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An investigation into the influence of friction damper device on the performance of steel moment frames

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ABSTRACT: - Friction damper device belongs to those passive control systems made according to friction mechanism. Since, friction is a great source of energy dissipation; it is used in structures in order to decrease the structure response against wind and earthquake load. In this paper, steel moment frames with 3, 7 and 12 stories equipped with the mentioned damper is investigated under seismic analysis. Finally, it is concluded that by adding dampers, the reduction percentage of roof displacement of frames will be decreased by increasing the number of stories. It is also concluded that 7 stories frame equipped with dampers has a better performance.

Keywords: - *Friction damper device, passive control systems, seismic analysis, roof displacement, energy dissipation.*

I. INTRODUCTION

Using the dampers or energy dissipation devices are one of the controlling methods of structures vibration under seismic loads. The applications of these devices in design the new buildings and retrofitting the existence buildings are possible [1]. Friction dampers are one of the passive control systems which have an increasing application in moment frames. These are lots of project of such dampers all over the world [2]. Friction damper is functioned according to friction mechanism among rigid materials. In fact, friction is a great mechanism of energy dissipation, employed in car brake systems successfully and extensively. A base metal selection of friction damper is of high importance. Since, there are different materials employed for slippery surfaces [3, 4, 5]. A new friction damper device was employed for the first time by Mualla in his PhD thesis [6]. Full scale experiments for three stories structure equipped with such damper on shaking table was done in Taiwan [7]. In order to increase the seismic capacity of existing structures, it is possible to use the friction damping system connected to high strength tendons [8]. Three steel moment frames with 3, 7 and 12 stories equipped by friction damper devices are investigated under nonlinear time history analysis in present study. The influence of dampers on seismic performance of frames is studied by comparing the parameters like base shear, displacement and energy dissipation of frames with and without dampers.

II. FRICTION DAMPER DEVICE

The components of friction damper device are central vertical plate, two lateral horizontal plates and two circle friction pads placed between the steel plates [9]; (Fig. 1).

Figure 1: Friction damper device [10].

A single story frame equipped with friction damper device is presented in Fig. 2. When a lateral external force excites a frame, the beam starts to displace horizontally. The damper will follow the horizontal movement of the frame because of the hinge connection, which transfer the forces to the damper parts. The bracing system and the frictional forces developed between the frictional surfaces of steel plates and friction pad materials will resist the horizontal movement. The central plate will start to move horizontally and rotate around the hinge. The clamping force in the bolt, which makes the damper parts stick to each other, and due to this introduces frictional forces. These frictional forces will rotate the horizontal plates within the same value of rotation and direction as the central plate dose, because they are higher than the applied forces. The damper will continue being in sticking phase until the applied forces in the damper exceed the frictional forces, at this slip moment, starts and the central plate rotates relatively to the friction pads, around the bolt [6].

