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Strengthening an existing industrial building by optimally designed passive dampers under seismic and service loads

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ABSTRACT: Vibration control systems can improve the building performance effectively, not only under earthquake excitation, but also under dynamic service loads. In this paper, it is aimed to evaluate the responses of a two story industrial building containing two cranes, both under seismic and crane load. The structure is designed preliminary based on the Iranian national codes. Afterward, its responses under seismic and crane load are evaluated by time history and stochastic analysis method respectively. In order to enhance the responses under both loadings, three different optimally designed passive dampers including viscous damper, buckling restrained braced, and friction damper are compared. Building responses show that viscous damper works well in both loadings. However, friction damper only boosts the performance of structure under seismic action, and there is no trace of effectiveness for cranes load; exactly the same as what is observed for buckling restrained braced system.

Keywords: Industrial building, Stochastic analysis, Viscous damper, BRB, Friction Damper, Crane load.

1 INTRODUCTION

Nowadays beside the developments of hi-tech factories, which are highly sensitive to the vibrations, it is needed to build industrial buildings and factories that suppress the vibration noise due to different types of loadings. In addition, the buildings shall withstand the natural hazardous loading like probable earthquake or wind. As an effective method, it is applicable to use the passive vibration control systems to enhance the response of structure. There are different types of passive devices like viscous dampers, yielding dampers, friction dampers, tuned mass dampers, and wide variety of base isolations each of which has their own advantages and disadvantages. In this study, three more practical ones are selected to be studied: viscous damper, buckling restraint braced (BRB), and friction damper.

There are many theoretical and practical projects conducted to evaluate the performance of these damping devices separately. However, there are few comparative studies on these systems. Symans et al. (2008) prepared a comprehensive review on the passive devices from both theoretical and practical point of view. Fabio et al. (2013) assessed the ability of passive energy damping devices to improve the response of a 6 story reinforced concrete structure.

Khansefid and Ahmadizadeh (2015) also studied the effectiveness of passive and active vibration control devices in nonlinear building under different seismicity level.

In this research, it is purposed to evaluate the effectiveness of different types of passive vibration control devices including viscous damper, buckling restrained brace, and friction damper to improve the response of a two story gable structure with two cranes. Two different loadings including earthquake, as well as handmade noise by cranes are taken into account. Building responses to the earthquake excitation are obtained by the time history analysis method while the responses due to cranes noise are calculated using stochastic analysis procedure. Results show that viscous damper is the best system to reduce cranes noise while the other two ones do not have any positive effect. From the other side, viscous damper and friction damper both improve the seismic behavior of the structure in the same level, far beyond the BRB.

2 BUILDING MODELING

A two story gable structure includes two separate cranes in the first and second story by weight lifting capacity of 1250 and 320 KN respectively is considered. Building shape and dimensions are illustrated in Figure 1. All the elements are made of steel with yielding capacity of 360 MPa. The structure is designed based on the Iranian national seismic code (2013). Floor's dead and live load are equal to 65 KN/m^2 and 100 KN/m^2. Final design of beams and columns sections are all I-shape, their height varying from 240 to 600 mm. Bracing elements are UNP 110 and 200 mm.

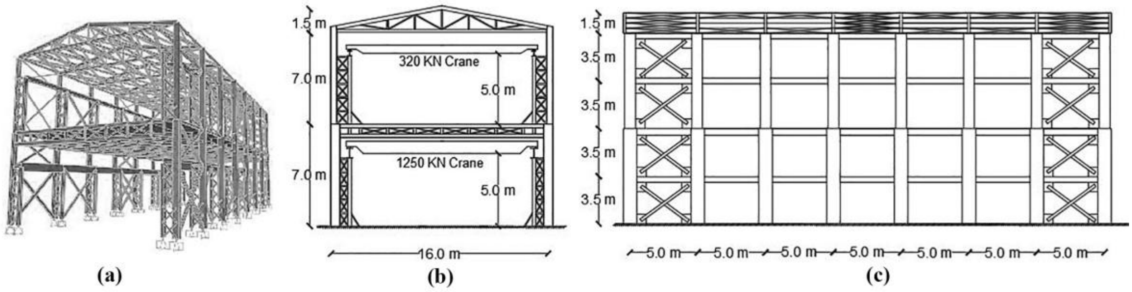


Figure 1. Industrial building shape and dimensions, a) 3D view, b) Cross section, c) Longitudinal view.

