International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:3, No:10, 2009

A Parametric Assessment of Friction Damper in Eccentric Braced Frame

J.Vaseghi, S.Navaei, B.Navayinia, F.Roshantabari

Abstract**—**In This paper, the behavior of eccentric braced frame (EBF) is studied with replacing friction damper (FD) in confluence of these braces, in 5 and 10-storey steel frames. For FD system, the main step is to determine the slip load. For this reason, the performance indexes include roof displacement, base shear, dissipated energy and relative performance should be investigated. In nonlinear dynamic analysis, the response of structure to three earthquake records has been obtained and the values of roof displacement, base shear and column axial force for FD and EBF frames have been compared. The results demonstrate that use of the FD in frames, in comparison with the EBF, substantially reduces the roof displacement, column axial force and base shear. The obtained results show suitable performance of FD in higher storey structure in comparison with the EBF.

Keywords**—**Friction Damper (FD), Slip Load, Nonlinear Dynamic Analysis, Performance Index.

I. INTRODUCTION

THE observed damages in recent earthquakes shows that it is necessary to choose new methods in improvement designing of structures.

In many earthquake prone countries, buildings are continuously being retrofitted or constructed with control devices to reduce stresses, displacements and base shear during seismic activity. The three main types of control devices employed in structures are active control, semi-active control and passive control.

There are several different types of passive devices and dampers are the part of these seismic controls. Passive friction dampers utilize Coulomb friction to dissipate energy from a structure. These dampers used widely in many retrofitting projects all over the world, because of their low cost and good performance [1].

A. Passive control system

Passive dampers are the oldest and most common form of control devices. Passive devices are commonly placed in the cross bracing between two adjacent floors. They directly use the displacement of these floors to produce a damping force on the building. Unlike 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. Without any type of sensing equipment or computation, passive devices are generally the least expensive and most widely used devices [2].

Passive control systems based on elements distributed throughout the height of main structure are recognized as a more suitable approach for seismic control of high rise and slender buildings. There is no conceptual difference between the ductile design and the energy dissipation approach. In both cases the structure is expected to control the floor displacements and storey shear forces by developing non-linear deformation mechanisms which will both dissipate large amounts of seismic energy [3].

Friction dampers are the prevalent of these passive control systems, because of using in different kind of braces, low cost and suitable efficiency [4].

B. Friction Damper (FD)

These devices rely on the resistance developed between two solid interfaces sliding relative to one another [2]. 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. Although friction has been used effectively to control motion for centuries, the development of friction devices for use in civil structures to control seismic response was pioneered in the late eighties [5]. 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 [6, 9]. These devices differ in their mechanical complexity and in the materials used for the sliding surfaces.

C. Slip Load

For friction dampers, the main step is to determine the slip load. The value of dissipated energy subjected to FD is product of slip load and drift of all dampers. Therefore dissipated energy of structure with FD is depended to slip load. If the slip load is chosen much, the structural system acts such as braced frame and if this amount is chosen low, the damper does not slip and cannot control drift in structure, between these amounts the proper slip load is existed that is obtained from nonlinear dynamic analysis. In the other hand when difference between input and dissipated energy is minimum, the best response is obtained [2, 5].

J. Vaseghi is with the Babol University of Technology, Babol, He is now with the department of Civil Engineering, IRAN (e-mail: Vaseghi@ nit.ac.ir).

B. Navayinia, is with the Babol University of Technology, IRAN (e-mail: Navayi@nit.ac.ir).

S. Navaei, is with the Babol University of Technology, IRAN (e-mail: S_Navaei2511@yahoo.com).

F.Roshantabari is with the Civil Engineering Department, University of Science and Culture, Tehran, IRAN, (e-mail: Farnosh_Civil_62@yahoo.com)

D. *Nonlinear Dynamic Analysis*

The slip load of friction damper in an elastic brace constitutes nonlinearity. Therefore, the design of FD buildings requires the use of nonlinear time-history dynamic analysis. With these analyses, the time-history response of the structure during and after an earthquake can be accurately understood [3]. In this paper, the nonlinear dynamic analyses were performed using three earthquake records. These records include El-Centro (1940), Tabas (IRAN, 1978) and Kobe (1995) earthquakes.

