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A passive metallic damper with replaceable steel bar components for earthquake protection of structures

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ABSTRACT

In this paper, a new passive earthquake damper termed as Bar-Fuse Damper (BFD) is presented for frame structures. The BFD is developed from common steel sections such as hot-rolled Square Hollow Sections (SHS), C-channels, plates and bars. It is economical, easy to install and build with no special fabrication technique. The key feature of the BFD is using round steel bars as energy absorber components that can be easily replaced in case of failure. The proposed device dissipates the energy with the replaceable bars as sacrificial elements through the flexural and tensile mechanism. The performance of several full-scale BFDs was evaluated with a series of monotonic and cyclic experiments, and the bars successfully performed their function as energy absorbers and fuses in all specimens. The effects of variations in the number, length and diameter of bars in the BFD along with the nuts arrangement were investigated in this experimental study. This study indicates that the recommended device has stable hysteretic behaviour under cyclic loads with two significant features: appropriate energy dissipation and replaceability of the fuses, which can be useful to protect the main elements of structures from plastic deformation and failure for several events. The results obtained for the BFD are promising for its use as a passive seismic damper in engineering structures in order to improve the seismic behaviour of structures as well as dissipating the earthquake energy.

1. Introduction

Generally speaking, structural control can be categorized as active, semi-active and passive control [1]. In active and semi-active control systems, the structural response varies based on the characteristics of the forces applied to the structure by an earthquake or wind. In other words, the structural response to the applied forces is adjusted by a control system to sustain the input loads. These control systems may consist of a power supply, sensors and hydraulic jacks [2]. On the other hand, the passive structural control is independent of the forces applied by an earthquake or wind and only depends on the type of equipment and material that were used in the damper. The main goal of the passive control systems is to reduce the contribution of the principal structural elements in dissipating the input energy by plastic deformation. Base isolators, metallic yielding dampers, friction dampers, viscous and viscoelastic dampers, tuned mass and liquid dampers are all classified as passive control systems [3,4].

In spite of their simplicity, metallic yielding dampers, as structural control systems, offer special features such as economic efficiency, while requiring neither advanced technology nor experts for fabrication and installation of the system. Another advantage of such dampers is the simplicity of their simulation through mathematical and finite element models, which is helpful in designing and predicting their behaviour. The energy dissipation in this type of damper is carried out by plastic deformation in different mechanisms such as bending, shear, torsion or a combination of them in the energy absorbers. Metallic dampers were first manufactured in Japan and New Zealand about 50 years ago. In Japan, Muto and Guerrero have implemented slitted wall and damping strips for partition walls respectively, in a number of buildings for earthquake energy dissipation [5,6]. In New Zealand, Kelly and Skinner have carried out experimental investigations on energy absorbers such as torsional beams, u-strips and flexural beams [7,8].

ADAS (Added Damping and Stiffness) and SSD (Steel Slitted Damper) are among the most familiar metallic yielding dampers that have been put into use in buildings in the US, Japan, Italy and Mexico [3,9]. ADAS consists of a series of X- or triangular-shaped steel sheets that dissipate the energy applied to the structure by bending [10]. The SSD damper is composed of one or more slitted sheets that dissipate energy through planar deformation and shear-bending mechanisms

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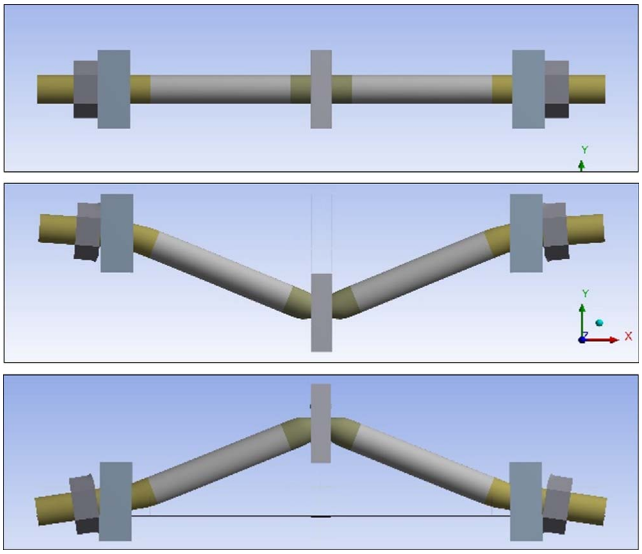

Fig. 1. Deformed and un-deformed states of a bar.

[11]. The two dampers named here are particular to Chevron braced frames and cannot be implemented on diagonal-braced frames. A new type of metallic damper, known as CSYB (Cast-Steel Yielding Brace), was introduced in Canada which is very similar to TADAS in performance [12]. Only different in that it is made of cast steel instead of steel and can be implemented in diagonal braced frames. Researchers have extensively studied new metallic dampers in recent years [13–16]. Some researchers, interestingly, gave the name fuse to metallic dampers, given that they are sacrificed in keeping the principal elements of the structure safe from damage [12,17,18]. Although, many of these dampers do not seem to be easy to replace after failure.

