

# EFFECT OF SOIL CONDITION ON RESPONSE CONTROL OF ADJACENT STRUCTURES CONNECTED WITH VISCOUS DAMPER

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## ABSTRACT

Dynamic response of two adjacent single degree-of-freedom (SDOF) structures connected by viscous damper, subjected to harmonic excitation is investigated. The coupled structures are considered to be supported on different soil conditions. A parametric study is also carried out to study the influence of soil parameter such as shear wave velocity and poisson ratio on response of coupled structure. It has been observed that shear wave velocity has significant effect on the performance of viscous damper, whereas the effect of poisson ratio is marginal. The seismic response of two adjacent multi degree-of-freedom (MDOF) structures connected by viscous damper is obtained considering different soil conditions. It has been observed that viscous damper is effective for response control of coupled structures. However, when coupled structures are supported on soft ground the efficiency of the viscous damper is decreases.

## INTRODUCTION

The implementing energy dissipation device in to structures is effective alternate to reduce excessive structural vibrations due to natural disturbance like earthquake and strong winds. It also prevent catastrophic structural failure as well as enhance human comfort. Structural control technology can also be useful for design of engineering structures to increase their safety and reliability against natural disturbances. In short, the subject of structural control deals with modifying the response of structures to undesirable excitations. The external excitation adds the additional energy to the structures, results unwanted structural vibrations. The structural control adds additional damping to the structures. The damper dissipates the some of the energy by either transforming in to heat or transferring it directly to any connected structure or mass damper. The control strategies are able to modify dynamically the response of the structure in a desirable manner. According to the energy consumptions of control systems, it can be classified as passive, active, semi-active and hybrid systems. Passive control systems do not require an external power source for their operations, and utilize the response of structures to develop the control forces. The various passive vibration control mechanisms are viscous dampers, visco-elastic dampers, friction dampers, tuned mass dampers tuned liquid dampers. The control system and the structure do not behave as independent dynamic systems but rather interact with each other. In addition, interaction effects also occur between the excitation and structure (i.e. soil-structure interaction).

In modern cities more buildings are often built closely to each other because of the limited availability of land resources and preference of centralized services. To achieve sufficient open space for parking, shops, restaurants and hotel lobbies at the ground level, some modern tall buildings are often built with podium structures. Thus the concept of linking adjacent buildings or connecting podium structures to main buildings using dampers has been proposed to improve their seismic resistant performance. Many researchers have been attracted to mitigate the dynamic responses of the adjacent structures connecting them by passive dampers. The concept is to allow exerting control forces upon one another to reduce the overall response of the system. Moreover, it also overcomes the problem of pounding which has been observed in many past earthquake events. The seismic responses of two multi-story buildings connected with various passive dampers have been studied. The dynamic behavior of two adjacent SDOF structures connected with a viscous damper under harmonic excitation as well as stationary white-noise random process have been studied and the close-form expression for optimum damper damping have been derived for undamped structures [1]. The seismic response of similar adjacent buildings connected with viscous dampers [2], and the seismic response of adjacent structures connected with Maxwell dampers have been studied [3]. The above studies confirm the effectiveness of passive dampers for response control of adjacent coupled structures,. However, during most of the above studies it is assumed that structures are supported on firm ground. In reality the stiff ground will not always been found at the site. Thus, it's need to investigate the effect of soil condition on the response control of adjacent structures connected by damper. Hence, the present study is aimed to investigate the performance of viscous damper for response control of adjacent coupled structures supported on different soil condition under harmonic and real earthquake excitations.

## MODELLING OF CONNECTED STRUCTURES

Let us consider the connected structures with rigid foundation slab, resting on the soil considered as elastic half space, as shown in Figure 1(a). The adjacent structure are idealized as SDOF system and referred as Structure 1 and 2. The two structures are assumed to be symmetric with their symmetric planes in alignment. The ground motion is assumed to occur in one direction in the symmetric planes of the structures so that the problem can be simplified as a two-dimensional problem as shown in figure. Both structures are assumed to be subjected to the same ground acceleration. The viscous damper is modeled as linear dash pot, in which the force is proportional to the relative velocity of its both ends. The corresponding mathematical model of the damper connected structures is as shown in Figure 1(b). Let  $m_1, k_1, c_1$  and  $m_2, k_2, c_2$  be the mass, stiffness and damping coefficient of the Structure 1 and 2, respectively. Let  $\omega_1 = \sqrt{k_1/m_1}$  and  $\omega_2 = \sqrt{k_2/m_2}$  be the natural frequencies and  $\xi_1 = c_1 / 2m_1\omega_1$  and  $\xi_2 = c_2 / 2m_2\omega_2$  be the damping ratios of Structures 1 and 2, respectively. Let  $\mu$  and  $\beta$  be the mass and frequency ratio of two structures, respectively, expressed as

