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Seismic Response of Pure-Friction Base Isolated Masonry Building with Restricted Base-Sliding

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الاستجابة الزلزالية لمبنى طابوقي ذي قاعدة احتكاكية محدودة الانزلاق

م. قمر الدين*١ و س. أحمد٢

الخلاصة:في هذه الورقة سيتم عرض دراسة للاستجابة الزلزالية لمبنى طابوقي ذي قاعدة احتكاكية محدودة الانزلاق. حيث يتولد سطح املس في مستوى القاعدة الحجرية للبناية فوق مدمال مانع الرطوبة،ويتيح للهيكل الغلوي حرية الانزلاق في هذا المستوى، ما عدا المقاومة الاحتكاكية والمثبتة الصلبة. وبما ان للهيكل العلوي حرية الانزلاق للانزلاق في مستوى القاعدة الحجرية، فسيكون هناك شعور عند شاغلي المبنى بانة قد يتحرك اكثر من حد الازاحة النسبي المسموح به للجانب الاعلى من المبنى، مما قد يخلق خوفا بين الشاغلين بأن البناية قد تنقلب. ونظر لهذا، فقد تم تطوير نموذج رياضي لتمثيل بناية طابوقية ذات قاعدة محدودة الانزلاق باستخدام مثبتة صلبة. وقد تم تحديد الموقع العملي للمثبتة الصلبة بحيث تكون الاستجابة الزلزالية للمبنى أقل بكثير بالمقارنة مع تلك المباني ذوات القواعد الثابتة. كما شمل البحث أيضا تحديد الاستجلبة الزلزالية للبنايات التى يختلف فيها زمن التردد، نسبة الكتلة، معامل الاحتكاك ومعامل التثبيط الترددي عند اخضاعها الى زلزال كوينا وخمسة زلالزل مزيفة اخرى. وقد ولدت الزلازل المزيفة اما بزيادة أو بنقصان التعجيل الارضي ومدة زلازال كوينا. وقد خلصت الدراسة الحالية الى ان نظام القواعد الاحتكاكية المنعزلة محدودة الانزلاق، ذات أثر فعال في انقاص القوة الزلزالية المؤثرة على البنايات الطابوقية ذوات معامل الاحتكاك المنخفض.

المفردات المفتاحية: الاحتكاك التام، نظام القواعد محدودة الانزلاق، زلزال كوينا، نسبة الكتلة، زلزال مزيفة، مثبتة صلبة، قوة الانزلاق.

Abstract: The earthquake response of pure-friction base isolated masonry building with restricted base sliding is presented in this paper. A clear smoothened surface is created at the plinth level of the building above the damp-proof course, and the superstructure rests at this level to slide freely, except for the frictional resistance and the rigid stopper. As the superstructure is free to slide at the plinth level, there will be a feeling to the occupants that it might slide more than the permissible relative displacement limit provided at the top of the substructure. This may create a fear among the occupants that the building may overturn. In view of this, a mathematical model was developed for masonry building with restricted base sliding system using rigid stopper. Feasible position of the stopper has been determined such that the seismic response of the structure is reduced considerably in comparison with that of corresponding fixed base structure. Investigation was also made to determine the seismic response of the buildings with varying time period, mass ratio, coefficient of friction and damping coefficient subjected to Koyna and five other pseudo earthquakes. The pseudo earthquakes were generated either by increasing or decreasing the ground acceleration and duration of the Koyna accelerogram. It turns out from the present study that the pure-friction isolated restricted base sliding system is effective in reducing the seismic force acting on the masonry building with low value of coefficient of friction.

Keywords: Pure-friction, Restricted base sliding system, Koyna accelerogram, Mass ratio, Pseudo earthquakes, Rigid stopper, Sliding force

1. Introduction

Occurrence of past earthquakes has shown (Arya et al. 1977; Monge, 1969; Steinbrugge, 1963) that masonry buildings have suffered the maximum damage compared to all other building systems. Strengthening measures for masonry buildings have been recommended (Arya, 1967; Krishna and Chandra, 1969; Moinfar, 1972; Plummer and Blume, 1953; Yorkdale, 1970) for achieving non-collapse masonry constructions. In-spite of poor seismic performance and mainly due to low cost of masonry structures, they are being used increasingly in all countries, except perhaps in the relatively more developed ones. A number of base isolation schemes have been developed and implemented (Beck and Skinner, 1974; Blakeley et al. 1979; Buckle *et al.* 1990; Caspe, 1970; Chopra *et al*. 1973; Fintel and Khan, 1969; Kelly, 1984; Megget, 1978; Skinner *et al*. 1975; Skinner and McVerry, 1975) in the last forty years in which a superstructure is connected to a

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substructure through flexible structural elements and /or energy dissipation devices. Most isolation systems are too advanced, as well too expensive for the application to masonry buildings in developing countries where about 80% of the houses are single or double storey and made of masonry. An alternative is to provide a base isolation system in which the isolation mechanism is purely sliding friction. Pure-friction seismic isolation (PFSI) is introduced between the superstructure and the substructure to provide lateral flexibility and the energy dissipation capacity.

The main idea for solving the seismic strength problem of masonry buildings has come from the past history of earthquakes. After the Dhubri earthquake, the damage study (Gee, 1934) showed that those buildings in which the possibility of movement existed between the superstructure and substructure suffered less damage than those buildings in which no such freedom existed. Based on such encouraging seismic behavior of small structures, a simple mathematical model was first introduced by Qamaruddin (1978) to compute the seismic response of masonry building with pure-friction seismic isolation (PFSI) system. This concept was established through analytical and experimental studies (Qamaruddin, 1978) made for masonry buildings. Feasibility study of the PFSI concept was made by testing (Qamaruddin,1978 and Qamaruddin *et al*. 1984) pilot house models by inserting different sliding materials between the house models and their base. It was observed by steady state testing of these models that there was no amplification of accelerations, whereas such acceleration amplification was observed in similar fixed-base structures. Thus, these pilot tests had strengthened the PFSI concept that by introducing a discontinuity at the plinth level of the superstructure, the effective seismic force can be reduced as compared to that of the conventional models. The concept of such system was further strengthened by the damage studies made (Li Li, 1984) after the Xintai (1966), Bohai (1969) and Tang Shan (1976) earthquakes in which it was found that adobe buildings which were free to slide on their foundations (by accident) survived with little or no damage whereas others which were tied on their foundations collapsed.

