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Experimental study on continuous energy-dissipative steel columns under cyclic loading

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ABSTRACT

This paper proposes a continuous energy-dissipative column (CEDC) system to improve the seismic resilience of framed structures. The CEDC system consists of two steel boundary columns connected by a series of replaceable steel strip dissipators (RSSD). The dual columns are continuous along the height of buildings and are connected by a rigid link at each storey level. The CEDC system is designed as a dual-function structural component under earthquake where inelastic deformation concentrates in the RSSDs, while the boundary columns remain elastic and sustain the gravity loads. Three full-scale cyclic loading tests are carried out to investigate the seismic behavior of CEDC systems and replaceability of RSSDs. The specimens differ in the distance between the dual columns, thickness and number of RSSDs, and loading schemes. The experimental results show that the proposed CEDC system has good load-bearing capacity and energy dissipation capacity. The equivalent damping ratios of all the specimens reach 0.4 for a storey drift ratio of 1/30. It was found that the boundary columns are in elastic when the steel strips first yield. The failure of CEDC systems is due to the ductile rupture of RSSDs rather than lateral or lateral-torsion buckling in them. Finite element models of CEDC systems are established and validated against experimental results. Parametric studies are carried out to investigate the effect of axial loads in the boundary columns on the seismic behavior of CEDC systems. The numerical results show that the ultimate capacity and post-yield stiffness of CEDC systems reduces as the axial load ratio increases due to the second order effect of gravity load. A simplified method to determine the design axial load ratio of CEDC under gravity loads is proposed and validated.

1. Introduction

The resilience of structural systems is a critical issue in performance-based seismic design [1]. One of the effective approaches to achieve a rapid recovery of buildings after earthquake is to install replaceable energy dissipating devices (e.g. replaceable coupling beams [2]). Ensuring desirable global failure mechanism [3] of structures under severe earthquakes is also an essential performance objective of structural seismic design. However, a large number of conventional moment-resisting frames have suffered from the undesirable weak-story failure (concentration of damage in stories with weak strength) in major earthquakes, such as the Mexico City earthquake in 1985 and the Wenchuan earthquakes in 2008 [4,5]. Use of pinned structural walls or spreader columns [6], as an effective solution to avoid weak-story failure of framed structures has been proven by comprehensive numerical analysis and retrofit engineering applications [7,8]. However, the conventional rocking walls or spreader columns have small lateral resisting stiffness and energy dissipation capacity, which limits their application in new constructions.

As an alternative, a concept of column energy dissipation has been introduced in the last decade [9–11]. Dusicka and Iwai [9] proposed a Linked Column concept, as shown in Fig. 1(a). The columns were vertically continuous and dissipated seismic energy by the yielding of interconnected shear links. A similar approach was proposed in a European Research Program “FUSEIS1” [12–14], as shown in Fig. 1(b). The interconnected pins and beams with RBS connections at both ends were used as energy-dissipation elements. Recently, a Dissipative Column approach was proposed as a new hysteretic damper [15] as shown in Fig. 1(c). Seismic energies were dissipated through the deformation of X-shape steel plates. For the Dissipative Column system, the related study is still limited in numerical simulation, the feasibility of construction and replacement has not been validated.

In this paper, a continuous energy-dissipative column (CEDC) system was proposed, as shown in Fig. 2. The bending moment in the distributed steel strips under lateral loads can be evenly applied to the boundary columns, thus greatly reducing the stiffness demand on the boundary columns compared with the approaches in the literatures [9,12,13]. To study the cyclic behavior of the proposed CEDC system, three full-scale CEDC specimens were designed and tested under cyclic

