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Evaluation of Friction Damper Device Effect on Structural Response under Blast Loads

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Keywords

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Maximum displacement,
Inter-story drifts.

Abstract

The increase in the number of terrorist attacks especially in the last few years has shown that the effect of blast loads on structures is a serious matter that should be considered in the important structure design process. Decreasing the damages that can be caused by the explosion is the main purpose of many researches. This paper evaluates the structural response under blast loads. Three moment frames with 3, 6 and 8 stories equipped with the mentioned damper are investigated under blast load and dynamic behaviors of them have been evaluated. The effect of strain rate for steel material also considered. The response of frames with and without dampers is compared in terms of inter-story drifts, maximum floor displacements and base shear. It is found that response of the structures can be reduced dramatically using friction dampers. Moreover, the reduction percentage of roof displacement of frames will be decreased by increasing the number of stories.

1. Introduction

In the past few years, structures subjected to explosion gained importance due to natural or accidental events. Disasters such as the terrorist bombings of Marine Barracks in Lebanon in 1983, the World Trade Center in 1993, the Murrah Federal Building in USA in 1995, the Khobar Towers military barracks in Saudi Arabia in 1996 and the U.S. embassies in Kenya and Tanzania in 1998 have proved the need for a thorough assessment of the behavior of buildings subjected to blast loads. Generally normal buildings are not designed for blast load because designing the buildings to be fully blast resistant is not a realistic and economical option. Therefore, the building is susceptible to damage from blast destructive load effects. Nowadays, comprehensive researches about blast loading and the response of structures against this load are being done in order to find solutions to reduce the damage. Generally the range of the failure against blast loads is noticeable for structures that are normally designed against only ordinary loads. On the other hand, protecting structures from the threat of terrorism measures is one of the most important challenges for civil and structural engineers today. Extensive study into blast effects techniques and analysis to protect buildings has been initiated in many countries to develop methods of protecting vital infrastructure and the built environment. For this purpose, some important parameters should be evaluated such as drift and displacement demand [1-4]. For this goal, many procedures have been developed by researchers in the past decades. Using the energy dissipation devices or dampers is one of the controlling methods to protect under blast loads. These devices may be considered in new structures design and retrofitting the existence buildings. There are many buildings equipped with dampers all over the world to resist against seismic loads [5, 6]. Friction dampers are one of the passive control systems which have an increasing application in moment frames. A new friction damper device was employed for the first time by Mualla in his PhD thesis [7]. So far, lots of friction devices have been evaluated analytically and experimentally [8-11] and many of them have been implemented in buildings all over the world. Vaezzadeh worked on passive control systems including viscous damper, TMD, BRB and friction dampers under external blast loading. He demonstrated that usage of viscous dampers and friction dampers are effective solutions to enhance structural performance under external blast loadings [12]. Friction dampers are functioned according to friction mechanism among rigid materials. Actually, friction is a great mechanism of energy dissipation, employed in car brake systems successfully and extensively.

Moment resisting frames (MRF) which are ordinary types of earthquake resisting systems for have considered in