Based on the above, for each of the rehabilitation schemes of the frame a realistic model has been prepared and several nonlinear dynamic analyses have been performed on the models. For this reason Two-dimensional nonlinear time-history dynamic analyses were carried out using the computer program SAP2000 (Nonlinear version), developed by Computers and Structures Inc [1].

II. INVESTIGATED FRAMES

Two hypothetical buildings are chosen as reference buildings for this study: (A) 5 storey and (B) 10 storey frame structures. Two buildings have an identical 3 bay layout in plan, 6m span and 3m storey height (as shown in Figure 1). Under the assumption that the seismic responses in two perpendicular directions are independent, a two-dimensional plane frame model is used in all the design analyses and seismic response simulations.

The eccentric bracing has been used in the X direction in centric span. The critical eccentric value for the brace has been calculated as 0.5m.

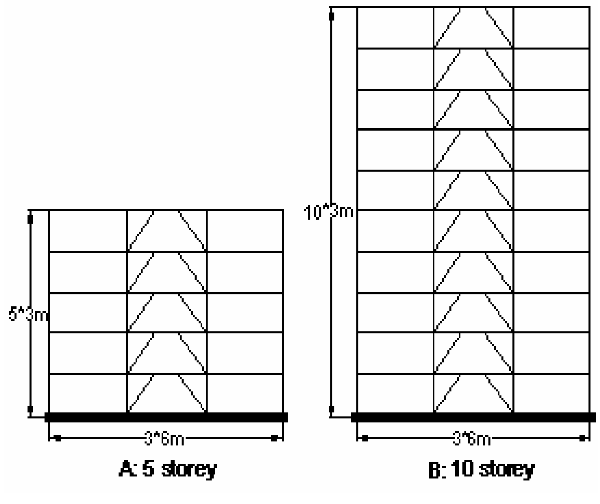

Fig. 1 Geometry of the base frames (5 storeys and 10 storeys)

III. PARAMETRIC ASSESSMENT OF FD FRAME

The methodology proposed in this paper is based on performing a numerical parametric analysis of building structures protected with FD system. For this reason four dimensionless performance indices are introduced to characterize the seismic efficiency of FD system. All these indices are defined as ratio between maximum values (displacement, base shear, dissipated energy), of protected frame (frame with FD) and the same values of base frame (frame without FD). These indices are always positive and their values range between 0 and 1. Values close to 0 indicate good performance and close to 1 mean poor performance.

Each index is described and discussed in the following subsections [8].

A. *Roof displacement Index*

This index (Rd) can be expressed as

$$Rd = \frac{D_f}{D_p} \tag{1}$$

Where D_f is maximum rood displacement along time of FD system and Dp is the same value of frame without damper.

B. *Base shear index*

This index (R_f) can be expressed as

$$Rd = \frac{V_f}{V_p} \tag{2}$$

Where V_f is maximum base shear along time of FD system and is V_p the same value of frame without damper.

C. *Relative Performance Index (RPI)*

The relative performance index (RPI) can be expressed as

$$RPI = \frac{1}{2}\left(\frac{ASE}{ASE_0} + \frac{U_{\max}}{U_{\max 0}}\right) \tag{3}$$

Where ASE is the area under strain energy time-history of FD frame and ASE_0 is the same value of frame without FD.

U_{max} is the maximum strain energy of FD frame and U_{max0} is the same value for frame without FD.

D. *Energy dissipated by FD Index (Re)*

This index is defined as

$$\mathrm{Re} = \frac{E_i - E_f}{E_i} \tag{4}$$

Where E_f is dissipated energy by friction damper for FD frame and E_i is total energy input energy.

This index does not provide relevant information about the performance of dissipater but quantifies energy dissipated by FD.

IV. RESULTS

In this section some results are presented. The results have been investigated in two sections. First section contain plots of four performance indices that defined above versus slip load, For each earthquake, the value of slip-load is varied from 0 to 30 percentage of total building weight. Fig.2, Fig.3 and Fig.4

show these results. In these diagrams the horizontal axis is slip load and the vertical axis is the amount of four performances indices.

