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Performance of High-Rise Buildings Equipped with Viscous Wall Dampers Under Earthquake Excitation

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Abstract: **This paper presents a comprehensive investigation on Viscous wall dampers “VWDs” as supplemental damping devices for high-rise conventional concrete buildings. A total of seven Far-Field ground motions are used to assess the performance of VWDs in reducing the seismic response of 57- story RC building. Non-linear response time history analysis “NRHA” of a benchmark RC structure with and without the use of the VWDs were performed. The NRHA results show that the displacement response is reduced significantly in structure equipped with VWDs.**

Keywords: **Viscous wall dampers; passive dampers; Nonlinear dynamic analysis; High rise building; Finite element.**

I. INTRODUCTION

In the recent decades, more research and representative work have been concerned across the world to investigate the effect of using damping system in high rise buildings. This is reflecting the importance of the damping devices as a solution for structures which poses challenges for their serviceability performance under strong windstorm or earthquake actions. There are more types of the structural supplemental energy dissipation systems based on their performance, passive, active and semi active systems. Passive systems have fixed properties and have emerged as special devices that are incorporated within the structure to absorb a portion of the seismic energy like Friction dampers [1], Visco-elastic dampers [2], Tuned mass damper [3] and Viscous Fluid dampers and there are more devices widely used in the market. While active systems change their properties based on the load demand and require an external energy source to be activated like active mass damper [1].

Viscous Wall Dampers “VWDs” are one of the new passive damping systems, material-based dissipation systems using high viscosity liquids as dampers. VWD manufacturer [4] has proposed an analytical model for the damper behavior. Fig. 1 shows a schematic representation for a typical wall damper. During seismic excitation, the relative floor movement causes the vane to move through the viscous fluid. Damping force of the VWDs can be enlarged by increasing the wall size and using double vane system [5]. VWDs are used to reduce the seismic acceleration and inter-story drifts as well as reduce wind-inducted vibration.

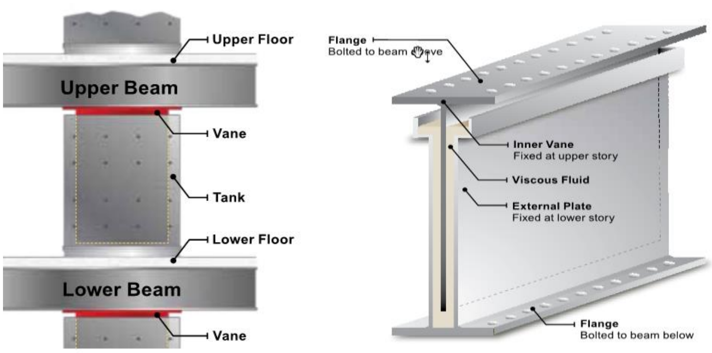


Fig. 1: Viscous Wall Damper

They were first developed in Japan in the late 1980s by engineers at Sumitomo Construction Company, Ltd. Japan is considered a seismic country, so structures are required to resist very strong seismic excitation. Much research has been carried out in Japan to analyse the effect of the VWDs in different types of buildings. Since then, VWDs have been used in over one hundred Japanese projects. Some experimental investigations were performed to evaluate the effect of using VWDs. Shake table tests were conducted on a four-story building with steel moment frame systems with and without VWDs [6]. Another comprehensive experimental investigation was performed on the control effects of VWD in seismic performance enhancement of RC frames [7]. These experimental tests showed a reduction for displacement response of the VWD system when compared to the conventional systems. Recently, VWDs have been introduced to the US market through DIS [4]. Prototype tests of 4 dampers were performed at UC San Diego. The dampers were tested to a variety of displacements and velocities (sinusoidal and earthquake motion) under single and bidirectional loading conditions, Tests were done according to ASCE 2005 [8]. The results from these tests were incorporated in the analysis and design of the first project in the US to use VWD along with steel moment frames. The first US project is California Pacific Medical Center (CPMC), located in San Francisco [9], [10]. California is considered a seismic active area so using VWD system indicates that this technology is promising and can be an effective solution in strong seismic areas. After then, Intense oscillation tests of VWDs were performed against large earthquake excitations. As a result, the damper was revealed to have no damage and is effective against stronger earthquakes [11].

