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Seismic analysis of 3-D two adjacent buildings connected by viscous dampers with effect of underneath different soil kinds

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Abstract. 3D two adjacent buildings with different heights founded in different kinds of soil connected with viscous dampers groups, with especial arrangement in plane, were investigated. Soil structure interaction for three different kinds of soil (stiff, medium and soft) were modeled as 3D Winkler model to give the realistic behavior of adjacent buildings connected with viscous dampers under various earthquake excitations taking in the account the effect of different kinds of soil beneath the buildings, using SAP2000n to model the whole system. A range of soil properties and soil damping characteristics are chosen which gives broad picture of connected structures system behavior resulted from the influence soil-structure interaction. Its conclusion that the response of connected structures system founded on soft soil are more critical than those founded on stiff soil. The behavior of connected structures is different from those with fixed base bigger by nearly 20%, and the efficiency of viscous dampers connecting the two adjacent buildings is reduced by nearly 25% less than those founded on stiff soil.

Keywords: 3D analysis ; adjacent buildings ; viscous damper ; couple buildings ; SSI ; connecting adjacent building with viscous damper ; optimum number of dampers

1. Introduction

Vibration control by connecting adjacent structures is very effective to mitigate the dynamic responses and also minimize the chances of pounding. By providing energy dissipation devices of appropriate capacity and at proper position between two adjacent structures, the passive control techniques increase the energy dissipation capacity of the structural system. The control force by control device is function of velocity. There should be a relative velocity between the two ends of the damper, connect the two adjacent structures for damper to be effective and two adjacent structures should be dynamically dissimilar (i.e., One soft structure and other stiff structure). This concept is to allow two dynamically dissimilar structures to exert control force upon the other to reduce overall response of the system. It also overcomes the problem of pounding which is more severing load condition than the case of vibration without pounding. But it alters the dynamic characteristics of the unconnected structures. The structural control criteria depend on the nature of dynamic loads and the response quantities of interest. Minimizing the relative displacement, absolute acceleration and shear force of the system has always been considered as the control

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objective. In case of flexible structures, displacements are predominant that need to be controlled. Whereas, in case of stiff structures, accelerations are more concern generating higher inertial forces in structures, which should be mitigated. The damages observed from seismic pounding, i.e., heavy and repeated collision of buildings, are devastating and particularly frequent in dense urban centers (Tesfamariam and Saatcioglu 2010).

Several studies have investigated the use of damper connectors in order to reduce pounding induced damage and to increase the seismic resistance of a structure (Bharti et *al*. 2010).

Hwang *et al.* (2007) employed viscous dampers at the connection between the exterior and interior structures to enhance earthquake resistant performance of the factory structures.

Viscous damping involves taking advantage of the high flow resistance of viscous fluids. When the damper is installed in a building, the friction converts some of the earthquake energy going into the moving building into heat energy. The force depends on the size and shape of the orifices and the viscosity of oil. Strong temperature dependence is observed. The forces developed in a viscous damper are proportional to the velocity of its deformation. Fluid viscous dampers put out virtually zero force at the low velocities associated with thermal motion.

Fluid inertial dampers have several inherent and significant advantages: linear viscous behaviour, insensitivity to stroke and output force; easy installation; almost free maintenance; reliability and longevity. Fluid viscous dampers allow the structure to re-centre itself perfectly at all times.

Kasai (1992) inserts a viscoelastic or viscous dampers in the closely spaced adjacent buildings thereby increasing their damping properties substantially. The dampers placed inside the adjacent buildings have the potential to reduce significantly the effect of pounding due to the following reasons:

• They reduce the maximum displacement of the buildings;
• They promote the in-phase motion of both buildings;
• Should the pounding occur the impact is absorbed by the dampers in the vicinity of pounding level, thereby preventing propagation of its effect to other storey levels.

Patel (2011) investigated the dynamic behaviour of two adjacent dynamically identical structures connected with viscous damper under harmonic excitations. The author concluded that the viscous dampers are found to be very effective in reducing the dynamic responses of adjacent structures under harmonic excitations, there exists an optimum value of damping coefficient of damper for which the peak responses of the connected structures attains the minimum value, The optimum parameter of damper are not much influenced by the damping in the connected structures implying that the optimum damping value damper damping of un-damped system can be used for damped coupled system, and The viscous damper becomes more effective in reducing the peak responses of the connected system, if the structures are stiffer at lower story in comparison with upper story and having uniform masses at both levels. (Uz 2009)

One of the most important damping devices in passive control is the fluid viscous damper. Fluid viscous dampers have the high flow resistance because of viscous fluids. The high flow resistance makes a big role in order to alleviate the earthquake responses of coupled buildings. Qi and Chang (1995) described the implementation of viscous dampers that have several inherent and significant advantages including linear viscous behaviour; insensitivity to stroke and output force; easy installation; almost free maintenance; reliability and longevity. Nowadays, the use of fluid viscous damper has been increased significantly on adjacent structures (Warnotte *et al.* 2007). Hadi and Uz (2009) investigated the important of viscous fluid dampers for improving the dynamic behaviour of adjacent buildings by connecting them with fluid viscous dampers. They observed the reduction of top floor displacement; acceleration and shear force responses of adjacent under the earthquake excitations, although the adjacent buildings are connected by dampers in one direction buildings.

Naserkhaki *et al.* (2012) studied seismic responses of adjacent buildings modeled as the lumped mass shear buildings and the pounding forces are modeled as the Kelvin contact force model subjected to earthquake induced pounding numerically. The developed model is solved numerically and a SDOF pounding case as well as a MDOF pounding case of multistory adjacent buildings are elaborated and discussed. Effects of different separation gaps, building heights and earthquake excitations on the seismic responses of adjacent buildings are obtained. Results show that the seismic responses of adjacent buildings are affected negatively by the pounding. More stories pound together and pounding is more intense if the separation gap is smaller. When the height of buildings differs significantly, the taller building is almost unaffected while the shorter building is affected detrimentally. Finally, the buildings should be analyzed case by case considering the potential earthquake excitation in the area.

