Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/03/jls.htm
2015 Vol. 5 (S3), pp. 2033-2040/Mirzaei et al.
Research Article

STUDY OF SEISMIC PERFORMANCE OF CIRCULAR FRICTION DAMPERS IN STEEL STRUCTURES

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ABSTRACT
Friction dampers are used in order to reduce dynamic response of structures against wind and earthquake loading. The operational mechanism of these devices is such that a large amount of energy inputting to the structure could be absorbed and amortized due to dynamic loading. Performance of the above devices causes to reduce energy of other structural components, so that significant deformation of components is avoided. Three frames of 5-, 10- and 15-storeys are evaluated. Non-linear static analysis and non-linear time history dynamic analysis have been used through Seismo Struct Software. Three scaled and modified acceleration recorders have been used for dynamic analyses. After doing dynamic analyses, it was found that the circular friction dampers in bending frames can provide immune and stable conditions as compared with the similar buildings because they can absorb and amortize a high percentage of energy inputting to the structure. After doing non-linear static analyses on studied structures it was determined that these dampers increase structural stiffness before getting to their slip-load rate; but after sliding, stiffness rate is equal to stiffness of a frame without damper. So, in structures which are benefited by increase of stiffness, this damper will improve their seismic behavior.

Keywords: *Circular Friction Damper, Optimum Slide-load, Non-linear Static Analysis (Pushover), Time History Dynamic Analysis*

INTRODUCTION
Friction is very cheap source of energy loss. Displacement-dependent dampers are divided into two groups: yielding dampers and friction dampers. The friction dampers have more advantages as compared with yielding dampers. Circular friction damper satisfies Rules of Seismic Improvements Instructions. The mechanism of above damper is such that a large amount of energy inputting to the structure can be absorbed and amortized due to dynamic loading. Friction damper can be easily adjusted after the earthquake; also they are not required to be changed. All bracing systems with important role against lateral loads have less ductility and less amortization power in relation to the bracing systems with friction dampers. Thus, friction dampers with energy loss and micro sliding along the friction interfaces (for example, bolted joints) provide a useful damping mechanism and play an important role in vibration behavior of structures.

The energy amortization into the friction dampers will be occurred because of friction between the friction components and sliding of levels on each other. Configuring of sliding friction components on each other can be very diverse, so there are various friction dampers. Circular friction dampers have been presented in order to improve the existing buildings and construction of new buildings on the basis of ductility. Movala (Building and Housing Research Center, 2005) has carried out the initial tests over a one-storey building equipped with circular friction dampers at the University of Denmark. Then full-scaled tests have been carried out over a three-storey building equipped with damper and on the vibration table in Taiwan (Deputy of Housing and Urbanization, 2013). All tests indicate proper efficiency of these dampers under a seismic event (Filiatrault and Cherry, 1990). Efficiency of friction damper depends on different factors such as reducing of displacement, increase of energy loss, increase of ductility and decrease of elastic strain energy (Keyvani, 2011).

Modeling
To evaluate the seismic performance of structures equipped with circular friction dampers, three frames of 5-, 10-, and 15-storeys have been analyzed and designed through ETABS. In 5-storey building both

bending frame structure with damper and bending frame structure without damper have been used. Thus, 10- and 15-storey buildings have been examined like as the 5-storey building.

