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OPTIMUM DAMPING IN ISOLATION SYSTEM

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SUMMARY

Base isolation is very promising and effective alternative technique for moderate height buildings. The approach is based on lengthening the time period of the building. Additional flexibility that is required to increase the time period of the base-isolated building results in large base displacements requiring large seismic gap at the isolation level. Amount of damping in isolation system plays very important role in controlling the structural response of the base-isolated building, particularly the base displacement. Large amount of damping is required for near field earthquakes to control the excessive displacements but it may allow energy to be transmitted to the superstructure subsequently adversely affecting the aim of providing human comfort and protecting the contents of the building. Thus it is obvious that heavily damped seismic base isolator is not remedy. In this analytical study, role of isolation damping is studied for moderate height base-isolated buildings in controlling their seismic response under different types of earthquake motions. Two reinforced concrete framed buildings are considered for this study. In order to study the effect of earthquake characteristics, eight real earthquake motions are considered. It is observed that the choice of damping in isolators is crucial as their larger values may result in increased forces and accelerations. Optimum value of isolation damping is also dependent upon the characteristics of input base motion and has low value for motions with high frequencies only.

INTRODUCTION

In the regions where underlying strata is of rock or stiff soil, the fundamental frequency of the conventional fixed base moderate height buildings is generally in the range of frequencies where earthquake energy is maximum. This may cause quasi-resonance condition and the building may act as an amplifier of the ground vibrations. Seismic base isolation approach has been established as a better alternative for such buildings (Kelly [1]). The approach instead of increasing the capacity believes in decreasing the demand. This design method involves two basic elements, which are (i) flexible mounting and (ii) energy absorbing device. Various flexible mounting devices have been proposed and mostly the energy absorption capacity is provided through these devices itself. In cases where higher damping is needed, external viscous or metallic dampers can be provided in parallel to the flexible devices.

Though the seismic base isolation approach is mainly based on lengthening the period of the building beyond the range of dominant frequencies of earthquake motions but in view of the broad spectral nature of earthquake the flexible mounting alone is not sufficient for the part of base motion having low energy

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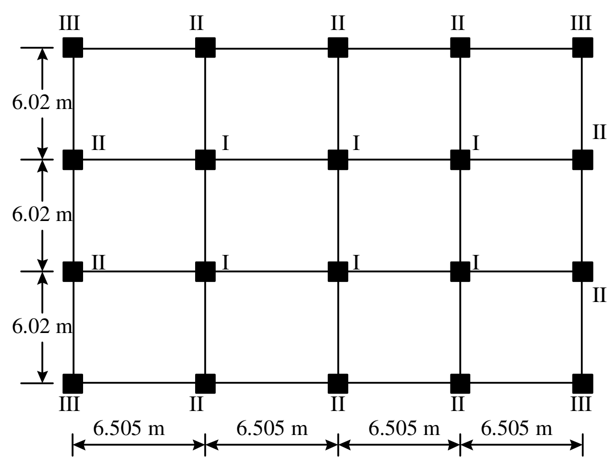
but high ground periods. It is necessary that certain amount of damping is present in the isolation system to avoid quasi-resonant condition at these higher period waves of ground motions. Also, the relative displacement at the isolator level is dominated by response of the system in its first mode of vibration and consequently the isolator deformation can be controlled by an increase of the damping in this mode. Significant damping can be introduced in the first mode of the base-isolated structure by increasing the energy dissipation capacity of the isolation system.

A study is made here to observe the effect of isolation damping on seismic response of moderate height base isolated buildings and to determine optimum damping in isolation system. Two buildings are considered for this study. Maximum storey shear, maximum roof acceleration and maximum base slab displacement are the parameters considered to evaluate the performance of the base isolated buildings.

DESCRIPTION OF STRUCTURES

The buildings of different height but with similar plans are considered for this analytical study. These buildings are reinforced concrete framed buildings with masonry infill walls. Plan of the buildings is a part of an office building and is shown in Fig. 1. One of these buildings is having six storeys and the other one is of four-storey height. Height of first storey for both the buildings is 3.3 m and for other storeys it is 2.9m each. Effect of infill walls is considered for loading and their contribution towards stiffness is neglected. The distribution of the structural elements at each floor is symmetrical in both directions. The mass of the structure and the load carried by the building are assumed to be concentrated at the floor levels. Equivalent viscous damping of superstructure is assumed to be 2 percent of critical in each mode. The first six natural periods of the buildings with fixed base condition, obtained using ETABS model, are given in Table 1.



