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Application of Viscous Dampers for Prevention of Pounding in Adjacent Reinforced Concrete Buildings

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Abstract

It is well known that a part of the structural damages that occur during earthquakes are due to pounding in adjacent reinforced concrete buildings. In this study, the application of viscous dampers, which are passive dampers, are investigated in order to avoid or mitigate the effect of pounding on adjacent buildings. In order to show the behavior and effect of viscous dampers two adjacent buildings are analyzed which are 20 and 10 storey buildings, respectively. Time history analyses are used for these two adjacent buildings which are subjected to earthquake ground motions. El Centro earthquake acceleration record (NS) is used for time history analysis. The cases of without damper, viscous damper and uniform damper application are compared for the model buildings. Storey drift and inter story drift values are used for comparison and interpretation of the buildings' behavior regarding the pounding effects.

Key words: viscous dampers, pounding, reinforced concrete buildings

1. Introduction

Especially, if story floor levels are not compatible and differences between elevations of adjacent buildings exist in between adjacent buildings under the strong earthquake or wind excitation, major damages appear inevitably due to the insufficient separation space. These kinds of damages are identified as pounding effect and pounding between adjacent structures is a very complex phenomenon, which may involve plastic deformation, local crushing as well as fracturing at the contact. These non-linear deformations are not easy to be incorporated into the modeling of pounding. Therefore, idealizations and assumptions have inevitably been used in theoretical models [1-5]. Prevention of pounding effect, which has been frequently ignored in the design, emphasizes that separation space should be more than maximum total absolute displacement of adjacent buildings. Dynamic characteristics of this kind of buildings are also very important, because adjacent structures may be exposed to out of phase vibration so that they can pound. Some recent earthquakes such as Mexico City earthquake (1985), Loma Prieta earthquake (1989), Kobe earthquake (1994), Marmara earthquake (1999) and New Zealand earthquake (2011) demonstrated that pounding of adjacent buildings and bridges caused significant seismic devastation. Damage statistics showed that out of 330 collapsed or severely damaged structures, pounding was the primary reason for collapse and severe damage of at least 15 per cent of them [6]. Figures 1 and 2 show damaged adjacent buildings during Marmara earthquake (1999). As shown in Figure.1, two buildings pounded to middle building in Sakarya, Turkey. Because of deficient separation space, they yielded big damage to this building. As shown in Figure. 2, one of the adjacent buildings, by pounding to another building and changing its direction, caused a big damage on the other building.

Fig.1- Two buildings pounded to middle building because of deficient separation space during Marmara earthquake (1999) in Sakarya, Turkey [7]

Fig. 2- One of the adjacent buildings pounding to another building and changing its direction during Marmara earthquake in Turkey [7]

Many studies have been conducted to reduce pounding damage effect using damper elements [8-17] and numerous reports about structural damages resulting from pounding of adjacent structures have been published in the literature [18-20]. Anagnostopoulos [21] put forward a calculation of hazard occurrences due to pounding. Optimal damping and stiffness values of the passive coupling elements are calculated by using the method of Zhu et al. [22]. Time history analyses are performed again, and maximum relative displacements are plotted by the period ratio of adjacent structures in case of adjacent structures being linked by a viscous damper. Stavroulakis and Abdalla [23] minimized potential energy of adjacent structures to determine the separation distance between structures under equivalent static horizontal forces. A method called Spectral Difference Method and Double Difference Combination rule based on random vibration theory was proposed by Jeng et al. [24] to determine the required separation distance and to prevent pounding. Lin [25] proposed a statistical method of the mean and standard deviation of separation distance of adjacent buildings based on random vibration theory to prevent pounding. Luco and Barros [26] calculated the minimum separation distance and used a different prevention technique to avoid pounding. Optimum interconnecting dampers that were uniformly distributed were calculated to minimize the transfer function amplitude of top displacement of the taller building [26]. Abdullah et al.[27] used a shared tuned mass damper which was attached adjacent to both of the structures to avoid likely pounding and to reduce structure's vibration.

In this study, the efficiency of passive viscous dampers on pounding effect is investigated. Therefore, effect of viscous dampers between 20 and 10 storey adjacent buildings are analyzed with El Centro-NS earthquake acceleration record by using time history analyses, so as to observe these two adjacent buildings behavior in terms of pounding effect. The cases of no damper, viscous damper and uniform distributed damper applications are compared with each other for the buildings' model considering storey drift and inter storey drift.

