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Investigating the Pounding of Adjacent Steel Braced Frames Equipped with Viscoelastic Damper

Mohsen Alikhah [1], Majid Alikhah [1], Vahid Saberi [1*], Hamid Saberi [1], Abbasali Sadeghi [2]

*[*1] Department of Civil Engineering, University of Eyvanekey, Semnan, Iran*

[2] Department of Civil Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran

(saberi.vahid@gmail.com)

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ABSTRACT

The collision of adjacent buildings with insufficient distance has been observed many times during earthquakes. The main reason for the collision between buildings is usually their out-of-phase vibration, which occurs due to the difference in the dynamic characteristics of the buildings. On the other hand, in the case of tall structures, the phenomenon of pounding between the upper parts of the structure is mostly caused by the effect of wave propagation. Among the issues that have happened in most of the huge earthquakes in the world is the issue of adjacent buildings hitting to each other. This phenomenon occurs due to out-of-phase vibration in buildings that are not far enough apart. Due to the increase in urban population, the vertical development of cities is inevitable. Since most of the large and important cities of the country are located in earthquake-prone areas, it is necessary to give more importance to the issue of buildings hitting each other during an earthquake and reducing its effect in order to reduce the life and financial risks associated with it. In this research, the modeling of adjacent structures and the effect of the impact force on the response of the structures and the examination of the distance of gap are checked. In order to investigate the effect of pounding on the structures, the steel braced frames (3 and 6 stories) are designed and nonlinear dynamic time history analysis is performed for the mentioned models and in case of pounding phenomenon, viscoelastic damper is used to reduce the impact force. The results showed that to apply viscoelastic damper has reduced the displacement significantly.

Keywords:

Pounding, Adjacent buildings, Steel braced frames, Impact, Viscoelastic damper, Gap.

1. Introduction

During the past earthquakes, pounding phenomenon is the main reason for extreme damages in adjacent structures with inadequate gap [1, 2, 3, 4, 5]. Therefore, the design codes need a minimum seismic gap between constructed buildings. Sato et al. [6] performed a full-scale shake table test to investigate the vulnerability of a four-story base-isolated (BI) reinforced concrete (RC) hospital structure under the different seismic excitations. The results showed that medical equipment generated large displacements with walls. Also, for controlling the pounding in adjacent buildings during an earthquake is connecting with dampers [7, 8]. Ye et al. [9] indicated an adjusted Kelvin impact model to check the behaviour of BI building pounding with adjacent structures. Then, three-dimensional finite element analyses that were conducted by Pant and Wijeyewickrema [10] to investigate the seismic behaviour of the BI building. A numerical impact element is presented by Masroor and Mosqueda [11] for simulating the pounding against surrounding walls. Mavronicola et al. [12] checked the influence of pounding during the peak response. Zhai et al. [13] investigated the seismic pounding response dimensional analysis. Matsagar and Jangid [14, 15] checked the behaviour of different isolation systems during the pounding and the gap distance of adjacent BI structures. Komodromos et al. [16] found that if the flexibility of isolation has increased to diminish the acceleration in the structure of the floor level above. Agarwal et al. [17] assessed the performance of a variable friction base-isolation model in order to reduce the pounding effects. Komodromos [18] evaluated how the effectiveness of seismic isolation is affected due to pounding adjacent structures. Polycarpou and Komodromos [19, 20] analyzed the pounding tall buildings when isolated buildings are surrounded by fixed bases on either side. Pant and Wijeyewickrema [21, 22] evaluated the responses of BI buildings for near-fault ground motions. Polycarpou et al. [23] presented a numerical simulation of the incorporation of rubber material in the seismic gap to prevent sudden impact pulses during pounding. A numerical pounding study of two multi-story buildings with rubber bumpers at seismic locations was also analyzed by Mavronicola et al. [24]. Saberi et al. [25] investigated the effect of steel damper with vertical slits on chevron braced frames with the number of different stories. The hysteresis curves were stable and without any loss, indicating high energy absorption by chevron braced frame equipped by a damper with vertical slits. Saberi et al. [26] modelled the structures with a number of different stories in SeismoStruct software and dampers have been applied to the structure. By observing the results, the damping causes decreasing the seismic response of the structures, but the relationship between the increasing the damping and lowering the responses is not linear. In the last decade, the investigation of the behavior of buildings adjacent to each other, which are designed and implemented based on new technology and equipment, has received more attention. Considering the earthquake-prone nature of Iran, investigating the behavior of these types of structures is of particular importance. First, two steel residential buildings are designed with a steel moment frame and eccentric steel braces in two ways with the number of 3 and 6 stories. The number of three near fault earthquakes are extracted and scaled. Then, the mentioned structures are subjected to nonlinear dynamic time history analysis, and the viscoelastic dampers are used to reduce the probability of the occurrence of the pounding phenomenon in two adjacent buildings. At the end, the seismic response of the displacement of the roof of the frames is compared in two cases with and without the viscoelastic damper, and the determination of the gap distance is evaluated to prevent the occurrence of pounding phenomenon.

