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THE EFFECT OF VISCOELASTIC DAMPER ON REDUCING SEISMIC RESPONSES OF STEEL FRAME STRUCTURES

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ABSTRACT

When subjected to an earthquake motion, a structure should absorb and dissipate lots of energy in different ways, allowing the structural members to enter the inelastic range enabling them to absorb the energy by their deformations. As structural members enter the inelastic range, permanent deformations occur, and to continue utilization of structure, those members which are too deformed or cannot be utilized anymore should be strengthened or replaced with new members, an operation which is difficult and costly. Therefore, the dampers installed in the structure, through energy absorption induced by earthquake, prevent other parts of the structure to enter inelastic range; as a result, following an earthquake, different parts of the structure can be either still utilized or fixed and replaced, if necessary, by checking the dampers.

According to the aforementioned things, this study aims to examine the structures to which damper is added as a retrofitting method. For this purpose, by selecting a number of intermediate steel moment frames, seismic vulnerability of these frames in the near- and far-field earthquakes was examined and such parameters as damage to frames and stories, relative story displacement, base shear and roof displacement were examined. In this study, viscoelastic dampers are used in order to reduce drift and structural damage. The results after dampers installation in the middle span of frames were compared with/without using damper, then it was concluded that viscoelastic dampers play an important role in absorbing energy and reducing damage in buildings. Moreover, drift and base shear as well as roof displacement decrease to a great extent. Comparing near- and far-field earthquakes, it was observed that the intensity of near-field earthquakes was higher causing devastating effects in buildings; installation of dampers, however, highly reduces these damages. Furthermore, the effect of dampers on taller buildings was found to be more, and greater reduction was seen in the examined parameters.

Keywords: Damage; dynamic analysis; retrofitting; viscoelastic damper.

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1. INTRODUCTION

Examination of forces caused by severe earthquakes in structures shows that it is impossible to design a structure such that it is not influenced by minor and major damages. Accordingly, seismic design codes for low- and mid-rise buildings, especially under extreme ground motions, permit considerable structural damage; however, they do not present a clear definition of allowable damage. Primarily, the design of earthquake resistant structures is based on damage prevention during moderate or intermediate tremors and on prevention of collapse during severe earthquakes.

Failure in structural member occurs when the members will experience non-linear cycles or permanent plastic deformations, stiffness and strength deteriorations [1, 2]. Indeed, after a strong earthquake, many buildings experience various degrees of damage and some collapse. One of the most difficult tasks of the post-earthquake inspection is to assess and quantify the seismic damage or estimate the seismic safety and further usability of the remaining building stock [3, 4].

The addition of energy dissipation system in structures provides a useful option to reduce building damage. Dampers have been widely used for reduction in structural damage as a means of energy dissipation. In this research, viscoelastic dampers have been used for damage reduction of structures. One advantage of using viscoelastic dampers is that to activate them, no level of external stimulation is needed, and unlike friction dampers which cannot be activated for less than slip force, viscoelastic dampers dissipate energy in an earthquake of any magnitude thereby reducing structural damage.

2. PARK-ANG DAMAGE INDEX

Following quantitative approaches to vulnerability assessment, some vulnerability criteria have been introduced by researchers. These criteria which express the concept of structural damage degree with a suitable theory, calculate a specific value called damage index. Park-Ang damage index is well-known and is among the most popular indexes. The damage index shows such a viewpoint that under seismic loading, structural members are generally damaged by a combination of stress reversals and high displacement excursions. This index is expressed as follows which is presented to calculate the index damage of each member [5].

$$D_{PA,i} = \frac{U_{max}}{U_u} + \frac{\beta}{Q_r.U_u}\sum dE \tag{1}$$

In Eq. (1), U_{max} is maximum deformation, U_u is ultimate deformation under static monolithic loading, Q_r is yielding strength, dE is the absorbed hysteretic energy and β is a non-negative factor of strength reduction which can be gradually obtained. The value for steel structures was recommended to be 0/025.

It is necessary to use weight method in order to obtain an index for total building damage. Park introduced one of these equations. In this Eq., the weight parameter is the amount of absorbed energy; hence, more attention has been paid to more damaged members. Eq. (2) is introduced by Park presented for calculation of index damage [5].

$$D_{story} = \frac{\sum D_i . E_i}{\sum E_i} \tag{2}$$

Kunnath et al. suggested a weighted average of local damage indices, as is shown in Eq. (3) [6]:

$$D_{global} = \frac{\sum_{i=1}^{n} D_i . E_i}{\sum_{i=1}^{n} E_i} \tag{3}$$

where n is the number of substructures, D_i is local damage index at the ith substructure, E_i is the dissipated energy at the ith substructure, and D_{global} is the overall structural damage index.