Many analytical research were conducted in US to evaluate the effect of using VWDs in short buildings. A 3-story RC structure is considered and equipped with VWDs subjected to dynamic load [12]. A 3-story building with steel frames and used VWDs was studied by Hidayaty, et al. [13]. Another analytical study on 6-story RC frames and equipped with VWDs under seismic excitation was conducted by S. Shaik, et al. [14]. Some analytical research were performed on taller buildings and located in active seismic area in Turkey [15]. A 30-story reinforced concrete (RC) building with core shear walls as lateral resistance systems is considered with and without VWDs for a study conducted by a. Dilsiz, et al. [16]. A15-story RC building with special moment frames resisting system (SMFRS) is also considered [17]. The latest research investigates the effectiveness of VWDs on the dynamic performance of 22-story high-rise RC building with Steel moment frames and having torsional irregularity [18]. All these studies were done according to the current updated codes ASCE 2017 [19] and seismic hazards definitions TBSC 2018 [15]. The analysis showed that the presence of VWD can substantially enhance the structure's seismic performance and the use of VWDs result in a significant reduction in the floor acceleration values as well as maximum inter-story drift. This Research investigates the possible enhancement of the lateral behavior of an existing conventional RC multi-story structure with 205.7m and consists of 57 floors after using Viscous Wall Dampers. Non-linear time history analysis using ETABs commercial software are used for this investigation [20].

II. FINITE ELEMENT MODEL

A. Prototype structure description

Numerical models are a suitable solution to investigate high rise building behavior. this section presented finite element analysis developed in ETABS, details of the prototype structure used and characteristic of viscous wall dampers modelling. The RC structure is located in Dubai and consists of 57 floors (ground floor + 7 parking floors + 48 typical floors) as shown in the 3D view in Fig. 2, total height is 205.7 m. TABLE I shows story height for the structure. Prototype plans and dimensions are shown in TABLE II and Fig. 3

TABLE I: Floor Heights

Floor Name	Floor Height (m)
Ground Level	5.4
1st – 5th Parking Levels	3.3
6th – 7th Parking Levels	5.5
Typical Levels	3.6

TABLE II: Floor Heights

Floor Name	Floor Length (m)	Floor Width (m)
Ground Level	40	45
Parking Levels	40	45
Typical Levels	32	45

The structure consists of reinforced isotropic concrete. Slabs are considered as two-way flat slabs with thickness 25cm for ground and parking slabs and 24cm for typical slabs and they are modeled in ETABS as shell-thin elements. The vertical system of the structure is different in the below levels from the upper levels as shown in Fig. 3. It consists of reinforced concrete walls with variable thicknesses with range from 25 cm to 160 cm in addition to two concrete cores at the middle of the slab with average walls thickness 40 cm and these cores are extend to the full height of the building. All walls are modeled in ETABS as shell – thick wall sections.

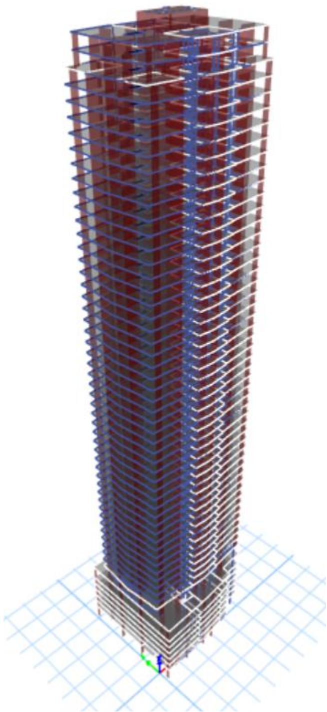
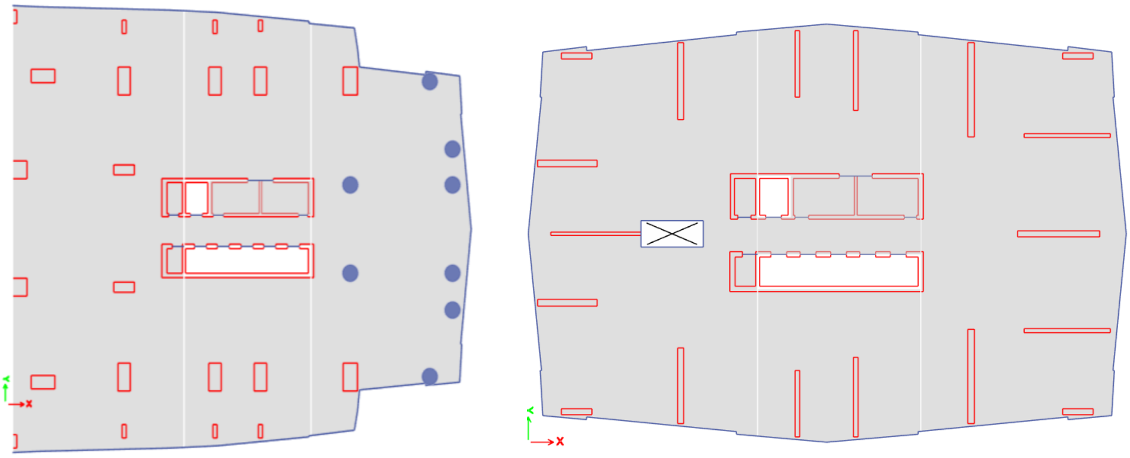