I, II and III: Category of the bearings

Figure 1: Plan of the Buildings

THE ISOLATION SYSTEM

The isolation system is considered as combination of low damping rubber bearings and viscous damper provided between foundation and the superstructure as shown in Fig. 2. Bearings and dampers are provided under each column. As shown in Fig. 1, the rubber bearings are grouped into three categories based on the magnitude of the vertical load transferred from different columns.

Table 1. Natural periods of the buildings with fixed base condition

Mode No.	Time periods (*sec*) for buildings	
	4 Storey	*6 Storey*
1	0.60	0.89
2	0.60	0.89
3	0.51	0.75
4	0.17	0.27
5	0.17	0.27
6	0.16	0.23

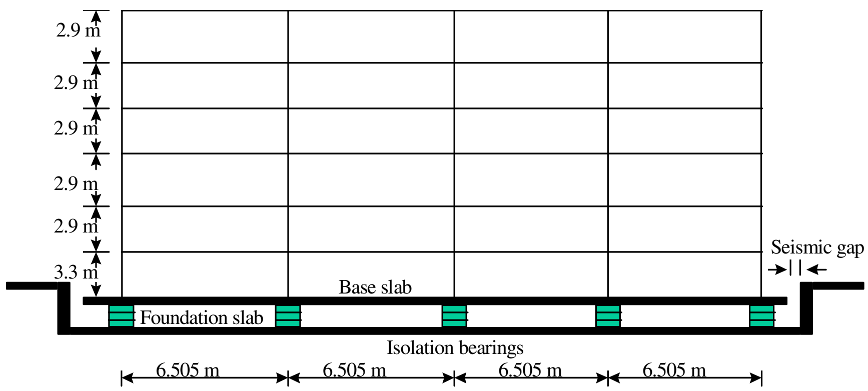


Figure 2: Elevation of the six storey base-isolated building

The isolation system is modelled as combination of elastic element and viscous dampers. Assuming the superstructure and substructure as rigid, the stiffness of elastic element is computed by:

$$k = \frac{W}{g}(2 \cdot \pi \cdot f)^2$$

Where f is the required frequency of the base isolation system and W is the design vertical load for the isolator. The equivalent viscous damping coefficient of the isolation system is computed by:

$$C = 2\omega\zeta M$$

Where ζ is the required viscous damping factor in the isolation system, M is mass over the isolation system and ω is the circular frequency associated with the effective stiffness of the isolation system.

In case of structure founded on rock or stiff soil, the isolation period is generally taken as 2.0 second (Constantinou [2]). Therefore, for this study, stiffness of isolation system is computed for design period of 2.0 second. The equivalent viscous damping factor of isolation system is assumed to be varying from zero percent to 50 percent of critical.

EARTHQUAKE MOTIONS CONSIDERED

In order to study the effect of earthquake characteristics, eight real earthquake motions are considered in this study. The records are for different magnitude (M) earthquakes on different soil strata. As shown in Table 3, the dominating frequencies covered by these ground motions range from 0.3 to 8.5 *Hz*.

The peak ground acceleration (PGA) for different earthquake motions covers a broad range of 0.63 m/s^2 to 6.19m/s^2. The earthquake motions are recorded at the sites with different types of underlying strata and have duration of record varying from as low as 10 *sec* to as high as 180 *sec*. The salient features of these ground motions are shown in Table 2 (Uang [3]; Chandrasekaran [4] and Naiem [5]). The time history of Koyna was recorded close to the epicentre of the shock and has relatively high acceleration pulses and frequency contents. It has a small peak near 0.5 *Hz*, the frequency commonly adopted for base isolation. Due to this peak, base-isolated buildings may behave differently for this earthquake motion. El Centro earthquake was recorded at about 50*km* from the epicentre of the shock and has low acceleration pulses as well as low frequency content. Mexico record is very long and periodic. Taft signal is having considerable low frequency energy with broad range of dominating frequencies, from 0.5*Hz* to 5.0 *Hz*. Frequencies lower than 1.0 *Hz* are absent from the earthquake motions recorded at NE India (*Berlongfer*) and Uttarkashi. Parkfield motion carries some energy in the range of 0.5 to 2.5 *Hz* also.

