A new rotational friction damper for vibration mitigation of reinforced concrete structures

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SUMMARY:
In this paper, the effect of a recently developed rotational friction damper, which is located in the diagonal braces of structures, has been studied for improvement of seismic behavior of reinforced concrete structures. This damper has high stiffness, high yield force and large energy dissipation capacity. For this purpose, the damper was tested dynamically by a hydraulic universal actuator first. Then by attention to the test results, the finite element model of the device was created and calibrated. In order to determine the effect of this new friction damper on the responses of multistory reinforced concrete structures under different ground excitations, the numerical models of two multistory structures were created and the model of the device was inserted in them. Nonlinear time history analyses were conducted on these structures when it is equipped with the damper and without it under several earthquake records. The results show that the proposed friction damper improved the response of the multistory structure significantly and the structures with damper have significantly lower floor displacements, story drifts and residual displacements than the structures without the devices.

Keywords: Seismic Retrofitting, Friction Damper, Passive Control

1. INTRODUCTION

Energy absorbing devices can be used both for making new buildings and retrofitting the existing ones. In the new buildings, these elements have crucial role in protection of the structure and dissipation of the internal energy. Consequently, by application of such devices in the building, the cross sections of the structural members are reduced significantly.
Generally, the structural control systems can be classified in three categories of Active, Passive and semi-active systems [Constantinou et al and Aiken et al]. In passive systems, the damping is achieved without using any external energy. They get the necessary power for dissipation of energy from the vibrations caused by seismic effects [Soong and Dargush]. Passive devices themselves are divided into two categories of permanent and disposable systems. Permanent devices need no replacement after the earthquake and remain permanently in structures. However, disposable energy absorbers need to be replaced after sever earthquakes [Constantinou et al, Aiken et al and Soong et al].

Friction dampers are one of the most common permanent passive dampers which have been widely used in structural vibration controls. One of the earlier researches was made by Fillitrailt & Cherry in 1987 by assessing of a friction damper in the diagonal bracing [Fillitrailt and Cherry]. By application of this system within the braces of the structure, its strength against earthquake loadings was improved significantly. During the seismic excitations, friction dampers slip and instead of plastic deformation of the main structural components, they dissipate the internal energy of to the structure.

Nonlinear time history analysis of the steel structures equipped with the friction dampers shows their better behaviour in comparison to the none-equipped structures. These dampers, due to their simplicity and low costs, can be used both in new and existing buildings. In these energy dissipaters, the slippage friction produced between solid interfaces is used as the main energy dissipating phenomenon. The disadvantage of these dampers is their exposure to the environmental effects such as moisture. This will cause an alteration in the friction coefficient [Constantinou et al, Aiken et al, Soong et al and Mualla et al].

The most important friction devices, which are currently manufactured and used in the buildings, are those of Pall and Damptech products. Pall dampers are located in the diagonal bracing and have translational displacements at its friction hinges. Damptech system is located in the chevron braces and its hinges have just rotational movements.

In this paper, a special kind of friction damper, which is located within diagonal bracing and has only rotational movements at its friction hinges, is introduced. Due to this rotational movement, the friction pads are kept away of the environmental effects and therefore the durability of the device is improved.

2. THE TECHNICAL DETAILS OF THE DAMPER

This damper, similar to PALL system, is applied at the intersection of X-shaped diagonal braces but its friction hinges have just rotational movements. This causes the friction interfaces to be away of the environmental effects. Fig. 1 shows the schematic representation of this modified friction damper and its cross section. The main elements of this modified device are 9 steel strips, 9 circular friction pads and 9 bolts, as shown in Fig. 1. Friction pads are located between the steel strips at friction hinges and clamped by 5 high strength bolts. The other four bolts are used to connect the device to the braces. This friction damper is installed inside of the X-shape bracing systems.

