PERFORMANCE OF ROTATIONAL FRICTION DAMPER (RFD) IN STEEL FRAMES

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ABSTRACT :

Rotational friction damper (RFD) was introduced in 2000. Primary experimental and numerical studies were done in Denmark. Optimal slip load has the most importance in performance of friction damper. Optimal slip load can be obtained from the minimum of performance indexes. There are two performance indexes, seismic performance index (SPI) and relative performance index (RPI).
In this paper three frames equipped with rotational friction damper, are modeled. These frames are studied with different slip loads, acceleration records and PGAs and 540 nonlinear dynamic time history analyses were done to specify the optimal slip loads.
The results show that different performance indexes can give similar slip load. Performance of RFD is improved by increasing the heights of the frame. Damage index significantly decreases in optimal slip load.
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KEYWORDS: Rotational Fiction Damper, Seismic Performance Index, Relative Performance Index, Damage Index

1. INTRODUCTION

Energy dissipation of friction damper is for the slip of frictional component. Rotational friction damper (RFD) was introduced by Mualla in 2000. This damper is applied for new construction and rehabilitation of existing buildings. Primary tests were done in Denmark [1], and it was tested by using a shaking table in Taiwan [2]. All tests expressed good performance of RFD in seismic events. Also a good agreement between numerical simulation and the results of tests were acquired [1, 2]. Friction damper are displacement-dependent devices, and NEHRP Guidelines presents some rules to use displacement-dependent devices [3].
Factors such as the reduction of displacement, base shear, elastic energy and the increase of energy dissipation of structure are effective on performance of friction dampers. The factors are defined in two indexes that which are: relative performance index (RPI) and seismic performance index (SPI). Optimal slip load can be gained from these performance indexes [1, 4].
In previous studies of RFD, effects of this damper are not investigated in real buildings. At first, in this paper RFD is modeled in SAP2000. To study the heights and period of buildings on performance of RFD, three frames with three, five and eight storeys equipped with RFD are investigated. For studying the intensity of earthquake, different PGAs are used.

2. INTRODUCE OF (RFD)

All components of RFD are seen in figure (1). The main elements of RFD are a vertical and two horizontal plates. Circular friction pad discs are between the plates. Vertical plate is jointed to the above beam. Energy dissipating is produced by rotating horizontal plates beside the vertical plate [5].

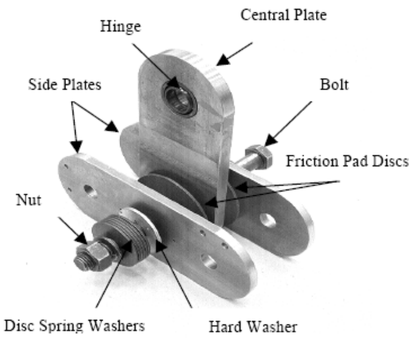


Figure 1 Component of rotational friction damper

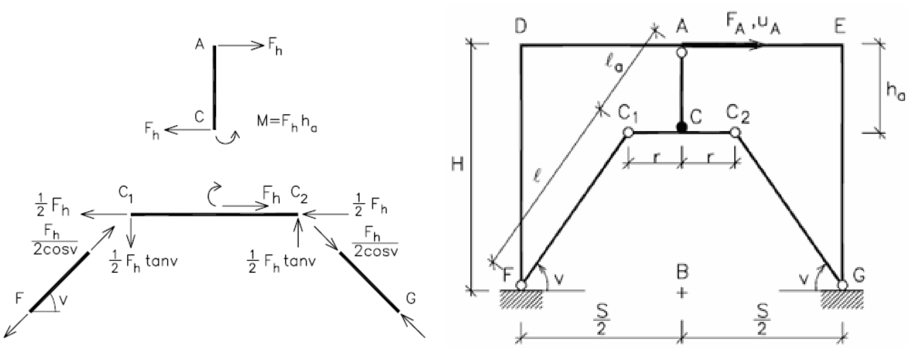


Figure 2 A single storey equipped with RFD

Figure (2) shows a single storey frame equipped with friction damper. Frictional hinge is located in C. The real behavior of RFD in frictional hinge is seen in figure (3), which is the same as Coulomb frictional behavior. In figure (3), F_h is the slip load. This force effects on RFD by the beam of frame, and frictional moment (M_f) on C.