Second section contain results of roof displacement, base shear, column axial force subjected to comparing FD and BF frames.

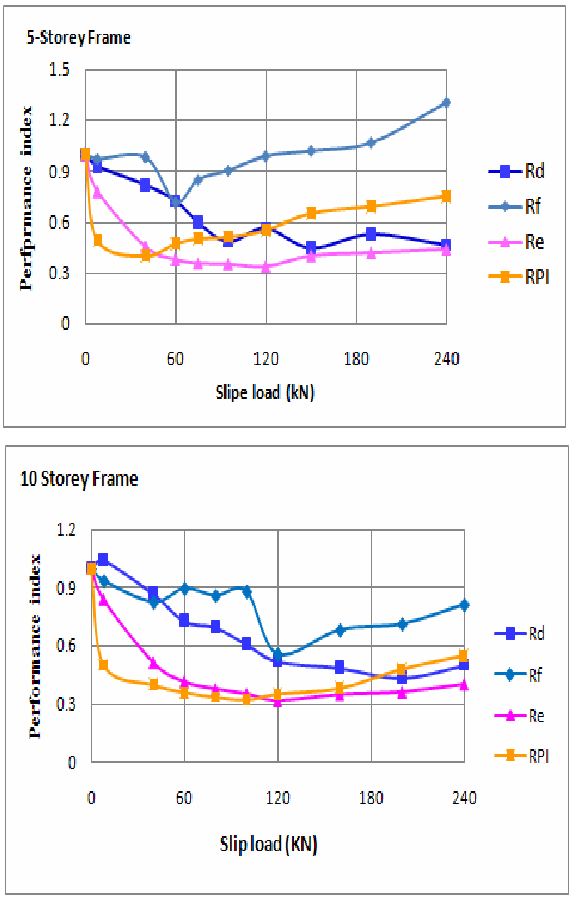

Fig. 2 Performance Indexes subjected to El-Centro earthquake

Fig.2 contains plot of four performance indexes for 5 and 10 storey frames that input earthquake is El-Centro. This Fig shows that for 5 storey frame if slip load >200kN the performance indexes are limited to steady values. In 5 and 10-storey frames, plots for R_d, R_f, R_e and RPI are equal 1 for slip load equal 0. In 5-storey frame the suitable value of slip load is 40 kN (0.08w=0.08 of total weight of frame) for RPI, 60 kN for R_f and 120 kN for R_e, R_d shows that the suitable value of slip load is 140 kN. The main difference between 5-storey plot and 10-storey is that the value of R_f for 5-storey frame is bigger than 1 if slip load exceed from 120 kN, which means that base shear is higher in braced frame than in base frame and FD cannot effective for reducing base shear of shorter buildings.

In 10-storey frame the adequate value of slip load is 100 kN (0.15w=0.15 of total weight of frame) for RPI, 120 kN for R_f and 120 kN for R_e.

Plots in Fig.3 were obtained taking again 5 and 10-storey frames using Kobe earthquake. This Fig shows that, plots for R_d, R_f, R_e and RPI are equal 1 for slip load=0. In 5-storey frame the adequate value of slip load is 95 kN (0.1w=0.1 of total weight of frame) for RPI, 75 kN for R_f and 95 kN for R_e. R_d shows that the suitable value of slip load is 140 kN. In 10-storey frame the adequate value of slip load is 120 kN (0.15w=0.15 of total weight of frame) for RPI, 120 kN for R_f and 120 kN for R_e.

Plots in Fig.4 were obtained taking again 5 and 10-storey frames using Tabas earthquake. This Fig allows deriving similar conclusions than those obtained from two previous figures. The main difference is that the plots for R_d reach minimum value in 160-190 kN, in 5-storey frame, which means, in this case FD are useful to reduce roof displacement in higher slip load if compared to other performance indices.