3 LOADINGS

Industrial buildings located in the high vulnerable seismic area, shall be designed to withstand the probable earthquake events during their lifetime. In addition to this major loading, in many cases, movement of cranes may cause very annoying noise disturbing the application of the other parts of building. In this research, both foresaid loadings are considered to evaluate the structural performance.

3.1 Seismic Load

Record selection is one of the most important source of uncertainty in seismic performance evaluation of any system. To overcome this problem, 10 artificial earthquakes are produced. All of these records are randomly generated by the SeismoArtif (2016) software and matched with the Iranian seismic spectrum of soil type 2 for a site with very high seismicity level. The information summery of artificial records are presented in Table 1, as well as their accelerograms, and spectrums in Figure 3 and 4.

Table 1. Summary information of randomly generated accelerograms

Earthquake Index	PGA(g)	PGV(cm/s)	PGD(cm)	Strong Motion Duration* (s)
A01	0.40	39.0	14.0	12.69
A02	0.52	42.9	18.0	18.36
A03	0.47	52.6	24.8	18.98
A04	0.45	54.9	20.8	19.70
A05	0.43	38.7	15.9	19.08
A06	0.47	51.5	18.0	20.01
A07	0.52	48.7	14.0	20.03
A08	0.45	53.6	15.8	18.08
A09	0.42	55.5	27.9	22.27
A10	0.53	54.2	20.5	22.97
mean	0.46	49.1	19.0	19.21

* Strong motion durations are calculated by the method of Trifunac and Brady (1975).

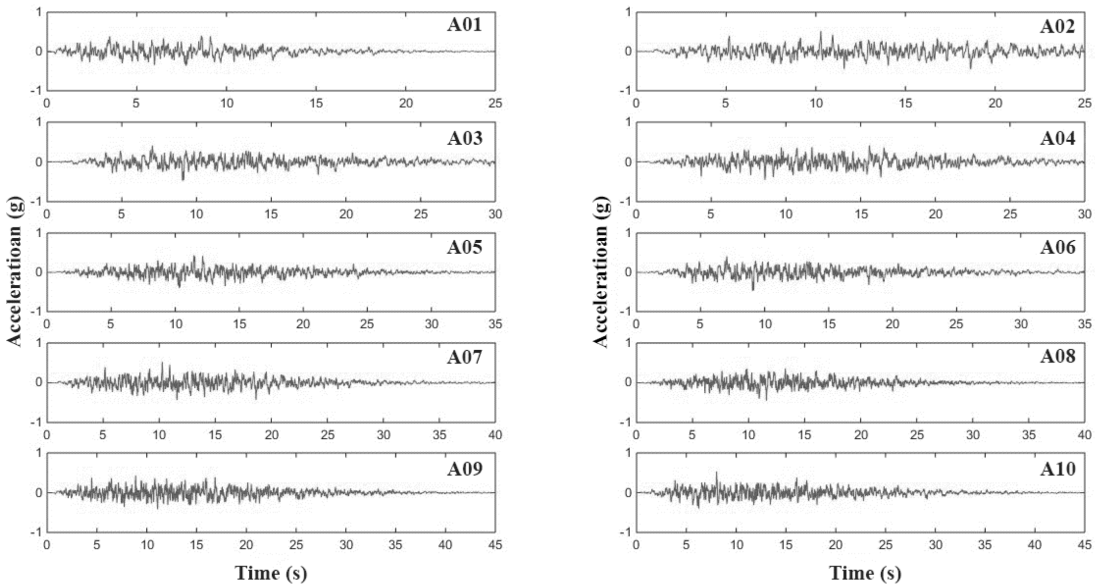


Figure 2. Acceleration time series of randomly generated earthquake.