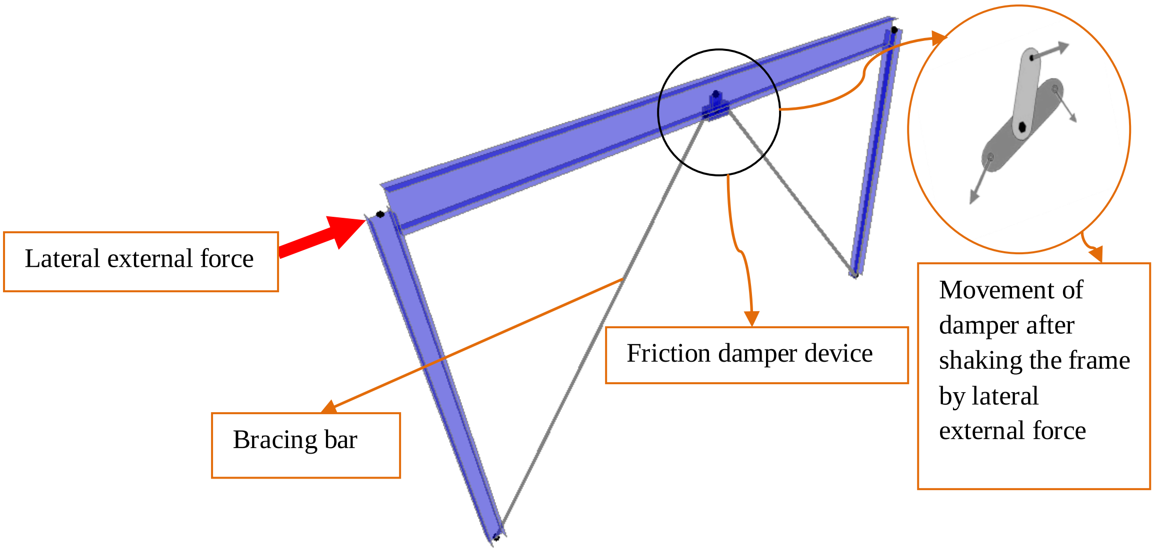

Figure 2: Frame equipped with friction damper device.

The horizontal plates also start to slip and rotate but in another direction because of the tensile forces in the bracing. In this sliding phase, the damper will dissipates energy by means of friction between the sliding surfaces. This phase will keep on and later will be changed to the sticking phase when the load reverses its direction [6]. To prevent the buckling of compression bar, the bars are pretensioned by F_p force according to equation 1.

$$F_p = \frac{M_f}{2h_a \cos v} \tag{1}$$

In which v is the bar slope angle with horizontal line. Therefore the cross-sectional area of bars is determined according to equation 2.

$$A_b = \frac{M_f}{\sigma_y h_a \cos v} \tag{2}$$

In which σ_y is the yielding stress of bracing bar. Friction damper has two phases: sticking and sliding phases. The stiffness of damping system in sticking phase is calculated according to equation 3.

$$k_{bd} = \frac{2EA_b}{l}\cos^2 v + \frac{2F_p}{L}\sin^2 v \tag{3}$$

Where E is elasticity module, A_b is bracing bar area, l is length of the bracing bar and L is length between the hinge which is existed on the top of the friction damper device and the end of bracing bar. The stiffness of damping system is ignored in sliding phase, as it is negligible [11].

III. MODEL VERIFICATION

To be sure the accuracy of modeling, the displacement results for a one story frame under El Centro earthquake excitation are compared with the results obtained by Mualla [9]. The response obtained by Mualla and Belev is shown in Fig. 3.a and the response of mentioned frame in the present study is given in Fig. 3.b.