According to the abovementioned issues, one can calculate damage value in members and then by taking average in story or between damage in stories, in overall structure. Over the past few years, many retrofitting techniques have been applied for buildings due to earthquake-induced damages to structures. One technique is application of energy absorption systems which are classified into different types based on their performance and the amount of energy required. Among structures control systems are passive control systems which do not need any external energy to operate. During an earthquake, the system is activated by the incoming wave of the earthquake, consuming lots of earthquake energy and protecting the structure. Nowadays, there are various types of passive control systems including viscoelastic dampers used in the current study.

3. VISCOELASTIC DAMPER

Viscoelastic dampers consist of viscoelastic material bonded to steel plates, as shown in Fig. 1. They include some steel plates with viscoelastic plates usually constructed from polymer with elastic and viscous properties, and the stress-strain relationship may be time-dependent. If the stress is held constant, the strain increases with time (creep); and if the strain is held constant, the stress decreases with time (relaxation) [7].

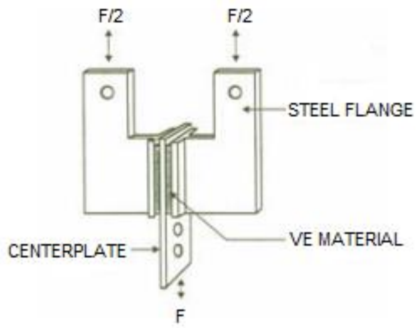

Figure 1. Viscoelastic Damper [7]

Viscoelastic materials have molecular, polymeric structure, in other words, they are long chains of repeating molecules. Due to the existence of the molecular network, viscoelastic material resists deformation, this behavior is one property of the material; more precisely, by addition of this material to the structure, structural system stiffness increases. On the other hand, while deformation is applied to this material, some of the molecular bonds are broken down and the heat is produced, depending on temperature and the loading frequency. So, some energy is spent to break the bonds, and is wasted. Damping of these materials is due to the breakdown of intermolecular bond. After loading over time, the material recovers their initial strength, and the amount of this recovery depends on the temperature of the material, stimulant frequency and strain amplitude. In short, one will face an increase in stiffness and damping in the structural system by using the material above in the structure. Installation of the dampers should not be limited only to braces, but they can be used with special arrangements throughout the structure in which shear deformations occur. If shear-storage modulus G' and shear-loss modulus G'' are known, damping and stiffness of the damper are obtained using Eq. (4).

$$K_d = \frac{G'A}{h} \qquad C_d = \frac{G''A}{\omega.h} \tag{4}$$

where A and h are the cross section and thickness of viscous layers, respectively; and w is stimulus frequency. Various mathematical models are presented to describe dynamic behavior of viscoelastic materials such as Maxwell and Kelvin models. Meanwhile, Kelvin model, which contains a spring and a linear damper arranged in parallel, is used to describe viscoelastic materials [8].

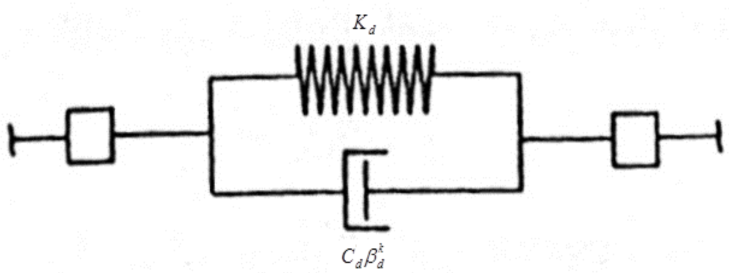

Figure 2. Kelvin analytical model for Viscoelastic Damper [8]

4. APPLICATION HISTORY OF VISCOELASTIC DAMPER

The application of viscoelastic materials to vibration control can be dated back to the 1950's, when Res et al., first used them on aircrafts as a means of controlling vibration-induced fatigue in airframes. Its application to civil engineering structures appears to have begun in 1969 when 10,000 viscoelastic dampers were installed in each of twin towers of the World Trade Center to help resist wind loads. Then, in 1982, 260 viscoelastic dampers were installed in 73-story structure at Columbia SeaFirst Building-America. In 1988, 16 viscoelastic dampers were installed in a 60-story structure to help resist wind vibrations.

The first application of viscoelastic materials to resist against earthquake dates back to 1993 in America, which was used in a 14-storey steel structure in Santa Clara County. This structure established in 1976 was retrofitted using 16 viscoelastic dampers. Other applications of viscoelastic dampers are in the Chain-Tam railroad station roof in Taipei, Taiwan in 1994 as well as in Turoshima tower in Japan in 1999 [9, 10]. Chang et al. investigated the effective factors in viscoelastic dampers performance such as temperature, frequency, etc. by installing three types of viscoelastic dampers with different properties in a 5-storey steel building through shaking tables test. They found out that these types of dampers play an important role in reducing seismic responses in all levels [11]. Chang et al. conducted some studies on non-linear behavior of a 3-storey steel structure by using shaking tables test at 28˚C and compared the results in cases with/without dampers. The results showed that viscoelastic dampers are effective in reducing the seismic response and inelastic ductility demand of structures with added viscoelastic dampers. Moreover, a damped structure using viscoelastic damper with high damping remains elastic under strong and large earthquakes [12].

