Incremental Dynamic Analysis of Steel Frames Equipped With Rotational Friction Dampers

Mohammad Amin Montazer [1], Amir Shirkhani [1,*]
Mohammad Hassan Mirabi Moghaddam[1], Saeed Rahmani [2]

[1] Department of Civil Engineering, University of Sistan and Baluchestan, Zahedan, Iran
[2] Department of Civil Engineering, Payame Noor University of Ilam, Iran

Abstract: **This research presents a study on the seismic assessment of steel frames with Rotational Friction Dampers (RFDs). The devices were used to protect structures from damage during earthquakes. In this study, steel moment frames equipped with RFDs is investigated under Nonlinear Time History (NTH) and Incremental Dynamic Analysis (IDA). Maximum interstory drift ratio is studied as Engineering Demand Parameter (EDP). According to the IDA curves, it is concluded that by adding RFDs, the behavior of steel frames changes from hardening phase to severe hardening phase.**

Keywords: **Rotational friction damper, incremental dynamic analysis, IDA curve, maximum interstory drift ratio, engineering demand parameter.**

I. INTRODUCTION

Passive energy dissipation devices have been successfully used to effectively protect buildings and structures against earthquakes and severe wind gusts. The basic reason for introducing energy dissipation devices into a structure is to decrease the dynamic response and damage of the frame [1]. Rotational Friction Dampers (RFD) was introduced for the first time by Mualla [2]. Full scale tests for three stories structures equipped with such damper on shaking table was done in Taiwan [3]. In order to enhance the seismic capacity of structures, it is possible to use combined system of rotational friction dampers connected to high strength tendons [4]. Three steel moment frames with 3, 7 and 12 stories equipped with RFDs are investigated under Nonlinear Time History (NTH) and Incremental Dynamic Analysis (IDA) in present study. The influence of RFDs on seismic performance of steel frames is studied by comparing the IDA curves.

II. ROTATIONAL FRICTION DAMPER (RFD)

The Rotational Friction Damper (RFD) consists of steel plates pre-stressed together by a steel bolt (Fig. 1); [5]. Between the steel plates there are circular friction pad discs. The energy absorbing potential of the RFD can be easily increased by adding more layers of friction pads and steel plates [1].

Fig. 1. RFD [1]

Fig. 2 shows the mechanism of the RFD under a lateral force in various directions. As it is displayed, the damper is very simple in its components. It can be arranged in many configurations of bracing system [6].

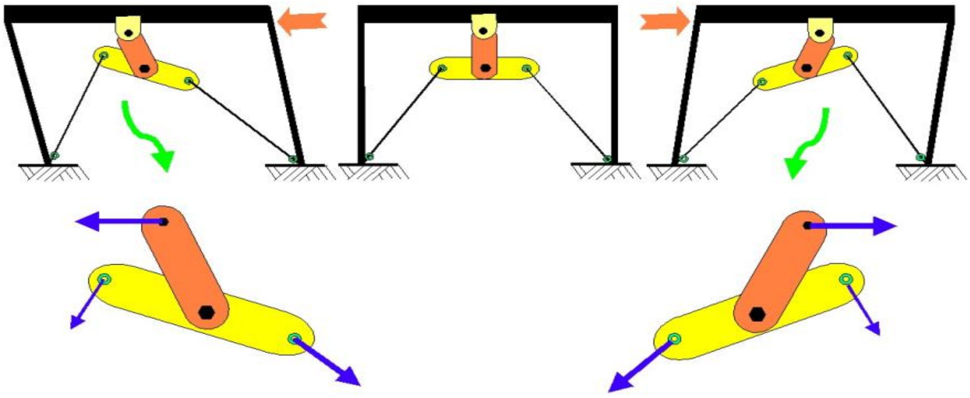
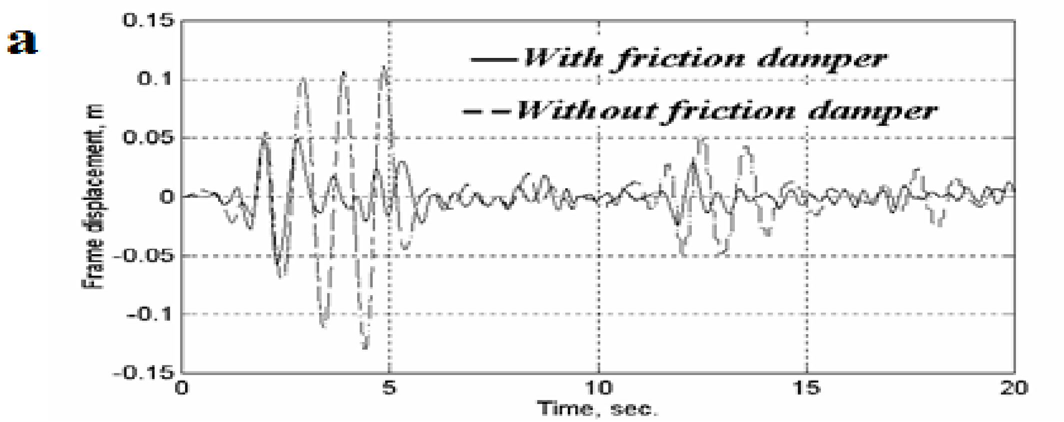