Skrekas *et al.* (2014) considered a typical case study of a “new” reinforced concrete (R/C) EC8-compliant, torsionally sensitive, 7-story corner building constructed within a block, in bi-lateral contact with two existing R/C 5-story structures with same height floors. A non-linear local plasticity numerical model is developed and a series of non-linear time-history analyses is undertaken considering the corner building “in isolation” from the existing ones (no-pounding case), and in combination with the existing ones (pounding case). The authors reported the results in terms of averages of ratios of peak inelastic rotation demands at all structural elements (beams, columns, shear walls) at each storey. The authors showed that seismic pounding reduces on average the inelastic demands of the structural members at the lower floors of the 7-story building. However, the discrepancy in structural response of the entire block due to torsion-induced, bi-directionally seismic pounding is substantial as a result of the complex nonlinear dynamics of the coupled building block system.

The dynamic response of buildings is modified depending on the structural and soil properties by the translational of the foundation relative to the soil during dynamic structure-soil interaction.

In order to carry out the use of dampers for two directions under the strong earthquakes, the analysis is investigated in both directions in the structural responses of two neighboring buildings, which have the same stiffness ratios and different heights, connected with two different damper parameters under various earthquake excitations in each model. The effectiveness of fluid joint dampers is then investigated in terms of the reduction of displacement, acceleration and shear force responses of adjacent buildings. Finally, an extensive parametric study is carried out to find the optimum damper placements in adjacent buildings both having the same stiffness.

2. Model description

Two buildings are assumed to be symmetric in plan (Fig. 1) and alignment. Each building is modeled as a linear multi-degree of freedom system where the mass is concentrated at each floor and the stiffness is provided by the mass less walls or columns. This assumption indicates that earthquake excitation considered here is not severe or due to the significant increase of energy absorbing capacity the buildings are able to retain elastic and linear properties under the earthquake. The floors of each building are at the same level, but the number of story in each building was different. Each viscous damper device is modeled as a combination of a linear spring and a linear dashpot (Fig. 2). For the uncontrolled system the first three natural frequencies corresponding to first three modes of the building A are 3.3, 9.9, 16.8 rad/s and that of the Building B are 6.9, 20.8, 34.1 rad/s respectively. These frequencies clearly show that the modes of the buildings are well separated. A 3D model were constructed with foundation system (Fig. 3) to represent the real effect of soil type on connecting two adjacent buildings under earthquake excitations.

Fig. 4 shows five system of connecting the two adjacent buildings used in this study.

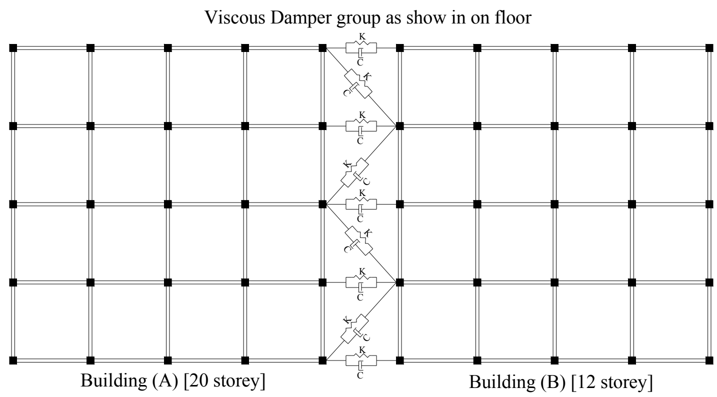


Fig. 1 Typical plan of the two connected buildings (Special arrangement of link dampers)

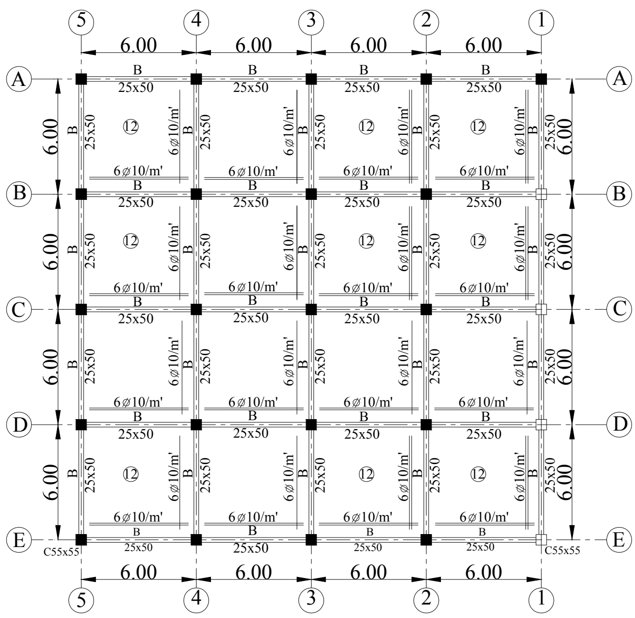


Fig. 2 Plan of the two buildings (A and B)

