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Precast segmental reinforced concrete walls under eccentric compressive loading: An experimental study

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ABSTRACT

Precast Segmental Reinforced Concrete Walls (PS-RCWs) are construction units recently developed for modern modular construction. A typical PS-RCW is comprised of cast-in-place concrete enclosed by two precast concrete panels. This paper experimentally investigates performance of the PS-RCWs under eccentric compressive loading. Eight specimens including seven PS-RCW specimens and one conventional cast-in-place reinforced concrete wall specimen were tested. Test results show that the bonding strength between the cast-in-place concrete and precast concrete panels controls the failure modes of the PS-RCWs under eccentric compressive loading. It is found that a PS-RCW with sufficient bonding strength between the cast-in-place concrete and precast concrete panels exhibits the more favorable failure mode in which a plastic zone forms in the wall as a result of the eccentric compressive loading. Testing data also revealed that the classic strain and stress diagrams assumed for reinforced concrete members under eccentric compressive loading can be extended to PS-RCWs. An analytical model recommended in the Chinese National Code for Design of Concrete Structures (GB50010-2012) was found to provide reasonable predictions for strength of the PS-RCWs under eccentric compressive loading and it is recommended for future practice.

1. Introduction

Modular construction fabricates fully or partially precast structural components. Since modular construction reduces the work required at construction sites, it has been identified as one of the future directions of construction engineering. Precast Segmental Reinforced Concrete Walls (PS-RCWs) are structural components recently developed for modular construction. As shown in Fig. 1, a typical PS-RCW consists of cast-in-place concrete surrounded by a pair of precast reinforced concrete panels. Moreover, T-shaped ribs are regularly provided either along the transverse or longitudinal directions on the precast panels to enhance the system integrity through their dowelling actions. Steel rebars penetrating the ribs are also used to reinforce the cast-in-place concrete. During the construction phase, the precast reinforced concrete panels can function as formwork for the cast-in-place concrete infill, which accelerates the construction process while eliminating the excessive cost associated with formwork erection and removal.

Attracted by these favorable features, the PS-RCW system has aroused increased research interests [1–6] and the research outcome accomplished to date has improved our understanding on different aspects of PS-RCW construction [7–12]. Nevertheless, there are remaining issues regarding structural performance of PS-RCWs subjected to gravity loads, limiting the widespread acceptance of the system. Recently, research efforts have been made to investigate structural behavior of PS-RCWs under concentric compressive loading representing gravity loads. However, it should be recognized that the compressive loadings on PS-RCWs as a result of the gravity loads, are rarely concentric, if ever, in an actual building. Therefore, further investigations are necessary to address performance of PS-RCWs under eccentric compressive loading.

Through testing of a series of specimens, this research investigates damage progression, failure mechanism and ultimate resistance of the PS-RCWs subjected to eccentric compressive loading. The test results obtained from this investigation form a basis for a better understanding of the fundamental behavior of the PS-RCWs under combined loading and help promote implementation of the PS-RCW system in future building constructions. The

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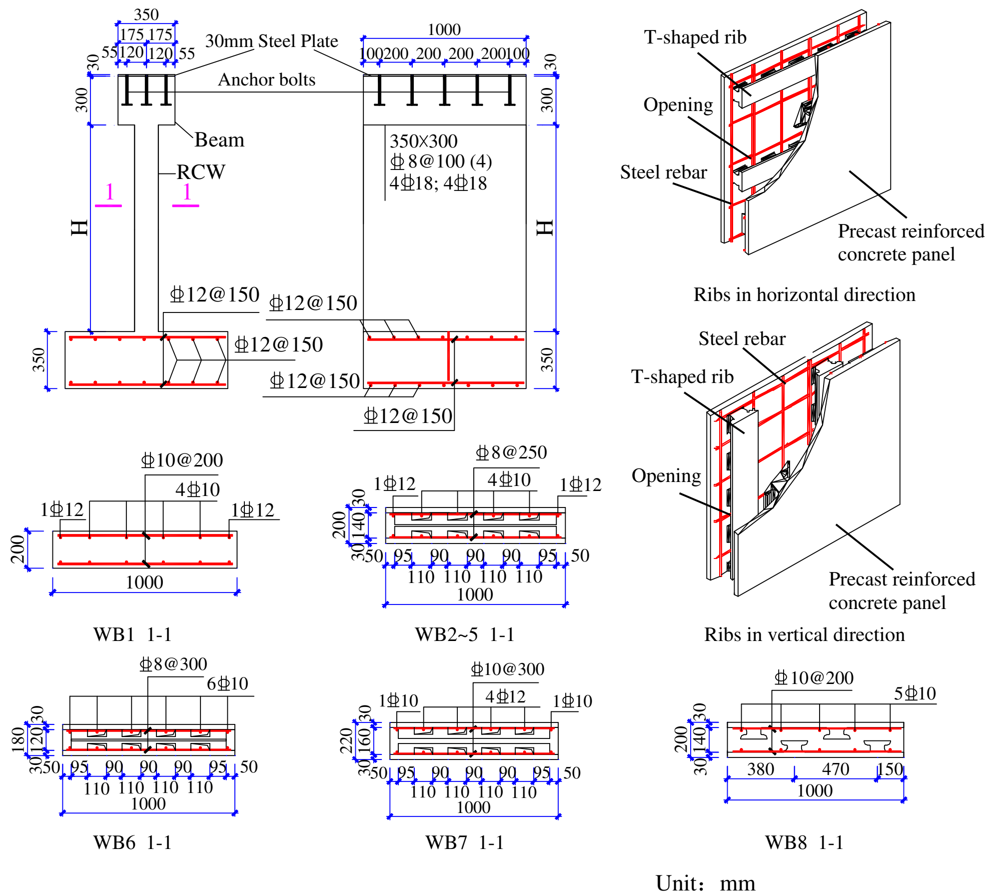