$$\mu = \frac{m_1}{m_2} \quad (1)$$

$$\beta = \frac{\omega_2}{\omega_1} \quad (2)$$

Let  $c_d$  be the damping coefficient of the damper. The damper damping is expressed in the normalized form defined as

$$\xi_d = \frac{c_d}{2m_1\omega_1} \quad (3)$$

where  $\xi_d$  is the normalized damping coefficient of damper. The soil stiffness and damping to horizontal motion are  $k_s, c_s$ ; and to that of rocking motion are  $k_\theta, c_\theta$ , respectively. The mathematical model of the coupled structures with soil spectrum is as shown in Figure 1(b). Let the height of the structures be  $h$ . The uniform free-field ground acceleration,  $\ddot{x}_g$  will then cause foundation forces to develop at the interface between soil and foundation of the structures, forcing foundation slab to translate and rotate. Let  $x_{01}$  and  $\theta_{01}$  be the translation and rotation of the foundation slab of the Structure 1; and  $x_{02}$  and  $\theta_{02}$  be the translation and rotation of the foundation slab of the Structure 2, respectively. The rotational component of ground motion is neglected. The rotational degree of freedom of the Structures 1 and 2 are also neglected. The governing equations of motion for the damper connected system on soil can be written for Structure 1, as

$$m_1\ddot{x}_1 + m_1\ddot{x}_{01} + m_1h\ddot{\theta}_{01} + c_1\dot{x}_1 + k_1x_1 + c_d(\dot{x}_1 - \dot{x}_2) = -m_1\ddot{x}_g \quad (4)$$

$$m_1\ddot{x}_1 + m_1\ddot{x}_g + m_1\ddot{x}_{01} + m_1h\ddot{\theta}_{01} + c_d(\dot{x}_1 - \dot{x}_2) - k_sx_{01} - c_s\dot{x}_{01} = 0 \quad (5)$$

$$m_1\ddot{x}_1h + m_1\ddot{x}_gh + m_1\ddot{x}_{01}h + m_1h^2\ddot{\theta}_{01} + c_d(\dot{x}_1 - \dot{x}_2)h - k_\theta\theta_{01} - c_\theta\dot{\theta}_{01} = 0 \quad (6)$$

for Structure 2, as

$$m_2\ddot{x}_2 + m_2\ddot{x}_{02} + m_2h\ddot{\theta}_{02} + c_2\dot{x}_2 + k_2x_2 - c_d(\dot{x}_1 - \dot{x}_2) = -m_2\ddot{x}_g \quad (7)$$

$$m_2\ddot{x}_2 + m_2\ddot{x}_g + m_2\ddot{x}_{02} + m_2h\ddot{\theta}_{02} - c_d(\dot{x}_1 - \dot{x}_2) - k_sx_{02} - c_s\dot{x}_{02} = 0 \quad (8)$$

$$m_2\ddot{x}_2h + m_2\ddot{x}_gh + m_2\ddot{x}_{02}h + m_2h^2\ddot{\theta}_{02} - c_d(\dot{x}_1 - \dot{x}_2)h - k_\theta\theta_{02} - c_\theta\dot{\theta}_{02} = 0 \quad (9)$$