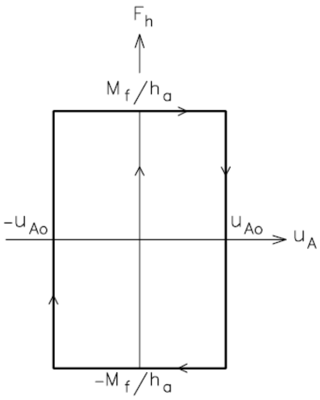


Figure 3 Behavior of frictional hinge

M_f produces tension and compression forces in braces. If the elastic deformation of moment frame and braces are negligible, the behavior in figure(3) can be true for the frame equipped with friction damper, and the rotational of frictional hinge can be related to the drift of frame. On the other hand, if the elastic deformation of braces is important, they should be checked to confine to the performance of friction damper. Tension and compression loads are:

$$F_a = \frac{M_f}{2h_a \cos(v)} \tag{2.1}$$

Where M_f is frictional moment, v is the angle of brace and h_a is the height of vertical plate.

The tension force in brace increases when the frame excited, therefore the braces are designed for this force.

$$A_b = \frac{M_f}{\sigma_y h_a \cos(v)} \tag{2.2}$$

Where, σ_y is yielding stress of the material of braces [6].

The main step in designing of friction damper is to specify the optimal slip load. Factors and indexes are usually between 0 and 1. Value of 1 means that, the slip load is zero or is very high, that friction damper cannot slip. Value of 0 is idealistic value, and it cannot be gained, therefore it's minimum value is selected.
Seismic performance index is introduced by Mualla:

$$SPI = \sqrt{R_d^2 + R_f^2 + R_e^2} \tag{2.3}$$

Where, R_d is response reduction factor, R_f is base shear reduction factor and R_e is remaining energy factor.

$$R_d = \frac{D_f}{D_p} \tag{2.4}$$

$$R_f = \frac{V_f}{V_p} \tag{2.5}$$

$$R_e = (E_i - E_h)/E_i \tag{2.6}$$

Where, D_f, V_f and E_h are, respectively displacement, base shear and hysteresis energy dissipating of structure equipped with friction damper. D_p, V_p and E_i are, respectively displacement, base shear and total input energy of primary moment frame. These formulas are normalized that the member of frame will be elastic [1]. Relative performance index is:

$$RPI = \frac{1}{2}\left(\frac{SEA}{SEA_{(o)}} + \frac{U_{\max}}{U_{\max(o)}}\right) \tag{2.7}$$

Where SEA and $U_{\max}$ are, respectively the area under the elastic strain-energy time history and the maximum strain energy for a friction damped structure; $SEA_{(o)}$ and $U_{\max(o)}$ are the response values of the primary moment frame. Both of the indexes have a concept that structure reaches the elastic mode. Therefore the minimum nonlinear hinges should be occurred in minimum of performance indexes, and damage index should be studied. Damage index is defined as the relative of members, which nonlinear hinges occur in them to total member of frame [7].

3. MODELLING OF RFD

The real behavior of frictional hinge is seen in figure (3). The value of frictional moment is acquired by a multiple of shear force to the height of damper. SAP2000 is utilized to model the rotational friction damper. Wan plastic is used to model this behavior of frictional hinge. This element can behave such as figure (4). It is similar to Coulomb frictional behavior. To show the accuracy of simulation, verification with the previous numerical study is achieved. Figure (5) and (6) show the comparison between Mualla's numerical simulation and simulation of this study. Dimension of moment frame is $7.6 \times 4.6m$ and column cross sections are wide flange with moment of inertia $34 \times 10^6 mm^4$ and the beam is a rigid element. For the assumed weight of $450kN$, the period of vibration is 1s. The EL Centro NS acceleration history with $PGA = 3.1417 \, m/s^2$ and 20s duration is used. Dimensions of damper are $r = 0.165m$ and $ha = 0.2m$.
The section area of brace is $201mm^2$ and the brace pre-stressing is according to the maximum force in earthquake duration [1].

