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OPTIMUM FRICTIONAL ELEMENT IN SLIDING ISOLATION SYSTEM WITH USING OF FRICTIONAL PENDULUM SYSTEM

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ABSTRACT

The optimum friction coefficient of a sliding system with a restoring force for the minimum acceleration response of a base-isolated structure under earthquake ground motion is investigated. The stochastic model of El-Centro 1940 earthquake which preserves the non-stationary evolution of amplitude and frequency content of the original record is used for the model of earthquake. The base-isolated structure consists of a linear flexible multi-storeystructure supported on the sliding system. The sliding system is modelled to provide a friction force (ideal Coulomb friction type) and a linear restoring force. The non-stationary stochastic response of the isolated structure is obtained using the time dependent equivalent technique as the force-deformation behaviour of the sliding system is highly non-linear. The response of the system is analysed for the optimum friction coefficient of the sliding base isolation system. The criterion selected for optimality is the minimisation of the root mean square top floor absolute acceleration. The optimum friction coefficient of sliding isolation system is obtained under important parametric variations such as: period and damping of the superstructure, ratio of the base mass to the superstructure floor mass, the damping ratio of the isolation system, the period of base isolation system and the intensity of earthquake excitation. It has been shown that the above parameters have significant effects on optimum friction coefficient of the sliding base isolation system.

KEYWORDS: Base isolation; Sliding system; Stochastic; Earthquake; Linearization; Optimum friction; Coefficient.

I. INTRODUCTION

To protect structures from earthquake damages, the use of base isolation systems have been suggested in contrast to the conventional technique of strengthening the structural members. The main concept in base isolation is to reduce the fundamental frequency of structural vibration to a value lower than the predominant energy containing frequencies of earthquake ground motions. The other purpose of an isolation system is to provide means of energy dissipation and thereby, reducing the transmitted acceleration into the super structure. Accordingly, by using base isolation devices in the foundations, the structure is essentially uncoupled from the ground motion during earth-quake. A significant amount of the recent research in base isolation has focussed on the use of frictional elements to concentrate flexibility of structural system and to add damping to the isolated structure. The advantages of a frictional type system over conventional rubber bearings are: (1) the friction forces developed at the base are proportional to the mass supported by that bearing implying that there is no eccentricity between the centre of mass of the superstructure and the centre of stiffness. Therefore, if the mass distribution is different from that which is assumed in the original design, the effect of torsion at the base are diminished, (2) the frictional isolator have no unique natural frequency and therefore, dissipate the seismic energy over a wide range of frequency input without the risk of resonance with the ground motion and (3) frictional type system ensures a maximum acceleration transmissibility equal to maximum limiting frictional force. Simplest frictional base isolation device is pure-friction without any restoring force. More advanced devices involve pure-friction elements in combination with a restoring force.

The restoring force in the system reduces the base dis- placements and brings back the system to its original position after an earthquake. Some of the commonly proposed sliding isolation system with restoring force includes the resilient-friction base isolator (R-FBI) sys-tem [3], Alexisismon isolation system [4], the friction pendulum system (FPS) [5] and elliptical rolling rods.[6]. The sliding systems performs very well under a variety of severe earthquake loading and are very effective in reducing the large levels of the superstructure's acceleration without inducing large base displacements [7]. Chen and Ahmadi [8] examined the sensitivity of the base-isolated structure to fluctuating component of the wind and found that the sliding systems are less sensitive to wind excitation as compared to conventional isolation systems. Jangid [9] investigated that the sliding systems are less sensitive to the effects of torsional coupling in asymmetric base-isolated structures. Comparative studies of base isolation systems show that the response of the sliding system does not vary with the frequency content of earthquake ground motions [10,11]. Inspite of several advantages, the sliding base isolation systems generate high frequency components in the acceleration response of the structure which could be detrimental to the structural contents [12]. However, this obstacle can be overcome by providing an optimum frictional element in the sliding system designed for a particular structural system.