2. Modelling process

In this research, two steel residential buildings are designed with a steel moment frame and eccentric steel braces in two ways with the number of 3 and 6 stories by considering the design codes [27-29]. Also, the height of each story is 3.5 meters. The regular plan of 25x25 meters with six span in each side is considered. The length of the connecting beam in eccentric braces is 1 meter. Fig. 1 shows the joint plan of the desired structures. The structures are designed by ETABS software [30]. The side frame of these structures will be subjected to nonlinear dynamic time history analysis in OpenSees software [31], and the results will be used to evaluate their seismic behavior under pounding scenario. Figure 1 shows the joint plan of mentioned structures and Figures 2 and 3 indicate the side frames of 3 and 6 story structures, respectively. Also, Figures 4 and 5 show the cross sections of beams, columns and braces of mentioned frames.

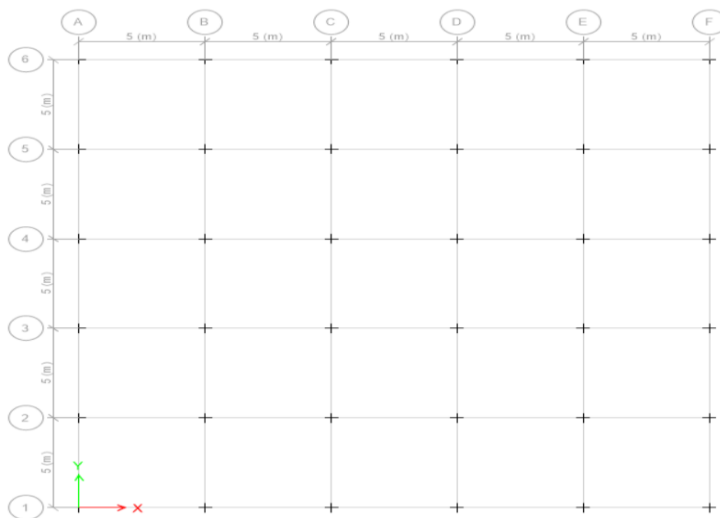

Figure 1. The details of joint plan.

