eqn. 3.3 is satisfied, the structure starts sliding in a direction opposite to the direction of the sum of total inertia force and restoring force at the isolator level. So, we have

$$\mathrm{sgn}(\dot{x}_b) = \frac{\left[\sum_{i=1}^{N} m_i(\ddot{x}_i + \ddot{x}_b + \ddot{x}_g) \right] + m_b(\ddot{x}_b + \ddot{x}_g) + m_t\omega^2{}_b x_b}{\left| \left[\sum_{i=1}^{N} m_i(\ddot{x}_i + \ddot{x}_b + \ddot{x}_g) \right] + m_b(\ddot{x}_b + \ddot{x}_g) + m_t\omega^2{}_b x_b \right|} \tag{3.6}$$

The signum function remains unchanged in a particular sliding phase. The end of a sliding phase is governed by the condition that the sliding velocity of the base mass is equal to zero, i.e., $\dot{x}_b = 0$ (3.7)

Once the sliding velocity is zero, the structure may enter a non-sliding phase, reverse its direction of sliding, or have a momentary stop and then continue in the same direction. To determine the correct state, the solution process needs to continue using equations of non-sliding phase wherein the sliding acceleration is forced to zero and the validity of the inequality Eqn. 3.3 is checked. If this inequality is satisfied at the same instant of time when the sliding velocity is zero, it shows that there is a sudden stop at that instant.

4. RESPONSE OF AN EXAMPLE STRUCTURE

The response of an example MDOF structure subjected to low frequency earthquake excitations has been presented in this section. The example structure is a five-storey shear structure. The example building is represented as a lumped mass model with equal lumped mass of 60080 kg and equal storey stiffness of 112600 kN/m for each floor. The example structure is analyzed for fifteen low frequency ground motions. Out of fifteen low frequency ground motions, two are historical records viz, Mexico City 1995, 180 component and Mexico City 1995, 270 component. Additional five records of Mexico City 1995, 180 component and three records of Mexico City 1995, 270 component are artificially generated using a developed program “spec” (Mathur A. K.). A site dependent acceleration response spectra having medium dominant frequencies (Seed et. al., 1976) is also considered and five artificial earthquake records are generated from this site dependent spectrum. The details of the ground motions used in this study are presented in Table 2.

Table 2. Details of low frequency earthquake records used in this study

Sr. No.	Name of the earthquake	Designation	PGA (g)	Duration (sec)
01	Victoria Mexico 1995, 180 Component	LFR-01	0.161	180.12
02	Victoria Mexico 1995, 180 Component, Generated 1	LFR-02	0.187	59.98
03	Victoria Mexico 1995, 180 Component, Generated 2	LFR-03	0.166	64.98
04	Victoria Mexico 1995, 180 Component, Generated 3	LFR-04	0.702	69.98
05	Victoria Mexico 1995, 180 Component, Generated 4	LFR-05	0.180	74.98
06	Victoria Mexico 1995, 180 Component, Generated 5	LFR-06	0.091	79.98
07	Victoria Mexico 1995, 270 Component	LFR-07	0.091	180.12
08	Victoria Mexico 1995, 270 Component, Generated 1	LFR-08	0.108	59.98
09	Victoria Mexico 1995, 270 Component, Generated 2	LFR-09	0.110	69.98
10	Victoria Mexico 1995, 270 Component, Generated 3	LFR-10	0.119	79.98
11	Site dependent, Generated 1	LFR-11	0.323	54.98
12	Site dependent, Generated 2	LFR-12	0.271	59.98
13	Site dependent, Generated 3	LFR-13	0.311	64.98
14	Site dependent, Generated 4	LFR-14	0.307	69.98
15	Site dependent, Generated 5	LFR-15	0.272	79.98

The LFR-01 to LFR-06 are medium band low frequency records (predominant period between 1.8 sec to 2.75 sec and peak slightly greater than 2 sec), LFR-07 to LFR-10 are narrow band low frequency records (predominant period between 1.95 sec to 2.15 sec and peak slightly greater than 2 sec), and LFR-11 to LFR-15 are broad band medium frequency records (predominant period between 0.5 sec to 1.25 sec and peak at 0.85 sec). The original record of LFR-11 to LFR-15 has a PGA of 1g. Hence it is scaled down to 0.25g and then the LFR-11 to LFR-15 records is generated.

