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SEISMIC POUNDING MITIGATION BY USING VISCOUS AND VISCOELASTIC DAMPERS

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ABSTRACT

This paper examines the effects of viscous and viscoelastic dampers as an efficient technique for seismic pounding mitigation. To aim that, 15 steel frame models with different numbers of stories and bays and also with different types of ductility were analyzed under 10 different earthquake records for assigned values of link damping and stiffness and the most suitable values of damper parameters (damping and stiffness) are presented. Moreover, it is demonstrated that viscous dampers can perform as efficiently as viscoelastic alternative with a more economical aspect for pounding mitigation purposes.

Keywords: Adjacent buildings;Viscous and Viscoelastic links;Separation distance;Pounding mitigation

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1. INTRODUCTION

When the separation distance between two buildings doesn't accommodate with their relative motion, the probability of structural pounding during strong earthquakes would increase. This phenomenon can cause minor local damages during moderate excitations and considerable damages, even up to overall collapse of structures, during strong ground shakes. The 1985 Mexico City earthquake is considered as an outstanding example of collision occurrence during an event [1] and regarded as base motivation for many researches in structural pounding thereafter. Of course, pounding is also observed in other strong ground motions, such as those of 1989 Loma Prieta [2] or 1971 San Fernando [3] and also in more recent events [4][5]. It is well-known that Difference in dynamic characteristics, i.e. mass and stiffness, of adjacent buildings may be regarded as the main reason of pounding [6]. However, the effects of variation in seismic waves traveling should also be taken into accounts for building with widespread footings [7][8], but not for regular buildings with limited in-plan dimensions.

Although structural pounding had been mentioned in a technical text near 90 years ago [9], the research done by Anagnostopolous [10] can be formally regarded as a pioneer study in the field, in which collisions of buildings in series were investigated and it was declared that exterior buildings may experience more severe damages than the interiors. Moreover, it was concluded that the structural response would not be affected considerably by the amount of stiffness and damping in contact elements used to simulate collisions. Other important publications would be those of Maison and Kasai [11][12], who demonstrated that ignoring pounding effects would result in non-conservative design of buildings. Their analysis however concerned mostly with elastic behavior of structures, similar to that of Anagnostopolous work [10] previously mentioned. On the other hand, Pantedillis and Ma [13] compared the results of the inelastic behavior of structures to that of elastic case. Considering the limiting cases of collisions, Davis [14] incorporates the impact of a building against a rigid and a very flexible neighboring structure. Contrary to previous works, he used nonlinear Hertz model for contact simulation and the presence of chaotic response, as a result of the nonlinearity, was clarified.

Following for 3-D analysis of pounding, Jankowski [15] studied the analysis of two three story frames with allowed translational as well as vertical degrees of freedoms under different components of El Centro earthquake. It was suggested that weaker building should be paid more attention in design or evaluation, whenever pounding is probable to occur. Jankowski [16] also carried out another comprehensive detailed pounding-involved analysis using Finite element method. This time, a hospital building and its independent stairway tower were modeled and analyzed under various components of San Fernando earthquake records. A gap-friction element was used in the study. Finally, karrayanis and Favvata [17] investigated the pounding problem between two RC buildings with non-equal heights, where mid-story collision of column with story slab of adjacent structure was considered and the critical seismic behavior and ductility requirements of this collided column was discussed.

In spite of being a straightforward and simple procedure, providing sufficient seismic gap is not always the best solution for pounding prevention since high land cost and dense population may become an important challenge. In this condition, some pounding mitigation techniques, such as linking the buildings or using bumpers or increasing stiffness and damping of buildings, can be potential alternatives. Among these techniques, connection of buildings seems to be a good candidate in a sense that it completely eliminates the pounding effects and makes the vibration periods of buildings to be tuned up. Westermo [18] was first to suggest the use of links, in the form of coupling beams, between two buildings for pounding prevention. He asserted that relative beam-to-structure rigidity would be effective in controlling structural responses. After that, many researchers have been working in the subject of structural connections, especially ones with efficient damping and energy dissipation properties [19][20][21][22][23].

In this paper, viscoelastic and viscous dampers are studied as two types of linking systems and values of stiffness and damping of the damper connections are considered. For this purpose, a number of steel moment/dual frames were analyzed under different earthquake records. The most suitable combination of damper parameters may be pursued.

Analytical Models

In this paper, 15 models of 3.2 m height and 4 m width steel moment frames with rigid diaphragms and with neglected secondary effects were constructed in sap 2000 commercial software and designed according to Iranian building codes. Figure 1 shows an analytical view of a typical frame. The models studies herein consist of different numbers of stories and bays and also of different types of structural systems and ductility.