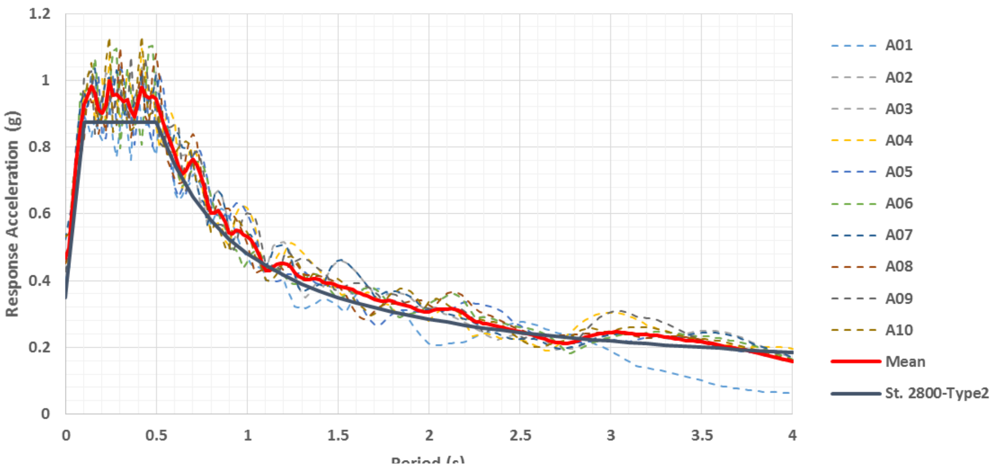


Figure 3. Acceleration response spectrum of Iranian national seismic code and the artificial accelerograms.

3.2 Operational load (cranes load)

In the industrial buildings, cranes may work at different frequencies. Hence, it is a good idea to consider their loading as a white noise which contains all possible frequencies for the input vibration imposed on all cranes rail. The white noise power spectral density function (PSD) is a constant value. Moreover, it is known that the area under the PSD diagram is equal to the variance of loading as presented by Lutes (2004):

$$\sigma^2 = \int_{-\infty}^{\infty} S(\omega) d\omega \quad (1)$$

where *S*, *w*, and σ are PSD function, frequency range, and standard deviation of loading respectively.

The nominal capacities of cranes weight lifting are 1250 KN, and 320 KN. To model cranes load, it is assumed that the coefficient of variation of their loading is equal to 0.1. Therefore, the standard deviation of the first and second story cranes will be obtained 125 KN, and 64 KN. Additionally, cranes working frequency are presumed to varies from 0 to 200 Hz. By using Eq. (1) it is found that the PSD of cranes are equal to 20.48 and 78.125 KN^2/rad for 320 KN and 1250 KN capacity equipment, respectively.

4 PASSIVE DAMPING DEVICES

There are many different types of passive energy dissipating devices all around the world like metallic dampers, friction dampers, viscous dampers, viscoelastic dampers, tuned mass dampers and etc. In this research, among all of them, three more common types are considered including viscous damper, buckling restrained brace, and friction damper. Viscous dampers are kind of velocity-dependent devices while the other two ones are displacement-dependent. Each of them has its own pros and cons from different aspect such as technical capability, installation, monitoring, maintenance, as well as the price while in this research only the first one is compared. The most important design parameter of passive dampers is their force-displacement relationship presenting in Figure 4.

