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BASE ISOLATION SYSTEM SUITABLE FOR MASONRY BUILDINGS

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ABSTRACT

Masonry construction is the most popular and suitable for housing purposes in almost all developing countries. Base isolation in the form of pure friction is the simplest (P-F) among all isolation so far developed which can easily applied to low cost brick masonry buildings. The effect of the earthquake ground motion on the behaviour of isolation system is investigated analytically by using a synthetic accelerogram that is compatible with the design spectrum of IS 1893 (Part 1): 2002 corresponding to the level of maximum considered earthquake in the most severe seismic zone (PGA=0.36g). It is observed that, maximum reduction in spectral acceleration occurs with decrease in coefficient of friction at the cost of increased base sliding displacement. But for structures with T_n <0.2 sec maximum sliding displacement is 50mm for coefficient of friction 0.1. As most of masonry buildings are stiff structures with time period less than 0.2 second the sliding displacement are within plinth projection of 75. Hence P-F isolation is one of the best alternatives for reducing earthquake energy transmission to super structure during strong earthquake leading to lesser damages in masonry buildings.

Keywords: Earthquake disaster mitigation; friction base isolation; masonry buildings

1. INTRODUCTION

Earthquake protection by base isolation of buildings has attracted considerable attention now days. Masonry construction is the most popular and suitable for housing purposes in almost all developing countries. The main concept of base isolation consists of decoupling the structure from the damaging effect of horizontal component of earthquake induced ground motion. Extensive reviews of practical base isolation systems are presented by Buckle and Mayes [2], Izumi [3], Jangid [4], Jangid and Datta [5] and Kelly [6] which can be broadly classified as:

- Laminated rubber bearing,
- Lead rubber bearing,

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- High damping laminated rubber bearing, and
- Sliding isolation system.

In the category of sliding isolation systems with restoring force include; Electricite De France (EDF) system, the Resilient Friction Base Isolator (RFBI) system, Sliding Resilient Friction which combines the desirable feature of EDF and RFBI system, TAISEI Shake Suppression (TASS) system, the Friction Pendulum system (FPS) and the elliptical rolling rods. Most of the base isolation devices employ some kind of recentering mechanism, which minimizes the possibility of any residual drift after an earthquake. These base isolation devices, however, tend to be rather large and heavy. An individual isolation can often weigh in excess of 1 Tonne and is produced by expensive manufacturing processes. The sliding isolation system without any recentring mechanism *i.e.* Pure Friction (P-F) base isolation system, simplest among all isolator [1, 9], however does not require any sophisticated manufacturing process and is ideally suited for use in low-cost masonry buildings. In P-F isolation system a smooth sliding interface (Figure 1) is introduced which decouples the super-structure from its foundation at the plinth level. Until the frictional resistance is not overcome, super-structure may continue to move together with the foundation, behaving as an elastic structure. Until the frictional resistance is not overcome, super-structure may continue to move together with the foundation, behaving as an elastic structure. Moreover, it is possible to provide a distributed isolation [7, 8] system arranged uniformly around the structure's base in the form of continuous pure friction layer at plinth level during normal construction.

The objective of present study is to investigate the effect of the earthquake ground motion on the behaviour of isolation system analytically by using a synthetic accelerogram that is compatible with the design spectrum of IS 1893 (Part 1): 2002 corresponding to the level of maximum considered earthquake in the most severe seismic zone (PGA=0.36g) of India.

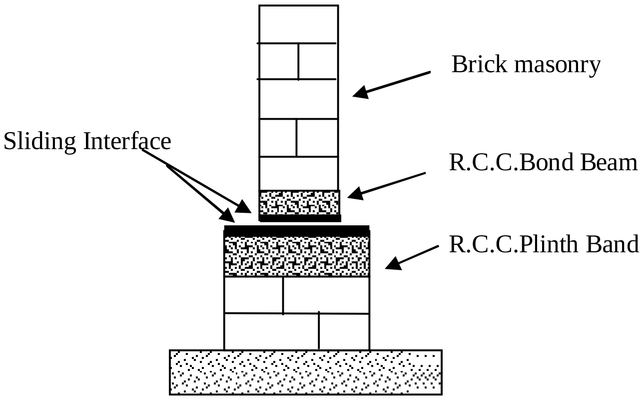


Figure 1. Construction detail for P-F isolation system in brick wall of a masonry building

