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Study on mechanical characteristics of accordion metallic damper

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ABSTRACT

This paper presents Accordion Metallic Damper (AMD) as a unique energy dissipating system that originated from the concept of thin-walled tubes used in machinery as the shock absorber. The AMD can perform as a repairable hysteretic fuse in structural frames to enhance the lateral ductility, energy-dissipation and damping potential of the frame systems during earthquakes. The AMD consists of the corrugated thin-walled tubes installed at the brace connection to the frame. The lateral displacement of the braced frame causes yielding of the AMD in axial deformation mechanism and dissipates energy due to forming of plastic hinges along the corrugated tubes in reversed cyclic deformations. In order to evaluate the performance of the AMD for upgrading the seismic behavior of the structures a series of quasi-static cyclic tests were conducted on pre-fabricated corrugated thin-walled tubes and hysteretic load-deformation response, lateral strength, initial stiffness, and dissipated energy was investigated. Numerical studies were also carried out to provide a large parameter results to explore the effect of geometry parameters such as shape, thickness, diameter and length of the corrugated tube on the mechanical properties. The analytical model was created based on finite elements method and non-linear inelastic analysis with considering large deformation capacity was employed for these studies. The results showed that the AMD exhibited enhanced energy-dissipation and damping potential with stable hysteresis loops and confirmed that the AMD is an excellent energy-dissipating device that can be used for upgrading the seismic behavior of framed structures.

1. Introduction

Traditional methods for seismic resilient structures are gradually losing their significance by developing the modern control systems such as energy dissipating systems [1]. Energy dissipating systems such as metallic dampers have been developed during the past four decades for controlling the structural vibrations due to earthquake. Tensional and bending beam and U shape bands were among the first dampers. Balendra conducted several works in this area from 1990 to 1997 [27]. X-shaped and V-shaped bending plates, known as ADAS and TADAS dampers are other types of dampers which take advantage of uniform yielding of steel and have been developed and are used in industry [2,3]. Using this system decreases the seismic vulnerability of the buildings significantly and provides enhanced performance and balance of energy absorption in the structural elements [4,5]. Also, there are many studies performed regarding the use of energy dissipating systems for retrofitting the reinforced concrete frames. Sahoo and Rai used aluminum shear links for seismic strengthening of non-ductile reinforced concrete frames [6]. The ring elements are the new flexural fuses which can be installed in CCBF's. Abbasnia, Vetr and Kafi conducted a testing program on ductile steel ring elements attached to braces [7]. Maleki, Bagheri and Mahjoubi studied pipe damper and dual-pipe systems in the frame connection and showed the potential of the system in energy dissipation during an earthquake [8,9]. Tagawa and Gao proposed a new vibration control system with U-shaped steel damper and evaluated the stiffness and strength of the system [10]. Motamedi and Ventura tested steel ring connections at mid-joint of X-brace steel frames and showed an enhanced energy-dissipation and damping potential for this system [11]. Furthermore, metallic dampers were suggested for timber structures with new mechanism such as rocking. Wrzesniak et al. investigated applicability of High-Force-to-Volume damping devices in rocking timber structures [12]. On one hand, there are so many experimental and analytical studies on using and application of metallic dampers for seismic retrofitting of structures [13]. On the other hand, certain studies performed on the energy-dissipation of thin-walled tubes due to impact loads. Many researchers have studied the plastic deformation mechanisms in axially compressed metal tubes used as impact energy absorbers [14–16]. Also square metal tubes were investigated under axial impact [17] while some studies were focused on the maximization of crushing energy absorption of cylindrical shells [18]. Moreover, study of behavior of axially crushed corrugated tubes under impact load was conducted [19]. Chen and Ozaki also performed numerical studies on axially crushed cylindrical tubes

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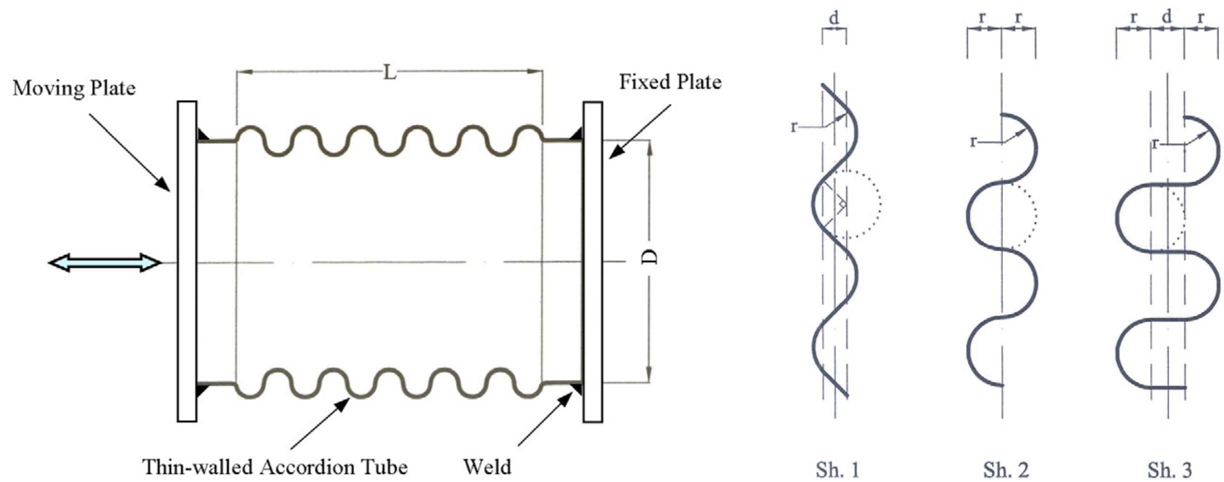

