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Experimental evaluation of flexural behavior of composite beams with cast-in-place concrete slabs on precast prestressed concrete decks

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A B S T R A C T

This paper focuses on a new type of steel-concrete composite beams consisting of cast-in-place concrete slabs on Precast Prestressed Concrete Decks (PPCDs). To evaluate flexural performance of such composite beams, this research team conducted an experimental investigation on twelve specimens. Test results show that the composite beams with PPCDs can exhibit desirable and stable flexural performance under monotonic loading. Based upon the test results, this paper also evaluates the influence of some key design parameters (e.g., concrete slab thickness, amount of shear studs and longitudinal reinforcement ratio) on flexural performance of the composite beams.

1. Introduction

Steel-concrete composite beams combine the advantages of structural steel such as high strength, ductility and ease of erection and those of reinforced concrete such as high rigidity and low cost. A conventional steel-concrete composite beam consists of a steel beam with I-shaped cross-section supporting a concrete slab cast on a steel corrugated deck. Through application of appropriate connectors (e.g., headed shear studs) between the steel beam and the concrete slab, their relative slip can be restrained, enabling shear force transfer between them and achievement of the composite beam action [1]. Recent investigations, both analytical and experimental, have shown that this type of structural components can exhibit high stiffness and strength, and behave in a ductile manner, making them a viable and cost-effective alternative to traditional structural steel or reinforced concrete beams [2–7]. Nevertheless, there are remaining issues limiting the widespread acceptance of such composite beams. For example, the wrinkled surface of steel corrugated deck as part of the steel-concrete composite beam may be unfavorable to building owners and architects in some cases. Adoption of suspended ceilings could alleviate this problem, but will reduce headroom and more importantly result in extra costs.

This research team explored a practical solution to the above issue, in which the Precast Prestressed Concrete Decks (PPCDs) were used as an alternative to the steel corrugated decks of conventional steel-concrete composite beams. The PPCDs, which will be described in detail in a following section, are a new type of construction units recently developed for modular construction [8]. While keeping the other favorable features of conventional composite beams, the composite beams with PPCDs offer additional aesthetic values (such as flat surface and similar or even reduced floor depth) and can be more affordable in some cases.

The objective of this research was to evaluate flexural performance of the composite beams with PPCDs. Through testing of a series of twelve specimens, this research team investigated damage progression, failure mechanism and other aspects of the composite beams under monotonic loading. The test results obtained from this investigation form a basis for a better understanding of the fundamental behavior of such composite beams and help promote their applications in future building constructions. The following sections describe in detail the proposed composite beams, specimen design and construction, material properties, test setup, loading program, observations, test results, and influences of key construction parameters on flexural performance of the composite beams.

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2. Descriptions of composite beams with PPCDs

As shown in Fig. 1, a PPCD is essentially a special precast concrete panel on which T-shaped ribs are regularly placed. The panel and the ribs are reinforced by prestressed steel wires parallel with the ribs. In addition, holes are regularly provided in the ribs to allow passage of steel rebars perpendicular to the ribs.

Fig. 2 illustrates a composite beam with PPCDs. As shown, the PPCD segments are placed on top of a steel beam and support the cast-in-place concrete slab. The PPCDs and cast-in-place concrete are integrated as a monolithic slab through the dowelling and interlocking actions of the PPCD ribs and steel rebars penetrating the ribs. Shear studs are attached along the top flange of the steel beam and extended into the cast-in-place portion of the concrete slab to transfer the shear force between the concrete slab and steel beam, hence enabling development of the composite beam action. Similar to the steel corrugated decks in conventional composite beams, the PPCDs, if sized properly, can function as the working platform and formwork for the cast-in-place concrete, which accelerate the construction process and eliminate the excessive cost associated with formwork erection and removal.

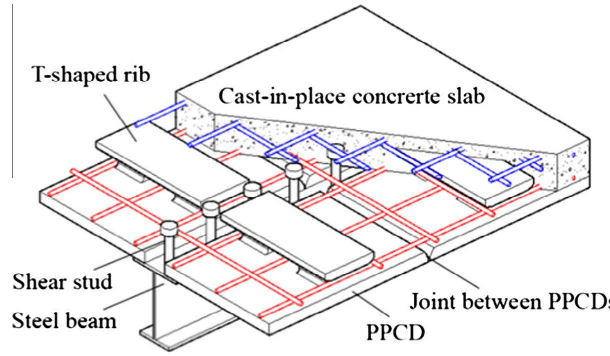

Fig. 2. Sketch of a composite beam with cast-in-place concrete slab on PPCDs.