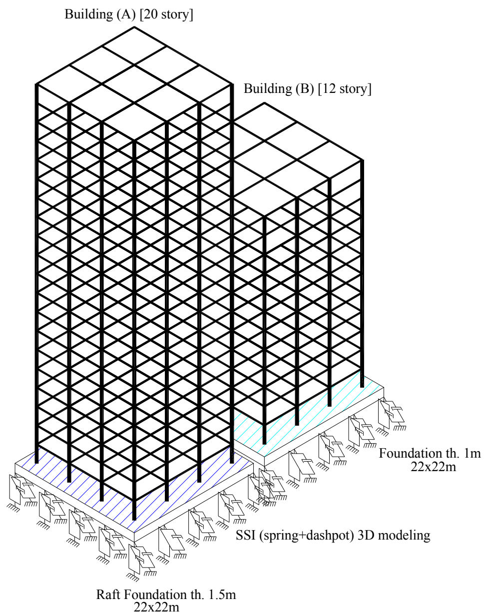
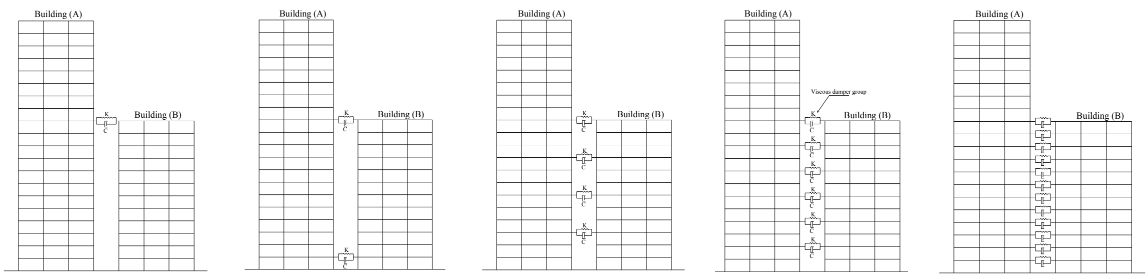


Fig. 3 3D view of the two adjacent buildings with raft foundation system



(i) One Damper group

(ii) Two Dampers groups

(iii) Four Dampers groups

(iv) Six Dampers groups

(v) Twelve Dampers groups

Fig. 4 Different placement of connected two buildings models with viscous dampers groups

3. Viscous damper representation

The linear damper behaviour is given by

$$F_T = CV^{c\exp} + KD_K = F_D + F_E \tag{1}$$

where F_T is total output force provided by the damper, C is the damping coefficient, K is the spring constant, V and D_k are the velocity across the damper and the displacement across the spring, respectively, $c\ exp$ is the damping exponent. The damping exponent must be positive. The practical range between $c\ exp$ = 0.5 and 2.0 is determined by Hou (2008) and Tezcan and Uluca (2003). In the numerical data of this study, *c exp* is taken as unity. It is evident that F_T consists of two parts. Damping force F_D which equals $C\ V^{c\ exp}$. Restoring force *FE* According to Xu *et al.* (1999), the damping coefficient was determined to be around $1x10^6$ N. *s m* with a small variation for adjacent buildings in their studies. Therefore, the damping coefficients in the five main examples are determined as c_d= $0.25x10^6$ N. *s m* and c_d= $0.85x10^6$ N. *s m* respectively.

For all modes, both buildings have damping ratios of 5% of the critical structural damping (ζ=0.05). The structural damping coefficient in SAP 2000n is automatically calculated from the expression at below.

$$[C] = \text{diag}(2M\xi\omega) \tag{2}$$

where [C] is the modal damping matrix, M, ξ and ω are the modal mass, the damping ratio and natural frequency, respectively. The mass and shear stiffness of each building are calculated. The same size of columns and beams has been used for the frames of two building models in order to investigate the sole control of fluid viscous dampers for different types of soils kinds.

Patel and Jangid (2010) concluded that the stiffness of the dampers affects its performance, which may otherwise increase the responses of structures, if it is not selected properly, and lesser dampers at appropriate locations can reduce the seismic response of the connected system almost as much as when they are connected at all floors and as the damping force is in proportion to the relative velocity of its both ends, the neighboring floors having maximum relative velocity should be chosen for optimal dampers locations.

4. Modeling of soil – structure interaction

In Table 1, G is the small strain shear modulus of the soil, *r* represents the plate radius, and ν, ρ are the Poisson's ratio and mass density of the soil, respectively. When a non-circular foundation is considered, an equivalent radius must be defined in order to use these equations. In the present study, the equivalent radius was obtained by equating the area of a circular plate to the square plate and solving for *r*. These constants were introduced to the spring-dashpot model developed in SAP2000. These coefficient is represented the stiff, medium and soft soil, just vertical and horizontal stiffness and damping were considered and the rotational damping and stiffness were neglected in this study.

Table 1 Values of Stiffness and damping coefficient of soil

Direction	Stiffness (K)	Damping (C)	Mass
Vertical	$\frac{4Gr}{1-\nu}$	$1.79\sqrt{K\rho r^3}$	$1.5\rho r^3$
Horizontal	$18.2Gr\frac{(1-\nu)^2}{(2-\nu)^2}$	$1.08\sqrt{K\rho r^3}$	$0.28\rho r^3$

r = plate radius; G =shear modulus; ν = Poisson's ratio; ρ =mass density
Source: Adapted from Fundamentals of Earthquake Engineering, by Newmark and Rosenblueth prentice-Hall, 1971

Table 2 Different parameters used to find K, and C of subsoil underneath foundation system of building A and B (Ahmed and Handy 2013)

Soil	$\rho(t/m^3)$	ν	E_s (t/m^2)	$G(t/m^2)$
Soft	1.40	0.35	2040	2.55
Medium	1.75	0.30	5100	20.4
Hard	2.10	0.25	10200	51

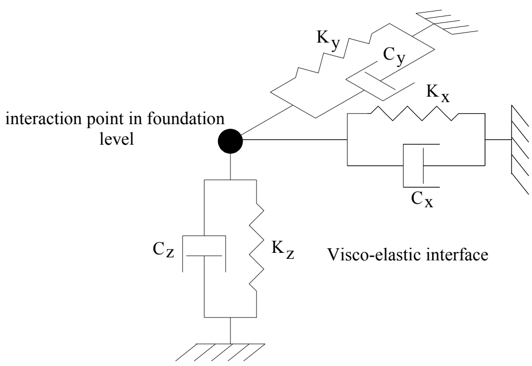


Fig. 5 3D Winkler Elements model SSI (Ahmed and Hamdy 2013)

Table 2 shows the values of different parameters of different kinds of soils used in the research. The different types of soils (soft, medium, and hard) were classified as Ahmed and Hamdy (2013), soft soil as brown clay, medium soil as silt clay and hard soil as sandy gravel.