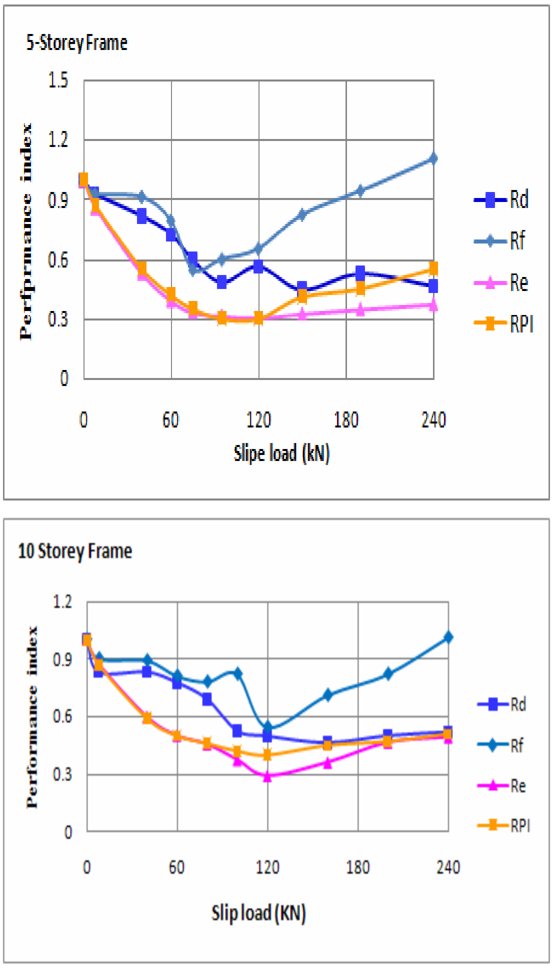

Fig. 3 Performance Indexes subjected to Kobe earthquake

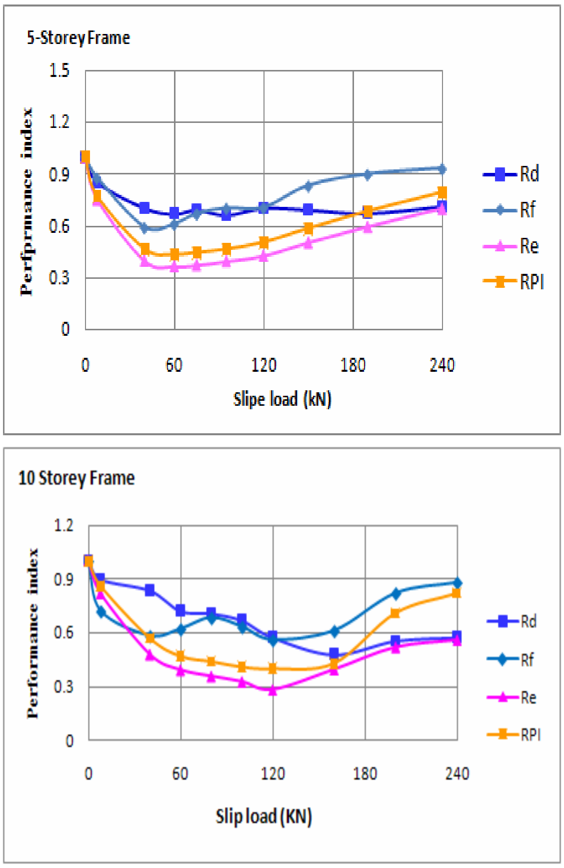

Fig. 4 Performance Indexes subjected to Tabas earthquake

Maximum envelope of roof displacement for 5 and 10 stories frames for 3 earthquake records are shown in figure 5. By the comparison of these diagrams can find out that use of FD decrease the roof displacement into braced frame (BF) for all earthquake records in 10 storey frame. This decrease roof displacement in 5 storey frame in some earthquake is occurred in BF.

In the Figure 6, the maximum base shear of frames for the use of BF and FD for different earthquakes is presented. By the comparison of these diagrams one can find out that use of FD decrease the base shear of BF about 50% for all earthquake records. For example, the base shear in FD in 10 story frame for El-Centro earthquake record is 86 ton. For BF, the same value is 210 ton, respectively. In general, the use of friction dampers resulted in an overall improvement in seismic response.

