Chapter 12
Using Pall Friction Dampers for Seismic Retrofit of a 4-Story Steel Building in Iran

Seyed Mehdi Zahraei, Alireza Moradi, and Mohammadreza Moradi

Abstract Past earthquakes in Iran have caused severe damage to existing steel buildings without adequate resistance and ductility against earthquakes. Competent methods for seismic retrofitting are required in order to prevent damage and casualty. Among effective seismic retrofit methods, passive control reduces seismic vulnerability by mitigating seismic demand and increasing ductility. One of the most suitable methods in passive control system is to use pall friction damper in the braced steel structures. Main advantage of this friction damper is its almost rectangular force-deformation hysteretic loops with high-energy dissipations, without any need to specific technology. In this paper, while introducing the performance of pall friction dampers and their design, seismic retrofit of an existing 4-story steel simple frame in Iran is investigated by using such dampers.

Keywords Seismic design and retrofit • Pall friction damper • Passive control • Ductility • Steel frame

12.1 Introduction

All the damages and losses during recent severe earthquakes have causes the concern of finding an appropriate solution to stand against this natural disaster. Nowadays, applying new methods in structural seismic design, and improving the quality of the structural materials, are among the common approaches to accomplish this objective. Recent methods, which are based on distributing energy in structures, have been developed to control seismic vibrations and reduce the effect of the earthquake force. The large amount of energy is exerted into the structures during an earthquake, including potential and kinetic energy, which somehow needs to be damped in the structure. If there is no damping system, the structure vibrates continuously. But, in practice there is a damping system caused by structural properties, which creates some reactions against structural vibration. Moreover, performance of the building can be improved by installing an energy absorber (damper). In this method, dampers absorb and dissipate part of the earthquake energy.

In this study, first, seismic vibration control of structures is presented and then, by considering friction dampers as one of the seismic vibration control methods, analytical evaluation of the effects of Pall friction dampers on the seismic response of the steel frame during earthquake is discussed.

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12.2 Seismic Vibration Control of Structures

Structural vibration control is actually an attempt to reduce structural displacement or acceleration, which are the main sources of structural damage during earthquake. There are several classifications to facilitate investigations about different control systems. These classifications are based on either dynamic properties of structures or location and distribution of the control system in the structures. Based on the latter classification, there are four control systems: Passive, Active, Semi-Active and Hybrid.

12.2.1 Passive Control Systems

A passive control system operates without requiring an external power source. This system consists of one or more devices designed to modify the structural properties such as ductility and stiffness and dissipate energy, leading to reduction in structural vibrations. Friction damper is a type of passive Control system [1].

12.2.2 Active Control Systems

Unlike passive control system, active control systems require an external power source for operation and controlling structural vibrations. In these systems, special devices generate and apply forces to the structure. These forces act opposite direction of the destructive forces and work as a damper. These systems need special equipments such as hydraulic actuator (as the external stimulator) and accurate control systems (sensitive receptor and hardware and software equipment) [1].

12.2.3 Semi-Active Control Systems

Comparing the performance of the active and passive control systems leads to development of semi-active control systems. In this system, the control force is developed through appropriate adjustment of the mechanical properties of the semi-active control system devices without applying external forces. These devices can be defined as the passive control dampers. Since these devices are able to actively control the vibration without requiring high-level external power force, they have been used a lot recently. Some of these semi-active systems have the ability to operate just by using battery, which is a remarkable property, since it is probable that the main power source becomes disconnected during earthquake [1].

12.2.4 Hybrid Control Systems

Using the combinations of active and passive control is called hybrid control system. The objective of developing such a system is to enhance the efficiency of the passive control system and to reduce the required external power in active control system. These systems work similar to active control systems during low amplitude excitation (weak and medium earthquake). Actually in low amplitude excitation, external excitation is not large enough for appropriate performance of the passive control systems and active control system operates just by low level of external force. The hybrid control systems work similar to passive control systems during high amplitude excitation (strong earthquake). During high amplitude excitation, active control systems do not perform properly because of the saturation limits on generating external power while the passive control system operates efficiently. Although, hybrid control system are more expensive, they are more efficient and have a better performance than the passive and active control system [1].