Lee et al. compared the accuracy and efficiency of different conventional analysis techniques for building structures with added viscous dampers that include the methods of direct integration, complex mode superposition, and the modal strain energy method for 10- and 20-story structures [13]. Madsen et al. conducted some studies on viscoelastic dampers reporting that, first, dampers performance changes in various earthquakes due to different frequency contents of earthquakes; second, viscoelastic dampers perform better in lower stories, i.e. the nearest place to input energy resource [14].

Tezcan and Uluca, presented a non-linear dynamic analysis of a 7-story steel frame and 10- and 20-story RC frames, then, investigating the base shear, roof displacement and absolute roof acceleration, they concluded that structures equipped with viscoelastic dampers, according to damping considered for them, show reduction in structural responses to a great extent [15]. Rahmatabadi, performed a parametric study on structural steel models with different stories and spans and investigated the effect of damping on structure using viscoelastic dampers as well as the effect of frequency content of earthquakes records on performance of these dampers; finally, they suggested an optimal dampers distribution model in structure height [16].

Min et al. conducted vibration tests for a full-scale five-story steel frame with viscoelastic dampers. They examined dampers performance by adding chevron viscoelastic damper in different stories at two temperatures of 24 and 30˚C, and found out that damper installation in the structure reduces acceleration responses to a great extent, and this reduction was more at 24˚C than at 30˚C [17]. Zeynali and Zahraei, investigated the effect of viscoelastic dampers application on reduction of structural seismic responses such as last story drift and the force created in members by examining 18 building frames of different heights and Moment frame system, bracing frame and dual frames [18]. Tehrani examined vulnerability and optimization techniques of steel frames by using different types of dampers such as viscous and viscoelastic dampers. For this purpose, they conducted a non-linear dynamic analysis of 7 accelerations on a 9-story steel building. The results show that using those dampers in the structure results in structural drift and damage reduction, and many columns remain elastic [19].

Qanbari examined the performance of viscoelastic dampers in reducing seismic responses by considering soil-structure interaction and examining 3D irregular structural models [20]. Saidi et al. suggested a new passive viscoelastic damper to reduce roof vibration of buildings by examining the effect of composite roofs. They found out that this type of damper can be easily regulated for natural frequencies and different damping amounts and reduce roof vibrations [21]. Moliner et al. presented a study on the energy absorbing capacities of viscoelastic dampers (VEDs) for reducing the resonant vibrations of simply supported high speed railway bridges of short to medium span. They placed the dampers underneath the bridge deck to mitigate flexural vibrations. Numerical results showed that the dynamic response of the structure can be significantly reduced in resonance with the proposed damping system [22].

Lewandowski et al. studied the frames equipped with viscoelastic dampers. Fractional and classical derivative models and the complex modulus were used for viscoelastic damper modeling; then, dynamic properties of the frames were compared, finally, a formula was obtained for energy dissipation. Finite element method was employed to obtain motion equations of the frames [23]. Pawlak and Lewandowski, evaluated dynamic analyses of structures equipped with viscoelastic dampers and presented a method for determination of dynamic properties of structures equipped with viscoelastic dampers which can use a number of models to describe a structure at the same time. Fractional derivative technique was used to describe deformation properties of damper dynamic force [24]. According the previous studies performed on viscoelastic dampers, the current study aims to investigate the effect of using viscoelastic dampers on reducing seismic damage of steel structures. For this purpose, three steel frames of different heights under seven near-field and far-field earthquakes records were investigated using non-linear dynamic analysis; then, the parameters were examined and compared before and after addition of dampers to frames.

5. VALIDATION OF VISCOELASTIC DAMPER MODELLING USING PERFORM 3D SOFTWARE

To validate viscoelastic damper modelling in Perform 3D software, a 3-story structure which was previously tested by Chang et al. [12], was modeled based on Kelvin model in this software. As can be seen in Fig. 3, viscoelastic damper was diagonally installed in all stories.

The viscoelastic damper placed in this structure was designed and tested with frequency of 1.6Hz, 60% strain at %0.5 drift and %15 damping at 28˚C. Moreover, viscoelastic material used in this experiment was 3MISD110 with shear storage modulus of $G' = 0.06\ {}^{KN}/_{cm^2}$ and $\eta = 1$. Moreover, damper stiffness value was considered to be 3.5 ${}^{KN}/_{cm}$. This structure is considered under EL Centro earthquake with 0.5g scale. Viscoelastic dampers are mainly characterized by hysteresis loop, which is formed by a combination of viscous loop in a horizontal-oval shape and elastic loops in linear shape.

Finally, hysteresis loop of viscoelastic damper is in oval shape. After modelling the structure in Perform 3D software, the hysteresis loop was examined. The results show that the hysteresis loops obtained from the modelling are in good agreement.

