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ORIGINAL CONTRIBUTION

Vibration Control of Dynamically Similar Buildings Optimally Connected by Viscoelastic Dampers

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Abstract Recently, the construction of similar high-rise buildings has increased due to the increasing population. Moreover, due to space constraints, these structures are being built next to each other. When such tall buildings are located in high seismic zones, earthquake protection becomes essential. There have been many studies on vibration control by connecting dampers to adjacent dissimilar buildings. However, reviews with specific recommendations on damper connections to adjacent similar buildings are found to be scarce. This study aims to control the building vibration that is dynamically similar and adjacent to each other through damper connections. In this study, two adjacent ten-storied, dynamically similar RC buildings are considered. The buildings are modeled with shear frame and lumped mass for efficient yet straightforward analysis. The idealized shear buildings were connected with viscoelastic dampers using different damper configurations and then subjected to seven seismic ground motions. A numerical integration technique is used to obtain the seismic response, and a single objective particle swarm optimization technique is employed to optimize the position of dampers. The viscoelastic dampers provided at their optimal locations improved the seismic performance of coupled buildings in an economical way.

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Keywords Similar adjacent buildings · Viscoelastic damper · Coupled control · Optimal damper configuration · Particle swarm optimization

Introduction

It is difficult to predict the exact location and timing of earthquakes. Earthquakes cause significant damages to many buildings, except for a few. The reason for the survival of these few buildings is their design and construction. Hence, it is essential to enable the buildings to resist an earthquake with an appropriate method to mitigate the damage and reduce seismic vulnerability. The seismic performance of buildings against earthquakes should be well studied to adapt a suitable technique to minimize damage. The buildings adjacent and close to each other can undergo damage due to the pounding effect. The pounding behavior of adjacent inelastic multistory structures was carried out [1]. Two plan asymmetric adjacent dissimilar structures were tested for the torsional ponding effect [2]. The pounding effect increases the response of stiff buildings while reducing the response of flexible buildings. The pounding force of a heavy and rigid structure is inadvertently complex to the mass ratio of adjacent structures [3]. The soil–structure interaction with the pounding of adjacent structures is addressed [4]. The pounding behavior between a base-isolated building and an adjacent retaining wall along with soil–structure interaction is studied under near field earthquakes [5]. Many techniques are proposed to mitigate the damage on adjacent buildings due to ponding effect.

One of the popular approaches to reducing the ponding and seismic response of adjacent buildings is the damper-connected control technique. The history of the connected control technique started in the early 1970s with bracings as link element between the high-rise buildings to reduce their wind response. Twenty years later, this technique was further used to prevent pounding effect between the adjacent buildings using dampers as link elements. A lot of research has been done on the coupled technique for adjacent asymmetrical plan buildings. Connected control methods are classified based on the following factors: degrees of freedom, type of connecting devise, damper configuration and number of structures coupled, etc. These damper connections are advantageous for close dissimilar buildings whose floor heights are at the same level. The connected control technique of such buildings with fluid dampers has been studied [6]. The maximum response reduction in base shear and floor displacement is reported with the installation of fluid dampers between the buildings. Shake-table experiments for scaled structural models of two adjacent dissimilar structures are carried out [7]. Structures connected to the second-floor level by means of elastic–plastic damper connections showed a significant seismic response reduction. Two buildings dissimilar to each other are connected with viscoelastic dampers, and their seismic behavior is also studied [8]. Two cases: (1) both the buildings were base-isolated, and (2) single building was base-isolated, are considered. The damper connection between base-isolated and fixed buildings showed substantial improvement in seismic performance than damper connection between both base-isolated buildings. The use of magnetorheological damper devise to reduce the seismic effect on dissimilar buildings [9], and three-dimensional adjacent buildings on pile foundations [10] are studied. Hybrid control of two adjacent buildings with seismic excitation has been proposed to bring about the effective and economical utilization of passive and active dampers [11]. From the above literature, it is observed that the connected control technique is very effective for adjacent dissimilar buildings.

In the present scenario, residential buildings, educational buildings, institutional buildings, etc., are a group of buildings next to each other with the same utility. More often than not, these adjacent buildings are designed with the same structural property for an economy in design, construction, and maintenance costs. The same architectural and structural design will make these buildings dynamically similar, having the same natural frequency and other dynamic properties. From the past earthquake case studies [12], it is evident that the dynamically similar buildings can also undergo damage during an earthquake and need proper seismic design. Even though buildings appeared to be identical, the degree of damage varied significantly [13]. The possibility of different behavior could be the quality of material, quality of construction, etc. It is essential to study the seismic response reduction of dynamically similar buildings and to provide an innovative control technique. When buildings are adjacent to each other, it is not economical to provide earthquake protection to these buildings individually. Instead, adopting a combined vibration control technique to minimize the dynamic response of both buildings can be cost-effective. However, the main challenge in connected damper technique for dynamically similar buildings is that a simple straight connection between the same floor levels is inadequate to improve the seismic performance. A very few studies appear in the literature trying to adapt this damper integration technique with some modifications for similar buildings. An optimal design strategy for an integrated control method is proposed for two structures that are dynamically similar using cantilever connection [14]. The behavior of two dynamic similar adjacent buildings connected with the cross and diagonal passive dampers subject to different seismic excitations has been studied, and the response reduction was observed in various cases [15]. The optimized value of the damping coefficient for viscous dampers is obtained through trial and error processes. Much of the literature has not explored the effective use of the technique connected with different configurations of dampers for dynamically similar buildings. Choosing the right damper for connected control technology is also very important from both efficiency and economic perspective.

In the present study, one of the passive control dampers known as viscoelastic (VE) device is used, which is simple yet effective. These dampers consist of sandwiched viscoelastic material between epoxy coated metal sheets. Past research [16, 17] has given attention to the properties of VE material by conducting a series of experiments under harmonic loads with varying frequencies, temperatures, and displacements. VE material as a damper has been used for vibration control over the last two decades. VE dampers are effective in reducing the seismic vibration in buildings due to earthquake excitation. The advantage of viscoelastic dampers is their added elasticity over fluid dampers. This elasticity contributes toward stiffness and helps the structure to remain elastic even under earthquake forces. VE dampers are used to address the pounding effect between adjacent buildings taking into account floor–structure interaction [18]. This study comments that the higher-mode effect on VE dampers should not be neglected for long-period buildings under seismic excitation. Viscoelastic dampers added to the buildings, and fatigue analysis was carried out to successfully reduce the dynamic response [19, 20]. The coupled technique is used for adjacent dissimilar reinforced concrete buildings with different heights by connecting with optimal viscoelastic dampers, and their properties are obtained by trial and error [21]. Recently, natural rubber-based VE dampers have been used for similar RC buildings to reduce the seismic response, and its performance is compared with different VE damper materials [22].