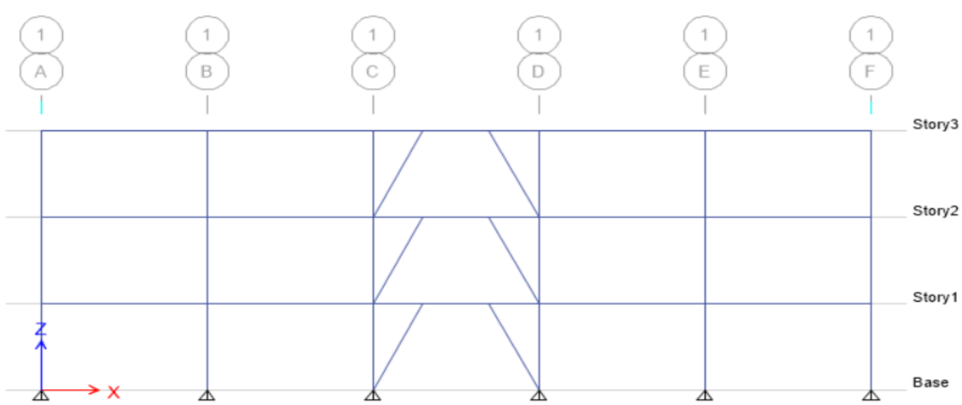

Figure 2. The side frame of *3* story structure.

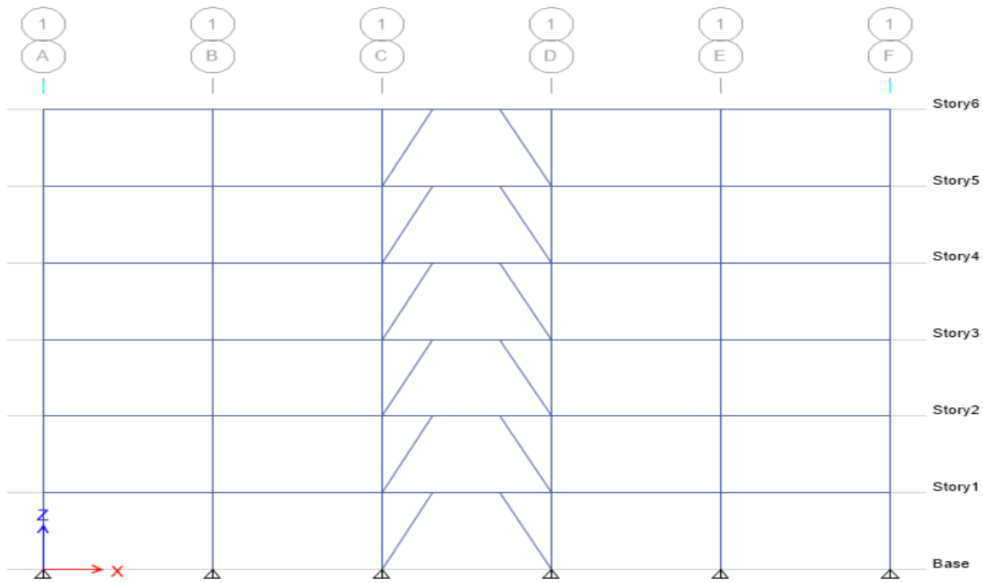

Figure 3. The side frame of *6* story structure.

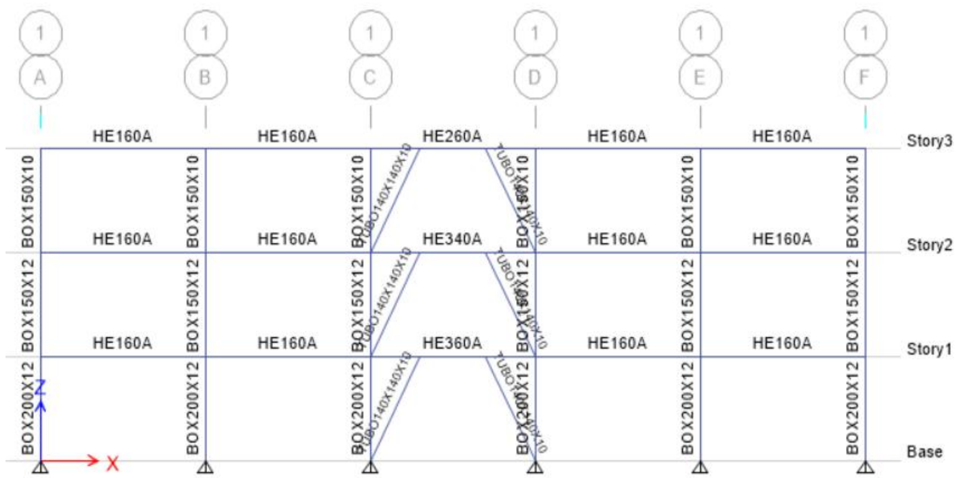

Figure 4. The cross section of elements of side frame of *3* story structure.