Fig. 2. Mechanism of FDD [6]

A. Verification of Model

The response of initial frame with RFD obtained by Mualla [5] is presented in Fig. 3(a) and the response obtained in this study is given in Fig. 3(b). Therefore, it can be said that the results are well-matched for Mualla model and that of the present study.



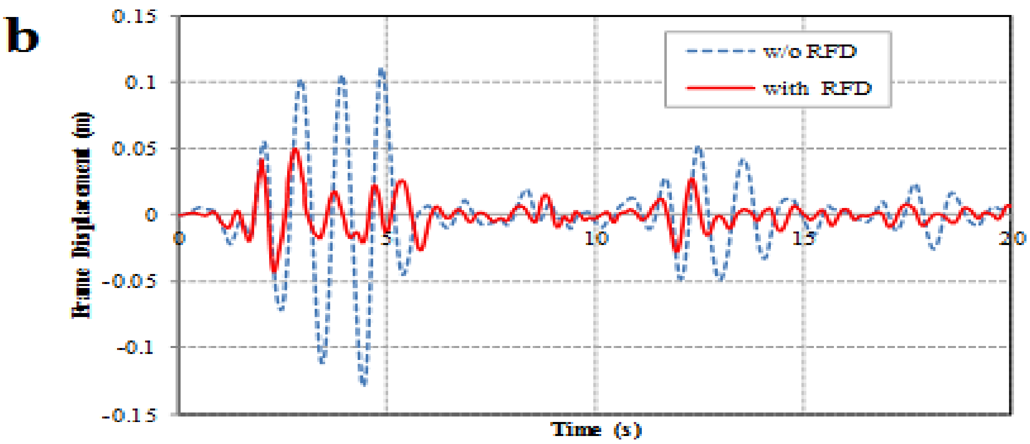


Fig. 3. Initial frame response with and without RFD, El Centro earthquake: (a) Obtained by Mualla [5]; (b) In present research

III. DESIGN OF STEEL FRAMES

Three steel moment frames with 3, 7 and 12 stories are investigated in this paper. All frames have three bays. These frames are designed based on Iranian National Building Code (INBC) Section 10 [7] which is close to AISC ASD design code [8]. The studied soil is type C of Standard ASCE/SEI 41-06 [9]. The length of each bay and height of each story in all frames are 5 m and 3.2 m, respectively. RFDs are installed in middle bay and total stories of frames. In the naming of frames, prefixes "FR" and "DFR" represents frames without and with RFDs, respectively. For example "FR12st" represents moment frame with 12 stories. The characteristics of the frames and the free vibration period of those with and without RFDs are shown in Tables I and II, respectively.