Table 2 : Characteristics of earthquake motions

Earthquake Date	*M*	*Station*	*Component*	*Duration (sec)*	*PGA (m/s^2)*	*Site Strata*	*Dominating frequencies*
NE(India) 06-08-88	6.8	Berlongfer	S76W	119.68	2.95	Sandy soil	1.5 - 3.0 Hz
			N14W		3.37		
Uttarkashi 20-10-91	6.5	Uttarkashi	N15W	39.92	2.37	Rock	2.5 - 6.5 Hz
			N75E		3.04		
Imperial Valley 18-05-40	6.3	El Centro	S00E	15.00	3.35	Alluvium	0.1-10.0 Hz
			S90W		2.10		
NE(India) 06-08-88	6.8	Silchar	N60E	46.76	0.63	Alluvium	0.5– 2.5 Hz
			S30E		0.89		
Koyna 12-12-67	6.5	Koyna dam	Long.	10.34	6.19	Rock	2.5– 8.5 Hz
			Trans.		4.22		
Mexico 19-09-85	8.1	Michoacan	N90E	180.1	0.80	Clay	0.3-0.5 Hz
			N00E		0.69		
Taft 21-07-52	7.7	Kern County	N21E	54.40	1.53	Alluvium on sandstone	0.5-5.0 Hz
			S69E		1.76		
Parkfield 27-06-66	5.6	Cholame Shandon	N85E	43.88	4.26	Alluvium	1.0 - 4.0 Hz
			N05W		3.48		

M: Magnitude and PGA: Peak ground acceleration

METHOD OF ANALYSIS

The time history analysis of the base isolated building is carried out using the computer program 3D-BASIS-TABS. A full three-dimensional representation of the superstructure is used in time history analysis of the base isolated buildings. The method of analysis is described in detail by Reinhorn [6]. Following assumptions are made for the analysis of base isolated buildings:

- The superstructure is elastic at all time and the non-linear behaviour is restricted in isolators only.
- All frame substructures are connected at each floor level by a diaphragm that is infinitely rigid in its own plane.
- Each floor has three degrees of freedom (two translation and one rotation) considered at the centre of mass of each floor.
- The isolation devices are rigid in the vertical direction and each has negligible torsion resistance.

RESULTS OF NUMERICAL STUDY

The base-isolated buildings are analyzed for bi-directional excitation. The component with larger PGA is applied along the transverse direction of the building while the weaker component is applied along the longitudinal direction. The results of the study are presented in following paragraphs.

Effect on maximum roof acceleration

Fig. 3 and 4 show the variation of maximum roof acceleration with isolation damping for 4 and 6 storey base-isolated building respectively. These figures include variation for different earthquake motions. It is observed that for all the ground motions, increase of damping from zero to two percent results in sharp decrease in the value of maximum roof acceleration. The acceleration starts increasing in the range of 2-5 percent damping for Uttarkashi and NE-India (*Berlongfer*) earthquake motions. In case of Parkfield, Taft and NE-India (*Silchar*) ground motions, the maximum roof acceleration for both the buildings decreases significantly up to 10% damping. Acceleration curves for Koyna and El Centro motions show that the amount of isolation damping, at which the maximum roof accelerations starts increasing, differs for 4 and 6 storey buildings. In case of Koyna motion this amount of isolation damping is 10 percent for 6 storey building and 15 percent for 4-storey building while in case of El Centro ground motion the value of damping for 6 storey building is 30 percent and for 4-storey building it is 40 percent. In case of these two motions, decrease in the acceleration is insignificant beyond isolation damping of 10% for both the buildings. Curves corresponding to Mexico earthquake motion do not show increasing trend even up to isolation damping of 50 percent, it has very low rate of decrease beyond isolation damping of 15 percent.