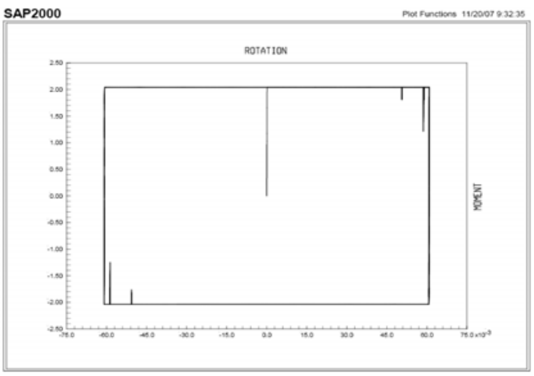


Figure 4 Behavior of frictional hinge by SAP2000

In this study, frame with RFD and mentained characteristics is modeled in SAP2000. But the brace prestressing is assumed to be zero.

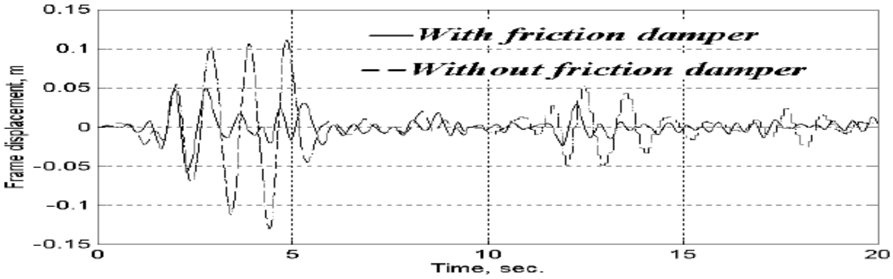


Figure 5 Response of frame with and without friction damper by Drain-2DX

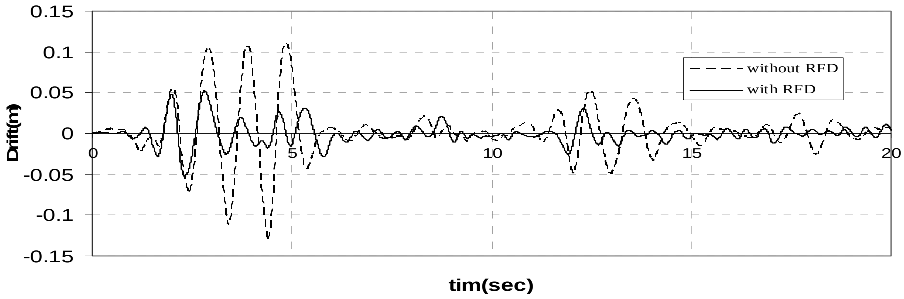
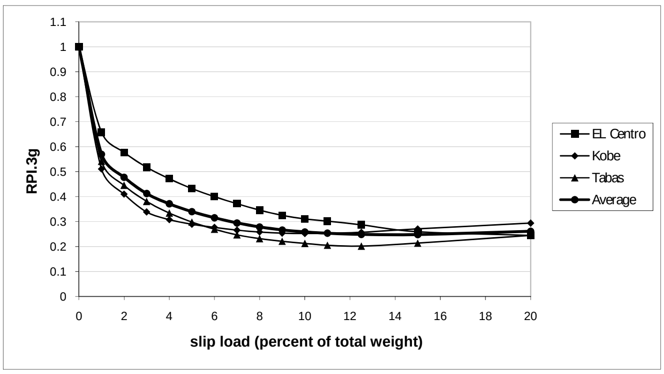


Figure 6 Response of frame with and without friction damper by SAP2000

Maximum responses in figure (6) by SAP2000 have a good agreement with figure (5) by Drain-2DX. But the discrepancy in low response is influenced by the zero brace pre-stressing in SAP2000 modeling. It shows that the brace pre-stressing dose not have a high influence on the response of frames equipped with RFD [8].