Fig. 2: 3D view for the benchmark structure



(a) Ground and Parking Floor Plan **(b) Typical Floor Plan**

Fig. 3: Benchmark structure plans

Fig. 4 is showing the design response spectrum curve of the structure where the mapped values of the short period Ss and 1-second spectral accelerations S1 are (Ss= 0.375) and (S1 = 0.15) respectively and long period transition period is used (TL = 8). The structure was analyzed and constructed with response spectrum analysis using response modification factor (R=8) and occupancy importance factor (I=1). in our study, the structure was analyzed using non-linear time history analysis.

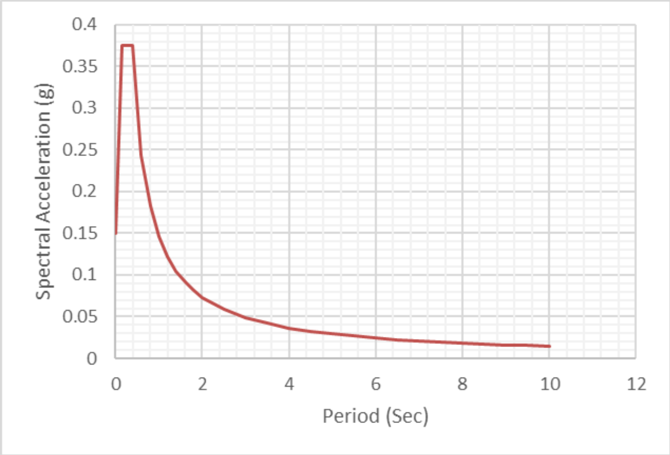


Fig. 4: Response Spectrum Curve

B. Viscous wall dampers modelling

VWDs are best represented by an Exponential Maxwell damper model as shown in Fig. 5. The seismic response of VWDs can be readily modeled using existing nonlinear elements in ETABS. The model consists of a linear spring, K, in series with an exponential damper characterized by C and α, such that the force in the damper is related to the velocity across the damper through the force-velocity relationship:

$F = CV^{\alpha}$ [4]

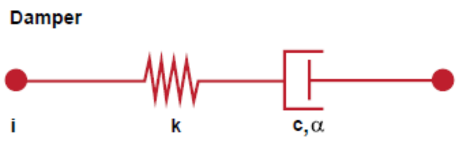
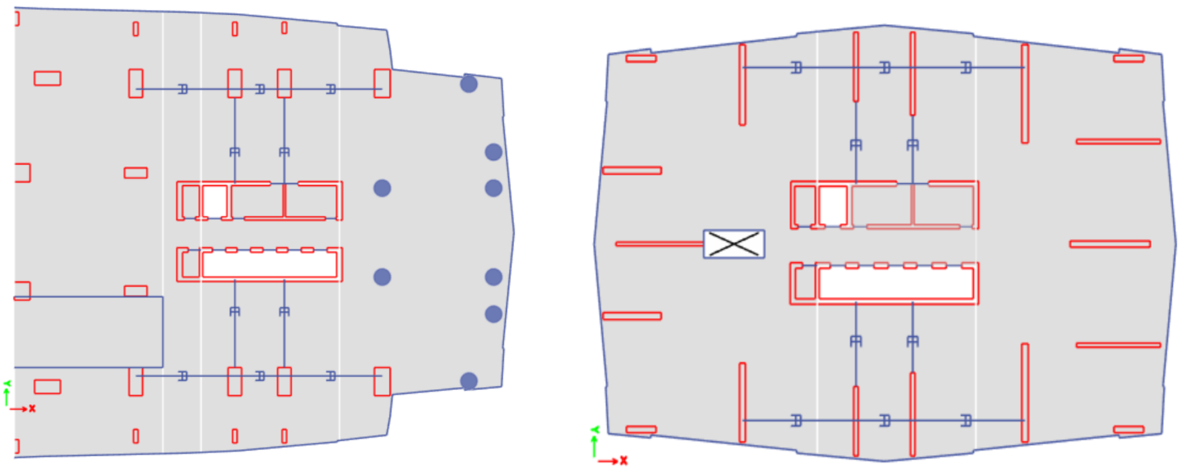