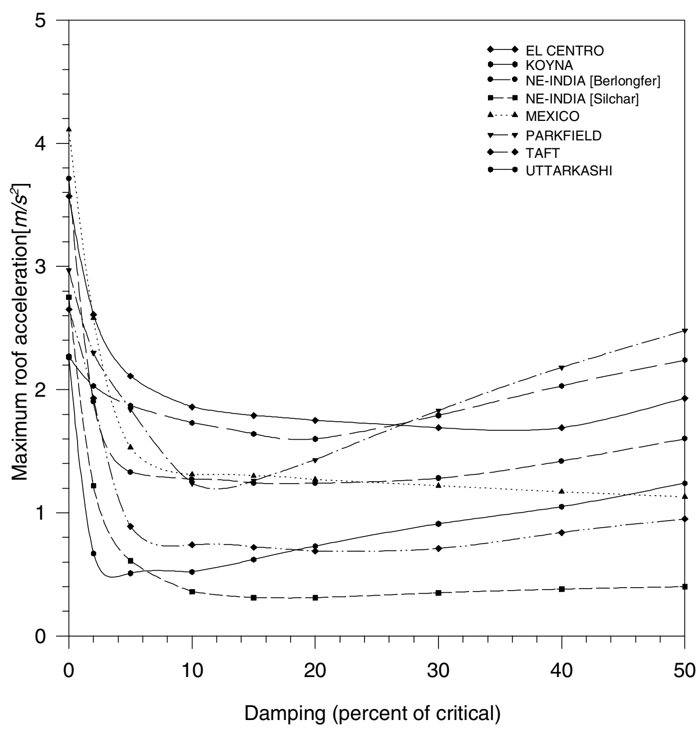


Figure 3: Variation of maximum roof acceleration with isolation damping
(4 storey building)

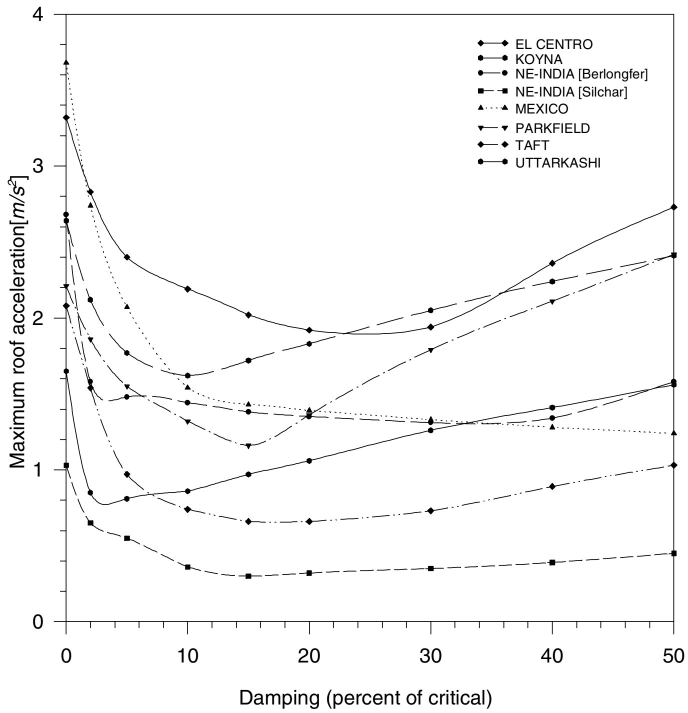


Figure 4: Variation of maximum roof acceleration with isolation damping
(6 storey building)

Effect on maximum base storey shear

Plot between maximum base storey shear and isolation damping for 4 storey base-isolated building is shown in Fig. 5. The maximum base storey shear response decreases sharply in the range of zero to two percent of isolation damping for all the ground motions. The decrease in maximum storey shear for Uttarkashi and NE-India (*Berlongfer*) earthquake motions is negligible beyond isolation damping of 5%. In case of NE-India (*Silchar*), Mexico and Taft motions, there is significant reduction in the maximum base storey shear for isolation damping increasing from zero to ten percent but beyond that, the maximum base storey shear remains more or less constant. Maximum base storey shear decreases significantly up to 15% damping for Koyna ground motion. While for El Centro motion, there is continuous reduction up to 50% damping, though the reduction in maximum base storey shear is insignificant beyond isolation damping of 10%. The values of isolation damping upto that there is significant reduction in maximum storey shear for Parkfield is observed to be different for 4 and 6 storey buildings. This value of isolation damping is 40% for 4 storey building and 30% for 6 storey building though the decrease in maximum base storey shear is insignificant beyond 20% of isolation damping for both the buildings.

