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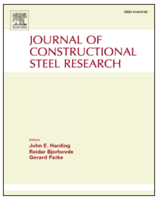

Experimental study of Pipe-Fuse Damper for passive energy dissipation in structures

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ABSTRACT

This study presents a novel passive metallic damper, Pipe-Fuse Damper (PFD), to improve the seismic response of structures with dissipation of the earthquake energy. The Fuse Damper (FD) was recently introduced by using steel bars as fuses, Bar-Fuse Damper (BFD), and its performance was evaluated experimentally. The Fuse Damper (FD) is built using common cross-sections found in engineering structures, such as square hollow sections (SHS) and U-shaped sections as well as metal sheets. As a special feature, the Fuse Damper (FD) uses replaceable components as an energy-absorber part with both flexural and tensile energy dissipating mechanisms. In this study, the Fuse Damper (FD) was evaluated with components of steel pipes experimentally and numerically. To assess the individual performance of this damper, the Pipe-Fuse Damper (PFD), a series of monotonic and cyclic experiments were conducted on real-scale specimens. The studied parameters for this replaceable element in the experiments were the number of pipes and their diameter, length, and thickness. The results indicate that, in addition to demonstrating a stable hysteretic behaviour and considerable energy dissipation within an appropriate displacement reversal, the proposed damper offers the easy replacement of pipe components after each failure. Moreover, the Pipe-Fuse Damper (PFD) showed less pinching effects on its hysteresis and a higher energy dissipation compared to the Bar-Fuse Damper (BFD) under the same conditions.

1. Introduction

Among passive control systems, metallic yield dampers are economical and do not require advanced production technologies, and they can also effectively improve seismic structural responses [1]. Moreover, these kind of dampers can be simply modelled mathematically and numerically, which is highly important in the development, design, and prediction of their behaviour. Energy dissipation in this type of damper occurs in the form of plastic deformation of the energy-absorber members through different flexural, shear, and torsional mechanisms. These dampers were first manufactured in Japan and New Zealand almost 50 years ago. In Japan, the slitted wall and the damping strips for the partition walls were employed by Muto and Guerrero in several structures to dissipate energy [2, 3]. Experimental research was conducted by Kelly and Skinner on energy absorption devices such as torsional beams, u-strips, and flexural beams in New Zealand [4, 5].

The Added Damping and Stiffness (ADAS) and the Steel Slitted Damper (SSD) are among the most popular metallic yield dampers, which have practical applications and are employed as passive control systems in a number of structures in developed countries [6, 7]. The ADAS is composed of a set of energy-absorber X-shaped or triangular steel sheets installed between the Chevron braces and its respective beam frame to dissipate the energy transferred to the structure through the flexural mechanism of the sheets. With a similar installation procedure to the ADAS, the SSD damper includes one or more slitted sheets that dissipate energy through in-plane plastic deformation and the flexural shear mechanism. These two dampers are specifically designed for Chevron braces and they cannot be installed in diagonal braces. A new damper, the Cast-Steel Yielding Brace (CSYB), performs similarly to the ADAS damper, with the exception of its constituting material which is made of cast steel, and it can be installed in diagonal braces [8]. In recent years, numerous and various innovations have been presented regarding metallic dampers by researchers, some of which are practically implemented in structures, while some of the others are still in the experimental stages [9, 10].

Since metallic dampers protect the main structural members against earthquakes by absorbing energy and directing possible destruction to their energy-absorber members, it can be claimed that they function like a fuse [11, 12]. However, this terminology mainly focuses on the protective characteristics of dampers and is less associated with the replaceable characteristic of fuses. Therefore, a new metallic damper, the Fuse Damper (FD), was designed to offer the capability of energy

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dissipation with flexural and tensile mechanisms through appropriate replaceable components (fuses), e.g. steel bars or pipes. The longitudinal energy absorber members in the FD can be produced from any material with any cross-sectional shape and geometrical dimensions if they can appropriately dissipate energy. The characteristics and behaviour of the proposed damper can be controlled through five factors related to its fuses: the material and shape of the components; and the number, length, and size of the components. The rigid body of the damper is designed such that the total applied displacement can be transferred to the fuses, which consequently causes their plastic deformation. The experimental and numerical study of the Fuse-Damper (FD) with steel Bars (BFD) was previously conducted and presented recently [13]. In the present study, simple steel pipes were used as the energy-absorber fuses in the FD.

In literature related to the structural control, almost the same framework of methodology can be found to evaluate newly proposed devices [14–20]. Following this common procedure, the current study evaluates characteristics of the Pipe-Fuse Damper (PFD) individually, while its effect on seismic structural behaviour will be examined in future works. The outline of this study is summarized as the following: the results of conducted experiments are presented to evaluate the hysteretic behaviour of the proposed damper. According to the results, two important properties of metallic dampers, namely the capacity of the dissipated energy, and the equivalent viscous damping ratio are calculated and presented. To verify the experimental results and also to conduct a parametric study, the PFD was modelled and nonlinearly analysed using general finite element software ANSYS. Based on the results of the parametric studies, the formulas for mechanical properties of the PFD were derived which can be useful for initial design of the damper. Moreover, the characteristics of FD with steel bar (BFD) and with steel pipe (PFD) are compared to assess the influence of different sacrificial elements to the proposed damper.