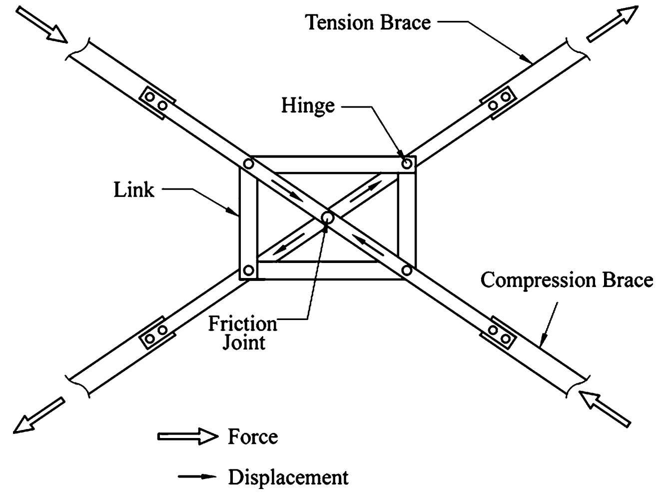

Fig. 12.1 Details of the Pall friction damper

12.3 Pall Friction Dampers

The most effective, reliable and economical method to dissipate energy and extract kinetic energy from a moving body is the friction brake. In 1979, the principle of friction brake inspired Pall and his colleagues and they started to develop the friction dampers for structures. Actually, friction dampers use the mechanism of solid frictions to dissipate energy. Similar to automobiles, the motion of vibrating building can be reduced by dissipating energy in friction. These studies led to the development of the Pall friction damper in 1982 [2, 3].

The Pall friction damper is made of a set of special steel plates, which can create the convenient frictional performance. These plates are bolted together with a high strength screws and they are designed not to slip during wind. These dampers slide over each other at the determined optimum slip load prior to yielding of structural members and dissipate the big portion of the earthquake energy. This makes the structure remain in the elastic range or delay the yielding of the structural member during major earthquake [4]. Figure 12.1 shows the details of the pall friction damper.

Figure 12.2 shows five stages of behavior of the pall friction dampers during a typical load cycle including deformed shape of the frame in each stage. Response of the frame member in each stage is described below [5]:

First stage: Both braces are active and behave elastically in tension and compression.
Second stage: The compression brace buckles while the tension brace continues to behave elastically in tension.
Third stage: Before yielding is started in the tension brace, the device is designed to slip. When slippage occurs, the four links are activated and deform into a rhomboid shape; this deformation pattern eliminate the buckled shape of the compression brace. Therefore, after the slippage, the compression brace is still straight and the axial force in compression brace equals to buckling load.
Fourth stage: The straightened brace can immediately absorb energy in tension when the load is reversed.
Fifth stage: Load in brace 1 becomes more than the buckling load and the second stage is repeated. This is followed by the third stage and cycle is completed.

It should be noted that the Pall fiction dampers works properly if the device slips before the structural members and tensional brace yields or compressive brace deforms significantly. Moreover, to be more efficient, slip load should be set such that the friction mechanism does not work during weak and medium earthquakes [5].

12.4 Using Pall Friction Dampers to Retrofit a 4-Story Steel Frame

In this study, one of the internal frames of a 4-story steel frame is chosen for retrofitting. Since the old buildings in Iran do not have bracing as the lateral resistance system, a simple frame with hollow-tile as the floor system is considered. It should be mentioned that the existing infill panel is considered as a support for lateral resistance system. The building is hospital in a region with high risk of earthquake and the soil is type 3. Since the building is old, it was just designed for gravity load and not the lateral load. Dead load for the floors and roof are 650 and 600 kg/m^2 respectively and live load for the floors