Effect on maximum base displacement

The other important function of damping in isolation system is to reduce displacement at isolation level within the feasible limits. Fig. 6 shows that there is a continuous reduction in the base displacement with the increase in the damping though the rate of reduction is generally less for damping beyond 10%. This value of damping is observed to be dependent on the characteristics of the earthquake motion. In case of Uttarkashi motion, the maximum base displacement becomes more or less constant from 5% isolation

damping while in case of Taft, NE-India (*Berlongfer*) and Mexico earthquake motions the reduction in base displacement is insignificant beyond 10% damping. Base displacement reduces significantly up to 15% damping for NE India (*Silchar*) motion beyond which there is no appreciable reduction. Significant reduction is observed right up to 50% isolation damping for El Centro, Koyna and Parkfield ground motions though the rate of decrease reduces to a very low value beyond 20% damping.
It is observed that damping in isolation system is very effective in controlling the base displacement of the base-isolated buildings. In all the cases of earthquake motions, it is observed that for both the buildings, the maximum base displacement reduces to less than 200*mm* as the isolation damping reaches 5% level.

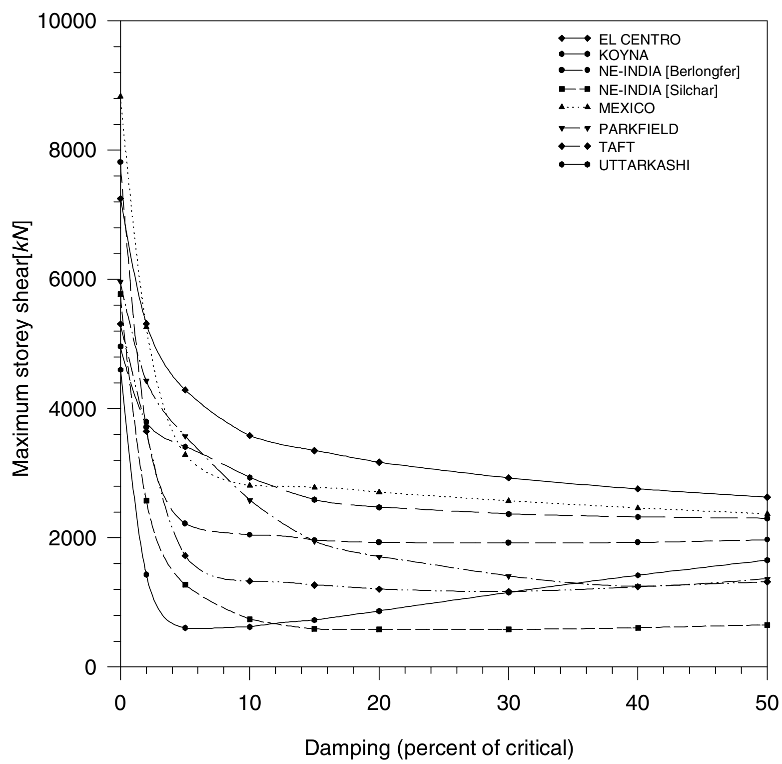


Figure 5: Variation of maximum base storey shear with isolation damping
(4 storey building)

DISCUSSION OF RESULTS

The results of time history analysis are interpreted in the context of the objectives of the study that is to investigate the effect of isolation damping on structural response of base-isolated buildings and effect of characteristics of earthquake motion on the required damping. Based on the above observations, it is found that damping in isolation system is important in controlling the response parameters of the base-isolated buildings. The addition of damping has more effect in the region of small damping than in the region of higher damping. It can be seen that optimum damping in isolation system for one response parameter may be different than that for the other. In case of roof acceleration response, the curves for most of the earthquake motions show that the roof acceleration starts increasing beyond a certain value of damping. This may be due to increase in higher mode participation. This makes it simple to identify the optimum damping with respect to the acceleration response parameter. In case of storey shear response, the trend is not so clear right upto the isolation damping of 50% for most of the earthquake motions and therefore the optimum isolation damping corresponding to the storey shear response parameter is