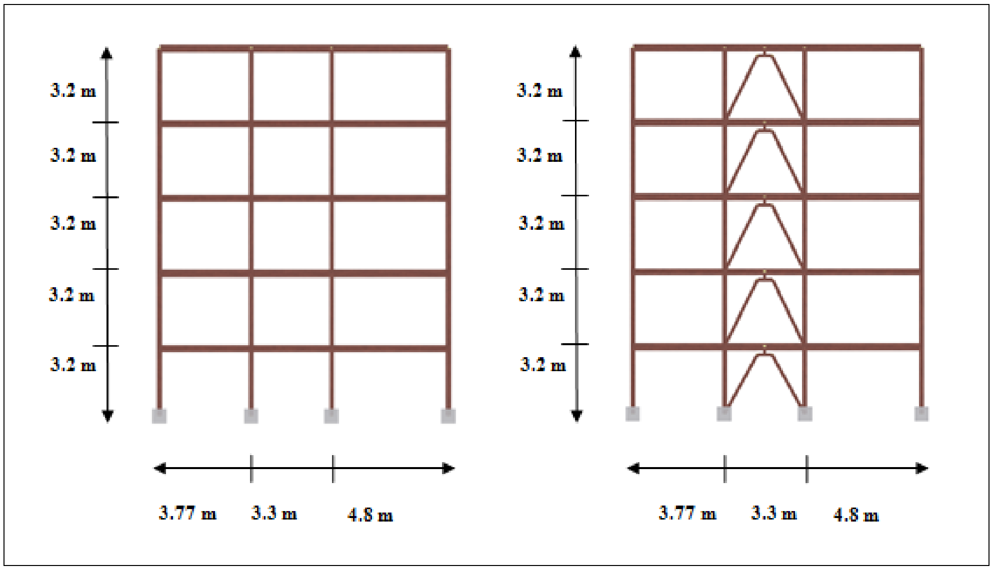

Figure 1: Configuring a structural model

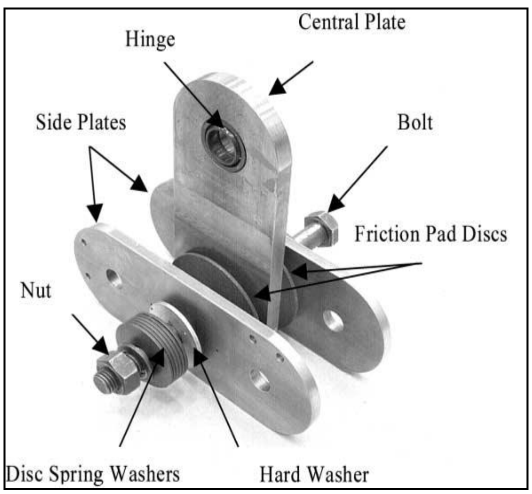

Figure 2: Performance of Circular friction dampers (Building and Housing Research Center, 2005)

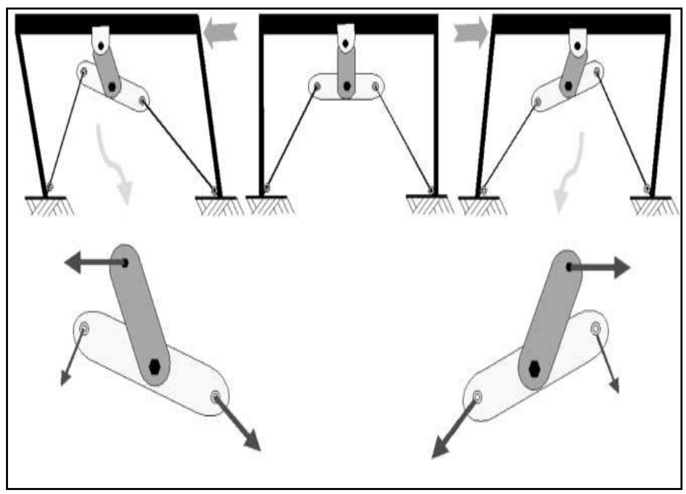

Figure 3: Circular friction damper (Filiatrault and Cherry, 1990)

Table 1: Sections of frames

Bracing	Column	Beam	Storey
BOX140x14010	BOX200x200x20	IPE300	5-STOREY
BOX160x160x10	BOX300x300x30	IPE300	10-STOREY
BOX160x160x16	BOX550x550x50	IPE300	15-STOREY

Determination of Optimum Slide Load of Damper

Determination of optimum slide load of circular friction dampers is the most important parameter to have a structure with proper ductility and useful energy amortization and also displacement of storeys. Factors and indexes related to performance of damper are divided into two levels.

Above mentioned values are limited to 0 (zero) and 1 (one). Value of 1 (one) means that either slide value is zero and there is no energy loss in the damper, or slide value is very high and the damper doesn't operate. In the first case, damper acts as bending frame and in the second case, damper acts as braced bending frame (Mualla and Bellev, 2002).

