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Optimum friction pendulum system for near-fault motions

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Abstract

The analytical seismic response of multi-story buildings isolated by the friction pendulum system (FPS) is investigated under near-fault motions. The superstructure is idealized as a linear shear type flexible building. The governing equations of motion of the isolated structural system are derived and the response of the system to the normal component of six recorded near-fault motions is evaluated by the step-by-step method. The variation of top floor absolute acceleration and sliding displacement of the isolated building is plotted under different system parameters such as superstructure flexibility, isolation period and friction coefficient of the FPS. The comparison of results indicated that for low values of friction coefficient there is significant sliding displacement in the FPS under near-fault motions. In addition, there also exists a particular value of the friction coefficient of FPS for which the top floor absolute acceleration of the building attains the minimum value. Further, the optimum friction coefficient of the FPS is derived for different system parameters under near-fault motions. The criterion selected for optimality is the minimization of both the top floor acceleration and the sliding displacement. The optimum friction coefficient of the FPS is found to be in the range of 0.05 to 0.15 under near-fault motions. In addition, the response of a bridge seismically isolated by the FPS is also investigated and it is found that there exists a particular value of the friction coefficient for which the pier base shear and deck acceleration attain the minimum value under near-fault motions.

Keywords: Base isolation; Earthquake; Near-fault motion; Friction pendulum system; Friction coefficient; Superstructure flexibility; Optimum parameters

1. Introduction

A significant amount of the past research in the area of base isolation has focused on the use of frictional elements to concentrate flexibility of the structural system and to add damping to the isolated structure. The simplest sliding system device is a pure-friction (P-F) system without any restoring force [1–3]. The P-F system supporting a relatively rigid superstructure is very effective for a wide range of frequency input and transmits a limited earthquake force equal to the maximum limiting frictional force [1,2]. However, the large sliding and residual displacement in the P-F system render it unsuitable for practical applications to important structures. To overcome this, the sliding systems with restoring force had been proposed and studied such as the resilient-friction base isolator (R-FBI) system [4], the Electricite de France (EDF) system [5], the friction pendulum system (FPS) [6], the sliding-resilient friction (S-RF) base isolator [7] and the elliptical rolling rods [8]. The sliding systems perform very well under a variety of severe earthquake loadings and are quite effective in reducing the large levels of the superstructure's acceleration without inducing large base displacements [4]. Comparative study of different base isolation systems has shown that the response of sliding system does not vary with the frequency content of earthquake ground motion [7,9,10]. In addition, the sliding systems are also less sensitive to the effects of torsional coupling in asymmetric base-isolated buildings [11]. Among the various sliding isolation systems, the FPS is found to be more attractive due to its ease in installation and simple mechanism of restoring force by gravity action [6,12]. The FPS had been used for practical seismic isolation of buildings (i.e. Washington State Emergency Operations Center at Camp Murray, the US Court of Appeals Building in San Francisco etc.), bridges

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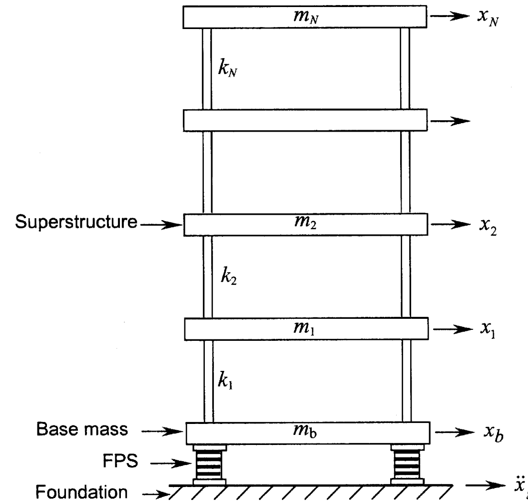
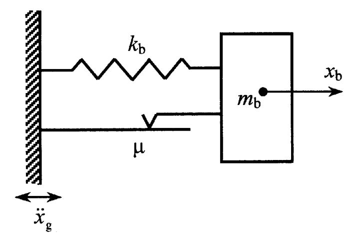
(i.e. Benicia-Martinez Bridge in the San Francisco Bay Area, American River Bridge at Lake Natoma in Folsom etc.) and storage tanks (i.e. LNG storage tanks on Revithoussa island near Athens).

Several seismologists have suggested that base-isolated buildings can be vulnerable to the large pulse-like ground motions generated at near-fault locations [13,14]. Such ground motions may have one or more displacement pulses with peak velocities of the order of 0.5 m/s and durations in the range of 1 to 3 s. These pulses are obviously going to have large impact on the isolation system with a period in this range and can lead to a large isolator displacement. This leads to considerable interest to the researchers and recently several studies for understanding the dynamic behaviour of base-isolated buildings under near-fault motions were reported [15–17]. The bearing displacements under near-fault motions were found to be significantly large and can cause instability in the isolation system. The performance of the FPS system with selected properties was also not reported to be very satisfactory under near-fault motions in the above studies. Since the FPS system is a very common isolation system equipped with all desirable features of base isolation, it is necessary to study the dynamic behaviour of the FPS system and investigate the optimum parameters under near-fault motions.

Herein, the response of multi-story buildings and bridges isolated by the FPS is investigated under near-fault motions. The specific objectives of the study are (i) to study the performance of structures isolated by FPS under near-fault motions, (ii) to investigate the optimum parameters of the FPS for minimum earthquake response of the base-isolated buildings under near-fault motions, (iii) to study the variation of optimum parameters of the FPS under different system parameters of superstructure and isolation systems, and (iv) to investigate the seismic response of bridge with FPS under near-fault motions.



(a) Flexible superstructure with FPS.



(b) Schematic diagram of FPS.

Fig. 1. Model of N-story base-isolated building and schematic diagram of the FPS.

2. Modelling of base-isolated building with FPS

Fig. 1 shows the structural system under consideration which is an idealized N-story shear type building mounted on the FPS system. The FPS makes use of spherically shaped, articulated sliding bearings. The unique feature of the FPS is that movement of one part of the bearing with respect to others resembles pendulum motion in the presence of friction. The lateral force needed to induce a lateral displacement of the building–bearing system depends primarily upon the curvature of the spherical sliding surface, and the vertical load on the bearing. The lateral force is proportional to the vertical load, a property which minimizes adverse torsional motions in structures with asymmetric mass distribution. Various assumptions made for the structural system under consideration are: (i) floors of each story of the superstructure are assumed as rigid, (ii) force–deformation behaviour of the superstructure is considered to be linear with viscous damping, (iii) the friction coefficient of the FPS is assumed to be independent of the relative velocity at the sliding interface. This is based on the findings that such effects do not have noticeable effects on the peak response of the isolated structural system [8], (iv) the restoring force provided by the FPS is considered as linear (i.e. proportional to relative displacement), and (v) the structure is excited by a single horizontal component of near-fault earthquake ground motion and the effects of vertical component of the earthquake acceleration are neglected.