II. STRUCTURAL AND BASE ISOLATION MODEL

Assumption made in this base isolation model as follows

Fig. 1 shows the structural system under consideration which is an idealised N-storey shear type structure mounted on the base isolation system. The sliding isolation system is ins-tall between base mass and the foundation of the structure. Various assumptions made for the structural system under consideration are:

1. Floors of each storey of the superstructure are assumed as rigid.
2. Superstructure is assumed to remain in the elastic range during the earthquake excitation. This is a reasonable assumption, since the purpose of base isolation is to reduce earthquake forces in sucha way that the system remains within the elasticlimits.
3. Frictional force provided by the siding system follows ideal Coulomb-friction characteristics. Although, the friction coefficient of various proposed sliding systems is typically dependent on velocity and interface deformations. However, Fan and Ahmadi [13] has shown that this dependence of the friction coefficient has no noticeable effects on peakresponse of the isolated systems
4. The restoring force provided by the sliding system is linear (i.e. proportional to relative displacement). Inaddition, sliding isolation system also provides a vis-cousdamping.

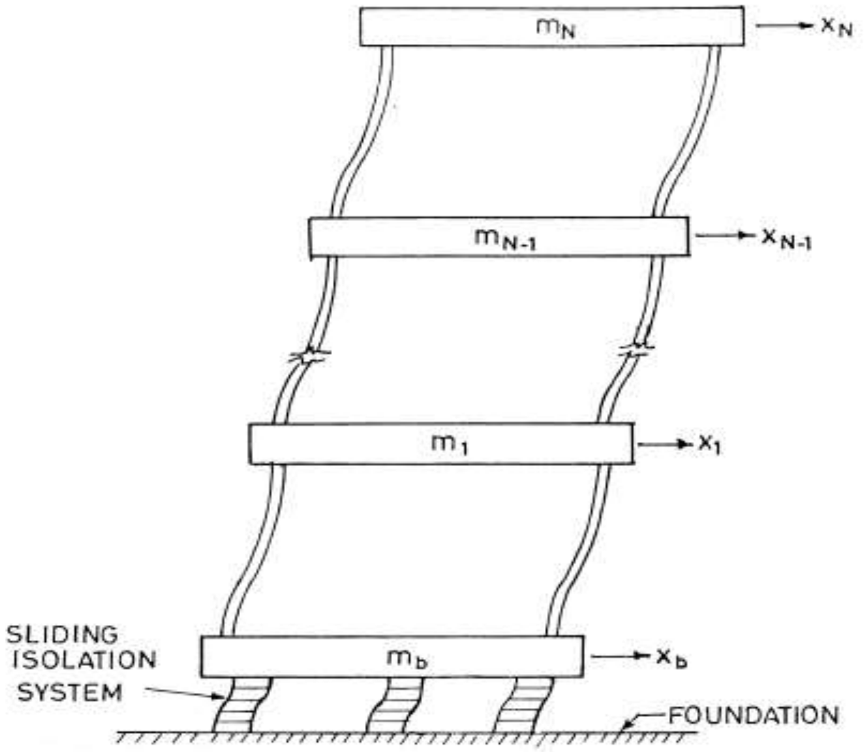

Fig. 1. Structural model of structure supported on sliding system.

5. No overturning or tilting will occur in the super structure during sliding over the base isolation system.
6. It is assumed that the friction coefficient of the sliding system is low and the system remains most of the time in the sliding phase during earthquake excitation
7. Effects of vertical component of the earthquakeacceleration are neglected.

With the above-mentioned assumptions, the resultinmathematical model of the isolated system can beexpressed as shown in Fig. 2. At each floor and basemass one lateral dynamic degree-of-freedom is considered. Therefore, for the N-storey superstructure thedynamic degrees-of-freedom are N + 1: The slidingbase isolation system is characterised by the parameters namely: the lateral stiffness (kb), the dampingconstant (cb) and coefficient offriction (μ) The viscousdamping constant of the sliding system is expressed interms of the damping ratio.