In this study, capacity spectrum curve and the following relations (Mualla and Bellev, 2002) are used to obtain above slide load and extended to 5-, 10- and 15-storey buildings.

$$\alpha = (-1.24N_s - 0.31)\frac{T_b}{T_u} + 1.01N_s + 0.43) \quad (3\text{-}1)$$

$$\beta = (-1.07N_s - 0.1)\frac{T_b}{T_u} + 1.01N_s + 0.45 \quad (3\text{-}2)$$

In the above equations

N_s= Number of storeys

T_u= Period of un-braced structure

T_b = Period of braced structure

Note: $\frac{T_b}{T_u} < 0.4$

In the next step, value of slide load will be calculated by use of design spectrum of slide load of frame. Figure 4 shows design spectrum of slide load of frame.

Step-by-step Process to Determine Optimum Slide Load of a 5-storey Building

Step One: Determine T_b and T_u

As previously mentioned, ETABS software is designed in order to determine levels of beam, columns and bracing; and also by the use of above software T_b and T_u (period of braced and un-braced structures) are achieved.

Formula (4-1)

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Step Two: Determination of the parameters of T_g and a_g according to regulations of 2800

According to Regulations of 2800 (Liao *et al.*, 2006), soil type 3 has T_g = 0.7s, and the maximum ground acceleration is 0.35g.

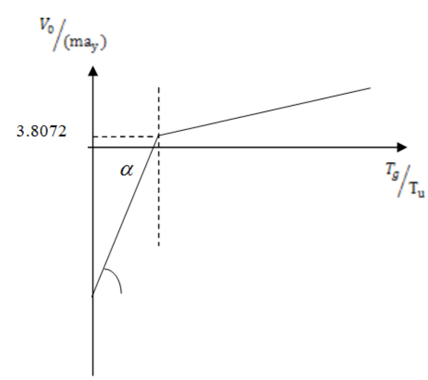

Figure 4: Diagram slide load spectrum

T_g = 0.244

$= \alpha \ \tan\gamma$

$$ama_g \tan\gamma = \frac{V_0 / ma_g}{\frac{T_g}{T_u}} \Rightarrow V_0 = \frac{T_g}{T_u}$$

$m = \frac{153000}{9.81} = 15596$

Total load

$\Rightarrow V_0 = 0.244 \times 3.8072 \times 15596 \times 0.35 \times 9.81 = 49744$ kg

By dividing the total load to total storeys:

$V_s = \frac{V_0}{N_s} \Rightarrow \frac{49744}{5} = 9.948 \ ton$

Table 2: Values of optimum slide load

Title	mass	Period of braced structure	Period of Un-braced structure	Max. ground acceleration	Period of structure	Period of structure	Alfa	Total shear load	Shear load
Unit	m	T_b	T_u	T_g	$\frac{T_b}{T_u}$	$\frac{T_g}{T_u}$	α	V	$V_s = \frac{V_0}{N_s}$
5-storey	15596	0/799	2/86	0/7	0/28	0/244	3/8072	49744	9/948
10-storey	39366	1/51	4/89	0/7	0/3	0/143	7/01	135491	13/54
15-storey	72375	2/057	5/37	0/7	0/38	0/13	8/84	190380	19/038

The Acceleration Recorders

The time history dynamic analysis the selected acceleration recorders shall be applied according to Regulations of 2800 (Mualla, 2000).

According to Regulations of 2800 (Mualla, 2000) acceleration recorders shall have the real earthquake conditions and acceleration recorders need to be scaled based on max. acceleration rate.

For this purpose, three acceleration recorders, soil type 3 near to the fault have been used for time history dynamic analysis.

RESULTS AND DISCUSSION

By modeling of damper in software, by equalization of acceleration recorders, by doing time history nonlinear static analysis and time history nonlinear dynamic analysis; the pushover curves resulted by nonlinear static analysis and displacement resulted by time history nonlinear dynamic analysis were studied.