Many researchers have carried out experimental investigations to study the dynamic behavior and to compare the performance of the PFSI house models with that of the conventional ones. Half-scale models of brick house were tested (Qamaruddin, 1978) under shock loading. Out of these eight models, there were six conventional ones, and two models with a sliding substructure. Tests results showed that the house models with sliding base had a significant reduction in response and exhibited adequate behavior up to very high base accelerations as compared with the similar models with fixed base. Similar PFSI concept has been proposed and tested in China (Li Li, 1984; Fu, 1988) with encouraging results. Model studies were also carried on aluminum and masonry specimens with PFSI scheme (Zongjin *et al*. 1989). There was reasonably good agreement between the experimental and theoretical results for the sliding structure.

Several researchers (Chandrasekaran, 1970; Lin *et al*. 1986; Malushte *et al*. 1989; Mittal, 1971; Mostaghel et al. 1983a and 1983b; Newmark, 1965; Qamaruddin, 1978; Qamaruddin et al. 1986a and 1986b; Younis et al. 1984; Westermo *et al*. 1983) have investigated behavior of sliding systems subject to harmonic and earthquake-type excitations. Tehrani and Hasani (1996) presented the seismic behavior of conventional real structures in Iran. They have considered the mathematical model for low-rise masonry buildings as a rigid body system for earthquake behavior and response study. They have obtained the well-established results that as the friction coefficient (0.10 to 0.30) of the sliding layer is increased, maximum acceleration of the rigid structure is increased linearly up to a maximum value of base acceleration.

In the case of base-isolated structure, with the addition of flexible layer at substructure level the peak base displacement increase significantly during earthquakes and the structure can collide upon adjacent structures like boundary retaining walls, entrance ramps, etc. Further, in the case of long buildings, expansion gaps are invariably provided to accommodate the displacements taking place due to temperature variations. For such a long base-isolated buildings, there are likely chances of impact to occur at the expansion gaps when the two buildings vibrate out of phase. Such incidence of impact in such buildings has been reported during 1994 Northridge earthquake resulting in higher accelerations in the superstructure than the predicted accelerations (Nagarajaiah *et al*. 2001). Nagarajaiah *et al*. (2001) have evaluated seismic performance of the base isolated Fire Control and Command (FCC) building in Los Angeles during the 1994 Northridge earthquake and the effect of impact. It is shown that the seismic performance of the FCC building in the Northridge earthquake was satisfactory, except for increased shear and drift due to the impact. This building had no PFSI system. Malhotra (1997) has investigated the effects of seismic impacts between the base of an isolated building and the surrounding retaining wall. No PFSI system has been provided in the building studied by the researcher. Tsai (1997) investigated the effect of bumping of the base isolated building against its surroundings providing a space for the deformation of the isolation system. The results indicate that the impact wave induced by the bumping can create an extremely high acceleration response in the structure. PFSI system has not been provided in the building studied by Tsai. Dimova (2000) has presented a study on modeling of collision in sliding systems subjected to seismic excitations. Matsagar and Jangid (2003) have investigated the seismic response of multistory building supported on various base isolated systems during impact with adjacent structures.

In view of the above investigations, it turns out that the seismic response of single storey masonry building with PFSI system and restricted base sliding has not been studied. Even if proper plinth width has been provided in the free sliding of the superstructure at plinth level, there will be a feeling to the occupants that such building might slide more than the permissible limits provided. This may create a psychological fear regarding over-turning or tilting of the building. Further increasing the damping does reduce the displacement, but at the expense of increasing acceleration and the storey drift. Keeping this in view, the investigations has been carried out with the following objectives to:

1. Develop the mathematical model for a single storey masonry building with restricted base sliding system (provision of rigid stopper).
2. Determine the most feasible position of the stopper such as to reduce the seismic response of the building with restricted base sliding in comparison with that of the fixed base.
3. Study the acceleration response of masonry building subjected to Koyna earthquake and five pseudo earthquakes with different time period, mass ratio, coefficient of friction and damping coefficient.

2. Mathematical Idealization

2.1 Mathematical Model

It is assumed that a layer of a suitable material with known frictional coefficient is laid between the contact surface of bond beam of superstructure and plinth band of substructure of a single-storey masonry building with restricted base sliding. The superstructure is allowed to slide at certain limit, which is restricted by the rigid stoppers provided around the building. The restricted sliding type building is idealized as a discrete mass model with two degree of freedom for computing the earthquake response (Fig. 1). The spring action in the system is assumed to be provided by the shear walls, which resists shear force parallel to the direction of earthquake shock. Internal damping is represented by a dashpot that is parallel with spring. The mass of roof slab and one-half of the height of walls is lumped at the roof level, other half height of the walls is lumped at the level of bond beam, the lower mass assumed to rest on a plane with dry friction damping to permit sliding of the system at certain limit.

The coefficient of friction (assumed as static) between the sliding surfaces is considered to be constant throughout the motion of the system. Materials used for building construction are linearly elastic within the limit of proportionality, thus the idealized spring is linear elastic. Its stiffness is computed by considering bending as well as shear deformations in the wall element. Sliding displacement at contact surface between the bond beam and the plinth bond can occur without overturning or tilting. The building is assumed to be subjected to only one horizontal component of ground motion at a time. The effect of vertical ground motion is not considered here. The stoppers, which restrict the sliding displacements, are considered as rigid.

2.2 Equations of Motion

Phase 1:

Initially, bottom mass moves with the base so long as sliding force does not overcome the frictional resistance. So the building behaves as a single degree of freedom system and therefore equation of motion is:

$$M_t\ddot{X}_t + C_s(\dot{Z}_t - \dot{Z}_b) + K_s(Z_t - Z_b) = 0 \qquad (1)$$

$$\text{or,}\quad \ddot{Z}_t + 2\omega\xi\,(\dot{Z}_t - \dot{Z}_b) + \omega^2(Z_t - Z_b) = -\ddot{y}(t) \qquad (2)$$

where, C_s= coefficient of the viscous damper; K_s = spring constant; M_t = top mass; M_b = bottom mass; $\ddot{X}_t$, $\ddot{Z}_t$ = absolute and relative acceleration of the top mass respectively; y(t) and $\ddot{y}(t)$ = ground displacement and acceleration at time t respectively; Z_b, Z_t = lateral relative displacement of masses M_b and M_t respectively; $\dot{Z}_b$, $\dot{Z}_t$ = relative velocity of masses M_b and M_t, respectively; ω=natural frequency (=1/T, where T is time period), ξ = damping ratio, $X_t = Z_t + y$ and $X_b = Z_b + y$.

