Journal of Constructional Steel Research 112 (2015) 354–362

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Experimental and numerical study of a new adjustable frictional damper

Hamid Rahmani Samani, Masoud Mirtaheri *, Amir Peyman Zandi

Depatment of Civil Engineering, K.N. Toosi University of Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received 16 August 2013
Accepted 13 May 2015
Available online 19 June 2015

Keywords:
Frictional damper
Energy dissipation
Passive control
Semi-active control
Hysteretic loading

ABSTRACT

In this paper, the concept of a semi active frictional damper called Adjustable Frictional Damper (AFD) is introduced. The clamping force of such damper is secured by hydraulic pressure, which not only reduces the manufacturing costs but also makes it possible to control the seismic response of the structure by changing the clamping force of the dampers.

The hysteretic behavior of AFD is studied by experimental means as well as by numerical model. Experimental process involves tests with various hydraulic pressures (which cause various frictional forces) at nearly static loading as well as dynamic loading with various frequencies. The results show that the proposed damper has significant energy absorption by stable hysteretic loops, which can be used for enhancement of the performance of structures subjected to earthquake loads with various intensities. Force–displacement characteristics of AFD such as slippage load, dissipated energy, effective stiffness and equivalent viscous damping for consecutive cycles of loading is calculated. The system is qualified based on the requirements for displacement-dependent devices according to ASCE/SEI 41-06 specification. Furthermore, the hysteretic behavior of AFD is studied by numerical method and a close agreement between the experimental and numerical results is observed.

1 . Introduction

Seismic response control techniques involve addition of devices to the system in order to dissipate the energy imparted by earthquake motion (for a survey of such techniques see e.g. [1–4]). Frictional based dampers are one class of such devices which dissipate the energy through frictional mechanism caused by two solid bodies sliding relative to each other. A conventional frictional damper compromises a frictional sliding contact surface and a clamping mechanism that produces normal contact force on the surface and heavily relies on coefficient of friction between surfaces. In a passive frictional damper, the clamping force of the damper and consequently the slippage force is a pre-determined constant value selected by design. If the axial force in the damper which is usually placed in a bracing system overcomes the static frictional force, the passive damper starts to slip and a considerable amount of mechanical energy can be transformed to heat energy and dissipated.

Many different types of passive frictional energy dissipation devices have been developed and tested for seismic applications in recent years, and more are still being investigated. Pall and Marsh [5] proposed frictional dampers installed at the crossing joint of the X-brace. Tension in one of the braces forces the joint to slip thus activating four links, which in turn force the joint in the other brace to slip. This device is usually called the Pall frictional damper. Wu et al. [6] introduced an improved Pall frictional damper (IPFD), which replicates the mechanical properties of the Pall frictional damper, but offers some advantages in terms of ease of manufacture and assembly. Sumitomo friction damper [7] utilizes a more complicated design. The pre-compressed internal spring exerts a force that is converted through the action of inner and outer wedges into a normal force on the friction pads. Fluor Daniel Inc. has developed and tested another type of frictional device which is called Energy Dissipating Restraint (EDR) [8]. The design of this friction damper is similar to the Sumitomo friction damper since this device also includes an internal spring and wedges encased in a steel cylinder. The EDR utilizes steel and bronze friction wedges to convert the axial spring force into normal pressure on the cylinder. A full description of the EDR mechanical is given in [9]. Constantine et al. [10] proposed frictional dampers composed of a sliding steel shaft and two frictional pads clamped by high strength bolts. Mualla and Belev [11] proposed a friction damping device and carried out tests for assessing the friction pad material. Habib Saeed Monir and Keyvan Zeynali [12] introduced and tested a modified friction damper (MFD) which is similar to pall friction damper however it is applied in the diagonal bracing. Recently Mirtaheri et al. [13] proposed an innovative type of frictional damper called cylindrical friction damper (CFD). In contrast with other frictional dampers the CFDs use shrink fit mechanism in lieu of high-strength bolts to induce friction between contact surfaces. This reduces construction costs, simplifies design computations and increase reliability in comparison with other types of frictional dampers.

* Corresponding author at: K.N. Toosi University of Technology, Department of Civil Engineering, No. 1346, Valiasr St., Mirdamad intersection 19967, P.O. Box. 15875-4416, Tehran, Iran.