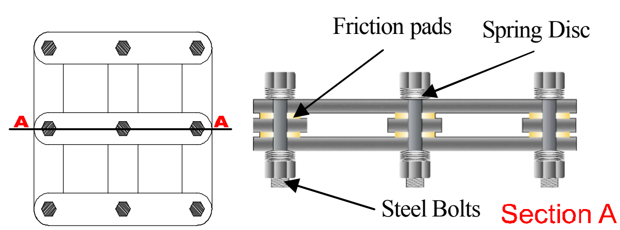

Figure 1. Friction damper and A-A cross section

By attention to Fig. 2, Eqn. 2.1 can be established for the yield moment of the damper:

$$F = \frac{5M}{L\cos\theta} \tag{2.1}$$

in which F is the yield limit of the device, M is the yield moment of the friction hinges and L is the length of the steel strips. Angle "θ" has been shown in Fig. 2.

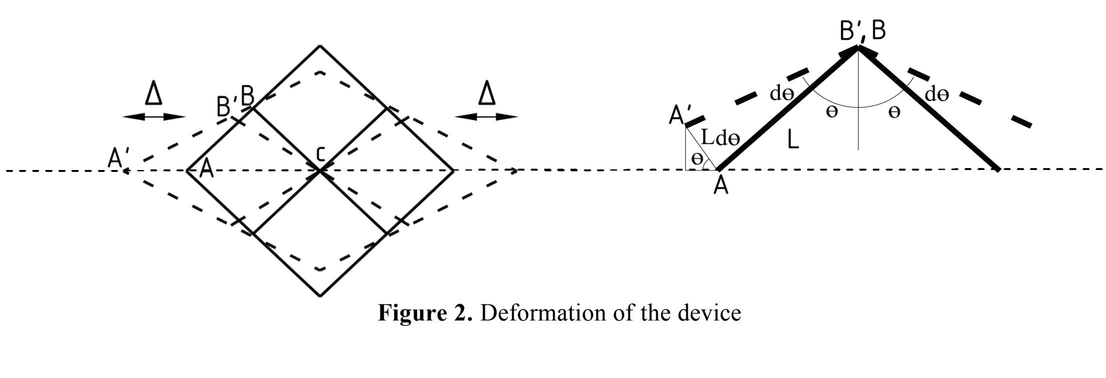

Figure 2. Deformation of the device

The prototype device was made of 9 rectangular strips with 20 cm height, 4 cm width and 0.5 cm thickness. These stripes were connected to each other by using 9 high strength bolts with 8 cm center to center distances. Friction pads with 1 cm thickness were used between the stripes.

3. EXPERIMENTAL TESTS

The device, with the dimensions shown in Fig. 4, was built at the earthquake engineering laboratory of Urmia University. Then the hydraulic displacement-controlled actuator of Urmia University was used for universal testing of device. Fig. 3 shows the experimental set up for this purpose.

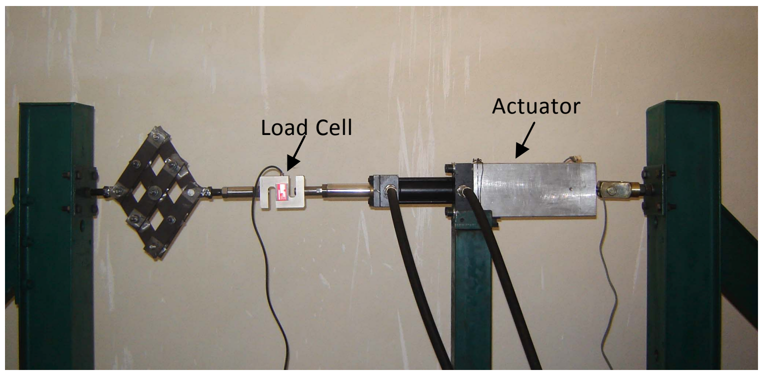

Figure 3. The experimental universal set up

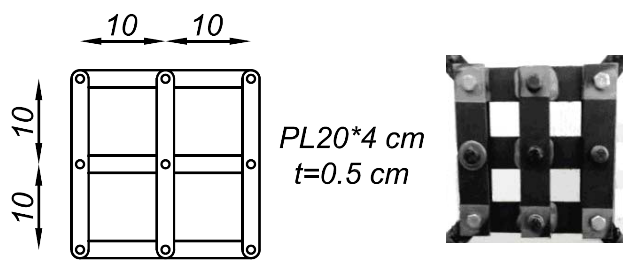

Figure 4. Dimensions of the prototype device

The loading curves and their recorded load deflection curves are shown in Fig. 5, 6 and 7 for 0.2 Hz loading frequency and 2.5, 3 and 5 cm displacement domain respectively.