Fig. 5: Exaptational Maxwell damper model

In our study, 10 VWDs were modelled and added to the benchmark structure, four VWDs in Y- direction and six VWDs in X- direction as shown in plans in Fig. 6. VWDs are modelled in the typical levels only with total number 480 VWDs. The VWDs were modelled in ETABs using midfloor nodes that are connected to the floors through very stiff frame elements, while the midfloor nodes are connected by a non-linear link. The properties of the Non-linear link are used as per manufacturer recommendation and guidelines [4]. In our study, exponential damper is used with single vane with the following characteristic: VWD 2.4 x 2.4, K= 35500 KN/m , C= 1475 KN-(Sec/m)α , "α = 0.5".



(a) Ground and Parking Floor Plan **(b) Typical Floor Plan**

Fig. 6: VWD Modelling in ETABS in plans

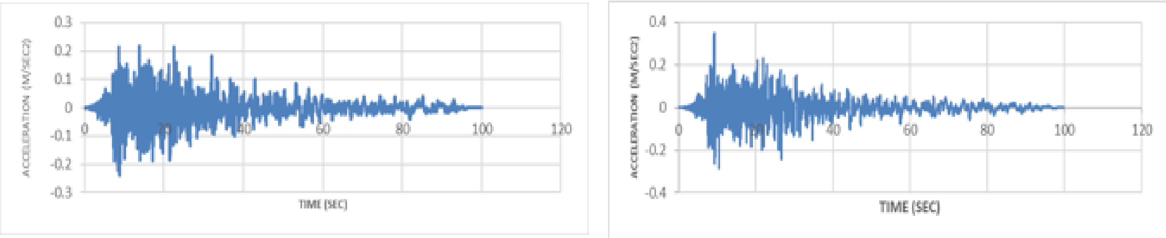
III. NONLINEAR DYNAMIC ANALYSIS

This section describes the nonlinear procedure used for studying the behavior of the prototype structure equipped with VWDs. It defines the set of input ground motions and specifies how nonlinear dynamic analyses are conducted on the bench-mark model.

Analysis requirements is based on criteria specified in applicable sections of the latest edition of ASCE/SEI 7, Minimum Design Loads for Buildings and Other Structures [8] and other applicable material reference standards, such as ACI 318, Building Code Requirements for Structural Concrete [21]

A. Ground motions

Ground motions record were selected from The Pacific Earthquake Engineering Research Center - Next Generation Attenuation "PEER NGA" database [22], [23]. A suite of seven Far-Field ground motions is selected for each target spectrum which consists of pairs of orthogonal horizontal ground motion component and the vertical earthquake effects is not considered. To study the effectiveness of using viscous wall damper, the benchmark structure is subjected to these seven pairs of ground motions with databases shown in TABLE III.



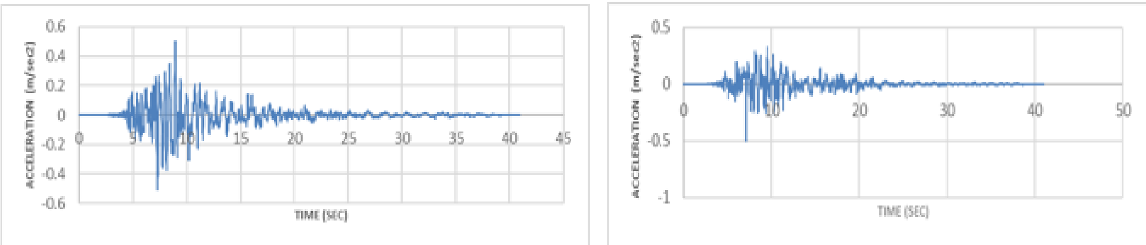


Fig. 8 and

Fig. 9 show Accelerograms which record the acceleration of the ground with respect to time for two pairs of ground motions EQ05 and EQ07 respectively.