2. Formulation of the Problem

Adjacent structures can be physically modeled as single degree of freedom systems as shown in Figure 3. The structural system on the left side is called primary structure and the other structure is called secondary structure. Firstly, primary (A) and auxiliary (B) structures are uncoupled as two single degree of freedom systems subjected to ground motions as shown in Figure 4. The m_A and m_B are masses of the A and B structures, the k_A and k_B are the spring constants of A and B structures, the c_A and c_B are damping constants of the A and B structures. The parameter $\ddot{u}_g$ is the horizontal acceleration. In case of the adjacent structures subjected to horizontal acceleration without linked dampers, the differential equations of motion of the A and B individual structures are given to be uncoupled as follows:

$$m_A\ddot{u}_A + c_A\dot{u}_A + k_A u_A = -m_A\ddot{u}_g \tag{1}$$

$$m_B\ddot{u}_B + c_B\dot{u}_B + k_B u_B = -m_B\ddot{u}_g \tag{2}$$

If Equations (1) and (2) are arranged as a matrix-vector form, they can be written as

$$\begin{bmatrix} m_A & 0 \\ 0 & m_B \end{bmatrix}\begin{bmatrix} \ddot{u}_A \\ \ddot{u}_B \end{bmatrix} + \begin{bmatrix} c_A & 0 \\ 0 & c_B \end{bmatrix}\begin{bmatrix} \dot{u}_A \\ \dot{u}_B \end{bmatrix} + \begin{bmatrix} k_A & 0 \\ 0 & k_B \end{bmatrix}\begin{bmatrix} u_A \\ u_B \end{bmatrix} = -\begin{bmatrix} m_A & 0 \\ 0 & m_B \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix}\ddot{u}_g \tag{3}$$

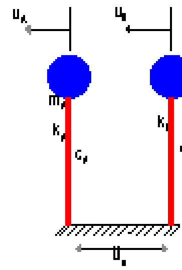
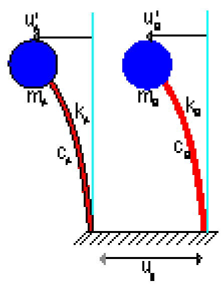


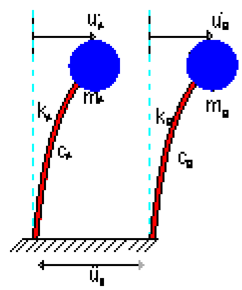
Fig.3-Physical model of adjacent buildings

Damping coefficient $c_i = 2\xi_i \omega_i m_i$ in which $i = p, a$ and c_i is taken as proportional to mass. Relative displacement z between the primary and secondary structure is taken as:

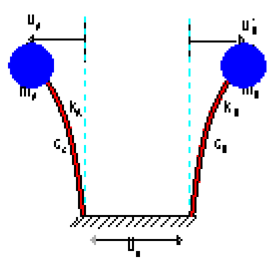
$$z = u_B - u_A \tag{4}$$

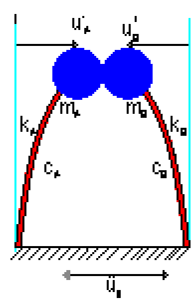
z is also specified as difference between displacements of primary(A) and auxiliary (B) structures.





(a)-Forward complimentary vibration response (b)-Backward complimentary vibration response





(c)-No pounding problem (d)-Pounding risk due to out of phase vibration

Fig.4-Vibration response scenarios for adjacent structure models

As shown in Figure 4 behavior of adjacent buildings subjected to a ground motion appears in four different shapes. Structures either act in phase or out of phase during earthquake. As seen in Figures 4 (a-c), if vibration characteristics of adjacent buildings are similar at any time *t*, these buildings are just compatible, so there is no risk with regard to pounding. If these buildings don't have same vibration characteristics, buildings act out of phase as shown in Figure 4(d) so they move away from each other. At any time, *t* while earthquake occurs, adjacent buildings either move away or approach to each other. Figure 4(d) shows action of out of phase and risk of pounding occurrence which means that relative displacement is positive. Therefore, increasing positive value of z increases pounding risk and pounding causes a big damage between adjacent buildings. For these reasons positive value of relative displacement should be decreased so that this parameter z can be chosen as a control parameter.

