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Innovative multi-level control with concentric pipes along brace to reduce seismic response of steel frames

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ABSTRACT

The Painful experiences of past earthquakes and their related financial and physical damages have shown poor seismic performance of some structures; thus using new tools and equipment are inevitable. Application of two-level control systems is one of the cases that recently attracted the attention of researchers. The main idea of these systems is to combine two separate control devices with different strength and stiffness resulting in dual seismic behaviors due to their different energy dissipation levels. In this study, at first a multi-level pipe in pipe passive control system is presented and its cyclic behavior is evaluated with nonlinear static and dynamic analyses using finite element method by ABAQUS software. Then, hysteresis curves are studied representing a highly ductile behavior for the proposed damper. In addition, obtained hysteresis curves show that the multi-level system as expected can reliably dissipate energy in different energy levels leading to ductility ratios about 15 to 37 and equivalent viscous damping ratios about 36 to 50%. Finally for the 5, 10 and 15-story steel frames with the proposed dampers, maximum displacements decreased up to 79%, 63% and 27%, respectively, compared to bare frames.

1. Introduction

The terrible experiences of past earthquakes and their casualty and financial loss have demonstrated poor seismic performance of some structures reminding the necessity of using new devices. Using metallic dampers is one of the effective and applicable methods to improve the seismic performance of structures. The main idea is to use fuses dissipating the significant amount of the input energy and preventing plasticity in other main members and buckling in the braces. This idea is widely considered to improve the seismic behavior of Concentrically Braced Frames, CBFs.

Balendra et al. in 1991 presented a new fuse element as knee braced frame [1]. High stiffness and suitable ductility are the advantages of this system. Fuse element is designed to yield and prevent buckling of the brace. Rezai et al. [2] in 1999 conducted laboratory studies on the behavior of CBFs with metallic fuses to have more energy dissipations. Moreover, Motamedi et al. in 2006 [3] proposed accordion pipe connection to effectively improve ductility and energy dissipation of CBFs. Oh et al. [4] in 2008 proposed new slit damper to improve the weaknesses of the beam to column connections. The results of their analysis show appropriate cyclic behavior on connections equipped with new dampers.

Kafi in 2009 conducted numerical and experimental research on the effects of hollow steel pipes to improve seismic behavior of CBFs [5] showing significant influence on the frames ductility and delay in brace buckling. In another study, Franco et al. in 2010 [6] suggested new yielding damper based on plastic properties of metals under torsional stresses. This damper consists of a pipe with various diameters and torsional movements. High fatigue strength and buckling prevention are its advantages. Steel pipes are widely used to improve seismic behavior of CBFs. Maleki and Bagheri in 2010 [7] studied the hollow steel pipes filled with concrete to explore the possibility of their using as hysteresis dampers under shear stresses. The results presented that the stiffness and strength of the pipe increased linearly with increasing the length and nonlinearly with increasing the thickness and reducing the diameter. Steel pipes filled with concrete show no ductile behavior caused by concrete failure while hollow steel pipes have stable hysteresis behavior and high equivalent viscous damping ratios.

Maleki and Mahjoobi in 2013 studied dual pipe system based on using pipe bending capacity [8]. The damper is made of two adjacent pipes, welded to the upper part of chevron or diagonal bracing or the beam to column connections under the lateral loading to increase energy dissipation. The results of the numerical nonlinear static analysis and laboratory tests on four samples indicated stable hysteresis curves with a significant increase in ductility and energy dissipation. Also, another sample of such dampers consisting of two nested pipes was proposed in 2014 [9]. The gap between the outer pipe and the inner one is full

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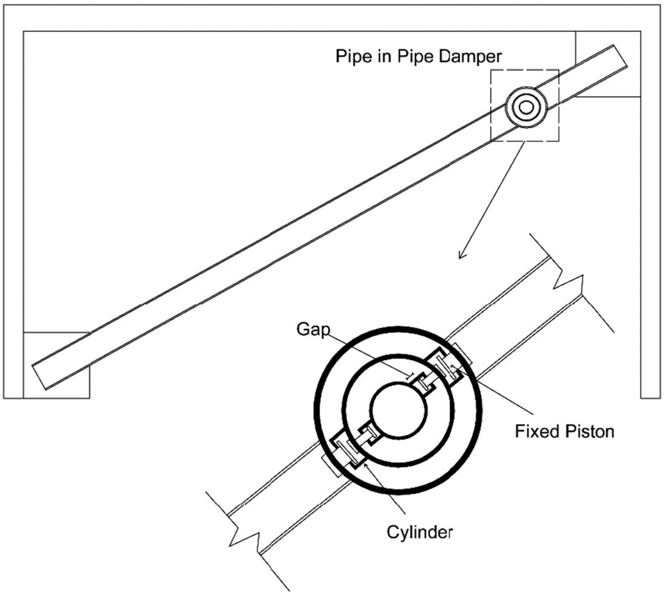

Fig. 1. The main idea of this research using pipe in pipe damper along the brace.

of metals such as lead and zinc. The damper energy dissipation mechanism is based on plastic deformations of the concentric pipes, metal core and internal friction between the internal and external pipes. The results of laboratory tests on six samples showed high damping ratios and stable hysteresis behaviors. The numerical modeling was also followed to determine the optimum size of the damper and design procedure.