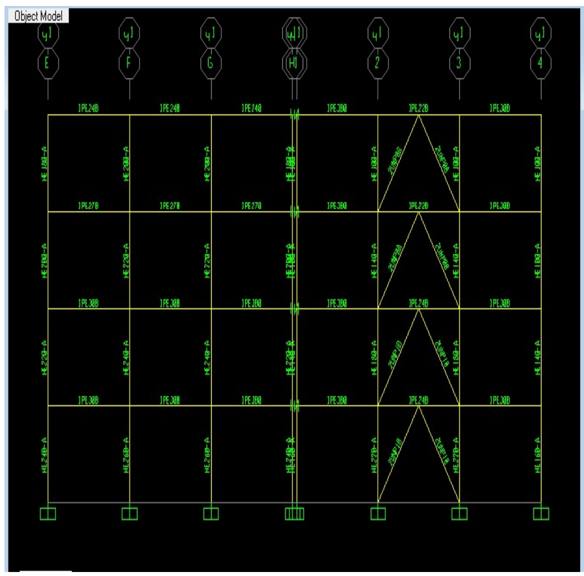

Fig.1. Model of two frames with a gap between them

In the first phase of study, no links (dampers) were placed between buildings, so that they could vibrate freely. This phase was scheduled not only for getting insight into the seismic performance of each frame and estimating the most suitable behavior among these individuals, but also for comparing the result for both cases of free and pounding-involved cases of behavior. Use of gap element introduced in the program is highly beneficial for simulating pounding problems.

The analysis of the frames was conducted under 10 different earthquakes listed in Table 1 and for different gap sizes ranging from 0.005 up to 0.02 of lower building height. In the analysis of buildings, the assumption of regularity, both in plan and in elevation, was applied. The stiffness of gap element was assigned equal to 1×107 kg/m2 that acts only in compression. This element was placed in all critical points that probability of collisions exists.

Second phase of the analysis dealt with adding viscoelastic and viscous dampers to initial models. Finding the most suitable values of damping and stiffness would be the central interest at this stage. For that, a range of stiffness from 10 to 1×109 kg/m and a range of damping from 1 to 1×107 kg.s/m. were considered. In this step, a gap size of 0.01of (lower) building height was assigned in all models, as this gap size had presented the most satisfactory behavior than others in the first phase of analysis.

2. RESULTS AND DISCUSSION

In figures 2-4, seismic response of first phase of study for different moment frames are compared for both linked and unlinked (free) cases and for the gap size value equal to 0.01 of building height. As can been seen, the effects of pounding is negligible, at both beginning and end of the response time histories, due to having small value of ground motion there. On the other hand, the most influential effects of pounding occurs typically near the time of maximum ground acceleration. This is especially true for the collision with a dual system consists of moment frame and inverted bracing. Moreover, the peak axial force of a typical column in one of the colliding buildings for different earthquake and gap sizes are presented in table 2. It is clear that the gap size of 0.01 of building height resulted in the most appropriate response than other choices, so that this value was selected to be assigned in second phase of the analysis.

The seismic response for a number of moment frames connected by viscoelastic links are presented in Figs. 5 and 6 for two different earthquake records and also, for different values of damping and for a constant stiffness in each figure. From these figures, there exists a damping coefficient, for which the response takes the minimum value, as indicated in each figure. Furthermore, it can be understood that the period of flexible structures tends to be less affected by the stiffness of the viscoelastic links (dampers). This is in contrast to rigid frames, whose period of vibration depends highly on the stiffness of the connector.

The analysis can also be applied to the case of smaller gap size (0.005 of the lower building height), in order to generalize the result for the case of more probable collisions. It was verified that again damper can be very effective in reducing the response of the structures, although more pounding effects may be expected to occur due to the smaller gap size.

At the final stage of second phase, results for the case of viscous damper (with a low damper stiffness of 1×10^4 kg/m2) are presented here. In Figs. 7 and 8, seismic responses of the structures are compared to the case of using viscoelastic dampers. It is clear that using viscous dampers instead of viscoelastic ones slightly increase the response. Thus, it can be a suitable choice for pounding prevention, considering the higher cost of providing viscoelastic links with considerable high stiffness characteristics.