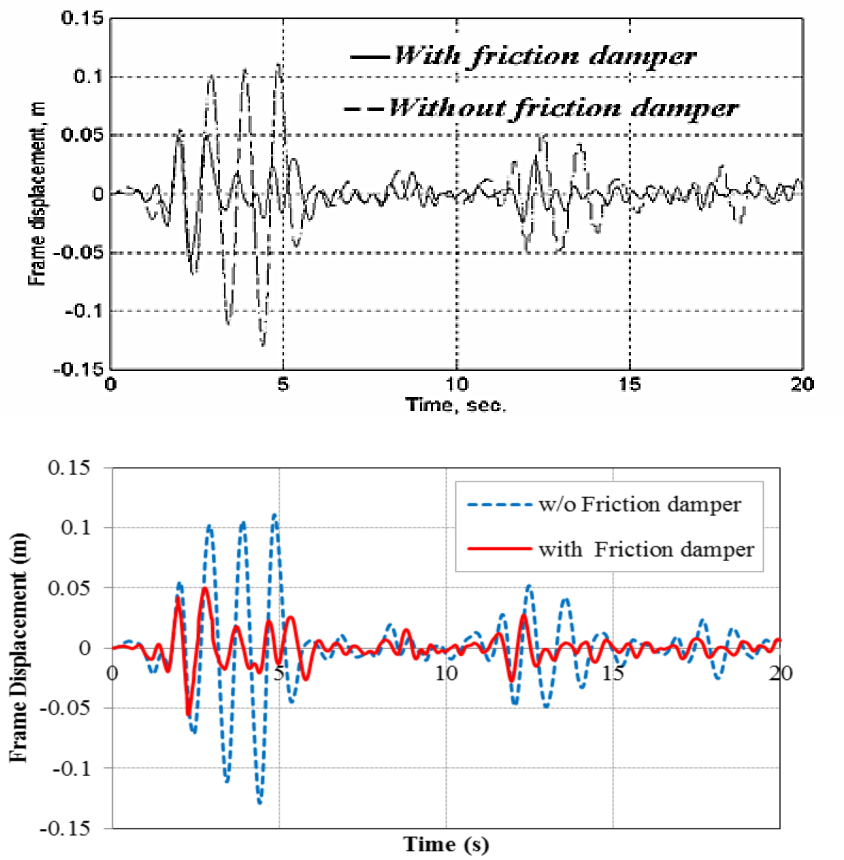

Figure 3: Displacement response: a) results by Mualla [9], b) results of this study.

These figures show that results are well-matched for Mualla and Belev model and that of the present study.

IV. DESIGN OF STEEL FRAMES

To investigate the performance of steel moment frames with and without friction damper devices, two-dimensional frames with 3, 7 and 12 stories are considered in this study. The length of each bay and height of each story in all frames are 5 m and 3.2 m, respectively. These frames are designed based on AISC ASD design code [12].The studied soil is type C of Standard ASCE/SEI 41-06 [13]. In the naming of frames, prefixes “MF” and “IVRMF” represent moment frames without and with friction damper device, respectively. For example “MF7s3b” represents moment frame with 7 stories and 3 bays. Dampers are installed in middle bay and total stories of frames. The specifications of the frames of the present study and the period of free vibration of frames with and without friction damper devices are presented in Tables 1 and 2, respectively.

Table 1: Specifications of the frames

Frames	Number of Stories	Weight (ton)	Design base shear (ton)
Mf3s3b	3	148.63	18.58
Mf7s3b	7	355.92	31.89
Mf12s3b	12	618.29	42.29

Table 2: The period of free vibration of frames with and without dampers

Frames	Period of free vibration (s)
MF3s3b	0.945
IVRMF3s3b	0.477
MF7s3b	1.422
IVRM7s3b	0.953
MF12s3b	2.018
IVRMF12s3b	1.539

V. GROUND MOTIONS

Seven ground motions are selected from a set of 20 used record in FEMA440 [14] which are recorded on soil type C. The characteristics of ground motions are shown in Table 3.

Table 3: Ground motions employed in this study [14]

Date	Earthquake name	Magnitude (Ms)	Station number	Component (deg)	PGA (g)	Abbreviation
06/28/92	Landers	7.5	12 149	0	0.171	LADSP000
10/17/89	Loma Prieta	7.1	58 065	0	0.512	LPSTG000
10/17/89	Loma Prieta	7.1	47 006	67	0.357	LPGIL067
10/17/89	Loma Prieta	7.1	58 135	360	0.450	LPLOB000
10/17/89	Loma Prieta	7.1	1 652	270	0.244	LPAND270
04/24/84	Morgan Hill	6.1	57 383	90	0.292	MHG06090
01/17/94	Northridge	6.8	24 278	360	0.514	NRORR360

According to ASCE/SEI 41-06, the ground motions be scaled such that the average of the ordinates of the 5% damped linear response spectra does not fall below the design spectrum for the period range $0.2T_i$–$1.5T_i$, where T_i is the fundamental period of vibration of each frame [15]. The response spectra of selected seven records and hazard level BSE-2 of ASCE/SEI 41-06 are presented in Fig. 4. The scale factors of seven records for frames with (IVRMF) and without (MF) friction damper devices are shown in Table 4.

