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Performance Evaluation of Mid-Height Steel Moment Resisting Frames Rehabilitatetd by Visco–Plastic Dampers Using Nonlinear Linear Time History Analysis

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ABSTRACT

Nowadays advancements of control systems are due to vast parametric and laboratorial experiments which are available. The main objectives of such studies are to optimize the total expenditures, ease of accessibility, and credible performance in seismic performance of buildings. In this essay too, the aim is to review the performance of one of the newest dampers that has been derived from combination of two dampers namely, viscous –Elastic damper and streamed damper and has been called viscous –Plastic damper or VPD. In this essay the seismic performance of the mid-height buildings reinforced with VPD is evaluated by using nonlinear dynamic time history analysis of each models under near and far fields earthquakes and considering the effect of large deformation and $P\text{-}\Delta$. Also the effects of VPD on parameters such as the maximum storey displacement demand, the time history of roof displacement and base shear force, flexural moment of base floor columns, inter-storey drift index, and the fundamental period of structures will be reviewed. General evaluation of results confirms the significant effect of this damper on the decrease of the response history of roof displacement, the inter storey drift**,** and the flexural moment of base floor columns**.** On the other hand the results show that while the system changes the natural period of due to initial stiffness of VPD, has no a significant effect on the response history of base shear and even sometimes increases it. On the other hand the amount of structure's Residual deformation decreases severely after earthquake and above mentioned damper acts as a fuse.

KEYWORDS: Viscous –Plastic Damper; Near and Far Fields Earthquake; Floor drift, Response History of Base Shear Force; Residual Deformation.

INTRODUCTION

The passive control systems are those adjunct outer elements to the structures that have no need to outer force for absorbing and dissipation the earthquake energy. Such systems consist of two categories: the velocity- and the displacement-based systems. In the case of latter category, while the stiffness of structure increases, the absorbing energy mechanism with the help of slipping friction is carried out. In this level under low excitation due to stiffness increase, the displacement of structure decreases. By increasing input excitation amplitude while uses the additional stiffness, the dissipation energy component caused by damping comes in and restricts the forces imposed on structure. So far many different displacement-based passive systems have developed such as frictional damping ([1] and [2]), ADAS dampers ([3] and [4]), and inelastic buckling steel bracing ([5]). In velocity-based systems, the absorbing and dissipation energy mechanism is carried out via shear deformation of visco-elastic materials. So far many different of such systems such as visco-elastic dampers ([6], [7], [8] and [9]) and slimy fluid viscous dampers ([8] and [9]) have been manufactured. One of the most prevalent types of such dampers is visco-elastic damper that can improve the dissipation energy procedure in the structure without any significant change in stiffness. The results of studies confirm that one strategy for improving damper performance is amplifying the damper's vibration amplitude. Therefore toggle dampers have been amplified in order to with the minimum change in the floor, moving along the damper is reinforced and its effect is improved [11].

One of the pivotal objectives in designing structure with damper is to determine the most optimized form of stiffness and damping. Owing to dependence of these two factors, creating such a balance is so hard. So one of the main aims of this study is identifying visco-plastic damper that henceforth is showed as VPD and by defining different parameters, the two factors namely, stiffness and damping can be controlled. Other purpose of this essay is to evaluate steel moment resisting frames (SMRF) that are designed according to strength criterion but they don't comply with the deformation regarding to UBC97 drift control regulations. On the other hand reviewing of structures behavior reinforced by VPD which are affected by real acceleration time

*New passive control system on seismic rehabilitation process.

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history records from the point of view of the response history of top floor storey displacement, the base shear response history, the maximum lateral deformation of floors, the floors inter-storey drift, the flexural moment of base floor columns, and dynamic properties (seismic period) are the aims of this study. On the other hand for the purpose of evaluating the effect of VPD on mid-height structures, three structures of 5, 8, and 12 floors were modeled. Also horizontal component of modified ChiChi earthquake (Taiwan) was considered as the near and far fields input records.

It seems that application of VPD causes lateral response and Floor drift improvement and yet due to initial stiffness of damper element, stiffness of structure increases and consequently the fundamental period of structure decrease. On the other hand it is expected that like the most passive control systems, time history response of base shear force remains without any change and even increases in some cases. On the other hand it is expected that due to reduction of the storey displacement caused by this system, columns flexural moment decreases noticeably.

1. Introduction to Visco-Plastic Damper

This damper system consists of two main components. The first component consists of two curved steel elements that usually are formed like channel and between which, according to the specific length of the element, there is solid viscous-elastic material of rubber with high damping property ([17] and [15]). The rubber is a combination of natural rubber, resin, oil, and particles of carbon black and other fillers that have been produced by MPPRA in Malaysia [13] and its damping property in the 100% Shear strain has been estimated as 20%. Employing filler in rubber causes an increase in stiffness, elasticity model, and tensile strength. On the other hand the energy absorption mechanism in this system proceeds as: with the exertion of axial compression or tension force on damper, while longitudinal axial deformation takes place, due to a significant transverse deformation of the viscous rubber block, absorbing and dissipation energy accomplish. If the motion intensity is low, energy is absorbed by longitudinal axial deformation in visco-elastic block. It is worth to mention that the form of curved steel beams exerts no significant change on the stiffness of the whole structure. So it is possible that the great shear force exerted on the structure can be obviated. During strong motion in addition to energy dissipation property of rubber, the imposed energy is absorbed by forming axial-moment plastic hinge and by using potential yield of steel element. This is the reason of plastic term appellation in this system. Once the force component on the VPD is compressive, due to the significant rigidity property of visco-elastic material and due to symmetrical placements of steel elements, the out of control inelastic buckling of steel elements are prevented. This mechanism is like the performance of buckling- resistant braced frames. On the other hand it is suggested to control transverse element deformation; dampers are used in pairs so that if it undergoes some tension, the second damper controls deformation with its compressive performance. The results of studies show that the most important factors affected VPD behavior are:

- Element's length, breadth, and thickness
- the element's ratio of thickness to its length
- the curved form of steel elements
- the steel element's size of section and form (chanel, plate, or T shape)
- the residual behavior of steel
- the visco-elastic's behavior
- the way that visco-elastic joins to steel element (conjunct or non- conjunct)

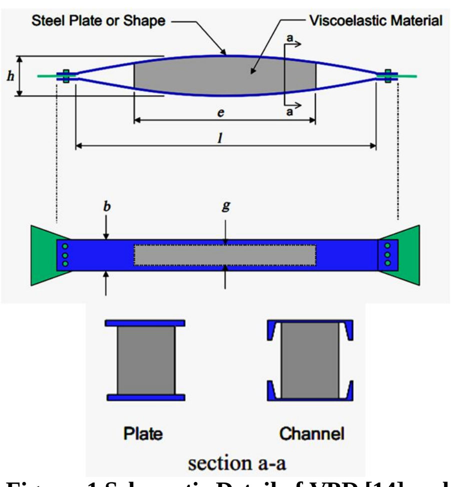


Figure .1 Schematic Detail of VPD [14] and [17].

