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Seismic Performance of a Novel Configuration of Rotational Friction Damper in X Bracings

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ABSTRACT: Seismic performance of a cruciform rotational friction damper has been evaluated in this article. Horizontal and vertical arms' length and sliding threshold moment are three adjusting parameters of this device which shall be optimized to assure the damper efficiency. It has been shown that the energy dissipation rate increases for shorter arms due to more relative rotation between frictional contacting surfaces. The best dimensions for friction device arms have been evaluated in this study. A simple method has also been suggested based on static analysis and aiming to find the optimum sliding threshold moment for friction damper implemented at different stories. Closed form solutions of kinetic and kinematic equations of the damper dynamic have been employed on this regard. Dissipaters' seismic performance indexes have been evaluated through nonlinear dynamic analyses to validate the reliability of the proposed method. It has been shown that the variant values of sliding threshold moment for optimum FD at different stories improves the seismic performance index in comparison with the case of identical devices utilized on all stories. Implementation of identical friction device on all stories may cause inactiveness of the dissipaters on upper stories where the inter-story shear force is not high enough and it acts as ordinary X bracings. The proposed method provides a simple and efficient approach for FD optimum design on different stories of building without multitude of time consuming nonlinear dynamic analyses. According to the dynamic analyses results inconstant optimally designed FDs will be active on all stories while identical FDs may not be sliding at upper stories during the earthquake. Performance of optimally designed FDs has been evaluated for 4, 8 and 12 story buildings under low, medium and high intensity earthquakes. It has been concluded that the proposed dissipater is more effective for high rise buildings and its efficiency increases for severe earthquakes. Although FD utilization on X-braces increases the inter-story drifts; base shear and residual energy considerably decrease. At last it results in 5%-20% improvement in seismic performance index. 3%-6% more reduction in SPI can be achieved using different sliding threshold moments for dampers on each story.

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1- Introduction

Various types of friction dampers have been utilized as efficient dissipative devices against dynamic excitation of structures [1]. Their performance has been evaluated within last three decades [2] in different forms [3] such as pretension slotted connections [4], Pall damper [5] and Mualla rotational friction damper [6]. Experimental studies have been performed to evaluate the performance of innovative types of friction dampers under cyclic loadings [7] and also to raise their rate of energy dissipation [8]. Authors assayed them for fatigue damage mitigation in special structures [9]. New configurations have been innovated for this device [10-12] in passive and semi active applications [13] and they have been optimized for multi objective criterion [14]. It has been concluded that the optimum tuning of sliding moments leads to activation of all devices utilized in different stories of a building [15].

An innovative rotational friction damper has been evaluated in this article. The proposed damper is easy to fabricate and this device has a plain configuration in comparison with Pall damper. It is practical for ordinary X-braced frames in spite of Mualla FD which is mostly utilized under the beam in pre-tensioned chevron bracings [16]. It is a cruciform device including several horizontal and vertical arms' that are perpendicularly linked to each other by pre-tensioned bolt. Mathematical model has been derived for moment-rotation relationship of this device considering finite element analyses results. It includes rectangular loops which are in accordance with Mualla experimental studies. Horizontal and vertical arms' length and sliding threshold moment are three adjustable parameters of this device which shall be optimized to assure the damper efficiency. A simple method has also been suggested based on static analysis and aiming to find the optimum sliding threshold moment for friction damper implemented at different stories. Closed form solutions of kinetic and kinematic equations of the damper dynamic have been employed on this regard.

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2- Proposed Configuration

General configuration of proposed device is shown in Figure 1 and it includes a frictional joint in the center of an X bracing. Diagonal chords should be designed for axial force of:

$$F_{design} = \max\left\{\frac{M_f}{2r_h \sin\alpha_1}, \frac{M_f}{2r_v \cos\alpha_2}\right\} \quad (1)$$

M_f is the sliding threshold moment. r_h and r_v are horizontal and vertical arms lengths.