Narasimhan and Nagarajaiah (2006) have proposed a variable friction system to adjust the level of friction in the base isolated structure. Panchal and Jangid (2008) proposed a sliding surface by varying the friction coefficient along the sliding surface in the form of curve of FPS and called isolator as VFPS (Variable Friction Pendulum Isolator). In this case the value of coefficient of friction is changing from minimum of 0.025 to maximum of 0.15 and then again reduces and approaches nearly to 0.015. Agrahara Krishnamoorthy (2010) proposed Variable Frequency and Variable Friction Pendulum Isolator (VFFPI). Here the value of coefficient of friction is changing from a minimum of 0.08 to a maximum of 0.1 for 0.0 m to 0.18 m from the centre of the sliding surface. These studies show that a sliding isolator with either a varying radius of curvature or a varying friction coefficient may be used as an effective isolator for isolating the structure. However, practically a sliding surface with a continuous variable coefficient of friction may be difficult to achieve. Also study of performance of these systems under low frequency ground motion is limited. Hence in the present study performance of PF, FPS, VFPI and CFPI under low frequency ground motion has been carried out.

The analysis is carried out for constant coefficient of friction and variable coefficient of friction. The value of constant coefficients of friction is considered as 0.05 and 0.1. In case of variable coefficient of friction an initial value of μ_1 = 0.05 and final value of μ_2 = 0.1 have been considered. The coefficient of friction is changed at a distance of d_f = 0.1m, 0.3m, and 0.5m from centre of isolator. This will enable larger energy dissipation for larger sliding displacement which may help to control the sliding displacements. The parameter values of isolators are taken as given in Table 1, so that initial period of all isolators is 2s. Further for VFPI, FVF value varied from 1.0 per m to 10.0 per m. The structural damping is assumed as 5% of critical for all modes.

4.1 Time History Response

The response quantities are evaluated by solution of the equations of motion as discussed in the preceding sections. The main response quantities of interest are sliding displacement of isolator and absolute acceleration of top storey. To show the effectiveness of VFPI with respect to other isolators a typical time history response graphs are plotted as shown in Fig. 2 to Fig. 7. For medium and narrow band record the graphs are plotted for strong motion period only as the total excitation period for these two records is very large.

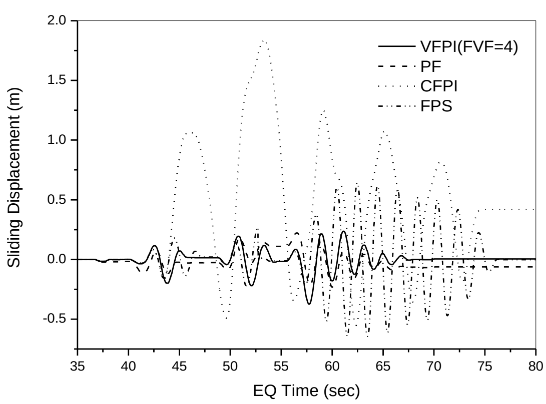

Figure 2. Time history of isolator sliding for Medium band record (LFR-01), $\mu = 0.05$

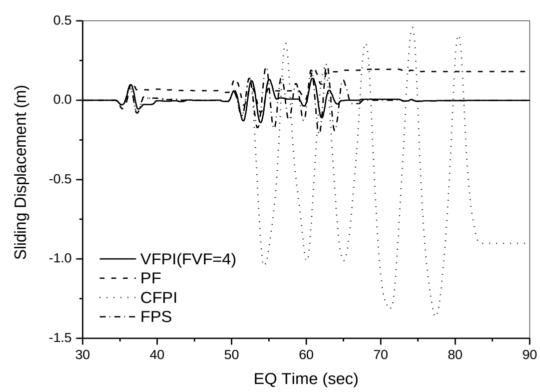

Figure 3. Time history of isolator sliding for Narrow band record (LFR-07), $\mu = 0.05$

