16TH EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING
THESSALONIKI 18 - 21 JUNE 2018

OPTIMAL DAMPER CONNECTED CONTROL TECHNIQUE FOR SIMILAR BUILDINGS SUBJECTED TO EARTHQUAKE

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ABSTRACT

Controlling the seismic response of two adjacent buildings through connected control technique is very efficient when the buildings are having different dynamic properties. If the dynamically similar buildings (having same natural frequency and mode shapes) are connected with straight dampers then this method will become inefficient. So, the configurations other than the straight connection have to be used in case of similar buildings. It is not necessary to provide the damper in all the stories of the building. There is some optimal location where if the dampers are provided the response reduction is almost comparable to the response produced when dampers are provided all over the floor. The effective damper parameter along with optimal location of these dampers between two adjacent dynamically similar buildings has to be obtained. The objective of the study is to provide an economically efficient way of connecting the given number of viscous dampers between dynamically similar adjacent buildings, which can improve the seismic performance of both the buildings simultaneously. Two adjacent dynamically similar 15 storey symmetric buildings are considered in the study. The number of dampers limited to four in this study, from the economy point of view. The dampers will be effective when they are placed between the points with maximum relative velocity. The optimal locations are obtained using Particle Swarm Optimization, considering all the possible locations and damper configurations. The seismic response of the coupled buildings with the optimal damper locations has been reduced considerably compared to that of uncoupled building.

Keywords: Dynamically similar building, Connected Control Technique, Particle Swarm Optimization, Optimal Damper Configuration.

1. INTRODUCTION

No one can predict earthquake which can occur at anywhere and at any time. But not all the buildings are collapsed by the earthquake. Some buildings can survive, while other buildings can fail due to the same earthquake. Hence, all the buildings have to be constructed properly in order to mitigate the damage and catastrophic failure. Therefore, performance of building during earthquake has to be studied well in order to reduce the damage. Seismic performance of the building is defined as the measure of recorded or expected ability of the structure to sustain its due functions (safety and serviceability) during and after earthquake. The level and the consequence of the damage in the building due to the earthquake depend on number of factors. One of the main factors is the response of the building to the ground shaking and other earthquake effects - the deformation, velocity and acceleration demands of structural components of the buildings. The parameters considered for estimating the seismic performance are peak floor acceleration, peak floor velocity, residual story drift ratio, peak story drift ratio at each floor in each direction ((FEMA P-58-1, 2012).
In present scenario, group of buildings which serves the same facility, like educational buildings, institutional buildings, residential buildings, etc. are built adjacent to each other and having same structural frame, which are dynamically similar to each other. If seismic protection is to be provided

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individually in each of the building then it will be a costly issue. Instead, adopting the connected vibration control method that controls the response of both the buildings simultaneously prove to be a cost effective. From the past earthquake case studies, it can be clearly seen that the dynamically similar buildings also undergo damage during earthquake especially when they are inclined to each other. Hence, it is important to study the seismic performance of dynamically similar buildings.

The history of the connected control technique started in early 1970's when the dampers between the buildings were used to reduce the wind response of high rise building. Twenty years later it was further used to prevent pounding effect between the adjacent buildings. Many research works has been carried out under the coupled technique for dissimilar buildings classified based on the factors: Number of degree of freedom, Type of the control technique adopted, Type of the dampers used, Type of excitation, Type of damper configuration, Number of buildings coupled, etc. The connected control technique with the rigid links was used by Passoni et al. (2014) to avoid pounding effect between two dissimilar buildings. Athanassiadou et al., (1994) studied the seismic response of adjacent series of structures with similar and different dynamic characteristics subjected to five different seismic excitations. They concluded that, the effect of pounding from adjacent buildings on the seismic behaviour of a structure is more pronounced for the end structures in a row. Chiara et al., (1997) concluded that when two adjacent buildings are similar, i.e. the mass, stiffness and height ratios tend to unity, the dampers have no effect because the buildings have the same displacements and velocity in the same direction and the damping force becomes zero. Hence, initially it was considered that the coupled control method is not applicable to the dynamically similar buildings. But, currently the research work proves that it can be used for dynamically similar buildings with some modification.