An economical and effective way to control the dynamic response also depends on the number of dampers and their location. Besides, appropriate damper properties are also required to adopt the coupling method economically. The particle swarm optimization was used to obtain the optimal actuator positions for a combined RC structure with a shear wall [23]. Suitable damper-connected control technique for similar buildings with different viscous damper configurations and optimal locations with a limited number of dampers are proposed [24]. It was observed that the adjacent similar building connected with optimal damper configuration is efficient and economical.

As observed from existing literature, a limited study has been done on the seismic control of dynamically similar buildings using a connected control technique. In some of the studies, dynamically similar buildings are differentiated by base isolation or bracing. None of the studies in the current literature have investigated the suitable viscoelastic damper configuration for effective seismic control of dynamically similar buildings. Hence, the present study focuses on optimal damper configuration for seismic control of dynamically similar buildings using viscoelastic dampers.

Methodology

Two ten-story RC buildings (Fig. 1), which are dynamically similar in nature, are considered for the present study. Each building plan dimension is 10 m × 10 m, and each story height is 3 m, column size is 400 mm × 400 mm, beam size is 400 mm × 300 mm rectangular sections, and reinforced concrete slab thickness is 125 mm. Young's modulus of concrete is taken as 24.9 GPa, and the moment of inertia is calculated based on section of beams and columns. Total mass at each floor, including slab and column and beam, is calculated to be 64,719.4 kg, and stiffness has been calculated $12EI/L^3$ for 16 columns stiffness leading to each story stiffness of 3.7774×10^5 kN/m at each story has been considered. The earthquake ground motion has been applied along the lateral direction. An assumption has been made that the two buildings have sufficient space for installing dampers. Around 5% of the damping ratio has been considered. The striking effect of these similar buildings was ignored due to similar mode shapes, and the Newark-beta method [25] is used in the study to solve the dynamic equations of motion for building with dampers subject to ground motions.

The entire simulation and optimization have been carried out using MATLAB R2015a. The particle swarm optimization (PSO) algorithm is used to find out the best suitable position of the limited number of dampers while minimizing the seismic response of both buildings simultaneously. PSO is a modern heuristic computational method based on flocking of birds that optimizes solutions to the problem by repeatedly trying to improve the candidate solution with respect to given measurement quality. Also, the optimal damper parameters have been obtained through PSO for the given location of the dampers. Initially, a parametric study is carried out to find the suitable damping coefficient and stiffness coefficient of dampers by considering all possible damper configurations. Then, the optimal positions of the limited viscoelastic dampers are identified so that the reduction in seismic response of buildings is closer to that of dampers provided on all floors. The optimal locations of dampers have been obtained through the optimization technique.

Matrix Formulation

The matrices required for the equation of motion are formed based on the number of floors in each building, indicating the "n" degrees of freedom (DOF), as shown in Fig. 2. There is a change in displacement response in both buildings when dampers are installed randomly. Therefore, the horizontal displacement on the top story of both buildings is considered for minimization. The sum of "$2n$" degrees of freedom is considered for dynamically similar coupled buildings. The building floors are considered to be rigid, and therefore, the beams along with the mass of the slab are lumped, allowing to model as shear building. The mass matrix of an individual building becomes the diagonal matrix with the mass of each story as given below.

Mass matrix is

$$[m] = \begin{bmatrix} m_1 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & m_n \end{bmatrix} \quad (1)$$

Similarly, the stiffness matrix of an individual building with each story stiffness is represented as given below.

Stiffness matrix is

$$[k] = \begin{bmatrix} k_1 + k_2 & -k_2 & 0 & 0 \\ -k_2 & k_2 + k_3 & -k_3 & 0 \\ 0 & -k_3 & \ddots & -k_n \\ 0 & 0 & -k_n & k_n \end{bmatrix} \quad (2)$$

Here, m_1, m_2 …, m_n are the mass of each story and k_1, k_2 …, k_n are the stiffness of each floor. After calculating the mass matrix and stiffness matrix, the natural frequency and

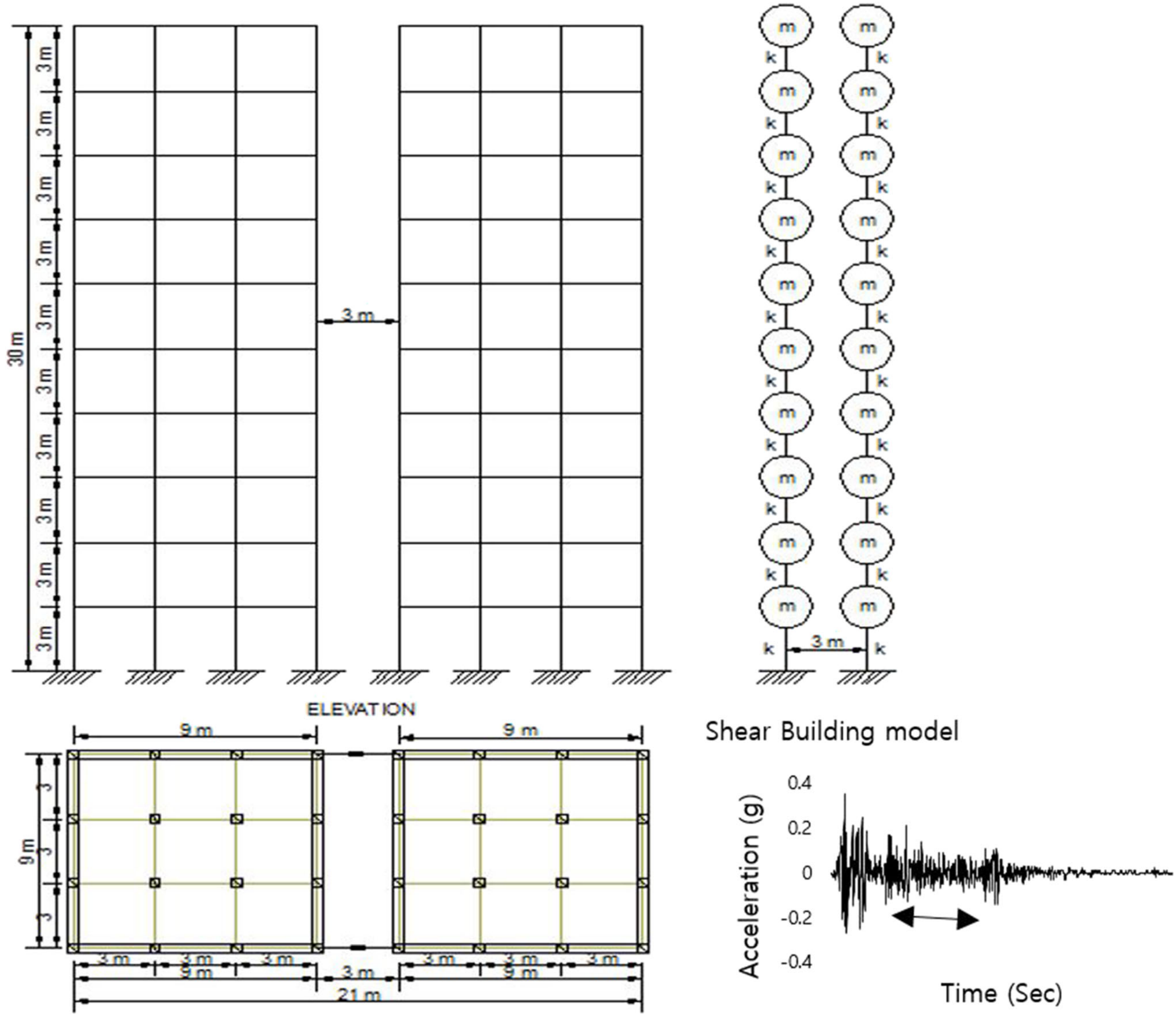


Fig. 1 Two adjacent RC dynamical buildings with shear building models and El-Centro ground acceleration