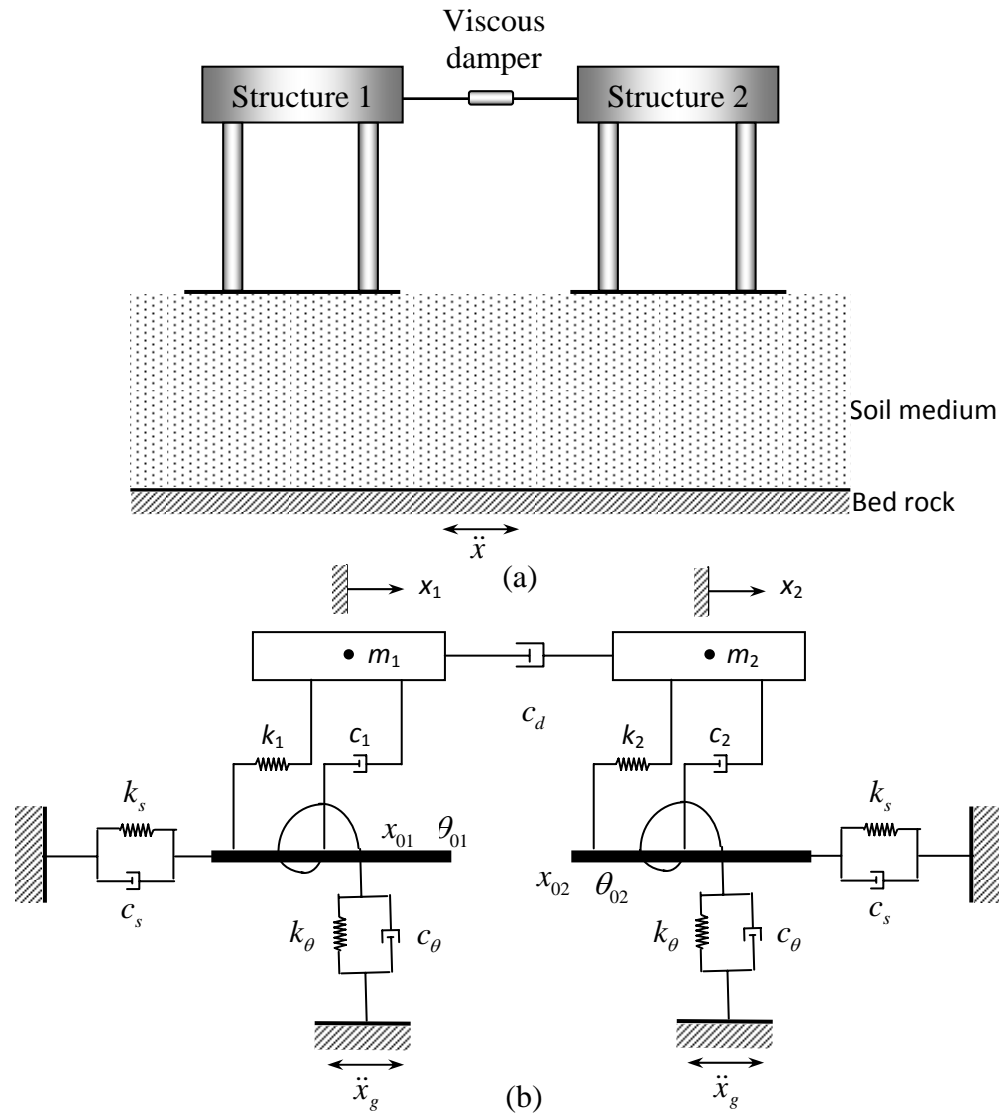


Fig. 1 Structural model of viscous damper connected two SDOF adjacent structures supported on soil medium  
 Solving the above equations for  $x_1$  and  $x_2$  will gives the displacement responses of Structures 1 and 2, respectively.  
 The absolute acceleration response of the Structures 1 and 2 can be calculated as

$$\ddot{x}_{a1} = m_1(\ddot{x}_1 + \ddot{x}_{01} + h\ddot{\theta}_{01} + \ddot{x}_g) \tag{10}$$

and

$$\ddot{x}_{a2} = m_2(\ddot{x}_2 + \ddot{x}_{02} + h\ddot{\theta}_{02} + \ddot{x}_g) \tag{11}$$

**NUMERICAL STUDY**

Two adjacent structures connected with viscous damper resting on soil are considered to investigate effect of soil condition on the performance of viscous damper. The fundamental time period of Structure 1,  $T_1$  is taken as 2 sec and that of Structure 2,  $T_2$  as 1 sec. The Structure 1 is considered as flexible structure and Structure 2 is

considered as stiff structure. The damping ratio in both the structure is considered as 5 %. The mass  $m_1$  of Structure 1 is considered as 1000 kg. Considering mass ratio  $\mu = 1$ , the mass  $m_2$  of the Structure 2 is 1000 kg. The soil stiffness and damping for translational and rocking motion are calculated as (Tongaonkar and Jangid, 2003)

$$k_s = \frac{8 G a}{2-\nu} ; \quad c_s = \frac{4.6 G a^2}{(2-\nu)V_s} \tag{12}$$

