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Exploring the Efficiency of Dampers for Repair and Strengthening of Existing Buildings

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Abstract

In this paper, seismic behavior of the existing buildings equipped by friction dampers is studied. Seismic performance of6-story, 9-story and 12-story steel buildings with damper and without damper were studied. The finite element modeling technique (SAP2000 Software) is used for analysis. Time History analyzing was done to achieve this purpose. For nonlinear dynamic analysis, the responses of the structures to three earthquake records (Tabas, Naghan, and artificial waveform) were obtained. A series of analyses were made to determine the optimum slip load of the friction dampers to achieve minimum response. Also, in order to evaluate the performance of the friction dampers in asymmetric structures, an asymmetric structure was utilized. The obtained results show significant improvement of seismic behavior and efficiency of the friction damper for seismic retrofitting to these buildings.

Key words: Friction damper, Slip load, Nonlinear dynamic analysis, Seismic retrofitting, existing building.

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1. Introduction

The observed structural damages in recent earthquakes show that it is necessary to choose new methods for designing of earthquake resistance structures. In many earthquake prone countries, buildings are being retrofitted or constructed with control devices to reduce stresses, displacements and base shear during seismic activity. These aims can be achieved by adding braces, shear walls, energy dissipation and control devices. The main types of control devices employed in structures are used to provide an active control, semi-active control and passive control system. There are several different types of passive devices such as dampers. Passive dampers are the oldest and most common form of control devices. They directly use the displacement of building floors to apply a damping force on the structure. Without any type of sensing equipment or computation, passive devices are generally the least expensive and more widely used devices [1]. Hence active and semi-active devices, passive devices cannot change their damping properties based on the structure's response and therefore do not require any power or control algorithms to operate.

Friction dampers are the most prevalent of these passive control systems, because of being used in different kind of braces, low cost and suitable efficiency [2].The development of friction devices for use in civil structures to control seismic response was pioneered in the late eighties [3]. Several design variations of these dampers have been studied in the literature and different forms of patented hardware, now available commercially are X-braced friction, diagonal braced friction and chevron braced friction, slotted bolted connection and Sumitomo friction [4,5]. These devices differ in their mechanical complexity and in the materials used for the sliding surfaces.

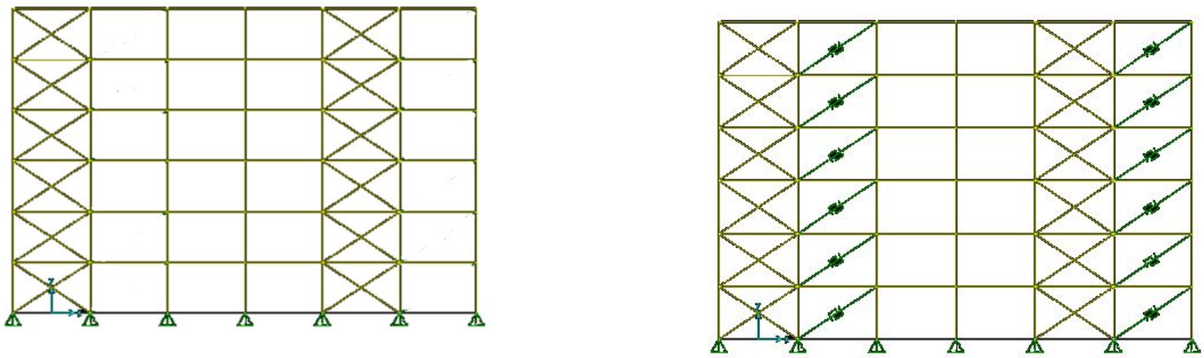
Friction dampers rely on the resistance developed between two solid interfaces sliding relative to one another [1]. During severe seismic excitations, the device slips at a predetermined load, providing the desired energy dissipation by friction while at the same time shifting the structural fundamental mode away from the earthquake resonant frequency.

Pall and Marsh proposed a friction damper installed at the crossing joint of the X-brace to avoid the compression in the brace member [6]. Constantine et al. introduced friction damper composed of a sliding steel shaft and two friction pads clamped by adjustable bolts [7]. Liand Reinhorn verified the seismic performance of a building model with friction dampers both analytically and experimentally [8]. Grigorian et al. examined the energy dissipation effect of a joint with slotted bolt holes [9]. Mualla and Belev proposed a rotational friction damper with adjustable slip-moment [10]. Cho and Kwon conducted numerically modeling and analysis of a wall-type friction damper in order to improve the seismic performance of the reinforced concrete structures [11]. Fu and Cherry proposed a design procedure of the friction dampers using a force modification factor [12]. Ciampi et al. developed a simple approach for determining the distribution of stiffness and strengths within the elastic and inelastic structures [13]. Kim and Choi calculated the yield load of the buckling-resistant-brace system using energy spectrum [14].