mode shapes were obtained by solving the characteristic equation of free motion. The internal damping matrix, which represents the building's equivalent viscous damping, is calculated by considering mass and stiffness proportional damping. For this purpose, the Rayleigh damping constants are obtained by taking a damping ratio of 5%. Rayleigh damping matrix of a single building is given by:

$$[c] = \alpha[m] + \beta[k] \tag{3}$$

where α and β be the mass and stiffness proportional Rayleigh coefficients. Additional damping and stiffness matrix for viscoelastic damper-connected buildings are obtained based on a non-classical approach.

Dynamic Equation of Motion for a Coupled System

The dynamic equation of motion for a viscoelastic damper coupled similar buildings is given by

$$M\ddot{X} + (C + C_D)\dot{X} + (K + K_D)X = -MI\ddot{x}_g \tag{4}$$

where mass matrix $[M] = \begin{bmatrix} [m] & [0] \\ [0] & [m] \end{bmatrix}$, stiffness matrix $[K] = \begin{bmatrix} [k] & [0] \\ [0] & [k] \end{bmatrix}$ and damping matrix $[C] = \begin{bmatrix} [c] & [0] \\ [0] & [c] \end{bmatrix}$ of the connected buildings. Here, C_D and K_D are the damping matrix and stiffness matrices for the coupled buildings. The C_D and K_D matrix formulation is based entirely on the configuration of the damper of the adjacent buildings. Depending on the connected ends of the dampers, the external damping and stiffness matrices are formulated.

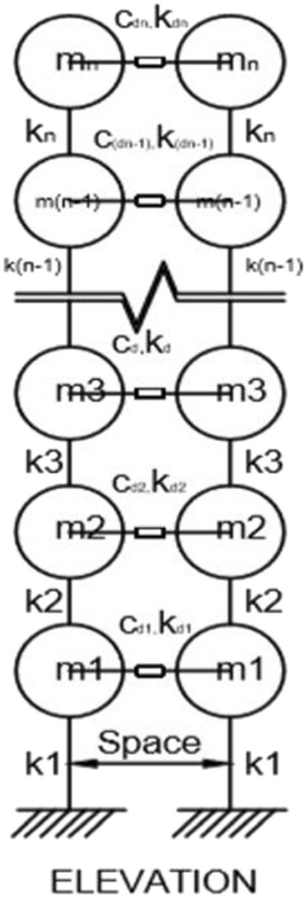


Fig. 2 Mathematical model of dynamically similar adjacent buildings

Furthermore, I = vector matrix, $\ddot{x}_g$ = seismic earth acceleration.

Parametric Study for Optimal Range of Viscoelastic Damper Coefficients

To study the effect of variation in damper coefficients for minimizing the seismic response of a building, various configurations of viscoelastic dampers are connected to the adjacent buildings, as shown in Fig. 3. The roof displacement is calculated by changing the value of the damping coefficient from 0 to 1×10^{10} N s/m and stiffness coefficient value from 0 to 1×10^{10} N/m. The coupled building is subject to El-Centro ground motion, and the correct damper parameters are obtained by PSO. The damper configurations, case 2, case 3 and case 4, have been considered, as shown in Fig. 3. It has been observed that connecting the dampers straight between the same floor levels of adjacent similar buildings has no effect in reducing the response. Therefore, the straight damper configuration at all the floor levels has been ignored. For each case, sensitivity analysis is carried out using trial and error method to obtain an optimal range of damping coefficient and stiffness. The optimal damping coefficient and stiffness values obtained have shown the minimum response. Further increase in damping coefficient and stiffness beyond these optimal values has not yielded significant reduction in the seismic response.

Determination of the Optimal Stiffness Coefficient (k_d) for the Viscoelastic Damper

The stiffness coefficient of the damper has an influence on natural frequency and displacement response of the structure within a certain range. This optimal range for damper stiffness coefficient has to be examined for selecting a suitable viscoelastic damper for particular buildings. Hence, the following two individual parametric studies have been conducted considering the natural frequency and seismic response of the building.

Optimal Stiffness Range for Damper Based on the Natural Frequency of Building

To determine the suitable stiffness coefficient for the external viscoelastic damper, it is expected that after the installation of dampers, the natural frequencies of the two individual buildings must not change even though the displacements have been reduced. A number of trial and error iterations were performed for the damper stiffness values from 1000 to 1.0×10^{12} N/m, while keeping the damping coefficient to zero. Figure 4 shows the variation of natural frequencies of both buildings against the damper stiffness. It can be observed that the modal frequencies of both the buildings are not much altered, when the damper stiffness is between 1×10^4 and 1×10^9 N/m. Beyond this range of stiffness, the modal frequencies of the building change significantly. However, a comparison of these values with the corresponding values without dampers (unconnected buildings) shows that the frequencies are almost similar when the damper stiffness is up to 1×10^9 N/m.

Optimal Stiffness Range for Damper Based on Seismic Response of Building

Seismic analysis is performed by varying the stiffness coefficient of dampers, and the variation in the top story displacements of adjacent buildings is observed. This study has been performed to verify the optimal range of damper parameters identified from the seismic analysis under given El-Centro earthquake excitation compared to the natural frequency variation. The variations of the top floor displacement response of left-side and right-side buildings, respectively, with varied damper stiffness, are shown in Fig. 5. By observing the graphs, it can be concluded that the displacements of both the buildings are influenced by damper stiffness when it ranges between 1×10^{6} and 1×10^{10} N/m. The fact that response reduction is not sensitive to reducing stiffness within a certain range is very useful for practical applications of connecting dampers.

