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Mitigating seismic response of RC moment resisting frames using steel energy-dissipative columns

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ABSTRACT

A novel system of steel Energy-Dissipative Columns (EDCs) is proposed to mitigate seismic responses of reinforced concrete Moment Resisting Frames (MRFs). The EDC-MF dual system aims to not only dissipate seismic energy by replaceable steel strip dampers in EDCs but mitigate inter-story drift concentration to avoid soft/weak-story failure of conventional MRFs. A simplified numerical model of EDC-MF dual system is established by using lumped mass shear model for MRFs and finite element model for EDCs. Parametric studies are conducted to investigate the effect of storey number, stiffness ratio, soft story factor and seismic intensity factor on the mitigation efficiency of EDCs. The results show that the lateral stiffness ratio of EDC to MRF, the story irregularity factor of MRFs, and the ratio of story shear capacity of EDC-MF systems to seismic base shear are the most important parameters. It is found that both the maximum inter-story drift and the inter-story drift concentration can be effectively mitigated due to the presence of EDCs, compared to traditional MRFs. The mitigation efficiency of EDCs increases with increasing lateral stiffness ratio and story irregularity factor under various ground motion intensities. A rational range of lateral stiffness ratios of 0.02–0.2 is recommended for the seismic design of EDC-MF dual systems.

1. Introduction

Steel or reinforced concrete (RC) Moment Resisting Frames (MRFs), consisting of rigid beam-to-column connections, have become the most common and important lateral-load resisting systems for low-rise buildings in earthquake regions. However, the conventional RC MRFs have suffered from severe damage such as weak story failure during major earthquake events [1,2], as shown in Fig. 1. Steel MRFs may also be subject to soft-story collapse under overdesign seismic actions as reported in a recent E-Defense shaking table test [3], although they are always designed with better seismic resisting ability due to ductile detailing and strong column-weak beam criterion in current seismic design provisions [4–6].

The formation of weak or soft stories are due to various reasons such as vertical discontinuities of structural members at a particular story, different inter-story height at a particular story from other stories and lack of infill at one story [7]. Therefore, measures are needed to improve the seismic behavior of MRFs in addition to the strong column-weak beam criterion. Adding vertical continuous structural components to the building systems, such as pinned structural walls [8] or spreader columns [9], as an effective solution to avoid weak-story failure of framed structures has been proven by comprehensive numerical analysis and retrofit engineering applications [8,10–15]. However, the conventional rocking walls or spreader columns have negligible lateral resisting stiffness and energy dissipation capacity, which limits their application in new constructions.

As an alternative, the column dissipative mechanism has been introduced in the last decade [16–19], as shown in Fig. 2. Dusicka and Iwai [16] proposed a Linked Column concept, as shown in Fig. 2(a). The columns were vertically continuous and dissipate seismic energy by the yielding of interconnected shear links. Malakoutian et al. [17] evaluated the seismic response of the linked column frame (LCF) system. Results shown that the LCF system can provide both collapse prevention and limiting economic loss by reducing structural damage. Later on, Dimakogianni et al. [18] developed the "FUSEIS1" device and introduced the design procedures for steel and composite buildings. A novel system of Energy-Dissipative Column (EDC) has been proposed by the authors [20], as shown in Fig. 3. The EDC system consists of two steel boundary columns connected by distributed replaceable steel strip dampers along the structural height.

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Fig. 1. Weak story failure of RC MRFs in Wenchuan earthquake in China.