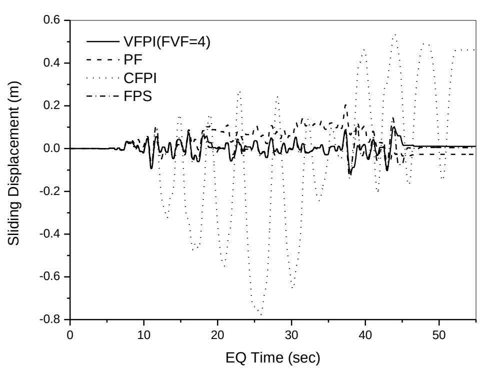

Figure 4. Time history of isolator sliding for Broad band record (LFR-11), $\mu = 0.05$

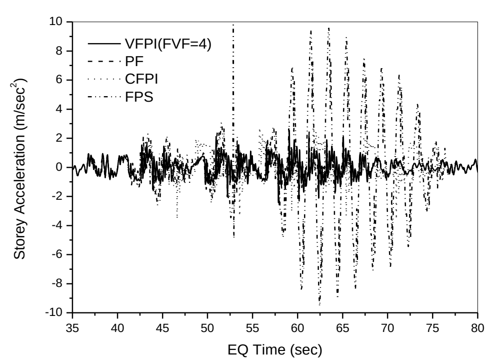

Figure 5. Time history of storey acceleration for Medium band record (LFR-01), $\mu = 0.05$

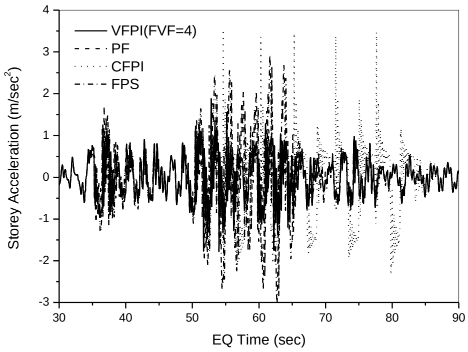

Figure 6. Time history of storey acceleration for Narrow band record (LFR-07), $\mu = 0.05$

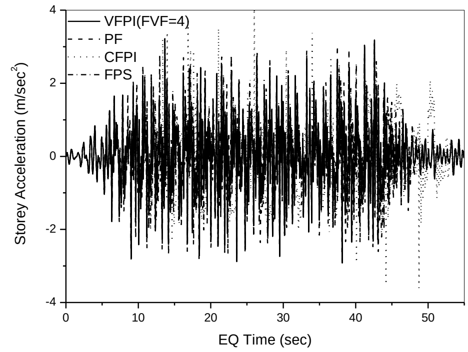

Figure 7. Time history of storey acceleration for Broad band record (LFR-11), $\mu = 0.05$

Fig. 2 to Fig. 4 show the isolator sliding time history for medium, narrow and broad band records respectively. The graphs show clearly the control on sliding, as well as residual displacement of isolator with VFPI. In case of VFPI it is observed that isolator remains in sliding phase for short duration as compared to other isolators. CFPI sliding is too high. FPS sliding is also comparatively at higher level. PF, CFPI and FPS have more residual displacement as compared to VFPI.

Fig. 5 to Fig. 7 show the storey acceleration time history for medium, narrow and broad band records respectively. The graphs show the control on storey acceleration with VFPI. Storey acceleration due to VFPI, and PF are close to each other. But acceleration in case of FPS and CFPI are very high. Therefore it can be seen that both response quantities are effectively controlled by VFPI.

4.2 Effect of Variable Coefficient of Friction

Under low frequency excitations, FPS leads to large sliding displacements, as the peak period of excitation force and isolator coincides. Also it may lead to very high level of structural accelerations due to high level of restoring force. Varying the coefficient of friction will not help in case of FPS to control sliding accelerations as the restoring force increases with sliding displacements. Further due to restricted sliding as a result of spherical surface the FPS may not be able to accommodate the possible sliding displacement and may fail completely. On the other hand VFPI can control the accelerations as well as sliding displacements as VFPI can never be in resonance with excitation due to varying frequency of isolator. VFPI with variable coefficient of friction is likely to further control both accelerations and sliding displacements due to larger energy dissipation for higher sliding displacements. Similarly due to zero frequency after d_b CFPI also have a larger sliding. Varying the coefficient of friction may be able to control sliding of both PF and CFPI.

5. RESULTS AND DISCUSSION

For different cases under consideration, time history analyses have been carried out for all the fifteen low frequency ground motions indicated in Table 2. The average of the maximum responses is considered for discussion.