$$k_\theta = \frac{8 G a^3}{3(1-\nu)} ; \quad c = \frac{0.4 G a}{(1-\nu)V} \tag{13}$$

where  $G, V_s$  and  $\nu$  are the shear modulus, shear wave velocity and Poisson ratio of the soil respectively, and  $a$  is the radius of foundation slab respectively. For the present study the soil parameters considered are, Poisson's ratio is 0.4; the soil shear modulus value is 3.57 MPa, 0.357 MPa and 0.179 MPa for hard, medium and soft soil, respectively; the soil shear wave velocity is considered as 394 m/s, 134 m/s and 99.6 m/s for hard, medium and soft soil, respectively [4]. Let us consider the coupled system supported on different soil condition, subjected to harmonic base acceleration given by

$$\ddot{x}_g = a_0 e^{i\omega t} \tag{14}$$

where  $a_0$  and  $\omega$  are the amplitude and excitation frequency, respectively of the harmonic ground motion. The variation of displacement response and acceleration response of both the structures against excitation frequency is given in Fig. 2. It is observed that the peak response quantities, displacement as well as acceleration of both structures are reduced up to certain value of the damper damping coefficient after which they are increased. This is because, the higher damper damping coefficient reduces relative velocity of damper and hence the energy absorbing capacity from damping force decreases. When the damper damping coefficient is too high, the relative velocity and displacement of the two structures become nearly zero so that the two structures behave as through they are almost rigidly connected. Significant reduction can be achieved in response of both the structures when they are connected with viscous damper of optimum damping implying that the viscous damper are quite effective in enhancing the harmonic performance of connected structures. The peak response quantities of both the structures supported on different soil condition, for different damping coefficient of damper are given in Table 1.

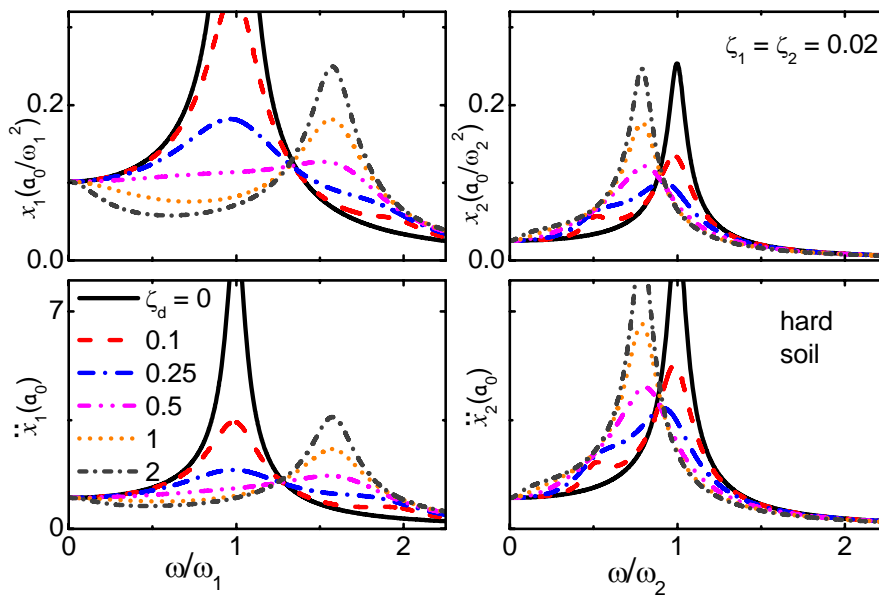


Fig. 2 Variation of displacement and acceleration response on hard soil for different damper damping

It is observed that coupled structure behavior is similar in nature for different soil condition, however, the optimum value of damping coefficient of damper is different for different supporting soils, which indicates the soil condition affects the optimum damping coefficient of damper. Two adjacent MDOF structures with 20 and 10 stories are considered, such that the floor mass and inter-story stiffness are assumed to be uniform for both structures. The mass and stiffness of each floor are chosen such that to yield a fundamental time period of 2.0 sec and 1.0 sec for Structures 1 and 2, respectively. The earthquake time histories selected to examine the seismic behavior of the two structures are: Imperial Valley (1940), Kobe (1995), Northridge (1994), and Loma Prieta (1989).