2. NUMERICAL STUDY

A two-mass model, as shown in Figure 2, is used to describe the seismic behavior of a single story building with a sliding interface. The structure above the sliding joint is assumed to remain elastic as the purpose of base isolation is to reduce the earthquake forces in such a way that the system remains within elastic limit. The mass of the roof in addition to one half the mass of the wall is lumped at the roof (M_t) while the rest is lumped at the base with the mass of the bond beam (M_b). The base mass is assumed to rest on a plane with dry friction damping of coulomb type to permit sliding of the system

Let the ground acceleration be denoted by $\ddot{x}_g$; x_t and x_b represent the relative displacement of top mass with respect to bottom mass and relative displacement of the bottom mass with respect to ground respectively; and $q\ (=M_t / M_b)$ be the mass ratio (MR). The natural frequency of the non-sliding system (ω_n) is related to the stiffness (K) and the top mass as $w_n = \sqrt{K / M_t}$, and $\xi (= C / 2w_n M_t)$ is the fraction of critical damping, where C is the damping coefficient. The rocking effect is assumed to be neglected. The coefficient of friction (μ), assumed same for both static and dynamic friction.

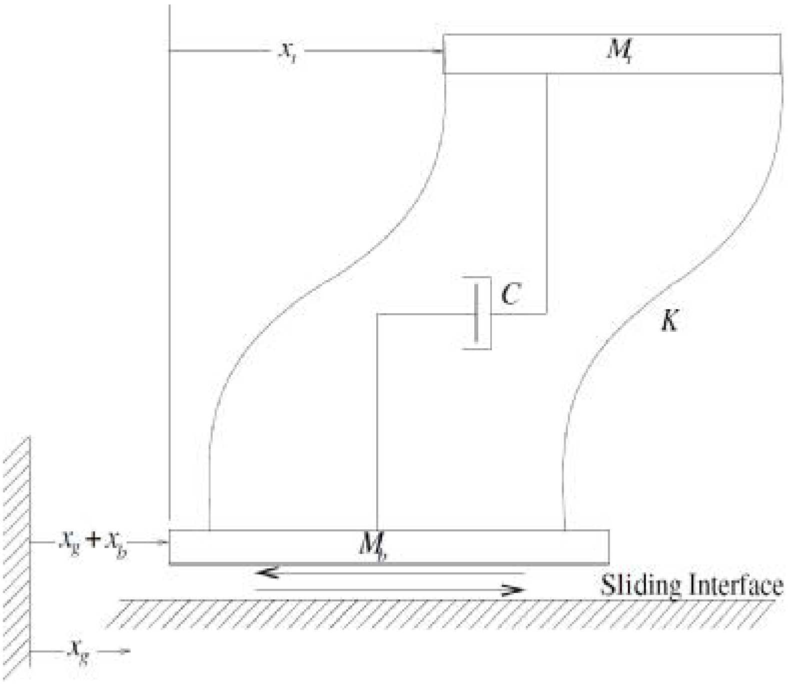


Figure 2. Analytical model for system with a sliding interface

2.1 Non-sliding condition

The governing differential equation for non-sliding condition can be obtained from equilibrium considerations as:

$$M_t(\ddot{x}_g + \ddot{x}_t) + C\dot{x}_t + Kx_t = 0$$

which may be rearranged as:

$$\ddot{x}_t + 2xw_n\dot{x}_t + w_n{}^2 x_t = -\ddot{x}_g \tag{1}$$

The above equation governing the dynamic response of the system to base excitation during non-sliding condition is exactly same as that for a fixed base system.