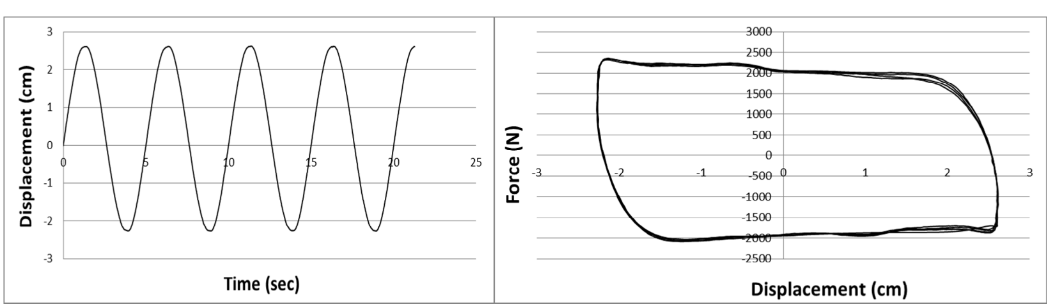

Figure 5. The applied displacement loading with displacement amplitude of 2.5 cm and its hysteresis load deflection curve of the device

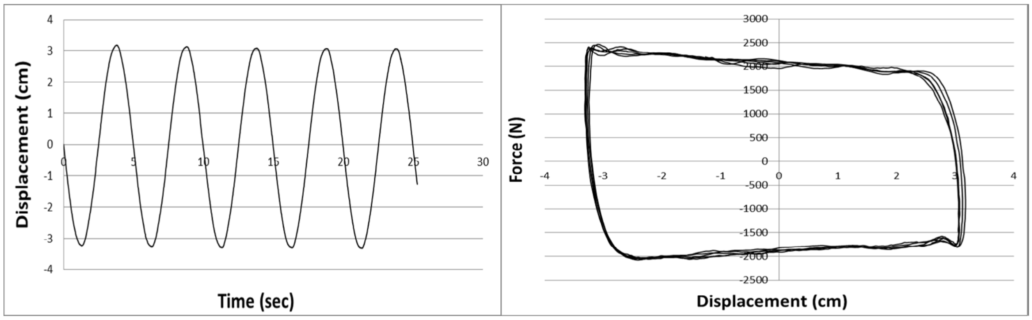

Figure 6. The applied displacement loading with displacement amplitude of 3 cm and its hysteresis load deflection curve of the device

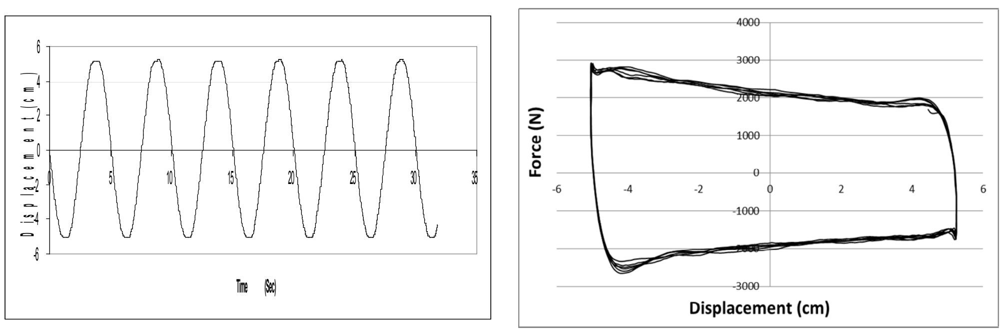

Figure 7. The applied displacement loading with displacement amplitude of 5 cm and its hysteresis load deflection curve of the device

4. EVALUATION OF DAMPER ON SEISMIC BEHAVIOUR OF STRUCTURES

4.1. Finite Element Model of the SDOF Frame Equipped with the Friction Damper

In order to analyze the responses of multi story structures equipped with this modified damper, the finite element model of the SDOF steel frame was created first, Fig. 8.