On the other hand in a simplified taxonomy the most important properties of VPD are categorized as:

- the possibility of producing of damper from common accessible materials
- usability in almost all steel structures
- the minimum required expenses for maintenance and production
- need of replacement just in very strong earthquakes

2. FEM Model Description for VPD

For the purpose of modeling VPD in FE software such as Abaqus, it is required that usable properties and behavioral models in modeling process is evaluated precisely. Usually for visco-elastic modeling a rigid 3-dimensional element is employed that has the capability of being analyzed in deformations and large strains. For modeling of steel elements, it is suggested that the 8-node shell elements with capability of decreased integrality is used.

On the other hand for modeling inelastic behavior of VPD rubber block, the model presented by Odgen [16] is used. For this purpose the stored strain energy in volume unit is defined as a function of deviatoric stress. The studies carried out by Raos show the creditability of Odgen model for estimation of strain energy.

For defining Inelastic behaviors in FE software, the results from a study presented by Yoshida has been used [18]. He examined a couple of an-axial and multi-axial tensile tests on high-damping rubbers. For the case of compressive behavior, we can use the results of Amin [19] studies. On the other hand the suggested poisson ratio is 0.475. A sample of results has been showed in the Fig 2. For defining visco-elastic material behavior, we can use the results of 3-steps rubber resting test carried out by Yushida. For the steel elements the Yield standard is Von-Mises criterion and isotropic steel strain-hardening model is suggested.

3. The Simplified VPD Model in SAP2000.

Due to limits in modeling process and its complications, using FE model always leads researchers and engineers to more simplified models which can be performed in prevalent software such as SAP2000 [20]. So many different models have been suggested in the reference [15] and the M3 model is used in this study but visco-elastic material damping is considered as an equivalent centered one. For this purpose the information such as the section surface of steel elements, the yield stress of steel, the rubber block volume, the thickness of block at the center of VPD, the behavioral phase angle of rubber, the elasticity model of visco-elastic material, and the applied load frequency are required. In the Figure 2 the applied simplified model is depicted.

For the purpose of modeling damper's element mass, the nodal mass model with 10 lumped masses has been used. For evaluating equivalent damping, the effect of different factors such as the type of visco-elastic material, axial strain, and the volume of rubbery core should be considered. With the longitudinal axial deformation on VPD, an orthogonal axial strain on which is created and according to this, dissipated energy per unit volume of rubbery material is:

$$\Delta E = \pi \sigma_0 \varepsilon_0 \sin \delta \qquad (1)$$

Where $\boldsymbol{\sigma_o}$ and $\boldsymbol{\varepsilon_o}$ are the stress and strain amplitude respectively and $\boldsymbol{\delta}$ is angle phase of rubber. So the whole dissipated energy in each cycle is defined as:

$$E_T = \Delta E V_r \qquad (2)$$

In this statement, $\mathbf{V_r}$ is total volume of rubber block. The main required parameter in the Eq.2 is the angle phase of rubber. So it is necessary that a rubber block with specified dimensions is exposed to some harmonic stress scenarios with specified fields and stress-strain diagram during each cycle is depicted. This diagram has been illustrated in schematic form in Fig 4. If $\mathbf{h_1}$ is equivalent stress to zero strain and $\mathbf{h_2}$ is equivalent stress to the maximum strain, then phase angle is:

$$\sin \delta = \frac{h_1}{h_2} \qquad (3)$$

On the other hand it is expected that the maximum axial strain in VPD is 50%, so if orthogonal deformation of VPD in the midst of span is depicted as $\mathbf{d_{VL}}$ then the amplitude of orthogonal axial strain is:

$$\varepsilon_0 = \frac{2d_{VL}}{h} \qquad (4)$$

On the other hand the maximum strain amplitude could be estimated by multiplying Equation 4 by average of initial elasticity model of rubber block. Finally if we replace Equation 4 in Equation 2:

$$E_T = \frac{4\pi E_0 d_{VL}^2}{h^2} \sin \delta V_r \qquad (5)$$

The whole dissipated energy in a cycle under harmonic loading for an SDOF is:

$$E_T = \pi\omega C U_{\max}^2 \qquad (6)$$

In above equation $\mathbf{U_{max}=2d_{VL}}$, $\boldsymbol{\omega}$ is loading frequency, and C is the damping constant. If the whole damping of a rubber block is modeled by a centralized damper, damping coefficient could be estimated by replacing Eq.6 and Equation 5. So:

$$C = \frac{E_0 V_r}{\omega h^2}\sin\delta \qquad (7)$$

With the citation of presented results by [17] and [15] references, in this study damping constant is supposed to be 150 KN-s/m. On the other hand the elasticity model of rubber block and its volume are supposed to be 2240 KN/m^2 and 0.11706 m^3 respectively. The thickness of which is supposed to be 30cm and its Poisson ratio is equal to 0.46. C15X50 is selected For steel element and it is supposed to be a Axial-moment plastic hinge in its midst length that its plastic hinge length is 5% of element's length. For modeling rubber block, a shell element with 1m length and 30cm thickness is used. Also it is supposed that 5cm for the maximum horizontal axial deformation and 10cm for the maximum orthogonal axial deformation in the midst of VPD. At the end of this section for the purpose of veracity of VPD simplified model in comparison with FEM, the analysis results of both models which are done by Abaqus is depicted in the figure 3.

4. Model Description

Since the use of VPD element in rehabilitation of steel buildings is very common, so in research process three intermediate steel moment frames with 5, 8, and 12-storey have been used. All buildings have 5 spans and each width of each span and height of each storey are supposed 4.5 m and 3 m respectively. On the other hand loading system is in plaid pattern and the width of loading frame is 4 m. The dead load of odd and even spans is defined as 4.14ton/m and 0.84ton/m respectively. Live load also with residential application and for odd spans is defined as 1.1 ton/m. All buildings have been designed according to strength criterion of AISC-LRFD99. For the purpose of estimating force of earthquake imposed on buildings, it is supposed that the building is on the soil type D with very high risk possibility of earthquakes. On the other hand the Floor drift index limitation is ignored deliberately and with the help of VPD, this limitation is controlled. In the figure 4 schematic view of frames with the VPD localization are showed. It worth to mention that all models initially are designed by ETABS [21] software and then for frame analysis in the presence of VPD, the results are transferred to SAP. All of the column's sections are in box shape and beams are in girder forms. Also in all of modeling processes the inherent damping of structures is supposed to be 3%. To acquaint with the whole process, a flowchart (1) has been presented in the following pages.

5. Earthquake Scenarios and the Method of Structure Analysis

As one the main objectives of this essay is evaluation of structure performance reinforced by VPD affected by real acceleration time history records, two scenarios of earthquake related to Chi-Chi earthquake (Taiwan) are used that these two records coincided with the soil type D of UBC97 standard and the first record was taken from the station CHY065 that was far fault with 0.6g PGA. The second record was taken from the station TCU068 that was near fault with 0.56 g PGA [22].

Considering the effect of large deformations and P-Δ, nonlinear time history analysis (NTHA) has been used. All models are evaluated in both situations namely, with and without VPD and the effect of different parameters. In the table (1) the characteristics of earthquakes are showed. On the other hand damping coefficient is considered commensurate with the first and second modal period of buildings.