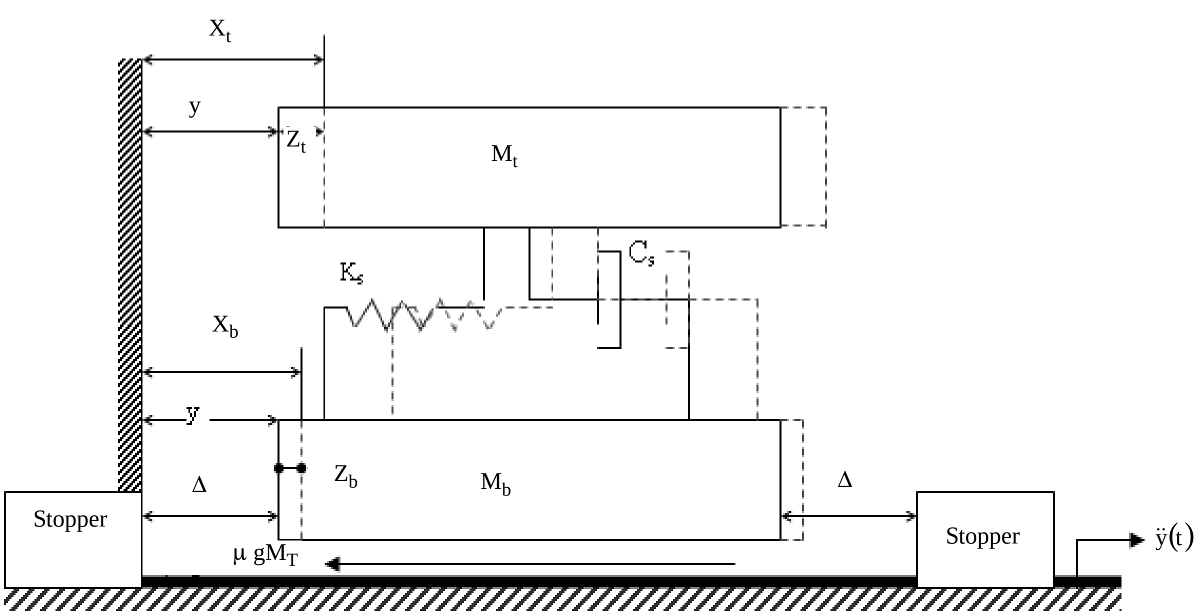

Figure 1. Mathematical model for masonry building with restricted base sliding

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Phase 2:

The sliding of the bottom mass begins when the sliding force overcomes the frictional resistance at the plinth level. The force to cause sliding S_f, is given by

$$S_f = C_s(\dot{Z}_t - \dot{Z}_b) + K_s(Z_t - Z_b) - M_b\ddot{X}_b \quad (3)$$

Sliding of bottom mass occurs if $|S_f| > \mu M_T g$ (4)

where, g = acceleration due to gravity; total mass (M_T) = $M_b + M_t$ and μ = coefficient of friction.

The building now acts as a two degree of freedom system for which the equations of motion can be written in a simplified form as:

$$\ddot{Z}_b - 2\omega\xi\theta(\dot{Z}_t - \dot{Z}_b) - \omega^2\theta(Z_t - Z_b) + F = -\ddot{y}(t) \quad (5)$$

$$\ddot{Z}_t + 2\omega\xi(\dot{Z}_t - \dot{Z}_b) + \omega^2(Z_t - Z_b) = -\ddot{y}(t) \quad (6)$$

where, $F = \mu g(1+\theta)\,\mathrm{sign}(\dot{Z}_b)$; $\ddot{Z}_b$ = relative acceleration of bottom mass; $\mathrm{sign}(\dot{Z}_b)$ = +1 if $(\dot{Z}_b)$ is positive; $\mathrm{sign}(\dot{Z}_b)$ = –1 if $(\dot{Z}_b)$ is negative and $\theta = \frac{M_t}{M_b}$ = mass ratio.

Phase 3:

The stopper is assumed as rigid such that the bottom mass rebounds with the same force as it strikes the stopper. It is also assumed that the initial velocity of the mass is zero at the rebound phase. The stopper is positioned in such a way that at some instant t_1 when the displacement of base mass $Z_b(t_1)$ reaches Δ, the system strikes the stopper. Therefore, the motion of the system will be reversed if the frictional resistance at the plinth level is overcome by the sliding force (S'_f), given below:

$$S'_f = M_b\ddot{X}_b + C_s(\dot{Z}_t - \dot{Z}_b) + K_s(Z_t - Z_b) - M_T\ddot{X}_b \quad (7)$$

The sliding of the bottom mass occurs backward if $|S'_f| > \mu M_T g$ and the equations of motion are given as follows:

$$M_b\ddot{X}_b - C_s(\dot{Z}_t - \dot{Z}_b) - K_s(Z_t - Z_b) + M_T\ddot{X}_b + \mu g M_T \mathrm{sign}(\dot{Z}_b) = 0$$

$$\text{or, } \ddot{Z}_b - 2\omega\xi\theta\beta(\dot{Z}_t - \dot{Z}_b) - \omega^2\theta\beta(Z_t - Z_b) + F\beta = -\ddot{y}(t) \quad (8)$$

$$\text{and, } \ddot{Z}_t + 2\omega\xi(\dot{Z}_t - \dot{Z}_b) + \omega^2(Z_t - Z_b) = -\ddot{y}(t) \quad (9)$$

where, $\beta = 1/(2+\theta)$.

When the bottom mass moves backward the equations of motion will remain the same as given in Phase 2.