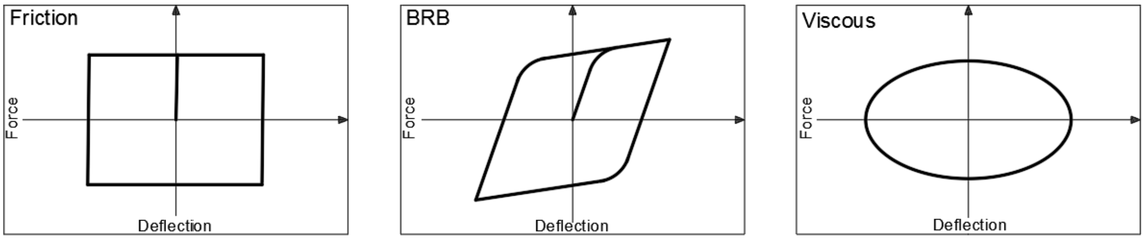
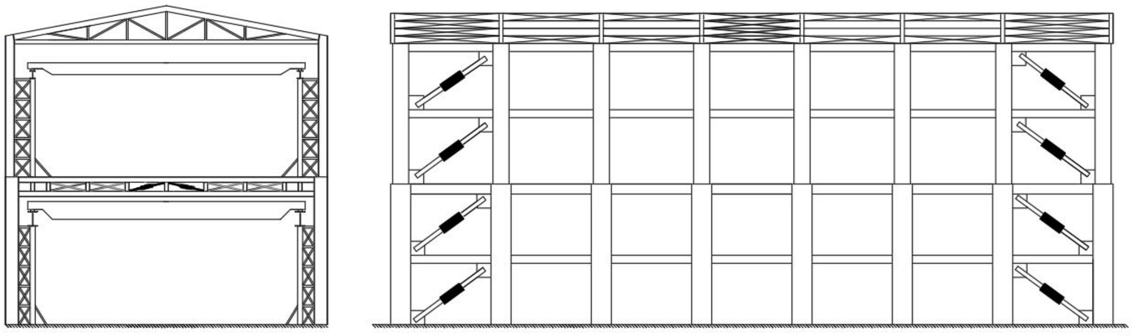


Figure 4. Idealized force-displacement relationship of passive dampers

These devices are used in two different positions. One set is mounted among the truss elements of first floor deck (Figure 5-a) in order to reduce the floor vertical vibration due to cranes load. In each of the transverse frame, two separate devices are used which leads to the total number of 16 dampers. Another set of dampers are considered to be installed in two main longitudinal frames of structure (Figure 5-b) to improve the seismic response of whole structure. As it is seen, there is 8 devices in each of the longitudinal frames. In the other words, 16 devices are installed in both frames. Finally, 32 viscous dampers are located in the industrial building.



(a) **(b)**

Figure 5. Location of viscous damper. a) Devices used to reduce cranes vertical vibration, b) Devices used to reduce the response of building due to earthquake excitation.

5 ANALYSIS PROCEDURE

Since there are two different types of loadings on the structure, two separate analysis procedures are considered in parallel. To calculate the seismic response of building, a time history analysis method is followed whereas the linear stochastic analysis is adopted to model the behavior of floor deck of building due to cranes vibration.

Dampers design properties are possible to be calculated by two different methods, code based as well as optimization based. In this work, the second one is selected since there is no specific design code for using passive energy dissipating device in the industrial building. Each of the three dampers considered in this study has its own design properties, damping coefficient for viscous damper, yielding force for BRB, and sliding force for friction damper. To find the optimal value of design parameters, a sweeping optimization method is used. Accordingly, the best value is selected from the wide possible range of design parameters. In this regard, for viscous damper 17 different damping coefficient values including 2, 10, 50, 150, 250, 350, 500, 750, 900, 1000, 1250, 1500, 2500, 3500, 5000, 7500, 10000 KN.s/m; for BRB 12 different yielding forces including 6, 10, 15, 20, 50, 75, 100, 150, 200, 250, 300, and 400 KN; and for friction damper 12 different sliding forces including 1, 2, 3, 4, 6, 8, 10, 12, 15, 20, 50, 100 are considered. All the dampers used in the longitudinal frames are in the same type and size whereas the dampers installed in the floor truss deck are the same as each other. Finally, 410 3-

D elaborated finite element analysis are done by SAP2000 (2016) software under earthquake excitation to find the best values of design parameter of dampers located in longitudinal frame, while 41 analyses are done to acquire the best design values of damper's parameter for reducing cranes vibration.