Many researches were also carried out by combining the coupling technique method with other seismic protection techniques like base isolation and bracing techniques. The recent research work carried out in the field of the coupling of building is, combining the concept of coupling with the base isolation technique but all the above research works were done mainly on the dynamically dissimilar buildings. Matsagar et al. (2005) studied the behaviour of the two dissimilar coupled building in which one of the building was base isolated. The seismic performance of the two buildings coupled with viscoelastic damper under three cases (both the buildings were fixed , one fixed and other base isolated, both the buildings were base isolated) are studied and it is concluded that the system will be most effective when one building is base isolated and other is fixed. He concluded that by this hybrid method both the buildings can resist the long duration earthquake as well as near fault earthquake. Kasagi et al. (2016) studied the same hybrid method coupling the base isolated building to a podium structure. Farshid et al. (2016) made a research work by connecting two similar moment resisting frame along with base isolation technique. Kwansoon et al. (2015) studied the performance of two buildings with same dynamic properties but with different heights. In one of the building the active tendons acting as bracings are placed in its optimal position and are coupled with another building through passive dampers.

In order to adopt the coupling technique in an economical way, optimization of the damper properties is necessary. Patel et al. (2011) connected two DOF (Degree of Freedom) structures and made a study to get the optimal stiffness and damping value of the damper. Later Jangid et al. (2013) continued the same study in two MDOF (Multi Degree of Freedom) similar buildings connected with viscoelastic dampers. Makita et al. (2007) did analysis on two MDOF similar structures experimentally which were connected to dampers by means of cantilever structure and arrived at an expression for optimal stiffness value of that cantilever structure. Optimization for the number of dampers has less effect on increasing the seismic performance of the building compared to the location of the dampers.

Some more research were focused on control statergy for the adjacent buildings. Richard et al. (2000) focused on the using 'smart' dampers for controlling the three tall buildings. Bharti et al. (2010) examined the effectiveness of MR damper under passive-off, passive-on and semi-active control strategies for mitigation of the seismic response of adjacent multi-storey buildings Kang et al. (2011) proposed the hybrid control model by combining skyhook model and ground hook model for reducing the seismic response of the adjacent building coupled with Magneto rheological (MR) dampers. For active control strategies of coupled building many studies has been carried out. Both the semi active control and active control provides the same seismic performance to the buildings with different natural frequencies and coupled with the dampers located at the non-dominant node of the vibratory mode.

Few experimental works were also carried out to verify the analytical study on coupled buildings. Christenson et al. (2007) experimentally proved the better seismic performance of actively controlled coupled building over uncoupled and rigidly coupled buildings by considering the two adjacent 2DOF building. Yamazaki et al. (2001) experimentally investigated the relationship of the damper characters with the vibration control for two SDOF (Single DOF) system coupled with steel damper. It is experimentally showed that there is a seismic response reduction of passively controlled coupled building with elastoplastic dampers. Baselli et al.(2014) validated their control algorithm for the Coupled building with MR damper through experimentation. Yang et al. (2003) investigated. The influence of the number, location, linking pattern and the ground motion is studied experimentally by considering 22 different cases using a 3D shake table and torsional response was also investigated.