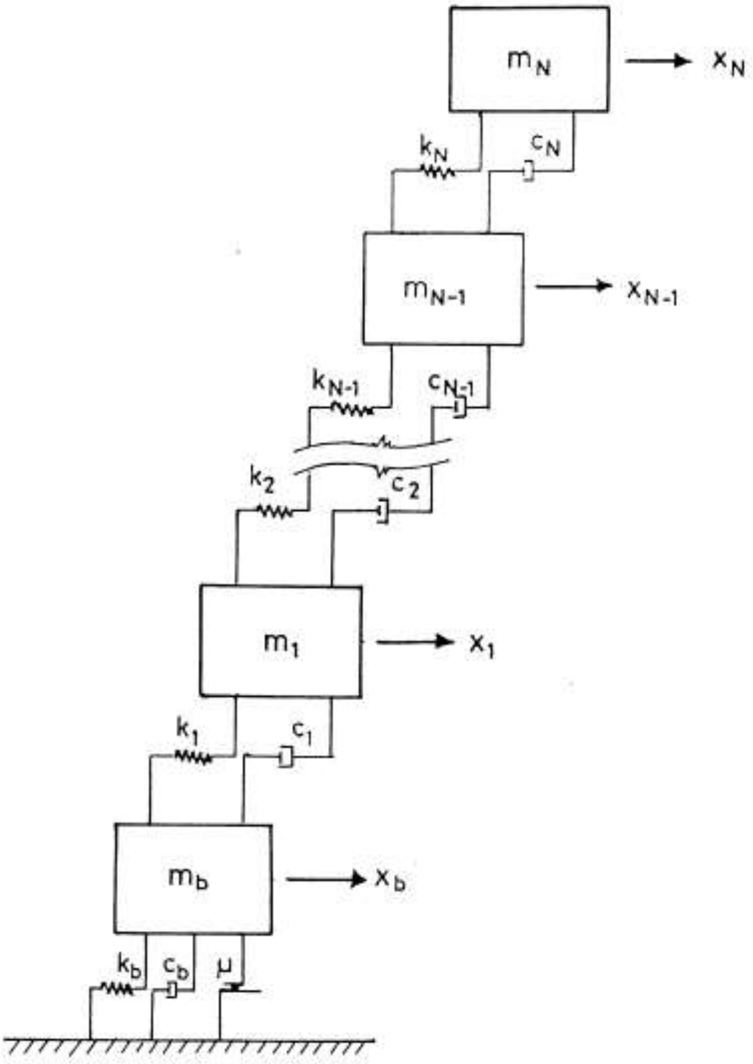

Fig. 2. Mathematical model of isolated structural system.

cb= 2ξb(mb+∑mi)ῶb

whereξb is the damping ratio of the sliding system; mbis the mass of base raft; mi is the mass of ith floor of the superstructure; ῶb= 2π/Tb is the base isolationfrequency; and Tb is the period of base isolation defined as