At each floor and base mass one lateral dynamic degree of freedom is considered. Therefore, for the N-story superstructure the dynamic degrees of freedom are $N + 1$. The governing equations of motion for the fixed-base N-story superstructure model are expressed in matrix form as

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = -[M]\{1\}(\ddot{x}_g + \ddot{x}_b) \qquad (1)$$

where $[M]$, $[K]$ and $[C]$ are the mass, stiffness and damping matrices of the fixed base structure, respectively, of the order $N \times N$; $\{x\} = \{x_1, x_2, \ldots, x_N\}^T$ is the displacement vector of the superstructure; x_j $(j = 1, 2, \ldots, N)$ is the lateral displacement of the jth floor relative to the base mass; $\{1\} = \{1, 1, 1, \ldots, 1\}^T$ is the influence coefficient vector; $\ddot{x}_b$ is the acceleration of base mass relative to the ground; and $\ddot{x}_g$ is the acceleration of earthquake ground motion. Note that the damping matrix of the superstructure, $[C]$, is not known explicitly. It is constructed by assuming the modal damping ratio which is kept constant in each mode of vibration.

The governing equation of motion of the base mass is expressed by

$$m_b\ddot{x}_b + F_b - c_1\dot{x}_1 - k_1x_1 = -m_b\ddot{x}_g \tag{2}$$

where m_b is the mass of the base raft; F_b is the restoring force mobilized in the FPS (refer Fig. 1(b) for the schematic diagram); and k_1 and c_1 are the stiffness and damping of the first story of the superstructure, respectively.

The restoring force of the FPS is expressed by

$$F_b = F_x + k_bx_b \tag{3}$$

where F_x is the frictional force in the FPS; and k_b is the stiffness of the FPS provided by the curvature of the spherical surface through inward gravity action.

The limiting value of the frictional force, Q, to which the FPS can be subjected (before sliding) is expressed as

$$Q = \mu W \tag{4}$$

where μ is the friction coefficient of the FPS; $W = Mg$ is the total weight of the isolated building; $M = (m_b + \sum_{j=1}^{N} m_j)$ is the total mass of the base-isolated building; m_j is the mass of the jth floor; and g is the acceleration due to gravity.

The stiffness, k_b, of the FPS is designed such a way to provide the specific value of the isolated period, T_b, expressed as

$$T_b = 2\pi\sqrt{\frac{M}{k_b}}. \tag{5}$$

Thus, the modelling of FPS requires the specification of two parameters, namely the isolation period (T_b) and the friction coefficient (μ).

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 FPS. As a result, the governing equations of motion are solved in the incremental form using Newmark's step-by-step method assuming linear variation of acceleration over a small time interval, Δt. The system remains in the non-sliding phase ($\dot{x}_b = \ddot{x}_b = 0$) if the frictional force mobilized at the interface of FPS is less than the limiting frictional force (i.e. $|F_x| < Q$). The system starts sliding ($\dot{x}_b \neq 0$ and $\ddot{x}_b \neq 0$) as soon as the frictional force attains the limiting frictional force (i.e. $|F_x| = Q$). The governing equation of motion of the base mass is also included for the solution during the sliding phase of motion. Whenever the relative velocity of the base mass becomes zero (i.e. $\dot{x}_b = 0$), the phase of the motion is checked in order to determine whether the system remains in the sliding phase or sticks to the foundation. The maximum time interval selected for solving the equations of motion is $0.02/20$ s.

3. Numerical study

For the present study, the mass matrix of the superstructure, $[M]$, is diagonal and characterized by the mass of each floor which is kept constant (i.e. $m_i = m$ for $i = 1, 2, \ldots, N$). Also, for simplicity the stiffness of all the floors is taken as constant expressed by the parameter k. The value of k is selected such as to provide the required fundamental time period of superstructure as a fixed base. The damping matrix of the superstructure, $[C]$, is not known explicitly. It is constructed by assuming the modal damping ratio which is kept constant in each mode of vibration. Thus, the superstructure and the base mass of the isolated structural system under consideration can be completely characterized by the parameters, namely, the fundamental time period of the superstructure (T_s), damping ratio of the superstructure (ξ_s), number of stories in the superstructure (N), and the ratio of base mass to the superstructure floor mass (m_b/m). For the present study, the parameter m_b/m is held constant with $m_b/m = 1$.

The seismic response of the base-isolated structure is obtained under the normal component of six near-fault earthquake ground motions. The peak ground acceleration of these selected earthquake motions is given in Table 1. For the base-isolated building, the response quantities of interest are the top floor absolute acceleration (i.e. $\ddot{x}_a = \ddot{x}_N + \ddot{x}_b + \ddot{x}_g$) and the relative bearing displacement (x_b). The absolute acceleration is directly proportional to the forces exerted in the superstructure due to earthquake ground motion. On the other hand, the relative bearing displacement is crucial from the design point of view of the isolation system.

Table 1
Peak acceleration of normal component of six near-fault motions

Near-fault earthquake motions	Peak acceleration (g)
October 15, 1979 Imperial Valley, California (Array #5)	0.36
October 15, 1979 Imperial Valley, California (Array #7)	0.45
January 17, 1994 Northridge, California (Newhall station)	0.70
June 28, 1992 Landers, California (Lucerene Valley station)	0.71
January 17, 1994 Northridge, California (Rinaldi station)	0.87
January 17, 1994 Northridge, California (Sylmar station)	0.72
Average	0.64

Fig. 2 shows the time variation of the top floor absolute acceleration and bearing displacement of a structure isolated by the FPS under Imperial Valley, 1979 earthquake motion. The response is shown for two values of the friction coefficient i.e. $\mu = 0.05$ and 0.1 with $T_b = 2.5$ s. The superstructure considered has five stories with fundamental

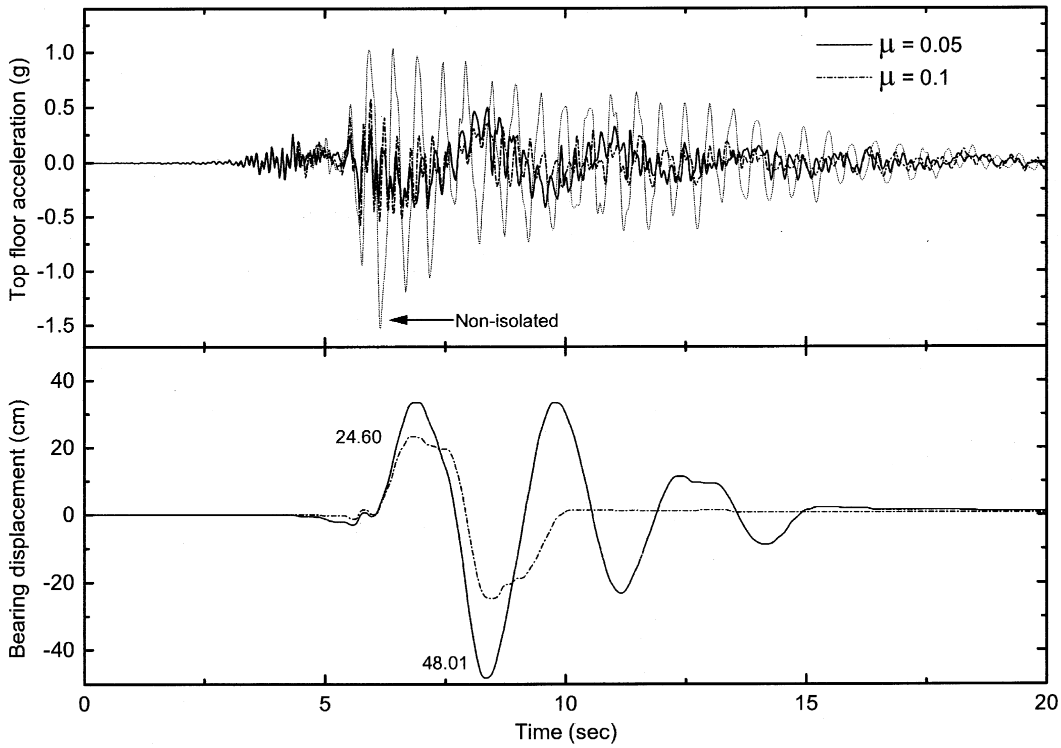


Fig. 2. Time variation of top floor absolute acceleration and bearing displacement of a five-story base-isolated structure under Imperial Valley, 1979 (Array #5) earthquake motion ($T_s = 0.5$ s, $\xi_s = 0.02$ and $T_b = 2.5$ s).