Tabel.1 Peak responses of coupled structures supported on different soil, for different damping coefficient of damper

$\xi_d$	Hard ground				Medium ground				Soft ground			
	$x_1$	$x_2$	$\ddot{x}_{a1}$	$\ddot{x}_{a2}$	$x_1$	$x_2$	$\ddot{x}_{a1}$	$\ddot{x}_{a2}$	$x_1$	$x_2$	$\ddot{x}_{a1}$	$\ddot{x}_{a2}$
0.00	1.014	0.253	0.673	10.01	1.010	0.254	0.658	10.03	1.007	0.066	9.943	10.11
0.10	0.345	0.133	0.801	5.281	0.343	0.135	0.788	5.309	0.341	0.070	3.413	5.358
0.25	0.182	0.089	1.139	3.886	0.181	0.101	1.128	3.902	0.180	0.086	1.884	3.927
0.50	0.127	0.0722	1.706	4.555	0.126	0.121	1.696	4.548	0.125	0.120	1.690	4.549
1.00	0.181	0.066	2.573	6.600	0.181	0.176	2.562	6.578	0.180	0.176	2.557	6.573
2.00	0.250	0.067	3.601	9.161	0.249	0.246	3.589	9.131	0.249	0.246	3.588	9.132

The two structures are connected with viscous dampers at all floors and the optimum damping in dampers is considered same in all dampers. To investigate the effect of soil condition on the performance of the viscous damper, the seismic response of the structures is obtained for unconnected, connected with optimum damping coefficient of damper on hard soil and on soft soil condition. The time history of the displacement responses and acceleration responses of connected structures for considered earthquakes are shown in Figs. 3 and 4, respectively. It is observed that viscous damper is effective for seismic response control of adjacent coupled structures; however, the efficiency of viscous damper is decreases for soft soil. It is also observed that the ground motion also affects the performance of the viscous damper for seismic response control of coupled structures on different soil conditions.

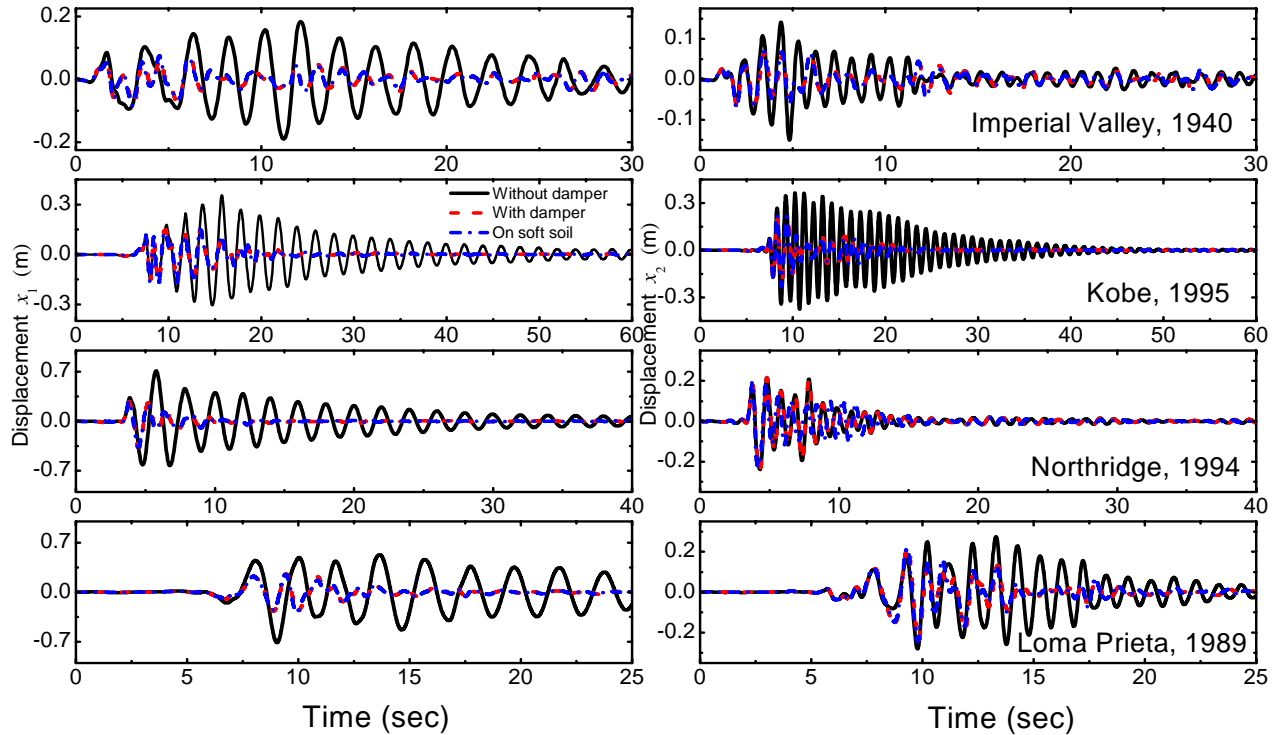


Fig. 3 Time history of displacement responses for adjacent structures connected with viscous damper