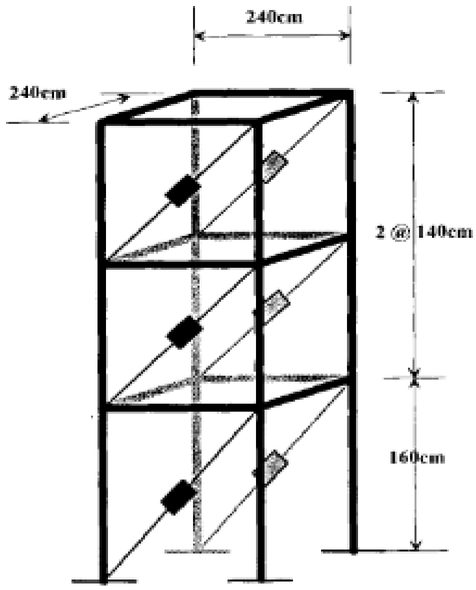

Figure 3. Layout and Dimention of test frame [12]

6. MODELING

In this study, three 2D intermediate moment resisting frames and 4-, 8- and 12-story structures of similar height of 3m and span width of 5m were selected. For example, Fig. 4 illustrates frame geometry of 4-story structure before and after damper addition. Effective load width is equal to half of span width (i.e. 2.5 m). Frame members of interest are made of steel with Modulus of Elasticity (MOE) of $2.1*10^6$ ${Kg}/{cm^2}$, yielding stress of 2400 ${Kg}/{cm^2}$ and ultimate fracture stress of $3700 {Kg}/{cm^2}$ Cross sections are made of IPE for beams and of IPB for columns. Dead load applied on each structure in all frames and stories including roof and middle stories were equal to $600 {Kg}/{m^2}$ and live load applied on each story including roof and other stories was considered to be $200 {Kg}/{m^2}$. UBC97 code was used for calculation of earthquake force imposed on the structure. Based on this code, structure weight is equal to dead weight of the structure plus 20% of live load of the structure. ETABS program was used for linear analysis and design of frame cross sections, stress ratio of members ranges between 0.9 to 1. Perform 3D software was used for dynamic analysis of frames [25].

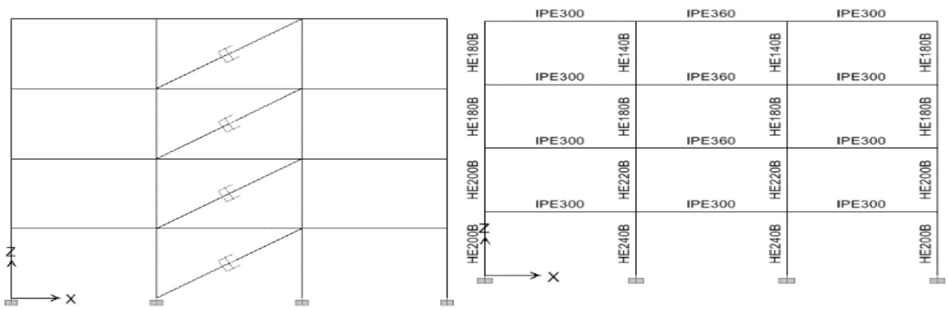

Figure 4. 4-story frame before and after adding viscoelastic damper

In this research, the Kelvin model is used as conventional one to model the dynamic behavior of the viscoelastic damper, which contains a spring and a linear damper arranged in parallel. Dampers design and determination of their properties is performed based on structure frequency with and without dampers at 24˚C and 20% strain (third of the maximum strain generated in damper) and 15% damping. Based on Soong’s studies [9] and the method designed by him, first, shear-storage modulus and shear-loss modulus were determined using structures frequency in case of no damper. In this study, $\eta = 1.1$. After G' and G'' are determined, damper area is calculated. Moreover, thickness of the damper can be determined based on the maximum allowable damper deformation, which is equal to 3.74cm in this study. Damping and stiffness of damper are determined. It should be noted that the stiffness of dampers was determined proportional to the stiffness of each story.

7. THE APPLIED ACCELERATIONS

In order to perform time-history non-linear dynamic analysis seven near- and far-field earthquake records have been selected. Accelerations have been selected such that the earthquake conditions are close in terms of their field. Therefore, it has been tried to select near- and far-field earthquake records from one earthquake such that other properties such as frequency content, duration of earthquake and conditions of earthquake source can be as close as possible. A rather complete description of these records is presented in Table 3. Based on the assumptions, frames were located in high-risk seismic regions and soil material was of type 2. Based on structure period, the selected PGAs following the regulations are: 0.69 for 4-story structure; 0.89 for 8-story structure; 1.07 for 12-story structure in far-field earthquake; and 0.58 for 4-story structure; 0.85 for 8-story structure; 0.95 for 12-story structure in near-field earthquake.