Jangid et al. (2006) studied about the optimum value of the friction force for the damper connecting the two building and observed that, if the fundamental frequency of building is closer to the main frequency of the excitation then the coupling control is more effective

3. MATHEMATICAL MODEL:

Two dynamically similar 15 storey symmetric steel moment resisting frame is considered in the present study. The earthquake motion is applied along the plane of the two dimensional frame. Both the buildings are assumed to be on the same floor level. The spatial variation of the ground motion is neglected in the study assuming that the buildings are close to each other and at the same time sufficient distance is available between the buildings for the damper installation. The frames are assumed to rest on rigid foundation and hence the soil structure interaction effect is not considered. The building frame is designed as per the strong column weak beam concept. The damping ratio of the building is taken as 2% as per IS 1893: Part I (*cl.7.8.2.1*) .The dead load and live load that contribute to the mass matrix is considered as per the codal provision IS 1893-Part I. As the buildings are dynamically similar the effect of pounding during the earthquake is not considered. The distance between the two buildings is sufficient enough to provide the dampers. The check for serviceability and stability of the frame has been done. Further, the mathematical model for dynamic analysis of the building and coupling has been done as per described in the following subsections.

3.1. Matrix formulation:

The analysis is made considering the lumped mass system. As both the buildings are dynamically same, the number of storey in each building 'n' represents the number of the DOF in the analysis as shown in Figure 1. But the installation of the damper unsymmetrically introduces the changes in the response of both the buildings. Hence, the total DOF is '2n' for the dynamically similar coupled building. The floor of the building is assumed to be rigid and hence the mass of the slab alone is being considered in the shear building concept. The mas of the columns are considered to be negligible compared to floor mass and hence, the mass of columns are neglected. Then, the mass matrix is $[m] = \begin{bmatrix} m_1 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & m_n \end{bmatrix}$ will be diagonal matrix with mass of each floor and the Stiffness matrix is $[k] = \begin{bmatrix} k_1 + k_2 & -k_2 & 0 & 0 \\ -k_2 & k_2 + k_3 & -k_3 & 0 \\ 0 & -k_3 & \ddots & -k_n \\ 0 & 0 & -k_n & k_n \end{bmatrix}$, where, $k_{1,}$ $k_{2...,}$ k_n are stiffness of each floor and $m_{1,}$ $m_{2...,}$ m_n are mass of each floor,

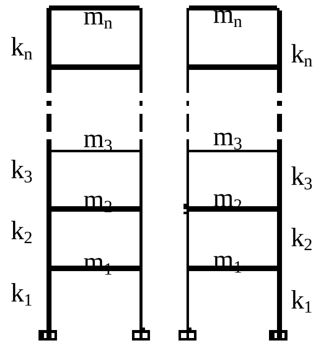


Figure 1. Similar buildings modeled as plane frame with shear building concept

After obtaining the mass and stiffness matrix through the characteristic equation, the natural frequency and mode shapes are obtained. Internal damping matrix which indicates about the equivalent viscous damping of the building is obtained through the Rayleigh damping. As the building considered is symmetric, the internal damping matrix is a proportional damping matrix. The function of the proportional damping is energy dissipation only. Rayleigh damping matrix of the single uncoupled building is $[c] = \alpha\ [m] + \beta\ [k]$ where, α and β are the mass proportional coefficient, stiffness proportional coefficient. External damping matrix for coupled building is formed through the non-classical approach. For non-proportional damping both energy transfer as well as energy dissipation occurs.

3.2. Equation of motion for the coupled system:

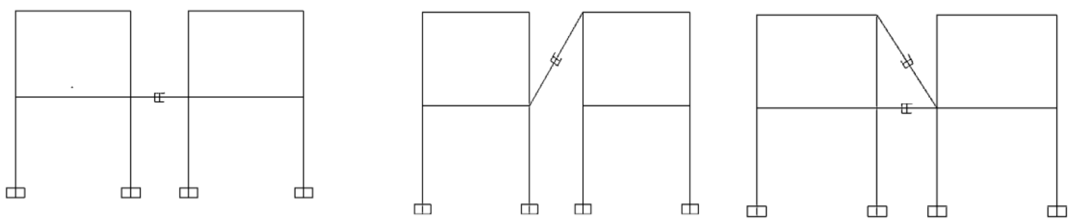
The equation of motion of the coupled system is given by