Phase 4:

At any time during the motion of the system if $|S_f|$ or $|S'_f| < \mu M_T g$, then the sliding of the bottom mass is stopped but the top mass continues to vibrate. Therefore, the system will behave as a single degree of freedom and its equatio n of motion is the same as given in Phase 1.

2.3 Solution of Equations of Motion

Modal superposition technique cannot be employed in the solution of equations of motion as (a) the force-deformation behaviour of the sliding systems is non-linear and (b) the system is non-classically damped because of difference in the damping in the isolation system in comparison with the damping in the building superstructure. Therefore, the equations of motion are solved numerically for different phases using Runga-Kutta fourth order method (Bennet *et al*. 1956) for obtaining the complete seismic response time-history. This method was used for numerical integration, since it is self starting and the solutions are stable and accurate to a definite precision. A computer programme has been developed to compute the time-wise earthquake response of masonry building with restricted sliding-base system. The solution methodology and the implementation of the programme are presented in detail elsewhere (Hoda, 2002)

3. Parametric Study

The parameters considered in the present study are: time period (T, TP*), mass ratio (θ, MR*), dry coefficient of friction (μ, CoF*) and damping ratio (ξ, Zeeta*) for estimating forces and displacements of single-storey masonry building with restricted sliding. The response has been computed for Koyna (longitudinal component) Earthquake of December 11, 1967 and five pseudo earthquakes, which have been generated either by increasing or decreasing the duration and ground acceleration of Koyna earthquake as shown in Table 1. These pseudo earthquakes cover a variety of different type of earthquakes. The seismic response of interest are: (1) absolute acceleration (2) the maximum relative displacement of the superstructure and (3) the residual relative displacement of the superstructure at top of the substructure at the end of the ground motion. The range of different parameters' value that has been estimated to cover a wide variety of single-storey masonry buildings are as shown in Table 2. (* Marked notations are used in Figs. 3 to 7 for convenience)

It is assumed that a coefficient of friction less than 0.10 in sliding will be difficult to obtain in actual building construction, and for a μ value greater than 0.25, no sliding motion may occur in most real earthquakes and the system may act like a fixed base structure. Depending upon the time period, mass ratio plays an important role in the masonry buildings. The mass of the roof slab and one half of the height of the walls are lumped at the roof level and

Table 1. Scale factors for pseudo earthquakes

Type of earthquake	Koyna Earth-quake	Pseudo Earth-quake-1	Pseudo Earth-quake-2	Pseudo Earth-quake-3	Pseudo Earth-quake-4	Pseudo Earth-quake-5
Time factor (TF)	1.00	1.50	1.50	1.00	1.00	0.50
Acceleration factor (AF)	1.00	0.50	1.00	1.50	0.50	1.00

Table 2. Data for computing seismic response

Time Period (T) (TP) sec.	Mass Ratio (θ) (MR)	Damping Ratio (ξ) (Zeeta)	Coefficient of friction (μ) (CoF)	Restricted base Sliding range (Δ),mm (Delta)
0.06	2.0,2.5,3.0	0.05,0.10,0.15	0.15	2 to 26
0.07	2.0,2.5,3.0	0.05,0.10,0.15	0.15	2 to 26
0.08	2.0,2.5,3.0	0.05,0.10,0.15	0.15	2 to 37
0.09	2.0,2.5,3.0	0.05,0.10,0.15	0.15	2 to 37
0.10	2.0,2.5,3.0	0.05,0.10,0.15	0.15	2 to 37

the other half of the height of the walls is lumped at the top of the substructure. As the height of the single-storey building increases, the mass ratio increases. The lower mass assumed to rest on a plane with dry friction damping to permit sliding of the system at the base of the structure.

The distance of the stopper to be provided at the top of the substructure measured from the superstructure for a combination of T, θ, ξ and μ under different earthquakes is important for the design of the structure.

4. Discussion of Results

Response of free sliding (FS), restricted base sliding (RS) and fixed base (FB) of single-storey masonry buildings with various parameter combinations subjected to Koyna and other five-pseudo earthquakes (Fig. 2) are presented in this investigation. The parametric study showed the effect of several parameters on the seismic response of the structure, however, some of the parameters depicted little changes if any. In view of this, the upper limit and lower limit effects of the parameter are shown in the figures. The seismic response of single-storey building with restricted base sliding has been compared with free base sliding and fixed base. The results of this study are discussed in the following sections.

4.1 Effect of Viscous Damping

The representative acceleration response curves (Figs. 3 and 4) show that at a particular mass ratio, time period and coefficient of friction in the case of restricted base sliding buildings, an increase in damping ratio (from 0.05 to 0.15) decreases the acceleration response.

4.2 Time Period Effect

It is seen from Figs. 3 to 7 that for a particular time period and damping ratio, as the coefficient of friction increases, the peak displacement decreases in the case of building with free sliding base. Similar trend is generally true in the buildings with restricted base sliding system. The slight departure in this trend observed in few cases is due to the fact that positions of stopper are different in different building parametric cases. It is also observed from the Figs. 3 to 7 that for Koyna and all five pseudo earthquakes (only representative results for Koyna and pseudo earthquake-3 are shown in Figs. 3 to 6), there is not much variation in the absolute acceleration for structure with restricted base sliding with increase in time period at a particular coefficient of friction, mass ratio and damping ratio. It is also observed that the acceleration response of the free sliding system is independent of its time period.

4.3 Influence of Stopper Position

Table 2 shows the position of the stopper for different time periods of the system ranging from 0.06 to 0.10 seconds subjected to Koyna and five-pseudo earthquake shocks. Influence of stopper's position is seen from Figs. 3 to 7. If the stopper is placed close to the building (before its sliding), then its acceleration approaches to the corresponding values as obtained in the case of fixed base. But, if the stopper is placed at a distance approximately equal to the peak displacement of the free sliding system, far away from the building, then its acceleration is very near to that of the corresponding values of the free sliding system. In between, acceleration increases by decreasing the stopper distance from the building. This trend has been observed in all the cases subjected to Koyna and other five-pseudo earthquakes (only representative graphs for Koyna earthquake and pseudo-earthquakes-3 have been presented in this paper). These are the most feasible ranges of stopper positions for different mass ratios. This study shows that if the stopper is placed anywhere in this range, then the absolute acceleration of the top mass of the system is much less than the corresponding fixed base system. So, the occupants of the buildings will have psychological comfort by providing stopper in the sliding base system.