Table 1: Complete description of far- field records

Earthquake	Identifier	Magnitude	PGA(g)	Distance (km)	Year
Landers	JOS000	$M_S = 7.4$	0..274	21.2	1992/06/28
Kocaeli	ARC000	$M_S = 7.8$	0.218	17	1992/08/17
Imperial Valley	H/VCT075	$M_S = 6.9$	0.122	43.5	1979/10/15
Tabas	BAJ/L1	$M_S = 7.4$	0.094	121.2	1978/09/16

Loma Prieta	A3E090	$M_S = 7.1$	0.084	57	1989/10/18
Park Field	C12320	$M_S = 6.1$	0.063	17.3	1969/06/28
San Fernando	WTW025	$M_S = 6.6$	0.061	60.7	1971/02/09

Table 2: Complete description of near- field records

Earthquake	Identifier	Magnitude	PGA(g)	Distance (km)	3
Landers	CLW-TR	$M_S = 7.4$	0.417	11.3	1992/06/28
Kocaeli	SKR090	$M_S = 7.8$	0.376	3.1	1992/08/17
Imperial Valley	H-CPE147	$M_S = 6.9$	0.169	26.5	1979/10/15
Tabas	TAB-TR	$M_S = 7.4$	0.852	3	1978/09/16
Loma Prieta	STG000	$M_S = 7.1$	0.512	13	1989/10/18
Park Field	TMB205	$M_S = 6.1$	0.357	9.9	1969/06/28
San Fernando	PCD164	$M_S = 6.6$	1.22	2.8	1971/02/09

8. RESULTS ANALYSIS

After each frame model was prepared and constructed using Perform 3D software, the frames behavior was investigated under seven near- and far-field earthquake records. Then, after the outputs were extracted from the software, the values of drift, damage distribution, overall building damage index, base shear and roof displacement were calculated. After addition of dampers to the above frames, they were again investigated using dynamic analysis and the outputs were again calculated. In the following, each output is separately investigated.

8.1 Drift analysis

Fig. 5 to Fig. 7 illustrate average drift for the above frames under seven near- and far-field earthquake records with and without damper in order to present a general comparison of drift values reduction under near- and far-field earthquakes. Notably, graphs titled with VED (viscoelastic dampers) show the results after addition of viscoelastic damper.

As can be seen in Fig. 5 to Fig. 7 which are respectively related to 4, 8, and 12-story frames, middle stories displacement is more than other stories; and the frames under near-field earthquakes undergo more displacement compared to those under far-field earthquakes. Moreover, after installing a damper system in all stories, stories drift respectively decreases by 62%, 63% and 62% for 4, 8, and 12-story frames under far-field earthquakes, and by 59%, 75% and 70% for 4, 8, and 12-story frames under near-field earthquakes. It is concluded that VEDs are effective in reducing drift, and this effectiveness is higher in buildings with greater number of stories. In general, among the three fames under study, the effect of this damper on reducing displacement of 8-story frame under near- and far-field earthquakes was more compared to others.

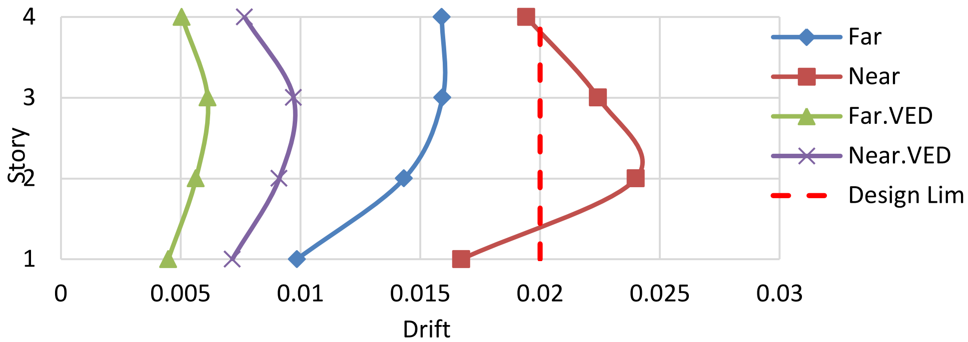

Figure 5. Average Drift under near- and far-field earthquake records with and without damper in the 4- story frame

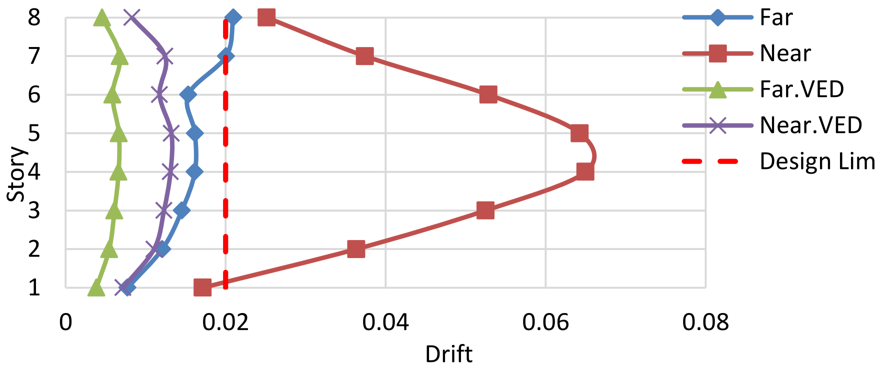

Figure 6. Average Drift under near- and far-field earthquake records with and without damper in the 8- story frame