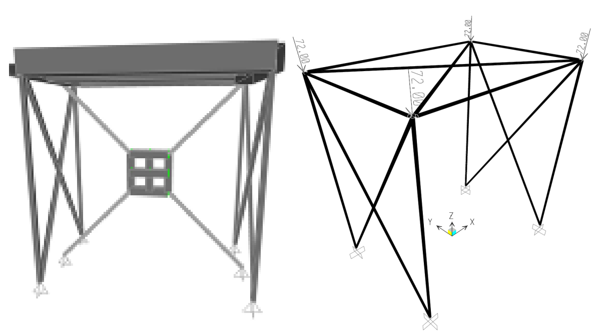

Figure 8. The numerical model of the SDOF steel frame

Fig. 9 shows the friction moment versus the lateral displacements of the SDOF frame. Table 4.1 is the details of the applied earthquakes.

Table 4.1. Earthquake details for analysis and experimental work

R	Earthquake	Station	Magnitude	Latitude	Longitude
1	Tabas (1978)	Iran 9101.Tabas	7.35	33.5800	56.9200
2	Kobe Japan (1995)	99999 TOT	6.90	35.4850	134.2400

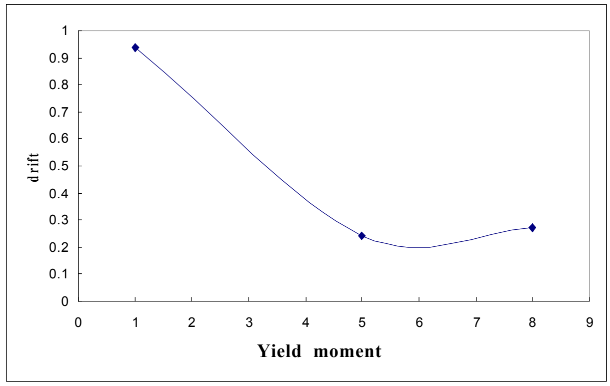

Figure 9. The maximum displacement of the frame versus yield moment

Non-linear time history analyses of the SDOF frame under Tabas and Kobe earthquakes were performed and compared to that of the frame equipped with the damper. The comparison of these two cases are shown in Figs. 10 and 11. The yield moment of the friction hinges in these analysis and tests was 5 Kg-m. By attention to these displacements-time curves, it can be concluded that the application of this damper in the SDOF frame has significant reduction in the responses.

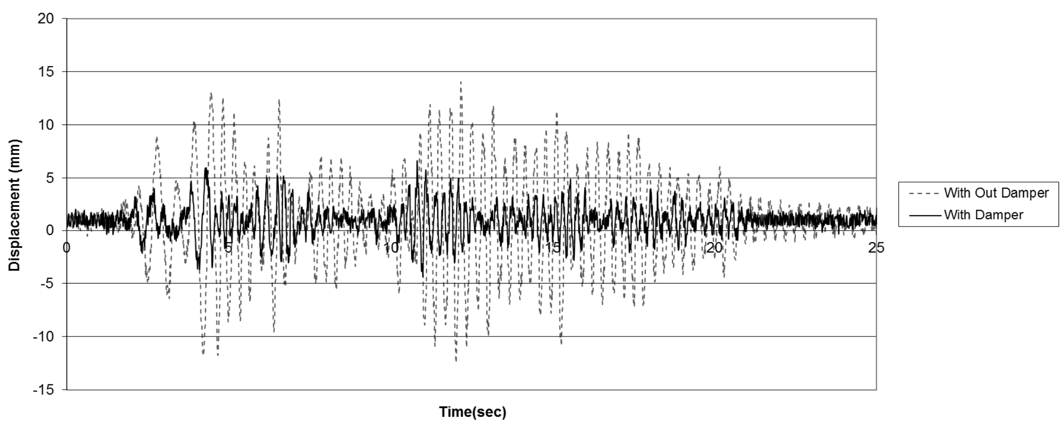

Figure 10. Time-displacement curve of the SDOF frame with the damper under Tabas earthquake excitation