Curves of Non-linear Static Analysis (Pushover)

Table 3: Comparison of absorption and energy amortization

Title	With damper	Without damper	%of absorption and energy amortization
5-storey structure	3/15	2/83	%11
10-storey structure	3/61	3	%17

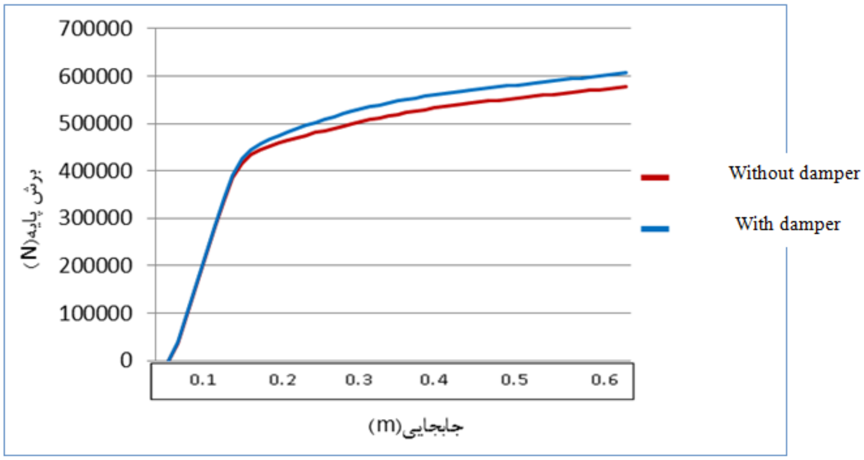

Figure 5: Comparative curve of 5-storey structure with damper and without damper

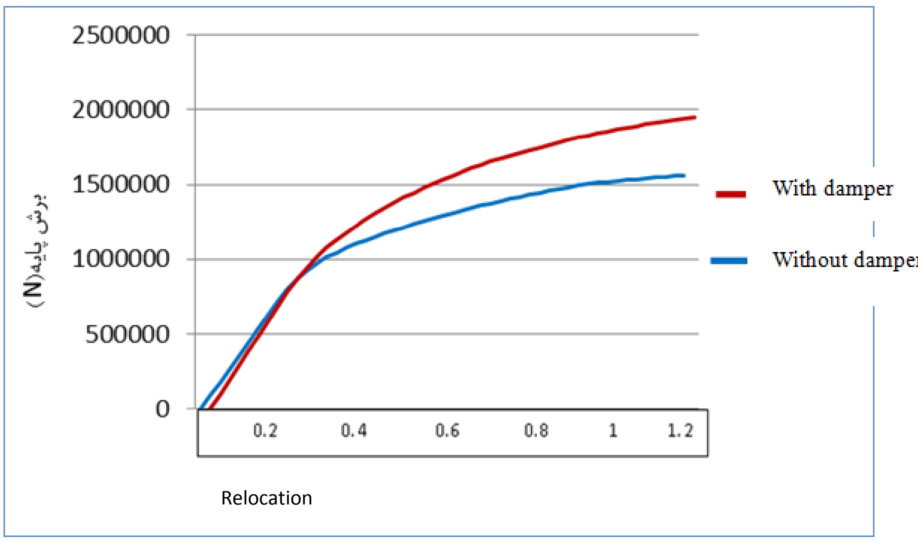

Figure 6: Comparative curve of 10-storey structure with damper and without damper

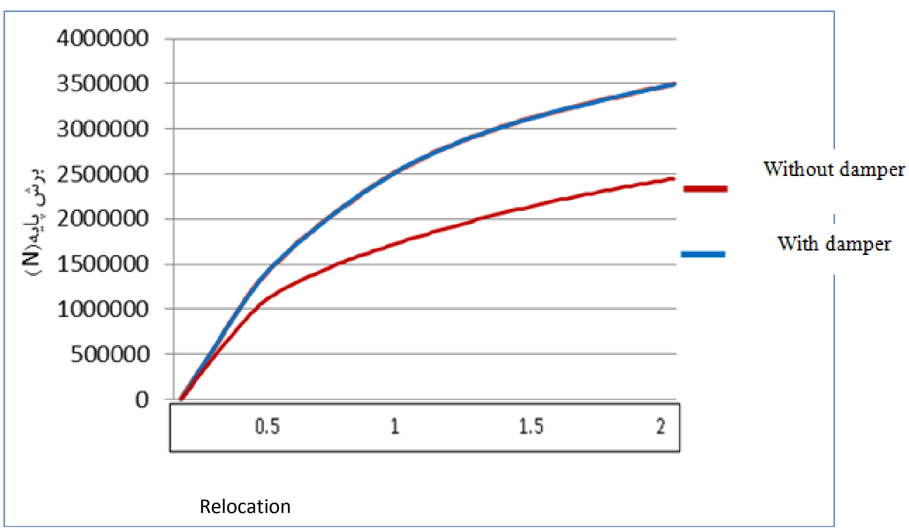

Figure 7: Comparative curve of 15-storey structure with damper and without damper