Figure 5 shows mechanical model of single degree of freedom adjacent building model supported by a damper. If passive energy dissipating element such as viscous damper is supplemented between adjacent structures as shown in Figure 5, equation of motion is coupled as follows:

$$m_A\ddot{u}_A + (c_A + c_v)\dot{u}_A - c_v\dot{u}_B + k_A u_A - k_v u_B = -m_A\ddot{u}_g \tag{5}$$

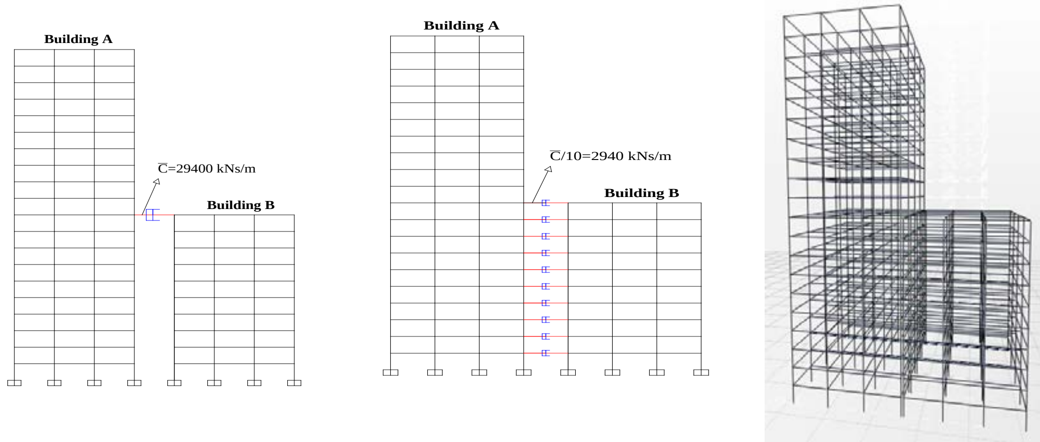
$$m_B\ddot{u}_B + (c_B + c_v)\dot{u}_B - c_v\dot{u}_A + k_B u_B - k_v u_A = -m_B\ddot{u}_g \tag{6}$$

Equations (5) and (6) can be written as following matrix-vector form:

$$\begin{bmatrix} m_A & 0 \\ 0 & m_B \end{bmatrix}\begin{bmatrix} \ddot{u}_A \\ \ddot{u}_B \end{bmatrix} + \begin{bmatrix} c_A + c_v & -c_v \\ -c_v & c_B + c_v \end{bmatrix}\begin{bmatrix} \dot{u}_A \\ \dot{u}_B \end{bmatrix} + \begin{bmatrix} k_A & 0 \\ 0 & k_B \end{bmatrix}\begin{bmatrix} u_A \\ u_B \end{bmatrix} = -\begin{bmatrix} m_A & 0 \\ 0 & m_B \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix}\ddot{u}_g \tag{7}$$

3. Numerical Example

In this study 20 and 10 story reinforced concrete adjacent buildings which have a 20 cm separation distance are chosen as an example. Column sections are 70x70 cm and beam sections are 25x60 cm. Beams are taken as flanged sections which have a 90 cm flange width and a slab height of 14 cm is chosen. Span of each bay has 600 cm for both of two directions; and then story height is taken as 300 cm. Foundation is fixed such that it has a rigid connection. After that as shown in Figure 5(a) only one viscous damper which has 29400 kN s/m damping coefficient used between adjacent building then also uniformly distributed damping in which every damping coefficient which is shown in Figure 5(b) are 2940 kN.s/m are located at each story from story 1 to story 10. Both of these two cases are compared for El Centro-NS earthquake record (Figure. 6) considering time history analyses; and the records are shown graphically in Figure 7. In Section 2, in order to define pounding problem two kinds of single degree of freedom system have been used; and simple equation of motion also has been defined. In this Section 3, two-dimensional 20 storey and 10 storey adjacent building model frames modeled with Sap2000 software [28] are used for this example, as seen in Figure 5(c).



(a) (b) (c)

Fig.5-Single and uniformly distributed viscous dampers in between 20 and 10 story adjacent buildings

In Figure 5(a) single viscous damper which has $\overline{C}$ =29400kN.s/m damping coefficient located at 10th story in between adjacent buildings A and B is shown while in Figure 5(b) uniformly distributed viscous dampers which have $\overline{C}$ /10=2940 kN.s/m coefficient located for each story from 1st to 10th stories in between adjacent buildings A and B is provided.