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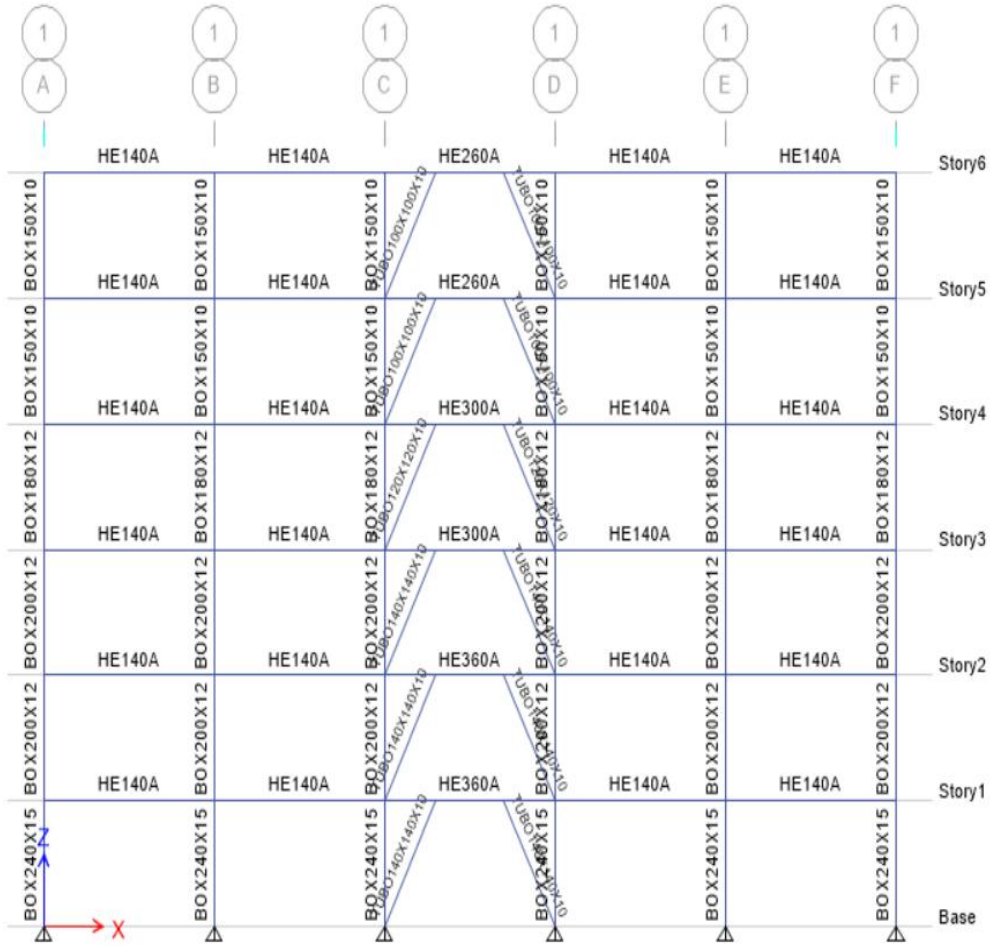

Figure 5. The cross section of elements of side frame of *6* story structure.