The most important point to reach to the best design value is to define the performance index for the system. Average of inter-story drift and absolute acceleration (Eq.(2)) is defined as seismic performance index and the vertical velocity (Eq.(3)) of deck floor is considered for cranes response.

$$PI_{Seismic} = \frac{1}{2}\frac{||\mathbf{A}||_{With\ Damper}}{||\mathbf{A}||_{Without\ Damper}} + \frac{1}{2}\frac{||\mathbf{D}||_{With\ Damper}}{||\mathbf{D}||_{Without\ Damper}} \quad (2)$$

$$PI_{Crane} = \frac{||V||_{With\ Damper}}{||V||_{Without\ Damper}} \quad (3)$$

where **A** and **D** are the vectors of maximum absolute acceleration and inter-story drift response of structure under seismic loading. V is the vertical velocity of deck floor due to cranes load which is monitored at the center of floor deck.

6 RESULTS

In this part, firstly, the optimal value of damper's design parameters will be evaluated, and in the next section responses of the best designs will be securitized to assess the effectiveness of dampers on improving the performance of industrial structures under different types of loading. As it is indicated in Figure 6, for the seismic response, the optimal value for viscous damping coefficient, BRB yielding force, and friction damper sliding force are 750 KN.s/m, 250 KN, and 12 KN respectively.

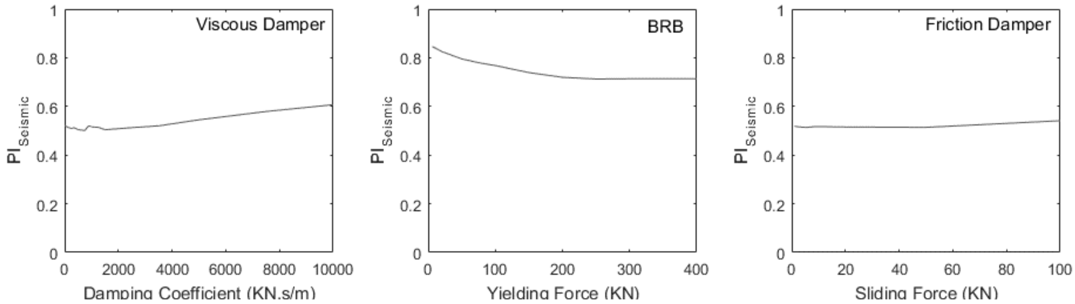


Figure 6. Optimization results of dampers for seismic loading.

For cranes load, the output of stochastic analysis shows that there are three separate frequencies at which the vertical vibration of deck floor is intensified. These frequencies are 14, 25, and 43 Hz. Among these three frequencies, 14 Hz is more close to the human comfort zone, thus it is more critical than other two ones. As it is declared in Figure 7 either BRB or friction damper, not only cannot improve the response of structure to cranes load but also in some frequencies make it worse which is due to inactivation of devices, i.e. dampers activation force does not reach at all. On the other hand, viscous damper enhances the behavior of structure greatly insomuch as it does not need to activation, and works even in very low level of loadings. The optimal damping coefficient design value is selected equal to 5000 KN.s/m since the higher ones does not improve the performance of system tangibly (less than 5%) while the damping coefficient increases up to 15000 KN.s/m.