Curves of Area in a Pushover Analysis

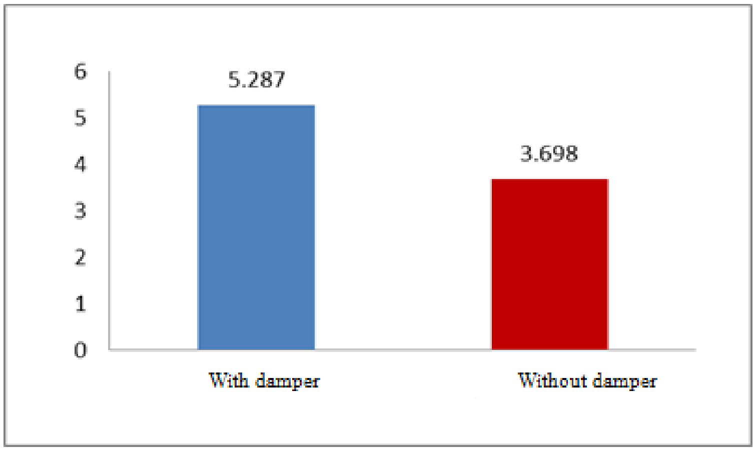

Figure 8: 5-storey structure

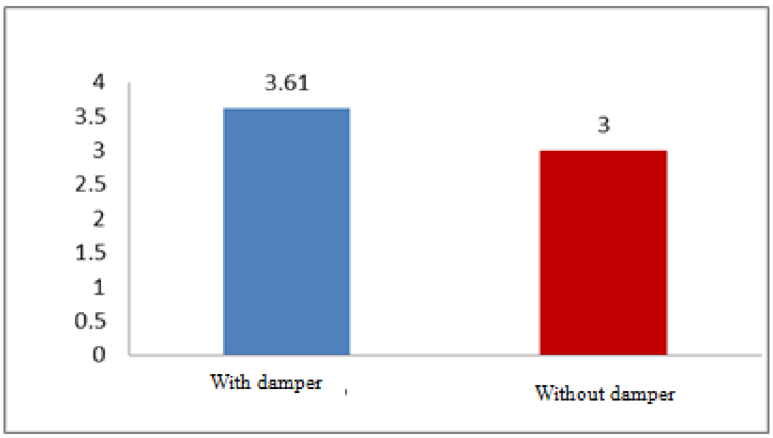

Figure 9: 10-storey structure

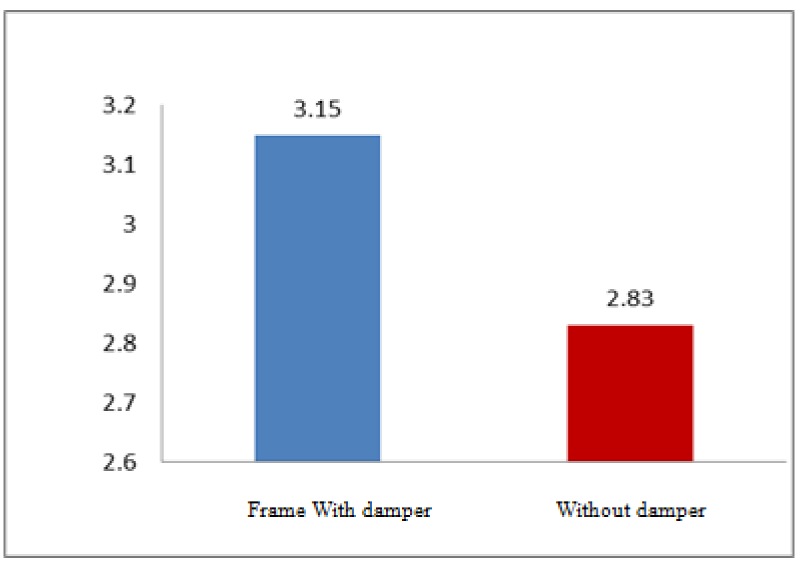

Figure 10: 15-storey structure

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The Results of Time History Nonlinear Analysis