$$M\ddot{X} + (C + C_D)\dot{X} + KX = -MI\ddot{x_g} \tag{1}$$

where, $[M] = \begin{bmatrix}[m] & [0]\\ 0 & [m]\end{bmatrix}$ is the mass matrix, $[K] = \begin{bmatrix}[m] & [0]\\ [0] & [m]\end{bmatrix}$ is the stiffness matrix, $[C] = \begin{bmatrix}[c] & [0]\\ [0] & [c]\end{bmatrix}$ is the damping matrix of the coupled building. Here, C_D is the damping matrix for the dampers provided between the similar buildings. The C_D matrix formulation depends entirely on the configuration of the dampers which are connected in between the two buildings. Depending on the nodes to which ends of the dampers are connected, the external damping matrix is formulated. Further, I = unit vector, $\ddot{x_g}$= earthquake ground acceleration.

4. METHODOLGY:

To capture important characteristics of damper connected adjacent buildings, the two-dimensional fame systems with shear building concept connected by viscous dampers is considered in the present study. The time history analysis is carried through the numerical method –Newmark's Beta method out for the various configurations. The entire analysis including optimization is done through MATLAB programming. The combinations of the damper configuration shown in the Figure 2 by considering the straight and diagonal dampers are studied.



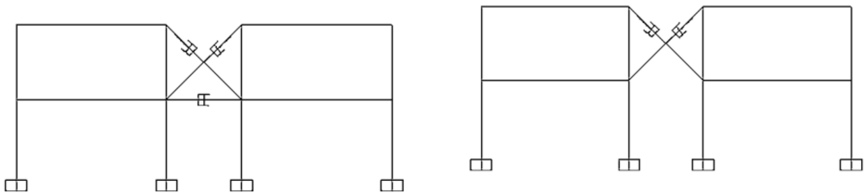


Figure 2. Various configurations possible by combining straight and diagonal connection

Particle Swarm Optimization (PSO) technique is used in the present study to find the optimal damper parameters required to reduce the seismic response. The PSO technique is found to reduce the computational time in finding the optimal parameters of the dampers along with its optimal location compared to point by point search method (by considering all the combinations). Hence, the Particle swarm optimization is employed for obtaining; the optimal location of the damper when the number of dampers to be used for coupling is fixed, the optimal damping coefficient of the each damper for the given location of the damper.

At first, the optimal location for the given number of dampers are obtained by considering all possible damper configurations while keeping the same damping coefficient for all dampers. It is not necessary to provide the damper in all the stories of the building. There is some optimal location where if the dampers are provided the response reduction is almost comparable to the response produced when dampers are provided all over the floor. The damper is fully utilized when it is placed between the points with maximum relative velocity. Instead of carrying out sensitivity based analysis for finding the locations with maximum relative velocity, PSO technique is adopted in which the search space is taken as set of all the possible location of the four dampers by considering all the combinations of the damper configuration. The damping coefficient of the damper is selected through trial and error method based on the fact that seismic response is insensitive to the particular range of damping coefficient.

Then, the optimal damping coefficient value of the dampers at their optimal location is obtained through PSO. The damping coefficient needed for the dampers connecting the lower floors are different from the damping coefficient needed for the dampers connecting the upper floors. Hence providing the dampers with constant damping coefficient is uneconomical.

The roof displacement is taken as the objective function. The minimisation of the objective function is carried out using PSO

5. MODEL VALIDATION:

The lumped mass model of the considered building frame is modeled in SAP2000 by restraining its nodes movement in all directions except in horizontal direction. The SAP2000 and MATLAB natural frequency values are exactly matching with each other. The models were subjected to El Centro ground motion. The seismic displacement response value of the 15^{th} floor obtained through SAP and MATLAB is found to be exact (Figure 3), which shows zero percent error with SAP results overlapped by MATLAB results, thus validating the model.