The amplitude scaling is constructed by using the average of square root of the sum of the squares spectrum (SRSS) for each pair of the selected motions. The SRSS was taking for the 5% damped response spectrum. SRSS was scaled with an identical scale factor applied to both horizontal components such that the average of the maximum-direction spectra from all ground motions generally matches or exceeds the target response spectrum over the period range which is considered from 0.2T to 2T, where T is defined as the maximum fundamental period of the building. So, the period in our structure is 7 sec and the rang is from 1.4 sec to 14 sec.

The average scale factor of the seven SRSS scaled spectrum is considered for design earthquake level (DE) as 0.343 as shown in Fig. 7. That is in addition to another scaling, was used to match maximum considered earthquake (MCE), While seismic performance factors apply to the design earthquake, taken as two-thirds of the MCE spectrum (ASCE 2017), code-defined MCE ground motions are considered the appropriate basis for evaluating structural collapse. if a structure experiences a level of ground motion 1.5 times the design level, the structure should have a low likelihood of collapse (FEMA 2009). TABLE III summarizes the magnitude, year, and name of the event, as well as the name and owner of the station for each record set used in this study. Also, it shows design earthquake scale factor for these record set.

TABLE III: Far-Field Ground Motions

EQ	Earthquake			Recording Station		Scale Factor
ID	Name	Year	M	Name	Owner	DE
01	Northridge	1994	6.7	Beverly Hills - Mulhol	USC	0.4

02	Northridge	1994	6.7	Canyon Country-WLC	USC	0.35
03	Duzce, Turkey	1999	7.1	Bolu	ERD	0.2
05	Imperial Valley	1979	6.5	Delta	UNAMUCSD	0.3
06	Imperial Valley	1979	6.5	El Centro Array #11	USGS	0.3
07	Kobe, Japan	1995	6.9	Nishi-Akashi	CUE	0.4
08	Kobe, Japan	1995	6.9	Shin-Osaka	CUE	0.45