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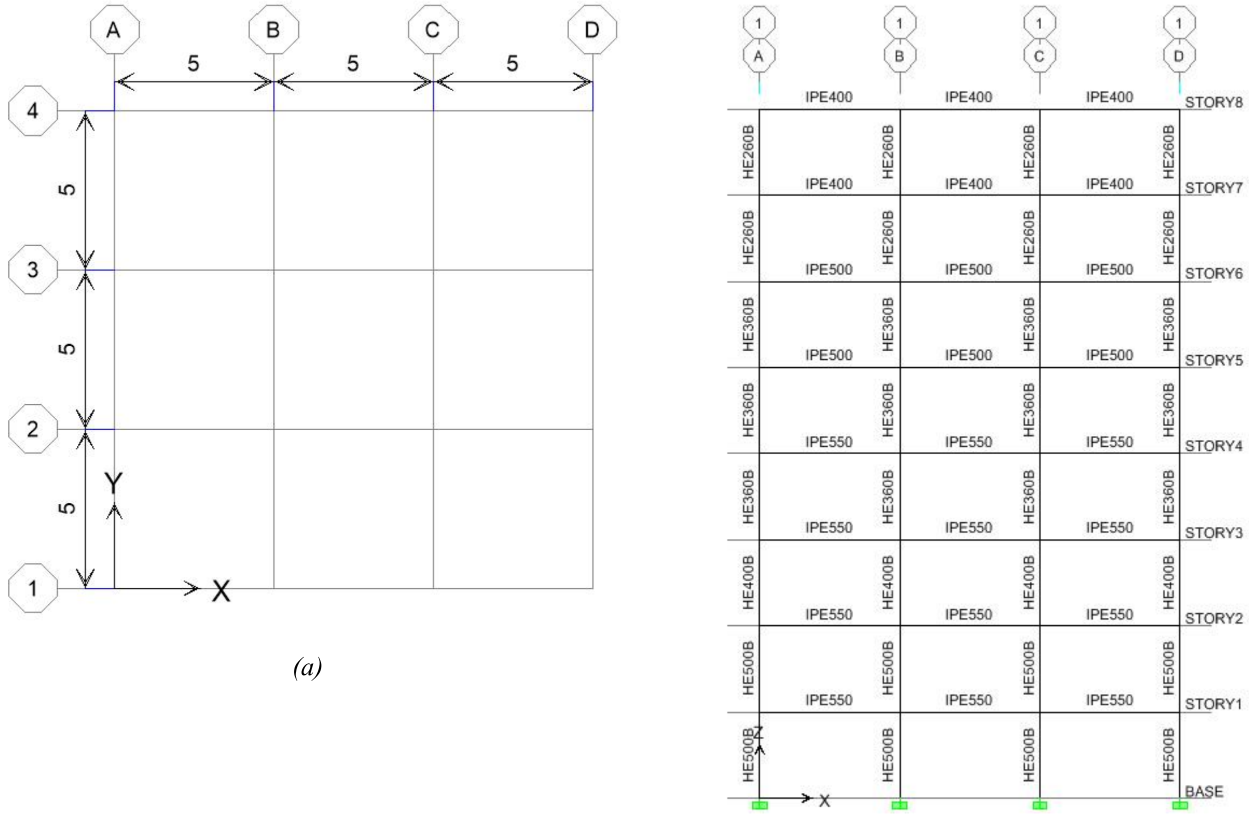
this research. For this purpose, the frames and dampers have been modeled in OpenSees software [13]. Three moment resisting frames with 3, 6 and 8 stories equipped with friction damper devices are investigated under nonlinear time history analysis. The influence of dampers on performance of frames against blast load is studied by comparing the parameters including displacement, inter-story drift and base shear of structures with and without dampers. It is found that these parameters of the structures are reduced significantly with the addition of friction dampers.

2. Description of Considered Frames

Three moment resisting frames with 3, 6 and 8 stories are considered in this paper. The buildings have 3 bays in X and Y direction. The plan dimensions of selected building are 15m×15m and story height of 3.2m is same for all floors. The building considered is symmetric in plan. As per code, response reduction factor for the special moment resisting frame has been taken as 5. These frames are designed based on Iranian National Building Code (INBC) [14] which is close to AISC ASD design code [15]. The considered soil is type C of Standard ASCE/SEI 41-06 [16]. Friction dampers are installed in middle bay and total stories of frames. In the naming of frames, "MRF" and "FDF" (friction damped frame) represents frames without and with friction dampers, respectively. To summarize the models configuration, Figure 1 shows the structural plan and elevation of an eight-story frame.



(a)

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Figure 1. Configuration of considered models

3. Friction Dampers

Using dampers is one of the most widely adopted methods available to extract kinetic energy from a moving body. Actually, it is the most effective and economical method to dissipate energy. So far, several types of friction dampers have been developed. For example, Figure 2 shows the details of a Pall friction damper. For frame buildings, friction dampers are available for tension cross bracing, single diagonal bracing and chevron bracing. In these types of dampers, the braces in a moment resisting frame incorporated frictional devices. When load is applied to this damper, the tension brace induces slippage at the friction joint. Consequently, the four links force compression brace to slip. Energy is dissipated in both braces even though they were designed to be effective in tension only. As shown in Figure 3, friction dampers possess large rectangular hysteresis loops, similar to an ideal elastic-plastic behavior, with negligible fade over several cycles of reversals. For a given force and displacement in a damper, the energy dissipation of friction damper is the largest compared to other damping devices.