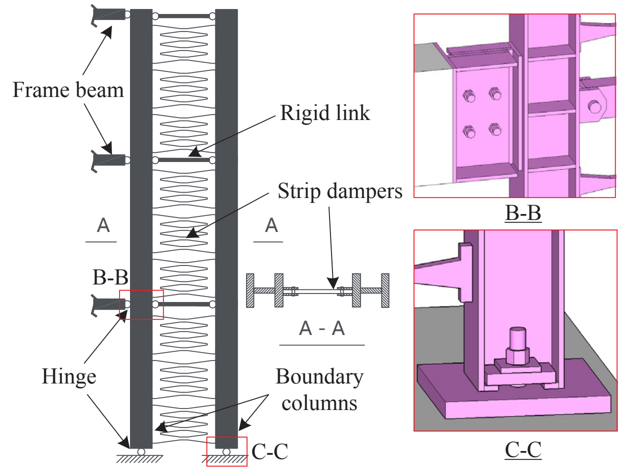
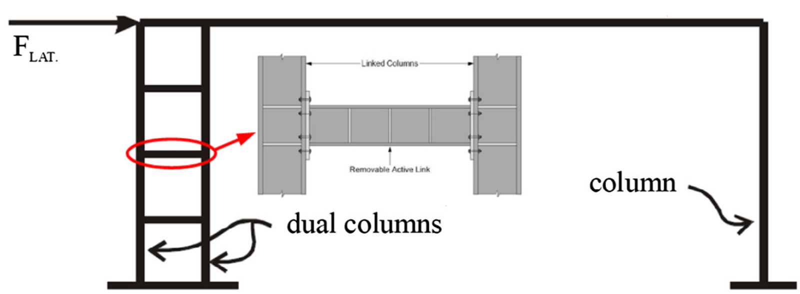


Fig. 3. Schematic of Energy Dissipative Column (EDC) system.

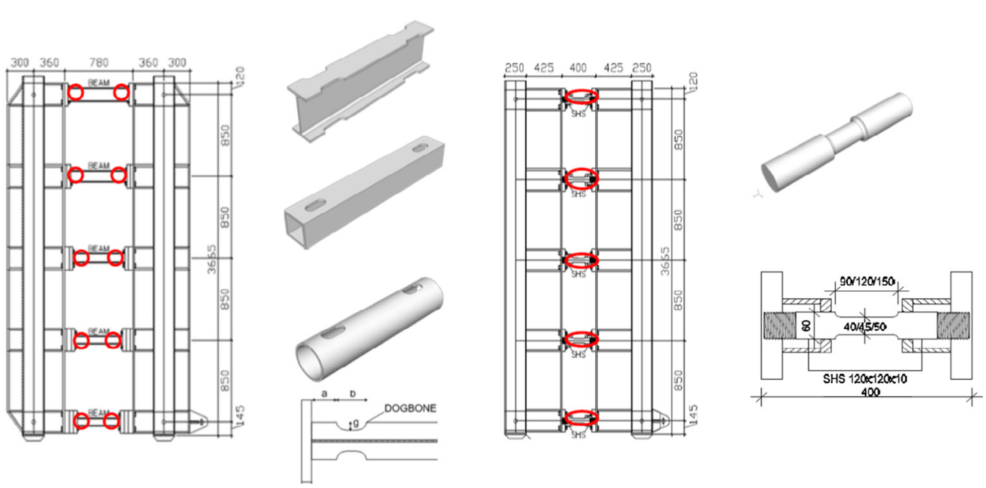
The EDC system works in a similar way to a pin-supported coupled shear wall [21] under lateral loads, in which the bending moment in the distributed steel strips can be evenly transferred to the boundary columns. Thus greatly reducing the stiffness demand on the boundary columns compared with the approaches in the literatures [16,18,22]. Full scale experimental study results indicated that the EDC system has stable load bearing capacity and energy dissipation capacity [20], as shown in Fig. 4.

In the EDC-MF system, the framing beams are simply connected to the boundary columns of EDC where the moment transfer is negligible, as illustrated in Fig. 3. Benefiting from advantages of energy dissipation and vertical continuity of EDC, the EDC-MF dual system tends to form a global plasticity failure mode rather than the local plasticity failure mode of MRF, as shown in Fig. 5. Coupling between EDC and MRF can provide superior performance by preventing damage concentration and reducing residual deformation compared with conventional MRFs [23]. However, the previous study only focused on the experimental validation and capacity based design of such systems [18,22,24], the effect of other parameters (e.g. stiffness) of dual column systems on mitigating maximum and inhomogeneity of inter-story drifts of this EDC-MF system is still unclear.

In this paper, a simplified nonlinear numerical model was established to investigate the seismic response of coupled steel EDC and RC MRFs, i.e. EDC-MF dual systems. A comparison to conventional RC



(a) Linked Column Frame System [13]



(b) FUSEIS1 System [14,15]

Fig. 2. Schematic of different column energy dissipative systems.