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Shear capacity of concrete-filled steel plate composite coupling beams

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ABSTRACT

The concrete-filled steel plate (CFSP) composite coupling beam is a newly developed form of coupling beam that possesses high deformation and energy dissipation capacities. In this paper, the shear capacity of concrete-filled steel plate composite coupling beams was investigated. An analytical model was proposed based on the force mechanism of the composite coupling beam and was proved to have adequate accuracy compared with the available test results. The shear capacity of the composite coupling beam was found to be governed by flexural strength, shear strength, or flexural-shear strength, depending on the material and geometrical properties of the coupling beam. By incorporating the effect of flexural-shear interaction, a unified equation was finally developed.

1. Introduction

Coupled shear wall systems that consist of two or more shear walls connected by coupling beams are efficient lateral force resisting systems; such systems have been widely used in mid-rise and high-rise buildings. As the building height increases, the internal forces in the structural members increase significantly, which makes the conventional reinforced concrete (RC) coupled shear wall system uneconomical for use in super high-rise buildings. To overcome this problem, a new coupled shear wall system, referred to as the concrete-filled steel plate (CFSP) composite coupled shear wall system, was proposed by the authors [1], as shown in Fig. 1. In the proposed coupled shear wall system, CFSP composite wall piers are coupled by CFSP composite coupling beams. Because the two structural members have similar configurations (both consist of surface steel plates and concrete infill), it is easy to design them with matched stiffness, load-carrying, and deformation capacities.

Over the past three decades, great efforts have been made to develop new forms of coupling beams to improve the seismic performance of coupled shear wall system. The steel plate-reinforced concrete composite coupling beam is an effective alternative for the conventional RC coupling beam. Compared with the conventional RC coupling beam, the steel plate-reinforced composite coupling beam can resist larger shear forces and withstand substantial inelastic deformations [2]. The pinching problem of the conventional RC coupling beam was significantly alleviated due to the presence of the embedded steel plate. In addition to the experimental studies, finite element models [3] and design procedures [4] were developed for this composite coupling beam.

The composite coupling beam proposed by Gong and Shahrooz [5] was similar to the steel plate-reinforced composite coupling beam, though the embedded steel plate was replaced by an I-shaped steel beam. Component and subassembly testing [6] were both conducted to study the seismic behavior of the composite coupling beams, the beam-wall connections and the overall behavior of the composite coupled wall system. Based on the experimental studies, guidelines for the proper design and detailing of the composite coupling beams and beam-wall connections were proposed [7].

In the U.S., recent research efforts on coupled shear wall systems were focused on the hybrid coupled shear wall system, in which the reinforced concrete shear walls were connected by steel coupling beams. Pushover analysis [8–9] and nonlinear dynamic analysis [10] were conducted, and design recommendations were developed (e.g., [11]).

Several research studies have been conducted on the CFSP composite shear walls and coupling beams. For the CFSP composite shear walls, experimental and theoretical studies have been performed and design recommendations have been made [12–13]. Experiments have been conducted to study the seismic behavior and mechanism of CFSP composite coupling beams. Six coupling beam specimens with varying values of the span-to-height ratio, steel plate thickness, and bending-to-shear capacity ratio were tested under reversed cyclic loading [1]. The progressions of the limit states, hysteretic behavior, deformation capacity, and energy dissipation of the coupling beams have been studied.

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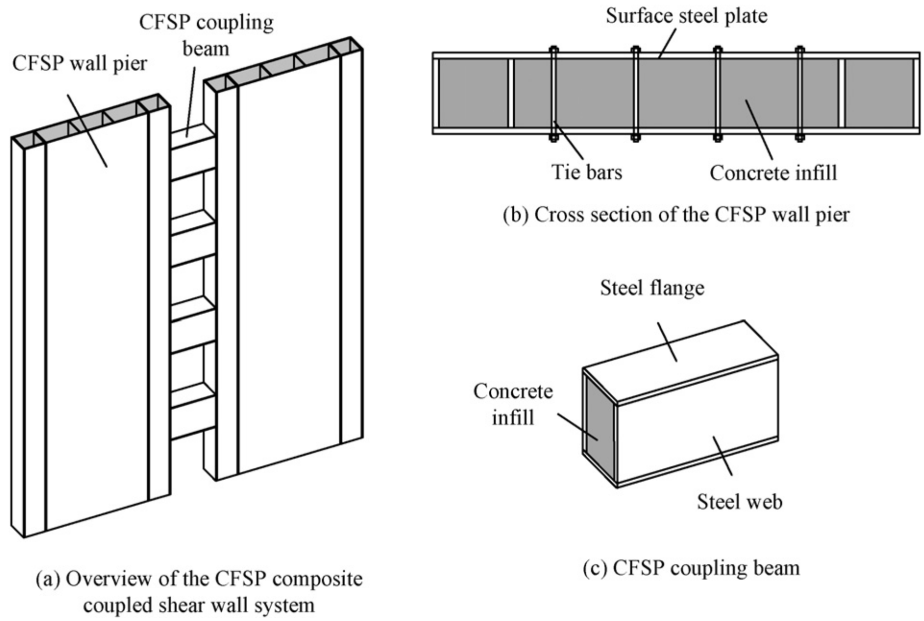

Fig. 1. Details of the CFSP composite coupled shear wall system.