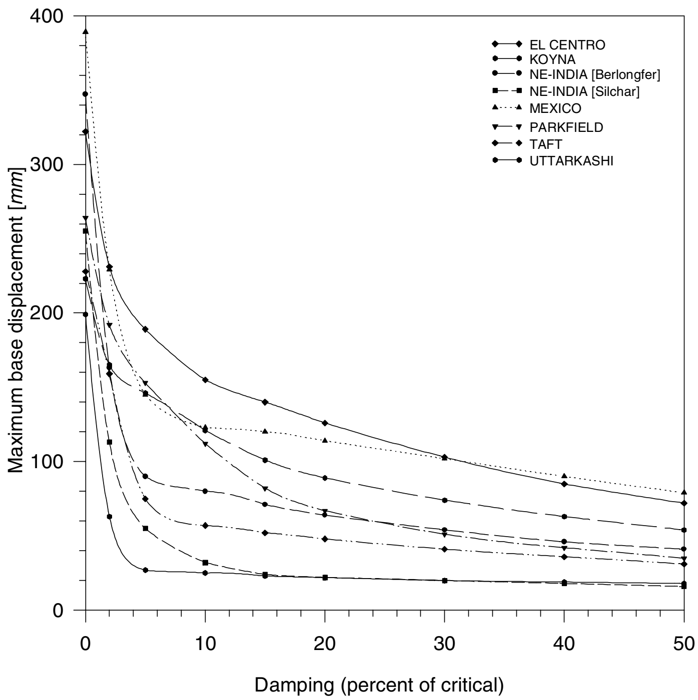


Figure 6: Variation of maximum base displacement with isolation damping *(4 storey building)*

identified as the value of damping beyond which there is insignificant decrease in maximum storey shear. The same method is adopted for optimum isolation damping with respect to maximum base displacement parameter, as there is continuous decrease in base displacement with increase in isolation damping. Further, the optimum damping is chosen as the minimum value of isolation damping which optimizes all the above three response parameters of these base-isolated buildings simultaneously without inducing the participation of higher modes. Based on the above results, the optimum damping for the isolation system of the 4 and the 6 storey base-isolated buildings, for different earthquake motions, are presented in Table 3.

Table 3: Optimum isolation damping for different earthquake motions

Earthquake motion	*Dominating frequencies*	*Optimum isolation damping*	
		4 storey	*6 storey*
El Centro	0.5-2.5 *Hz*	10%-15%	10%-15%
Koyna	2.5-8.5 *Hz*	10%-15%	5%-10%
NE India (*Berlongfer*)	1.5-3.0 *Hz*	2%-5%	2%-5%
NE India (*Silchar*)	0.5-2.5 *Hz*	10%-15%	10%-15%
Mexico	0.2-0.5 *Hz*	5%-10%	5%-10%
Parkfield	0.5-6.5 *Hz*	15%-20%	15%-20%
Taft	0.5-5.0 *Hz*	5%-10%	5%-10%
Uttarkashi	2.5-6.5 *Hz*	2%-5%	2%-5%

It can be observed from the table that in general not more than 15% damping is required in the isolation system. The value of optimum damping depends upon the characteristics of ground motion and has low value for earthquake motions with high frequency contents. It can be seen that for Koyna earthquake motion, optimum damping is more for four-storey building when compared to six-storey building while it is same for other ground motions.

CONCLUSIONS

It is observed that isolation damping is effective in reducing displacement at isolation level. Increase in the damping up to a *certain level* reduces roof accelerations and storey shears beyond which the increased participation of higher modes leads to increase in the response. This value of damping changes with the response parameter. There exists an optimum value of damping which gives low value of base displacement without increasing the participation of higher modes. Optimum damping depends upon the characteristics of ground motion and has low value for earthquake motions with high frequency contents. Presence of high acceleration pulse in base motion and energy near the base isolation period may increase the value of optimum damping for that motion. It is observed that in general not more than 15% damping is required in the isolation system.

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