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Concrete filled steel plate composite coupling beams: Experimental study

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ABSTRACT

This paper presents an experimental study on the concrete filled steel plate composite coupling beams to evaluate and improve their seismic behavior. Six coupling beam specimens with varying span-to-height ratio, steel plate thickness and bending-to-shear capacity ratio were subjected to reversed cyclic loading. The progression of limit states began with the fracture of the steel plates at the beam corners which gradually propagated to the middle of the steel webs and steel flanges. There was limited increase in the shear capacity of the coupling beams after fracture initiated. Two local buckling phenomena including compression local buckling at the beam ends and shearing buckling of the steel webs were observed. No compression failure phenomena were observed in the infill concrete, and the concrete crack patterns were consistent with the deformation of steel plates. The deformation capacity of specimens without butt welds in the connection between the coupling beam web and the shear wall was shown to be larger than that of the specimens with butt welds at that location. Stable and full hysteretic behavior was developed by the coupling beams, indicating stable energy dissipation capability.

1. Introduction

Coupled shear wall systems that consist of two or more shear walls connected by coupling beams are common in many countries for medium to high-rise structures. The coupling is advantageous for several reasons including reduction in moments at the base of each wall pier, distributed energy dissipation along the height of the building, and increased lateral stiffness compared to individual wall piers. The frame-core tube hybrid structural system has been widely used in high-rise buildings in China. However, as the building height increases, the internal forces at the base of the wall piers increase significantly. Quite a few new high-rise buildings in China have adopted steel plate-concrete composite shear walls, referred to as composite plate shear walls (C-PSWs) in the U.S. [1], in the core tube to improve economy. The composite shear walls used in the practice can be categorized into two types: steel plate reinforced concrete composite wall, as shown in Fig. 1 (a), and concrete filled steel plate composite wall, as shown in Fig. 1 (b).

The steel plate reinforced concrete composite wall has been implemented in high rise buildings in China, such as the Beijing Fortune Plaza [2] and World Trade Center [3], in the U.S., such as the Moffit Hospital [4]. The steel plate reinforced concrete composite wall has also been investigated with precast concrete on only one side of the steel plate [e.g. 5].

On the other hand, the surface plates of the concrete filled steel plate composite wall can be used as the formwork for concrete casting, and protect the concrete cracks from exposure. Therefore, compared to the steel plate reinforced concrete composite wall, the concrete filled steel plate composite wall possesses advantages in service performance and constructability and is the subject of this paper. The concrete filled steel plate composite wall has been used in practice in China (e.g. the Yangcheng TV Tower [6]).

Several experimental and theoretical research studies on the concrete filled steel plate composite wall have been conducted [e.g. 7–10], and design procedures have been proposed [1,11]. Previous research has typically focused on the behavior of cantilever composite shear walls, whereas the behavior of composite coupled wall systems and composite coupling beams is less well understood. In the U.S., development of composite coupled shear walls has focused on systems that use steel beams in conjunction with reinforced concrete shear walls, referred to as hybrid coupled wall systems. Tests have been conducted [e.g. 12] and design recommendations have been developed [e.g. 13,14].

Several research studies have also been conducted on steel plate-reinforced concrete composite coupling beams. The steel plate-reinforced composite coupling beam was first proposed by Lam et al. [15]. One conventional reinforced concrete coupling beam and two steel plate-reinforced composite coupling beams with and without shear studs were tested. Compared to the conventional reinforced concrete coupling beam, the steel plate-reinforced composite coupling beam could resist larger shear forces and withstand substantial inelastic deformations. The presence of the embedded steel plate with proper

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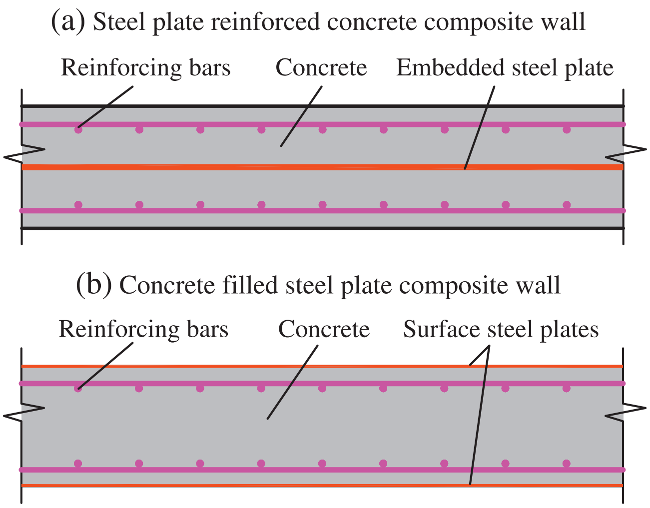

Fig. 1. General details of two steel plate-concrete composite walls.

anchorage could significantly alleviate the pinching problem of the conventional reinforced concrete coupling beam. Shear studs were required to provide sufficient load transfer between the steel plate and concrete in order to achieve good inelastic performance at large shear deformations. Su et al. [16] tested five steel plate-reinforced composite coupling beams to investigate the importance of shear connectors on the degree of composite action. Based on the experimental studies, a two-dimensional finite element model [17] and a design procedure [18] were proposed.