Fig. 4 Damper stiffness versus modal frequency for different damper configuration cases for both the buildings ▶

Thus, after a certain limit, the effectiveness of dampers reduces quickly. This is due to decreases in the relative displacement as the stiffness of the damper increases, which, in turn, decreases the energy absorbing capacity

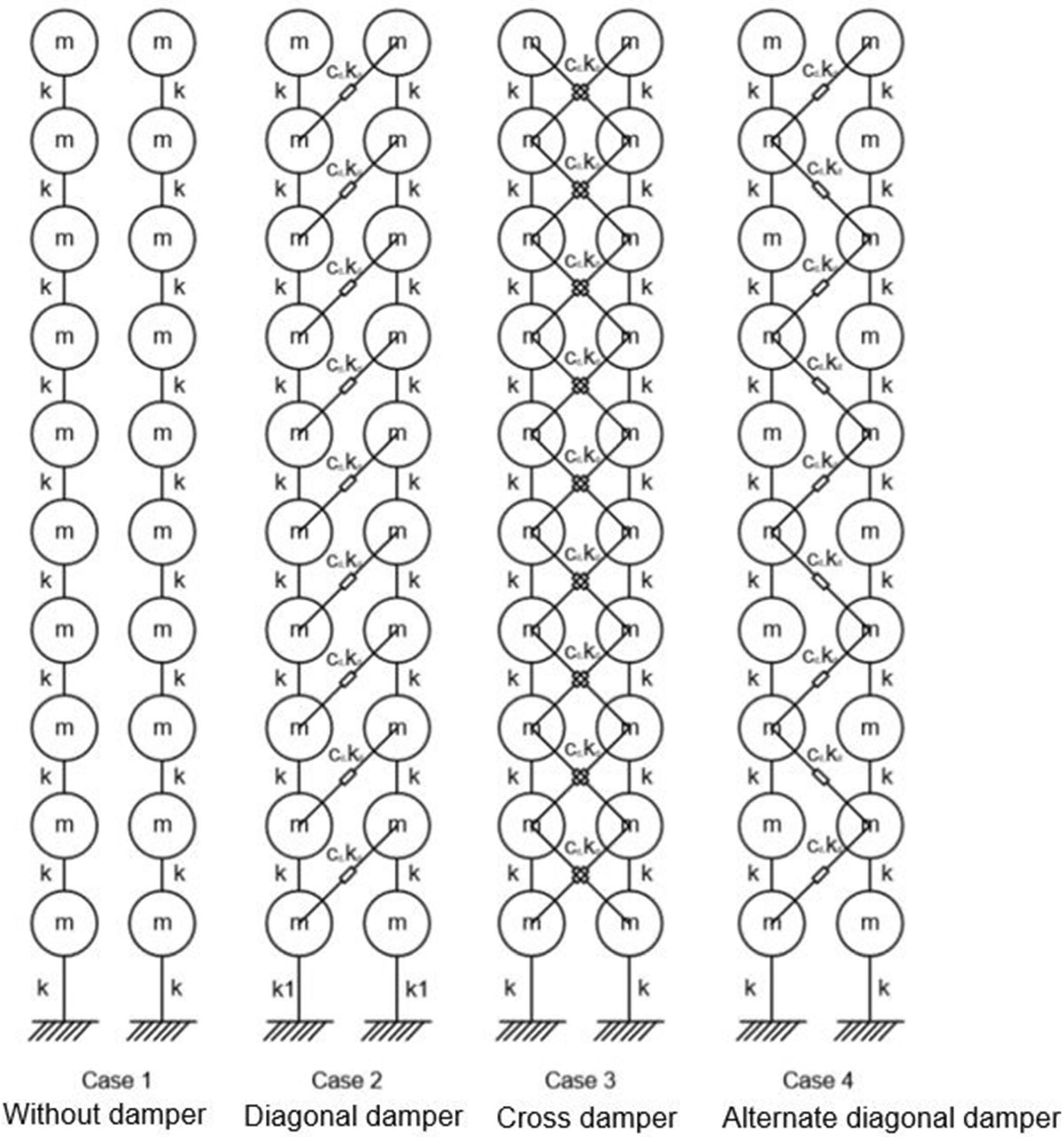
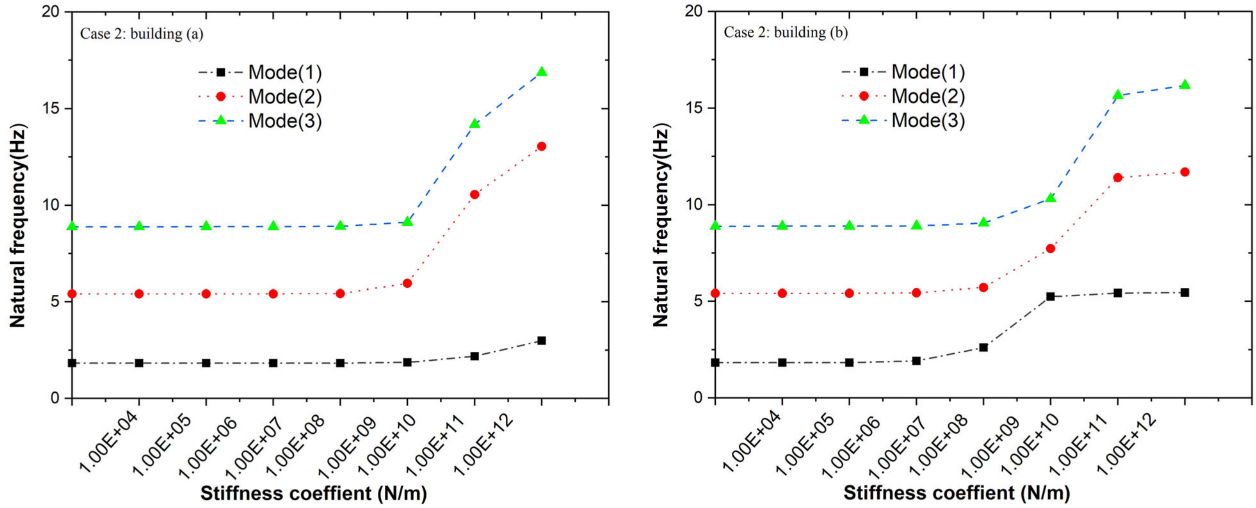
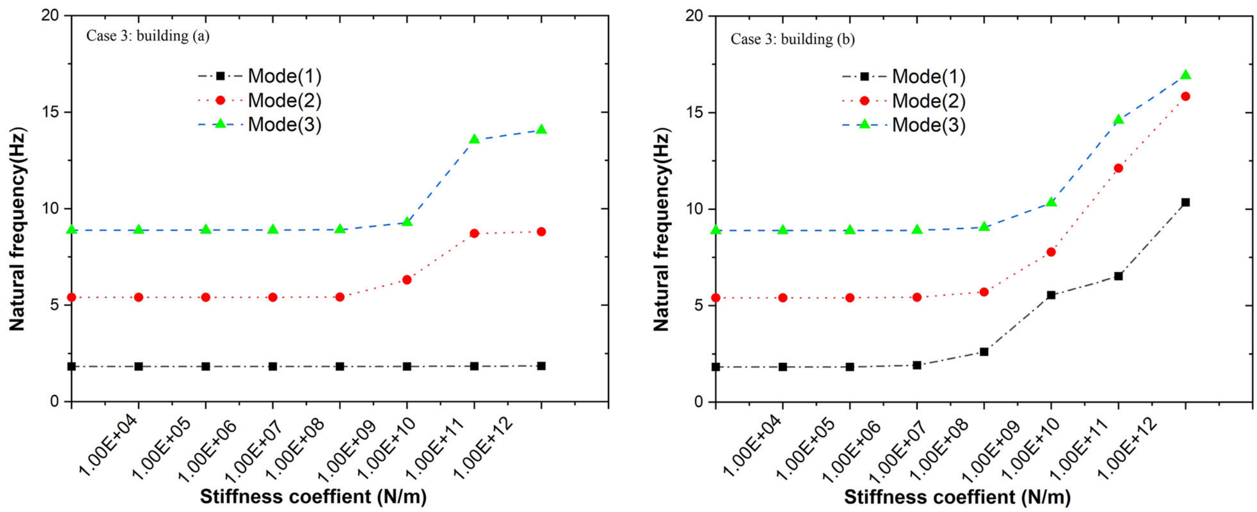