Fig. 5(a) FEM model has been purposely developed by subdividing the substructure (connected to superstructure) into a finite number of beam and shell element, connected to the surrounding ground by a series of frequency-dependent springs and dashpots in parallel representing the effects of ground deformability and energy dissipation.

5. Input loading

Total dead and live load on the area of the plane floor are 0.65 t/m^2 and weight volume of RC is 2.5 t/m^3. For dynamic loads acted on the system are earthquake time histories selected to examine the seismic behavior of the two buildings are: El Centro, 1940, and Northridge, 1994. The peak ground acceleration of El Centro and Northridge earthquake motions are 663 cm/cm^2, and 665 cm/cm^2 respectively (http://nisee.berkeley.edu/data/strong_motion/sacsteel/motions/la10in50yr.html) (g is the acceleration due to gravity). These earthquakes have magnitudes of 7.1, and 6.8 respectively in Richter scale. A time history analysis was carried out using El Centro earthquake and ten models are excited by three orthogonal components of seismic motion which has maximum acceleration 0.5 g (Fig. 6) (The earthquake affects on two directions X, and Y of the tested model). Two different time histories acceleration were used in this study to emphasize the results for different kid of earthquake vibrations.

Fig. 3 Connected structures on different kinds of soil and considering the equilibrium of each mass, the equilibrium equation for each mass can be written as (Patel 2008)

$$m_A \ddot{x}A + (c_d + c_A)\dot{x}A - c_A \dot{x}g - c_d \dot{x}B + k_A x_A - k_A x_g = -m_A \ddot{x}g \tag{3a}$$

$$m_s \ddot{x}g + (c_s + c_A)\dot{x}g - c_A \dot{x}A + (k_s + k_A) - k_A x_A = -m_s \ddot{x}g \tag{3b}$$

$$m_B \ddot{x}B + (c_d + c_B)\dot{x}B - c_B \dot{x}g - c_d \dot{x}A + k_B x_B - k_B x_g = -m_B \ddot{x}g \tag{3c}$$

$$m_s \ddot{x}g_B + (c_s + c_B)\dot{x}g_B - c_B \dot{x}_B + (k_s + k_B)x_g - k_B x_B = -m_s \ddot{x}g \tag{3d}$$

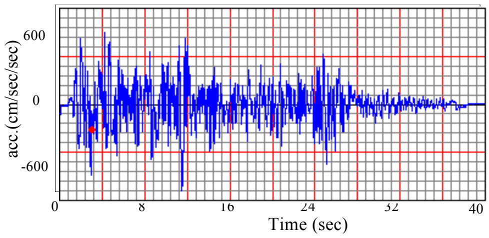
The governing equation of motion for the given system can be written in matrix form as

$$[M]\{\ddot{X}\} + [C]\{\dot{X}\} + [K]\{X\} = -[M]\{1\}x_g \tag{4}$$

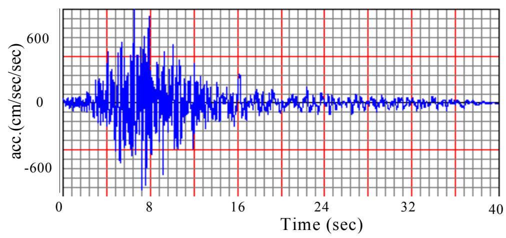
where, x_1 and x_2 are the displacement responses, relative to the ground of structure *1* and *2* respectively, and $\ddot{x}_g$ is the ground acceleration.

6. Results and discussions

Two adjacent buildings with 20 (Building (A)) and 12 (Building (B)) stories are considered. The floor mass and inter-story stiffness are considered to be uniform for both buildings. The masses of the two buildings are assumed to be same and the damping ratio in each building is taken as 5%. The stiffness of each floor of the buildings is chosen such that to yield a fundamental time periods of 1.9 and 0.9 s for Buildings A and B, respectively. Thus, Building A may be considered as softer building and Building B as stiffer building. The adjacent buildings considered above are first connected with 1, 2, 4, 6, and 12 groups viscous dampers groups at the floor levels with fixed base cases (no), then by using three types of soil (stiff, medium, and soft) represented by 3D Winkler model with raft foundation system, the two adjacent buildings were connected by the same way by viscous dampers. To get the optimum damper numbers and effect of different kinds of soil on connecting the two adjacent buildings, the displacements of each floor, top floor absolute accelerations and shear force of the each building is plotted with the damper number and changing of soil type as shown in Fig. 7-10 for the two selected earthquakes.