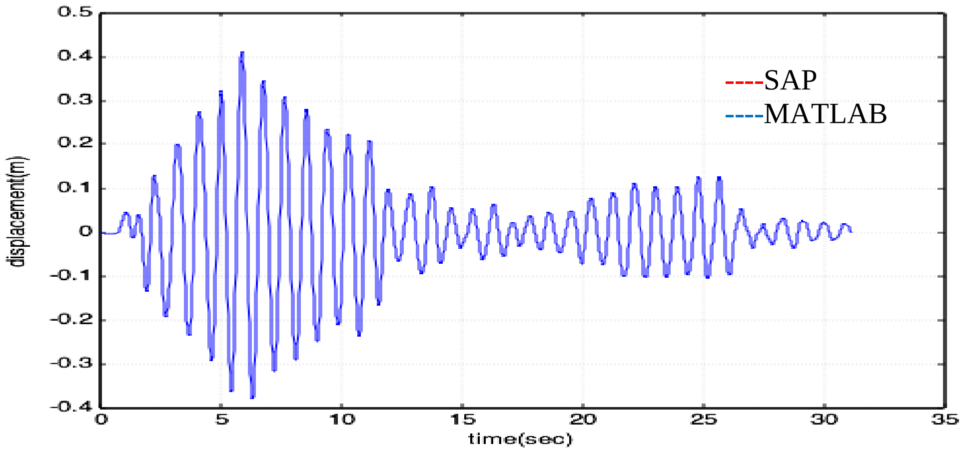


Figure 3. Uncoupled building 15 th floor displacement response obtained in MATLAB and SAP

6. RESULTS AND DISCUSSIONS:

In order to study the effect of damping coefficient value in reducing the seismic response of the building, the dampers were provided throughout the building for various configurations as shown in the Figure 4 .The roof response was calculated by varying the damping coefficient value from zero to 1×10^{13} N-s/m. The coupled building is subjected to El centro ground motion and the optimal damping coefficient values are obtained through PSO.