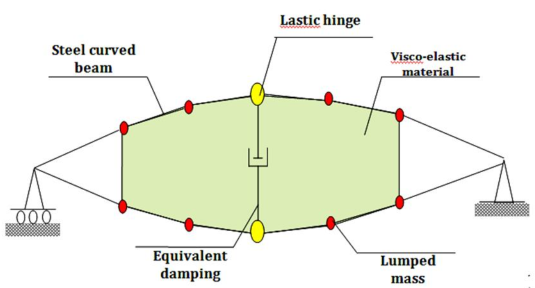


Figure .2 VPD simplified SAP2000 ([17] and [14]).

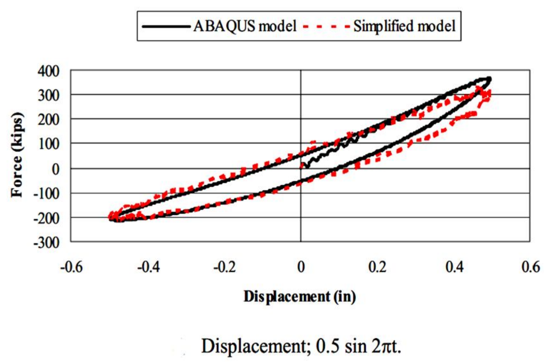


Figure .3 Comparisons between simplified model and the FE model ([17] and [14]).

Table1 - Earthquake Characteristics Selected Through Analysis.

Row	Location of earthquake	The year of occurrence	Station name	Distance (km)	PGA(g)	The type of earthquake
1	Chi-Chi in Taiwan	1999	CHY065	43.83	0.6	Far from fault
2			TCU068	0.32	0.56	Near to fault

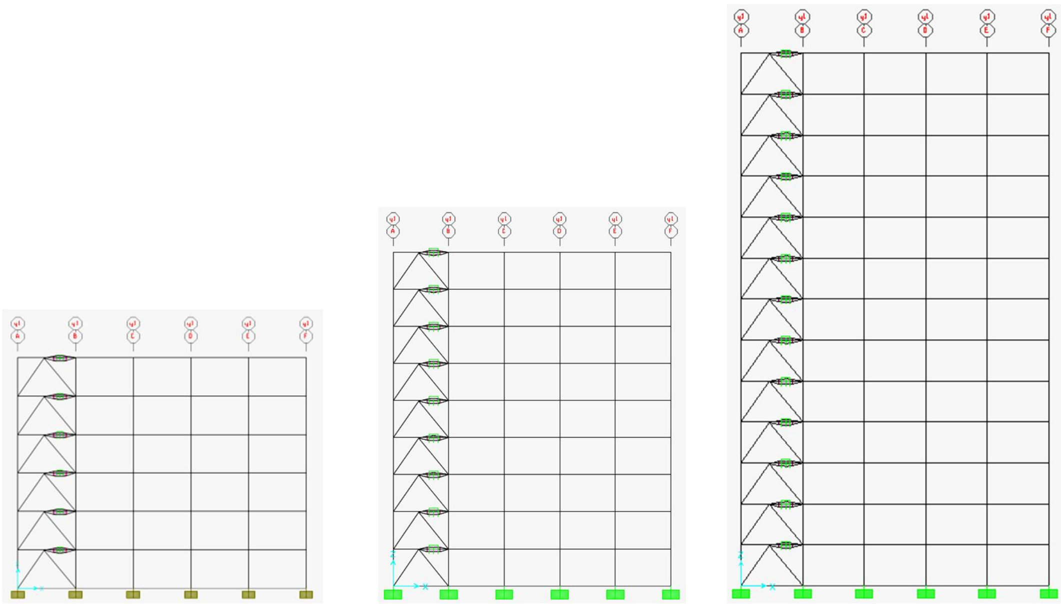
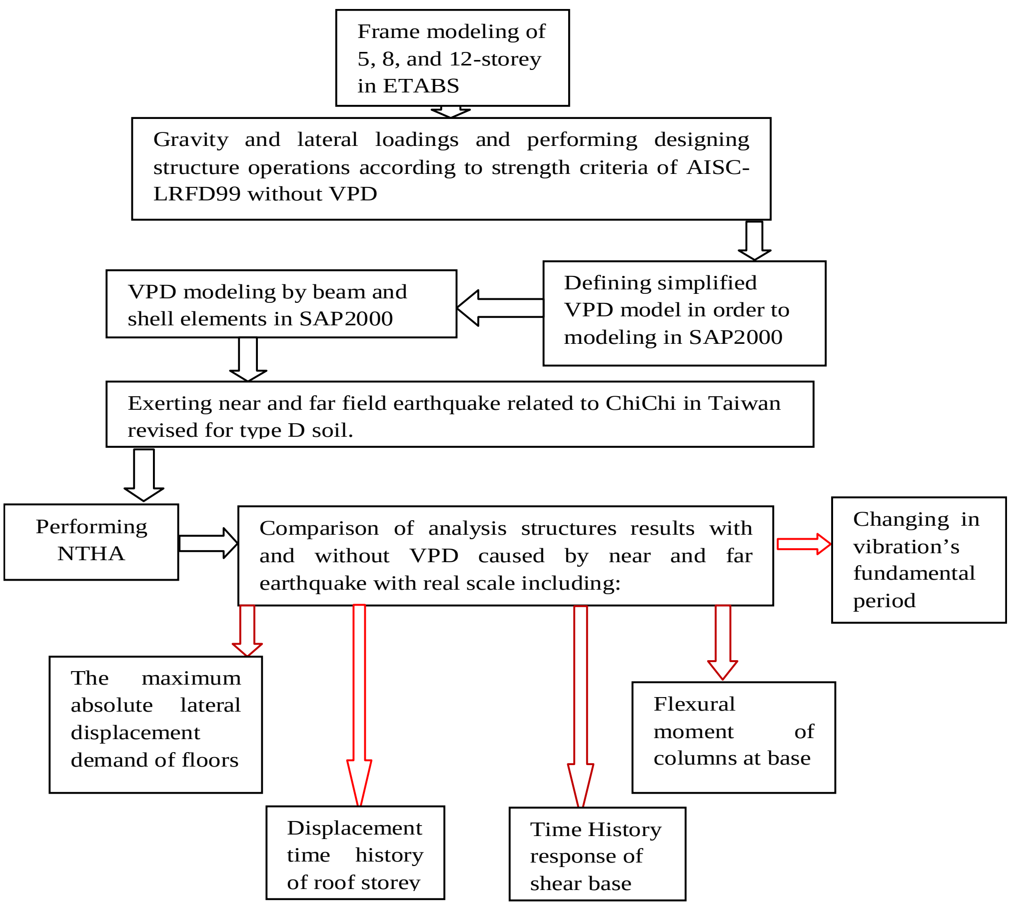


Figure .4 Schematic views of frames with 5, 8, and 12 storeys with localization of one VPD.