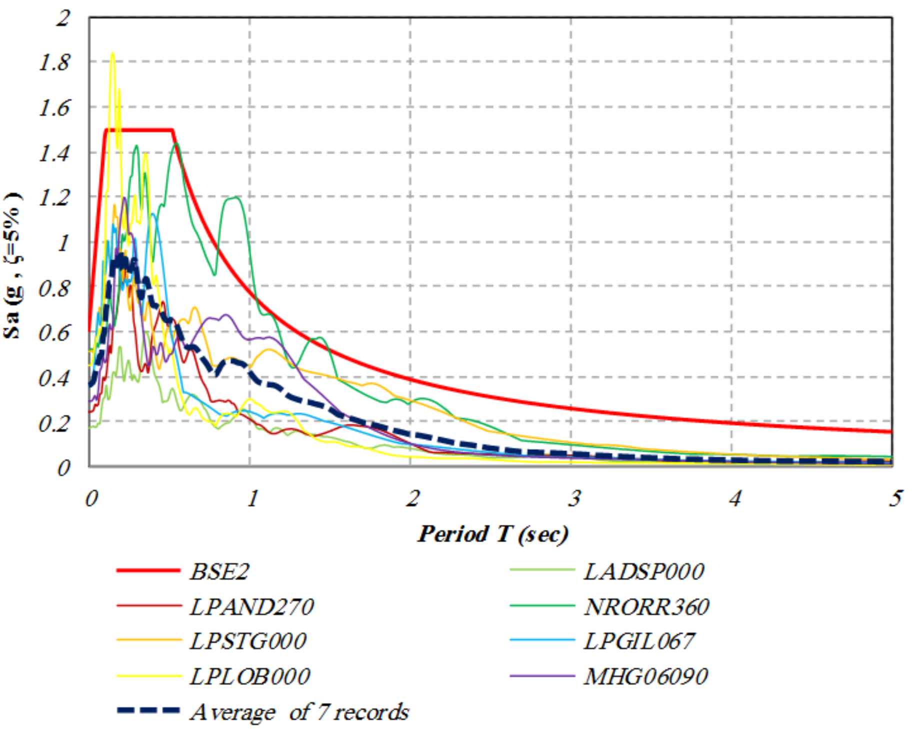

Figure 4: Response spectra of seven records and hazard level BSE-2 of ASCE/SEI 41-06.

Table 4: Scale factors of seven ground motions for frames with (IVRMF) and without dampers (MF)

Frames	LADSP 000	LPAND270	MHG 6090	LPGIL067	LPLOB000	LPSTG000	NRORR360
MF3s3b	3.98	2.98	1.75	2.62	2.73	1.85	1.09
IVRMF3s3b	3.87	2.49	2.22	2.14	2.11	2.02	1.32
MF7s3b	4.20	3.13	2.05	2.83	3.74	1.66	1.13
IVRM7s3b	3.98	2.99	1.75	2.62	2.74	1.84	1.09
MF12s3b	4.78	3.65	2.78	3.47	5.46	1.71	1.31
IVRMF12s3b	4.33	3.27	2.20	2.94	4.08	1.65	1.15

VI. SEISMIC ANALYSIS RESULTS

The frames are subjected to nonlinear time history analysis. The energy dissipated by friction damper device and its behavior (the hysteresis curve of moment-rotation) are investigated in the present study. A comparison of base shear history is made between MF7s3b and IVRMF7s3b frames under record LADSP000 (Fig. 5). According to the base shear history of mentioned frames, it is observed that by adding friction damper devices to MF7s3b frame, the maximum base shear will be decreased by 47.18%.