$$T_b = 2\pi\sqrt{\frac{\left(m_b + \sum_i m_i\right)}{k_b}}$$

III. RESPONCE EVOLUTION

a) Effects of friction coefficient on system response

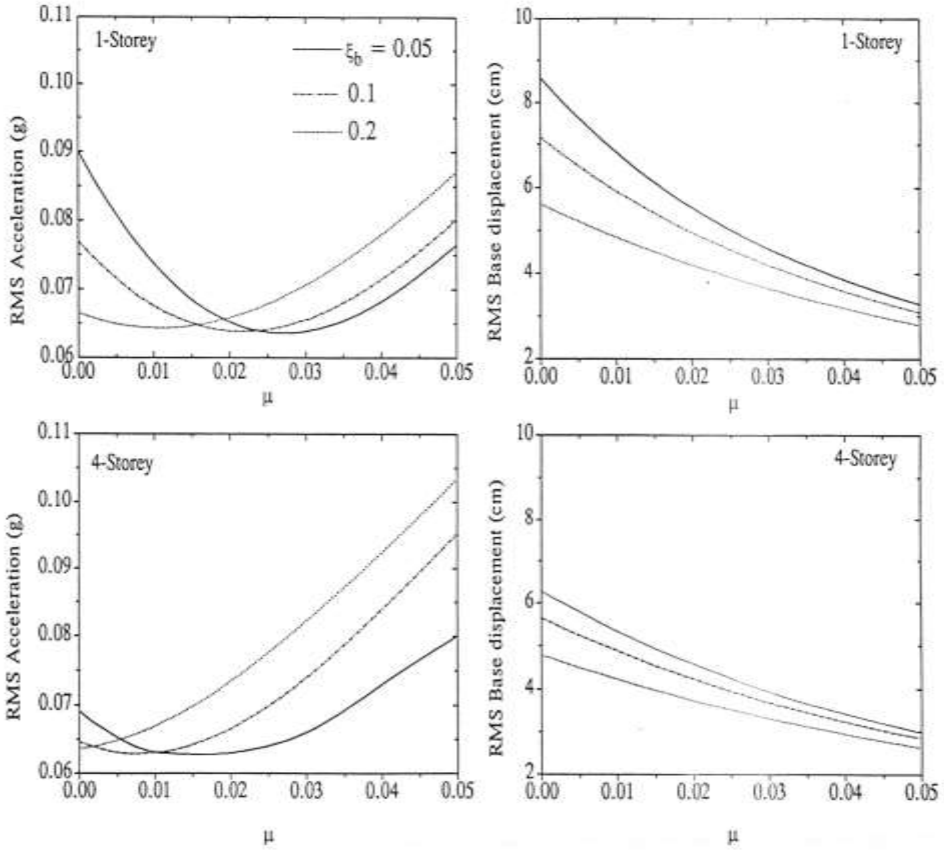

Fig. 3. Variation of RMS top floor absolute acceleration and base displacement against μ for $T_s = 0.5$ s, $\xi_s = 0.05$, $m_b/m = 1$ and $T_b = 2$ s.

It is observed from the figure 3 that as the µ increases the RMS absolute acceleration first decreases attaining a minimum value and then increases with theincrease of µ This indicates that there exists a value ofm for which the top floor absolute acceleration of agiven structural system attains the minimum value.

This is referred as the optimum friction coefficient ofthe sliding system. This occurs at µ= 0.027, 0.022 and0.012 (one-storey system) and µ=0.016, 0.009 and0.001 (four-storey system) for ξb= 0.05, 0.1 and 0.2,respectively. Thus, it shows that the optimum µdecreases with the increase of the damping ratio ξbThis is due to fact that the optimum total damping(due to viscous and friction) for a given system is constant . Therefore, for a system withhigher viscous damping, ξbthere will be less requirement of frictional damping, as a result, the optimumcoefficient of friction is reduced. Further, the optimumcoefficients of friction for the four-storey structure arelower than those for one-storey structure having thesame value of Ts,ξs, mb/m, ξb and Tb. Thus, the optimum friction coefficient of the sliding system decreases with the increase of number of storey in the super-structure. Further, as expected the base displacementdecreases with the increase of coefficient of friction forboth one- and four-storey structures. This indicatesthat the high friction coefficient of the isolator can been effective in reducing the sliding base displacement butenlarge the superstructure acceleration.

b) Effects of system parameters on optimum µ

It is seen in the earlier section that for a given particular structural system and specific excitation there exist an optimum friction coefficient of the sliding system which produces a minimum peak RMS top floor absolute acceleration. It will be interesting to study the variation of the optimum m and the corresponding RMS base displacement under important system parameters such as Ts, ξs, mb/m and Tb. Since the sliding system is a non-linear system, therefore the effect intensity of earthquake excitation, so on the optimum friction coefficient are also investigated. The above study is carried out for three damping ratios of the sliding system (i.e. ξb=0.05, 0.1 and 0.2) and number of storey in the superstructure,N = 1 and 4.

Note that the criterion selected here for the optimality is the minimisation of top floor absolute acceleration with unlimited base displacement. However, there may be other criterion also such as (1) the minimum top floor absolute acceleration with a specified maximum base displacement, (2) the minimum top floor relative displacement and (3) the minimum inter-storey drift

Fig. 4 shows the variation of optimum m and corresponding RMS base displacement against the fundamental time period of superstructure

For ξs=0:05,mb/m= 1 and Tb =2 s. It is observed from the figure 4that as the time period of the superstructure increases (in the range 0<Ts≤0.5s) the optimum µ decreases. However, for further increase in the time period there is increase in the optimum m: Thus, optimum m first decreases and then increases with the increase of time period of the superstructure. Further, by comparing the figures for one- and four-storey system, it is seent hat increase in the number of storey decreases the optimum µ.The RMS base displacement corresponding to the optimum m increases with the increase of the time period of superstructure (in the range 0 <Ts<0.5s). However, for further increase of the time period of superstructure the base displacement decreases for theone-storey structure and remains invariant for the four-storey structure.