E-mail addresses: samani@dena.kntu.ac.ir (H.R. Samani), mmirtaheri@kntu.ac.ir (M. Mirtaheri), zandi@kntu.ac.ir (A.P. Zandi).

http://dx.doi.org/10.1016/j.jcsr.2015.05.019
0143-974X/

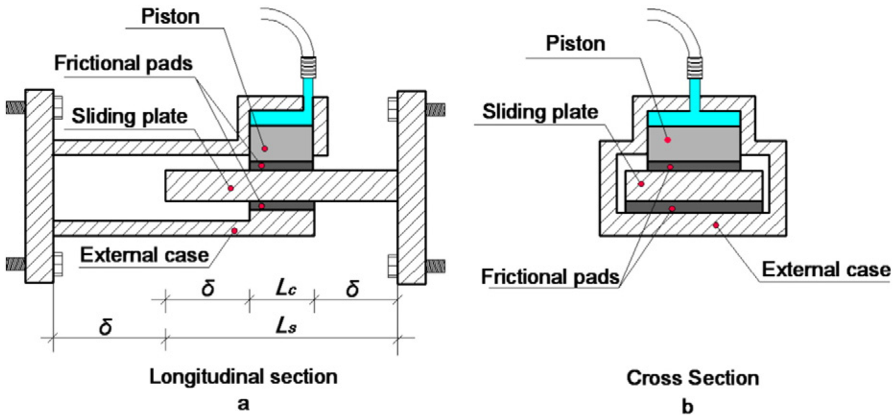

Fig. 1. Schematic view of AFD; a. longitudinal section; b. Cross section.

However, a frictional damper is not able to dissipate energy unless slippage force is exceeded. When the damper is not slipping, it has no advantage over a regular bracing member. So in high probable seismic events and if activating forces are overestimated in design the system cannot benefit from the added damping. The concept of semi-active control can be utilized to improve the efficiency of frictional dampers. A semi-active friction damper can adapt its slippage threshold during earthquake excitation according to structural responses in a smart fashion. Akbay and Aktan [14] were the pioneers in this field by introducing Active Slip Bracing Device (ASBD). The device allows the brace to axially elongate or contract through slippage when the brace loads reach the slippage force, which is controlled by a hydraulic actuator. Gaul and Nitsche [15] proposed semi-active joint connections in which piezoelectric stack disk is used as a washer to control in real time the normal force in the friction interface of joints based on feedback from sensor outputs. If a voltage is applied to the piezoelectric washer, the stack disk tends to expand, which results in increasing the normal force and slippage threshold. Chen et al. [16] introduced piezoelectric friction damper (PFD). The clamping force in such a damper is regulated by piezoelectric actuators. However, piezoelectric based frictional dampers are not applicable to building structures due to the fact that the force produced by a piezoelectric actuator is rather small in value. Moreover piezoelectric actuators are not cost effective. Agrawal and Yang [17] proposed an electromagnetic frictional damper. This device is based on the regulation of friction force across the damper using electromagnetic field. Similar to piezoelectric ones, activating force of electromagnetic based devices can also produce forces which are rather small in value.

In this investigation, the hysteretic behavior of a semi-active type of frictional damper called the Adjustable Frictional Damper (AFD) is studied experimentally and numerically. The clamping force of such damper is secured by hydraulic pressure. The advantage of AFD is the fact that it is capable of producing large forces. In terms of construction costs, this system is more cost effective.

First of all, the hysteretic behavior of AFD is studied experimentally with various hydraulic pressures causing different slippage forces at the rate of 0.1 Hz which is nearly considered static. The results show that the proposed damper has significant energy absorption by stable hysteretic loops, which can improve the performance of structures subjected to earthquake loads with various intensities. Force–displacement characteristics of AFD such as slippage load, dissipated energy, effective stiffness and equivalent viscous damping for consecutive cycles of loading are found by test and calculated by standard methods. Also, dynamic loading of the device is conducted at various frequencies to assess the effects of dynamic loading on the response of AFD for possibility of decay of slippage force. The hysteretic behavior of AFD is also studied by numerical method. The results of numerical model closely correlate with experimental results.

2 . Components and mechanism of adjustable frictional damper

The mechanism of AFD is similar to a car braking system. This damper consists of three main parts; external case, piston and sliding plate. As

Fig. 2. AFD prototype.

Fig. 3. Test setup.