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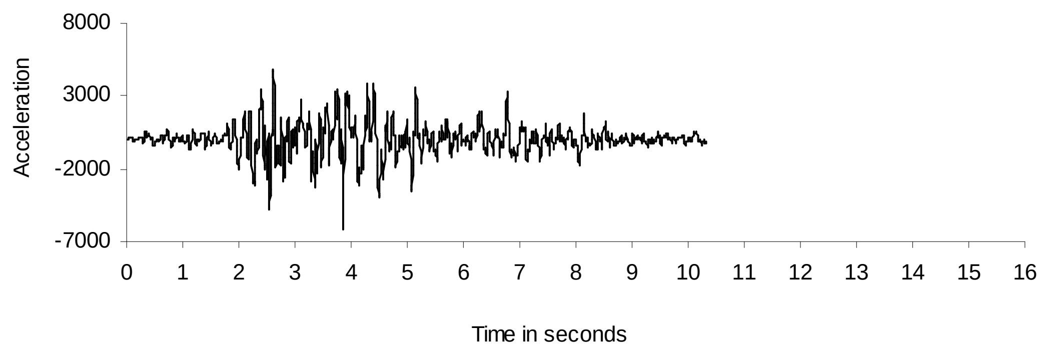

Figure 2(a). Accelerogram (mm/s/s) of Koyna earthquake

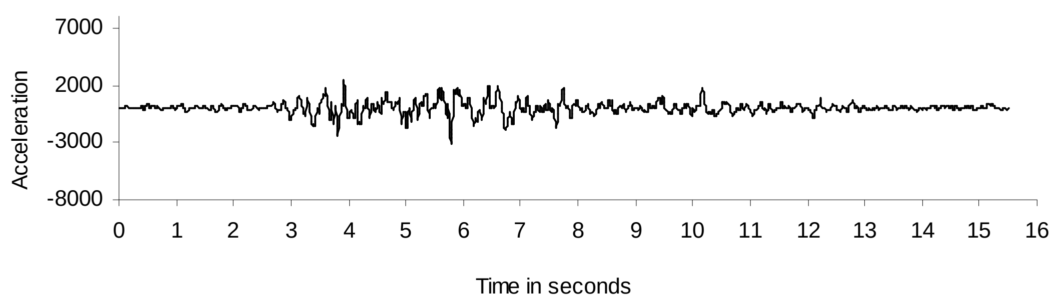

Figure 2(b). Accelerogram (mm/s/s) of Pseudo earthquake-1

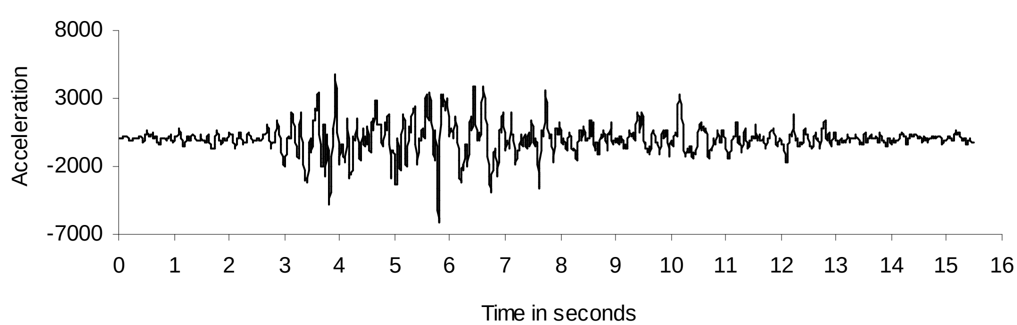

Figure 2(c). Accelerogram (mm/s/s) of Pseudo earthquake-2

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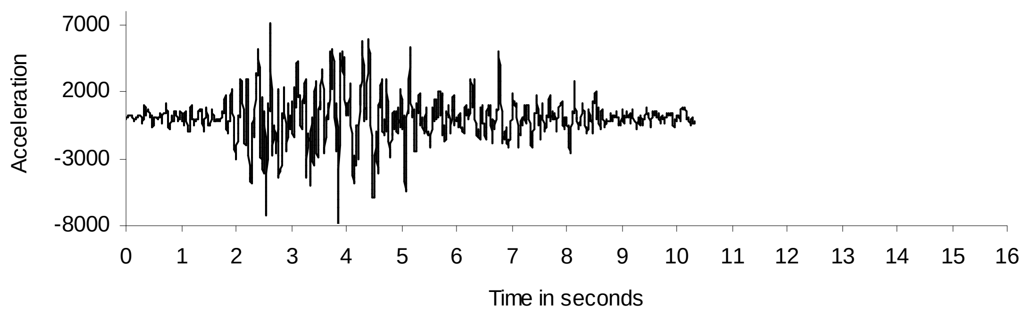