In the research studies of Gong et al. [19–21], an I-beam was embedded in a reinforced concrete coupling beam. Component testing as well as subassembly testing were carried out to investigate the cyclic response of the composite coupling beams, their connections to reinforced concrete walls, and overall behavior of the composite coupled wall system. Based on the experimental studies, guidelines for proper design and detailing of the composite coupling beams and beam-wall connections were developed.

Steel plates have been used as a retrofit method to strengthen reinforced concrete coupling beams. The external steel plate strengthened reinforced concrete coupling beams with a span-to-height ratio of 2.5 and 1.11 were tested under reversed cyclic loading by Su et al. [22] and Cheng et al. [23], respectively. The reinforced concrete coupling beams were strengthened by bolted external steel plates on the side faces of the coupling beams, and the external steel plates were also laterally restrained at the edges in the test of the deep coupling beams. The experimental results showed that this retrofitting method could effectively increase the deformation and energy dissipation capacities of both the medium-span and deep reinforced concrete coupling beams. Moreover, it was found that the deformation, ductility and energy dissipation capacities of coupling beams could be greatly increased by using laterally restrained steel plates.

Based on the previous research work on concrete filled steel plate composite walls, a concrete filled steel plate composite coupled wall system is proposed, as shown in Fig. 2 (a). The coupling beams of the composite coupled wall system consist of surface steel plates and infill concrete, so it is easy to proportion the wall piers and coupling beams with matched stiffness, load-carrying and deformation capacities. The construction of the wall-beam connections is shown in Fig. 2(b), (c). The steel flanges of the coupling beam are extended into the wall piers, and welded to the surrounding steel plate. The steel webs of the coupling beam are spliced with the surface plates of the wall piers using welded butt joints.

In this paper, six coupling beam specimens were tested under reversed cyclic loading. The progression of limit states, hysteretic

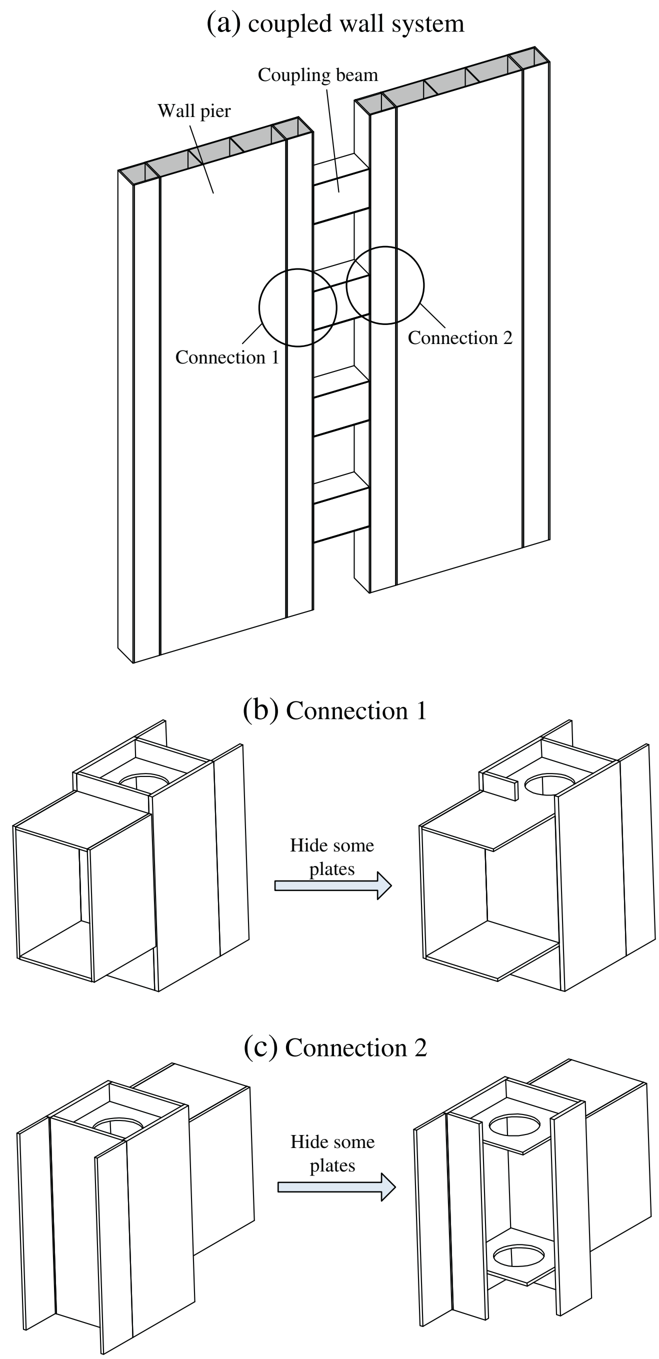

Fig. 2. Details of the concrete filled steel plate composite coupled wall.

behavior, deformation capacity, energy dissipation, etc. of the coupling beams were studied.

2. Experimental program

2.1. Test specimens

Six specimens were designed with coupling beams between two shear wall piers. The wall piers were each rigidly attached to end plates that allowed the specimen to be bolted to the test setup as shown in Fig. 3. The coupling beam width and height were 150 mm and 300 mm, respectively, and the shear wall thickness was 150 mm consisting of concrete filled steel sections with plate thickness equal to 5 mm for all the specimens. The parameters that were varied between