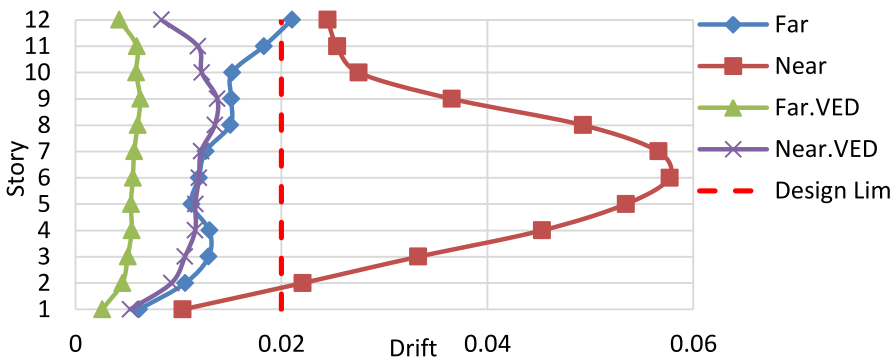

Figure 7. Average Drift under near- and far-field earthquake records with and without damper in the 12- story frame

8.2 Seismic damage distribution

Fig. 8. to Fig. 10 illustrate average damage index of stories for the frames under seven near-

and far-field earthquake records before and after retrofitting, in order to present a general comparison of reduction in damage index values under near- and far-field earthquakes after addition of dampers to the frames.

As can be seen in Fig. 8. to Fig.10 which are respectively related to 4, 8, and 12-story frames, the frames under near-field earthquakes undergo more damage compared to those under far-field earthquakes. After installing a damper system in all stories, stories drift respectively decreases by 58%, 57% and 62% for 4, 8, and 12-story frames under far-field earthquakes, and by 66%, 76% and 83% for 4, 8, and 12-story frames under near-field earthquakes on average. Therefore, it is concluded that VEDs are effective in reducing the frames damage, and this effectiveness is higher in buildings with greater number of stories. In general, among the three fames under study, the effect of this damper on reducing 12-story frame damage has been found to be greater compared to other stories.

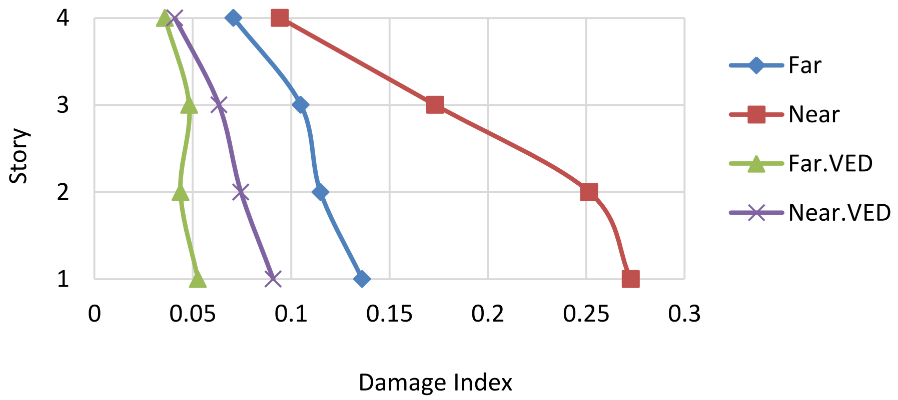

Figure 8. Average Damage Index of stories under near- and far-field earthquake records with and without damper in the 4- story frame

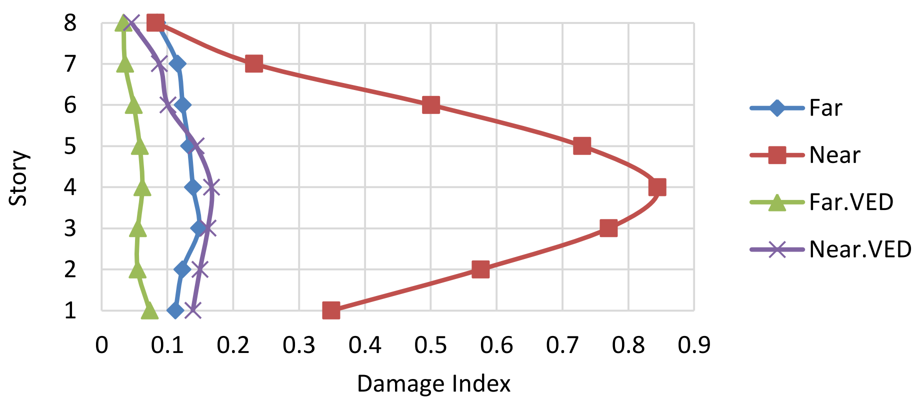

Figure 9. Average Damage Index of stories under near- and far-field earthquake records with and without damper in the 8- story frame