Figure 2(d). Accelerogram (mm/s/s) of Pseudo earthquake-3

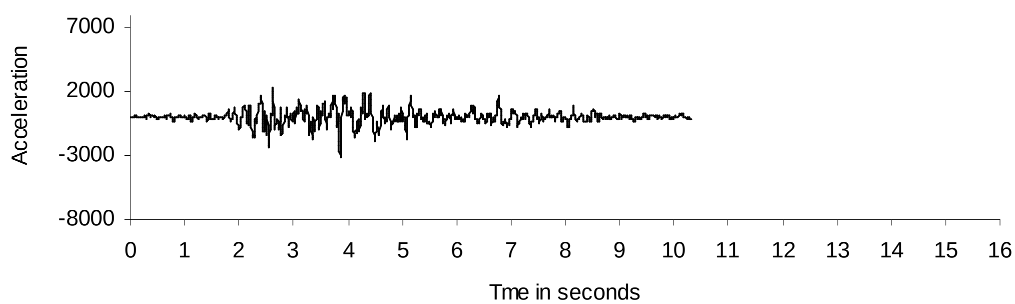

Figure 2(e). Accelerogram (mm/s/s) of Pseudo earthquake-4

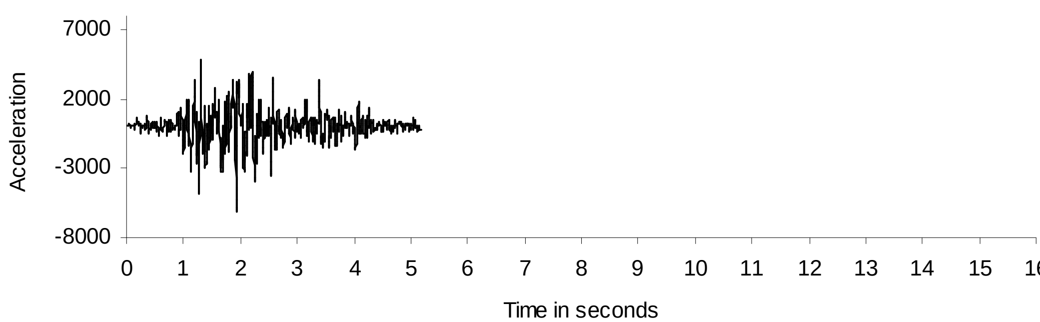

Figure 2(f). Accelerogram (mm/s/s) of Pseudo earthquake-5

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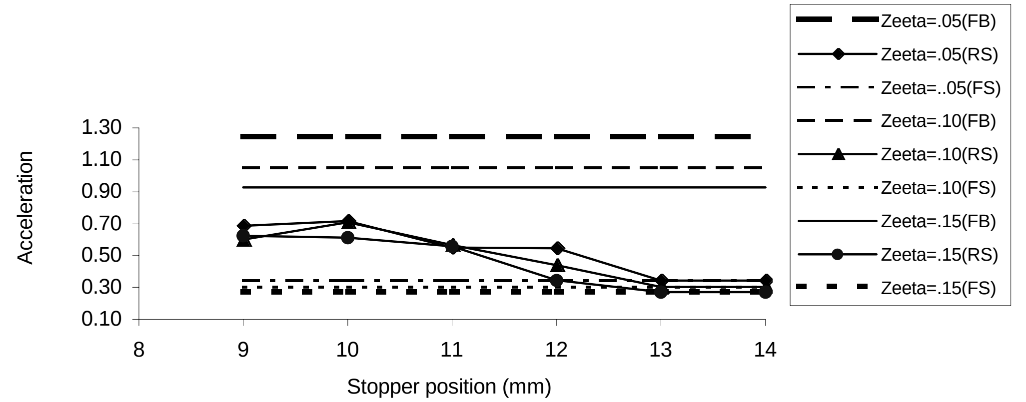

Figure 3(a). Variation of absolute acceleration (g) with stopper position for Koyna earthquake (TP = 0.06, CoF = 0.15, MR = 3.0)

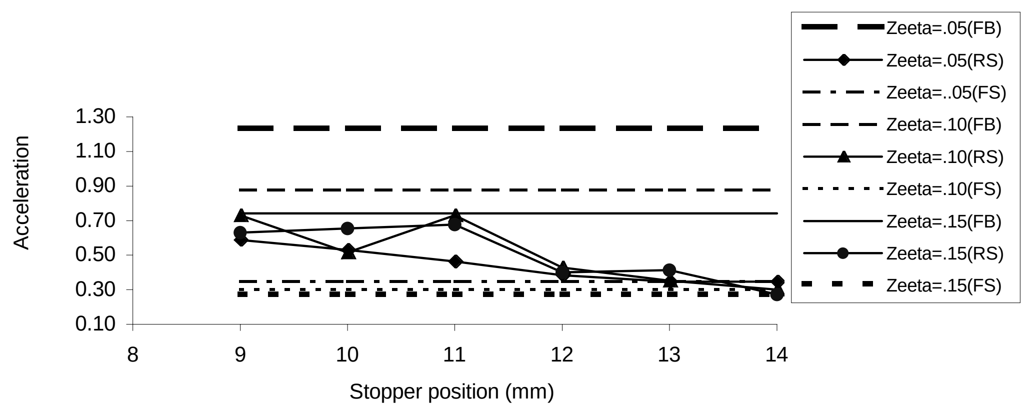

Figure 3(b). Variation of absolute acceleration (g) with stopper position for Koyna earthquake (TP = 0.10, CoF = 0.15, MR = 3.0)

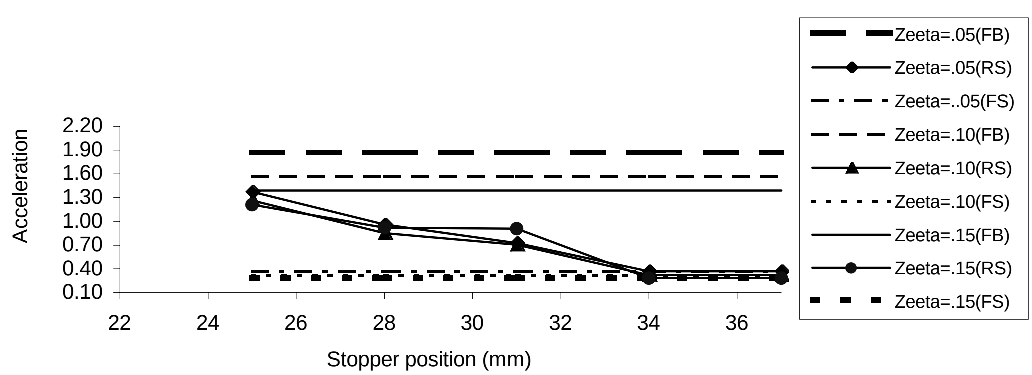

Figure 4(a). Variation of absolute acceleration (g) with stopper position for Pseudo earthquake-3 (TP = 0.06, CoF = 0.15, MR = 3.0)