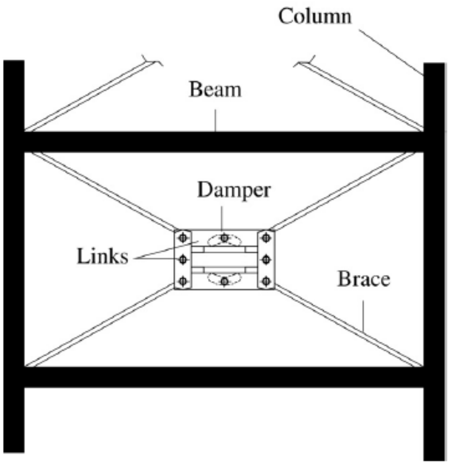


Figure 2. Typical location and general arrangement of Pall dampers

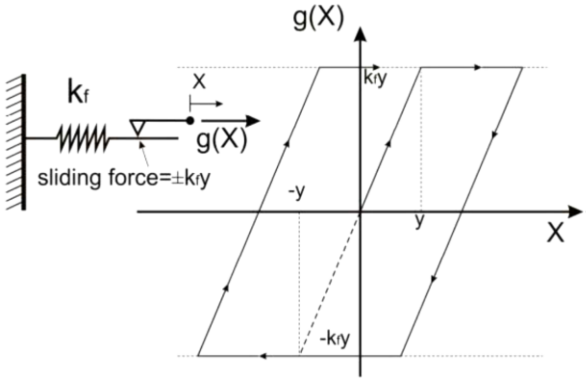


Figure 3. Friction device idealized behavior

4. Characteristics of Explosive Shock Waves

In general, blast loading of structures is a well understood topic and is treated extensively in the literature [17]. The simplified blast modeling assumes that the pressure is instantaneously applied and to decay linearly to the atmospheric pressure over time t (duration of the blast). Integrating the pressure function over the duration yields the impulse of the blast. Therefore, a blast load can be defined by its pressure and impulse values as shown in Figure 4.

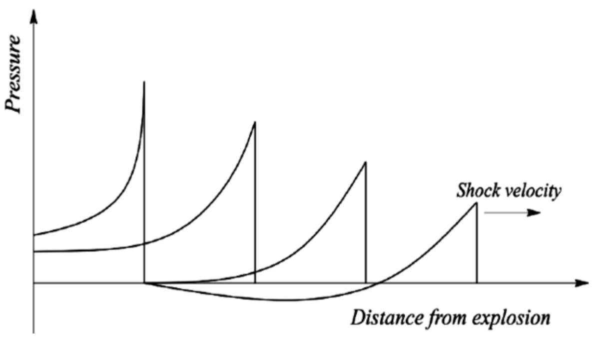


Figure 4. Variation of blast pressure versus distance [17]

Figure 5 shows a typical blast pressure profile. At the arrival time t_A, following the explosion, pressure at that position suddenly increases to a peak value of overpressure, P_{so}, over the ambient pressure, P_o. The pressure then decays to ambient level at time t_d, then decays further to an under pressure P_{so}- (creating a partial vacuum) before eventually returning to ambient conditions at time t_d + t_d-. The quantity P_{so} is usually referred to as the peak side-on overpressure, incident peak overpressure or merely peak overpressure [17]. The incident peak over pressures P_{so} are amplified by a reflection factor as the shock wave encounters an object or structure in its path. Except for specific focusing of high intensity shock waves at near 45° incidence, these reflection factors are typically greatest for normal incidence (a surface adjacent and perpendicular to the source) and diminish with the angle of obliquity or angular position relative to the source. Reflection factors depend on the intensity of the shock wave, and for large explosives at normal incidence these reflection factors may enhance the incident pressures by as much as an order of magnitude.