time period, $T_s = 0.5$ s and $\xi_s = 0.02$. The figure indicates that there is same reduction in the top floor acceleration of the building for both values of the friction coefficients of the FPS. However, there is significant difference in the peak values of the bearing displacement. The peak bearing displacements are 48.01 and 24.60 cm for $\mu = 0.05$ and 0.1, respectively. This implies that under the near-fault motions, the increase in the friction coefficient may reduce the bearing displacement significantly without much alteration to the peak superstructure accelerations. Similar differences in the response of a base-isolated building for two values of the friction coefficients are also depicted in Fig. 3 under 1994 Northridge earthquake motion (recorded at Sylmar station). Thus, it is possible to reduce the peak displacement in the FPS by increasing its friction coefficient without sacrificing the benefits of base isolation in the reduction of superstructure accelerations. Further, there is an interesting feature to be noted in the time variation of the top floor superstructure acceleration of the isolated building shown in Figs. 2 and 3. The superstructure acceleration is associated with dominating high frequency components which can be detrimental to the high frequency sensitive equipment installed in the building. This is in accordance with the results of earlier studies [18,19] concluding that the sliding system may not be suitable for flexible buildings supporting high frequency secondary systems or equipments.

In order to distinguish the difference in the response of the isolated building for two values of the friction coefficients, the corresponding force–deformation loops are plotted for comparison in Fig. 4. The figure indicates that the relatively better performance of the FPS at higher friction coefficient is not due to energy dissipation through friction (as there are not many force reversal cycles). The better performance can be attributed due to stiffening effects produced by the higher friction coefficient under near-fault motions. This stiffening effect resulted in an effective period of the isolated structure away from the typical pulse periods (i.e. in the range of 1 to 3 s). For relatively low values of the friction coefficient, the effective period of the isolated structure is about 2.5 s which is quite close to the pulse duration resulting in large bearing displacements. On the other hand, for higher friction coefficient, the isolated system remains more time in the non-sliding phase decreasing the effective period away from the pulse durations. Thus, the friction coefficient of the FPS should be such that it should provide enough initial rigidity as well as the isolation by shifting the effective period away from the duration of pulses associated in the near-fault motions.

Fig. 5 shows the variation of the peak top floor absolute acceleration and the bearing displacement against the friction coefficient, μ, under different near-fault motions. The responses are shown for one- and five-story buildings with $T_s = 0.5$ s, $\xi_s = 0.02$ and $T_b = 2.5$ s. It is observed from Fig. 5 that the top floor absolute acceleration first decreases, attains a minimum value and then increases with the increase of friction coefficient. This indicates that

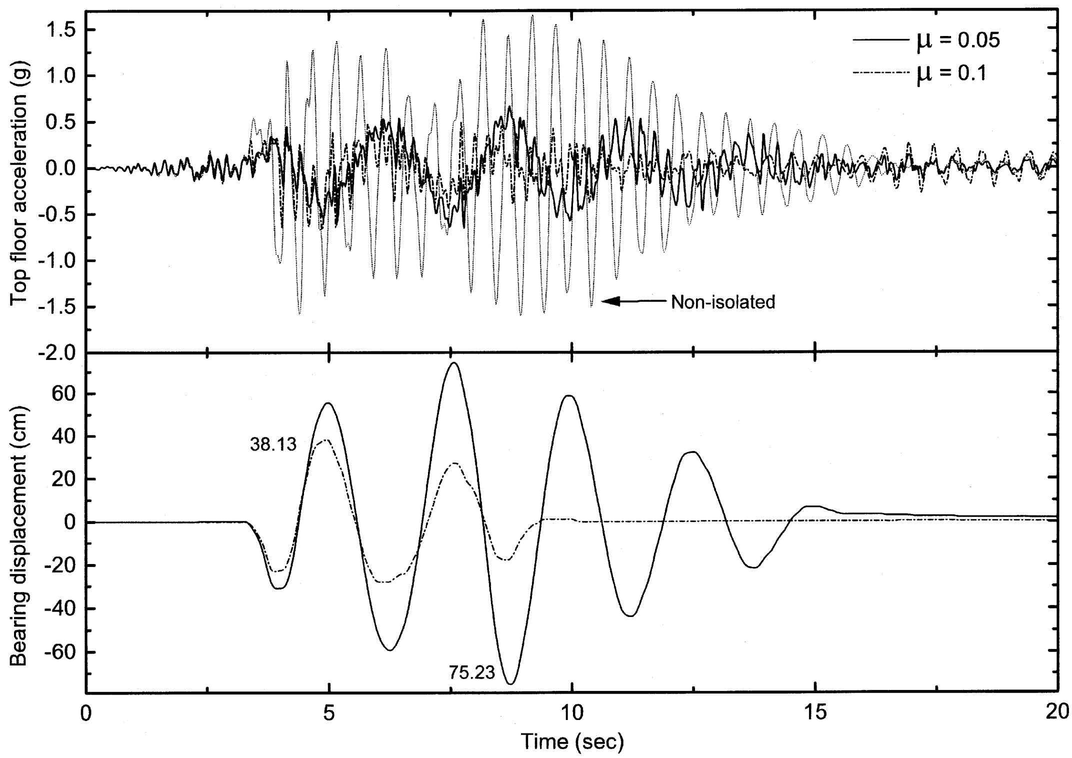


Fig. 3. Time variation of top floor absolute acceleration and bearing displacement of a five-story base-isolated building under Northridge, 1994 (Sylmar station) earthquake motion ($T_s = 0.5$ s, $\xi_s = 0.02$ and $T_b = 2.5$ s).