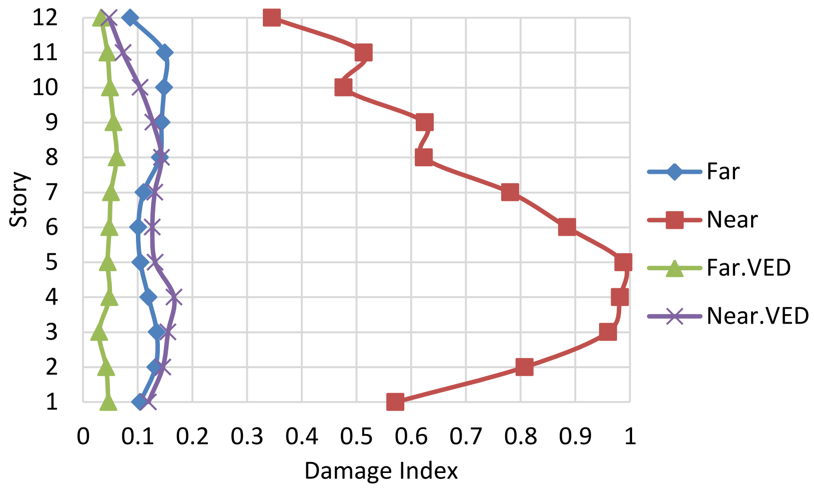

Figure 10. Average Damage Index of stories under near- and far-field earthquake records with and without damper in the 12- story frame

8.3 Evaluation of overall building damage index

The values of overall building damage for average near- and far-field earthquakes with and without damper have been shown in Fig. 11 as bar graphs.

Park-Ang determined damage index of 0.4 as the severe damage [5]. It should be mentioned that if the overall damage is less than 0.4, the overall index damage under a specific earthquake or the local damage index in structural members may be more than this value. This confirms the issue that the member has been severely damaged. As can be seen from the graphs, frames damage is more in near-field earthquakes than far-field earthquakes, and as the number of stories increases, damage also increases. Comparing and analyzing the damage index values in near- and far-field earthquakes, it can be observed that the 4-story frame under near-field earthquake undergo 0.25 damage value, which is quite close to the average value of Park-Ang damage index. However, 8 and 12-story frames undergo more than 0.4 damage value under near-field earthquakes which indicates a severe damage. By retrofitting the frames using VED, it is observed that the damage indices of 8 and 12-story frames reach to around 0.1 which is considered as a significant reduction in the amount of frame damage. By addition of damper to the frames under near- and far-field earthquakes, it is concluded that the value of damage indices for 4, 8 and 12-story frames are respectively reduced by 60%, 54% and 63% under far-field earthquakes and 66%, 77% and 83% under near-field earthquakes. Therefore, the effect of VED on reducing damages of high-height frames is more. In addition, they show a good performance in reducing damage under near-field earthquakes.

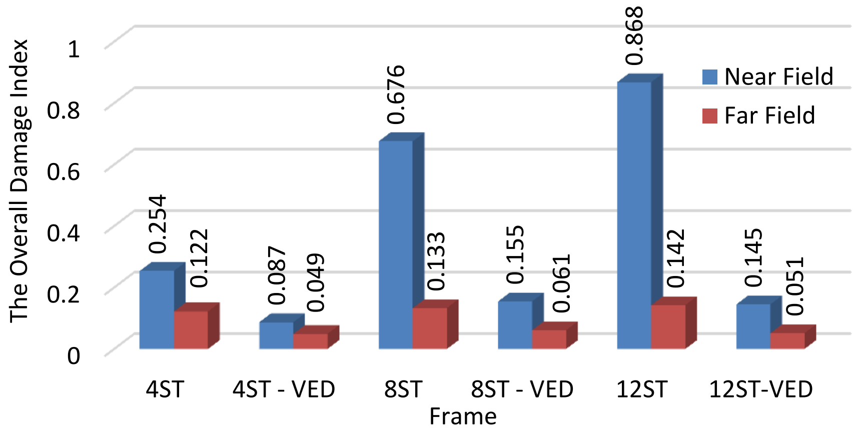

Figure 11. Overall building damage for average near- and far-field earthquakes with and without damper

8.4 Analysis of base shear of frames under study

The base shear values of the structure for average of near- and far-field earthquakes with and without damper are shown as bar graphs in Fig. 12.