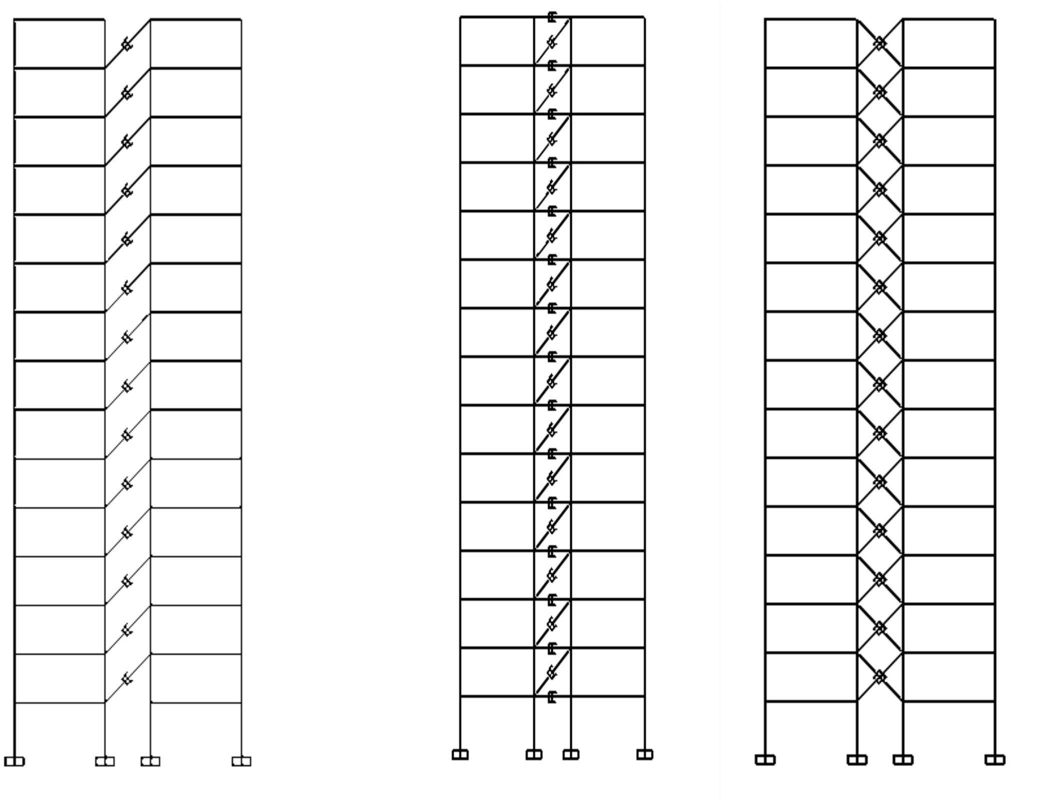


Figure 4. Configurations considered, a) case-1, b) case-2, c) case-3

From the optimal damping coefficient values shown in Figure 5, it is understood that there exists an optimal damping coefficient value at which the response is minimum. After a particular value of the damping coefficient the seismic response remains unaltered in reducing the seismic response rather than number of the damper. When the damping coefficient value is 1×10^{8} Ns/m, 91.1% reduction in the roof displacement is achieved in case-2 and case-3, which is observed from the graph.

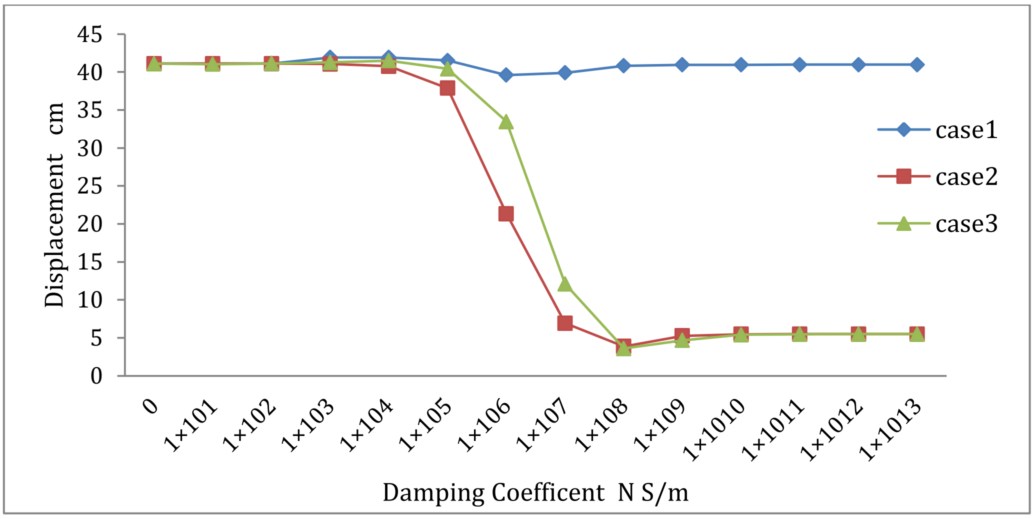


Figure 5. Variation of the roof displacement for the various cases considered

When the number of the dampers is fixed as four the optimal location of those four dampers is found through PSO technique, which is shown below in the Figure 7.