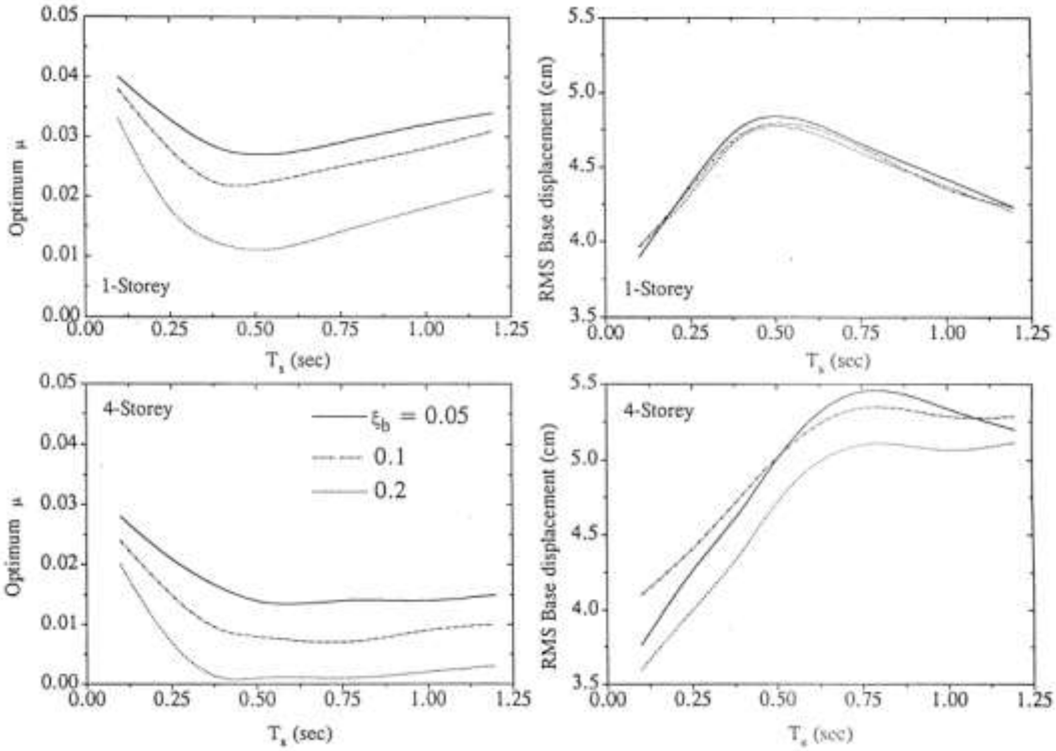

Fig. 4. Effects of the superstructure time period on optimum μ and base displacement for $\xi_s = 0.05$, $T_b = 2$ s, $m_b/m = 1$ and $S_0 = 1$ cm^2/s^3.

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c) Effects of superstructure damping ratio (ξs)

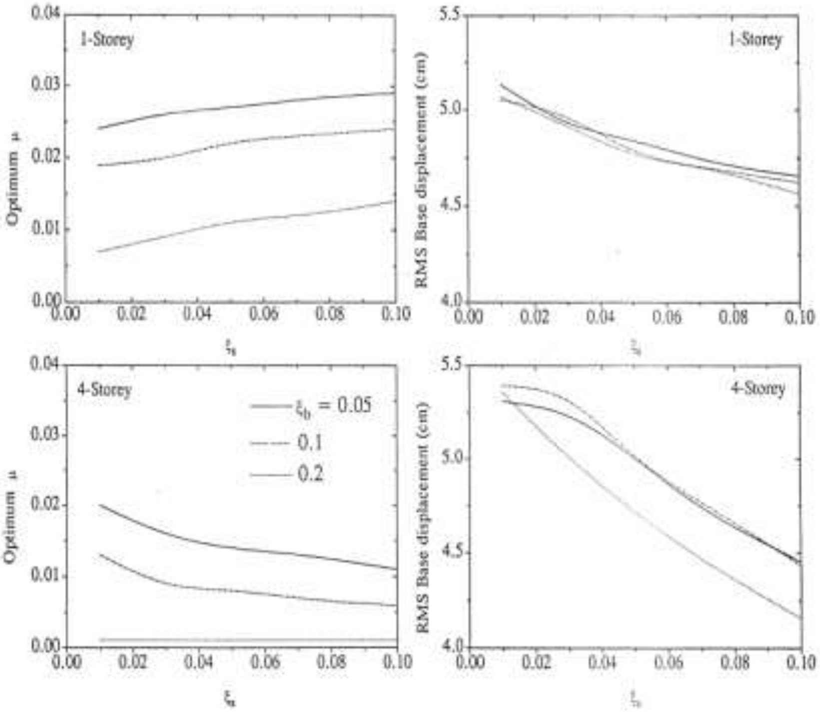

Fig. 5. Effects of the damping ratio of the superstructure on optimum μ and base displacement for $T_s = 0.5$ s, $T_b = 2$ s, $m_b/m = 1$ and $S_0 = 1$ $\mathrm{cm^2/s^3}$.