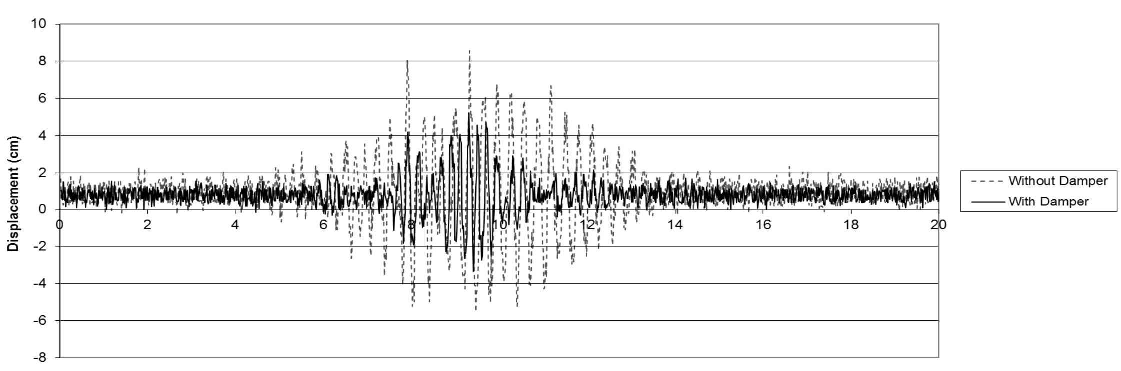

Figure 11. Time-displacement curve of the SDOF frame with the damper under Kobe earthquake excitation

4.2. Multi Story Reinforced Concrete Structures Equipped With the Modified Friction Damper

In this section, two five and seven story structures have been used for analysis. Both structures were designed according to ACI 318-99 and Iranian seismic code, 2800. Both structures have the same plan. In Fig. 12 these structures are shown.

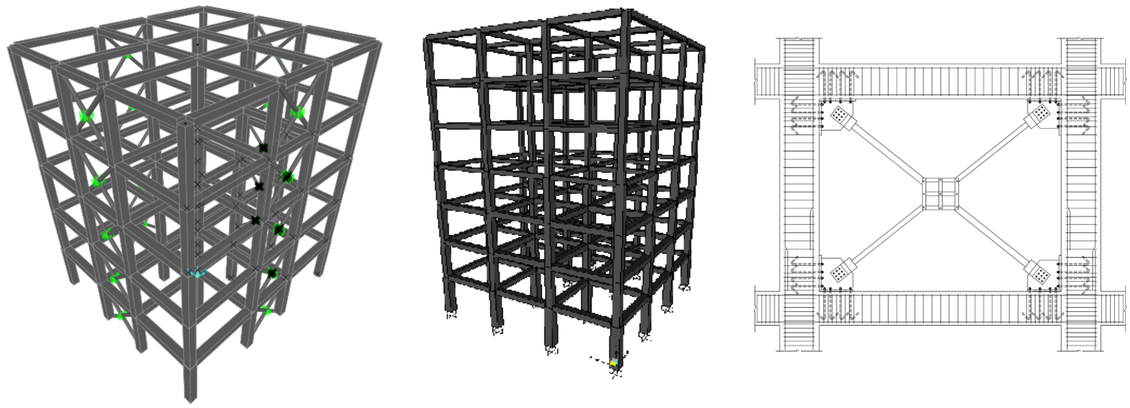

Figure 12. Five and seven story reinforced concrete structures

In these modeling, the yield loads of the dampers were reduced along the height of the structures. By following a trial and error method, it is found that a linear reduction along the height has better performances than uniform distribution. The optimal amounts for dampers yield load were obtained according to the minimal base shear and the relative story drifts. Nonlinear dynamic analyses were conducted on the structures under scales Tabas earthquake with o.35g and 0.5g peak acceleration as base excitations. The time intervals of these analyses were chosen small enough to obtain sufficient accuracy. In Figures 13 and 14, maximum displacements of the stories of the structures are shown.

