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Experimental and theoretical study of a lead extrusion and friction composite damper

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ABSTRACT

A new lead extrusion and friction composite damper (LEFCD) is proposed for multi-level seismic protection. Compared with conventional metallic dampers, LEFCD is an assembly of components which are changeable and can provide specific performances. For small and moderate earthquakes, the LEFCD uses only the lead extrusion dampers. For strong earthquakes, the LEFCD uses both the lead extrusion and friction dampers simultaneously to dissipate the seismic energy. To investigate the performance of LEFCD, theoretical analyses and experimental cyclic loading tests of LEFCD were carried out. Also, finite element models of the LEFCD were established and were compared with the testing results. The theoretical analysis results indicated that the LEFCD can provide different mechanical behaviors for different LEFCD setups. Results of testing and numerical analysis showed that the LEFCD had good energy dissipation capacity and that the finite element modeling was accurate compared to the test results.

1. Introduction

Structural passive control systems have been intensely researched since the 1970s. For practical applications, passive systems are advantageous compared to the active systems since they have lower costs and lesser maintenance requirements. One such passive control method is setting supplemental damping devices on a structure. These damping devices reduce the seismic related damage of the structure by absorbing seismic energy and reducing the energy dissipation required by the structure itself. Supplemental damping devices are commonly installed between floors or on the top of a building. Common supplemental damping devices are metallic yield dampers, friction dampers, viscous dampers, viscoelastic dampers, shape memory alloy (SMA) dampers, tuned mass dampers and tuned liquid dampers, etc. Each type of damper has advantages and disadvantages. However, passive dampers typically cannot adjust their performance according to the level of external excitation being experienced. Consequently, a number of passive dampers that are composed of different energy dissipation mechanisms or different materials have been developed recently.

Banisheikholeslami et al. [1] investigated a beam-to-column connection with visco-elastic and hysteretic dampers for seismic damage control. Marshall et al. [2,3] developed a hybrid passive control device (HPCD) consisting of a high-damping rubber (HDR) damper in series with a buckling-restrained brace (BRB) to provide an innovative two-phase system for improving structural response to earthquakes. Then, a nine-story, five-bay steel moment-frame was used for the analysis, and six different seismic resisting systems were analyzed and compared [4]. A new passive earthquake damper called a bar-fuse damper (BFD) for frame structures was proposed by Aghlara et al. [5]. This bar-fuse damper has good energy dissipation, and the fuses are replaceable; thus, it can be useful to protect the main elements of structures from plastic deformation and failure for several events. Silwal et al. [6,7] developed a superelastic viscous damper (SVD) that strategically combined a viscoelastic device and shape memory alloy cables in parallel, investigated its performance in improving the response of steel frame structures subjected to multi-level seismic hazards. A multi-action hybrid damper (MHD) to have independent hysteretic characteristics for small and large loading conditions was designed by Roh et al. [8], and they studied its control performance for building structures excited by wind or earthquake loads. Zhang et al. [9] proposed a combined magnetorheological (CMR) damper consisting of a lead extrusion (LE) damper connected in series with a magnetorheological (MR) damper. They then investigated the nonlinear hysteretic behavior, magnetic saturation property, energy dissipation capability, and fatigue property of the CMR damper. Lee et al. [10] proposed a new hybrid damper which combines a friction damper and steel strip damper for improving the seismic performance of structures at multiple levels of ground motion. A hybrid energy dissipation device by combining a steel slit

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plate and friction pads was developed by Kim et al. [11] to be used for seismic retrofit of structures. They studied its effectiveness by comparing the life cycle costs of the structure before and after the retrofit. Lee et al. [12] developed a new hybrid energy dissipation device by combining a steel slit damper and rotational friction dampers in parallel to be used for seismic retrofit of structures. Kang et al. [13] investigated the seismic energy dissipation capacity of a hybrid passive damper. A new visco-plastic damper (VPD) was developed by Ibrahim et al. [14] for seismic protection of structures. The VPD device consisted of a block of a high-damping viscoelastic material sandwiched between two steel shapes bent in a certain configuration to amplify the deformations in the device to obtain large tensile and compressive strains in the viscoelastic material. Ozbulut et al. [15] proposed a re-centering variable friction device (RVFD) which has two sub-components for control of civil structures subjected to near-field earthquakes. The two sub-components are SMA wires and variable friction damper (VFD). Then, Ozbulut et al. [16] investigated the seismic response control of a 20-story nonlinear benchmark building with RVFD. Yamamoto et al. [17] proposed a damper system that used a serial connection of a metallic yielding component and viscoelastic damper with a displacement limit mechanism. A hybrid seismic device that provided both energy-absorbing and re-centering capabilities was developed and evaluated by Yang et al. [18]. The hybrid device was composed of three components: a set of re-centering shape memory alloy wires, two energy-absorbing struts, and two high-strength steel tubes to guide the movement of the hybrid device. Miller et al. [19] presented a self-centering buckling-restrained brace (SCBRB) which consisted of a typical BRB component to provide energy dissipation, and pre-tensioned superelastic nickel-titanium (NiTi) SMA rods to provide self-centering and additional energy dissipation. Vargas et al. [20] investigated the seismic performance of single degree of freedom systems with metallic and viscous dampers installed in parallel to determine the effectiveness of using metallic dampers to reduce lateral displacements simultaneously with viscous dampers to minimize acceleration demands. Visco-elastic dampers and hydraulic actuators were used as the passive and active controllers, respectively, in a hybrid actuator–damper–bracing control (HDABC) investigated by Zhang et al. [21]. Hu et al. [22] evaluated the inelastic behavior of a superelastic SMA slit damper system by refined finite element analysis.