In Fig. 5 the variation of optimum μ and corresponding μ base displacement are plotted against the damping ratio of the superstructure, ξs for Ts=0.5s,mb/m=1 and Tb= 2 s. Figure indicates that for the one-storey structure increase in the damping ratio of the superstructure increases the optimum m: However, there is opposite trend for the four-storey structure. Thus, increase in the superstructure damping can either decrease or increase the optimum m depending up on the number of storey in the superstructure. The RMS base displacement corresponding to optimum m decreases with the increase of the superstructure damping ratio. Thus, the high damping in the superstructure will produce less displacement in the base isolation system at optimum friction coefficient.

d) Effects of base isolation period (Tb)

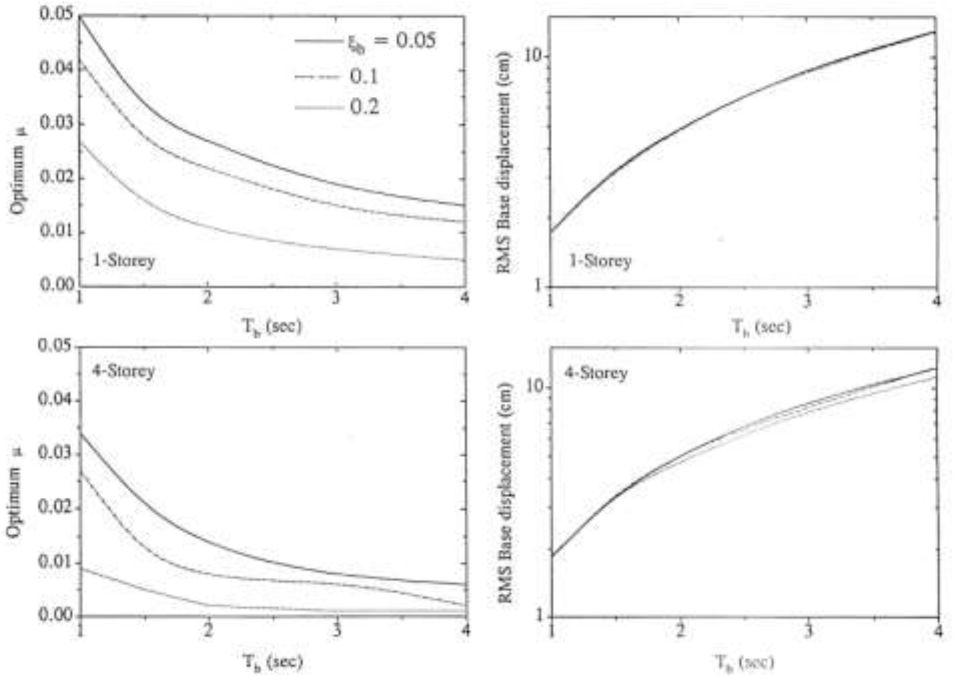

Fig. 6. Effects of the period of base isolation on optimum μ and base displacement for $T_s = 0.5$ s, $\xi_s = 0.05$, $m_b/m = 1$ and $S_0 = 1$ cm^2/s^3.

Fig. 6 shows the effects of base isolation period, Tbon optimum µ and corresponding base displacementfor Ts=0.5 s, ξs. 0.05 Andmb/m =1. It is seen fromthe figure that the optimum m decreases with theincrease in the base isolation period for both one andfour-storey systems. On the other hand, the corresponding RMS base displacement at optimum µ.Increases with the increase of the base isolation period. This is due to fact that increase in the isolation period increases the flexibility in the system resulting in more displacements. Thus, increase in the period of base isolation decreases the optimum friction coefficient of sliding isolation system.

e) Effects of mass ratio (mb/m)

In Fig. 7 the variation of optimum µand corresponding base displacement are plotted against themass ratio, mb/m for Ts = 0.5 s, ξs= 0.05 and Tb = 2s. It is observed from the figure that the optimum decreases with the increase of the mass ratio mb/mbeing more pronounced for one-storey structure ascompared to four-storey structure. The RMS base dis-placement corresponding to optimum µ increases withthe increase of the mass ratio. Thus, increase in themb/m ratio decreases the optimum friction coefficientof the sliding system.