2.2 Sliding condition

The sliding of bottom mass begins when the sliding force overcomes the frictional resistance at the plinth level. The building now acts as two degree of freedom system and governing differential equation of motion of top mass can be derived from equilibrium considerations:

$$M_t(\ddot{x}_g+\ddot{x}_b+\ddot{x}_t)+C\dot{x}_t+Kx_t=0$$

which can be simplified as:

$$\ddot{x}_t+\ddot{x}_b+2\xi\omega_n\dot{x}_t+\omega_n^{\,2}x_t=-\ddot{x}_g \tag{2}$$

while the motion of the bottom mass may be described by:

$$M_b(\ddot{x}_g+\ddot{x}_b)-C\dot{x}_t-Kx_t+\mu(M_t+M_b)\mathrm{g}\ \mathrm{sgn}(\dot{x}_b)=0$$

which may be rearranged as:

$$\ddot{x}_b-2\xi\omega_n\theta\,\dot{x}_t-\omega_n^{\,2}\theta\,x_t+\mu(1+\theta)g\,\mathrm{sgn}(\dot{x}_b)=-\ddot{x}_g \tag{3}$$

where, $\mathrm{sgn}(x)=\begin{cases}1, & x>0\\ -1, & x<0\end{cases}$ denotes the signum function.

The non-sliding condition prevails when the horizontal inertia force of bottom mass does not exceed the opposing friction force at plinth level, *i.e.*

$$\left|C\dot{x}_t+Kx_t-M_b(\ddot{x}_g+\ddot{x}_b)\right|<\mu(M_t+M_b)g$$

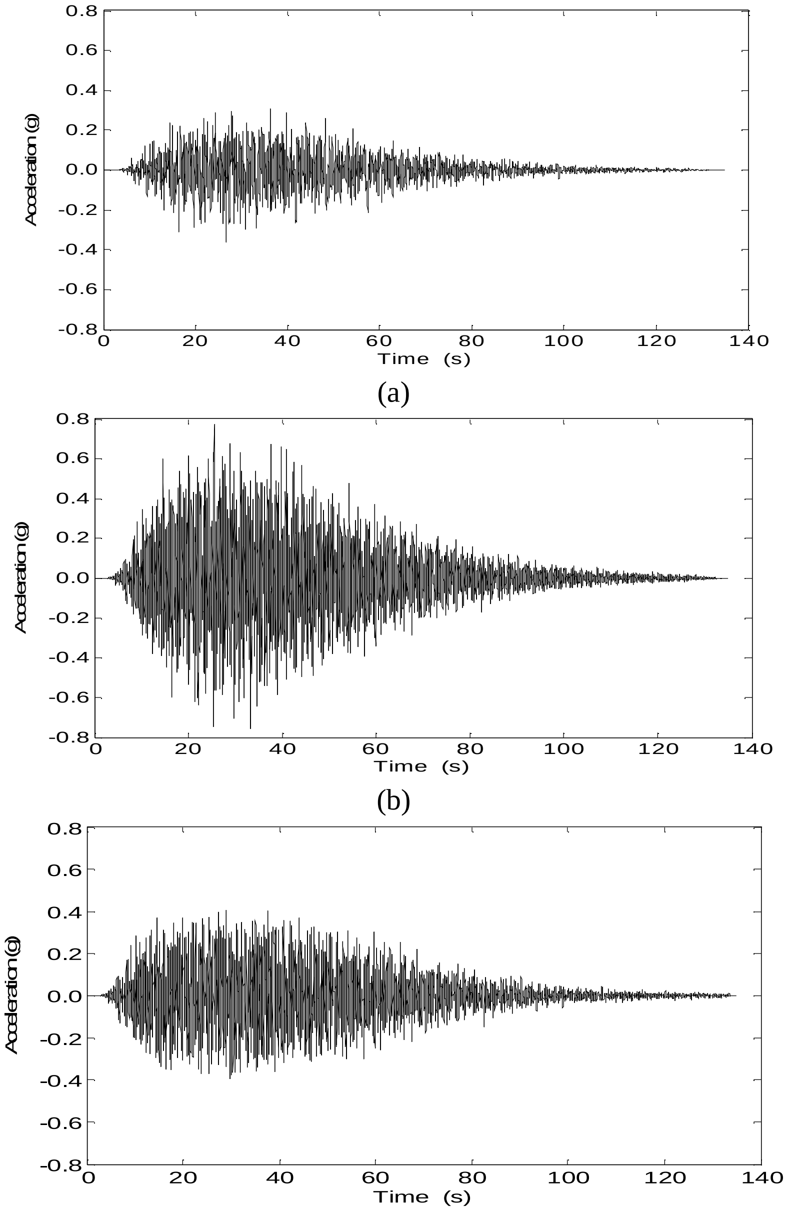
or

$$\left|2\xi\omega_n\dot{x}_t+\omega_n^{\,2}x_t-(\ddot{x}_g+\ddot{x}_b)/\theta\right|<\mu(1+1/\theta)g \tag{4}$$