2. Pipe-Fuse Damper (PFD)

The proposed damper is a metallic yield damper that uses steel pipes as replaceable fuses to absorb energy. All the geometric details of the PFD are presented in Fig. 1. As shown in the figure, the PFD is composed of three main parts that includes an outer part, an inner part, and a fuse part. The inner and outer parts are two rigid parts of the PFD, which interconnect to each other by the flexible fuse part.

The outer part has three main components: one hollow square steel profile, two reinforced steel plates, and one end steel-plate. For passing of the steel pipes through the outer part, some suitable holes are embedded in two opposite sides of the hollow square profile. Two perforated reinforced plates are fully welded to the profile from the outside to prevent the profile's body from local buckling. The end steel-plate in the outer part is devised to connect the PFD to the brace that has the similar plate at its end through appropriate bolts.

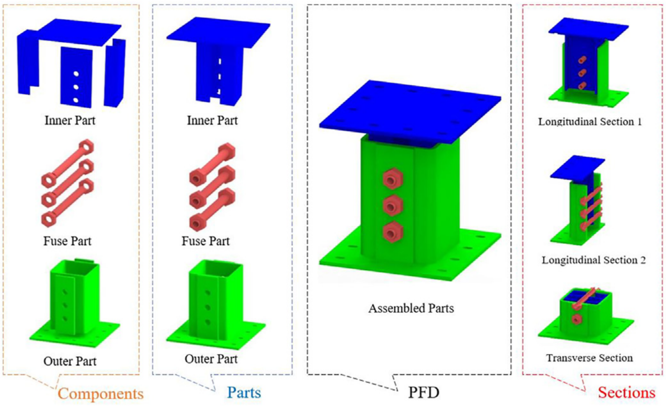

Fig. 1. Geometric illustration of Pipe-Fuse Damper (PFD).

The inner part of the PFD also has three main components: two channel profiles, one perforated steel plate, and one end steel-plate. As shown in Fig. 1, the perforated steel plate connects the two channels to each other symmetrically along with the end plate at one end of the three components. The holes in the perforated plate are there to pass the steel pipes and the end plate has the same function as the one in the outer part. All the components of the inner parts, like those for the outer part, are properly welded to each other to form a rigid part to ensure negligible deformation under the axial loading of the braces. It is needless to say that the holes for the passing of the pipes are drilled in a similar pattern for both the outer and inner parts.

The fuse part consists of threaded steel pipes that interconnect the outer and inner parts to each other conveniently. The easy replacement capability of the steel pipes (fuses) in the case of failure is the key feature of the proposed damper. The compressive and tensile axial forces in the braces induced by earthquakes, produce back and forth motions of the inner part inside the outer part. In result, these motions cause consecutive plastic bending deformations at the middle of the steel pipes in two opposite directions. In essence, a portion of input energy of an earthquake into a structure is dissipated by the flexural plastic deformation of the steel pipes to reduce the plastic deformation demands in primary structural elements.

The PFD can be installed on different types of conventional braces at favourite locations with fewer limitations in comparison with the other metallic dampers. For example, the PFDs are installed at the middle of the diagonal and Chevron braces in a frame, as shown in Fig. 2. Furthermore, the proposed damper can be utilized for seismic retrofitting purpose of steel/concrete structures in the form of an arrangement suggested by Lee, similar to the configuration scheme of the knee braces [10].

As noted earlier, some part of the seismic energy that exerted on the system can be dissipated through the deformation of the plastic pipes in the damper. Thus, the rest of members in the frame are protected through a reduction in the plastic deformation. The energy absorption mechanism in the PFD is largely dependent on the amount of motion. In other words, for small motions the mechanism is the flexural type, while for large motions the mechanism is the flexural-tensile type. This variation in the mechanisms can be considered as one of the strengths of the PFD because it increases the secondary strength and stiffness of the damper as will be observed from results in the next sections.

3. Experimental study

To study the behaviour of the proposed damper and to assess its mechanical properties, several component tests were conducted on four full-scale PFDs. The influence of four key parameters has been evaluated on the performance of the damper, namely the number, diameter,

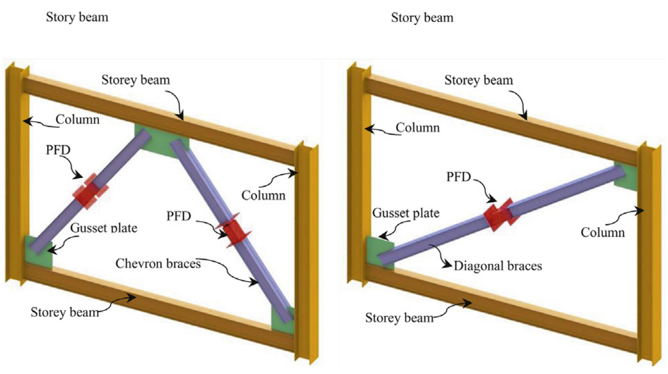

Fig. 2. Two proposed placements for Pipe-Fuse Damper (PFD).