Table 1. Earthquake records used in this study

Earthquake Record Definition				PGA(g)		
Title	Event	R (km)	M	x	y	z
R1	Borrego Mountain (1968)	45	6.8	0.13	0.118	0.09
R2	Cape Mendocino (1992)	23.6	7.1	0.114	0.116	0.049
R3	Kocaeli, Turkey (1999)	17	7.4	0.149	0.218	0.086
R4	Loma Prieta (1989)	28.2	6.9	0.159	0.172	0.093
R5	Northridge (1994)	15.8	6.7	0.42	0.356	0.489
R6	San Fernando (1971)	21.2	6.6	0.174	0.21	0.136
R7	Superstition Hills (1987)	13.9	6.7	0.258	0.358	0.128
R8	Naghan (1977)	5.6	6.1	0.889	0.587	0.577
R9	Manjil (1990)	176	6.2	0.041	0.020	0.048
R10	Tabas (1978)	55	6.4	0.862	0.731	0.915

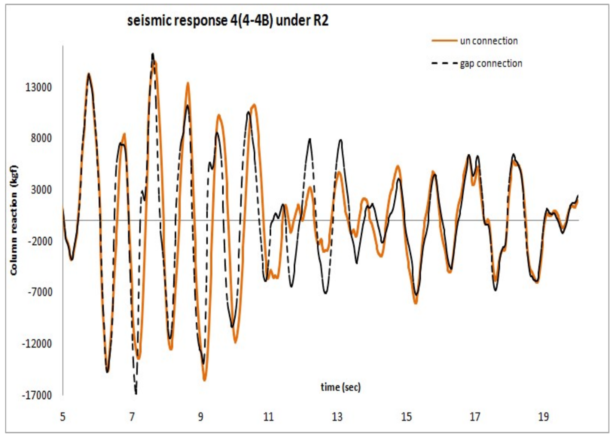

Fig.2. Free (-) and pounding-involved (--) Seismic response for collisions an intermediate moment steel frame with adjacent inverted-braced frame under record R2 of table 1.

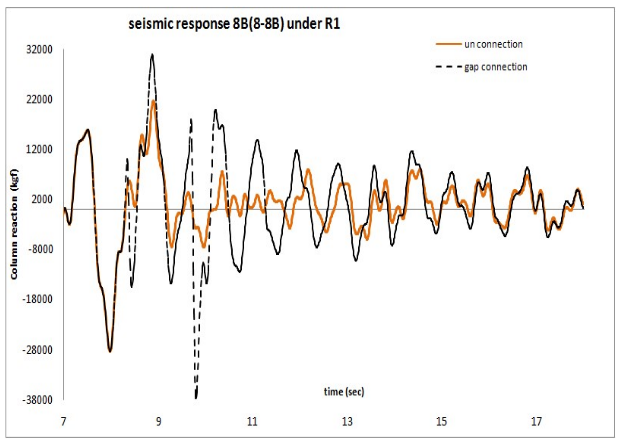

Fig.3. Free (-) and pounding-involved (--) Seismic response for collisions of an intermediate steel frame with a dual system of moment frame + invert bracing under record R1 of table 1.

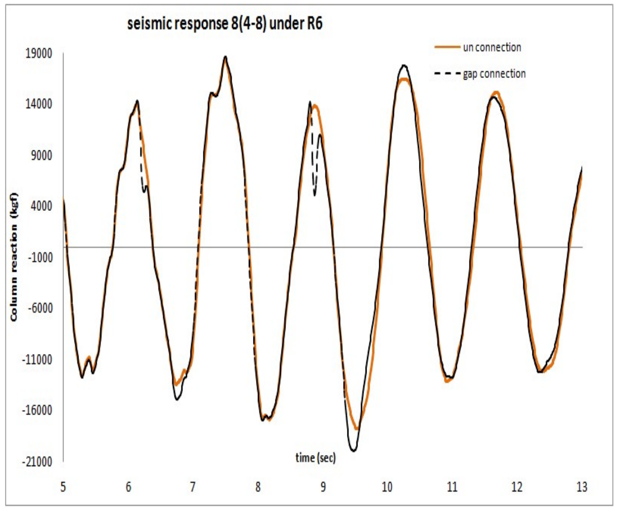

Fig.4. Free (-) and pounding-involved (--) Seismic response for collisions of two intermediate steel frames under record R6 in table 1

Table 2. Comparison of peak column axial force for different gap sizes and for collision between an intermediate and a special moment frames

Peak column reaction (Ti/Tj=0.6567), kgf					
Distance (×H)	R1	R2	R3	R4	R5
0.005	27050	17440	6298	13770	16370
0.0075	28780	21350	6298	12760	15550
0.01	31380	23870	6298	12760	15020
0.0125	31570	24590	6298	12760	15020
0.015	29200	24590	6298	12760	15020

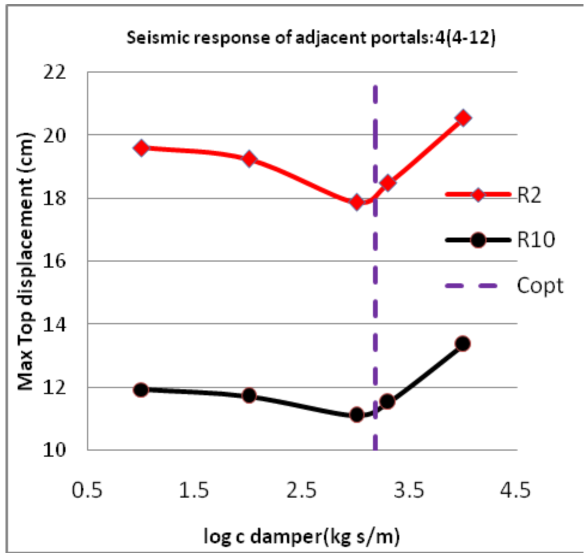

Fig.5. Peak response of two colliding intermediate steel frames for different records vs. damping of damper