Flowchart .1 Steps of research on VPD dampers behavior

6. Reviewing of Structure Response Parameters

As stated earlier, the aim of VPD usage is improvement of seismic performance of structures against real earthquakes. The parameters which are reviewed in this case are:

- The maximum absolute lateral displacement of floors (absolute storey drift)
- The drift response history of roof.
- the history of base shear force
- The flexural moment of all columns located at base floor.
- Maximum inter-storey drift index
- Fundamental period of each models

It is worth to mention that all above results have been depicted separately in the case of w/wo VPD against two real time history accelerations as near and far field earthquakes.

6.1. Maximum Inter-story Drift

In this section results related to the absolute lateral displacement of floors at the maximum deformation time of floor affected by exertion record in 5, 8, and 12-story structures have been showed. In the figure 5-a results related to far field earthquake are depicted and in the figure 5-b the results related to near field earthquake are shown too.

By referring to figure 5, the first inferred point is that in the three studied structures, the use of VPD damper causes a decrease in the absolute lateral displacement demand of floors. But with an increase in the number of floors, the effect of damper in both situations of near and far field earthquake decreases. From the quantitative point of view, for building of 5, 8, and 12 floors affected by far field earthquake, displacement decrease are estimated as 86%, 60%, and 60% in comparison with structures w/o VPD usage respectively. In contrast, under near field earthquake these decrease percentages are 68%, 73%, and 35% respectively. So for created models, we may conclude that in models affected by far field earthquakes, once the number of floors is increased, the ratio of displacement decrease is on average 1.18 times more exposed far field records. So under the effect of near field earthquake, once the number of floors is increased, the effect of damper in the displacement decrease is less than far field one. So it is suggested that for high-rise buildings built in places with high risk of near fault earthquake, the number of VPD dampers in each floor should increase in order to compensate these defects.

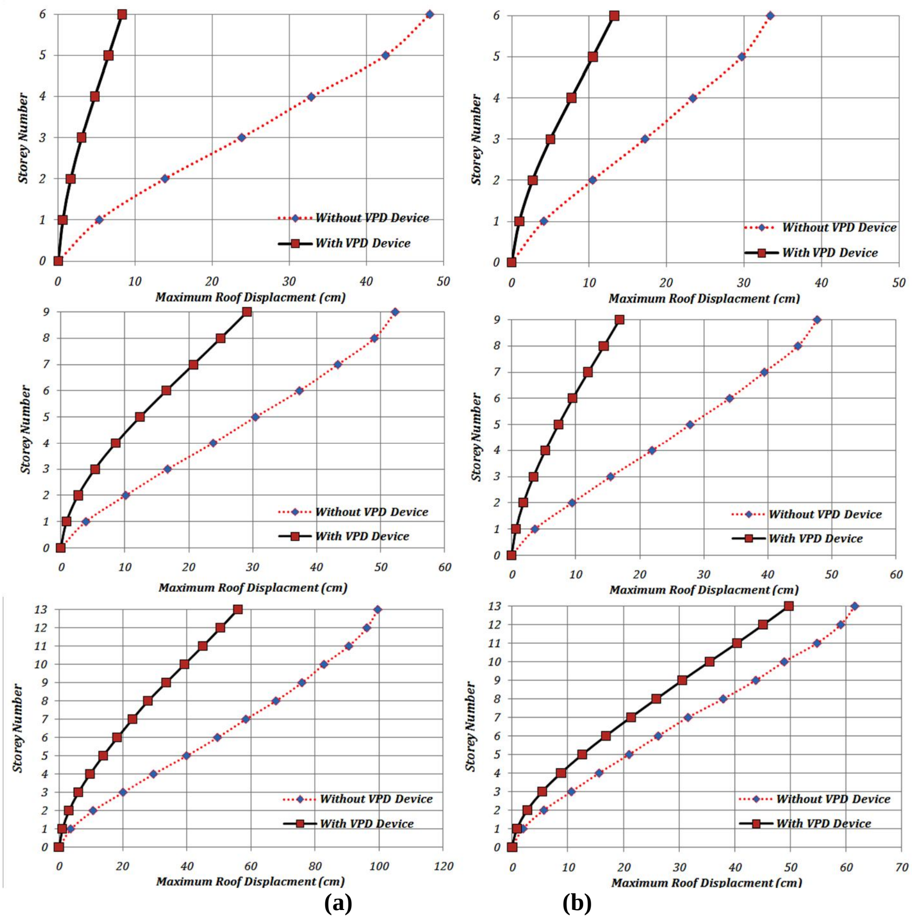
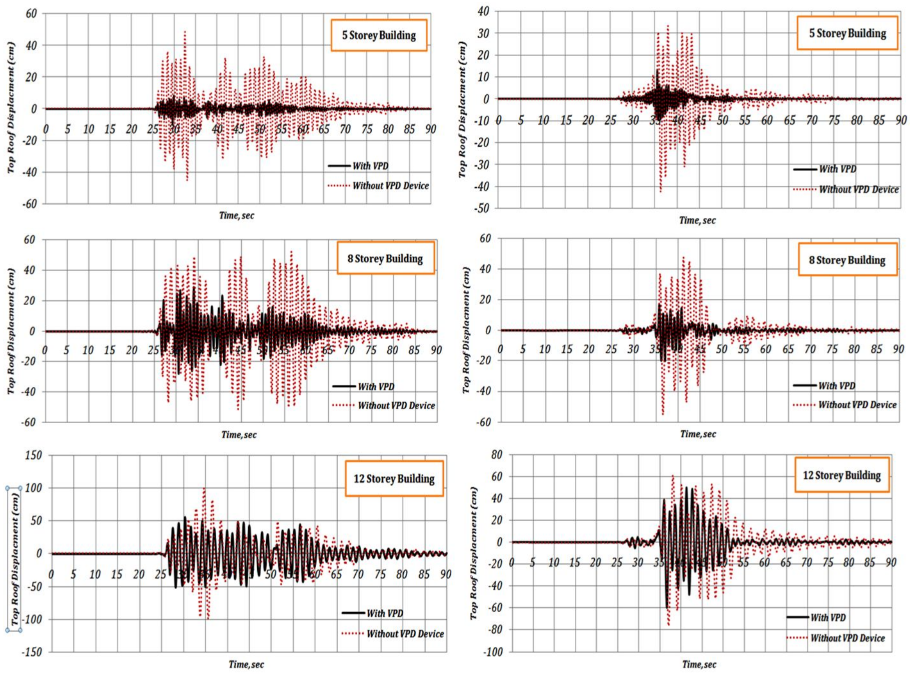


Figure .5 Absolute lateral displacements of storey affected by (a) Chi-Chi far field earthquake (b) Chi-Chi near field earthquake.

6.2. Roof Displacement Response History.

One of main and important factors in evaluation of VPD performance for improvement of structure lateral response is reviewing diagram of the roof storey lateral response history of each floor. The related results are shown in the figures (6-a) and (6-b).