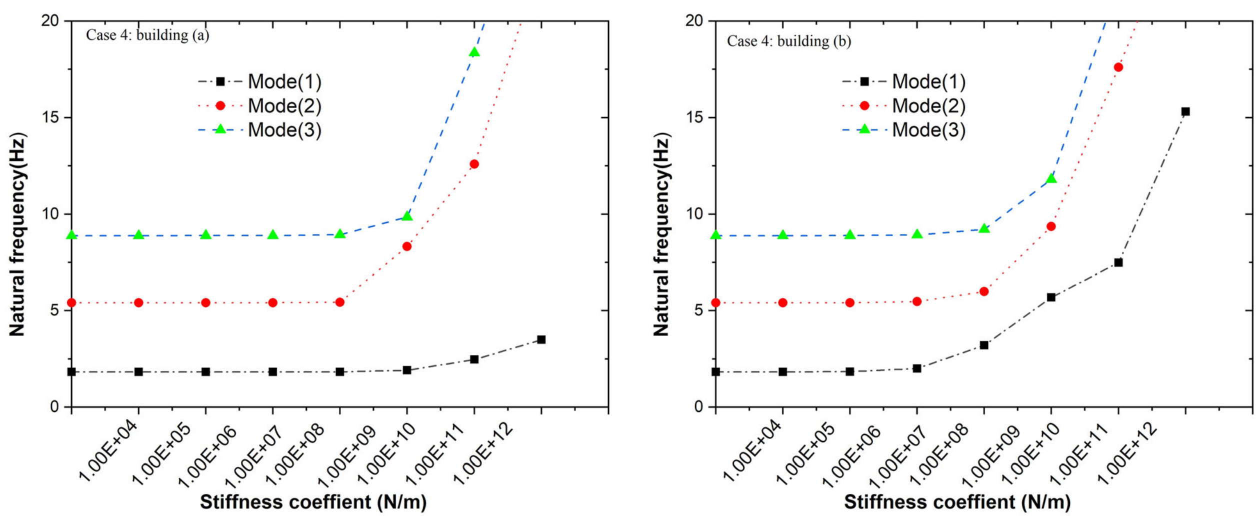
Fig. 3 Various possible configurations of viscoelastic dampers connected to adjacent buildings


Case 2: building (a)
Case 2: building (b)
Mode(1)
Mode(2)
Mode(3)
Natural frequency(Hz)
1.00E+04
1.00E+05
1.00E+06
1.00E+07
1.00E+08
1.00E+09
1.00E+10
1.00E+11
1.00E+12
Stiffness coeffient (N/m)

(a) (b)


Case 3: building (a)
Case 3: building (b)
Mode(1)
Mode(2)
Mode(3)
Natural frequency(Hz)
1.00E+04
1.00E+05
1.00E+06
1.00E+07
1.00E+08
1.00E+09
1.00E+10
1.00E+11
1.00E+12
Stiffness coeffient (N/m)

(a) (b)


Case 4: building (a)
Case 4: building (b)
Mode(1)
Mode(2)
Mode(3)
Natural frequency(Hz)
1.00E+04
1.00E+05
1.00E+06
1.00E+07
1.00E+08
1.00E+09
1.00E+10
1.00E+11
1.00E+12
Stiffness coeffient (N/m)

(a) (b)

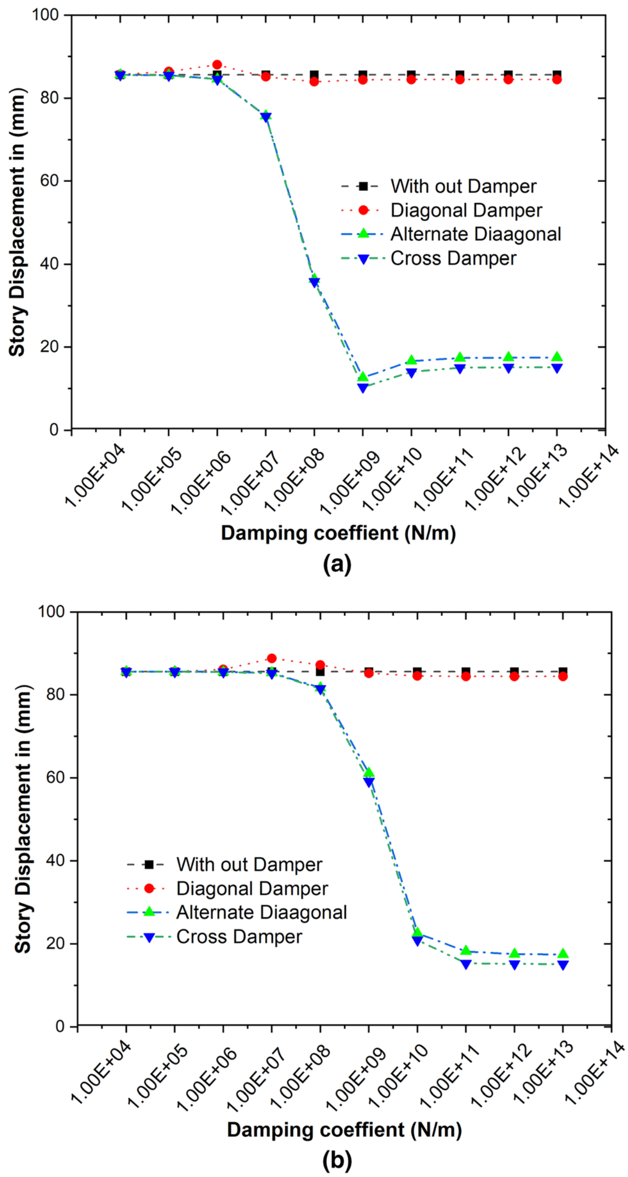


Fig. 5 Maximum top floor displacement versus damper stiffness for left building for both the buildings