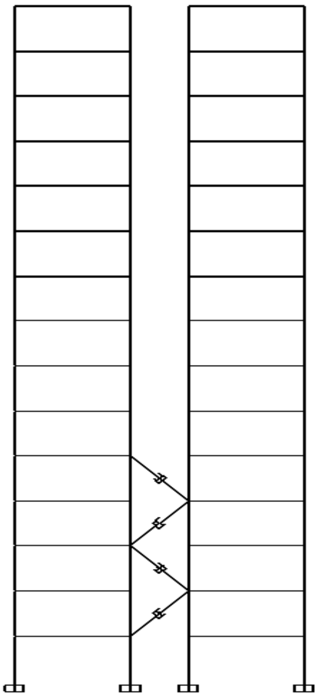


Figure 7. Optimal locations for the four dampers

In PSO technique sensitivity analysis is being carried out and the results has been verified using point by point search method. The percentage reduction in the seismic response has been found to be 66.18%.The comparison of the seismic response of the original uncoupled building with that of the building coupled with four dampers at its optimal location is showed in the Figure 8.

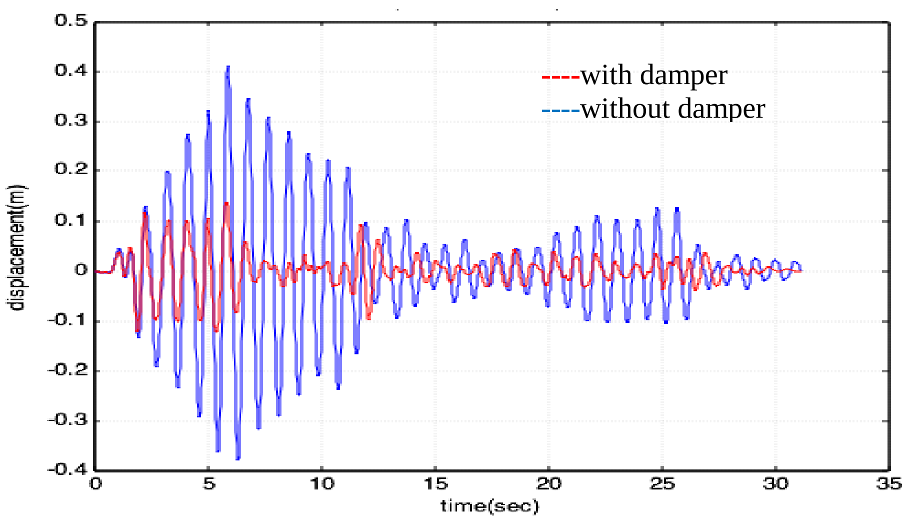


Figure 8. Comparison between the roof seismic response of uncoupled building and buildings coupled with dampers at its optimal location

After detecting the optimal location for the given number of the dampers the optimal damper parameters of the damper is found using PSO technique. The maximum and the minimum value of the damping coefficient in PSO is taken as 1×10^{6} N-s/m and 1×10^{13} N-s/m. while running the optimization, it is observed that when the damping co efficient is greater than 1×10^{13} N-s/m there was no change in the seismic response. Hence, the upper limit is chosen in the PSO technique. Table1 shows the optimized values of the four dampers from bottom to top for the configuration shown in Figure 7.

Table 1. Optimal damper parameter

Damper Designation	**Damping Coefficient (N-s/m)**
Damper 1	645636479
Damper 2	56510306
Damper 3	7236763
Damper 4	206900673

7. CONCLUSION:

The two dynamically similar adjacent building frames considered for the study has been modeled using both shear building. The dynamic properties of the building and its displacement under the seismic excitation were obtained in SAP 2000 and MATLAB programming. The comparative study shows that the above results are very well matching, thus validating the MATLAB model. The study on effects of various configuration of the damper in reducing the seismic response shows that the straight damper is inefficient for dynamically similar buildings but when combined with diagonal configuration it is more efficient. There exists an optimal location for the dampers, when the dampers are provided at these locations the seismic response is reduced to greater extent. Hence, a complete optimization study has to be performed to identify the damper location. By fixing the number of dampers as four, the optimal parameters and optimal location are obtained using PSO technique. By providing the dampers at these optimised locations it is observed that the seismic performance of the coupled building has been improved, by decreasing the dynamic displacement. The efficiency of the proposed control technique has been carried out by considering the earthquake excitation alone.

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