In the selected frames, the dead and live loads on the beams are considered equal to 1500 kg/m and 600 kg/m, respectively. Also, a mass corresponding to half the gravity load plus 25% of the live load enters the external nodes of the structures. The materials used in beams and columns are all of ST37 type with modulus of elasticity equal to 200 GPa, yield stress and ultimate stress are assumed to be 240 MPa and 370 MPa respectively, and the basis of the Steel01 model with a hardness of 3% is considered [32]. In addition, according to ASCE41 regulations [33], in order to apply the non-linear behavior of structural materials in the model, an accurate analytical model should be used. In this research, for structural members, fiber cross-section has been used as an extended plasticity model. In these members, instead of the plasticization of the materials in certain points of the structure (such as points in the beam, which is near the column), the plasticization of the materials is considered distributed throughout the length of the member. In this research, non-linear force beam-column members have been used to model the beam and column members. In the following, the number of threaded sections is 200 and the number of integration points along the length of the beam-column members is assumed to be 5. Then, Maxwell model is used for modeling viscoelastic damper. In the following, in order to study the behavior of the desired frames in two cases with and without viscous dampers, three near fault earthquakes have been used

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according to Table 1. The mentioned earthquakes are adapted from the PEER database [34]. Figure 6 indicates the scale methodology of the studied seismic records.

Table 1. The details of studied earthquake records.

No.	Earthquake	Earthquake Station	Year	Magnitude	PGA (g)
R1	Chi-Chi	TCU078	1999	7.62	0.471
R2	Parkfield	PARKFIELD	2004	6	0.562
R3	Landers	JOSHUA TREE – FIRE	1992	7.28	0.287

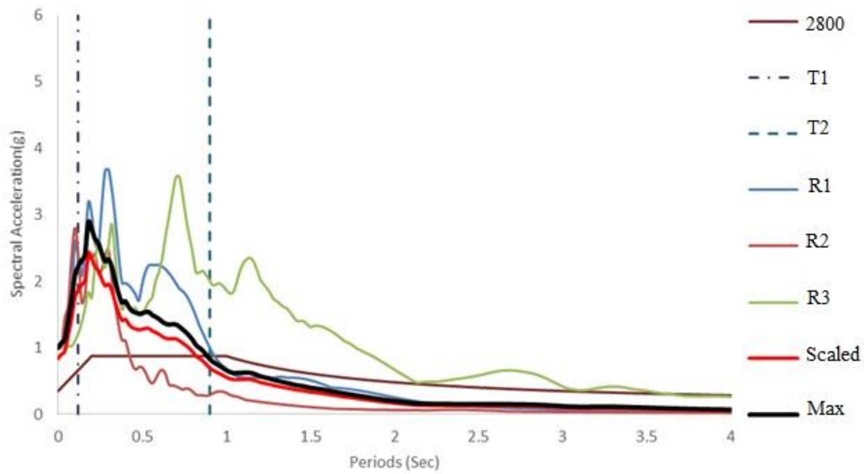

Figure 6. The scale methodology of earthquake.

3. Results and discussion

In this research, two two-dimensional with a steel moment frame and eccentric steel braces with 3 and 6 stories are modeled in order to investigate the effect of the pounding of the two steel buildings in question, then in order to strengthen the steel samples, a viscoelastic damper is applied at the pounding place. It is placed between two buildings and the amount of floor movement reduction due to this type of damper is analyzed. Then, time history of roof displacement is presented in the following. Seismic responses of 3 and 6-story frames with the mentioned lateral system under three near fault earthquakes are investigated and compared. Seismic responses in this research study include the maximum displacement of the roof of the 3-story frame and the third floor of the 6-story structure, and in case of pounding, a viscoelastic damper will be used in the 3-story structure. Based on Figure 7, it can be concluded that due to the nonlinear dynamic time history analysis under Chi-Chi earthquake, the maximum displacement of the third floor of the 6-story structure is about 20 cm and the maximum displacement of the roof of the 3-story structure is 14 cm.