Fig. 1. Geometries and steel rebar arrangements.

following sections present specimen design and construction, material properties, test setup, loading program, observations, discussion of test results, and applicability of existing formulas for calculating resistance of the PS-RCW system under eccentric compressive loading.

2. Specimen design and construction

This investigation tested eight specimens, which were designated as WB1 to WB8, respectively. All the specimens were PS-RCWs except that WB1 was a conventional cast-in-place reinforced concrete wall included here for comparison purpose. All the specimens had the same width of 1000 mm; however, their heights and thicknesses were varied from 2100 mm to 3900 mm and from 180 mm to 220 mm, respectively. Note that width of the specimens was kept constant at 1000 mm since the machine only manufactures the precast panels with standard widths (1000 mm, 2000 mm, etc.) and precast panels wider than 1000 mm are inconvenient in transportation and fabrication as reported by construction industry. Correspondingly, the height-to-thickness ratios of the specimens varied from 10.5 to 19.5. Steel rebars with nominal diameters of 8 mm, 10 mm and 12 mm were adopted to reinforce the walls along the transverse and longitudinal directions. According to the minimum reinforcement ratio requirement of ACI 318-05 [13], the transverse and longitudinal reinforcement ratios were selected to be on the orders of 0.38% and 0.54% in each specimen, respectively. Arrangement of the steel rebars in each specimen is presented in detail in Fig. 1. Specific reinforcement ratios of each specimen are provided in Table 1.

Construction of Specimen WB1 followed the conventional practice of cast-in-place reinforced concrete walls. Construction of each of the other specimens (i.e., those PS-RCWs) was completed through two steps: the precast panels were first prepared then the cast-in-place concrete was filled between two exterior precast panels. As shown in Fig. 2, each precast panel consisted of the T-shaped ribs regularly spaced on a 30 mm thick plate. Steel wires with nominal diameter of 4.8 mm were spaced at 100 mm to reinforce the plate along the direction parallel with the ribs. Moreover, two wires were used to reinforce each rib along its longitudinal direction. Geometries of the ribs are provided in detail in Fig. 2. Rib interval of each specimen is provided in Table 1. Rectangular openings (110 mm × 40 mm) were spaced at 200 mm along each rib to allow passage of the steel rebars reinforcing the cast-in-place concrete. The two exterior precast panels in each PS-RCW specimen were properly arranged such that different wall thicknesses and staggered rib distributions were achieved. All the PS-RCW specimens had the ribs orientated along the transverse direction except that Specimen WB8 had the ribs along the longitudinal direction.

At the top of each specimen, a 350 mm wide and 300 mm deep beam was cast. To reduce stress concentration, a 30 mm thick steel plate, on which a group of fifteen bolts with diameter of 19 mm and length of 200 mm were anchored, was placed at the top of the beam. Moreover, a 1000 mm long 1000 mm wide and 350 mm thick slab was cast at the base of each specimen to provide the fully fixed end condition.

3. Material properties

Properties of concrete, steel rebars and steel wires were determined from testing of material samples. For concrete, tests were conducted on both cubes (100 mm × 100 mm × 100 mm) and