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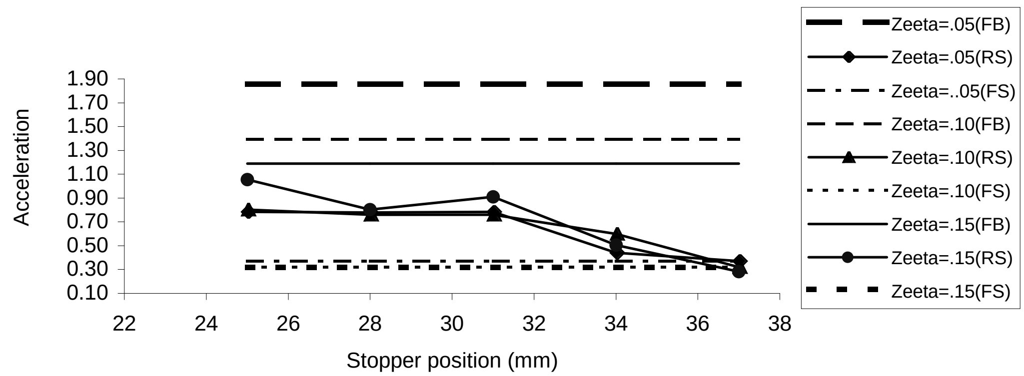

Figure 4(b). Variation of absolute acceleration (g) with stopper position for Pesudo earthquake-3 (TP = 0.10, CoF = 0.15, MR = 3.0)

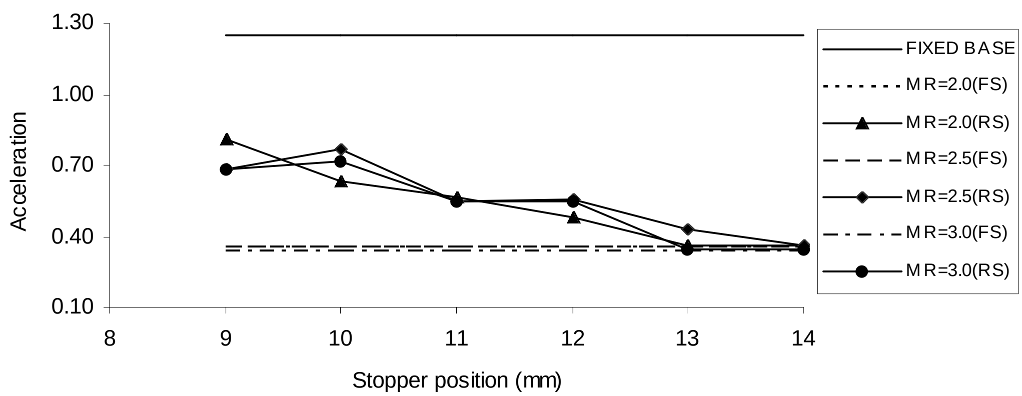

Figure 5(a). Variation of absolute acceleration (g) with stopper position for Koyna earthquake (TP = 0.06, CoF = 0.15, Zeeta = 0.5)

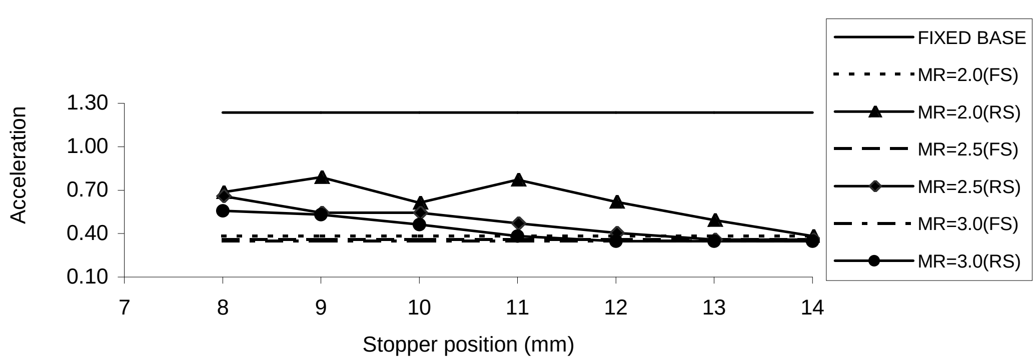

Figure 5(b). Variation of absolute acceleration (g) with stopper position for Koyna earthquake (TP = 0.10, CoF = 0.15, Zeeta = 0.05)

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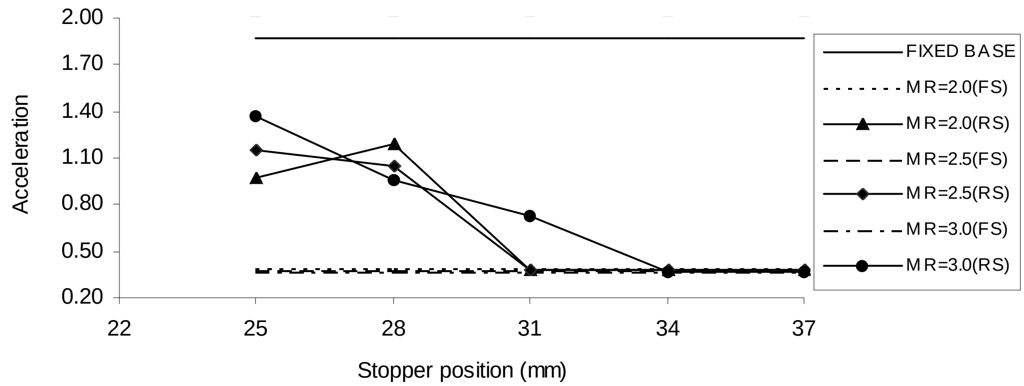

Figure 6(a). Variation of absolute acceleration (g) with stopper position for Pseudo earthquake-3 (TP = 0.06, CoF = 0.15, Zeeta = 0.5)

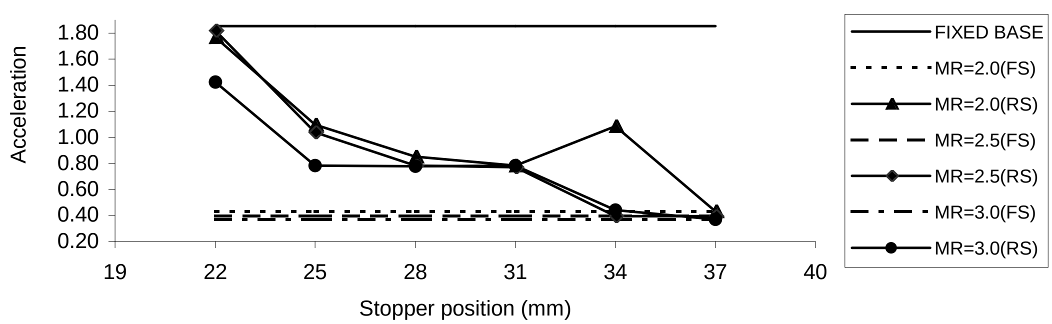

Figure 6(b). Variation of absolute acceleration (g) with stopper position for Pseudo earthquake-3 (TP = 0.10, CoF = 0.15, Zeeta = 0.05)