In this study, performance of friction dampers to retrofit of existing buildings is investigated. The finite element modeling technique (SAP2000 Software)[15] is used to evaluate structural responses. The results have been investigated in five sections. In the first section a 6-story steel building with damper and without damper has been modeled. The second section, the optimum slipping load of the friction dampers and structures were analyzed for the different values of slip loads and stiffness values .In the third section, to determine the performance of structure equipped by friction dampers, building undergoing different accelerations from low to very high is analyzed. The four the section evaluates the seismic behavior of tall building structures by friction damper. Two cases of 9 and 12 story buildings model are studied. In the fifth section, performance of friction damper in asymmetric structures has been investigated.

2. Investigated building

Generally this paper addresses seismic behavior of existing building by friction damper. To this end, 6, 9 and 12-storysteelbuildings and an asymmetric structure were selected as a case study. These buildings have a 6 bay layout at the X direction and 5 bay layouts at the Y direction. All buildings have 5m span and 2.5m height at the parking and 3.1m height at other stories. The configuration of frame with and without damper in the structure is shown in Fig 1.



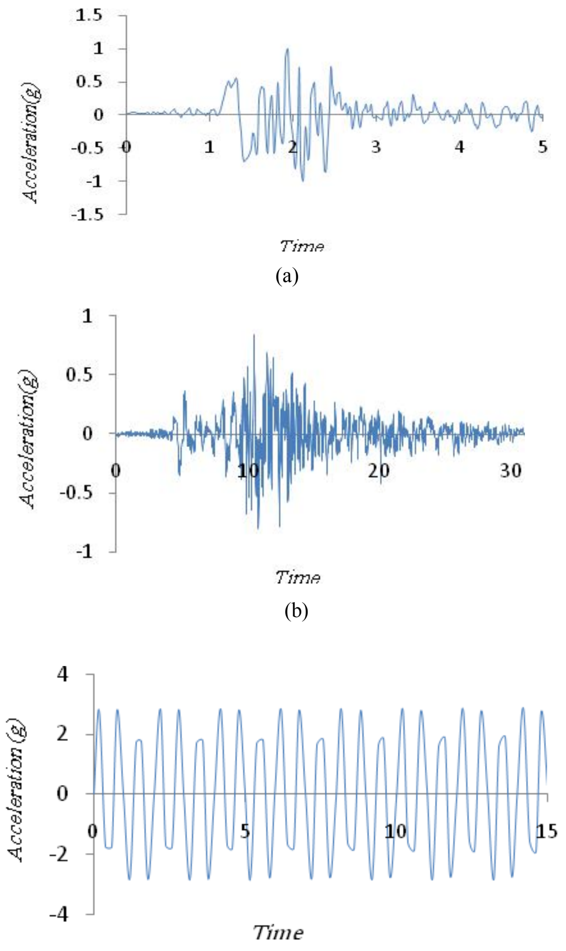
(a) (b)

Fig. 1, a) Frame without damper b) frame with damper

Table 1: Properties of materials

No	Material properties	Values
1	Mass per unit volume of steel	800
2	Weight per unit volume of steel	7849
3	s)υPoisson's Ratio of steel (	0.3
4	Modulus of Elasticity of concrete (Es)	2038901. 9 Kg f/ cm^2
5	Yield stress of bracing steel (Fy)	2400 Kg f/ cm^2
6	Ultimate stress of bracing steel(F_u)	3700 Kg f/ cm^2

The following material properties were used for the structures modeling and analysis (see Table 1).All sections of beams and columns are IPE and all sections of bracings are angle. In order to deal with the seismic forces, the X bracing was used in the X, Y direction and all the buildings do not have hinge plastic. The slip load of friction damper in an elastic brace constitutes nonlinearity. Therefore, analysis of friction damper buildings requires the use of nonlinear time-history dynamic analysis [16]. The nonlinear dynamic analyses were performed using three earthquake records. These records include Naghan and Tabas earthquakes with PGA of 0.35 as shown in Figures 2a and 2b. Furthermore, an artificial waveform representing is created for dynamic analysis as shown in Fig 2c.