In the Figure 7, axial force of frames for the use of BF and FD for different earthquakes is presented. By the comparison of these diagrams one can find out that use of FD decrease the axial force of columns of BF about 30-40% for all earthquake records. For example, the axial force in FD in 10 story frame for El-Centro earthquake record is 1758 ton. For BF, the same value is 2791 ton, respectively.

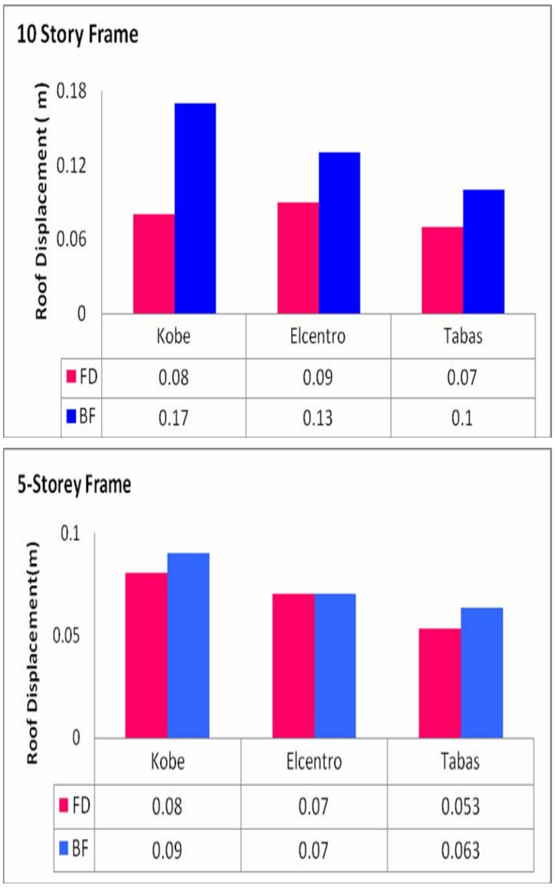

Fig. 5 Envelope of Maximum Roof Displacement

V. CONCLUSION

With the consideration of the case study under investigation and alternative methods rehabilitation suggested here, are summarize the following concluding remarks.

1. For friction dampers, the main step is to determine the slip load. Slip load is percentage of total weight of building that has been varied from 0% to 30% of total weight of building. With compared different responses of frames, with compared different response of frames, is estimated that slip load equal 8% to 15% is more appropriate.

2. Roof displacement for 5 and 10 stories frames for three earthquake records are shown in figure 5. By the comparison of these diagrams can find out that use of FD decrease the roof displacement into BF for two earthquake records. This decrease roof displacement in 5 storey frame in some earthquake is occurred in BF.