(i) El-Centrio Model Vibration

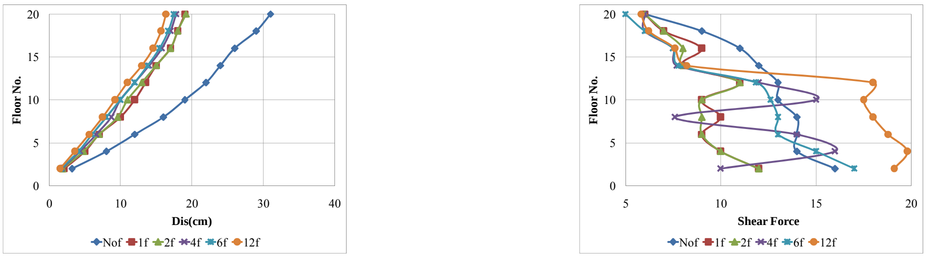


(ii) Northridge Model Vibration

Fig. 6 Acceleration Time Histories of the Earthquakes in N-S direction

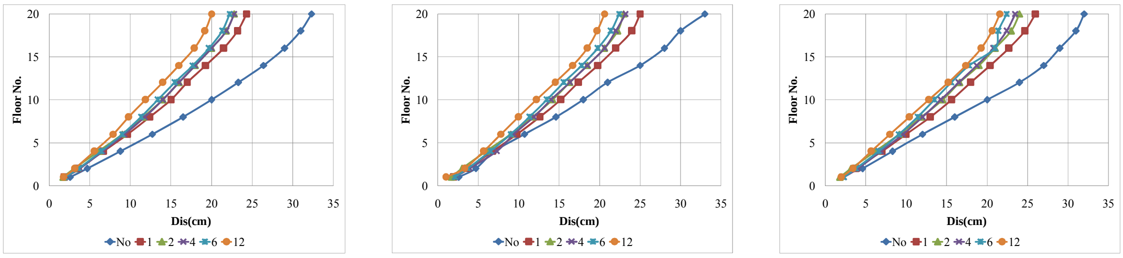
Fig. 7 shows the response of the two adjacent building under El-Centro earthquake excitation. Fig. 7(a) represent a comparisons between the different cases of connecting with 1, 2, 4, 6, and 12 groups dampers with fixed base case (f), it is clear the reduction in the displacement of the two building using one damper by nearly 1.6 times than no damper case increasing the number of connecting dampers the reduction of displacement increase slightly for building A. For shear force using one or two (1 or 2) dampers groups reduce shear force by nearly 1.4 times less than no case, but use more than 2 groups dampers shear force increase by more than 1.2 times than no case especially for columns in the floor connected with dampers. Fig. 7(b) shows displacement in different levels of building A on different kinds of soil connected with 1, 2, 4, 6, 12 groups dampers, and (No) case. From figure the top displacement constructed on stiff soil decreased by nearly 30% when use 1 damper than no case and when use 12 groups dampers top displacement decreased by 60% than no case. In medium soil, top displacement decreased by 1.32 and 1.6 times than No case using 1 and 12 connected dampers, and in soft soil top displacement decreased by 1.5 and 1.23 times than no case using 1 and 12 groups' dampers respectively. Fig. 7(c) represents shear force in different levels using 1, 2, 4,6,12 groups dampers and no case for building founded on different kinds of soil. In stiff soil shear force decreased by 1.17 times than no case using 1 or 2 groups dampers, whatever, shear force increase in columns at connected levels by nearly 1.4 times than no case, case of 12 groups dampers increase shear force of connected floor's columns by nearly 1.5 times bigger than no case. In medium soil shear force decreased by 1.15 times than no case using 1 damper, but shear increased by 1.5 times than no case in the connected floor's columns and when use 12 connected dampers shear force in columns increased by 2 times than no case. In soft soil shear force decreased by 1.2 times than no case using one damper but using 2 groups dampers increase base shear by 1.25 times than no case.

Fig. 8 represents the response of building B under El Centro exaction. Fig. 8(a) illustrated shear force in columns and floor displacements in different case of connected dampers. In fixed base case, shear force decreased by 2 times than no case when use 4 dampers and top displacement decreased by 2 times than no case. Generally connecting dampers in building (b) shows more uniformity in shear behavior of the building. Fig. 8(b) shows displacements in different building's levels in different kinds of soil founded. In stiff soil, top displacement decreased by 2.66 times using 2 dampers than no use case. Shear force decrease by 2 times using 2 dampers than no case. In medium soil displacement decreased using 2 dampers by 2.7 times than no case, soft soil shear force decreased by 2 times than no case, and base shear decreased using dampers by nearly 2.2 times than no case.



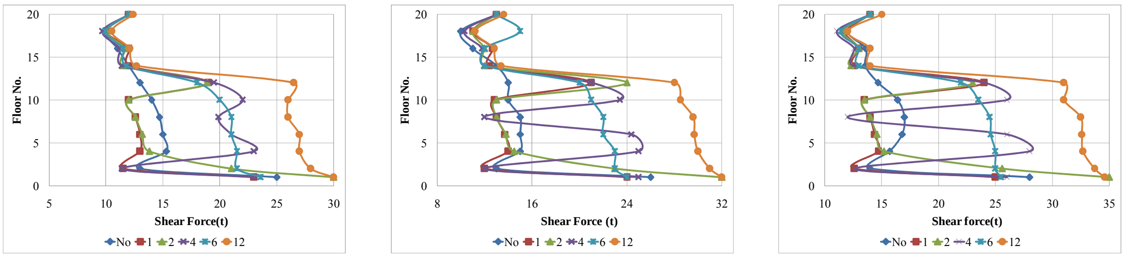
(1) Displacement (2) Shear force

(a) Response of building (A) connected with different numbers of link dampers groups with fixed base



(i) Stiff Soil (ii) Medium Soil (iii) Soft Soil

(b) Displacement of Building (A) (20 storey) with link damper and different kind's soil



(i) Stiff Soil (ii) Medium Soil (iii) Soft Soil

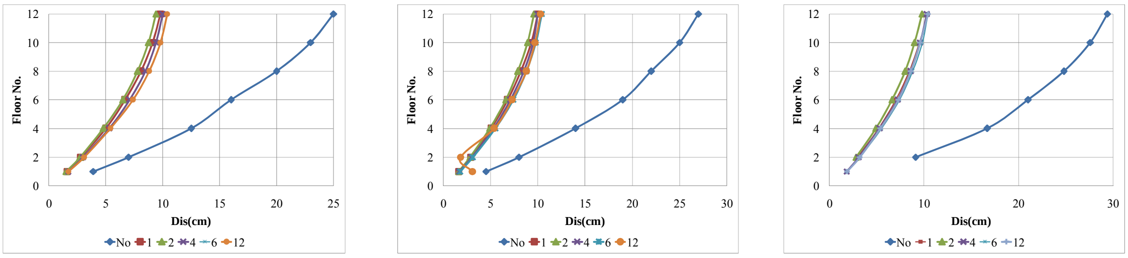
(c) Shear Force of Building (A) (20 storey) with linked dampers groups and different kinds soil

Fig. 7 El - Centro Earthquake response of buildings (A)

Fig. 9 shows top floor accelerations ratios of building A and B under El Centro earthquake. Fig. 9(i) represents top floor acceleration of building A, top floor acceleration decreased using 2 dampers groups by nearly 1.4 times than no case, but it is increased by using 4, 6, and dampers groups. In general acceleration decreased using 1 or 2 dampers groups in all kinds of soil than fixed base case. Fig. 9(ii) represents top floor acceleration of building B, top floor acceleration generally decreased when using dampers linked to building B by nearly 2 times than no case for all number of connected dampers. Table 3 shows the symbols used in Figs.