TABLE I: CHARACTERISTICS OF THE FRAMES

Frames	Number of Stories	Weight (KN)	Design base shear (KN)
FR3st	3	1458.06	182.27
FR7st	7	3491.58	312.84
FR12st	12	6065.42	414.86

TABLE II: FREE VIBRATION PERIOD OF FRAMES WITH AND WITHOUT RFDS

Frames	Period of free vibration (s)
FR3st	0.945
DFR3st	0.477
FR7st	1.422
RM7st	0.953
FR12st	2.018
DFR12st	1.539

IV. INCREMENTAL DYNAMIC ANALYSIS

Incremental Dynamic Analysis (IDA) is a parametric analysis method that has recently created in various forms to evaluate more thoroughly structural performance under seismic loads. It involves subjecting a structural model to one (or more) ground motion record(s), each scaled to multiple levels of intensity, thus producing one (or more) curve(s) of response parameterized versus intensity level. The IDA study is accelerogram and structural model specific; when subjected to different records a model will often create quite dissimilar responses that are difficult to predict a priori. Notice, for instance, Fig. 4(a–d) where 5-stories braced frame represent responses ranging from a gradual degradation towards collapse to a rapid, non-monotonic, back-and-forth twisting behavior.

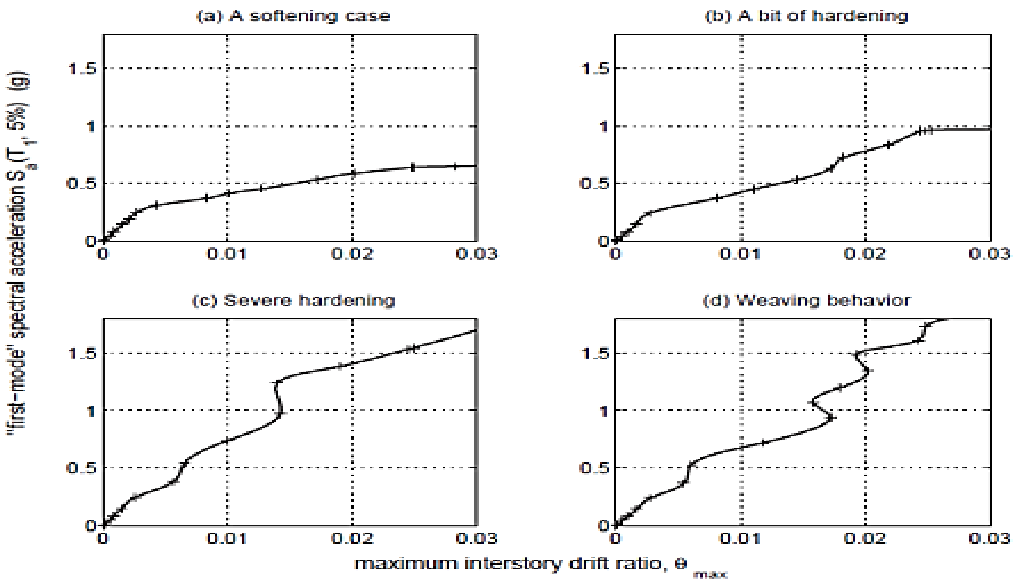


Fig. 4. IDA curves of a T_1 = 1.8 sec, 5-storey steel braced frame subjected to 4 different records [10]

Each diagram demonstrates the demands imposed upon the structure by each record at various intensities, and they are quite intriguing in both their similarities and dissimilarities. Focusing on the other end of the curves in Fig. 4, notice how they terminate at different levels of Intensity Measure (IM). Curve (a) sharply "softens" after the initial buckling and accelerates towards large drifts and eventual collapse. The twisting patterns that curves (c) and (d) display in doing so are successive segments of "softening" and "hardening", regions where the local slope or "stiffness" decreases with higher IM and others where it increases [10]. The characteristics of seven ground motions used in this study are shown in Table III.