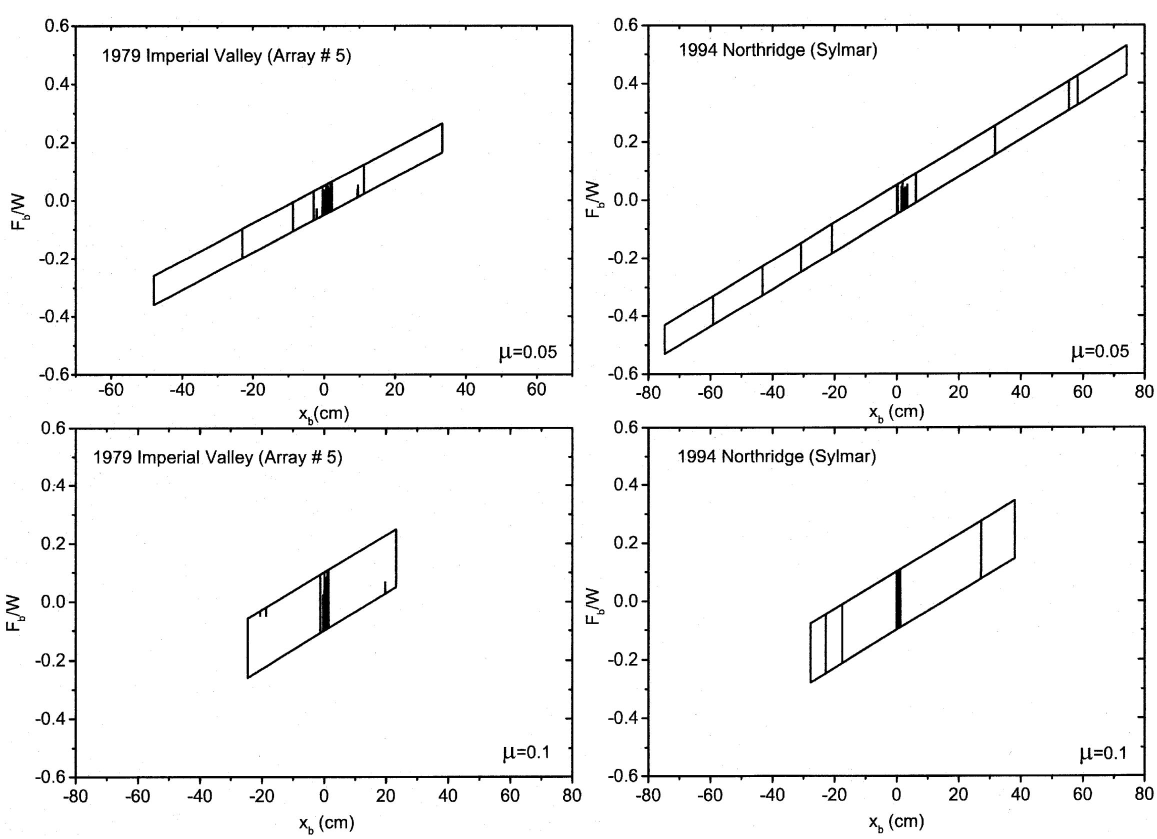


Fig. 4. Force–displacement behaviour of the FPS isolating the five-story building for two different levels of friction coefficients ($T_s = 0.5$ s, $\xi_s = 0.02$ and $T_b = 2.5$ s).

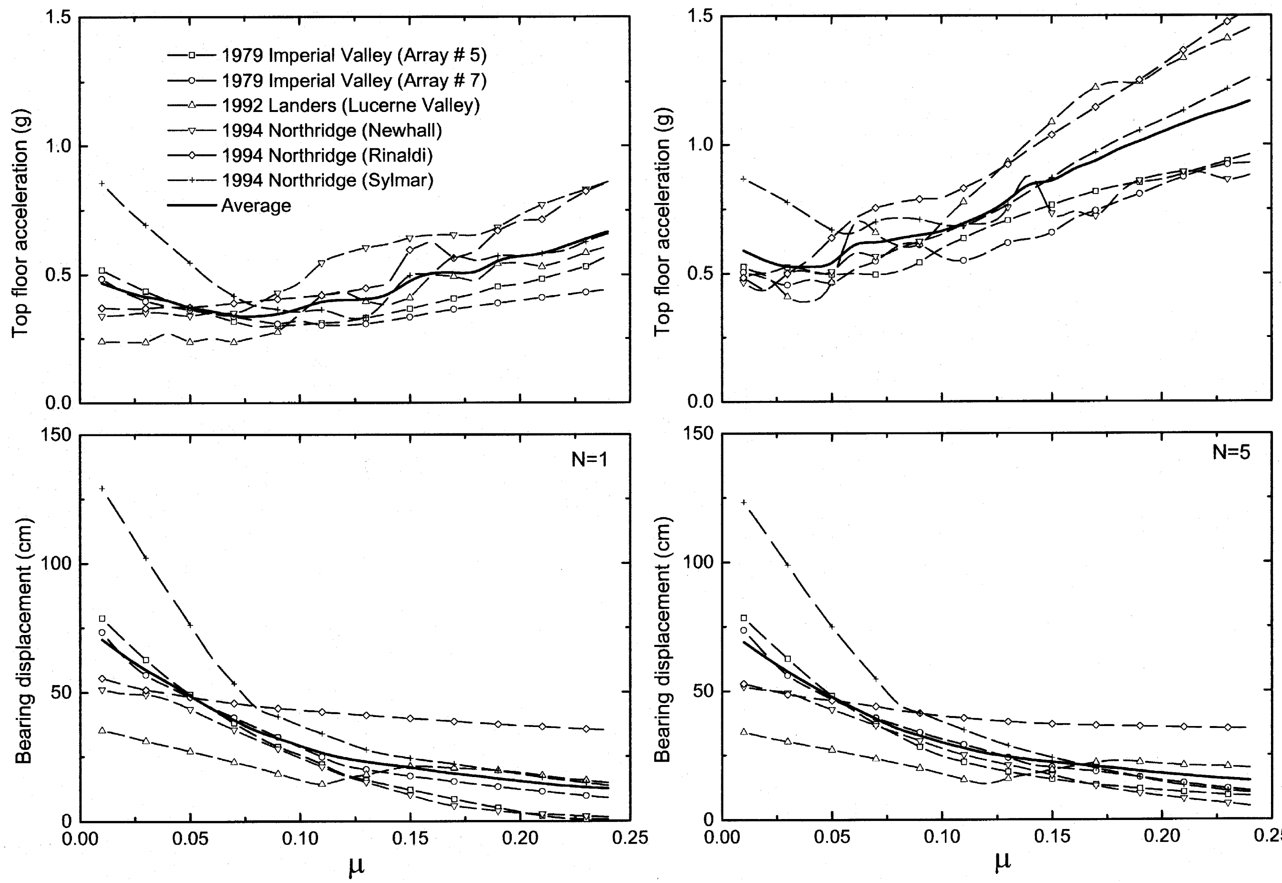


Fig. 5. Variation of peak top floor absolute acceleration and bearing displacement of base-isolated building against the friction coefficient of FPS ($T_s = 0.5$ s, $\xi_s = 0.02$ and $T_b = 2.5$ s).

there exists a particular value of the friction coefficient of the FPS of which the top floor superstructure acceleration of a given structural system attains the minimum value under the near-fault motions. In Fig. 5, the variation of the average top floor acceleration and bearing displacement is also plotted for comparison. The average top floor acceleration attains the minimum value at $\mu = 0.08$ and 0.04 for one- and five-story buildings, respectively. Further, the average top floor acceleration is not much influenced by the variation of the friction coefficient up to a certain value (i.e. upto 0.12). On the other hand, the bearing displacement continues to decrease with the increase in the friction coefficient of the FPS. The above observations imply that by designing an optimum FPS, it is possible to reduce the bearing displacements significantly without much increasing the top floor accelerations under near-fault motions.