Based on the test results, the internal force and deformation responses of the composite coupling beams were studied in a companion paper [14]. This study focuses on the shear capacity of CFSP composite coupling beams.

As shown in Fig. 2(b), when the coupled shear wall is subjected to lateral forces, coupling beams experience constant shear force, and the points of inflection are located at approximately the mid-span because the lateral stiffness of the wall piers is usually substantially larger than that of the coupling beams. Therefore, the shear capacity of the coupling beam, V_u, which is the maximum shear force attained in the coupling beam, can be determined as the smaller of the shear forces corresponding to the flexural strength at the coupling beam ends, $M_{u,fle}$, and shear strength, $V_{u,sh}$, if the flexural-shear interaction is ignored:

$$V_u = \min\left(V_{u,sh}, 2M_{u,fle}/l_b\right) \quad (1)$$

where $l_{b.}$ is the length of the coupling beam span.

Eq. (1) has been adopted in current design specifications (e.g., ACI 318-11 [15]; ANSI/AISC 341-10 [16]) to calculate the shear capacities of various forms of coupling beams, including conventional reinforced concrete coupling beams, diagonally reinforced concrete coupling beams [17], steel coupling beams and steel reinforced concrete composite coupling beams. The design equations of the shear strength, $V_{u,sh}$, are different for different forms of coupling beams because their shear mechanisms are different. The force mechanism of CFSP composite coupling beams is distinct from that of reinforced concrete or steel reinforced concrete composite coupling beams, so the current design equations for these coupling beams are not applicable to CFSP composite coupling beams. Thus, both analytical models and simplified design equations for the shear capacity of CFSP composite coupling beams must be established.

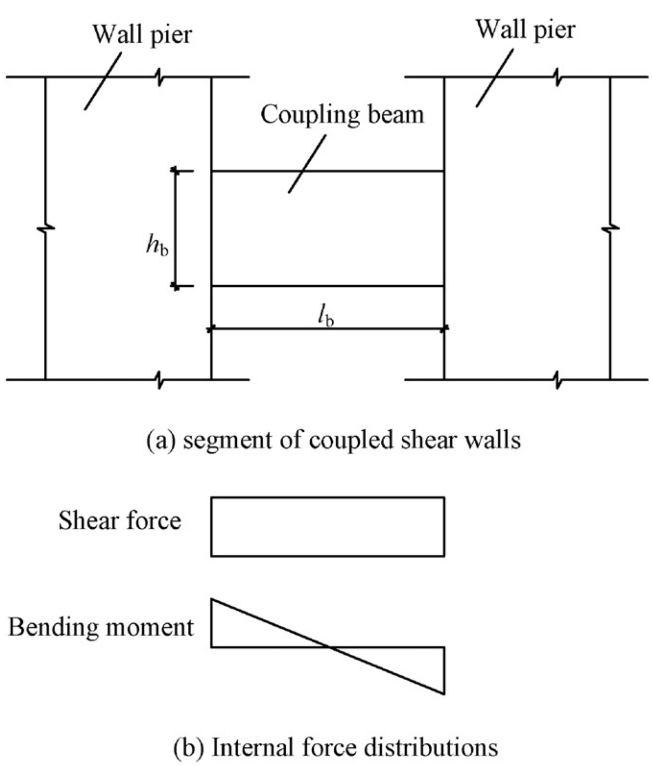

Fig. 2. Internal force distributions of coupling beam.

2. Force mechanism

Six concrete-filled steel plate composite coupling beams were tested by the authors [1]. The coupling beam width and height were 150 mm and 300 mm, respectively, and the key parameters are shown in Table 1. A schematic diagram of the test setup is shown in Fig. 3. The specimens were rotated 90° from their actual orientation in a building to be attached into the test setup through high-strength bolts. The center of action of the actuator passed through the center of the beam span, so the point of inflection was located at the mid-span of the coupling beam, and equal rotations at the two beam ends were maintained, which simulated the typical boundary conditions expected in real buildings. The specimens were subjected to reversed cyclic loading with gradually increased lateral displacement.

The distributions of the longitudinal stress, σ_{sx}, and shear stress, τ_{sxy}, of the steel plates along the height of beam end at the maximum shear