Considering the presented diagrams in figure 6, from qualitative point of view, this point could be inferred that using VPD in all reviewed situations causes a significant decrease in the roof storey response history affected by two far and near field earth- quakes. On the other hand with the increase of number of floors, the effect of VPD decreases. From the quantitative point of view the use of VPD in 5-floor buildings leads to 79% decrease of the maximum displacement affected by far field earthquake. In near to fault situation this effect has been estimated as 68.9%. With the increase in the number of floors in 8 and 12-story buildings affected by far field, the use of VPD causes a decrease in the structure response roof storey to 44.2% and 43.8% respectively. While for the same structures in the near field situation, the use of VPD decreases the roof storey maximum displacement to 63.5% and 21.9% for 8 and 12-story buildings respectively. Another important point to mention is when there's an increase in the number of floors, in spite of the fact that the use of VPD leads to a decrease in the roof storey maximum displacement demand, the rate of the displacement decrease through total time history response has no significant change. For example in 12-story building affected by far field earthquake in the period of 40-50 seconds, the use of VPD leads to an increase in the roof storey displacement history to 20%. In some cases the use of VPD in a specified period leads to no change in the roof storey response. In all of the used-VPD-conditions the residual displacement of all structures decreases at the end of earthquakes.



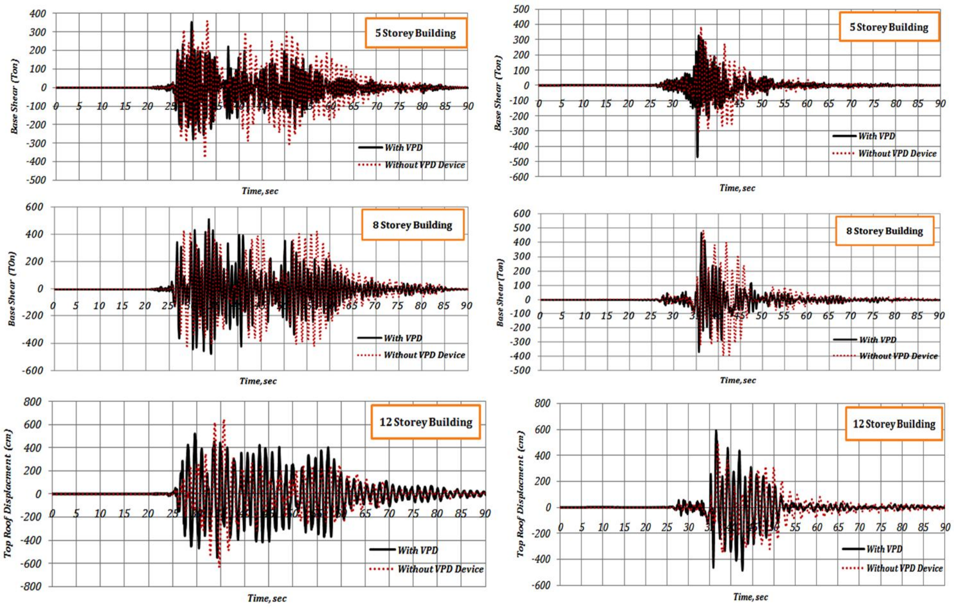
(a) **(b)**

Figure .6 Roof storey displacement history affected by
(a) Chi-Chi far field earthquake (b) Chi-Chi near field earthquake

6.3. Base Shear Force Response History.

The other important parameter that is considered in the reviewing structure performance reinforced by passive control system is the base shear force exerted on the structure. To deal with this parameter the results of base shear on 5, 8, and 12-storey buildings in two situations namely, far from and near to fault have been depicted in the figure 7.

By referring to figure 7 it could be inferred that from qualitative point of view the use of VPD has no significant effect on base shear force in two situations. Though this conclusion is on all passive control systems, in some cases the use of VPD, increases the maximum base shear and this is one of the most important drawbacks of passive control systems such as VPD. For the purpose of reviewing results from quantitative point of view, application of VPD for 5 and 12-floor structures causes the decrease of the maximum base shear to 1.4%and 14.9% respectively, yet for 8-floor building the maximum base shear has increased to 17.9%. If the recording is near to fault, the application of VPD in 5 an 8-floor buildings will lead to 16.3% and 2.7% decrease in the maximum base shear respectively.



(a) **(b)**

Figure .7 The base shear time history response affected by
(a) Chi-Chi far field earthquake (b) Chi-Chi near field earthquake.

While for 12-floor building, 18.3% increase in the maximum base shear will be observed. On the other hand with an increase of the number of floors, the use of VPD leads to increase of the base shear force in almost all of the exerted time history records. For example in the figure 7-a, for 12-floor building affected by far field, in a major part of the recorded history on base shear, an increase of 30% is observed. On the other hand for near field earthquake in a 12-stoery building, in addition of increase in base shear force, in most of periods the rate of base shear history increases too.

For evaluating VPD effect on the maximum of base shear, the figure 8 is depicted that its orthogonal axis is normalized base shear that is estimated by dividing the maximum shear force in the presence of VPD by its equal amount without VPD. It is obvious that in near field situation with the increase of the number of floors, the ratio of the maximum normalized base shear increases. But in the far field situation only for 8-floor structure this ratio is estimated to be 1.18 which indicated the maximum base shear increases when VPD is used.

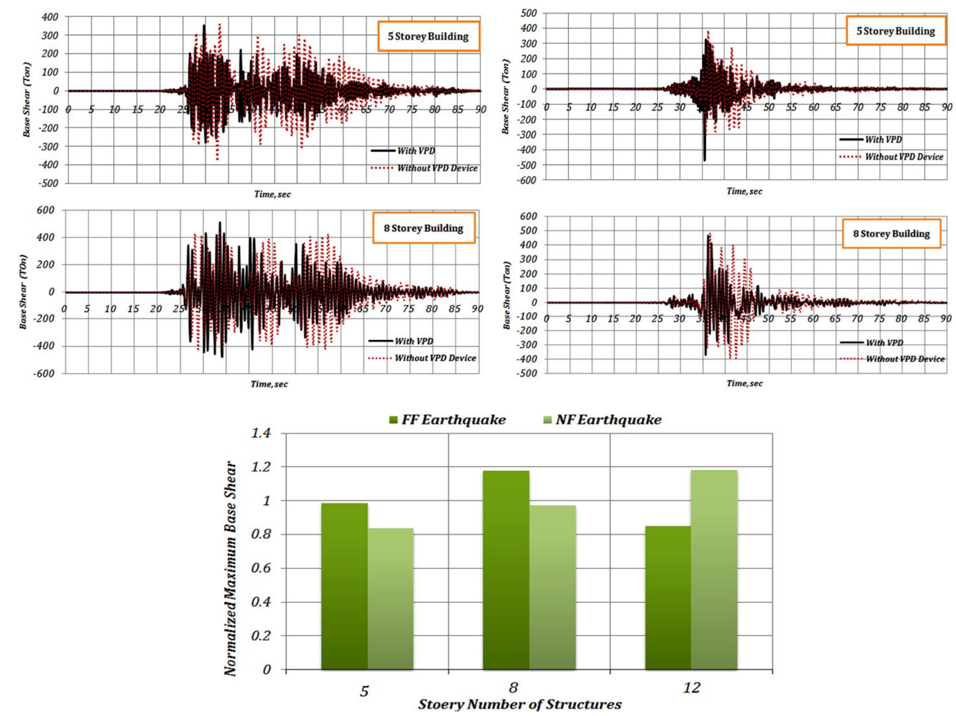


Figure .8 Normalized base shear force- the ratio of the maximum structure base shear with VPD to the maximum structure base shear without VPD