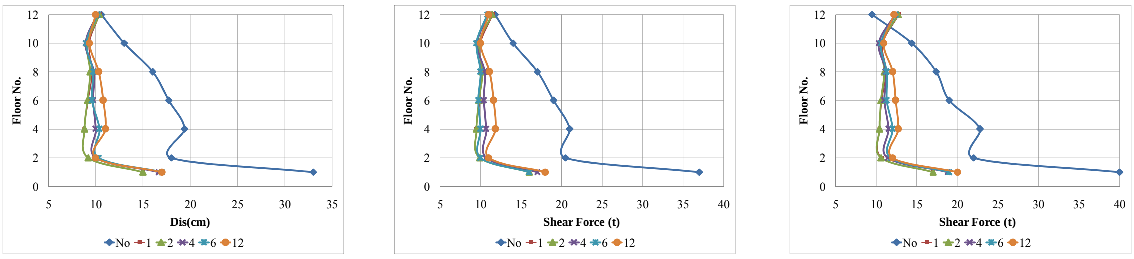
(1) Displacement (2) Shear force

(a) Response of building (B) connected with different numbers of link dampers groups with fixed base



(i) Stiff Soil (ii) Medium Soil (iii) Soft Soil

(b) Displacement of Building (B) (12 storey) with link dampers groups and different kinds soil



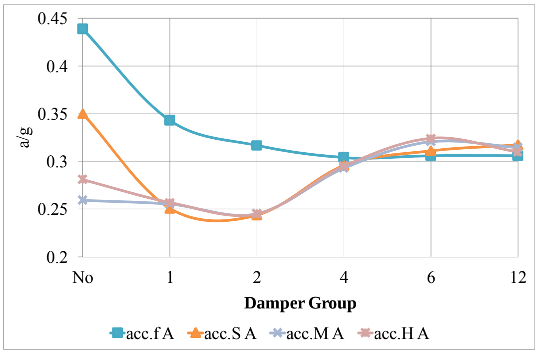
(i) Stiff Soil (ii) Medium Soil (iii) Soft Soil

(c) Shear Force of Building (B) (12 storey) with linked dampers groups and different kinds soil

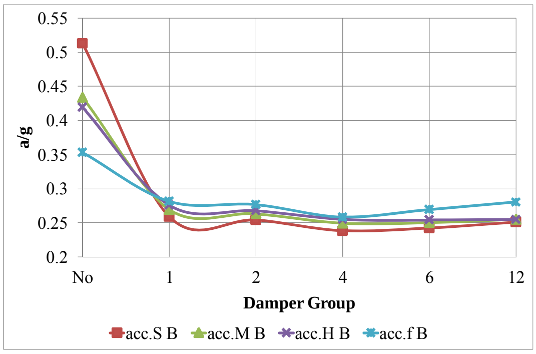
Fig. 8 El - Centro Earthquake response of buildings (B)

Table 3 Symbols Descriptions

Symbol	Description
Acc. F A	Top floor acceleration of fixed base building A
Acc. S A	Top floor acceleration of soft soil foundation of building A
Acc. M A	Top floor acceleration of medium soil foundation of building A
Acc. H A	Top floor acceleration of hard soil foundation of building A
Acc. F B	Top floor acceleration of fixed base building B
Acc. S B	Top floor acceleration of soft soil foundation of building B
Acc. M B	Top floor acceleration of medium soil foundation of building B
Acc. H B	Top floor acceleration of hard soil foundation of building B



(i) Top Floor acceleration of building A



(ii) Top floor acceleration of building B

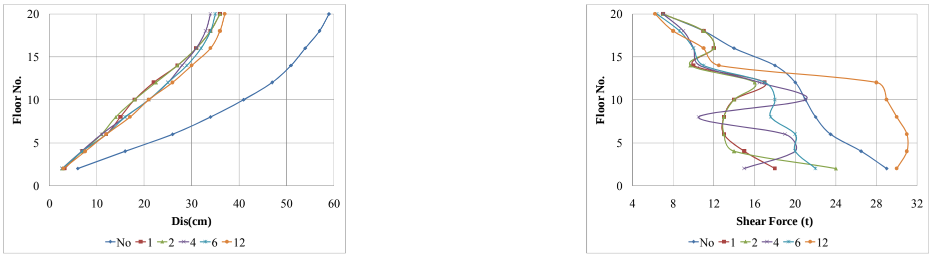
Fig. 9 Top floor acceleration of building A and B under El-Centro earthquake with SSI effect

Fig. 10 shows the response of the two adjacent building under Northridge earthquake excitation. Fig. 10(a) represent a comparisons between the different cases of connecting with 1, 2, 4, 6, and 12 dampers with fixed base case (f), it is clear the reduction in the displacement of the two building using 1 and 2 dampers by nearly 1.7 times than no use case increasing the number of connecting dampers the reduction of displacement increase slightly for building A. Shear force using one or two (1 or 2) dampers reduced by nearly 1.7 times less than no case, but use 12 groups dampers shear force increase by more than 1.3 times than no case especially for columns in the floor connected with dampers. Fig. 9(b) shows displacement in different levels of building A on different kinds of soil connected with 1, 2, 4, 6, and 12 groups dampers, and (No) case. From figure the top displacement of building A constructed on stiff soil decreased by nearly 1.6 when use 2 groups dampers than (No) case and when use 12 groups dampers top displacement decreased by 1.3 than No case. In medium soil top displacement decreased by 1.32 and 1.18 times than No case using 1 and 12 groups connected dampers, and in soft soil top displacement decreased by 1.4 times than no case using 1 and increased by 1.1 times using 12 groups' dampers. Fig. 10(c) represents shear force in different levels using 1 to 12 group's dampers and no case. In stiff soil shear force decreased by 1.77 times than no use case with using 1 or 2 dampers, whatever, shear force increase in columns at connected levels by nearly 1.3 times than no use case, case of 12 groups dampers increase shear force of connected floor's columns by nearly 1.65 times bigger than no case. In medium soil shear force decreased by 1.05 times than no case use 1 damper, but shear increased by 2 times than no case in the connected floor's column when use 12 connected groups' dampers. In soft soil shear force equal to no case using 1 and 2 dampers but using 12 groups dampers increase base shear by 2.25 times than no case.