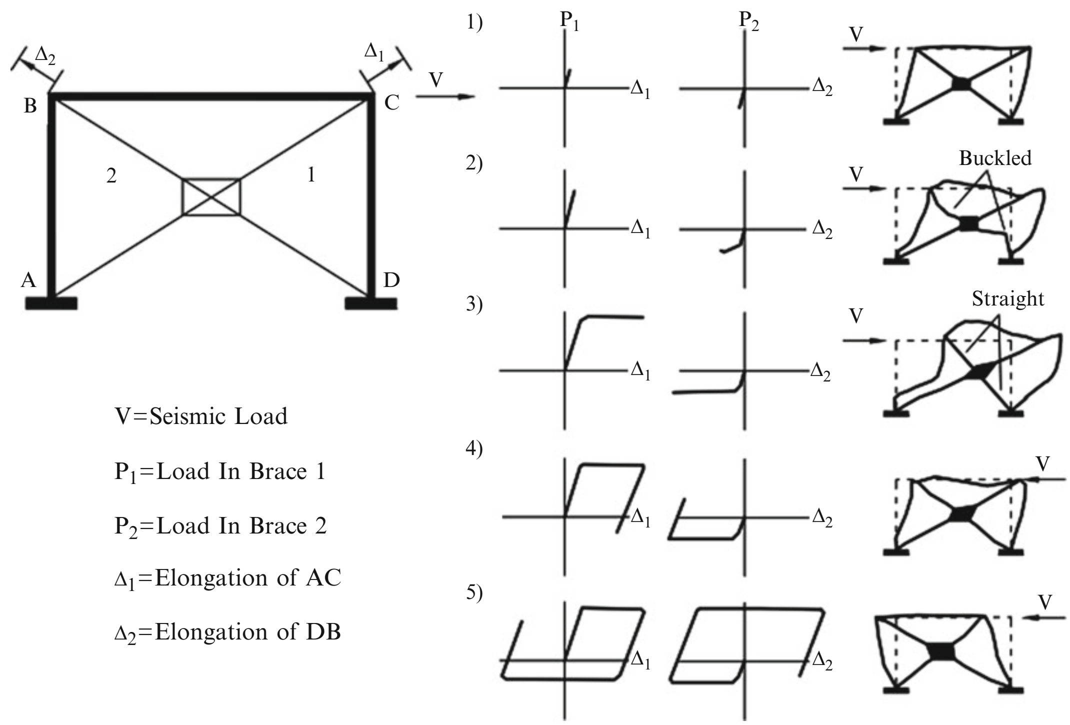

Fig. 12.2 Idealized hysteretic behavior of a simple one-storey friction damped frame [5]

and roof are 300 and 150 kg/m^2 respectively. These values are defined based on the Iranian National building regulation part 6: Loading. Figure 12.3 shows location of pall friction dampers in the frame and floor plan. All the spans are 5 m and each storey has 3 m height in the steel frame. Frame was designed using ETABS-9.1.4 based on AISC–ASD89 specification. Table 12.1 shows the information of the structural members.

12.5 Design of the Pall Friction Damper

The crucial part of the design of friction dampers is to determine the optimum slip load. The movement of the damper in an elastic brace constitutes nonlinearity. Moreover, the amount of energy dissipation is proportional to the displacement. Therefore, nonlinear time history dynamic analysis, which is used in this study, is an accurate procedure to find the value of the optimum slip load. In this method, structural response can be evaluated during and after earthquake [3, 6].

Hysteresis loop of the damper is similar to the rectangular loop of the material with elastic perfectly plastic behavior. Therefore, sliding load is considered as virtual yielding force in bracing. PERFORM-3D [7] is used for nonlinear time history dynamic analysis of the frame with the dampers. The analyses are based on the Iranian Standard Seismic Code No. 2800 third edition [8]. Three accelerographs, as presented in Table 12.2, are used in these analyses. H1 components are used for the analysis of this study.

In the analyses, yielding stress of the brace in tension is assigned equal to the stress in braces during sliding. The maximum displacements of the stories are considered as the frame response in nonlinear dynamic analysis. This procedure is performed for different values of yielding stress in tension. The sliding design load, which corresponds to the minimum structural response, is considered as the optimum sliding load.

Figure 12.4 shows the maximum story drift in terms of sliding load. It can be seen that displacement is reduced by increasing the sliding load and after passing the sliding load of 25 ton, displacement increases. Therefore, optimum sliding load is equal to 25 ton in all the stories.