6.4. Maximum Flexural Moment of Base Floor Columns.

In designing SMRF process due to the fact that a collection of columns and beams bear lateral forces in addition to gravity forces, therefore in addition to axial force caused by earthquake, owing to rigid connection of beam to column, a significant flexural moment is created in columns especially in base floor. In this case through strong ground motions, by forming a plastic hinge, causes one or more of lower columns deviated from their appropriate performance. The main reasons for flexural moment at the columns are lateral displacement of floors and created rotations at the connection nodes between beam and column. So it is expected that the use of VPD has a significant effect on the decreasing of flexural moment at basement columns. On the other hand because of using Chevron bracing configuration, so this system cooperates in shear force absorption of floors. To confirm this claim the results of the application of VPD damper in the manner of decreasing percentage of flexural moment of columns are depicted in the figure 9-a to 9-c. The orthogonal axis of these diagrams is decreasing percentage of flexural moment of columns with the presence of VPD. These decreasing percentages have been depicted for the far and near recording separately. From the qualitative point of view, the use of VPD has a significant and noticeable effect on the decrease of flexural moment at the ground floor columns. But from the quantitative point of view, in the 5-floor building according to figure 9-a, the use of VPD on average causes 90% decrease in flexural moment imposed by far field record and 80% decrease in flexural moment in the case of the near field. For the 8- floor building too, for the far and near situations this figure is illustrated 82% and 85% average reduction respectively. In the 12-storey structure on average the decreasing percentage of flexural moment in far field is 90% and in near field is 83%. So it could be inferred that due to significant effect of VPD on decrease of displacement, the bending at columns at all situations is decreased.

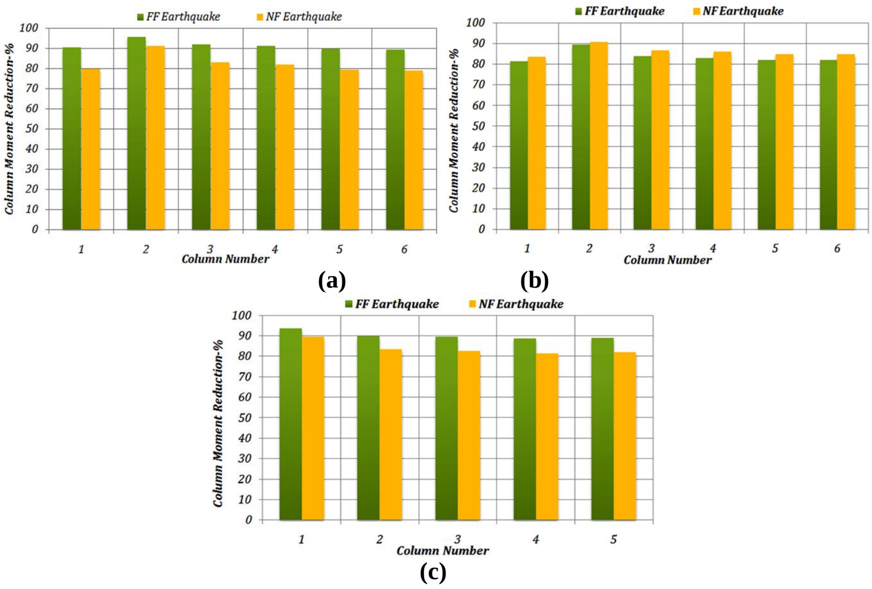


Figure .9 The decreasing percentage of flexural moment of columns on base floor of (a) 5-storey structure, (b) 8-storey structure, and (c) 12-storey structure.

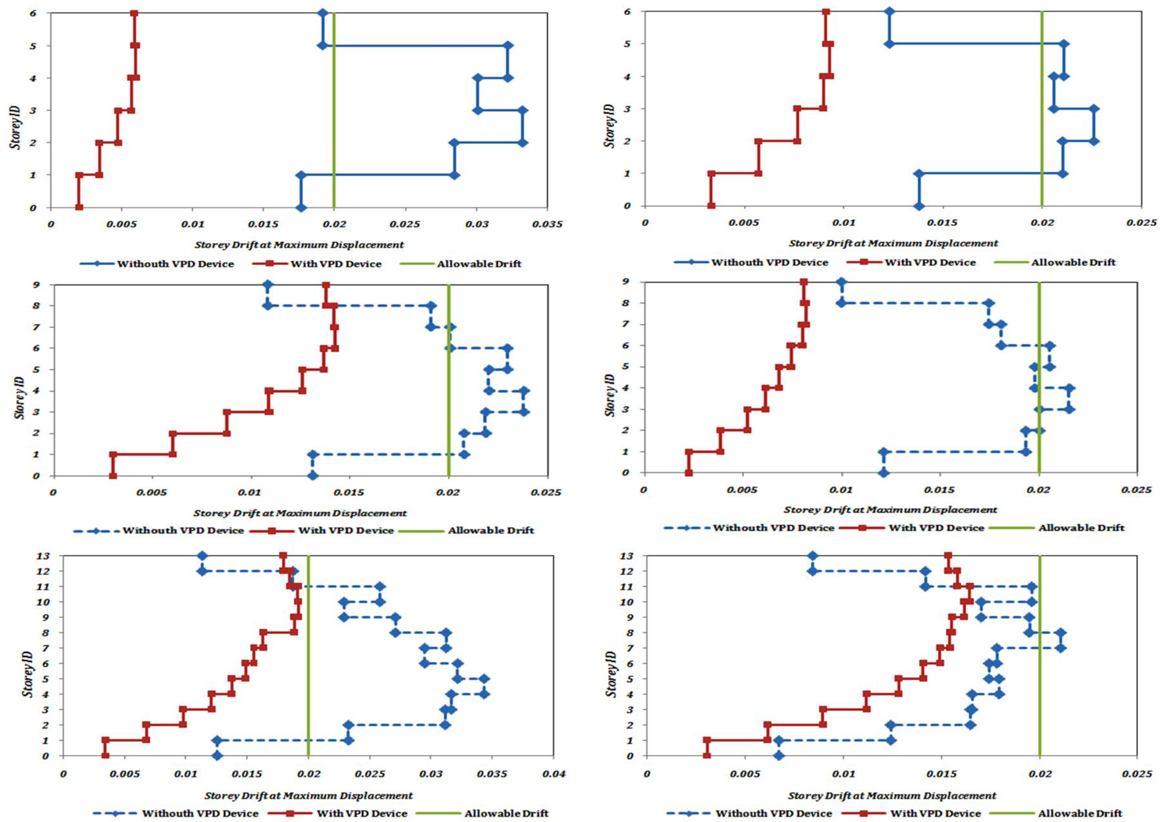
6.5. Inter-Storey Drift Index

In the majority of seismic analysis and design codes, such as UBC97, the displacement control limitation is defined as a main criterion in structure design. Most of researchers believe that this criterion is one the performance level that already exists in most seismic codes. On the other hand, displacement limitation is an introduction to performance base design of structures. One the most important advantage of behaving according to this regulation is limiting lateral displacement of structures in order to prevent from striking of two structures and causing pounding force. The other reason is the relief and welfare of residents. So controlling structure displacement is generally carried out in two levels; Operating level earthquake and deign level earthquake.