TABLE III: SEVEN GROUND MOTIONS USED IN THIS STUDY [11]

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

V. NTH AND IDA ANALYSES RESULTS

A comparison of the roof displacement is made between FR12st and DFR12st frames under NRORR360 record by NTH analysis (Fig. 5). According to the roof displacement history of these frames, it is obvious that by adding RFDs to FR12st frame, the maximum roof displacement will be decreased by 56%.

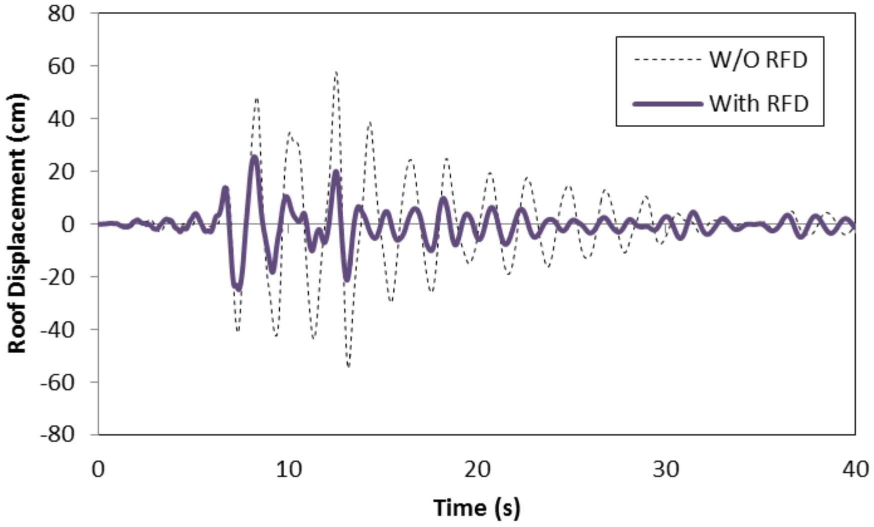


Fig. 5. Comparison between roof displacement of FR12st and DFR12st frames under NRORR360

To obtain the IDA curve, each ground motion is scaled to 0.2g, 0.4g, 0.6g, 0.8g, 1g, 1.2g and 1.4g. The vertical axis is considered as PGA and horizontal axis for maximum interstory drift ratio. IDA curves for 3 stories frame with and without RFDs are shown in Figs 6 and 7. Maximum interstory drift ratio is considered as Engineering Demand Parameter (EDP) in this research.

Figures 6 and 7 show that by adding RFDs to 3 stories frame, maximum interstory drift ratio is decreased for each level of PGA in IDA curve. It is concluded that by adding RFDs, the behavior of steel frames changes from hardening phase to severe hardening phase. The Mean of reduction percentage of maximum interstory drift ratio obtained from seven ground motions in different accelerations (PGA) and according to IDA curves for frames by adding RFDs is shown in Table IV.