Fig. 5 had shown that due to increase in the friction coefficient of the FPS there is a decrease in the bearing displacement without much increase in the superstructure accelerations under near-fault motions. In fact, there exists a particular value of the friction coefficient for which the superstructure acceleration is minimum. Further, it was also observed that in the vicinity of the particular friction coefficient, the top floor acceleration is not much influenced by the variation of the friction coefficient. One can take advantage of this kind of behaviour of the base-isolated structure in designing the optimum FPS under near-fault motions. The friction coefficient shall be kept to a value slightly higher than the corresponding particular value of minimum acceleration to achieve the maximum isolation with lesser bearing displacement. In view of the above, the optimum friction coefficient of the FPS is obtained by minimizing a force quantity defined as

$$f(\ddot{x}_a, x_b) = Q + 2k_b x_b + M\ddot{x}_a \tag{6}$$

where $f(\ddot{x}_a, x_b)$ is the force function selected for the optimum friction coefficient of the FPS which is a function of the peak top floor absolute acceleration, bearing displacement and the limiting frictional force of the FPS.

The term $M\ddot{x}_a$ in Eq. (6) indicates the maximum force exerted in the superstructure due to earthquake motion (more applicable under the rigid superstructure condition). The factor 2 used in Eq. (6) implies that relatively more weight is given for reduction in the bearing displacement in comparison to the reduction in the top floor absolute acceleration. This is due to the fact that $Q + k_b x_b \approx M\ddot{x}_a$ (i.e. the maximum bearing force is equal to the maximum earthquake force on the superstructure). If the factor 2 is not used in

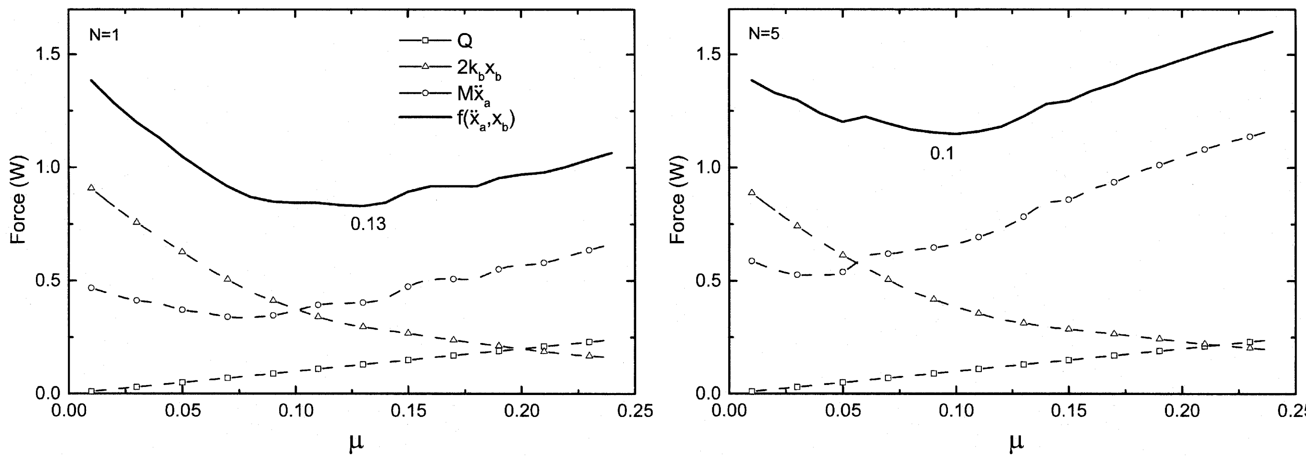


Fig. 6. Variation of the function $f(\ddot{x}_a, x_b)$ and its different terms against the friction coefficient of the FPS ($T_s = 0.5$ s, $\xi_s = 0.02$ and $T_b = 2.5$ s).

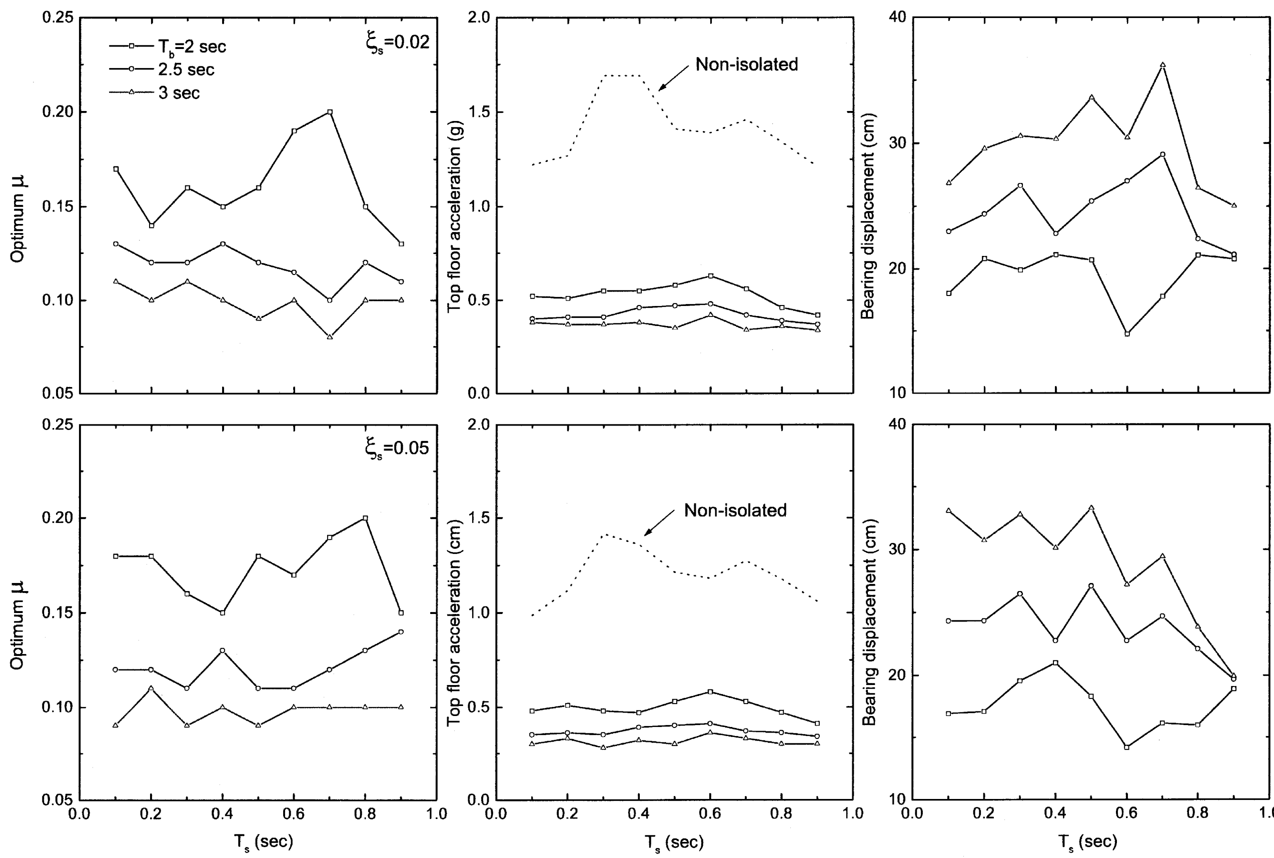


Fig. 7. Variations of optimum friction coefficient and corresponding peak average top floor absolute acceleration and bearing displacement of a one-story base-isolated building against fundamental time period of superstructure.