Fig. 11 represents the response of building B under Northridge exaction. Fig. 11(a) illustrates shear force in columns and floor displacements in different case of connected dampers with fixed base, shear force decreased by 2 times than no case when use 1, 2, 4 dampers and top displacement decreased by 2 times than no case. Generally connecting dampers in building (B) shows more uniformity in shear behavior of the building. Fig. 11(b) shows displacements and shear force in different building's levels in different kinds of soil founded. In stiff soil, top displacement decreased by 2.33 times using 1 an 2 dampers groups than no use case, but using 12 dampers groups decreased displacement by 1.4 times than no case. Shear force decrease by 1.9 times using 1 and 2 dampers groups than no case, but using 12 dampers groups decreased shear force by 1.3

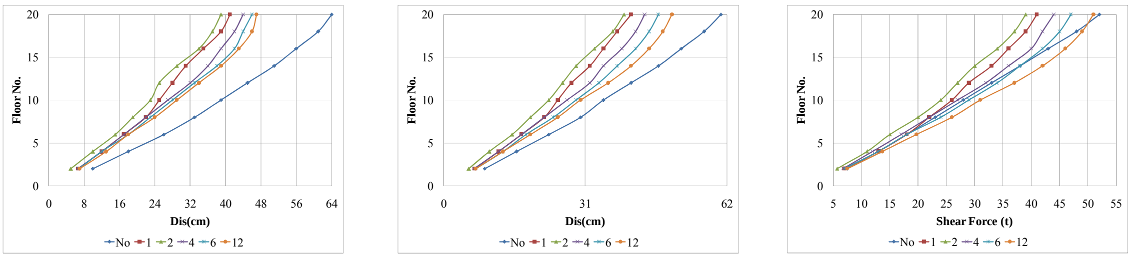
times than no case. In medium soil displacement decreased using 1 damper by 1.7 times than no case, soft soil shear force decreased by 1.9 times than no case when using 2 dampers groups.

Fig. 12 shows top floor acceleration ratios of buildings A and B under Northridge earthquake excitation. Fig. 12(i) shows top floor acceleration of building A with different kind of underneath soil and fixed base cases, for building A Top floor acceleration using two groups' dampers equal to no case, but top floor acceleration decrease using 4, 6 and 12 groups dampers than no case. Fig. 12(ii) shows top floor acceleration of building B with different kind of soils underneath foundation system of the building and fixed bas cases, for building B Top floor acceleration decreased when using 1and 2dampers linked to building B by nearly 1.12 times than no case.



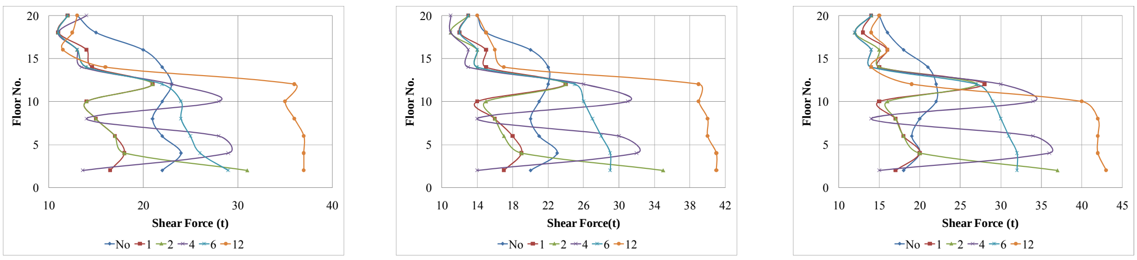
(1) Displacement (2) Shear force

(a) Response of buildings (A) connected with different numbers of link dampers groups with fixed base



(i) Stiff Soil (ii) Medium Soil (iii) Soft Soil

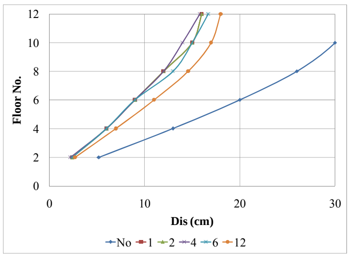
(b) Displacement of Building (A) (20 storey) with link dampers groups and different kinds soil

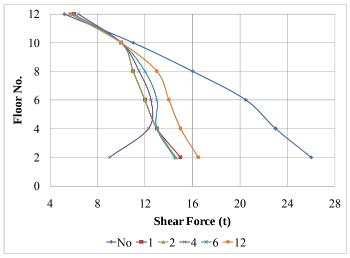


(i) Stiff Soil (ii) Medium Soil (iii) Soft Soil

(c) Shear Force of Building (A) (20 storey) with linked dampers groups and different kinds soil

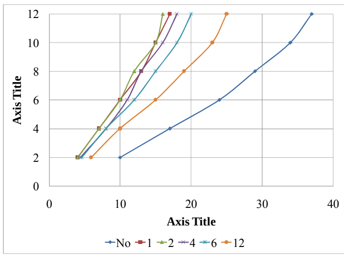
Fig. 10 Northridge Earthquake response of buildings (A)