(a) (b) (c)

Fig. 2, a) Naghan record b) Tabas record c) artifical waveform

Based on the above dissections, for each of the rehabilitation schemes of the building a realistic model was prepared and several nonlinear dynamic analyses were performed on the models. In all of the analyses, analysis of steps equal to 0.02 sec is considered.

According to the studies that have been done [10], since the hysteretic loop of the friction damper is similar to the rectangular loop of an ideal elastic-plastic material, the slip load of the friction-damper can be considered as a fictitious yield force. Hysteretic loop of a 20 KN friction damper is shown in Fig 3.

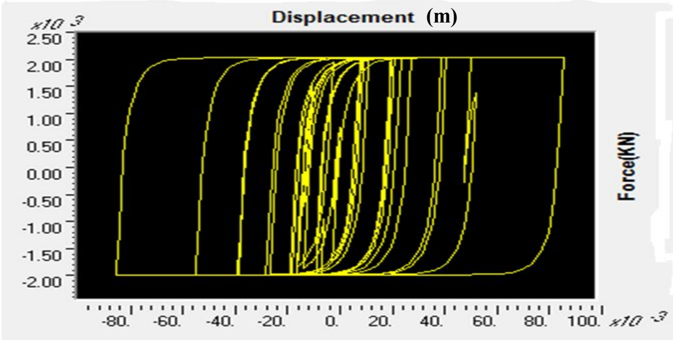


Fig. 3, Hysteretic loop of a 20kN friction damper in a diagonal brace at the 9story

In the analyses, friction dampers in single diagonal brace are modeled as damped braces having member stiffness equal to brace stiffness and nonlinear axial slip load equal to yielding load of the corresponding brace [17]. For the modeling of friction dampers in SAP2000, there are some link elements that only one of them can be used due to its elasto-plastic behavior. Therefore, Wen elasto-plastic link elements were used to define friction damper. For the 6-story building, 72 diagonal friction dampers of 20 KN slip load have been modeled. For the 9 story building, the 72 diagonal friction dampers of 20 KN slip load is used at the first to sixth stories and friction dampers of 15 KN slip load were used at the next stories. For the 12-story building, 96 diagonal friction dampers of 20 KN slip load is considered at first to six stories and friction dampers of 15 KN slip load have been modeled for next stories.

3. Result

As mentioned earlier, the results are presented in 5 sections along with their descriptions as indicated below.

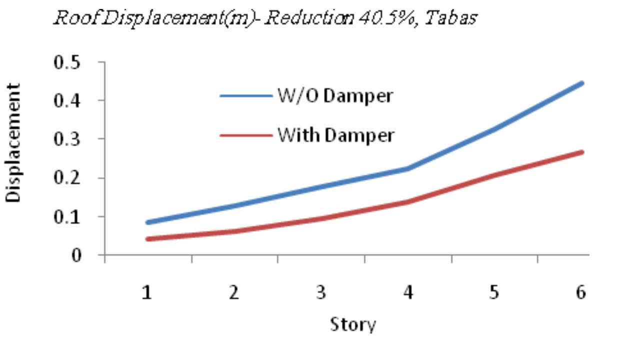
3.1. Time history analysis results of the six-story steel frame structure

The main aspects of comparison between un-damped and damped structure can best be treated under three headings:

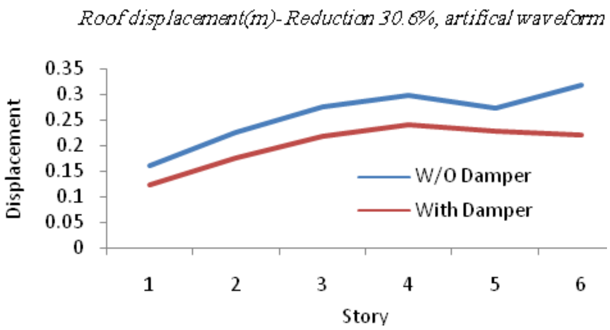
✓Roof displacement
✓Columns axial force
✓Base shear of structures

3.1.1. Roof displacement

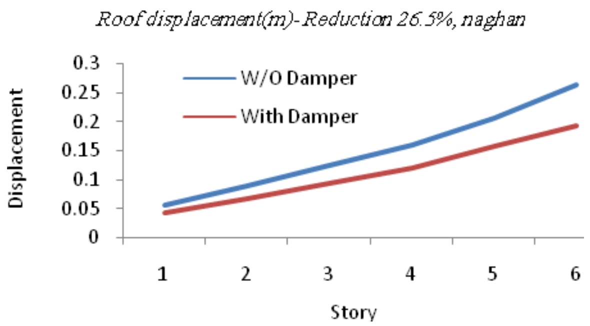
Maximum roof displacements for 3 earthquake records are shown in Fig4. The comparison of these diagrams may indicate that the use of Friction Damper decreases the roof displacement for all earthquake records. By increasing the damping of structure due to adding friction damper devices, the response of structure such as velocity and acceleration can be reduced and it will be the cause of reduction of displacement. Also, as Fig 4 illustrates, reduction of roof displacement in the Tabas record is more than the other records; this indicates that friction damper has more impact in the intense earthquakes.