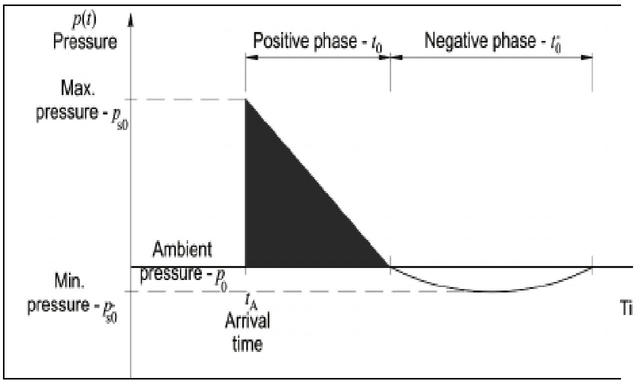


Figure 5. Pressure-time profile of the explosion wave [17]

5. Nonlinear Time-History Dynamic Analysis

The slippage of friction damper in an elastic brace constitutes nonlinearity. Also, the amount of energy dissipation or equivalent structural damping is proportional to the displacement. Therefore, the design of friction damped buildings requires the use of nonlinear time-history dynamic analysis. With this analysis, the time-history response of the structure during and after an explosion can be accurately understood.

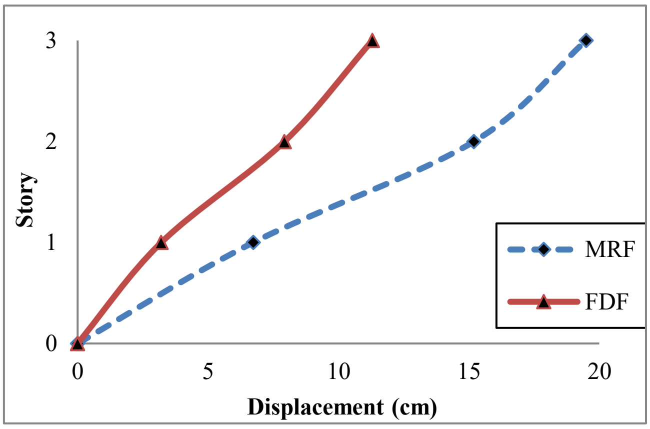
The modeling of friction dampers is very simple. Since the hysteretic loop of the damper is similar to the rectangular loop of an ideal elastic-plastic material, the slip load of the friction damper can be considered as a fictitious yield force. In the analyses, friction dampers in single diagonal brace are modeled as damped braces having member stiffness equal to brace stiffness and nonlinear axial yielding equal to the slip load. Friction damped braces are modeled as braces plus dampers. These dampers have nonlinear yield force in shear equal to the slip load.

6. Analysis Results

In this paper a nonlinear time-history dynamic analysis were conducted using the program code OpenSees for evaluation of structures under blast loads. The results of this research are categories in three different categories, which includes displacements, story drifts and story shears for moment resisting frames and frames quipped with friction damper device.

6.1. Displacements of Stories

The displacement of the structure with respect to base is shown in Figure 6. On comparison of overall story displacement, it is concluded that the overall displacement in friction damped structure decreases. Table 1 lists the roof displacement of frames with and without dampers. It is obvious that by adding friction dampers to MRF frames, the maximum roof displacement will be decreased significantly. It shows that the maximum roof displacement of the structures with friction damper reduce by 42.05%, 33.72% and 26.32% for 3, 6 and 8 story frames respectively.