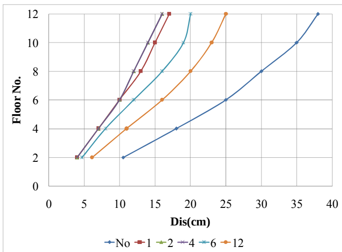


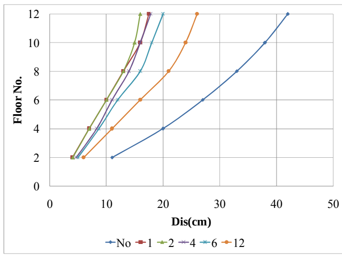


(1) Displacement (2) Shear force

(a) Response of buildings (B) connected with different numbers of link dampers groups with fixed base

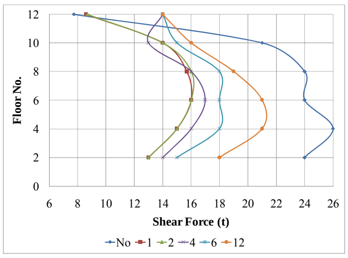


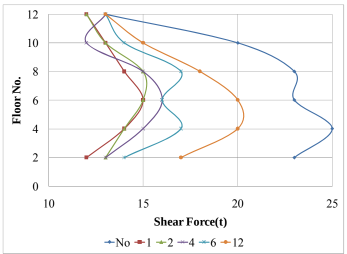


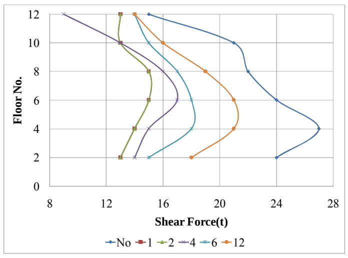


(i) Stiff Soil (ii) Medium Soil (iii) Soft Soil

(b) Displacement of Building (B) (12) storey) with link dampers groups and different kinds soil.





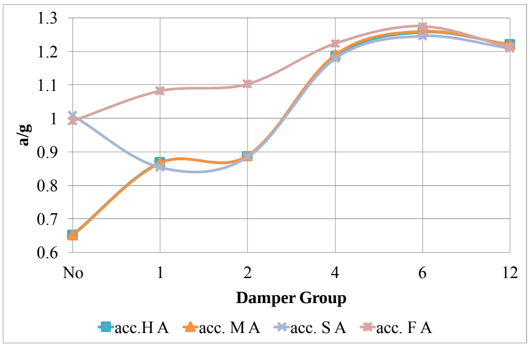


(i) Stiff Soil (ii) Medium Soil (iii) Soft Soil

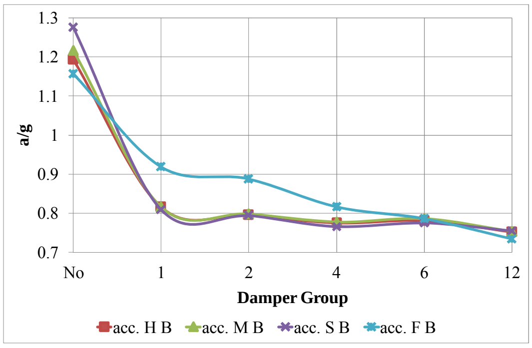
(c) Shear Force of Building (B) (12 storey) with link dampers groups and different kinds soil

Fig. 11 Northridge Earthquake response of buildings (B).

It can be observed that the responses of both buildings are reduced up to a certain value of number of damper's groups, after which they are again increased. Therefore, it is clear from the figures that the optimum damper numbers exists to yield the lowest responses of both the buildings. The optimum damper numbers give the lowest sum of the responses of the two buildings. In arriving at the optimum numbers, the emphasis is given on the displacements, and shear force of the two buildings and at the same time care is taken those accelerations of the buildings, as far as possible, are not increased.



(i) Top Floor acceleration of building A



(ii) Top floor acceleration of building B

Fig. 12 Top floor acceleration of building A and B under Northridge earthquake with SSI effect

7. Conclusions

3D real two adjacent buildings subjected to two earthquakes connected in special arrangement in plan and elevation connected with viscous dampers groups were investigated. The soil structure interaction represented by 3D Winkler model to give a real effect of three types of soil which the two buildings were founded on raft foundation system subjected to earthquake. Two fixed base adjacent buildings connected with viscous damper groups were taken as control case to the other cases. From the above results the following conclusion can be drawn:

- The viscous damper group is quite effective in response control of the connected structures and higher reductions in response can be achieved if the frequencies of the connected structures are well separated (different height of each connected buildings).
- Displacements of tall building increase by nearly 1.2, 1.33 and 1.4 times when founded on stiff, medium and soft soil respectively with respect to fixed base case, and shear force increased by 1.2, 1.4 and 1.6 times when founded on stiff, medium and soft soil respectively with respect to fixed base case.
- Using two dampers groups (at top and first floor of the short building) decreased top displacement of tall and short connected buildings in noticeable values (nearly by 1.5 times).
- Connected points with dampers groups increased shear force in columns by 1.25 times than not connected, so using two dampers groups decreased shear force in columns and also base shear.
- Buildings founded on stiff soil showed a similar response with fixed base especially in shear force.
- Efficiency of connected buildings founded on soft soil decreased by nearly 25% than those founded on stiff soil, although the buildings which connected with two dampers groups (top and the first floor) decreased its response by nearly 1.4 times than unconnected buildings.
- As increasing numbers of connecting dampers groups, there is no significant decrease of response beyond certain number, so it is not necessary to connect the two adjacent buildings by dampers at all floors but lesser dampers groups at appropriate locations can significantly reduce the earthquake response of the combined system. The responses of both buildings are reduced up to a certain value of the damping, after which they are again increased. Thus, the optimal numbers of dampers reduce the cost of dampers groups well as the displacements.

- Top floor acceleration generally, decreased with using dampers especially 2 dampers groups.

As a future work this system must be tested with different kinds of dampers to clarify the previous results and confirm the system.

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