(a)



(b)

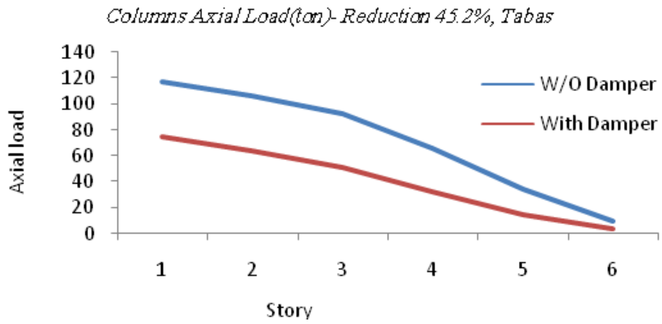


(c)

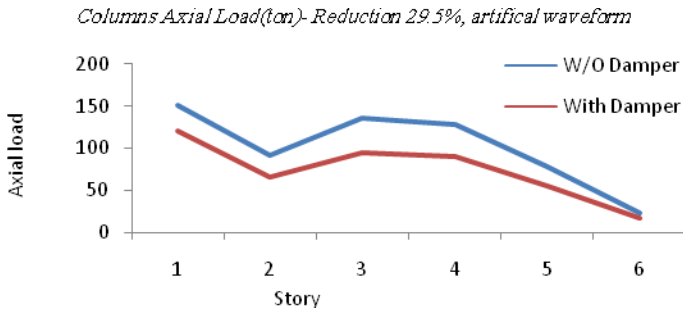
Fig. 4, Maximum of Roof Displacement

3.1.2. Columns axial force

A comparison of column's axial force at the 6-story steel structure is shown in Fig 5.As can be seen from Fig5, the amount of axial load of columns of un-damped structure is reduced to about 45.2% for Tabas record. This reduction is due to the dissipation of input energy by friction damper devices. In other words, high percentage of input energy or input forces is resisted by braces that are equipped by friction damper devices and, thus, the residual energy that is resisted by the frame is dramatically decreased. Also, asFig5shows, the friction damper in the member experience the more force will have the better performance.



(a)



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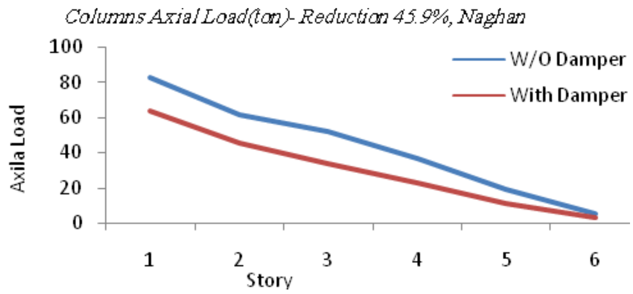

(c)

Fig. 5, Maximum of Columns Axial Load

3.1.3. Base shear

The maximum base shear of building using friction damper for different earthquakes is presented in Table 2. The amount of base shear of un-damped structure is reduced to about 37.5% for Tabas record, 36.2% for Naghan record and 22.6% for artificial waveform. This results indicate that friction damper have impact sin the intense earthquakes. In the intense earthquakes, higher number of dampers was slipped and more energy dissipation leads to reduction the earthquake forces.

Table 2: Maximum of base shear (ton)

	Tabas	artifical waveform	Naghan
Without Damper	557.7	736	281.14
With Damper	348. 4	526	179.5
Reduction (%)	37.5	28.9	36.2

3.1.4. Optimum slip load

The results of the effect of stiffness and slip load on the response structure are shown in Fig 6.