Fig. 1. Schematic view of Accordion Metallic Damper (AMD) device and the geometry parameters.

with corrugated surface [20]. Thin walled tubes under axial compression are considered as one of the best methods for absorbing the energy because of the large deformation capacity and long crippling length. However, these systems can deform and absorb energy only in impact condition.

In this paper, the performance of thin-walled accordion tubes has been studied under axial cyclic loading. The objective of this study was to explore the capability of this system as an energy dissipating system for upgrading the seismic behavior of frame structures. Therefore, a series of tests was planned and conducted to investigate the mechanical properties of Accordion Metallic Dampers (AMD) such as initial stiffness, ultimate load capacity and hysteretic energy-dissipation potential. Also, an analytical study was performed using a finite element model. The numerical models were verified with the experiments and employed in order to study the effect of geometry parameters on performance of the AMD.

2. Accordion metallic damper concept

Using thin-walled accordion tubes as an energy dissipating system has been currently suggested by Motamedi and Nateghi-A. [21]. They showed that thin-walled accordion tubes are suitable for using as hysteretic metallic damper if a proper inelastic deformation of corrugates occur along the tube during an earthquake. Schematic view of Accordion Metallic Damper (AMD) device and its geometry parameters is shown in Fig. 1. As it is shown, AMD is fabricated of a thin-walled accordion tube welded to a couple of plates at the ends. Energy dissipation in AMD device is based on plastic deformation of steel material mainly in flexural form. Relative displacement of the end plates generates axial deformation in the tube and flexural plastic hinges form in the corrugates. Formation of plastic hinges in several corrugates due to reversed cyclic loading dissipates energy. This behavior enhances the performance of the AMD in structures subjected to severe earthquakes. The accordion tube can be manufactured in different shapes; S-shape, C-shape and U-shape, (Sh. 1, Sh. 2 & Sh. 3, respectively shown in Fig. 1). Hence, L, D, t, r and N represent length of tube, diameter of tube, wall thickness, radius of wrinkles plate and number of corrugates along the tube, respectively. Obviously, the behavior and performance of the AMD and its mechanical properties severely depend on the shape of the tube. Therefore, an extensive parameter study is required to determine the optimal geometry parameters for the AMD to obtain the maximum energy-dissipation. The thin-walled tube should be fabricated from mild steel material with a minimum of 30% elongation in tensile coupon test to guarantee ductile behavior.

An applicable installation scheme of the AMD within a steel frame structure is illustrated in Fig. 2. The AMD is assembled either on top of an inverted-V brace and connected to the beam by two stiffened supports. When frame is subjected to lateral movement, lateral load on the frame is allowed to transfer to the braces and sever axial deformation concentrated in the AMD. In the shown position in Fig. 2 one accordion tube deforms in tension while the other one deforms in compression. This type called as "coupled AMD" in this paper.

3. Experimental studies

An experimental study was performed in order to investigate the behavior of thin-walled accordion tubes [26]. The objectives of this testing program were to study the behavior and performance of the AMD under cyclic large deformation, determine the mechanical properties of the AMD and collect valid data in order to validate the numerical models.

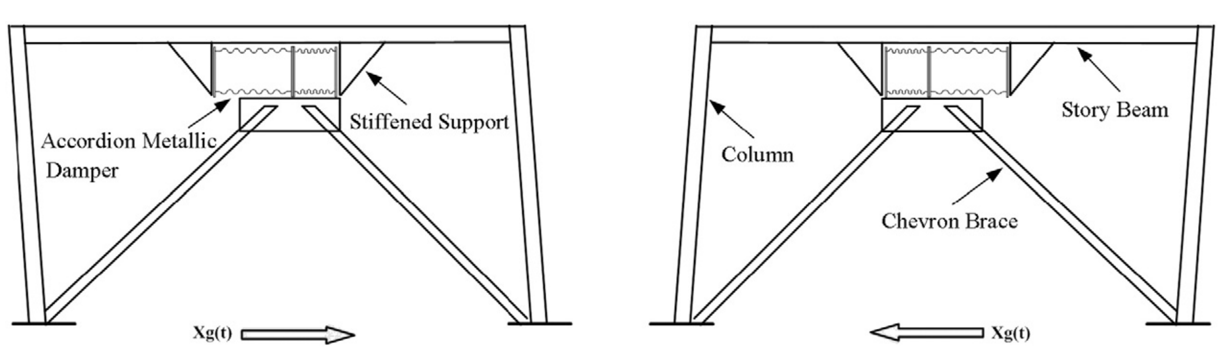

Fig. 2. Installation scheme for AMD and the deformation mechanism.