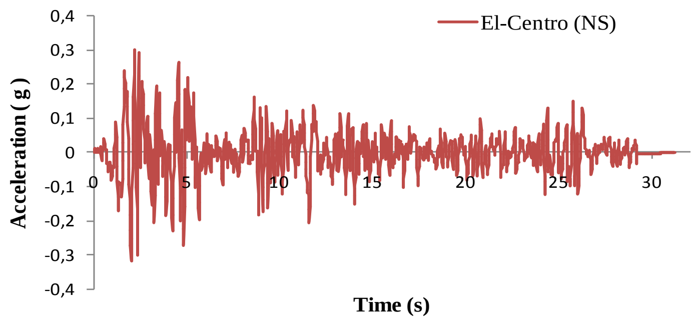


Fig.6-El-Centro(NS) earthquake acceleration record

For $\overline{C} = 29400$ kN.s/m damping coefficient of single viscous damper, Figure 7 shows 10th story displacement of buildings A and B with and without a single viscous damper located at 10th story. The damper substantially decreases story displacements of buildings, so it prevents pounding in between A and B buildings. As seen in Figure 8, single viscous damper located at 10th story sharply decreases relative displacement of adjacent buildings. It shows suppression of pounding effect in between adjacent buildings A and B.

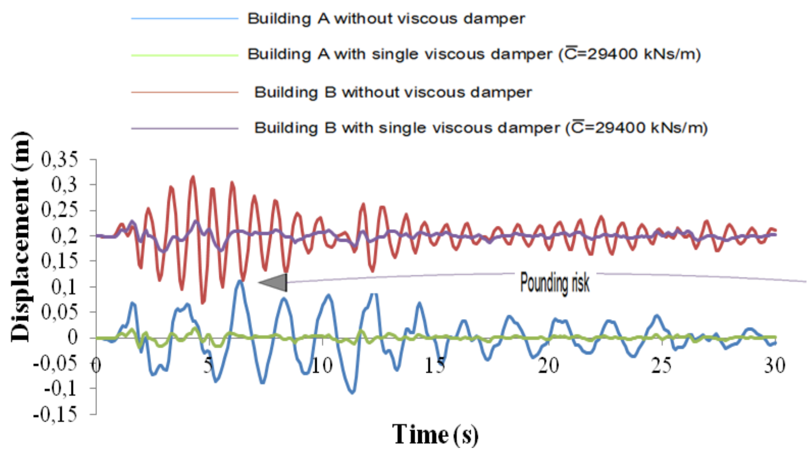


Fig.7- 10th Story displacement of buildings A and B with and without single viscous damper located at 10th story

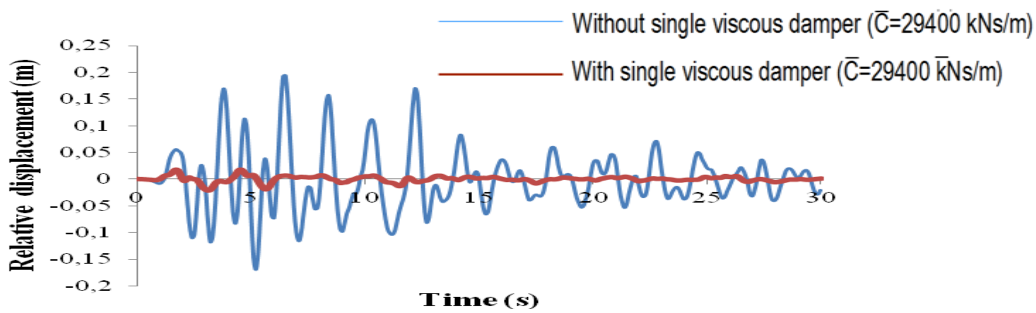


Fig.8- Single viscous damper located at 10th story sharply decreases relative displacement of adjacent buildings

Figures 9 and 10 show the comparison of effectiveness of a single viscous damper and uniformly distributed viscous dampers in terms of 10th story displacement and relative displacement of each story. Firstly, single viscous damper located at 10th story in between adjacent buildings; and secondly for each story uniformly distributed viscous dampers are located. In this study, total quantity of damping coefficient of uniformly distributed dampers equal to single viscous damper coefficient. As shown in Figures 9 and 10, effectiveness of both cases is almost the same since for both of the cases their graphs almost overlap.