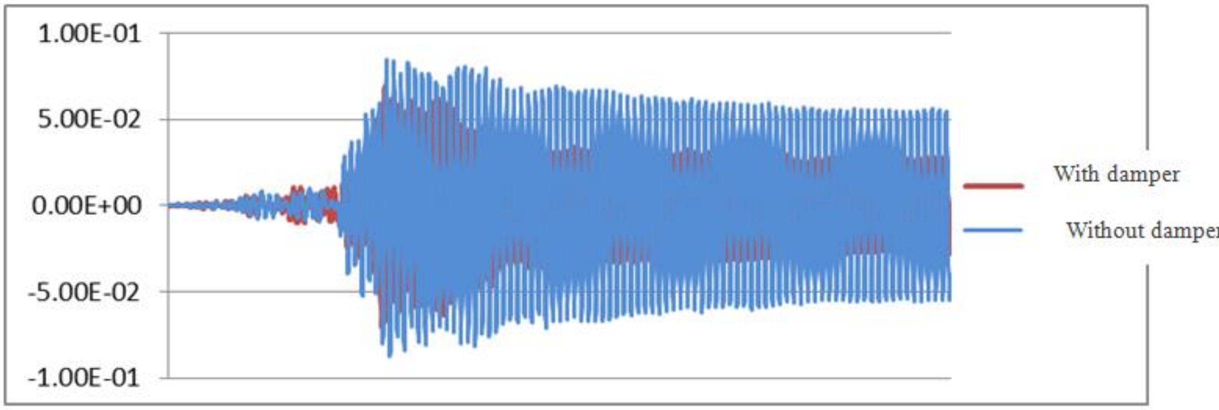

Figure 11: Comparison of 5-storey structure with damper and without damper

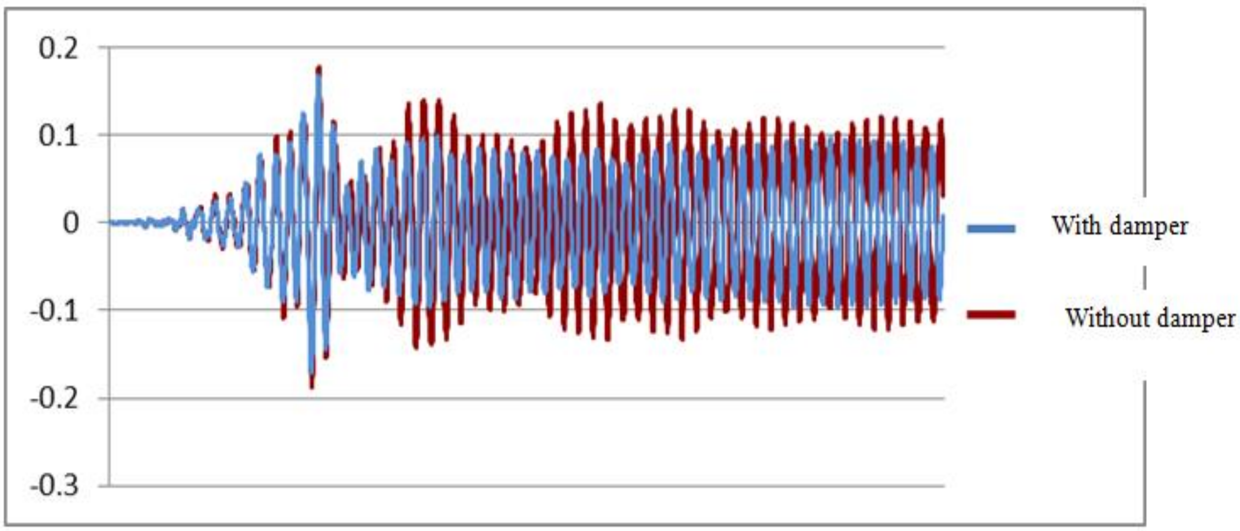

Figure 12: Comparison of 10-storey structure with damper and without damper

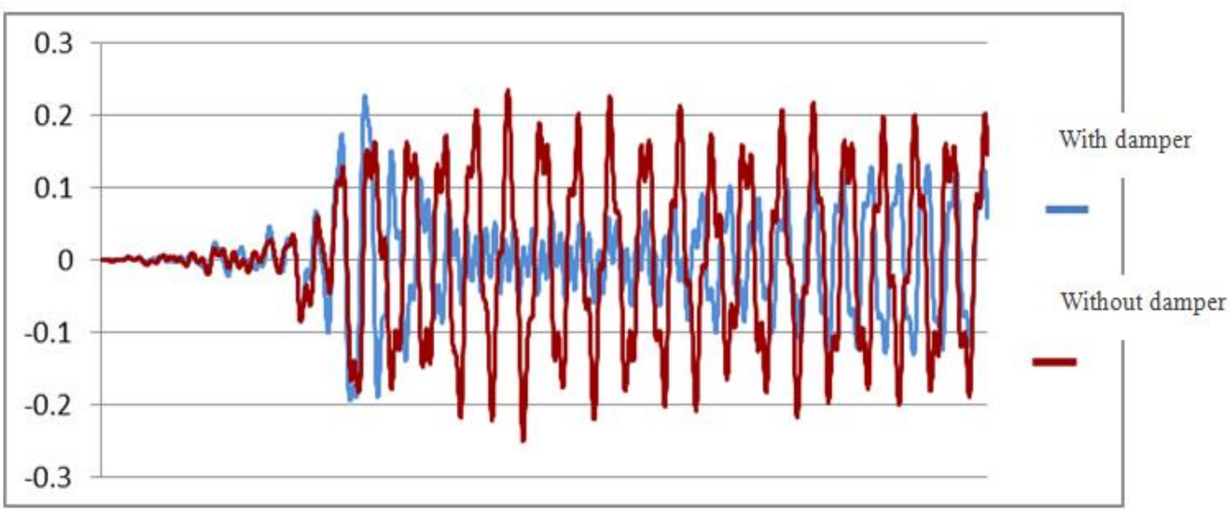

Figure 13: Comparison of 15-storey structure with damper and without damper

RESULTS AND DISCUSSION

1. Through the non-linear static analysis (pushover) it was seen that the area under the pushover curve in damper-frames of 5-, 10-, 15-storey was differ from frames without damper. The area under the pushover curve in nonlinear static analysis represents absorption and energy amortization caused by the lateral loads. This area can cause higher amortization and energy absorption if its measure is higher than the other frames. In 5-, 10- and 15-storey structures with damper, percentage of energy amortization is differ from the frames without damper that is equal to 11%, 17% and 30% respectively. It does not mean that the structures equipped with a damper have higher energy absorption and amortization rate; but the difference is related to above mentioned dampers in the structure.
2. Following the above results (1), a frame with damper is capable to absorb higher energy. According to section 10 of National Building Regulations (Mualla and Bellev, 2002), the joint is created as follow: at first the plastic joint is created in bracing components and then in beams and eventually in columns of structure. In structures with damper we have seen the desirable results so that the earthquake force has been applied into the damper and thus a significant percentage of energy is wasted in that dampers; and the rest of earthquake force is wasted in bracing and beams, so finally a very insignificant percentage of energy is applied to the columns of structure that plays the important role in the structure. By this way, property damage and loss of life will be decreased.
3. In time history nonlinear dynamic analysis, by applying three acceleration recorders for all three 5-, 10- 15-storey frames; it was concluded that the structures with damper have experienced lower displacement, drift and oscillation frequency as compared with the structures without damper.
4. In non-linear static analysis (pushover) through analysis of 5-, 10- and 15-storey frames with damper as compared with the frames without damper, it was concluded that if the number of storeys and height of frame is increased, then energy absorption and amortization in the frames will be increased.

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