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Testing and performance of a new friction damper for seismic vibration control

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ABSTRACT

In the last two decades, great efforts were carried out to reduce the seismic demand on structures through the concept of energy dissipation instead of increasing the stiffness and strength. Several devices based on different energy dissipation principles have been developed and implemented worldwide, however, most of the dissipation devices are usually installed using diagonal braces, which entail certain drawbacks on apertures for circulation, lighting or ventilation and architectural or functional requirements often preclude this type of installations. In this work, a conceptual development of a novel energy dissipation device, called Multiple Friction Damper (MFD), is proposed and examined. To verify its characteristics and performance, the MFD was implemented on a single storey steel frame experimental model and tested under different conditions of normal force and real time acceleration records. Experimental results demonstrated that the new MFD constitutes an effective and reliable alternative to control the structural response in terms of displacement and acceleration. A mathematical formulation based on the Wen's model reflecting the nonlinear behaviour of the device is also presented.

1. Introduction

It is well known that, to reduce the structural response, external energy dissipation devices may be advantageously used. Friction dampers are often used in passive vibration control because they offer high energy dissipation capacity at relatively low cost and maintenance. Several friction devices have been tested and some of them have been implemented in buildings around the world [1].

Pall and Marsh [2] developed a friction damper known as the Pall frictional damper (PFD) in which the braces of an ordinary braced frame structure can slip in both directions by connecting the friction pads by four links at the intersection of the cross-braces. Anagnostides et al. [3] presented two new types of linear and rotational friction devices that are able to produce broad and stable hysteresis loops during an earthquake. Fitzgerald in 1989 [4] conducted a complete investigation on Slotted Bolted Connections (SBC) installed on braces, which dissipate energy through two friction steel surfaces in tension and compression loading cycles. Then, Grigorian et al. in 1993 [5] suggested to replace, in the SBC, the steel plates by brass plates. Sumitomo's friction damper [6] utilizes a more complicated design in which a pre-compressed internal spring exerts forces that are converted through the action of inner and outer wedges into a normal force on friction pads. Loo et al. [7] proposed a different type of symmetric connector for the SBC that eliminates the need for

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shims which were considered expensive. Nims et al. [8] developed and tested a friction device called Energy Dissipating Restraint (EDR) that is similar to the Sumitomo's friction damper, except that the EDR utilizes steel and bronze friction wedges to convert the axial spring force into normal pressure on the cylinder. Mualla and Belev [9] proposed a friction damper device consisting of a central (vertical) plate, two side (horizontal) plates and two circular friction pad discs placed in between the steel plates, which are pin-connected, by braces to the frame. The energy dissipation occurs by the rotation of the central plate relative to the side plates when a horizontal deformation occurs in the frame. Cho and Kwon [10] developed a wall-type friction damper based on a Teflon slider to improve the seismic performance of reinforced concrete structures. Mirtaheri et al. [11] proposed an innovative friction damper called Cylindrical Friction Damper (CFD), which consists of two main parts, an inner shaft fitted inside an outer cylinder. Upon application of proper axial loading to both ends, the shaft moves inside the cylinder by overcoming the friction. This friction leads to considerable dissipation of mechanical energy. Khoo et al. [12] developed a self-centering sliding hinge joint that incorporates friction ring springs to improve the dynamic re-centering properties and reduce strength degradation, principally against major earthquakes. Later, Monir and Zeynali [13] presented a friction damper, which is assembled at the intersection of X-shaped diagonal braces. Recently, Samani et al. [14] presented the concept of a semi-active frictional damper called Adjustable Frictional Damper (AFD) in which the clamping force is secured by hydraulic pressure, which makes possible to control the seismic response of the structure by changing the clamping force of the dampers. The hysteretic behaviour of the AFD was studied numerically and good agreement with experimental results was found.

As regard to design procedures of friction energy dissipation systems, the following works may be included: Two design methodologies to determine systematically the quantity and the total slip force of friction damper–brace systems for elastic multi-storey building structures was presented by Filiatrault and Cherry [15] and Lee et al. [16]. Harmonic response of adjacent structures connected with a friction damper was studied by Bhaskararao and Jangid [17]. They observed that there exists an optimum slip force in the damper for which the peak displacement of a structure attains the minimum value, but the optimum slip force is different for each of the two connected structures. Park et al. [18] and Min et al. [19] presented new equivalent linearization techniques for a friction damper–brace system. Martinez et al. [20,21] proposed a robust and efficient design procedure to optimally define the energy dissipation capacity of added viscous and nonlinear hysteretic dampers on multiple-storey structures. Fallah and Honarparast [22] optimize the placement of type-Pall dampers through a genetic algorithm technique based on a multi-objective function. Performance of rotational friction dampers on frames of 3, 7 and 12 stories were studied by nonlinear time history dynamic analyses and evaluated experimentally by Mirzabagheri et al. [23]. Krack et al. [24] proposed a reliability based optimization of friction-damped systems using nonlinear modes, taking into account uncertainties in the friction coefficient, linear damping, and excitation level.

As specialized literature shows, traditional friction dampers are usually installed using diagonal braces, which entail certain drawbacks on apertures for circulation, lighting or ventilation and architectural or functional requirements often preclude this type of installations. Thus, this work presents a conceptual development of a novel energy dissipation device, called Multiple Friction Damper (MFD). This device, unlike traditional friction dampers, can be installed on any column without requiring major structural modifications. Another important feature of MFD is that the normal force necessary to attain the required friction force is applied through a preloading device resulting in a reduction of the axial force on the column where the MDF is installed. By means of experimental testing on a single-storey experimental model, the effectiveness on the structural response control, under different levels of normal force and characteristics of the excitation was assessed. A mathematical formulation based on the Wen's model describing the dynamical behaviour of the structure provided with the MFD is also presented.

2. Description of the Multiple Friction Damper (MFD)

The proposed friction damper consists of a set of friction elements stacked and coaxial with the column where it is installed (Fig. 1a). Each element is supported and assembled by two or four I-shaped steel plates that embrace the column to facilitate its installation (Fig. 1b). Both flanges (top and bottom) are provided with friction pads on which friction forces are generated during the relative motion between consecutive elements (slipping). Because of the axial symmetry, this type of connection enables the movement in any radial direction. Fig. 1c shows how the horizontal movement of the column is transmitted to each friction element through the toroidal ring connection. Indeed, when the column bends (elastic deformation), each toroidal ring clamped to it rotates freely inside the cylindrical bore and moves laterally pushing each friction element. Thus, the column transmits the lateral displacement, δ, to each friction element but, it does not transmit the rotation, θ. The relative displacement between contact friction pads generates friction forces.

The necessary normal force is adjusted by a preloading device (Fig. 1d), located at the top of the column. To ensure a correct operation of the MFD in slip phase, the normal force must not exceed the limit in which it might be prone to lock (stick phase). Thus, when the normal force is applied on the MFD, a reaction force against the roof (upper beam) is generated, and the axial force on the column is reduced because a fraction of the total initial axial force is taken by the stack of friction elements. The MFD can be installed on frames that undergo both, shear and bending deformations. In this latter case, it might be necessary the installation of a preloading device at each end of the column to absorb the small rotation of the beam-column join.