As stated in the introduction, analytical models of this essay are designed in such a way that in order to not to be accountable to displacement criterion. Then by devising a VPD damper in the first building span, it is aimed to comply with this criterion. In the figures 10-a and 10-b, the amount of floor drift index of 5, 8, and 12-story buildings for the far and near fields earthquakes have been depicted. In this figure admissible drift index according to UBC97, is considered 0.02. On the other hand the amount of drift with and without VPD for the purpose of comparison and evaluating the effect has been depicted too.

According to these figures from the qualitative point of view the use of VPD in all situations leads to complying floor drift. But with increasing the number of floors, the amount of controlled drift by structure with VPD, gets near to the structure without damper. On the other hand for 12-storey buildings, in the upper floors due to the far and near field earthquakes the drift index of a structure with VPD has been estimated to be more than structures without VPD. So it is suggested that in high-rise structures the number of visco-elastic dampers increases.

From the quantitative point of view and according to 5-storey building graph, in the far field situation the maximum amount of drift index decrease relates to the first floor that estimated to be 88.9%. On the other hand the minimum amount of drift decrease relates to the last floor that estimated to be 69.3%. These results for the near field are 76% and 26% respectively. For the 8-storey building and in the case of far field the maximum and minimum amounts of drift index decrease are 71% and 25% respectively. It is worth to mention that the use of VPD causes the last floor drift index has developed to 27%. The results of the near field are 79% and 19% respectively and in such a condition the use of VPD doesn't lead to drift increase. In contrast, for 12-storey building in the case of far field, the maximum and minimum amount of decrease is 16% and 5.72% respectively and the last floor drift index has developed to 58% but not beyond admissible extent. On the other hand, for the near field situation the maximum and minimum of decrease are 54.7% and 5.13% respectively. While in the last floor, the drift index has developed to 81% that is not beyond extent. An important point which worth to mention is that with the increase of height, the drift index using VPD increases. But in all analyzed models, just by occupying one VPD in each floor, the amounts of drift index have decreased significantly. Also in none of such situations the decreased drift index has not reached beyond admissible extent of the regulation. This issue is one of the most important properties of VPD in structure control science. Therefore in the situations in which high-rise structures have been built together and without considering suggested regulation for separation distance, the use of VPD can reduce the possibility of striking and its secondary effects.



(a) (b)

Figure .10 Storey drift index affected by: (a) Chi-Chi far field earthquake (b) Chi-Chi near field earthquake.

6.6. Building Fundamental Period

An issue that always limits researchers to deal with control tools is applied changes on dynamic properties of structures which have been reinforced by control elements. As most of passive control tools have initial stiffness, so cause a stiffness change and consequently cause a change in the structure period. As the damping of structure depends on stiffness and mass, by proportional damping definition, any change in the stiffness of structure causes changes in the structure damping, so creating appropriate balance between stiffness and damping is an important parameter. In VPD damper, due to curved form of steel elements (initial compulsory buckling), the role of these elements in increasing structure stiffness is no so significant. But due to stiffness of applied visco-elastic material in VPD, changing in structure stiffness is inevitable. For evaluating the effect of damper stiffness on dynamic properties of structures analyzed in figure 11, the normalized seismic structure fundamental period for 5, 8, and 12-storey buildings a bar graph has been depicted. Normalized seismic structure period means the ratio of structure period with VPD to the equivalent amount of which without VPD. As it is expected, due to the initial stiffness of damper element the final stiffness of structure increases and consequently the reinforced structure period decreases. From the qualitative point of view the ratio of the normalized structure period has been estimated always less than 1, but with the increase in height structure the ratio increases. From the quantitative point of view, the percentage of structure period decrease for a 5, 8 and 12 storey building is 52%, 38%, and 26% respectively. This decrease of structure period has a significant role in the dynamic spectrum analysis. Since in the design spectrum, by the decrease of period, quasi-acceleration of structures generally increases and consequently leads to base shear force increase which is produced by dynamic-spectrum analysis.

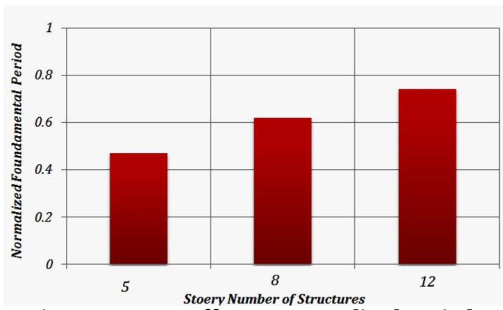


Figure .11 VPD effect on normalized period

7. Conclusion and Remarks

In this paper the seismic performance of steel moment resisting frames which were equipped with visco-plastic damper has been evaluated and analyzed. One of the most important aims of this study is evaluating the effect of VPD damper on the displacement demand of floor and consequently on the inter-storey drift of floors affected by far and near fields real earthquakes records. For such a researching, the nonlinear time history method has been used and the effects of large deformation and $P\text{-}\Delta$ have been considered. On the other hand the inherent damping of frame has been supposed 3% and to modeling the damping effect of visco-elastic part of the damper, the nonlinear element with behavioral model of Maxwell called NLLINK, has been used. For calculating damping coefficient of system, the damping property of proportional Rayleigh has been used. Evaluating of the results confirms the significant effect of VPD in limiting floor drift, displacement time history response of roof, and the maximum displacement of floors. Therefore for the structures in which the drift has not been controlled, those which just are accountable for strength criterion, the use of VPD could be accountable for the drift index control. The most important results gotten from model analysis are:

1. Due to axial stiffness of visco-elastic material (central core part of damper), during low amplitude motions because of orthogonal axial deformation of rubbery element, the earthquake’s energy is dissipated. But by the increase of motions, in addition to visco-elastic material, the steel element acts too and by forming plastic hinge at the centre of buckled steel elements, the earthquake’s energy is absorbed.
2. By reviewing 5, 8, and 12-story models, from qualitative point of view, the use of VPD dampers in all floors and only in one span, decreases the maximum lateral displacement of floors in the far and near fields earthquakes significantly. From quantitative point of view, for 5, 8, and 12 storey models in the far and near fields earthquakes, the average displacement decrease are 86%, 60%, and 60% respectively. In contrast, in the near field earthquakes these reduction percentages for displacement response are 68%, 73%, and 35% respectively. So we can conclude that in models affected by the far field earthquakes, with the increase in the number of floors, the ratio of the displacement decrease is on average 1.18 more than the near field situation.
3. From the qualitative point of view it can be inferred that the use of VPD in all situations, causes a significant decrease in the history of roof storey response in the far and near field earthquakes. On the other hand the increase of

the number of floors decreases VPD effect. From the quantitative point of view, in the far field the use of VPD in 5 storey buildings leads to 79% decrease in the maximum roof storey displacement. While for the near field this effect will be 68.9%. With the increase in the number of floors in 8 and 12 storey buildings in the far field, the use of VPD causes a decrease in the maximum roof storey response to 44.2% and 43.8% respectively while for the same group of structures in the near field, the maximum displacement demand of roof storey decreases to 63.5% and 21.9% respectively.