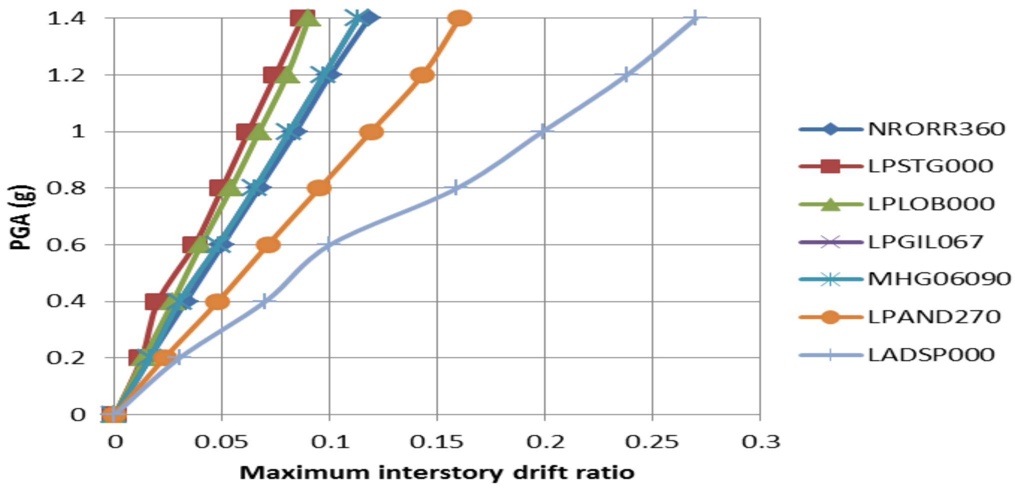


Fig. 6. IDA curves of FR3st frame for seven records

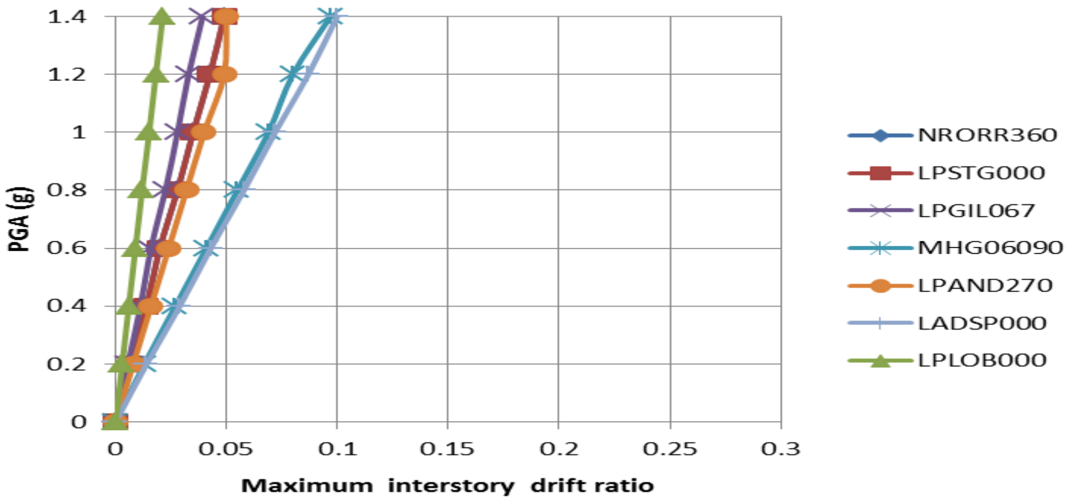


Fig. 7. IDA curves of DFR3st frame for seven records

TABLE IV: REDUCTION PERCENTAGE OF MAXIMUM INTERSTORY DRIFT RATIO OBTAINED FROM IDA CURVES FOR FRAMES BY ADDING RFDS

PGA (g)	Results mean of seven ground motions		
	3 stories frame	7 stories frame	12 stories frame
0	-	-	-
0.2	56.63	47.23	58.52
0.4	56.59	47.02	56.33
0.6	59.1	45.95	57.19
0.8	59.12	47.14	57.06
1	59.61	47.64	57.04
1.2	59.48	46.22	56.14
1.4	59.26	46.98	57.73

As can be seen in Table IV, maximum value occurs in PGA=1g for 3 and 7 stories frames, but it occurs in PGA= 0.2g for 12 stories frame.

VI. CONCLUSION

Incremental Dynamic Analysis (IDA) is an emerging analysis method that offers thorough seismic demand and capacity prediction capability by using a series of nonlinear dynamic analyses under a multiply scaled suite of ground motion records. In this study, RFDs are installed in steel frames. It is mentioned that RFDs have a proper performance in decreasing the maximum interstory drift ratio in different accelerations. It is also concluded that by installing RFDs, the behavior of steel frames changes from hardening phase to severe hardening phase. It shows that stiffness of steel frames increases with adding RFDs. It is concluded that the maximum of reduction percentage in maximum interstory drift ratio obtained from the results mean of seven ground motions by IDA occurs in PGA=1g for 3 and 7 stories frames, but it occurs in PGA= 0.2g for 12 stories frame.

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