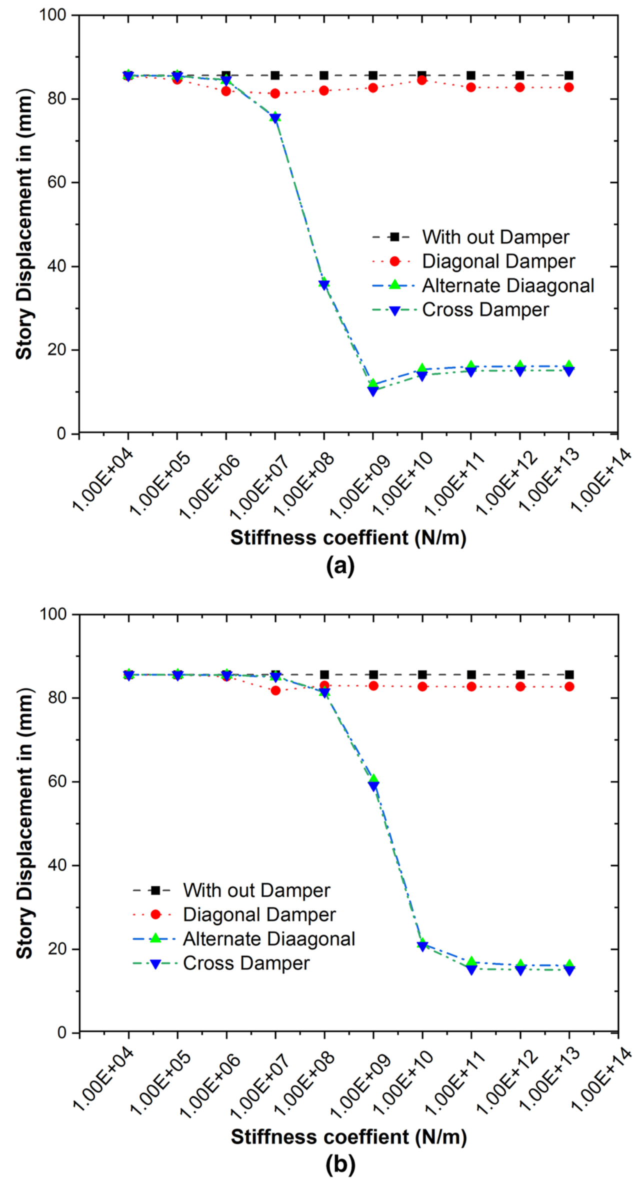


Fig. 6 Damping coefficient versus maximum floor displacement for different damper configuration cases for both the buildings

from the dampers. The above two parametric studies provide the criteria to choose an optimal range of damper stiffness for adjacent similar buildings. Hence, the optimal damper stiffness values are conservatively chosen between 1×10^6 and 1×10^9 N/m. Within this range, the viscoelastic damper will not considerably change the natural frequencies of the buildings.

Optimal Range of Damping Coefficient (c_d) of Damper Based on Seismic Response of Building

As the stiffness of the interconnecting viscoelastic dampers cannot be increased beyond a certain limit, the damping coefficient of damper should be in such a way that the displacements of both the buildings should be reduced. The damping coefficient also has a certain range beyond which its effect will become redundant. Hence, for obtaining the optimal range of damping coefficient, a variation of the maximum top floor displacement versus the damping coefficient is plotted subjected to El-Centro earthquake as shown in Fig. 6. A number of trial and error iterations were performed for the damping coefficient values from 1×10^4 to 1×10^{13} N s/m, while keeping the damper stiffness to zero. It has been observed that when the damping coefficient for viscoelastic damper is between 1×10^6 and 1×10^9 N s/m, the top floor displacement is largely influenced. Beyond that, there is no significant reduction in the displacements of both the buildings. This is due to

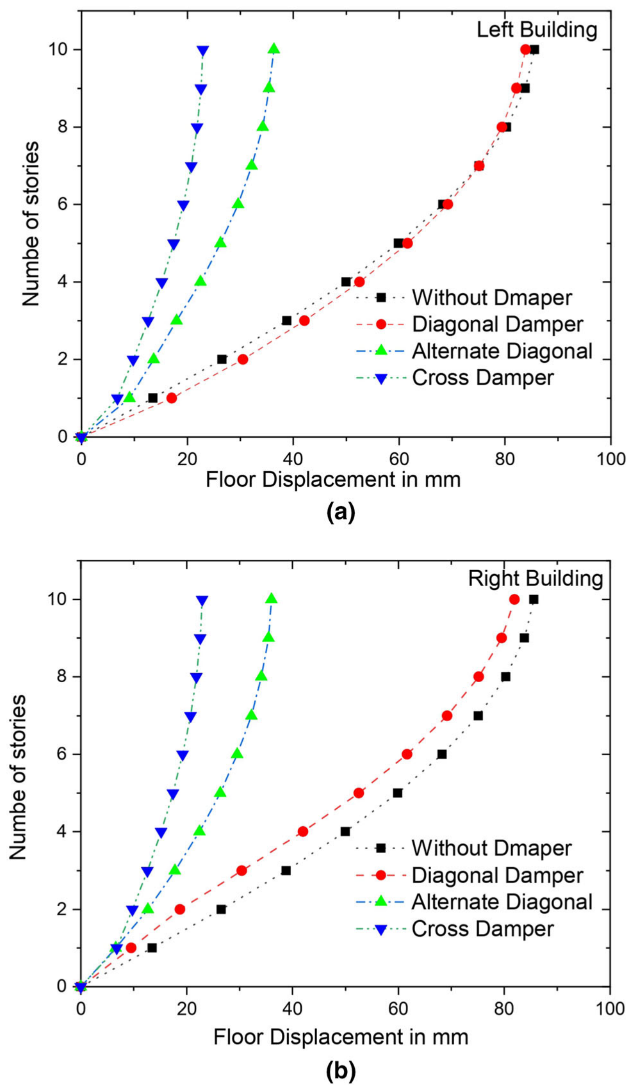
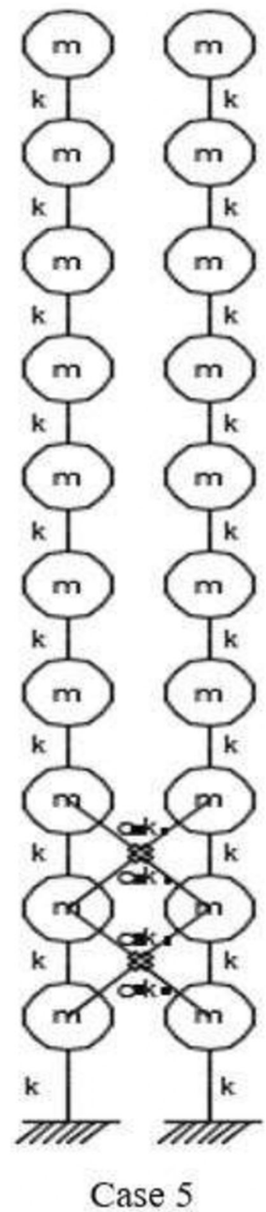


Fig. 7 Comparison between the seismic response of uncoupled building and coupled buildings with various cases for both the buildings

Fig. 8 Optimal locations of the damper in the coupled buildings



decreases in the relative velocity as the damping coefficient increases, which, in turn, decreases the dissipating energy capacity of the dampers.