5.1 Discussion of Results of Constant Coefficient of Friction

Medium band records (LFR-01 to 06) have moderate strong motion period. From analysis it is found that, for medium band records sliding displacement is higher for lower value of coefficient of friction $\mu = 0.05$, whereas storey acceleration is lower and vice a versa for VFPI. In case of FPS sliding is controlled for $\mu = 0.1$. For $\mu = 0.05$ FPS sliding is significantly high as compared to PF and for higher values of FVF of VFPI. Also storey acceleration of FPS for $\mu = 0.05$ is higher than $\mu = 0.1$. The period of FPS is 2s and the peak period of excitation force is also 2s. This leads to resonance problem in FPS. CFPI sliding is more in case of μ = 0.1 than μ = 0.05. This is due to the fact that frequency of CFPI suddenly becomes zero after d_b. If isolator stick at any position, as usually happen in case of μ = 0.1, it will not slide further due to lack of isolator frequency. Also in case of μ = 0.05 the sliding of CFPI is marginally higher than other isolators. But storey acceleration in case of CFPI is controlled at μ = 0.1. For PF isolator the sliding is substantially lower than all other isolators for both coefficients of friction, whereas storey acceleration values are close to other isolators. Sliding of VFPI for lower values of FVF is very close to PF sliding.

Narrow band records (LFR-07 to 10) have less strong motion period. Consequently it has lower value of excitation force. Due to this fact both response values of VFPI, FPS and PF, for μ = 0.05, are very close to each other. Storey acceleration of FPS is comparatively higher than VFPI and PF. In case of CFPI sliding displacement is marginally higher and storey acceleration is comparatively higher. For μ = 0.1 both response values of all isolators are exactly same.

Broad band records (LFR-11 to 15) have large strong motion period. But as the peak period of excitation is very less the isolator sliding is comparatively lower than medium and narrow band records. The VFPI, FPS and PF sliding are almost equal in all cases, whereas CFPI sliding is comparatively higher. The storey accelerations are also almost equal for all isolators in all cases of constant and variable coefficient of friction.

5.2 Discussion of Results of Variable Coefficient of Friction

When variable coefficient of friction is adopted, both response values fall in between the values of constant coefficient of friction. Again as the value of d_f increases the response graph is more closer to μ = 0.1 graph. The average values of responses are calculated for all cases of coefficient of friction and plotted from Fig. 8 to Fig. 11.