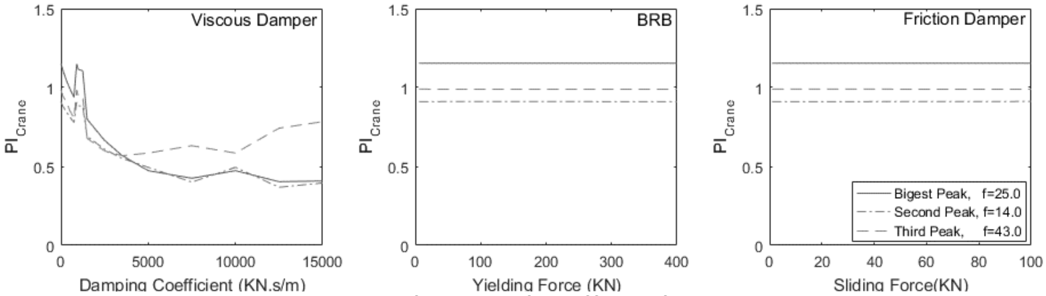


Figure 7. Optimization results of dampers for different frequencies under cranes load.

6.1 Seismic response

In this section, average of seismic responses of industrial building with and without dampers for all 10 earthquakes are presented. In Figure 8, response of inter-story drifts, absolute story accelerations, and base shear of building are illustrated. It is seen that all the devices improve the behavior of structure. Among the studied systems viscous damper shows better performance. It reduces the response of drifts, accelerations and base shear equal to 35%, 83%, and 80% respectively.

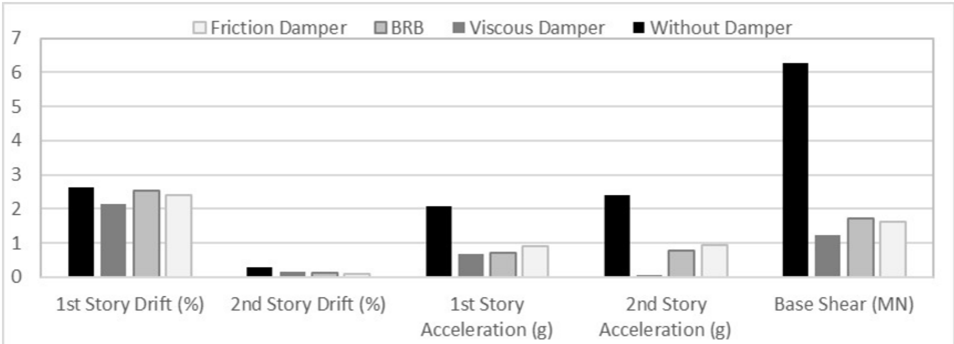


Figure 8. Average responses of building to all earthquake excitation.

The next important response of structures is the input seismic energy and its distribution in the building. Energy distribution in the structure is calculated based on the relationship proposed by Christopoulos and Filiatrault (2006) and the results are shown in Figure 9. It reveals that by using dampers, not only the input seismic energy is reduced, but also the total strain and inherent damping energy, as a representative of structural damage, is decreased significantly. Here again, viscous damper is the best system among all. It reduces the input energy up to 57%, and the total strain and inherent energy nearly 59% as well.

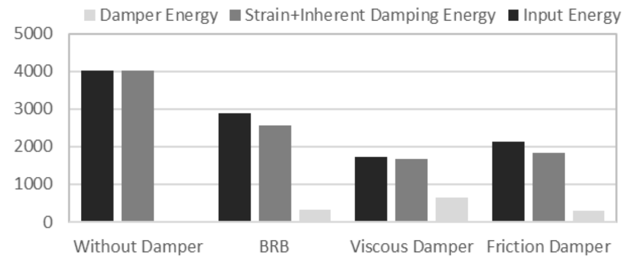


Figure 9. Input seismic energy and its distribution in the building for different types of dampers.

6.2 Response of floor deck

Here, the velocity response of floor deck is assessed owing to cranes operation load. Figure 10, shows the maximum vertical velocity response of floor deck regarding to the crane operation frequency. This is clearly seen that optimal viscous damper (5000 KN.s/m) reduces the peak velocity at all resonance frequencies (14.0, 25.0, and 43.0 Hz) very well, almost up to 50 percent while the other two systems do not.