The parametric study on adjacent similar buildings has been separately performed to choose the optimal range of damper stiffness and damping coefficient for the viscoelastic damper. Hence, in the present study, the optimal damper stiffness range of 1×10^6 to 1×10^9 N/m and the optimal damping coefficient range of 1×10^6 to 1×10^9 N s/m are considered. Within these ranges, the viscoelastic damper is expected to effectively help the similar adjacent buildings to reduce their seismic response (Fig. 7).

Results and Discussion

Comparative Study on Seismic Response of Uncoupled and Coupled Buildings with Different Damper Configurations

Viscoelastic dampers connected to the adjacent similar buildings have to be verified with all story displacement and story drifts for different damper configurations as shown in Fig. 3. Similar buildings with each case have been subjected to El-Centro ground motion, and the seismic response at each story has been obtained using Newark's beta method. It is observed that there is no significant change obtained from the straight damper connection. Initially, the damping coefficients of 1×10^8 N s/m and

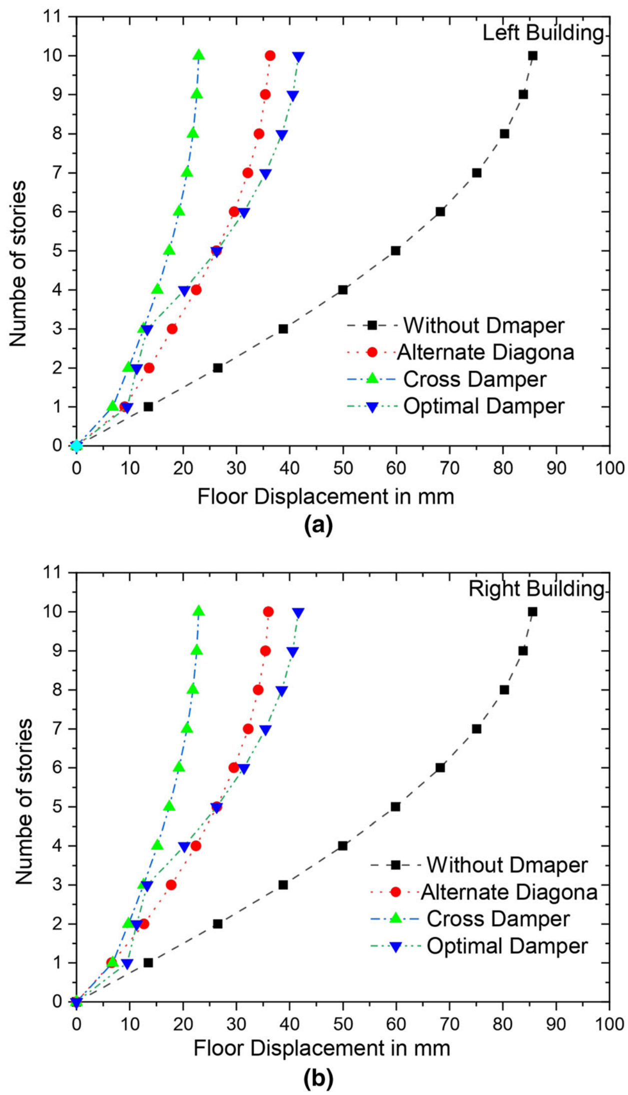


Fig. 9 Seismic response of buildings with optimal dampers and different configurations