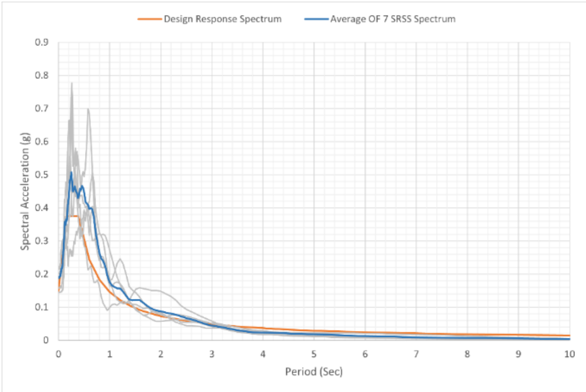


Fig. 7: Average of 7 SRSS scaled spectrum for the ground motions

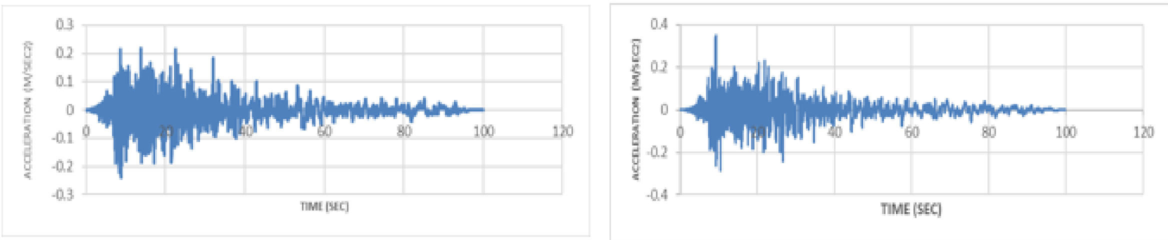


Fig. 8: Accelerogram for EQ05 in X and Y directions

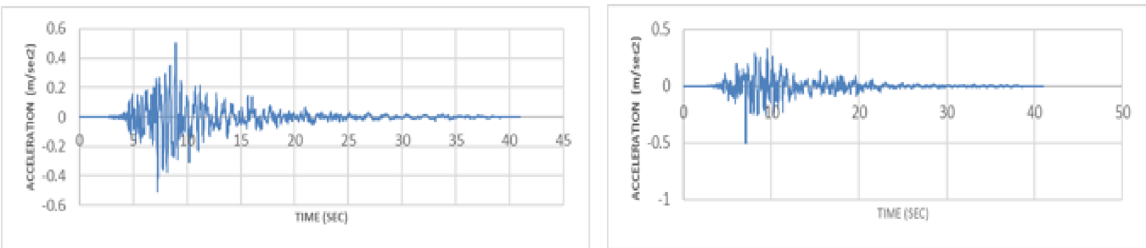


Fig. 9: Accelerogram for EQ07 in X and Y directions

IV. DESCUSSION OF RESULTS

The analysis carried out on four models with and without dampers for Design earthquake level (DE) and maximum considered earthquake level (MCE). The analysis was conducted using Fast Nonlinear Modal (FNA) time history analyses. The main parameter evaluated in this study is floor displacements as it is an important factor in high rise buildings to control the lateral displacement.

The displacement response is shown and presented in Fig. 10 and Fig. 11 for the average story displacement for all ground motions obtained for the structure without and with VWD in both X and Y directions respectively. From the interrelation curves, it was found that due to insertion of VWD in the structures, the displacements for maximum considered earthquake level have been reduced by a ratio up to 22% in X- direction and reduced by ratio of 16% in Y- direction. The Results revealed a noticeable reduction in the displacement for the structure equipped with VWDs.

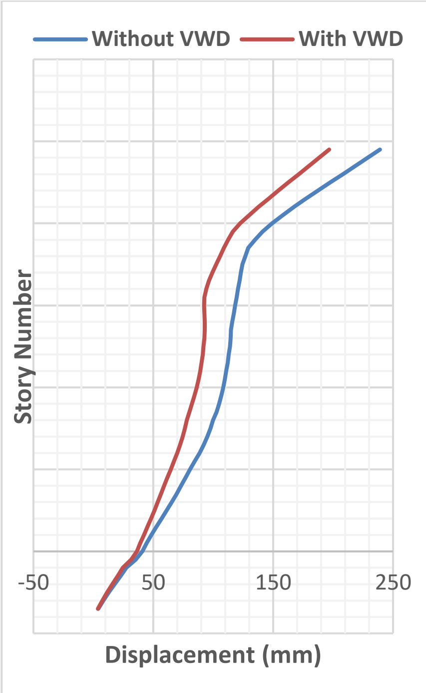


Fig. 10: Avg. Story displacement in X- direction for all ground motions

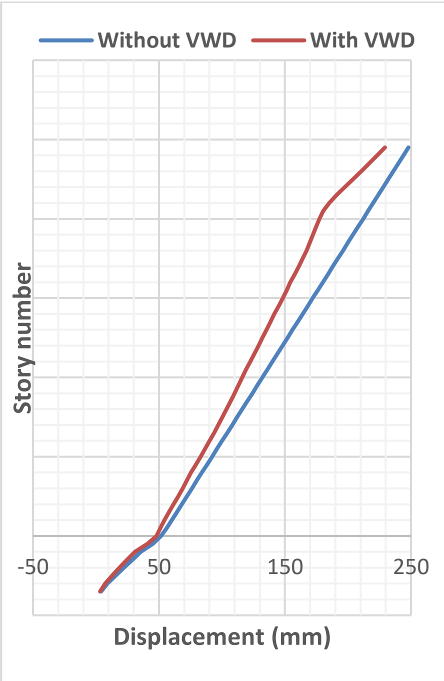


Fig. 11: Avg. Story displacement in Y- direction for all ground motions

V. CONCLUSION

In this paper, a 57-Story RC building with concrete shear walls, total height is 205.7 m is established by using the finite element software ETABS to study the behavior of high-rise building under seismic excitation and equipped with viscous wall dampers. The Nonlinear time history analysis was conducted according to the ASCE 2017. The viscous wall dampers have effectively reduced the story displacement in X and Y directions by ratio up to 22%.

REFERENCES

[1] Pall, A.S. and R. Pall, 1996, Friction-dampers for seismic control of buildings–a Canadian experience. Eleventh world conference on earthquake engineering, Acapulco, Mexico.