This study put forward a composite damper to control multi-level external excitation innovatively. The composite damper in this study is a lead extrusion damper and a friction damper composite damper (LEFCD). The position where the friction damper starts working is controllable. One of the typical uses of a composite damper such as the one in this study is that for a small earthquake or strong winds, only the lead extrusion damper is activated to dissipate energy, while for a strong earthquake, both the lead extrusion damper and friction damper work simultaneously for vibration control. The details of the composite damper are introduced first. Then, the theoretical derivation is performed to acquire the mechanical models of the composite damper. Next, results from the cyclic loading tests of the composite damper are presented to investigate its performance. The numerical analyses of the composite damper and its comparison with testing results follow.

2. Proposed LEFCD

As shown in Fig. 1, the proposed LEFCD is a rectangular box assembled from several pieces of steel plate and other components. The other key components inside the box included an active plate, lead extrusion damper protrusion (for instance, a trapezoidal or circular arc), lead, tapered friction block, friction plate, push plate, spring, and adjustable bolt. Corresponding positions on the top and the bottom plates were provided with a U-shaped groove. The left- and the right-side plates had a U-shaped hole. The upper and the lower ends of the active plate were U-shaped so that they could fit into the U-shaped groove of the top and the bottom plates. In combination with the U-shaped holes of the left and right plates, the movement of the active plate in the damper was allowed. The space of the box was divided into two parts by the active plate. The front part was a friction damper, while the back part was a lead extrusion damper. There were bolt holes on the front and back sides of the active plate to fix lead extrusion damper protrusions (LED protrusions) and a tapered friction block on both sides. Components inside the friction damper cavity included the tapered friction block, friction plate, push plate, spring, and adjustable bolts. The contact surface of the tapered friction block and the friction plate were two pairs of parallel inclined surfaces. The structure made the force of the friction damper symmetrical when it was loaded and unloaded. The surfaces of the tapered friction block and the friction

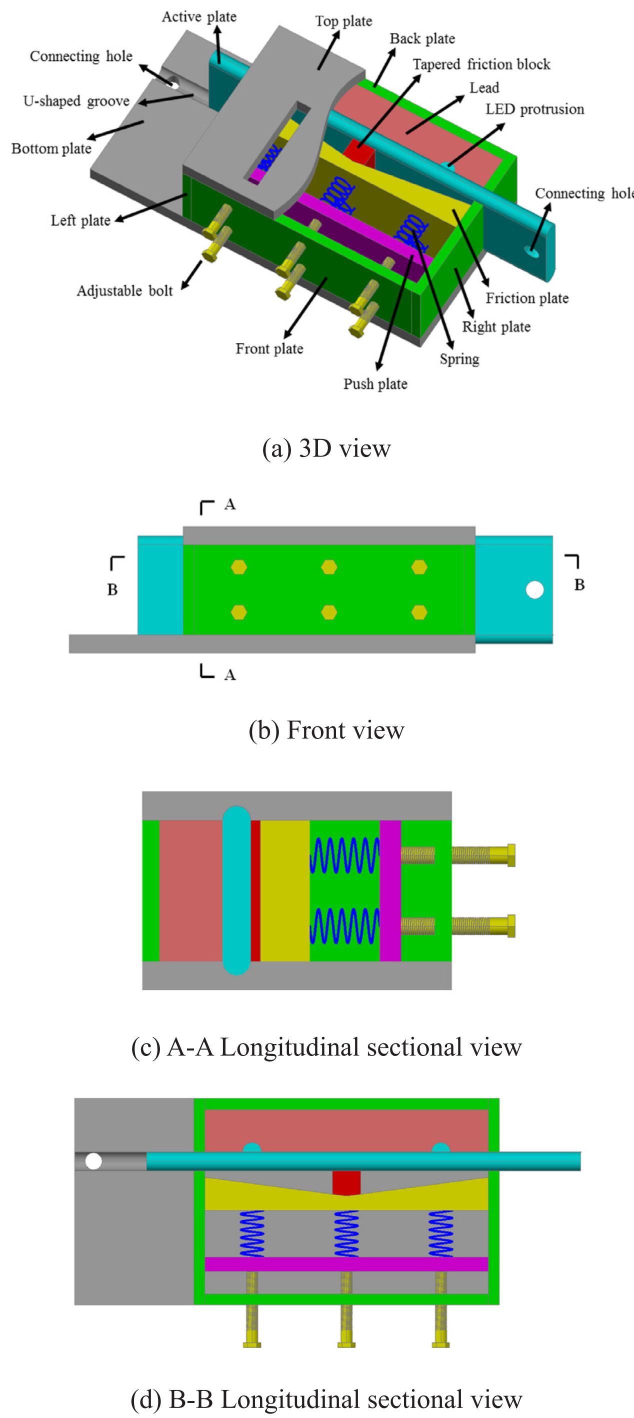

Fig. 1. Composition of LEFCD.