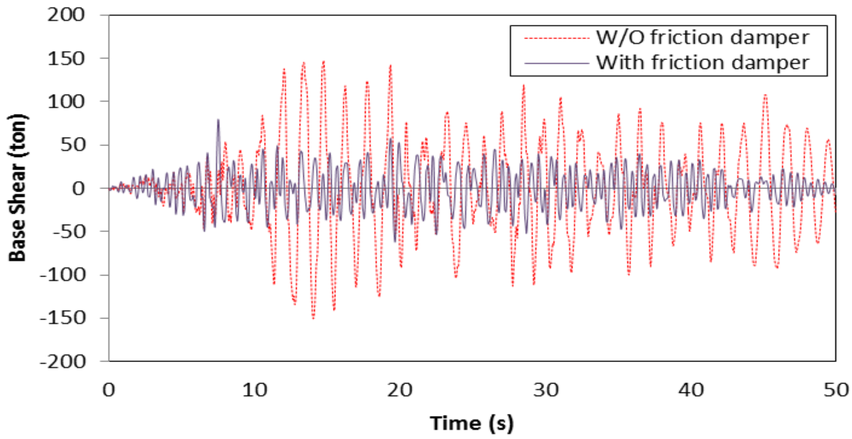

Figure 5: Comparison of base shear history between MF7s3b and IVRMF7s3b frames under record LADSP000.

A comparison of roof displacement history is made between MF7s3b and IVRMF7s3b frames under record NRORR360 (Fig. 6). According to the roof displacement history of mentioned frames, it is determined that by adding friction damper devices to MF7s3b frame, the maximum roof displacement will be decreased by 52.75%.

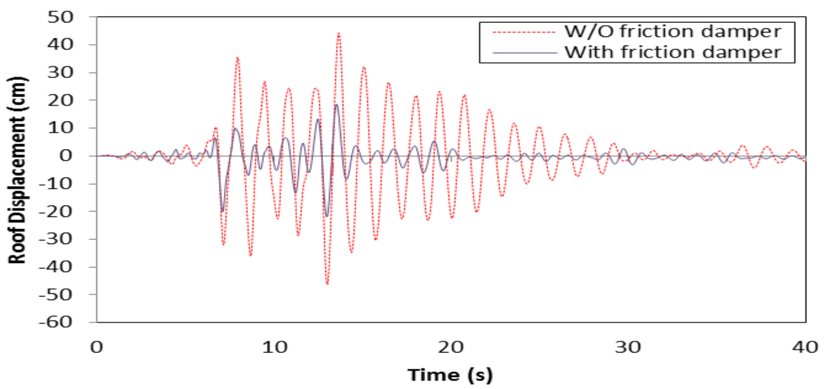

Figure 6: Comparison of roof displacement history between MF7s3b and IVRMF7s3b frames under record NRORR360.

The diagram of energy dissipated by damper in IVRMF3s3b frame under record NRORR360 is presented in Fig. 7. According to the diagram by adding dampers to MF3s3b frame, 47.61% of input energy will be dissipated.

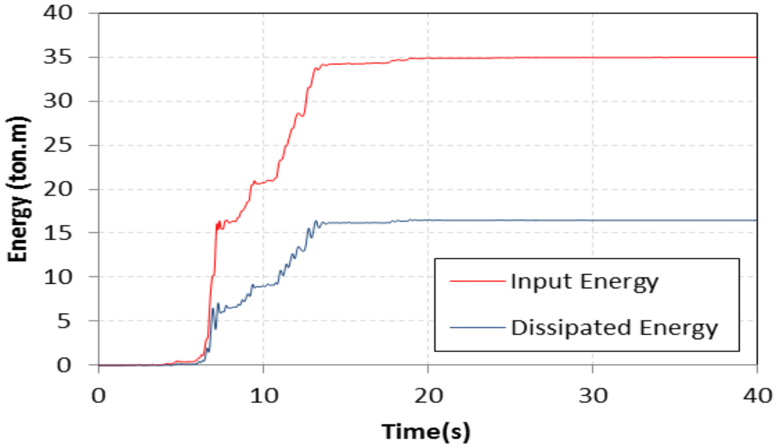

Figure 7: Energy dissipated by damper in IVRMF3s3b frame under record NRORR360.