Generally, the two important characteristics attributed to fuses are that they are made of inexpensive materials and are easily replaced. Considering these features, a new metallic yielding damper, named Fuse Damper (FD), was designed so that the replaceable parts, or fuses, offer reasonable energy dissipation by bending, as shown in Fig. 1. The fuses used in this damper can be made of any material, and in any cross-section geometry, provided that they have adequate energy absorption characteristics. Six factors control the behaviour of this damper, namely: the material and shape of the parts, the number of the parts, the dimensions (length and width) of the parts, and the fixing method of the parts. The body and geometry of the damper are rigidly designed to transfer all the displacement of the device to the fuses, thus being plastically deformed. In the first stage, a round steel bar was used as the fuse or sacrificial element, and the setting was named Bar-Fuse Damper (BFD). Provided it fulfils the requirements of a metallic damper, significant advantages can be cited for this device, including: the low weight of the fuses, their low cost, ease of replacement, fabrication with no need for complex and expensive material and equipment, the possibility of the device being made on the construction site, no need for maintenance during operation, applicable to different frame configurations, and familiarity of operation engineers with the material used and its behaviour. It should be noted that, as an advantage, the suggested damper only acts under earthquake force and has no role in resisting the static loads of the structure.

The aim of this study is to evaluate the characteristics of the BFD individually. The outline of this study can be summarized as follows: after initially designing the BFD, the effect of the rebar nuts configuration on the behaviour of the dampers was evaluated through a number of experiments and the most efficient configuration was

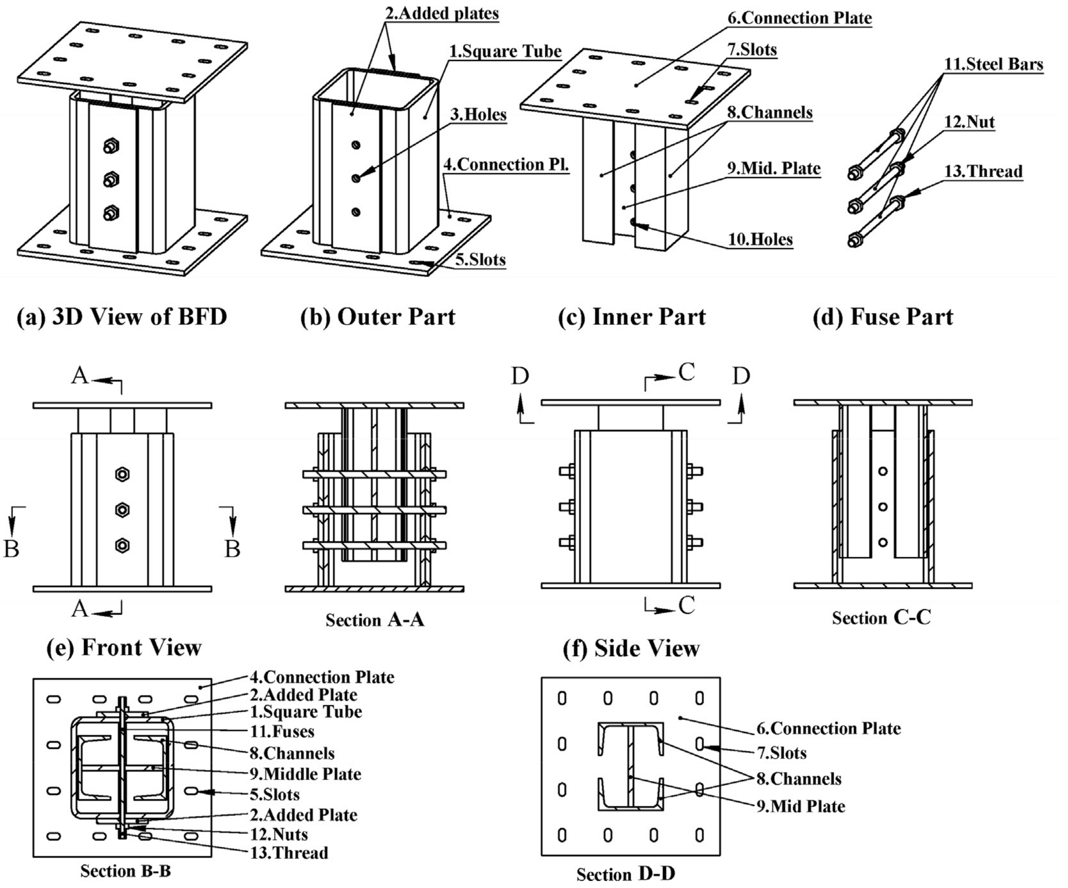

Fig. 2. Geometric illustration of the Bar-Fuse Damper (BFD).