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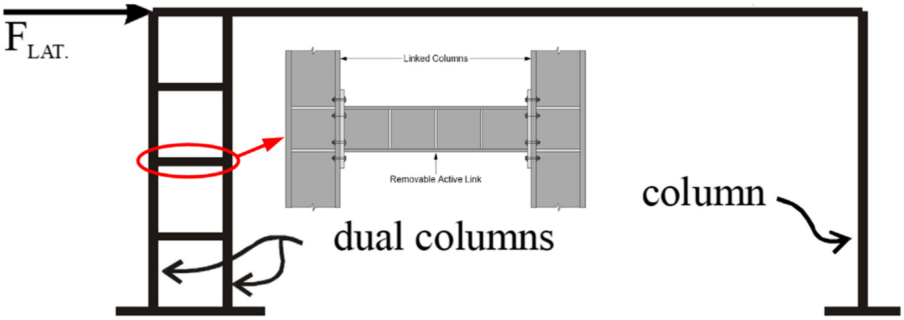
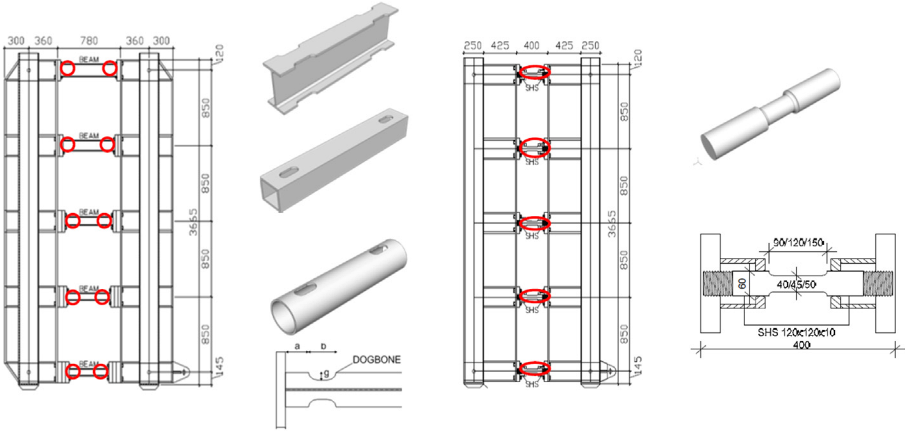
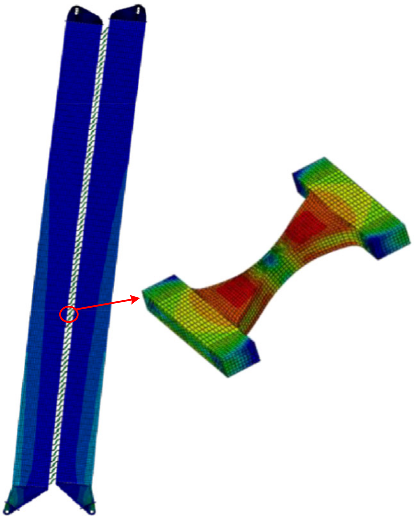


(a) Linked Column Frame System [9]



(b) FUSEIS1 System [12-13]



(c) Dissipative Column [14]

Fig. 1. Schematic of different column energy dissipation systems.

loads. The specimens varied in the distance between the dual columns, shape and number of steel strips and loading schemes. The failure modes and hysteretic behavior of CEDC systems were investigated. Finite element models were established to study the influence of axial loads in columns on the seismic behavior of CEDC systems.

2. Description of CEDC systems

2.1. Design of seismic performance of CEDC systems

The proposed CEDC system consists of two steel columns connected by replaceable steel strip dissipators (RSSD) as illustrated in Fig. 2(c). The interconnected RSSDs are in a dumbbell shape and act as energy-dissipation elements. The dual columns are pinned supported at the base and are pinned connected by a rigid link at the level of each storey. The rigid link is used to transfer the lateral force at the ends of beams which is to reduce axial forces in RSSD and ensure deflection compatibility of the dual columns. The CEDC system is thus designed as a dual-functional structural component to resist gravity loads and dissipate seismic energy.

The seismic performance of CEDC frames depends on the yielding sequence of structural components as illustrated in Fig. 3 (V is the base shear and Δ is the roof displacement). The V-Δ curve can be divided into three stages: elastic, rapid return to occupancy and collapse