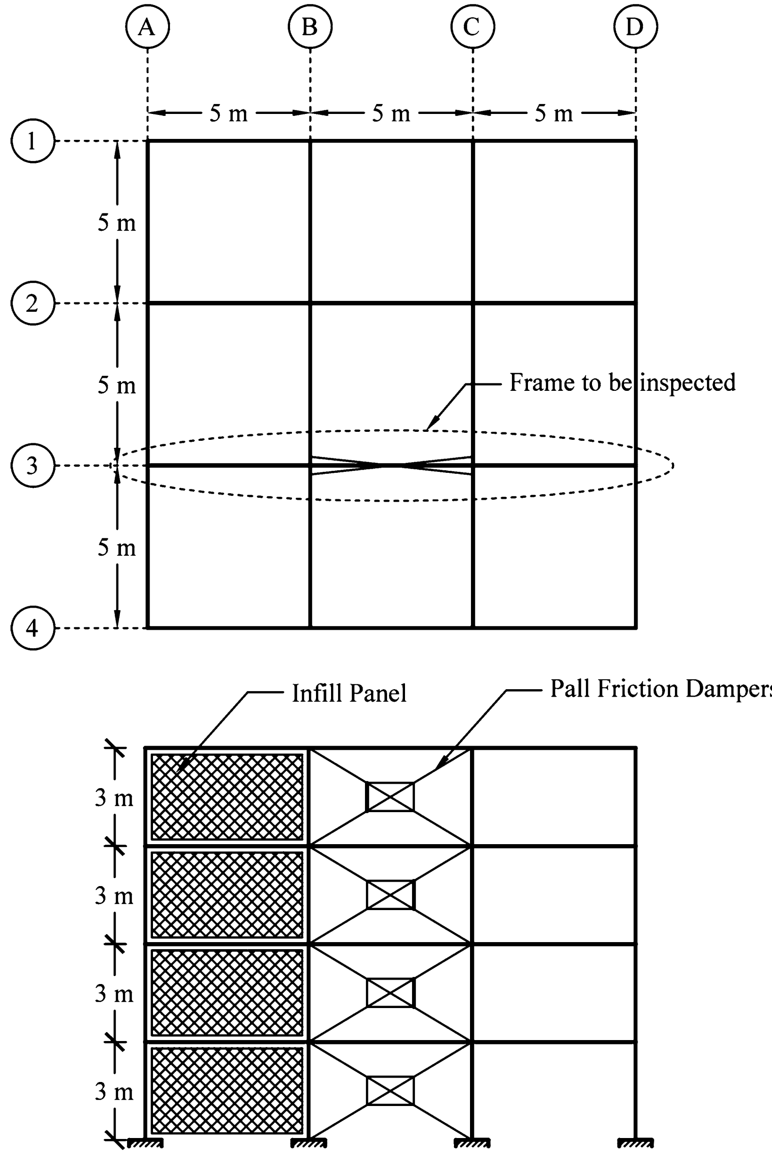

Fig. 12.3 Location of the Pall friction damper in the frame and floor plan

Table 12.1 Specification of the frame members

Floor	Beams	Interior columns	Exterior columns
4	IPE330 + PL120 × 5	BOX 100 × 5	BOX 100 × 5
3	IPE330 + PL130 × 10	BOX 150 × 10	BOX 120 × 8
2	IPE330 + PL130 × 10	BOX 150 × 10	BOX 120 × 10
1	IPE330 + PL130 × 10	BOX 200 × 10	BOX 150 × 10

Table 12.2 Specification of the earthquake records

Earthquake	Year	Station	Direction	PGA (g)	Soil type	Duration (s)
Tabas	1978	9101	H1	0.836	III	32.84
			H2	0.852		
Imperial Valley	1979	Bonds Corner	H1	0.588	III	37.61
			H2	0.775		
Cape Mendocino	1992	89156 Petrolia	H1	0.590	III	36
			H2	0.662		