3. Specimen design and construction

It was perceived that the composite beams with PPCDs can replicate the viable flexural behavior of the conventional composite beams with steel corrugated decks. However, very limited research, particularly experimental work, had been completed to confirm if the composite beams with PPCDs behave as expected. To this end, this research team tested twelve specimens designated as CB1–CB12. Specimens CB1–CB11 were composite beams consisting of PPCDs while Specimen CB12 was a composite beam with a full-depth cast-in-place concrete slab included here for comparison purpose. All the specimens employed H $200 \times 150 \times 100 \times 6 \times 8$ as the steel beams. Here, the designation of welded beam of I-cross-section reflects the depth, width of top flange, width of bottom flange, web thickness and flange thicknesses of a steel member (unit in mm). Width of the concrete slab was kept constant at 800 mm in all specimens; however, thickness of the concrete slab, h_f, was varied from 130 mm to 150 mm. All the specimens had the same length of 3000 mm (measured from beam ends) and span of 2700 mm.

The PPCDs in Specimens CB1–CB10 were arranged so that the PPCD ribs were perpendicular to the beam longitudinal direction. Specimen CB11 had the PPCD ribs parallel with the beam longitudinal direction. The same type of PPCDs was used in Specimens CB1–CB11. Fig. 3 shows the detailed geometries and reinforcement distributions of a typical PPCD segment. As shown, steel wires with the nominal diameter of 4.8 mm and prestressed to 30% of their yield strength (approximately prestressed to 471 MPa) were spaced at 100 mm to reinforce the PPCD along the direction parallel with the ribs. Moreover, two wires were used to reinforce each rib along its longitudinal direction. Rib interval was kept at 500 mm. Rectangular openings (110 mm $\times$ 40 mm) were spaced at 200 mm along each rib to allow passage of the steel rebars. As shown in Fig. 4, mortar was used to fill the joint between adjacent PPCDs. Steel rebars with diameters of 8 mm, 10 mm and 12 mm were used to reinforce the cast-in-place concrete of the specimens. Arrangement of the steel rebars in each specimen is presented in detail in Fig. 5. As shown, steel rebars were provided at both the top and the bottom of the cast-in-place concrete slab. The steel rebars at the bottom of the cast-in-place concrete slab were to enhance the integrity of the slab. Therefore, only the steel rebars at the top of the slab were considered in calculation of longitudinal reinforcement ratio, ρ. Specific reinforcement ratio, PPCD rib orientation, number of PPCDs used, and slab thickness of each specimen are provided in Table 1.

Shear studs were evenly distributed along the top flange of the steel beam in each specimen. Diameter and length of each shear stud were 19 mm and 100 mm, respectively. Note that shear studs are the critical component controlling whether or not the composite beam action can develop in the specimens [9]; however, there were no analytical models readily available for calculating the required number of shear studs in the composite beams with PPCDs. To this end, the formulae recommended in the *Chinese Code for Design of Steel Structures* (GB50017) [10] for the composite beams with full-depth cast-in-place concrete slab were used to estimate the shear strength of each stud (which was determined to be 79.5 kN). The required number and interval of shear studs, n_r and s, respectively, were determined based upon the shear strength of an individual shear stud and the shear force to be transferred along the interface between steel beam and concrete slab (taken as tensile yield strength of the steel beam in this research). The actual number of shear studs provided in each specimen, n_a, was determined based upon n_r. Table 1 lists the detailed design information about shear studs. As shown, in all specimens except Specimens CB7 and CB8, n_a was selected to be the same as n_r. Specimens CB7 and CB8 respectively had n_a values higher and lower than n_r and these two specimens were included for comparison purpose. It is recognized that the shear studs need to have both sufficient strength and stiffness to eliminate the slip deformation between the slab and steel beam for forming the fully composite bending moment resisting action. However, the factor, n_r, is only related to strength. Therefore, the specimens with n_a larger than

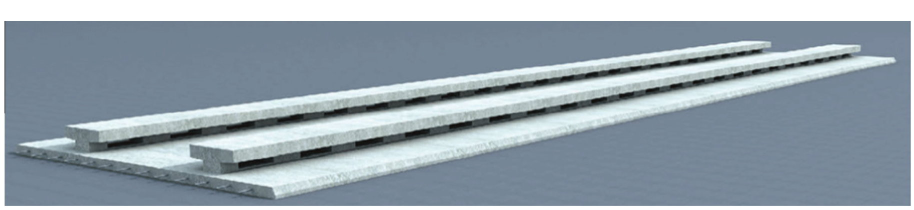

Fig. 1. A typical PPCD (before removal of extended rebars and bottom concrete panel at the PPCD ends).