4. The application of VPD has not a significant effect on the decrease of base shear force in the far and near field earthquakes. But this conclusion in majority of passive control systems is observed. In some cases the use of VPD, increases the maximum base shear and so this is one the main disadvantages of passive control systems such as VPD. For example in a 12 storey building affected by the far field, in a significant part of the recorded base shear, a 30% increase is seen. On the other hand for the near field in the same structure, in addition to the maximum base shear force in most times of this parameter increasing rate is seen.

5. As a strategy, considering good performance of VPD in the relative and absolute displacement decrease of floors, it is expected that the use of VPD decreases the flexural moment at columns significantly. From the quantitative point of view, in 5 storey building, the use of VPD on average causes moment decrease to 90% in the far fields and to 80% in the near fields. In 8 storeys building also the use of VPD on average causes moment decrease to 82% in the far fields and to 85% in the near fields. Also for 12 storey building, the use of VPD on average causes moment decrease to 90% in the far fields and to 83% in the near fields. So it can be inferred that due to significant effect of VPD in decrease of displacement, the moment at columns in all situations decreases significantly.

6. The use of VPD in all structures and affected by the far and near fields, causes a decrease in floor inter-storey drift index in the way that in all structures the existed drift index is estimated less than allowable drift index regarding to UBC97 related regulation. For example for a 12 storey building affected by the far field earthquake, the maximum and minimum amounts of decrease are estimated as 16% and 5.72% respectively and roof drift index increases to 58% and it is not beyond the allowable extent. On the other hand the maximum and minimum amounts of decrease have been estimated as 54.7% and 5.13% respectively for the near field earthquake and it is not beyond the allowable extent too.

7. From the quantitative point of view for evaluating the effect of visco-plastic damper on the structure fundamental period, the ratio of normalized period always has been estimated less than 1 but with an increase in the structure height, this ratio increases. From the qualitative point of view, the percentage of structure period decrease for a 5, 8 and 12 storey building is 52%, 38%, and 26% respectively. This decrease in period needs important consideration during dynamic spectrum analysis.

8. Suggestions

As evaluations resulted from this research confirm the significant effects of VPD damper on lateral displacement decrease of mid-height buildings, so the following points are suggested for the future researches:

1. Evaluating the effects of VPD damper on improvement of lateral response of asymmetrical buildings.
2. Reviewing VPD damper performance on striking two structures phenomenon in structures which have not enough separation distance.
3. Analyzing VPD damper behavior under the effect of pulse impact resulted from striking of two buildings
4. Evaluating performance of structures rehabilitated by VPD affected by the far and near fields earthquakes
5. Reviewing performance of high buildings strengthened by VPD, focusing on optimized localization and number of dampers.
6. Reviewing performance levels of structures reinforced by VPD according to ATC-40 and Fema353 rehabilitation regulations.

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REFERENCES

[1]. Cherry S, Filiatrault A. "Seismic response control of buildings using friction dampers". Earthquake Spectra 1993; 9(3):447–66.
[2]. Nims DK, Richter PJ, Bachman RR. “The use of the energy dissipating restraint for seismic hazard mitigation”. Earthquake Spectra 1993; 9(3): 467–89.
[3]. Dargush GF, Soong TT. “Behavior of metallic plate dampers in seismic passive energy dissipation systems”. Earthquake Spectra 1995; 11(4): 545–68.
[4]. Tsai K, Chen H, Hong C, Su S.” Design of steel triangular plate energy absorbers for seismic resistant construction”. Earthquake Spectra 1993; 9(3):505–28.
[5]. Wada A, Huang Y, Iwata M. “Passive energy technology for buildings in Japan”. Progressive Structural Engineering Materials 2000; 2:335–50.
[6]. Bergman DM, Hanson RD. “Viscoelastic mechanical damping devices tested at real earthquake displacements”. Earthquake Spectra 1993;9(3): 389–417.
[7]. Chang KC, Soong TT, Lai ML, Nielsen EJ. “Viscoelastic dampers as energy dissipation devices for seismic applications”. Earthquake Spectra 1993;9(3):371–87.
[8]. Symans MD, Constantinou MC. “Passive fluid viscous damping systems for seismic energy dissipation. In: Passive control of structures”. ISET Journal of Earthquake Technology 1998; 35(4):185–206 [special issue].
[9]. Symans MD, Cofer WF, Fridley KJ, Du Y. “Seismic behavior of wood framed structures with viscous fluid dampers”. Earthquake Spectra 2004; 0(2):451–82.
[10]. Reinhorn AM, Li C. “Experimental and analytical investigation of seismic retrofit of structures with supplemental damping”. Part III-Viscous damping walls. National Center for Earthquake Engineering (NCEER) report 95-0013. Buffalo (NY); 1995.
[11]. Constantinou MC, Tsopelas P, Hammel W. “Testing and modeling of an improved damper configuration for stiff structural systems”. NY: Center for Industrial Effectiveness, State University of New York at Buffalo; 1997.
[12]. McNamara RJ. “Practical solution to reduce the wind induced response of tall buildings”. In: Tall building conference. 2001.
[13]. Derham CJ, Kelly JM, Thomas AG. “Nonlinear natural rubber bearings for seismic isolation”. Nuclear Engineering Design 1985; 84(3):417–28.
[14]. Ibrahim YE. “A new visco-plastic device for seismic protection of structures”. Ph.D. thesis. Virginia Tech.; 2005.
[15]. Hibbitt, Karlsson, and Sorensen, Inc. ABAQUS/standard user’s manual. Pawtuckett (RI); 2002.
[16]. Raos P. “Modeling of elastic behavior of rubber and its applications in FEA”. Plastics, Rubber and Composites Processing and Applications 1993; 19(5):293–303
[17]. Ibrahim YE, Marshall J, Charney F.A. “A new visco-plastic device for seismic protection of structures”. Journal of Construction Steel Research 2007; 63:1515–1528.
[18]. Yoshida J, Abe M, Fujino Y. “Constitutive model of high-damping rubber”. Journal of Engineering Mechanics 2004;130(2):129–41.
[19]. Amin AFMS, Alam MS, Okui Y. “An improved hyperelasticity relation in modeling viscoelasticity response of natural and high damping rubbers in compression: Experiments, parameter identification and numerical verification”. Mechanics of Materials 2002; 34:75–95.
[20]. Computers and Structures. SAP2000 user’s manual. Berkeley (CA): Computers and Structures Inc.; 2007.
[21]. Computers and Structures. ETABS Ver: 9.5.0 user’s manual. Berkeley (CA): Computers and Structures Inc.; 2008.
[22]. Gerami M., Vaseghi A and Abdolahzadeh D, “Behavior Evaluation of Structures under Near Field Earthquake”. 4NCCE, Tehran University, Tehran, Iran, May 2008.
[23]. Tehranizadeh M., Rahim Labaf M.S., “Effective Parameters on Response of Structures During Near Filed Horizontal Axcitation of Seismic Source”. Journal of Road and Construction Society, 2005; Volume23.