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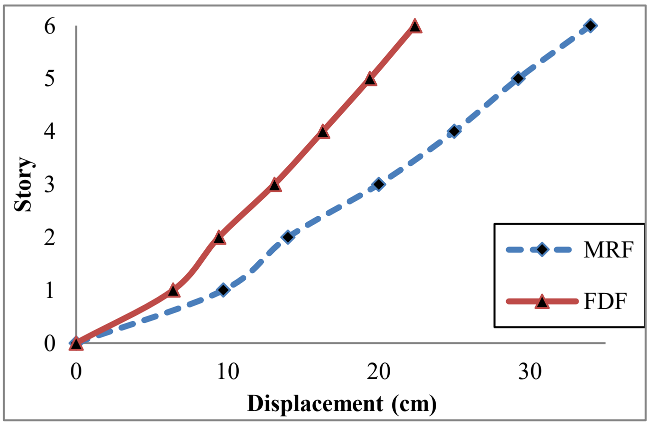

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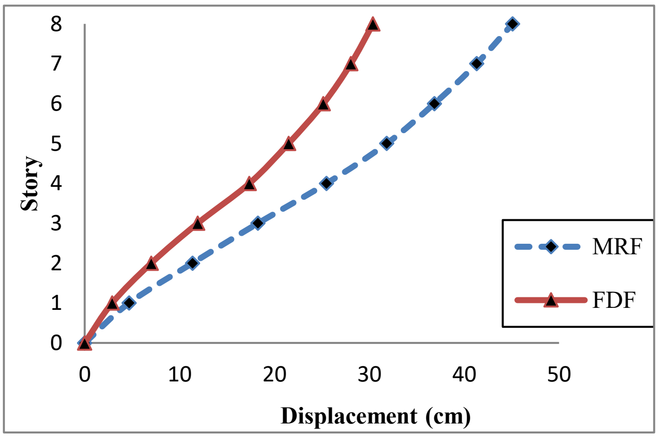
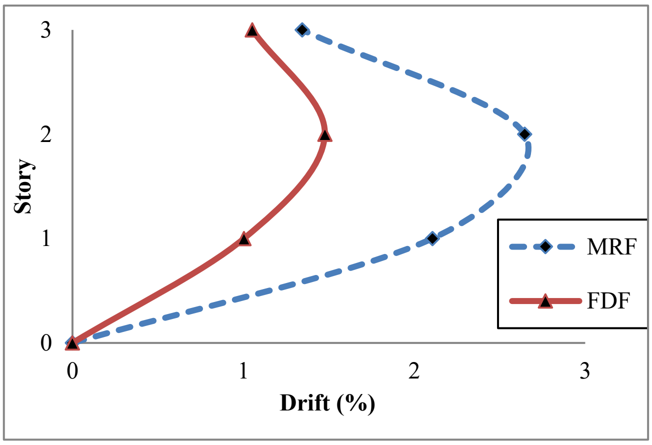


(c)

Figure 6. Displacements comparison of moment resisting frames versus friction damped frames for (a) 3 story (b) 6 story (c) 8 story frames

6.2. Story Drifts

As the number of story increases in the structure, the drift is more effective factor for multi-story building. The variance between the lateral displacements of two adjacent floors of the structure is defined as the story drift. It is shown in Figure 8 that for all frames inter-story drifts ratio in friction damped frames is less as compared to the moment resisting frames.



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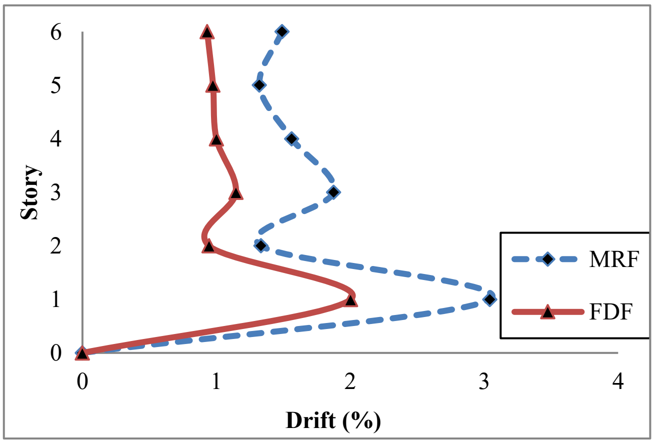