The hysteresis cycle for the damper in fourth story of IVRMF7s3b frame under record NRORR360 is presented in Fig. 8. As it is obvious, there is an appropriate correspondence between the hysteresis cycle and the real behavior of damper. So, it can be said that the approximate rectangular hysteretic behavior of damper reveal that its performance in energy dissipation is suitable.

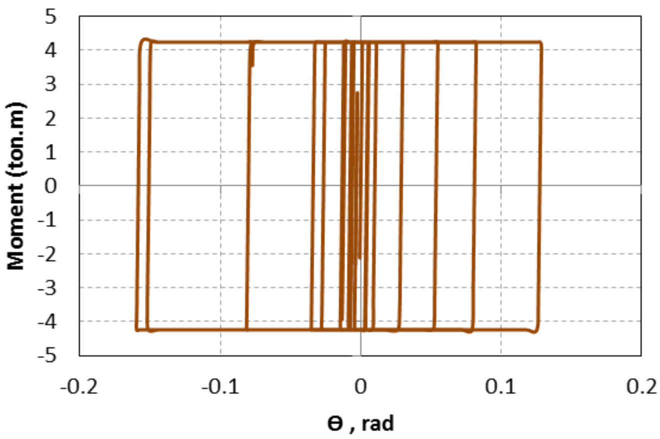

Figure 8: Hysteresis cycle for the damper in fourth story of IVRMF7s3b frame under record NRORR360.

After calculating the average of all the responses of analysis, the reduction percentage of parameters like base shear and roof displacement of frames by adding dampers and energy dissipated by dampers are determined. These items are shown in Table 5 to 7.

Table 5: Base shear of frames with and without dampers

Frame	Base shear of frames without dampers (ton)	Base shear of frames with dampers (ton)	Reduction of Base Shear (%)
MF3s3b	116.73	86.45	25.94
MF7s3b	171.49	122.07	28.82
MF12s3b	209.42	165.71	20.87

Table 6: Roof displacement of frames with and without dampers

Frame	Roof displacement of frames without dampers (cm)	Roof displacement of frames with dampers (cm)	Reduction of roof displacement (%)
MF3s3b	25.55	8.61	66.29
MF7s3b	40.68	19.95	50.96
MF12s3b	52.94	29.87	43.58

Table 7: Dissipated energy by dampers

Frame	Input energy for frames with dampers (ton.m)	Energy dissipated by dampers (ton.m)	Dissipated energy (%)
IVRMF3s3b	23.03	11.73	50.93
IVRMF7s3b	60.73	35.18	57.93
IVRMF12s3b	92.22	48.90	53.03

According to these tables, it is obvious that dampers have an appropriate performance in decreasing the roof displacement and base shear in steel moment frames. Energy dissipation is also done appropriately. As it is obvious, the maximum percentage of base shear reduction is occurred by adding dampers in 7 stories frame. By increasing the number of stories and increasing the free vibration period of structure, the reduction percentage of roof displacement will be decreased by adding dampers to the structure. The energy dissipated by dampers in 7 stories frame is more than other frames.

VII. CONCLUSION

As it is known, the free vibration period of structure will be decreased by adding friction damper devices. According to the results of the present study, it is obvious that, by increasing the number of stories and free vibration period of structure, reduction percentage of roof displacement will be decreased by adding dampers to the structure. The energy dissipated by damper in 7 stories frame is more than other frames. It reveals that 7 stories frame equipped with dampers has a better performance. It can be said that the friction damper device has a vital role in decreasing the displacement and base shear. According to the present study, this damper has a significant role in energy dissipation, since its hysteretic behavior is almost rectangular.

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