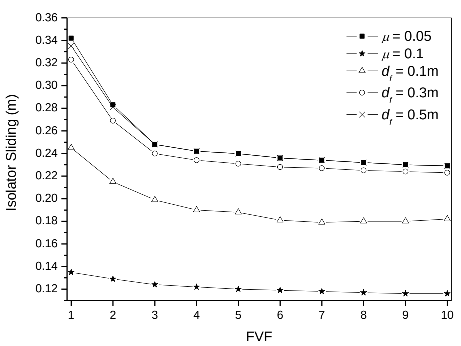

Figure 8. Average isolator sliding of VFPI for constant and variable μ

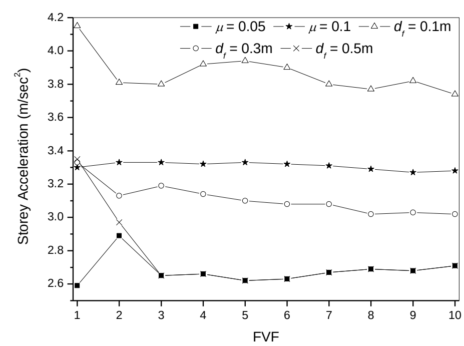

Figure 9. Average storey acceleration of VFPI for constant and variable μ

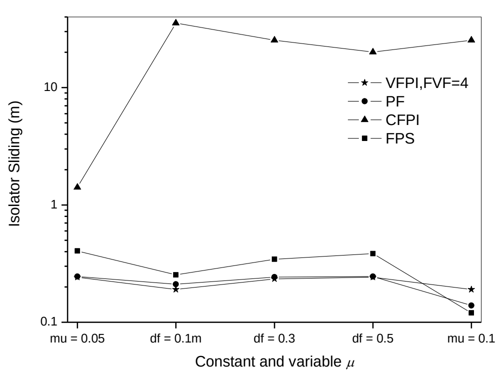

Figure 10. Average isolator sliding for constant and variable μ

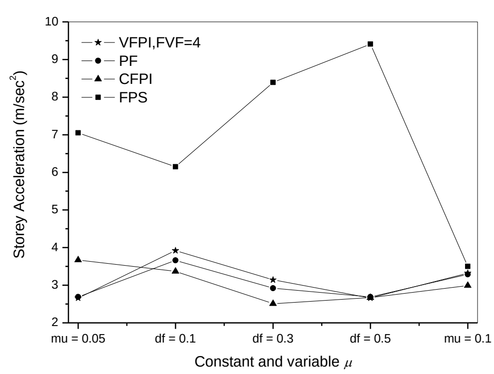

Figure 11. Average storey acceleration for constant and variable μ

Fig. 8 and Fig. 9 show the response of VFPI with constant and variable coefficient of friction for isolator sliding and storey acceleration respectively. As expected in case of VFPI the accelerations under a lower coefficient of friction of 0.05 are substantially lower than that with a higher coefficient of friction of 0.1. Vice versa sliding displacements are more for μ = 0.05 as compared to μ = 0.1. It is further observed that the accelerations at d_f = 0.1m are substantially lower than that at μ = 0.1. At d_f = 0.3m the accelerations are controlled effectively. Also it is observed that isolator sliding in all variable coefficient of friction cases (with different values of d_f) fall between the values of the two constant coefficients of friction cases. Accelerations are reduced for higher value of d_f, where as sliding displacement reduces for lower value of d_f. This is quite obvious since the higher value of d_f represents lower coefficient of friction in major part of isolator which implies lower acceleration and higher sliding displacement and vice a versa.

Fig. 10 and Fig. 11 show the response of VFPI (FVF = 4), PF, CFPI, and FPS isolators with constant and variable coefficient of friction for isolator sliding and storey acceleration respectively. The FPS and CFPI result shows that the variation is not consistent as in case of VFPI. In case of FPS acceleration values are in reverse order than expected, that is acceleration is more for μ = 0.05 and less for μ = 0.1. But displacement is as expected. Also displacement has been controlled for variable coefficient of friction. In case of CFPI the both isolator sliding and storey acceleration values are random. Particularly for μ = 0.1, displacement is increasing, rather than decrease. Whereas even though the variation is very little, acceleration is decreased at μ = 0.1 than at μ = 0.05. This is due to the fact that frequency of CFPI suddenly becomes zero after d_b. In case of PF isolator sliding is controlled by variable coefficient of friction. But storey acceleration values are not as expected.

In case of variable coefficient of friction these graph shows that isolator sliding of VFPI are controlled for all FVF and d_f values. Isolator sliding of FPS are controlled at d_f = 0.1. Isolator sliding of CFPI are very high, which even difficult to accommodate in design. Isolator sliding of PF is controlled for all values of d_f.

In case of variable coefficient of friction these graphs show that in all cases the storey acceleration of CFPI is lower, except the case of μ = 0.05. VFPI and PF accelerations are close to each other. They are higher at d_f = 0.1m. Storey accelerations of FPS are very high. In case of PF storey accelerations increase as d_f increases.

6. CONCLUSION

The effectiveness of isolation system, PF, FPS, VFPI and CFPI for vibration control of multi storied structure (5 storied lumped mass system) subjected to low frequency ground motions has been investigated in this paper. For effectiveness of isolation system i.e. for controlling both accelerations and sliding displacements, variable coefficients of friction for the sliding surface has been proposed in this paper. Based on the investigations the following conclusions can be drawn.

1. Due to the variable frequency of VFPI, VFPI never comes in resonance under any type of low frequency ground motion. Also by varying the coefficient of friction the responses of structures with VFPI can be more effectively controlled.
2. Due to the constant period of FPS, FPS may come in resonance with a low frequency excitation. Hence sliding and acceleration of FPS are quite high in low frequency ground motions. The sliding displacements may be so high that they may tend to exceed the geometrical limits of the isolator. Hence FPS is not found suitable for low frequency ground motions.
3. As the frequency of CFPI suddenly becomes zero after d_b, it leads to very high sliding and accelerations due to the constant isolator force acting. Even by varying coefficient of friction CFPI responses can not be controlled.

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