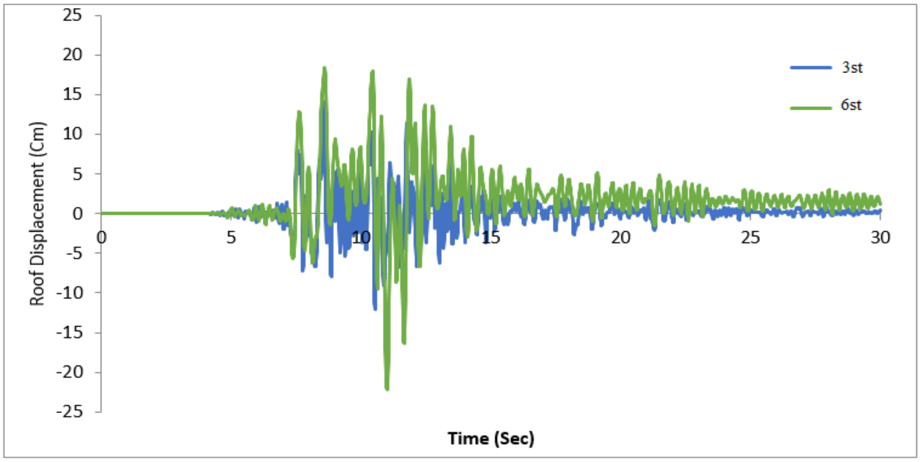

Figure 7. Time history of displacement of the roof of a *3*-story structure and the third floor of a *6*-story structure.

Based on Figure 8, it can be concluded that the 3-story structure is on the left side and the 6-story structure is on the right side. If the Chi-Chi earthquake force is applied in the horizontal direction, the 3-story structure will have displacement in positive and negative directions, which, considering that the 3-story structure is on the left side of the 6-story structure, will be considered the positive part.

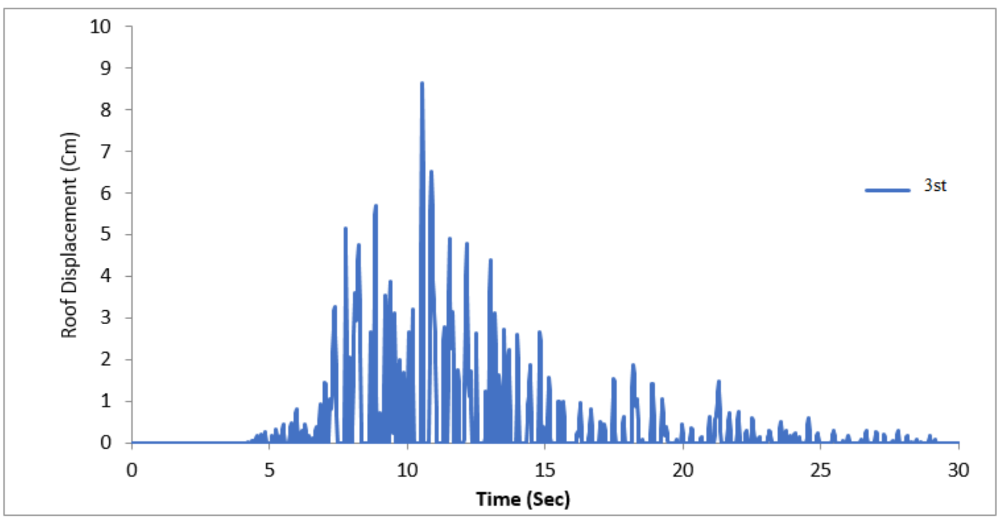

Figure 8. Time history of displacement of roof of *3*-story structure (positive part).

Based on Figure 9, it can be inferred since 3-story structure is on the left and the 6-story structure is on the right. If the force of the Chi-Chi earthquake is applied in the horizontal direction, 6-story structure will have displacement in positive and negative directions, which, considering that 6-story structure is located on the right side of the 3-story structure, so the negative part will be considered.