As long as the dynamic lateral force does not exceed the frictional resistance at the sliding interface, there is no relative movement between the bottom mass and the base/ground, *i.e.* $x_b=0$. The sliding initiates whenever the force acting at the base exceeds the frictional resistance and stops whenever the non-slip condition (Eq. (4)) holds. Thus at any time instant response of the building can be obtained by solving either Eq. (1) when the non-sliding condition (Eq. (4)) holds, or two coupled differential equations (Eqs. (2) and (3)) during the sliding phase. These equations are solved by using Runge-Kutta 4th order solver in MATLAB-SIMULINK environment.

3. RESULTS AND DISCUSION

Response quantities of interest are absolute acceleration of the super structure and relative sliding displacement of the base mass. As absolute acceleration is directly proportional to the shear forces and bending moment exerted in the super structure and relative sliding displacement is crucial in the design of base isolated structure subjected to earthquake ground motion.



(a)

(b)

(c)

Figure 3. (a) Ground motion, (b) Absolute acceleration response at roof level for sliding structure and (c) Absolute acceleration response at roof level for fixed base structure (MR=2, Tn =0.1)

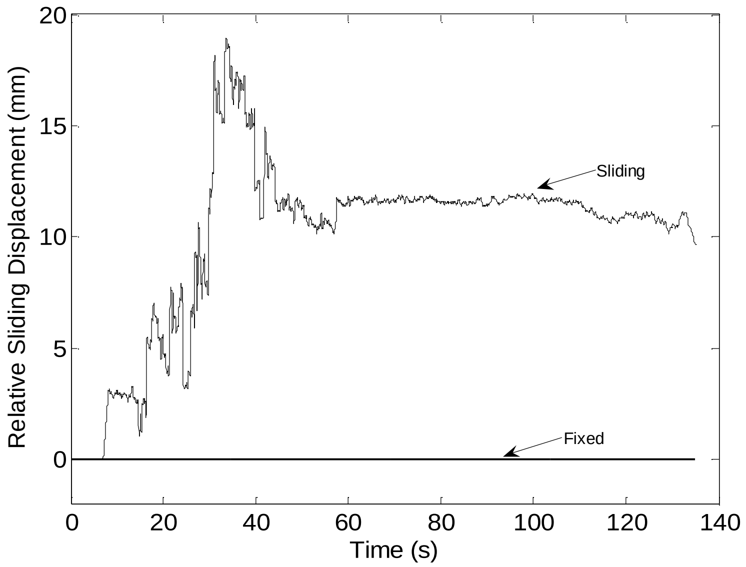


Figure 4. Relative base sliding displacement response for sliding and fixed base structure (MR=2, Tn =0.1)

Figure 3 shows the time history variation of ground motion and comparative absolute acceleration response at roof level for fixed and sliding single story building of mass ratio (MR)=2, natural time period 0.1 sec, damping coefficient 0.05 and coefficient of friction 0.1 of the sliding interface. In case of fixed building there is more than 100% increase in the peak acceleration response (~0.8g) The Peak absolute value for sliding structure at roof level is below 0.4g. Figure 4 shows the time history variation of the relative displacement of bottom mass at plinth level in mm. The maximum relative sliding displacement for sliding structure is below 20 mm which is within commonly applied plinth projection.