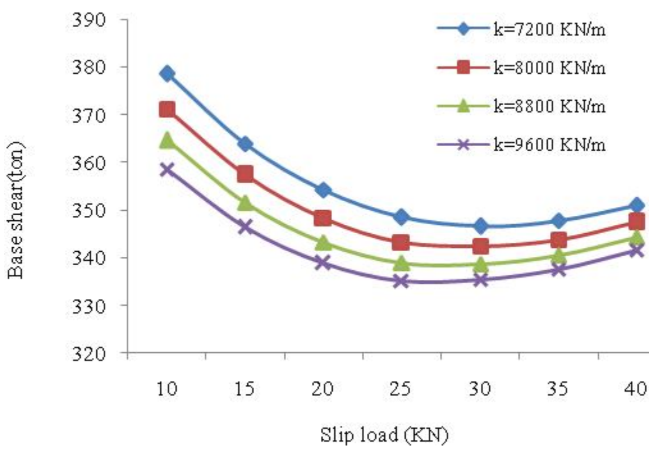

Fig. 6, Effect of stiffness and slip load in response structure

Dissipated energy of structure with friction damper is depended on the slip load. If the slip load is chosen to be high ,in weak seismic events, dampers do not slip; so, dampers do not affect the reduction of structural damage and the structural system acts such as braced frame and if this amount is chosen low, the damper will slip at low loads and cannot control drift of structure at intense earthquake Adding dampers will increase stiffness of the structure that in turn leads to the lower natural period and will increase base shear. Therefore, to reduce the base shear, optimum slip load should be chosen appropriately. In Fig 6, response of structure is shown for different stiffness (7200, 8000, 8800, 9600 KN/m) and slip load (10, 15, 20, 25, 30, 35, 40 KN).Optimum slip load gives the minimum response. In this study, the adequate value of slip load is 25 kN.

3.1.5. The effect of base acceleration on the response of structure

In order to investigate the effects of base acceleration on the response of structure, structural analysis was carried out with different accelerations (0.25g, 03g, 035g and 0.4g). For this study, friction dampers with 20 KN slip load and 8000KN/m stiffness were considered. As can be seen in Table 3, percentage reduction of the base acceleration exhibits nonlinear behavior with damper.

3.2. Seismic behavior of tall building structures by friction damper

In order to study the effects of friction damper for retrofit of the tall building, base shear is evaluated under Tabas record for the 6, 9 and 12-story models. In Table 4, these results are shown .Percentage reduction of base shear for 12-story models is more than 9 and 6-story ones. Percentage reduction of base shear for 9-story buildings is more than 6-story buildings. These results indicate better performance of friction damper in the tall buildings.

Table 3: Nonlinear behavior of structures with damper

(%) Reduction	Base shear(ton)	Base acceleration
	395	0.4g
11.9%		
	348	0.35g
15.5%		
	294	0.3g
17%		
	244	0.25g

Table 4: Reduction of base shear in the 6, 9 and 12 story steel buildings (ton)

	6story	9story	12story
Without damper	558	712	857
With damper	348	416	442
Reduction (%)	37.5	41.6	48.2

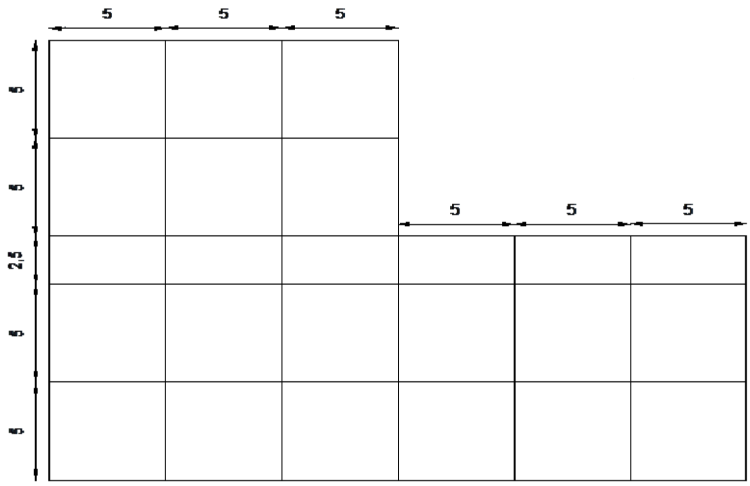

Fig.7, asymmetric structure (unit: metric)

3.3. Seismic behavior of asymmetric structures by friction damper

In order to evaluate the performance of friction damper in asymmetric structures, asymmetric structure plan (Fig. 7) was modeled and the responses of structures under Tabas record were evaluated. The effects of friction damper in the asymmetric structures is shown in Table 5 and one can conclude that friction damper in this structure has good performance and equipping the structure with dissipating energy leads to reduction of the earthquake forces.

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