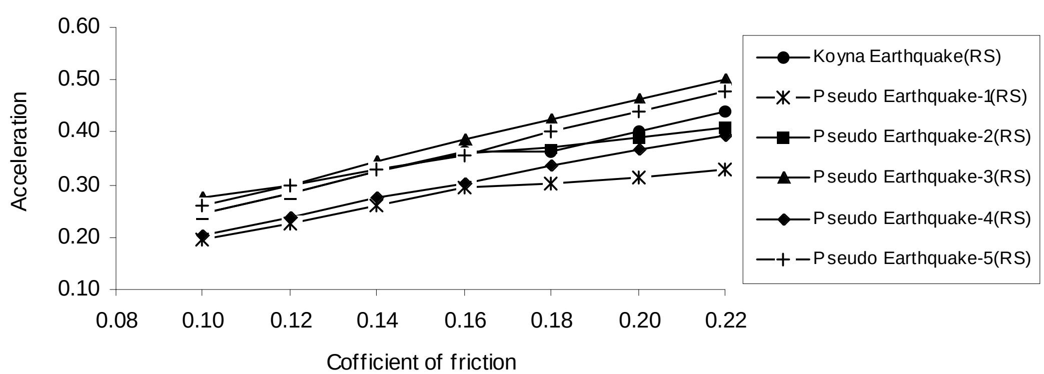

Figure 7(a). Variation of absolute acceleration (g) with coefficient of friction (TP = 0.06, MR = 3.0, Zeeta = 0.05)

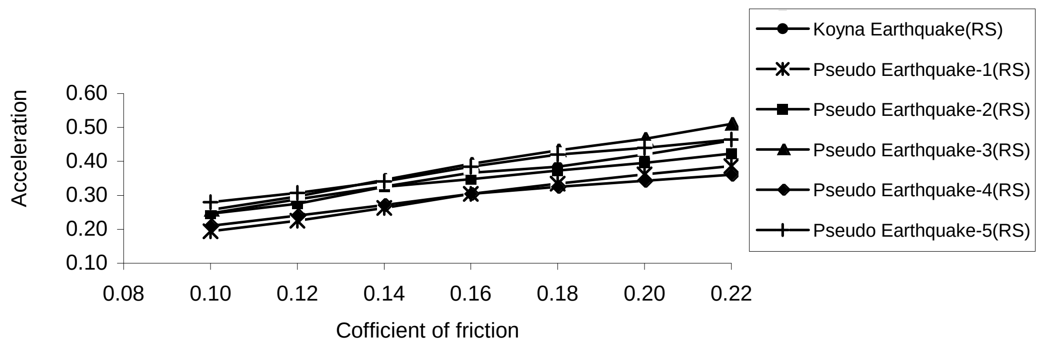

Figure 7(b). Variation of absolute acceleration (g) with coefficient of friction (TP = 0.10, MR = 3.0, Zeeta = 0.05)

4.4 Mass Ratio Effect

Effect of mass ratio is seen from Figs. 5 and 6 and it is observed that as the mass ratio increases, generally, the acceleration response decreases in all the cases of parametric combinations for a particular time period and damping ratio in the case of free sliding base. The possible reason for decrease in the acceleration response due to increase of mass ratio is that for a system, as the mass ratio increases for a given time period and damping, the values of bottom mass and total mass decreases. This implies that the input dynamic energy is decreased and thus the acceleration response decreases. But, generally, no definite pattern of acceleration response variation has been observed in the case of buildings with restricted base sliding with varying values of the mass ratio. In case of fixed base, acceleration response is independent of mass ratio.

4.5 Effect of Different Earthquake

For the Koyna and the other five-pseudo earthquakes, it is observed that acceleration of restricted base sliding structure is less than the corresponding fixed base structure for all the parametric combinations. It can be seen from Figs. 3 to 7 that for a particular time period, mass ratio and damping ratio, acceleration responses are similar for low coefficient of friction for all given earthquakes. But, with the increase of friction, acceleration response is high for pseudo earthquake-3 due to its maximum ground acceleration in comparison to other earthquakes. Similarly, increase in acceleration response is very small for pseudo earthquake-4 due to minimum ground acceleration. Among all the five cases of earthquakes under study, pseudo earthquake-4 has least acceleration response, whereas pseudo earthquake-3 has maximum response for each coefficient of friction at time period 0.06 sec. As the time period is increasing pseudo earthquake-2 has least value whereas pseudo earthquake-3 still has maximum response.

5. Conclusions

The following conclusions have been drawn from the seismic response investigation of single-storey masonry building with restricted base sliding system:

1. The restricted sliding base system is effective in reducing the effective seismic force acting on the building with low value of coefficient of friction.
2. The acceleration response decreases for the parametric combinations of time period, coefficient of friction and damping ratio as the distance of stopper from the restricted sliding base structure increases.
3. There is not much variation in the acceleration of the structure with restricted base sliding with increase in time period at a particular value of the coefficient of friction, mass ratio and damping ratio.
4. In the restricted base sliding system, the acceleration of the superstructure is much less than the corresponding fixed base system for the most feasible ranges of stopper positions for different mass ratios.
5. Generally, no definite pattern of acceleration response variation has been observed in the restricted base sliding structure with varying values of the mass ratio, whereas, the acceleration response is independent of mass ratio in the case of fixed base system.
6. The acceleration of the restricted base sliding structure is less than the corresponding fixed base structure but more than the corresponding free sliding system for all the parametric combinations in the case of. Koyna and the other five-pseudo earthquakes.
7. The restricted sliding base system will minimize the fear regarding overturning, over sliding or tilting of structure among the residents and provide psychological comfort to the occupants.
8. The effect of vertical component of an earthquake ground motion and the flexibility of the stopper on the seismic response of the system are recommended for future investigation.

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