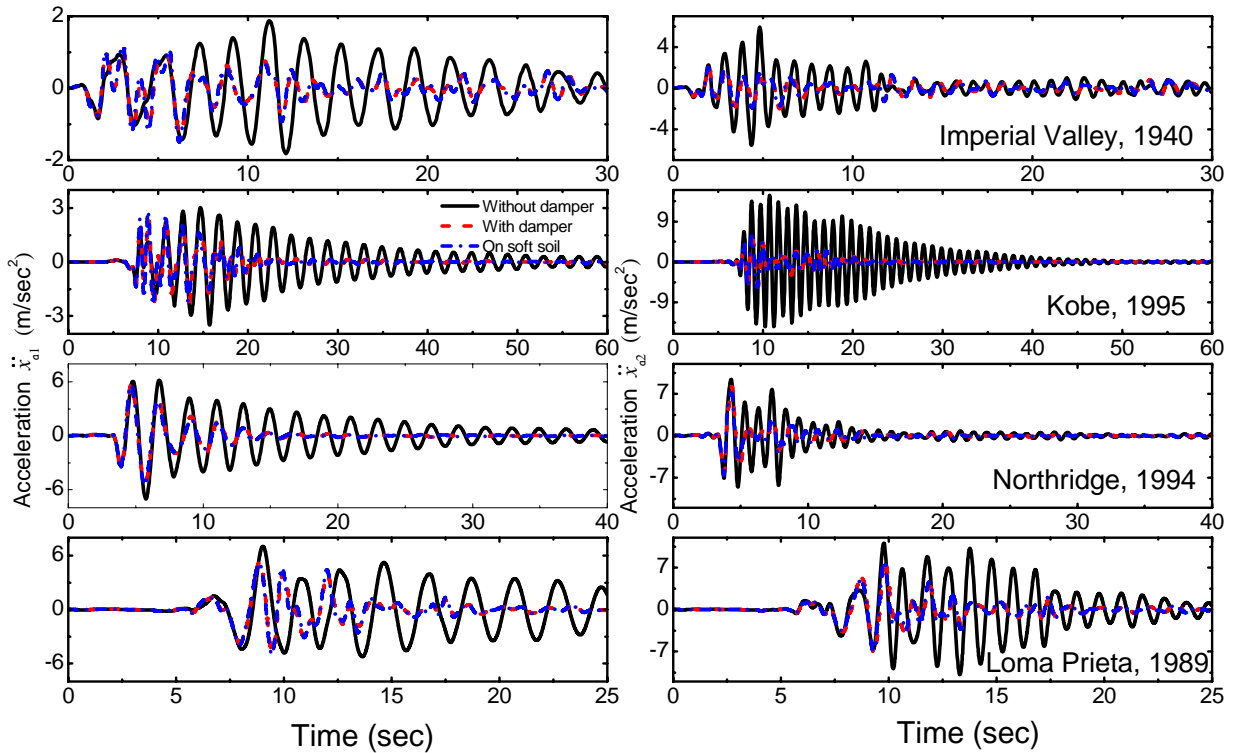


Fig. 4 Time history of acceleration responses for adjacent structures connected with viscous damper

## CONCLUSIONS

The dynamic behavior of two SDOF structures supported on different soil, connected with viscous damper is studied under harmonic excitations. The seismic response of two MDOF structures supported on different soil, connected with viscous damper is studied. From the trend of the results of the present study it can be concluded that The viscous damper is found to be effective for response control of adjacent coupled structures supported on different soil, under harmonic excitations. There exists an optimum damping coefficient of damper to yield minimum responses for both structures under harmonic excitations. The soil condition affects the viscous damper performance and viscous damper become more effective on hard soil for seismic response control of coupled structures. The ground motion also affects the performance of viscous damper for seismic response control of structures on different soil conditions.

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