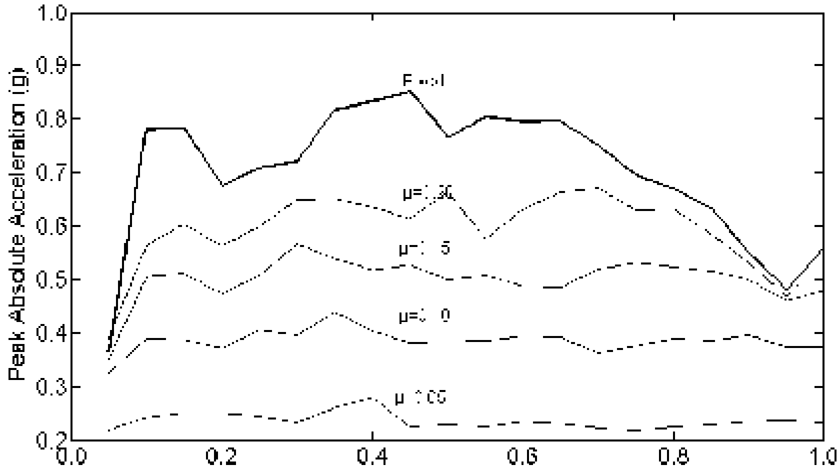


Figure 5. Absolute acceleration spectra for fixed and sliding base with different coefficient of friction

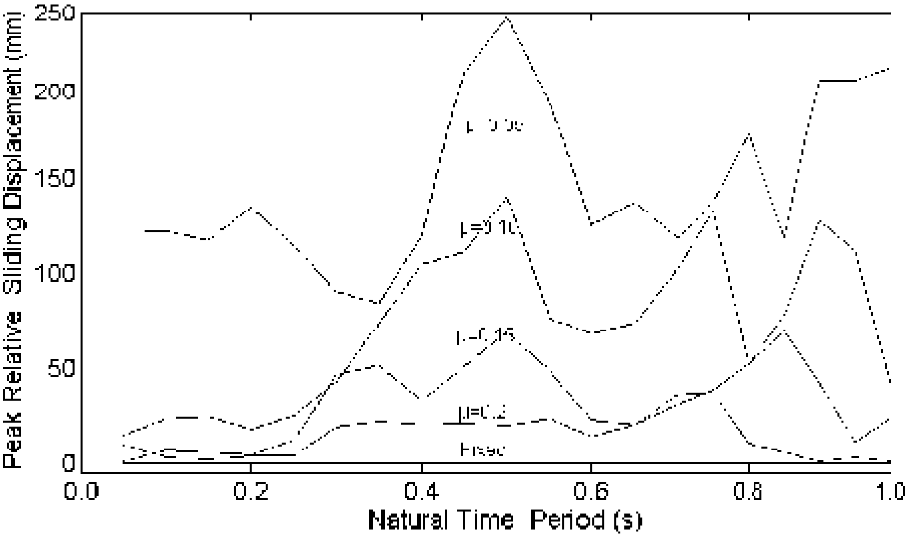


Figure 6. Relative displacement spectra for fixed and sliding base with different coefficient of friction

Figure 5 and 6 show acceleration response spectra of roof and relative displacement spectra of bottom mass for different coefficient of friction. It is observed smaller the coefficient of friction, higher is the reduction in spectral acceleration at the cost of increased sliding displacement at plinth level. But the spectral displacement is within 50 mm for short period structures i.e. T_n <0.2s with coefficient of friction 0.1. As most of masonry buildings are stiff structures with time period less than 0.2 sec and the sliding displacement would be within plinth projection of 75mm (3in). The resistance against sliding of the system decreases as the coefficient of friction between sliding structures decrease. Hence build up of larger inertia in the super structure gets restricted and spectral acceleration decreases. The flat spectral response shows the isolated structure is independent of frequency and the level of response depends entirely upon the coefficient of friction.

4. CONCLUSION

The performance of base isolated building by pure friction subjected to an artificial accelerogram that is compatible with the design spectrum of Indian standard (IS: 1983 (Part 1):2002) using time period of super structure, friction coefficient, mass ratio and damping on a single story structure is investigated. It is observed that the sliding structure is quite effective in reducing the seismic response of the structure. Maximum reduction spectral acceleration with decrease in coefficient of friction at the cost of increased sliding displacement. But for structures with T_n <0.2 sec maximum sliding displacement is 50mm for coefficient of friction 0.1. As most of masonry buildings are stiff structures with time period less than 0.2 second the sliding displacement are within plinth projection of 75. Hence P-F isolation is one of the best alternatives for reducing earthquake energy transmission to super structure during strong earthquake leading to lesser damages in masonry buildings.

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