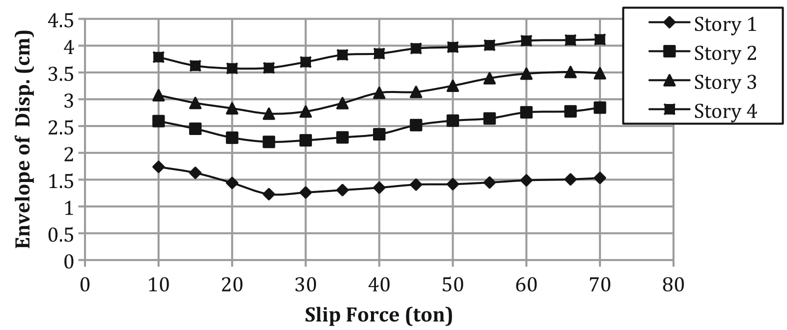

Fig. 12.4 The maximum story drift in terms of slip force under the Tabas earthquake

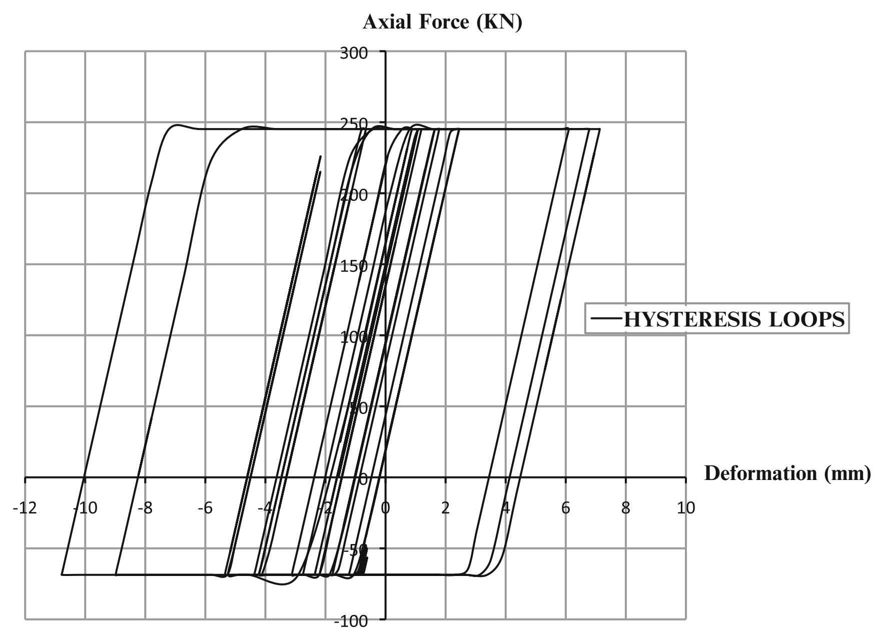

Fig. 12.5 Hysteresis loop of the Pall friction damper under Tabas earthquake

12.6 The Effect of the Pall Friction Damper on the Roof Lateral Displacement

Figure 12.5 shows the hysteresis loop of the Pall friction damper under Tabas earthquake. The area under this hysteresis graph represents the amount of the energy, which is absorbed by the friction damper. Figure 12.6 shows top floor drift for the frame with and without Pall friction damper under the Tabas, Imperial Valley and Cape Mendocino earthquake. As a case in point, it can be seen that installing Pall friction damper in the frame reduces the maximum displacement 80% for Tabas earthquake. This reduction is the result of the frame ductility caused by Pall friction damper absorbing in fact most portion of the earthquake energy that means the beams and columns absorb less energy and remain in elastic range. This leads to reduction of floor drift in the frame with Pall friction damper compared to the simple frame without Pall friction dampers.

12.7 Conclusion

Since Pall friction dampers are cheap and have simple mechanism, they are considered as one of the decent methods in structural vibration control. In this paper, a simple 4-story steel frame, which had a weak performance against earthquake, was retrofitted by adding pall friction damper. Nonlinear time history dynamic analysis was performed on the frame by applying the Tabas, Imperial Valley and Cape Mendocino earthquake based on the 2800 Iranian seismic code. Here is the result:

- Optimum sliding load equal to 25 ton is achieved by performing time history dynamic analysis
- Top floor drift is reduced in the frame with Pall fiction damper compared to the frame without damper. This is the reason of dissipation of large portion of the earthquake energy by Pall friction damper.