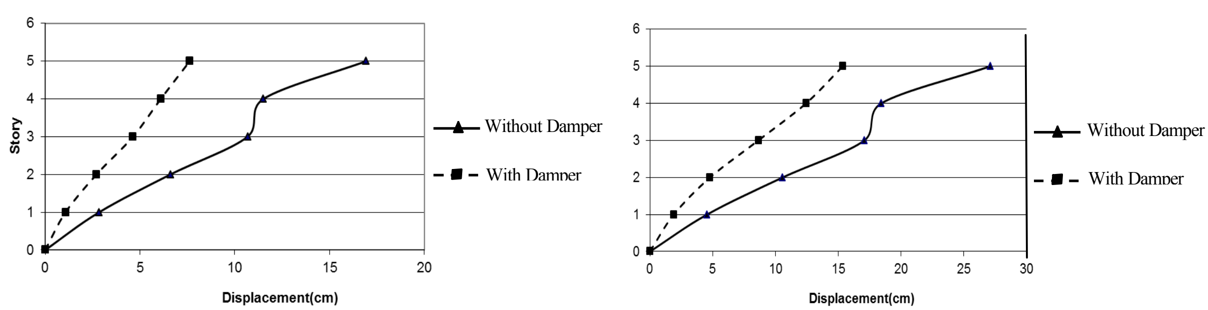

Figure 13. Displacements of the five story structure under Tabas scaled excitation 0.35g (left) , 0.5g (right)

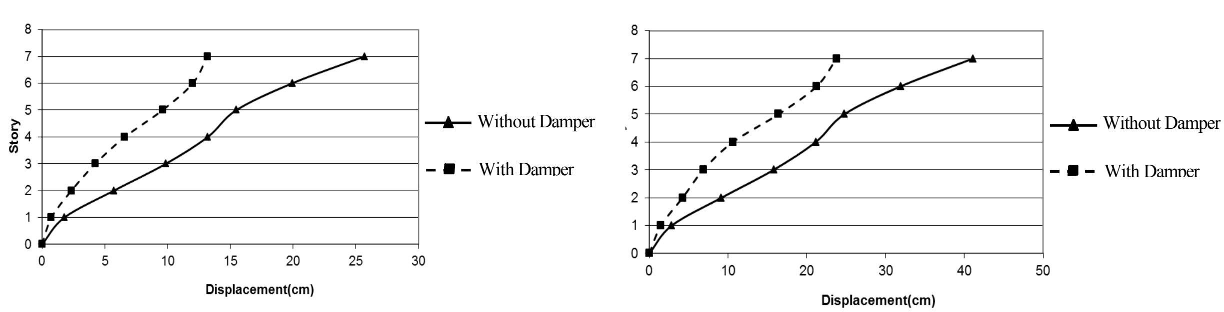

Figure 14. Displacements of the seven story structure under Tabas scaled excitation 0.35g (left) , 0.5g (right)

5. CONCLUSIONS

In this paper, some experimental works on a modified Friction Damper were presented and its application was introduced. The following conclusion can be drawn:

1. The introduced damper in this paper, not only provides additional structural stiffness, but also has good energy dissipating capabilities. The results showed that the device is an effective dissipative device and it is feasible to calculate the response of the structure with dampers by finite element method.
2. The modified friction damper has reduced the displacements and stories drifts. By attention to time-displacement curves, it can be realized that the average amount of the displacements in 5 and 7 story structures during Tabas earthquake excitations have been reduced by 24% and 28% factors respectively.
3. Linear distribution of yield moment of friction hinges over the height of structures is more suitable than uniform one.
4. A large percent of the internal energy has been dissipated by the dampers.

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