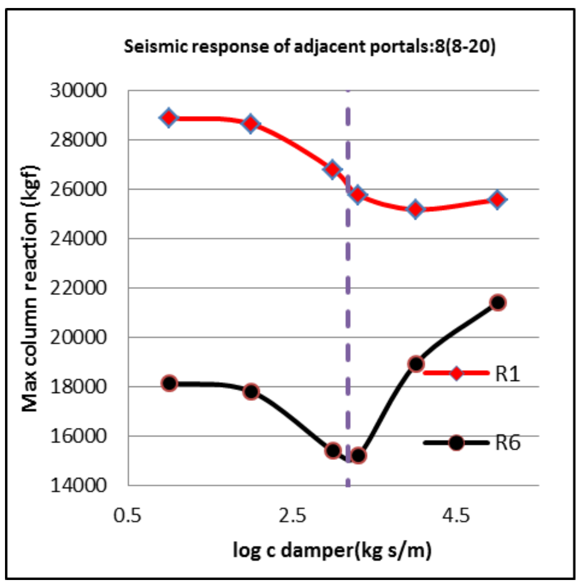

Fig.6. Peak response for colliding of an intermediate and a special steel frame for different records vs. damping of damper

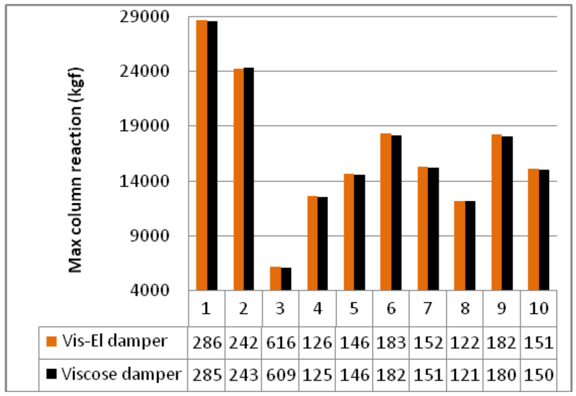

Fig.7. Comparison of peak response for collision of two intermediate steel moment frames for two cases of viscoelastic and viscous dampers

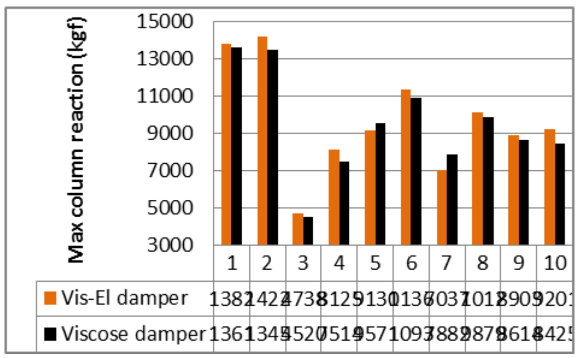

Fig.8. Comparison of peak response for collision of an intermediate and a steel moment frame for cases of viscoelastic and viscous dampers

3. CONCLUSION

In this paper, the effects of viscoelastic and viscous dampers on seismic pounding mitigation between two buildings during earthquake are investigated. A number of moment frames with different number of stories and bays and also different structural system were examined and the following results are outlined:

1- Increasing the gap size would decrease the effects of pounding to some extends.

2- The separation distance of 0.01 of lower buildings indicated in seismic codes seems to be insufficient for pounding, since models with such gap size experience more or less pounding effects.

3- The most important parameter in the pounding evaluation is the difference in the phase of the vibrations, so that the effects of pounding would decrease by getting the periods of two structures more closed.

4- The viscous and viscoelastic dampers are found to be considerably effective in reducing the seismic response of the buildings, even to an extend that can completely prevent collisions.

5- The performance of both viscous and viscoelastic damper depends on the optimal values of stiffness and damping. However, viscous dampers can reduce the seismic response comparable to viscoelastic dampers and only slightly lower, but not for buildings with very small gap sizes. By considering the lower cost of using viscous dampers, this can be a good choice for prevention of probable pounding in buildings.

It should be finally noted that the first two authors of this paper are now working on the application of random vibration theory, instead of relying to analyses under certain earthquake records, to evaluate the effect of viscoelastic links for seismic pounding mitigation. The results are under way to be published in the future.

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