Comparing near- and far-field earthquakes, it is observed that the base shear values under near-field earthquakes are more than the values under far-field earthquakes. Moreover, comparing different types of frames, it is concluded that as the height of frames increases, the values of base shear also increase. The results of base shear after addition of dampers to the frames are investigated. As can be seen from the graphs, these values decrease; in other words, by addition of dampers to the frames under near- and far-field earthquakes, it is concluded that the value of base shear for 4-, 8- and 12-story frames under far-field earthquakes are respectively reduced by 42%, 27% an 40% and by 52%, 45% and 58% under near-field earthquakes.

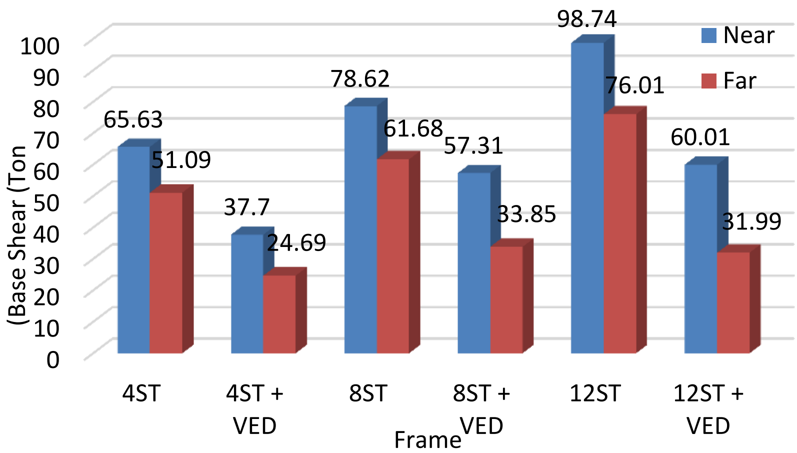

Figure 12. The base shear values of the structure for average of near- and far-field earthquakes with and without damper

8.4 Roof displacement analysis

Maximum roof displacement in terms of meter under far- and near-field earthquakes with and without damper is shown in Tables 3 and 4, respectively. Comparing far- and near-field earthquakes, it is concluded that the values of roof displacement under near-field earthquakes are more than far-field earthquakes. Furthermore, as the structure height increases, the values of base shear also increase. By addition of damper to the stories of the structure, the values of base shear decrease to a great extent. That is, the values for 4-, 8- and 12-story frames under far-field earthquakes are respectively reduced by 54%, 45% and 48% and by 55%, 68% and 64% under near-field earthquakes.

Table 3: Roof displacement for far- field earthquakes (cm)

Earthquake	4 Story Frame		8 Story Frame		12 Story Frame	
	Without Damper	With Damper	Without Damper	With Damper	Without Damper	With Damper
Landers	17.4	9.24	49.92	16	43.2	20.88
Parkfield	20.4	10.32	64	48	90	39.6
Loma Prieta	27.6	8.4	59.52	35.2	43.56	32.4
Tabas	8.28	3.84	30.4	16.69	48.24	18.72
Kocaeli	12	5.52	37.44	17.92	36.36	19.08
Imperial Valley	8.88	5.4	29.44	13.76	19.8	12.24
San Fernando	8.28	4.08	21.12	11.2	13.68	8.28

Table 4: Roof displacement for near- field earthquakes (cm)

Earthquake	4-Story Frame		8-Story Frame		12-Stpry Frame	
	Without Damper	With Damper	Without Damper	With Damper	Without Damper	With Damper
Landers	32.4	18	486.4	67.2	302.76	55.8
Parkfield	25.2	12	76.8	58.56	136.8	61.2
Loma Prieta	34.8	13.2	89.6	42.58	111.6	61.92
Tabas	18	8.64	39.68	30.4	122.4	36
Kocaeli	25.2	9.96	70.4	32	104.4	50.4
Imperial Valley	14.4	6.48	60.48	18.56	33.48	18.36
San Fernando	14.4	6	26.24	17.6	21.6	16.56

9. CONCLUSION

Analyzing the studies performed on the frames under study, it can be concluded that:

1. Installation of viscoelastic damper as a retrofitting technique in the frames under study plays an important role in reducing story drift and reduces all values to the allowed range; this reduction is significant for near-field earthquakes after addition of the damper.

2. Following calculation of story damage and overall structure damage, it is observed that buildings with higher number of stories experience more damages under near-field earthquakes compared to far-field earthquakes; such that for 8- and 12-story frames under near-field earthquakes, we see severe damages and a considerable amount of damage is reduced with damper addition.
3. The results show that addition of damper to frames with higher altitude performs better, thereby reducing structural damage to a greater extent.
4. By investigating base shear in frames under study, the results show that as the number of stories increases, base shear also increases. Addition of viscoelastic dampers to frames reduces base shear to a great extent, and this reduction is more for near-field than far-field earthquakes.

Comparing the level of roof displacement before and after damper addition to the structure, we observe that dampers reduce roof displacement to a great extent, and this reduction is almost more for near-field than far-field earthquakes.

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