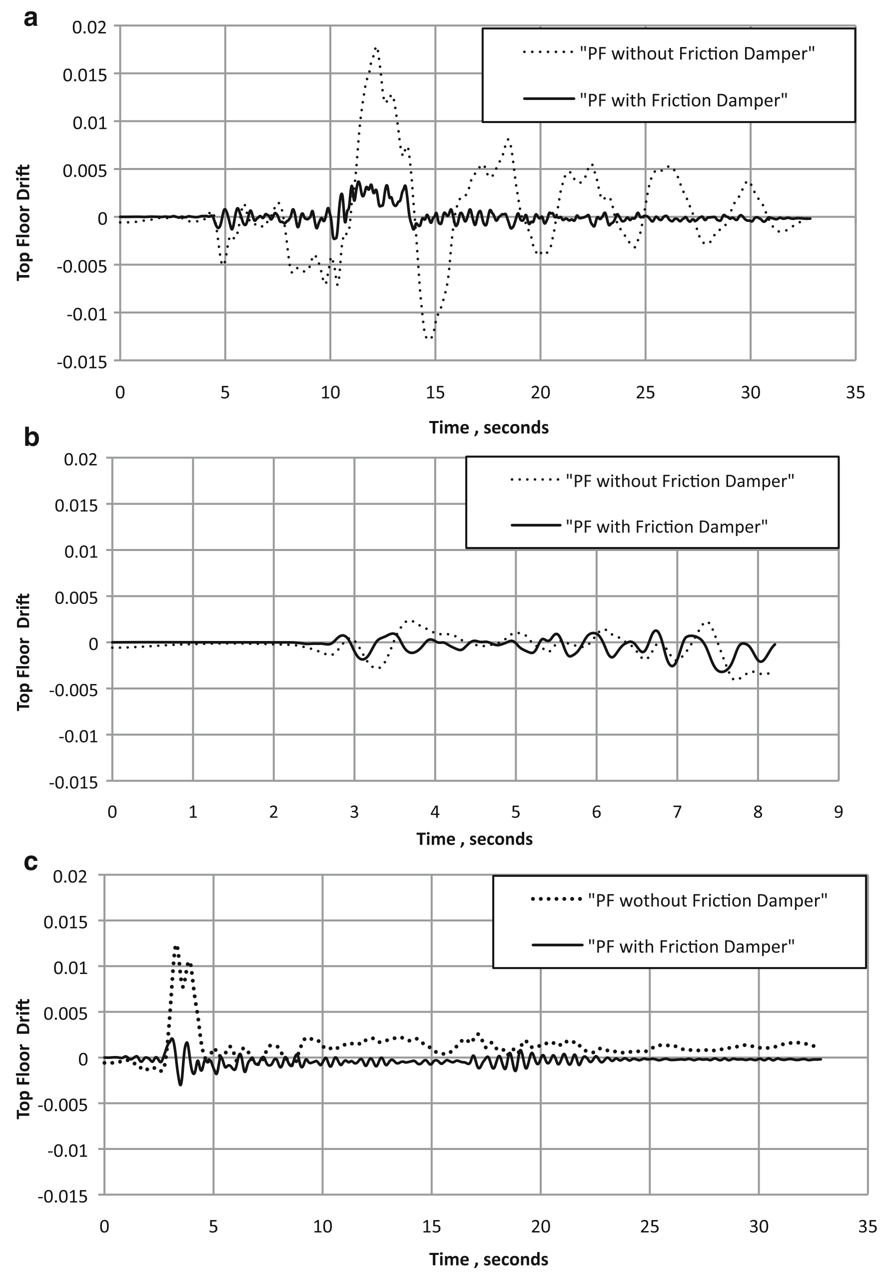

Fig. 12.6 Top floor drift for the frame with and without Pall friction damper under the (**a**) Tabas (**b**) Imperial Valley (**c**) Cape Mendocino earthquake

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