Eq. (6) then the forcing function, $f(\ddot{x}_a, x_b)$, will be minimum when the top floor acceleration is minimum. The factor 2 is selected by several trials and errors with the criterion that the superstructure acceleration does not increase significantly with the decrease in the bearing displacement under the selected near-fault motions.

Fig. 6 shows the variation of different terms of Eq. (6) against the friction coefficient of the FPS, μ for $N = 1$ and 5. The function $f(\ddot{x}_a, x_b)$ attains the minimum value for a certain value of μ and this is referred to as the *optimum* friction coefficient of the FPS. The optimum value of μ for one- and five-story buildings is found to be 0.13 and 0.1, respectively which is higher than the corresponding value of friction coefficient when the corresponding top floor superstructure acceleration attains the minimum values (i.e. $\mu = 0.08$ and 0.04). For the one-story building, the top floor acceleration

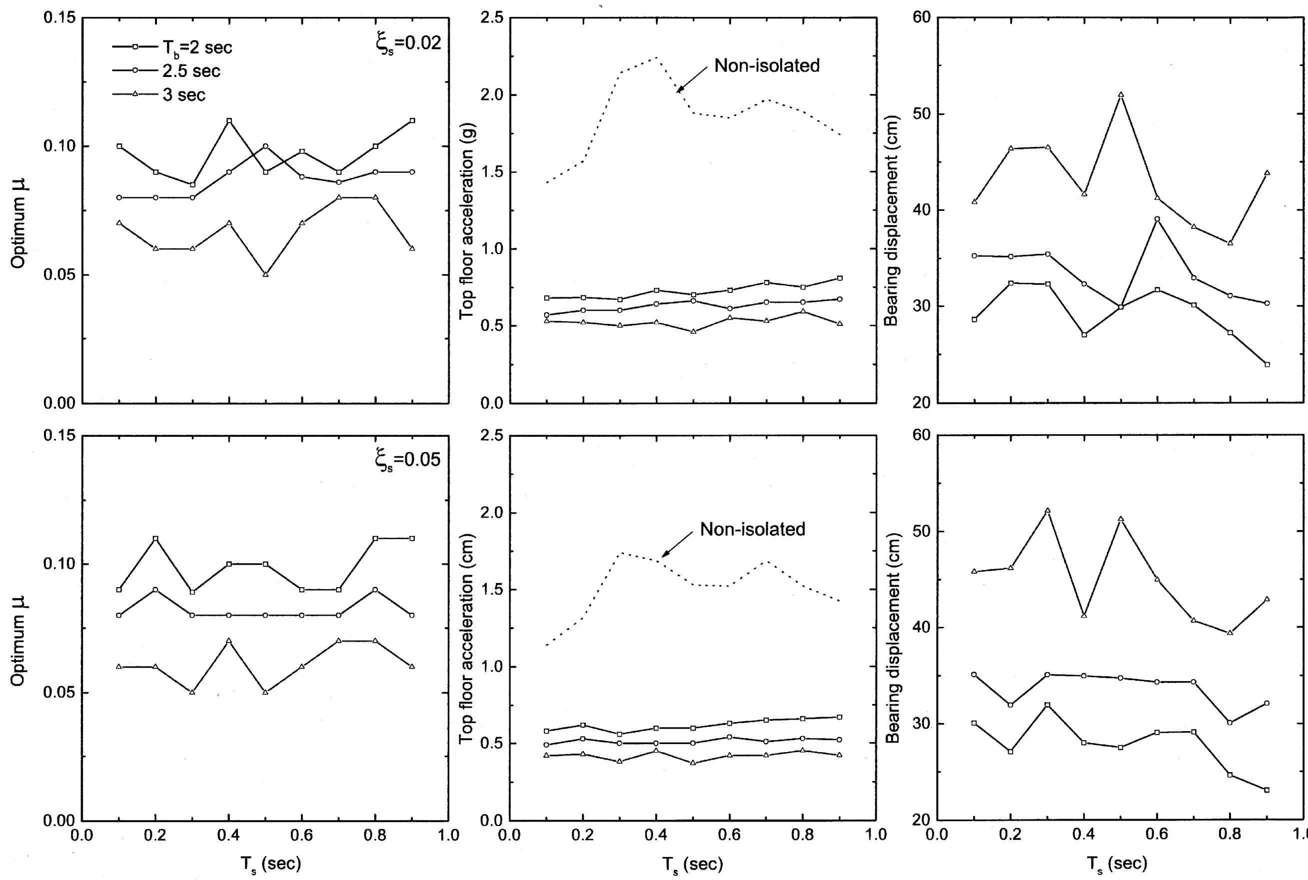


Fig. 8. Variation of optimum friction coefficient and corresponding peak average top floor absolute acceleration and bearing displacement of a five-story base-isolated building against fundamental time period of superstructure.

is found to be $0.34g$ and $0.4g$ and bearing displacements are 45.26 and 29.6 cm for $\mu = 0.08$ and 0.13, respectively. This implies that increasing the friction coefficient of the FPS beyond a particular value to the optimum value there is a significant reduction in the bearing displacement with marginal increase in superstructure acceleration. This also provides the justification of the proposed Eq. (6) for evaluation of the optimum friction coefficient of the FPS.

Figs. 7 and 8 show the variation of optimum μ of the FPS along with the corresponding peak top floor acceleration and relative bearing displacement against the fundamental time period of the superstructure, T_s, for one- and five-story superstructures, respectively. The optimum parameters are obtained for three periods of isolation (i.e. $T_b = 2$, 2.5 and 3 s) and two values of superstructure damping (i.e. $\xi_s = 0.02$ and 0.05). It is observed from these figures that the variation in the time period of the superstructure does not significantly influence the optimum μ. However, the optimum μ decreases with the increase of the isolation period of the FPS. The optimum μ values are relatively higher for the structure with $\xi_s = 0.02$ as compared to that with $\xi_s = 0.05$. On the other hand, the peak bearing displacement corresponding to the optimum μ decreases with the increase of the time period of the superstructure and isolation system. The corresponding top floor absolute acceleration increases mildly with the increase of the flexibility of the structure and decreases with the increase of the flexibility of the FPS. Thus, the optimum friction coefficient of the FPS decreases with the increase of the flexibility of the FPS and superstructure damping. In Fig. 9, the variation of the optimum μ of the FPS and corresponding top floor acceleration and bearing displacement are plotted against the number of stories in the superstructure, N. The period of the superstructure, T_s, is considered as $0.1N$ s. The effects of the superstructure and isolator flexibility on the optimum μ of the FPS and corresponding peak responses are similar to that observed in Figs. 7 and 8. Further, from Figs. 7–9 it can also be concluded that the optimum μ of the FPS for practical applications of building is in the range of 0.05 to 0.15 (barring some extreme cases).