[2] Soong, T. and B.J.E.s. Spencer Jr, 2002, Supplemental energy dissipation: state-of-the-art and state-of-the-practice. Engineering Structures 24(2002) 243-259.

[3] Umachagi, Venkataramana, Reddy, and Verma, 2013, Applications of dampers for vibration control of structures: an overview.: p. 6-11.

[4] DIS, Inc., 2017, Viscous Wall Dampers: Guidelines for Modelling, Dynamic Isolation Systems Inc., McCarran, NV (www.dis-inc.com) .

[5] DIS, Inc., 2009, Viscous Wall Dampers: Superior Earthquake Protection for Flexible Buildings. Dynamic Isolation Systems Inc., McCarran, NV. (www.dis-inc.com).

[6] Arima, Mitsuo Miyazaki, Tanaka, and Yutaka Yamazaki A study on buildings with large damping using viscous damping walls. Proceedings of the 9th world conference on earthquake engineering. 1988.

[7] Lu, X., Y. Zhou, and Feng Yan, 2008, Shaking table test and numerical analysis of RC frames with viscous wall dampers. Journal of structural Engineering 134(1): p. 64-76.

[8] ASCE, 2005, ASCE 7–05 Minimum design loads for buildings and other structures. American Society of Civil Engineers.

[9] Newell, Newell, J., J. Love, M. Sinclair, Y. N. Chen, and A. Kasalanati, 2011, Seismic design of a 15-story hospital using viscous wall dampers. Proc. of Structures Congress, Las Vegas, NV, USA.

[10] Newell, Love R, Newell J, Sinclaire M, Chen Y, 2012, Performance-based design of an essential hospital with supplemental viscous damping in a high seismic zone. Proc. 15 World Conf. on Earthquake Engineering. Lisbon, Portugal.

[11] Sasaki, K., M. Miyazaki, and T. Sawada. Characteristics of viscous wall damper of intense oscillation test against large earthquakes. Proceedings of the 15th World Conference on Earthquake Engineering. 2012.

[12] Hejazi, F., M. D. Shoaei, A. Tousi, and M. S. Jaafar, 2015, Analytical Model for Viscous Wall Dampers. Computer-Aided Civil and Infrastructure Engineering, 31 (5): 381–99. doi: 10.1111/mice.12161.

[13] Hidayaty, Setio, Surahman, and Moestopo, 2018, Numerical Analysis Of Viscous Wall Dampers On Steel Frame. MATEC Web of Conferences. 147: p. 01001.

[14] Shaik, S., F. Hejazi, and V. J, 2019, Effect of Viscous Wall Dampers on Response of Reinforced Concrete Structures Subjected to Seismic Excitation. International conference on Industry 4.0 and Advancements in Civil Engineering, i4ACE'19.

[15] TBSC, 2018, Turkish Building Seismic Code. Disaster and Emergency Management Presidency. Republic of Turkey Prime Ministry, Ankara, Turkey.

[16] Dilsiz, Mohammed MS, Moustafa MA, and Özuygur AR., 2018, Evaluation of wall damper effectiveness on the seismic performance of buildings. Proceeding of the 11th US National Conf. on Earthquake Eng. (11NCEE).

[17] Dilsiz, Mohammed MS, Moustafa MA, and Özuygur AR., 2020, Seismic Design and Performance of Reinforced Concrete Special Moment Resisting Frames with Wall Dampers. J Earthquake Eng.

[18] Dilsiz, Mohammed MS, Moustafa MA, and Özuygur AR., 2022, Suppression of the torsional irregularity of high-rise buildings using viscous wall dampers. Bulletin of Earthquake Engineering.

[19] ASCE, 2017, ASCE 7-16 Minimum design loads for buildings and other structures-American Society of Civil Engineers.

[20] ETABS, 2019, Structural Software for Analysis and Design. Computers and Structures, Inc. (CSI), CA, USA.

[21] ACI 318-14, Code, B. requirements for structural concrete in American Concrete Institute. 2014.

[22] PEER 2017, NGA-West2 Database of Pacific Earthquake Engineering Research Center. PEER, Berkeley,CA. http://ngawest2.berkeley.edu

[23] FEMA 2009, Quantification of building seismic performance factors, Federal Emergency Management Agency.