4. STUDDING OF RFD IN STEEL FRAMES

In order to study the influence of RFD in steel frames, three frames with 3, 5 and 8 storey frames are studied. Sum of slip load is increased from zero to the twenty percent of total frame weight ($0.2W$), and the performance indexes are acquired [8]. Weights of three, five and eight storey frames are, respectively 155, 280 and 460 tons. Shear slip load divides to the number of the friction dampers. The section area of braces is $908mm^2$. Dimension of damper (h and 2r) are equaled 5 percent of frame dimensions. 540 nonlinear dynamic time history analyses were done for frames with three acceleration records (EL Centro, Kobe and Tabas) and four PGAs (0.2g, 0.25g, 0.3g and 0.35g). A few of performance indexes are seen in figure (7) to (9). For instance the values of optimal slip loads for five storey frame present in table 4.1. The values of average optimal slip loads for all frames present in table 4.2.



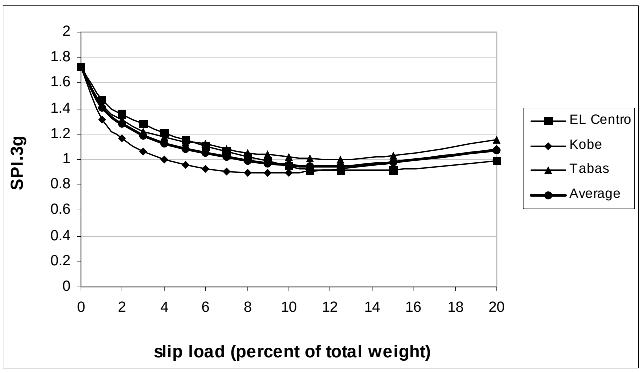


Figure 7 Left- relative performance index, Right- seismic performance index of 3 storey frame and PGA=0.3g

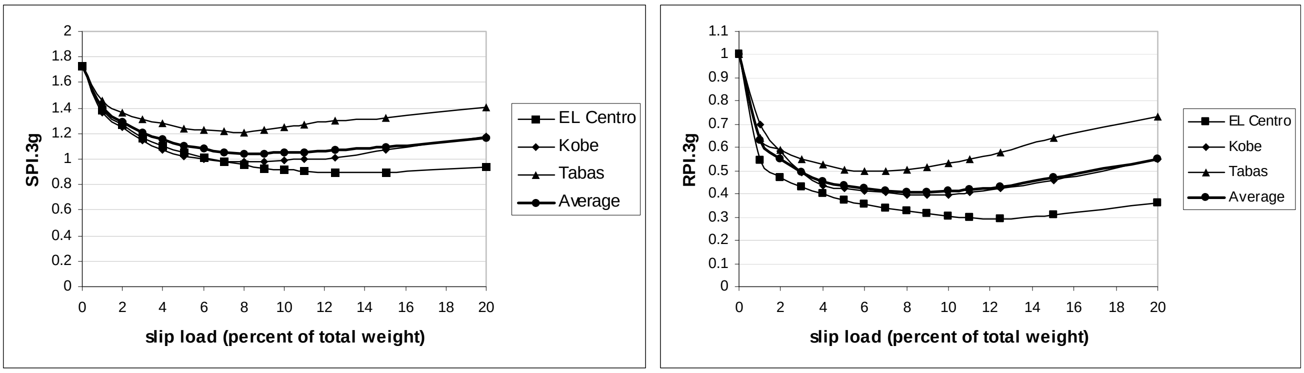


Figure 8 Left- relative performance index, Right- seismic performance index of 5 storey frame and PGA=0.3g