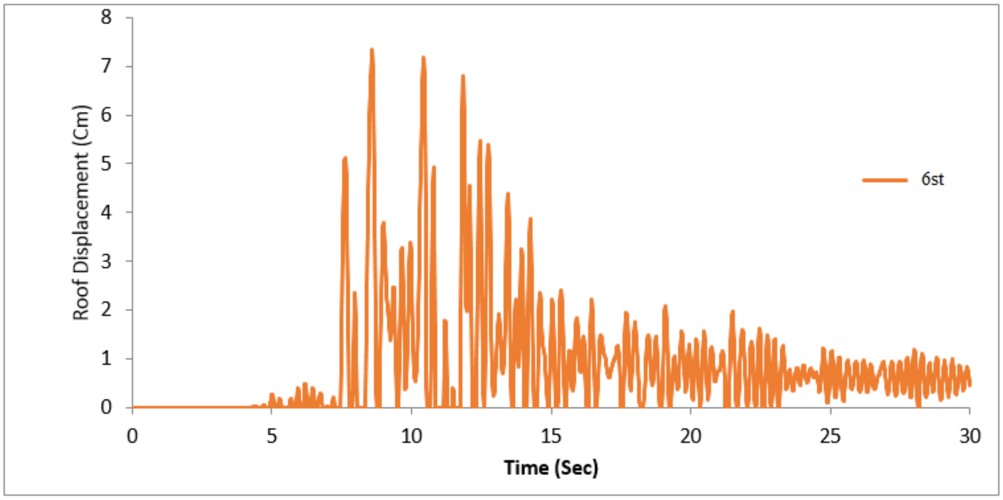

Figure 9. Time history of displacement of the third floor of *6*-story structure (negative part).

Based on Figure 10, it can be concluded that the total displacements created in 3 and 6-story structures are added together and then the value obtained with the amount of gap distance will be compared and reviewed. Based on this figure, it is clear that the displacement of the studied structures is approximately 32 cm, which is more than the amount of the gap distance, which is 21 cm, and the pounding phenomenon will be occurred.

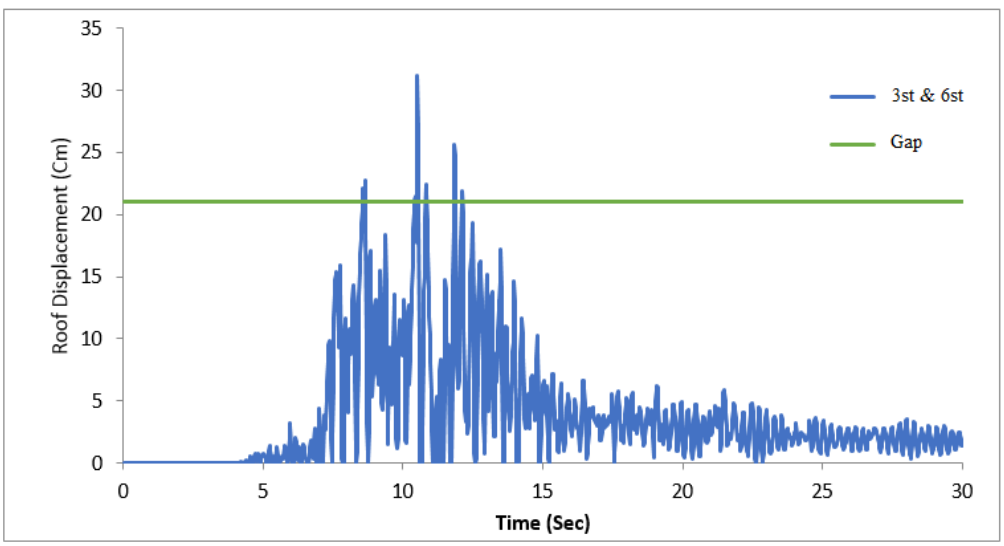

Figure 10. Time history of the total displacement of the third floor of *6*-story structure and the displacement of the roof of the *3*-story structure.

Based on Figure 11, it can be concluded that the total displacements created in the third floor of the 6-story structure and 3-story structure with viscoelastic dampers are added together, and then the value obtained is the amount of the gap distance. Also, it is clear that the displacement of the studied structures is approximately 18 cm, which is less than the amount of the gap, which is 21 cm, and the pounding phenomenon will not occur. Therefore, it can be concluded that the use of viscoelastic damper in the roof of the 3-story structure has reduced displacement by approximately 50%, which will practically prevent the occurrence of pounding between two buildings.