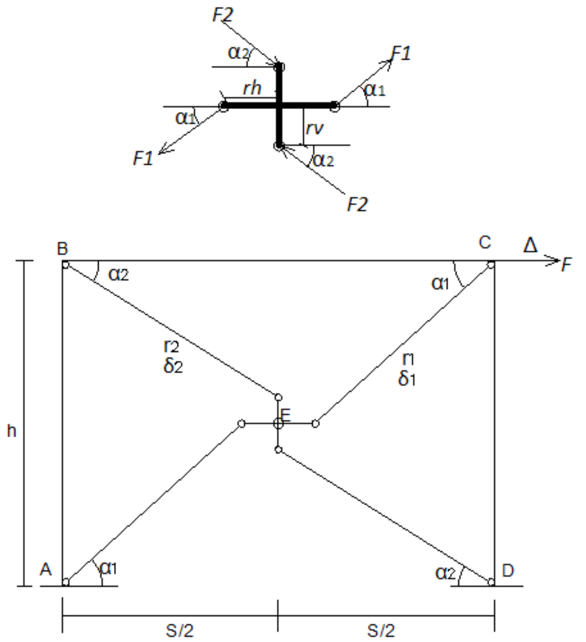

Figure 1. Rotational friction device configuration

This device provides the maximum energy dissipation rate when it complies the following equation where F is the lateral loading amplitude.

$$\frac{1}{r_v} + \frac{1}{r_h \tan\alpha_1} = \frac{F}{M_f} \quad (2)$$

This condition has been derived directly from the maximization of the rotation amplitude of frictional joint:

$$\varphi = \frac{F}{2K_f}\left(\frac{1}{r_v} + \frac{1}{r_h \tan\alpha_1}\right) - \frac{M_f}{4K_f}\left(\frac{1}{r_v} + \frac{1}{r_h \tan\alpha_1}\right)^2 \quad (3)$$

K_f is the lateral stiffness of the moment frame.

3- Modeling and Analysis

An analytical case study has been performed to validate Equation 2. Structure model has been created in SAP-2000 software using Wen plastic link type element to simulate frictional joints behavior. Its accuracy has been verified in comparison with experimental and analytical results reported by Mualla [16] and the same one span and one story steel frame has been modeled in this study. Following performance indexes have been evaluated for the steel frame utilized with the proposed friction damper in optimum configuration [6].

$$SPI = \sqrt{R_d^2 + R_f^2 + R_e^2} \quad (4)$$

$$R_d = \frac{D_f}{D_p}, \quad R_f = \frac{V_f}{V_p}, \quad R_e = \frac{E_i - E_h}{E_i} \quad (5)$$

It includes reduction factors in displacement response, base shear and kinematic energy respectively.

Table 1. Performance index for uniform and optimum configuration of FD in 12-storey steel frame

PGA (g)	Variable Distribution			Uniform Distribution		
	0.2	0.3	0.4	0.2	0.3	0.4
Rf	0.717	0.704	0.715	0.760	0.754	0.760
Rd	0.555	0.571	0.579	0.553	0.569	0.553
Re	0.341	0.353	0.361	0.408	0.390	0.408
SPI	0.968	0.972	0.988	1.024	1.022	1.024

4- Conclusions

Implementation of identical friction device on all stories may cause inactiveness of the dissipaters on upper stories where the inter-story shear force is not high enough and it acts as ordinary X bracings. The proposed method provides an efficient approach for FD optimum design on different stories of building without multitude of time consuming nonlinear dynamic analyses. According to the dynamic analyses results inconstant optimally designed FDs will be active on all stories while identical FDs may not be sliding at upper stories during the earthquake. Performance of optimally designed FDs has been evaluated for 4, 8 and 12 story buildings under low, medium and high intensity earthquakes. It has been concluded that the proposed dissipater is more effective for high rise buildings and its efficiency increases for severe earthquakes. Although FD utilization on X-braces increases the inter-story drifts; base shear and residual energy considerably decrease. At last it results in 5%-20% improvement in seismic performance index. 3%-6% more reduction in SPI can be achieved using different sliding threshold moments for dampers on each story.

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