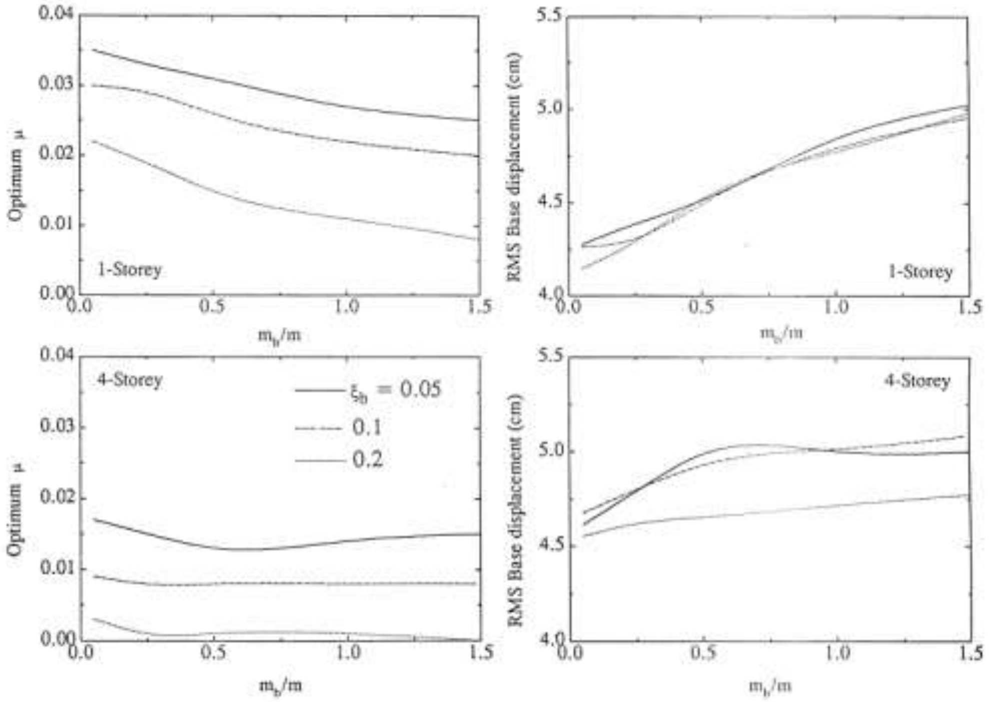

Fig. 7. Effects of the mass ratio m_b/m on optimum μ and base displacement for $T_s = 0.5$ s, $\xi_s = 0.05$, $T_b = 2$ s and $S_0 = 1$ cm^2/s^3.

IV. CONCLUSION

1. For a given structural system there exists an optimum friction coefficient of the sliding system forwhich the absolute acceleration of the superstructureattains a minimum value. However, the displacement response of the system goes on decreasingwith the increase of the friction coefficient.
2. Optimum coefficient of friction decreases with theincrease of the damping ratio of the sliding base isolation system.
3. Optimum friction coefficient of the sliding systemincreases with the increase of number of storeys inthe superstructure provided the other parametersare held constant.
4. Optimum coefficient of friction in the isolation system first decreases and then increases with theincrease of the fundamental time period of thesuperstructure.
5. Increase in the superstructure damping can eitherdecrease or increase the optimum coefficient of friction depending upon number of storey of superstructure. Further, high damping in thesuperstructure will produce less displacement in theisolation system.
6. Optimum coefficient of friction decreases with theincrease of the period of base isolation but the corresponding base displacement is increased for higher
7. Optimum friction coefficient of the sliding systemdecreases with the increase of the ratio of the basemass to the superstructure floor mass. The effects ofmassratio are found to be more pronounced for thestructure having less number of storeys.
8. Optimum friction coefficient of the sliding system isdependent upon the intensity of earthquake excitation. It increases with the increase of the intensityof earthquakes.

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