In accordance to the AISC design guide No.11 (2003) for floor vibration, the allowable velocity amplitude of floor vibration for buildings containing computer systems is equal to 200 μm. This criterion shall be satisfied for all dynamic activities with frequencies ranging between 8 to 50 Hz. By comparing the results of Figure 10, it is indicated that by using the viscous damper, velocity response of floor deck drops down below the allowable threshold.

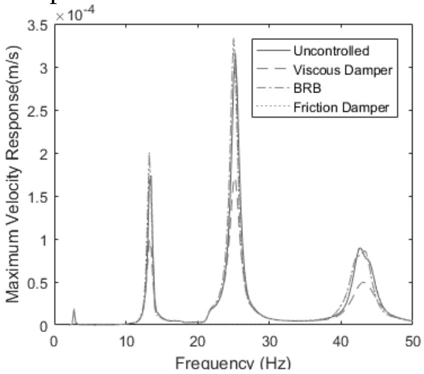


Figure 10. Velocity response frequency spectrum of floor deck with and without damper

7 CONCLUDING REMARKS

In this paper, the effectiveness of optimally designed passive dampers including viscous damper, BRB, and friction damper on the behavior of industrial building equipped with cranes are evaluated. In this regard, two of the most important type of loading during the life of structure is taken into account containing seismic load and cranes noise vibration, and imposed on both with and without damper structure. By implementing stochastic analysis, it is observed that the operating cranes vibration noise or in the other words the vertical velocity induced by cranes is remarkably reduced (about 50 percent) when viscous damper is used as a supplemental damping device. The other two dampers do not improve the structural performance at all which is due to their inactivation in low intensity loading. Moreover, viscous damper shows the best performance in seismic loading as well. It reduces the building responses up to 80%. These results reveal that viscous damper can greatly improve the structural performance under loading either with low intensity level like service loads or high intensity ones like earthquake excitation. However, BRB and friction damper cannot work under low level loads.

8 REFERRENCE

Building and Housing Research Center, 2013, *Iranian code of practice for seismic resistance building design*, Tehran, Iran.

Christopoulos, C., A. Filiatrault, 2006, *Principles of Passive Supplemental Damping and Seismic Isolation*, Italy: IUSS Press.

American Institute of Steel Construction, 2003, *Floor Vibrations Due to Human Activity*, Chicago, USA: AISC.

Computers and Structures Inc., 2016, SAP2000 Integrated Software for Structural Analysis and Design, Berkeley, California, USA.

Fabio, M., V. Alfonso, M. Mirko, and M. Giuseppe, 2013, Modeling and Nonlinear Seismic Analysis of Framed Structures equipped with damped braces. *7th WSEAS International Conference on Computer Engineering and Application*, Milan, Italy.

Khansefid, A., M. Ahmadizadeh, 2015, An investigation of the effects of structural nonlinearity on the seismic performance degradation of active and passive control systems used for supplemental energy dissipation, *Journal of Vibration and Control*, 22(16): 3544-3554.

Seismosoft Ltd, 2016, SeismoArtif V.2.1.: Software applications for generating artificial earthquake accelerograms, Pavia, Italy.

Lutes, L.D., S. Sarkani, 2004, *Analysis of Structural and Mechanical Systems*, Burlington, USA: Elsevier Butterworth–Heineman.

Symans, M.D., A.S. Charney, M.C. Constantinou, M.W. Johnson, and R.J. McNamara, 2008, Energy dissipation systems for seismic application: current practice and recent development. *Journal of Structural Engineering*, 134(1): 3-21.

Trifunac, M.D., A.G. Brady, 1975, A study on the duration of strong earthquake ground motion, *Bulletin of the Seismological Society of America*, 65(3): 581-626.