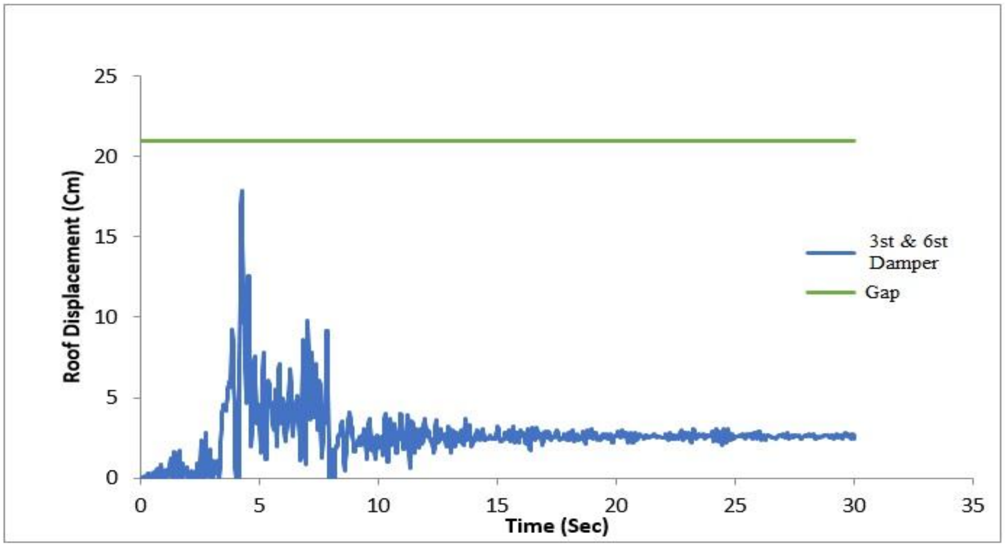

Figure 11. Time history of the total displacement of the third floor of *6*-story structure and the displacement of the roof of the *3*-story structure with viscoelastic damper.

In Table 2, the condition of adjacent frames 3 and 6-story steel structures has been investigated in two states with and without viscoelastic damper under three near fault earthquakes from the perspective of the pounding phenomenon.

Table 2. The status of occurrence pounding in studied frames.

Earthquake	Total displacement	Gap	Pounding	Viscoelastic damper	Total displacement with viscoelastic damper
Chi-Chi	32	21	Yes	Required	18
Parkfield	19	21	No	Not Required	-
Landers	22	21	Yes	Required	14

4. Conclusion

In this paper, two steel residential buildings are designed with a steel moment frame and eccentric steel braces with 3 and 6 stories are modeled in order to investigate the effect of the impact of the two buildings. Then, in order to strengthen the steel samples, a viscoelastic damper is placed in the impact area between the two buildings. And the amount of reduction in roof displacement due to this type of damper is analyzed. In addition, the loading, selection of materials and sections assigned to the structural elements are specified in the OpenSees software and based on the three near fault earthquake records and finally a nonlinear dynamic time history analysis has been performed and the outputs of OpenSees are extracted in the form of graphs. The summarized of results are presented in the following:

1. The use of viscoelastic dampers has a significant effect in reducing the maximum displacement of the floors and it has been reduced to the standard permissible range of Iranian seismic code 2800, which is an average of 40%.
2. The studied structures of 3 and 6 stories under three near fault earthquakes such as Chi-Chi and Landers had nonlinear behavior, which indicates the increased possibility of pounding phenomenon.
3. During Chi-Chi earthquake, two steel buildings of 3 and 6-story hit each other on the third floor and caused a pounding phenomenon, and the impact was strong considering the displacement of the floors which is 32 cm and the gap is 21 cm. If a viscoelastic damper is used, the amount of displacement can be reduced and the pounding phenomenon can be prevented.
4. By comparing the roof displacement values of the third floor before and after adding the damper to the structure, it can be seen that the dampers have greatly reduced the roof displacement, which is 40%.

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