4. Response of bridges isolated by FPS

Bridges are lifeline structures and act as an important link in the surface transportation network. Failure of bridges during a seismic event will seriously hamper the relief and rehabilitation work. There had been also considerable interest in earthquake-resistant design of bridges by seismic isolation in which the isolation bearings are used which

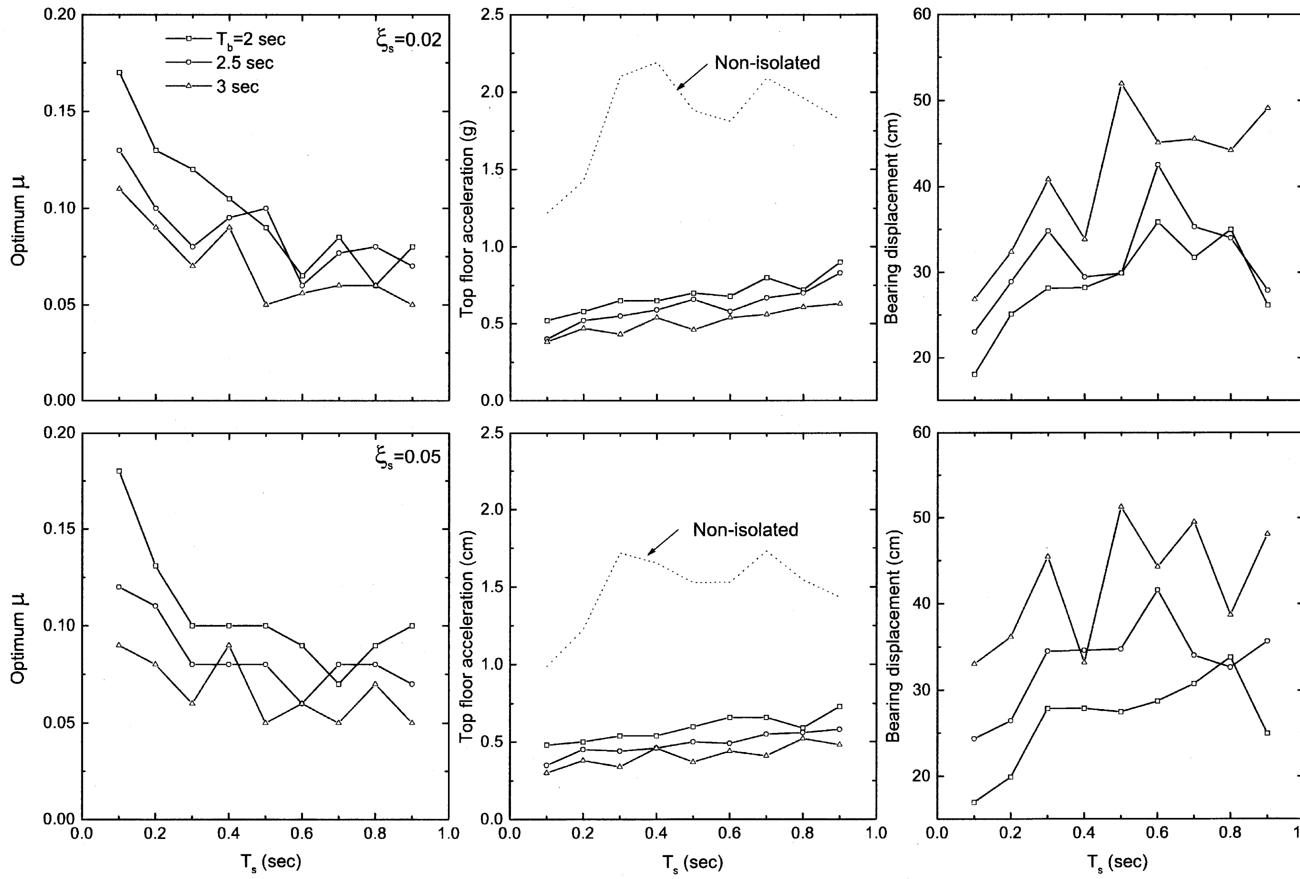


Fig. 9. Variation of optimum friction coefficient and corresponding peak average top floor absolute acceleration and bearing displacement of base-isolated building against number of stories of superstructure ($T_S = N/10$).

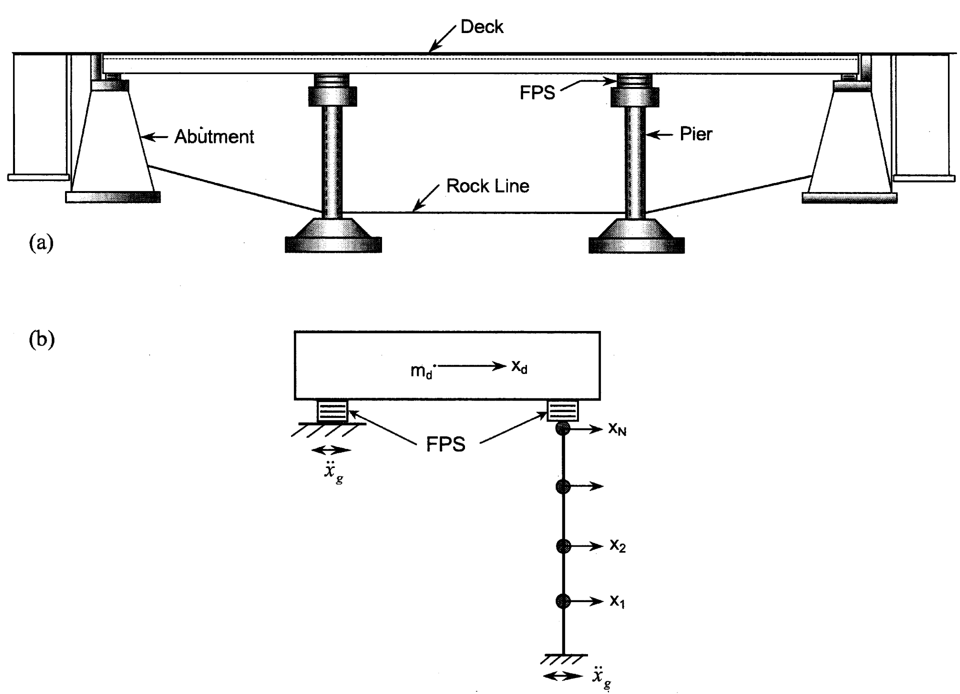


Fig. 10. Model of a bridge seismically isolated by the FPS.