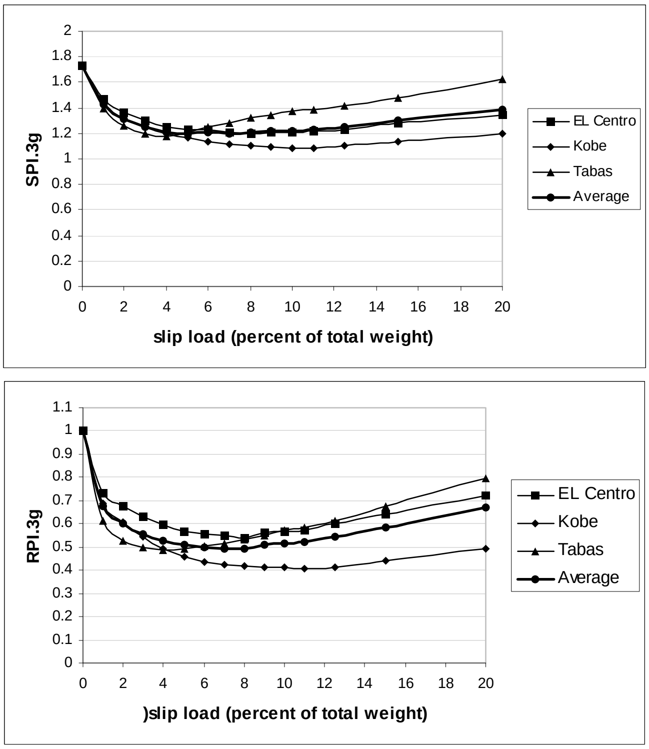


Figure 9 Left- relative performance index, Right- seismic performance index of 8 storey frame and PGA=0.3g

Table 4.1 The values of optimal slip loads fore five storey frame

earthquake	Performance index	Optimal slip loads (percent of total weight)			
		0.2g	0.25g	0.3g	0.35g
EL Centro	(SPI)	10	12.5	15	15
	(RPI)	9	11	12.5	15
Kobe	(SPI)	5	6	8	9
	(RPI)	6	8	9	10
Tabas	(SPI)	5	7	8	9
	(RPI)	5	5	7	8
	(SPI)	6	7	8	10

Table 4.2 The values of average optimal slip loads for all frames

Frames (story)	Performance index	Average optimal slip loads (percent of total weight)			
		0.2g	0.25g	0.3g	0.35g
3	(SPI)	8	10	12.5	15
	(RPI)	9	11	15	15
5	(SPI)	6	7	8	10
	(RPI)	6	7	9	10
8	(SPI)	5	5	7	7
	(RPI)	5	5	7	8

For the calculation of the performance indexes, reduction of displacement, base shear and remain energy factor should be obtained. Each of the factors can mean the reduction of force in structure and lead to the decrease of damage index. But nor of them can give a slip load that is in agreement to others. Using the reduction factors to calculate the seismic performance index (SPI) can give a slip load in agreement with relative performance index (RPI).

Equation 2.3 and 2.7 have a concept to reduce the damage index, therefore in the minimum of performance indexes; the yielding elements should be minimized. Except for the 5 storey frame in EL Centro earthquake with PGA=0.35g, in all of frames, PGAs and acceleration records, the damage indexes are zero. The performance of the damper is improved by increasing the height of frame, and need to less brace pre-stressing, because the period of higher frame equipped with RFD is relatively near to primary moment frame. This rationalizes the using of cable braces in RFDs. According to the table 4.2, the average values of optimal slip loads for 3, 5 and 8 storey frames, for PGA=0.35g are, respectively 15, 10 and 7.5 percent of total weight. According to figure (7), (8) and (9), the slip load is not sensitive in limit of 15 to 20 percent of optimal slip load. It can neutralize the manufacturing, installation and environment condition errors.

Maybe using one acceleration record is not suitable for the evaluation of performance indexes, and optimal slip load. But the average results of 3 acceleration records are reliable. There is no solicitude to unsuitable performance of RFD in lower PGAs. When RFDs are adjusted to higher PGAs, more than 40 percent of input energy is dissipated at least in lower PGAs. RPI and SPI result a similar slip load, therefore SPI can mean to minimize the elastic energy of structure such as RPI. The weight of RFD may be less than 2.5 percent of total structure weight, but it significantly decreases the damage index in structure. This is important for rehabilitation of existing building and construction of new building [8].

5. CONCLUSIONS

RFD is modeled in SAP2000 and verification with previous numerical analysis is acquired. Slip loads are obtained from performance indexes.

Nonlinear dynamic time history analyses indicate that:

1- Using the RFD significantly decreases the damage of structure in seismic events.
2- According to the table 4.2 the value of slip load for 8 story frame has 50% decrease relative to 3 storey frame, that indicates using of RFD in higher frame is more suitable than shorter frame.
3- Average optimal slip load of different acceleration records is reliable.
4- SPI and RPI can give similar slip loads.

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