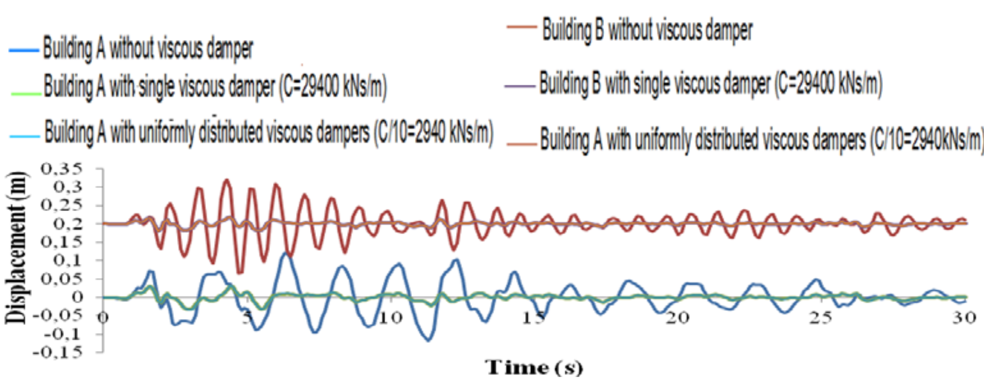


Fig.9- Comparison of effectiveness of single viscous damper and uniformly distributed viscous dampers in terms of 10th story displacement

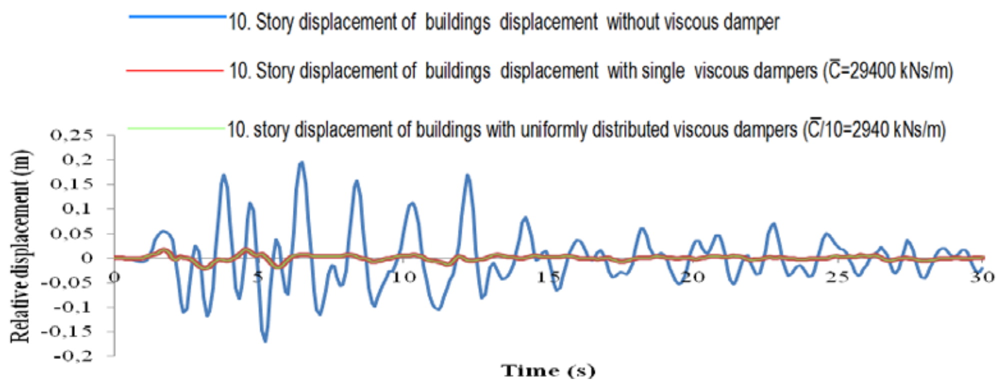


Fig.10- Comparison of effectiveness of single viscous damper and uniformly distributed viscous dampers in terms of relative displacement of each story

5. Conclusions

The purpose of this study is prevention of pounding effect of adjacent buildings using passive viscous damper devices. For this research 20 and 10 story adjacent buildings modeled without viscous damper, with a single viscous damper located at 10th story and with uniformly distributed viscous dampers are investigated. These models are analyzed by using El Centro (NS) earthquake ground motion. The results are compared to each other in terms of story displacements and relative story displacements. Application of viscous dampers for adjacent reinforced concrete buildings substantially reduce story displacements and inter story relative displacements. For this reason using a viscous damper in between adjacent buildings can prevent the pounding effect. According to presently applicable codes the Pounding problem remains in several countries for existing adjacent buildings where structural gaps do not exist in many cases, and it is too small in other codes since in the latter case indentation of dampers may be frequently feasible. In this study, total uniformly distributed viscous damper coefficients are taken equal to a single viscous damper coefficient, which is located at the 10th story. Uniform distribution of viscous dampers starts from the first floor and ends at the 10th floor. As understood from findings, uniformly distributed viscous dampers' performance is almost equal to the performance of single viscous damper in terms of reducing story displacements and relative inter story displacements. Therefore, based on results of this study, using a single damper may be more economical and advantageous than uniformly distributed viscous dampers in terms of quantity of material, time for application and workmanship. It has also the advantage of making inspection and maintenance easier during the structure useful life. However, analysis that is more detailed is necessary to confirm this conclusion to carefully check the effects of lateral forces applied by dampers to the buildings. An advantage of using a single damper may certainly be the possibility of an easier inspection and maintenance during useful life of the building, for instance for bridges in California, showed that periodic inspection and frequent maintenance are necessary for viscous dampers. The results also showed that the use of viscous dampers for adjacent reinforced concrete buildings is very useful and beneficial to prevent the pounding effect during earthquakes.

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