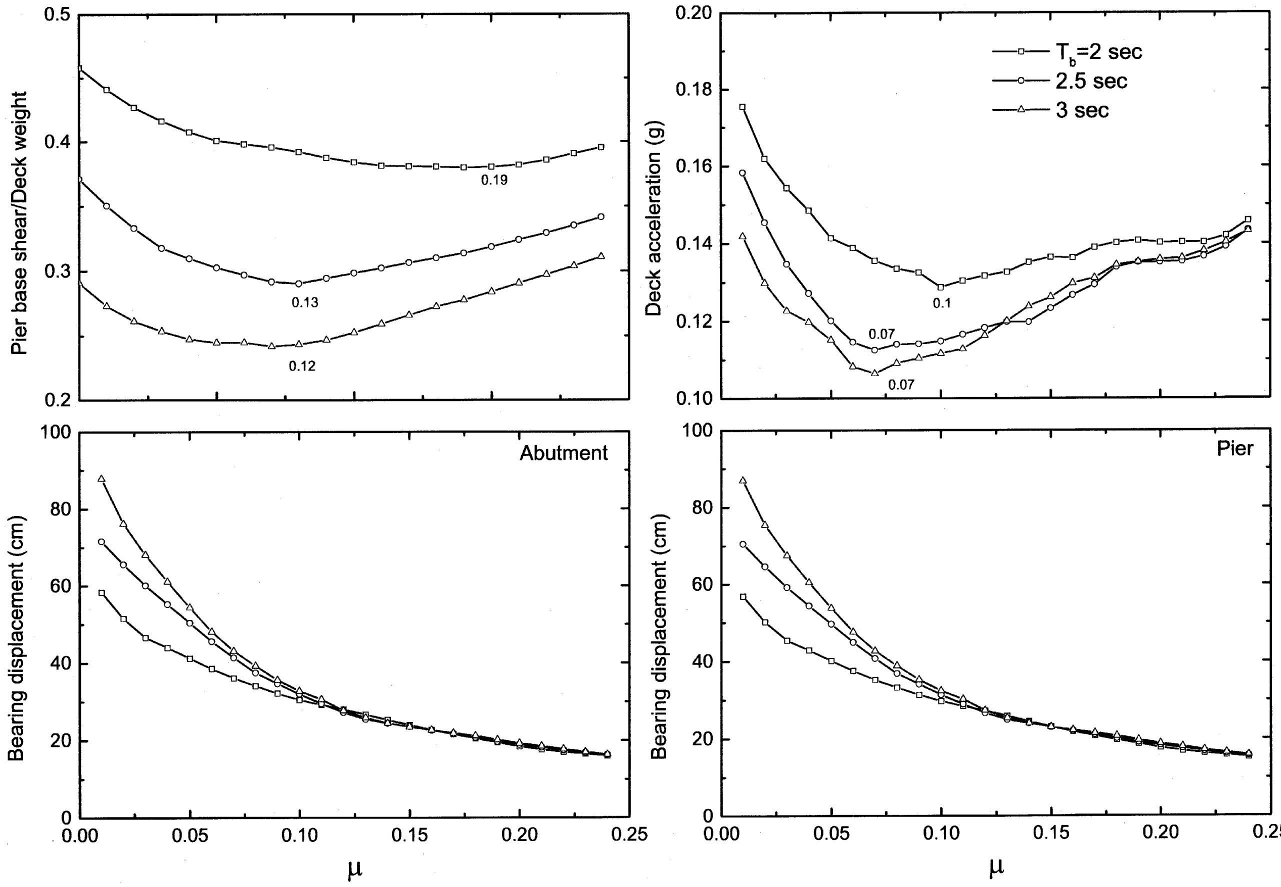


Fig. 11. Effects of friction coefficient of the FPS on the peak average pier base shear, deck acceleration and bearing displacement of the isolated bridge.

replace the conventional bridge bearings to decouple the bridge deck from the bridge substructure during earthquakes [20–24]. There are several bridges constructed and retrofitted using the seismic isolation devices including the FPS. In order to study the performance of FPS for bridges under near-fault motions, consider a three-span continuous deck bridge as shown in Fig. 10(a). The FPS is provided both at abutment as well as at pier level. For studying the seismic response, the bridge is mathematically modelled as shown in Fig. 10(b) assuming a rigid deck [21]. The same numbers of FPSs with identical properties are provided at pier and abutment levels. The entire FPSs are designed to provide the specific values of two parameters, namely, T_b and μ based on the parameter M equal to the deck mass, m_d (refer to Eqs. (4) and (5)). The properties of the three-span bridge taken from Ref. [22] are: deck mass $= 771.12 \times 10^3$ kg; mass of each pier $= 39.26 \times 10^3$ kg; moment of inertia of piers $= 0.64$ m^4; Young's modulus of elasticity $= 20.67 \times 10^9$ (N/m^2); pier height $= 8$ m; and total length of bridge $= 90$ m.

The variation of peak average base shear, deck acceleration and bearing displacements of the isolated bridge against the friction coefficient of the FPS is shown in Fig. 11 for the six selected near-fault motions. The responses are plotted for three values of isolation period (i.e. $T_b = 2$, 2.5 and 3 s) to study the effects of isolator flexibility. It is observed from the figure that with the increase in μ, the peak bearing displacement decreases. This is due to the fact that for higher values of friction coefficient the isolation system becomes relatively stiff; as a result, the bearing displacements are reduced. On the other hand, the pier base shear and deck acceleration first decreases, attains the minimum value and then increases with the increase of the friction coefficient. This implies that there exists a particular value of the friction coefficient for which the peak pier base shear and deck acceleration attains the minimum value under near-fault motions. The minimum value of the pier base shear and deck acceleration occurs for the value of μ in the range of 0.07 to 0.19 for different values of the isolation periods. It is also observed from Fig. 11 that the pier base shear and deck acceleration decreases with the increase in isolation period implying that the effectiveness of FPS increases with the increase of its flexibility. On the other hand, the relative bearing displacements are also relatively higher for the higher values of isolation periods especially for the lower friction coefficients.

Finally, the variation of the response of isolated bridge system in Fig. 11 indicates that the best FPS for the bridges under near-fault motions can be designed by taking the friction coefficient as 0.1 and selecting the curvature of the spherical surface that provides the isolation period about 3 s.

5. Conclusions

The analytical seismic response of the multi-story buildings isolated by the friction pendulum system (FPS) is investigated under near-fault motion. The normal component of six recorded near-fault motions is used to study the variation of the top floor acceleration and bearing displacement of the isolated building. The response of the isolated building is plotted under different system parameters such as superstructure flexibility, isolation period and friction coefficient. Further, the optimum friction coefficient of FPS is derived for different system parameters under near-fault motions. The criterion selected for the optimality is minimization of both top floor absolute acceleration and the bearing displacement. In addition, the response of a bridge seismically isolated by the FPS is also investigated under near-fault motions. From the trends of the results of the present study, the following conclusions may be drawn:

1. For low values of the friction coefficient there is significant displacement in the FPS under near-fault motions. The increase in the friction coefficient can reduce the bearing displacement significantly without much altering the superstructure accelerations.
2. There exists a particular value of the friction coefficient of the FPS for which the top floor absolute acceleration of the multi-story building attains the minimum value.
3. In the vicinity of the particular friction coefficient of the FPS, the top floor absolute acceleration is not much influenced by the variation of the friction coefficient. However, the sliding displacement decreases significantly with the increase of friction coefficient beyond the particular friction coefficient.
4. The optimum friction coefficient of the FPS based on the criterion of minimization of both top floor absolute acceleration of the building and bearing displacement is found to be in the range of 0.05 to 0.15 under near-fault motions.
5. The optimum friction coefficient of the FPS under near-fault motions is found to decrease with the increase of the flexibility of the FPS. However, the bearing displacement at optimum friction coefficient increases with the increase of the flexibility of the FPS.
6. The response of a bridge seismically isolated by FPS under near-fault motions indicated that there also exists a particular value of the friction coefficient for which the pier base shear and deck acceleration attain the minimum value.

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