Using two or multi-level control systems is one of the new methods that attracted the researchers in the recent years. The main idea of these systems is to combine different control systems with separate amounts of strength and stiffness resulting desirable energy dissipation in various earthquake intensity levels. Balendra et al. in 2001 proposed two-level passive control system consisting of a knee brace and a slotted connection [10]. In service loads and low forces, slit connection would create energy dissipation by friction damping, while in severe earthquakes, energy dissipation through plastic behavior of knee member is provided. Also, Zahrai and Vosooq in 2013 carried out research on dual system using a combination of vertical link beam and knee elements [11]. Plastic hinge on the vertical link within low forces, increases energy dissipation and plastic deformation of the knee increases the ductility and energy absorption during extreme forces to improve seismic performance. Another form of such innovative multi-level passive control systems is proposed and discussed in this paper. While some research projects might be found on pipe dampers, the multi-level pipe damper as a multi-level energy dissipation device has not been studied yet. It seems that the proposed damper despite its simplicity, applicability and relatively low cost, demonstrates good performance and is acceptable in reducing the seismic vibrations of braced steel frames.

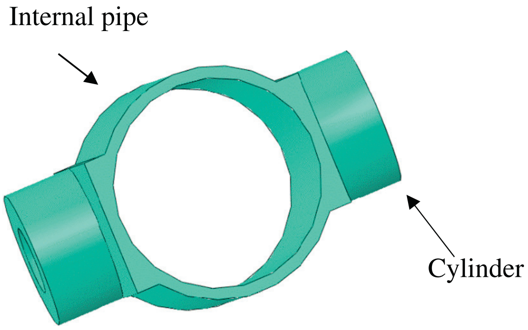

Fig. 3. Details of internal pipe.

2. Main idea of multi-level device

Regarding the fact that increasing the ductility and energy dissipation of structures in seismic areas is necessary, in this study a multi-level passive control system with ability to change dynamic behavior parameters like strength, stiffness and damping ratio for energy absorption at different earthquake levels has been discussed. The system consists of a combination of nested tubular components that absorb energy during moderate to severe earthquakes.

Under the slight seismic loads, in which the structure suffers a slight lateral relative displacement, the plastic hinge occurs in external pipe dissipating limited input seismic energy, while under a severe earthquake and due to larger vibrations, the plastic strains appear on both external and internal pipes noticeably increasing the level of energy dissipation. Concentration of damage on this fuse, results in damage reduction on the other main members. In addition, replacing the fuses after the severe earthquake will be easy and inexpensive. The main idea of the proposed damper is shown schematically in Fig. 1.

As shown in Fig. 1, the damper can consist of a number of nested concentric pipes connected together by some pistons. There is a gap between pipes determined based on the flexural stiffness of the outer pipe due to its length, diameter and thickness. By applying lateral force or displacement, deformation of external pipe results in plastic strain and energy dissipation. With an increase in earthquake excitations and thus further distortions of external pipe, the outer and inner pipes get connected together making an increase in strength and stiffness and

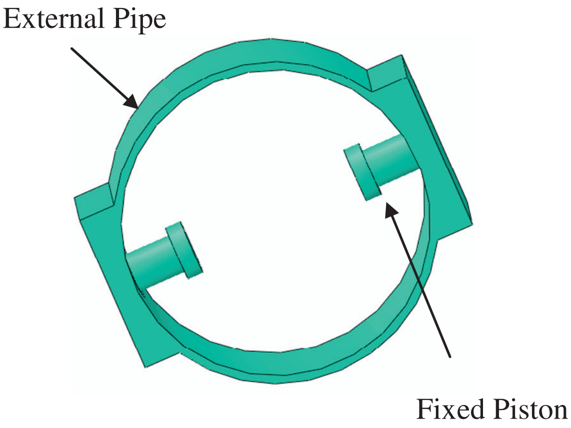

Fig. 2. Details of external pipe.

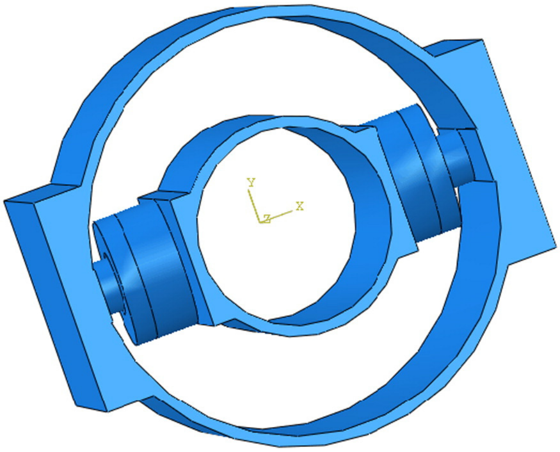

Fig. 4. Assembled proposed damper.