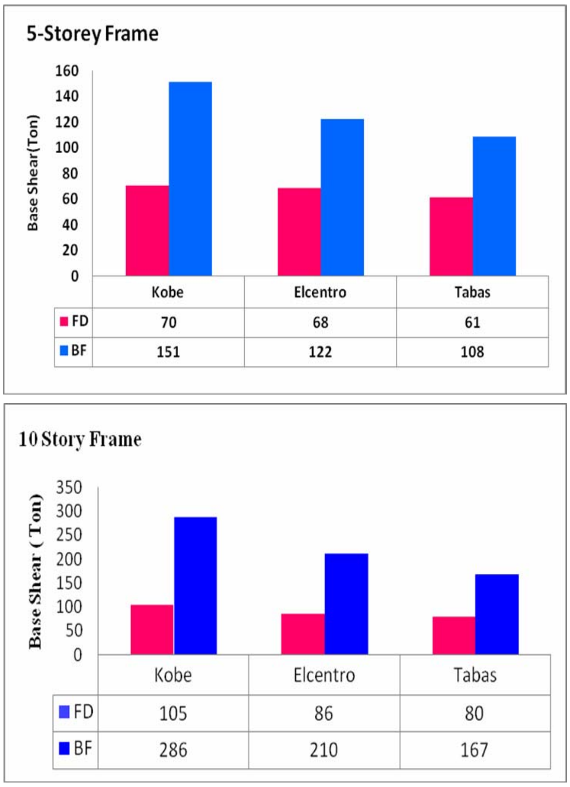

Fig. 6 Envelope of Maximum Base Shear

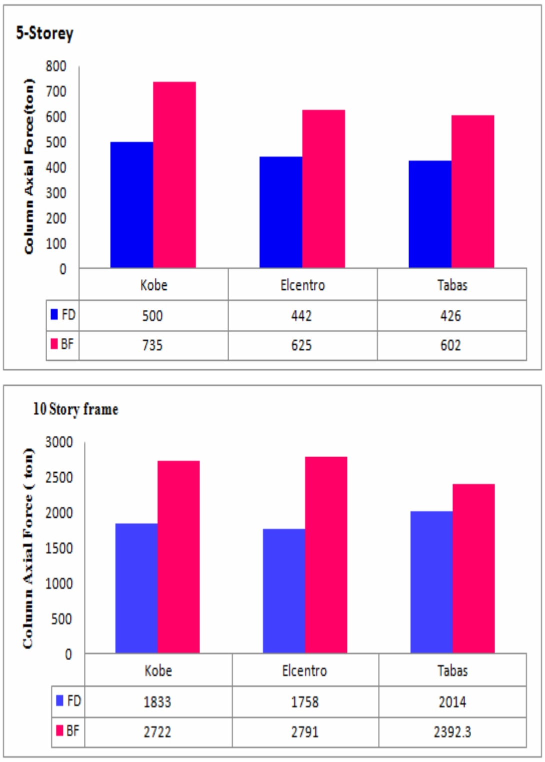

Fig. 7 Envelope of Column axial force

3. The FD reduces the seismic responses of frames when compared to brace frame (BF) in majority cases. In 5 storeys the BF is worked better than FD frame. In the other hand, this situation arises in short building (less than 5 storey),

4. Base shear of frames for BF and FD for different earthquakes is presented. By the comparison of these diagrams has been found out that use of FD decreases the base shear of BF about 50% for all earthquake records.

5. Total of Maximum envelopes for axial loads in column of braced bay is shown in Figure 6. The column axial forces in FD for Kobe, El-Centro, and Tabas earthquake record are about 35% of that for the BF.

RFERENCES

[1] A. Pall, C. March, “Response of friction damped braced frames”,ASCE Journal, PP.1313-1323.

[1] I.Aiken, D.Nims, A.Whittaker, J.Kelly,”Testing of passive energy dissipation systems, "Earthquake Spectra, 1993, PP.335-370.

[2] T.T Soong, G.F.Dargush, "Passive Energy Dissipation System Structural Engineering", 1997, Wiley Chichester.

[3] I.Aiken,”Energy dissipation devices”, 8NCEE, State of art, 2006, 100th anniversary earthquake conference.

[4] A. Pall, S.Marsh, C.Fazio, “Friction Joints for Seismic Control of Large Panel Structure Journal of the Prestressed Concrete Institute, 1980, PP.38-61, 25(6).

[5] Sumitomo Metal Industries, "Friction Damper for Earthquake Response Control, " In-House Report, 1987-12.

[6] F.Gerald, T.Anagnos, T. Goodson, M. and Zsutty, "Slotted Bolted Connections in A seismic Design for Concentrically Braced Connections", Earthquake Spectra1989, Vol.5, PP.383-391.

[7] Julius Marko, D.Thambiratnam, Nimal Perera,” Influence of damping Systems on building structures subject seismic effects”, Elsevier, Engineering, 2004, 26:1939-1956.

[8] I.Aiken, D.Nims, A.Whittaker, J.Kelly,”Testing of passive energy basis dissipation systems”, Earthquake Spectra, 1993:9(3), PP.335-370.

[9] Jim.Corner,”Introduction to structural motion control”, E-book, MIT University,2000.

[10] Imad H. Mualla a, Borislav Belev, "Performance of steel frames with a new friction damper device under earthquake excitation", Engineering Structures, Vol.24, 2002, PP.365-371.

[11] R.Tina PALL, “Hightech Seismic Design of Le Nouvel Europa Montreal", 13th World Conference on Earthquake Engineering, 2004, No.2014, PP.1-6.