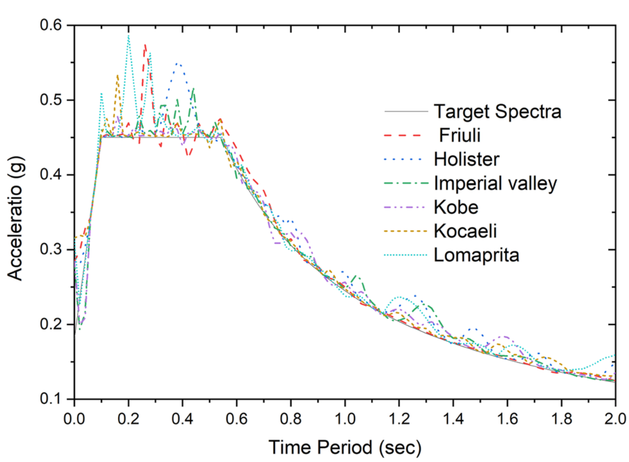


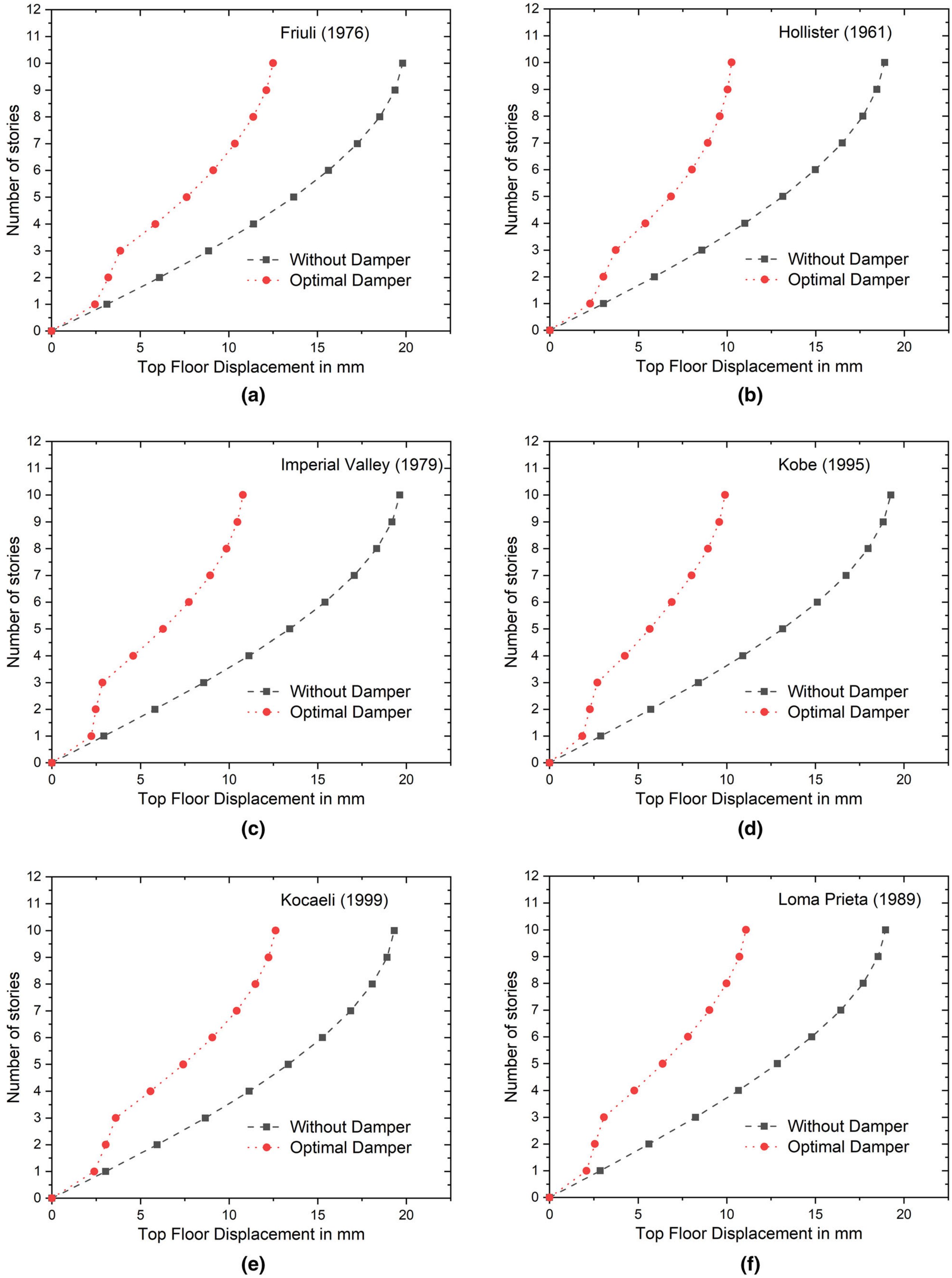
Fig. 10 Spectral matched ground motions

Fig. 11 Seismic response of the top floor displacement of the dynamically similar buildings in different time histories for one building ▶

stiffness coefficient of 1×10^7 N/m was considered for all the cases based on the previous parametric study. A different damper configuration has been analyzed to obtain the roof displacement and story drifts of all the floor levels, and it is represented in Fig. 8. It is observed that the performance of adjacent buildings connected to cross dampers (case 3) and alternative diagonal dampers (case 4) is more efficient in reducing each floor displacement compared to only diagonal damper configuration (case 2). Also, it is observed that the alternate diagonal seems to be more economical compared to cross dampers, as the number of dampers required will be less for same response reduction. Furthermore, to see the maximum possible response reduction in the building, the maximum values of the damping coefficients and the stiffness coefficient within the appropriate range were used, and the time history analysis is performed. When the damper is provided with the stiffness of 1×10^9 N/m and damping coefficient of 1×10^9 N s/m, 80% reduction in roof displacement was observed for case 3 and case 4. It is not necessary to provide dampers on all floor levels of buildings. Placing dampers in strategic locations is expected to effectively reduce the response. If a very high value of the damper damping coefficient and the high value of stiffness is chosen, the structure becomes stiff and overdamped. Hence, an optimization technique has been used to obtain the optimal damper configuration in the following section.

Optimal Damper Configuration Using Particles Swarm Optimization

Particle swarm optimization (PSO) is a simple and efficient algorithm that can be easily implemented [26]. In the current study, the maximum number of the dampers is restricted, and stiffness and damping coefficients are limited within the effective range. The possible solutions include the connection of dampers between the floors of both adjacent similar buildings with all possible orientation. The objective function is the minimization of roof displacement, while the variables are damper stiffness, damping coefficient and all possible damper connections. The constraints are fixed number of dampers and minimum and maximum limits for the damper stiffness and damping coefficient within an effective range. The PSO algorithm coded in MATLAB environment is used for the minimization of the single objective function with nonlinear optimization constraints. Compared to the point search method (taking into account all combinations), PSO is


Friuli (1976)
Hollister (1961)
Imperial Valley (1979)
Kobe (1995)
Kocaeli (1999)
Loma Prieta (1989)
Number of stories
Top Floor Displacement in mm
Without Damper
Optimal Damper
(a)
(b)
(c)
(d)
(e)
(f)

observed to decrease the calculation time required in obtaining the best suitable location of damper along with their optimal damper properties.

The optimal configuration and position of the dampers obtained using the PSO are shown in case 5 in Fig. 8. The comparison between seismic responses of the original uncoupled building with that of building, coupled with four dampers at its optimal location, is shown in Fig. 9. The limits for damping coefficient and stiffness value in the PSO technique have been taken as 1×10^6 N s/m to 1×10^9 N s/m and 1×10^6 N/m to 1×10^9 N/m, respectively. The obtained damper parameters are coefficient of damping, $c_d = 2.05 \times 10^8$ N s/m, and stiffness, $k_d = 9.7 \times 10^7$ N/m, for optimized locations with four dampers as shown in Fig. 8. The optimal damper configuration reduces the dynamic response of buildings considerably in an economical and efficient way compared to fully connected dampers to adjacent buildings.

Verification of the Obtained Optimal Configuration Under an Ensemble of Several Ground Motions

The efficiency of optimal damper configuration obtained under the El-Centro (1940) earthquake is further verified by subjecting to another six earthquakes time histories. Various earthquake records having different ground motion characteristics to El-Centro ground motion were considered and matched with response spectra confirming to Zone-V of IS 1893 (Part-1:2016). For this zone, the max spectral acceleration is 0.36 g, and soil type is medium stiff, the importance category is as per residential buildings. With this as target spectra, another six ground motion records chosen using Seismo-Match-2018 (academic license) software. Accordingly, the matched earthquake ground motions are Friuli (1976), Hollister (1961), Imperial Valley (1979), Kobe (1995), Kocaeli (1999) and Loma Prieta (1989). These ground motions scaled to match the IS response spectra are shown in Fig. 10. Then, the matched response spectra of each earthquake are converted into time history data and given as input force to the adjacent buildings. The maximum displacement at each floor level for buildings without damper and buildings connected with optimal VE dampers is shown in Fig. 11. Since both the buildings are symmetrical even with dampers connection, the displacements of both buildings are identical. From Fig. 11, it is clearly evident that the optimal damper connection is effective in reducing seismic response even under various ground motions. Hence, the proposed technique of optimal VE damper configuration for adjacent similar buildings is efficient as well as economical.

Conclusions

The seismic vibration control of adjacent dynamically similar buildings with various viscoelastic dampers and their optimal configuration is studied to derive the following inferences. The comparative study with various damper configurations has shown that alternative diagonal dampers are more effective and economical in seismic response reduction compared to diagonal and cross damper configurations. It is not necessary to provide dampers at all the floor levels, and there exists an optimal location for the dampers to achieve better performance in an economical way. The optimization study with a limited four number of dampers has been carried out using the PSO technique, and the optimal damper coefficients and optimal damper locations are obtained. By providing only four dampers at optimized locations, the seismic performance of the coupled building has been economically improved compared to alternate diagonal dampers connected on all floors. Finally, the proposed technique of optimal VE damper configuration for adjacent similar buildings proved to be effective, even under various ground motions confirming to a particular zone.

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Compliance with Ethical Standards

Conflict of interest The authors state that they have no conflict of interest.

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