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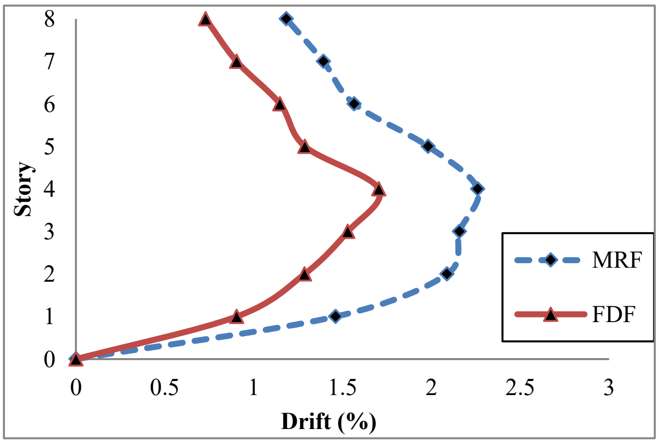

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Figure 8. Inter-story drift comparison of moment resisting frames versus friction damped frames for (a) 3 story (b) 6 story (c) 8 story frames

Table 1. Roof displacement of frames with and without dampers

Frame	Roof displacement of frames without dampers (cm)	Reduction of roof displacement (cm)	Reduction of roof displacement (%)
3story	19.5	11.3	42.05
6 story	33.8	22.4	33.72
8 story	45.1	33.23	26.32

6.3. Base Shear

The story shear taken by a building mainly depends on the lateral force resisting system of the structure. The stiffer the system the greater will be stiffness (resistance) and so will be the story shear taken by the structure. The flexible the structure, means greater is the ductility of the structure, less will be the story shears and greater will be the story drift. During an explosion, lateral loads are transferred to the structure. Greater the inertial mass of a story greater will be the lateral load and thus greater story shear. Hence more stiffness is needed to withstand the story shear [18-19]. Table 2 shows that story shear of the structures equipped with friction damper reduce by 28.45%, 23.56% and 20.32% for 3, 6 and 8 story frames respectively. The story shear in MRF frame is very high in the three story but drastically reduced in next story, while the distribution of story shear was uniform in case of friction damped frames.

Table 2. 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 (%)
3 story	131.27	94.63	28.45
6 story	172.24	131.51	23.65
8 story	203.15	159.19	20.32

7. Validation of This Study

To validate this study, the results are compared with Vaezzadeh's work [12]. He worked on improving structural response under blast load via passive control devices. Figure 9 describes the comparison of displacements for this study versus Vaezzadeh's work. As it shown, this work is in good agreement with previous work by Vaezzadeh.

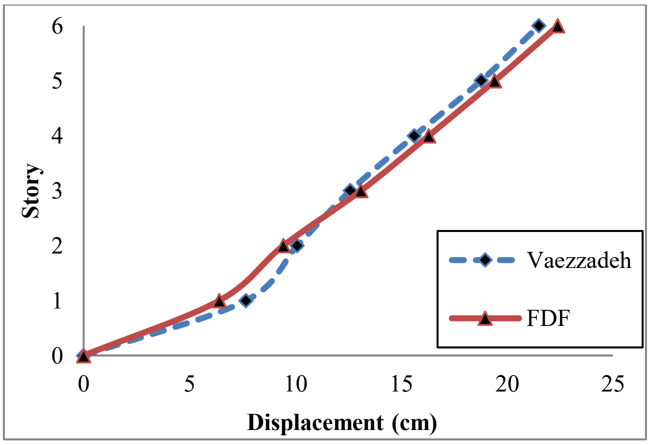

Figure 9. Comparison of 6 story frame displacements for this study versus Vaezzadeh's work

8. Conclusion

The responses of three frames to the blast load were investigated in this study. It showed that the maximum roof displacement of the structures with friction damper reduced by 42.05%, 33.72% and 26.32% for 3, 6 and 8 story frames respectively. Moreover, the story shear of the structures with friction damper reduced by 28.45%, 23.65% and 20.32% for 3, 6 and 8 story frames respectively. These results of this study demonstrate that the response of the structure can be reduced dramatically using friction dampers. The relative story displacement and story drifts of structure element were decreased, subsequently causing reduction in the inertial force in beams and columns. Moreover, the story shear and drifts of FDFs were reduced in comparison with MRFs. According to the results, the use of friction dampers has shown to provide a practical and economical solution for the upgrade of the structures.

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