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Numerical study on mechanical and adhesive splices for ribbed GFRP plates used in concrete beams

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ABSTRACT

A new concrete beam design, comprising concrete core and glass fiber reinforced polymer (GFRP) ribbed side plates has been developed. Plate splicing is made by using a mechanically fastened or adhesively bonded spliced form through end ribs. This paper presents the development, calibration, and application of comprehensive finite element models for the hybrid beam. The models incorporate material and geometric nonlinearities along with bond-slip interfacial relations. Interfacial behavior at the plate-to-plate splice, whether adhesively bonded or mechanically fastened, as well as plate-concrete interface are considered. Parametric study was performed to examine the effects of fastener spacing and adhesive coverage length of the 4 mm thick GFRP plates. It was shown that the ultimate strength of beams with adhesively bonded splices was 28% higher than the beams with unbonded splice (i.e. without any adhesive or fasteners). Decreasing fastener spacing from 47 to 3.8 times the fastener diameter resulted in increasing ultimate load by about 20%. No further reduction in load occurs beyond fastener spacing larger than 47 times the diameter. The beam stiffness at service load is not affected by the fastener spacing or the adhesive coverage length.

1. Introduction

Infrastructure deterioration and deficiency problems have become a main concern for local and federal authorities, prompting remedial actions such as routine inspection, rehabilitation, and at times replacement. Innovative systems and non-corrosive materials are sought for both retrofitting of existing structures and construction of new ones. Fiber reinforced polymer (FRP) materials are certainly strong candidates. In addition to their well-known favorable characteristics [1–4], the availability of FRPs in multiple shapes and products (e.g. plates, rods, tendons, pre-fabricated, in-situ made) make them attractive not only for conventional reinforced concrete members but also for non-traditional hybrid systems.

In addition to their familiar applications as internal reinforcement, external strengthening system, and confining jacket [5–9], FRPs have emerged as an effective material for stay-in-place (SIP) formwork in concrete construction. SIP formwork, traditionally in the form of thin precast prestressed concrete slabs or corrugated steel sheets [10], offer a reduction in construction cost and time [11,12]; protection for the member from environmental hazards such as corrosion, moisture, and freeze-thaw cycles [13]; and elimination or reduction of internal reinforcement [12].

Several research studies have implemented the FRP SIP formwork for concrete beams [14,15], one-way slabs [10,16], two-way slabs [16,17], bridge decks [18–20], and columns [21–23]. Enhancement to strength and serviceability as well as reductions in cost and construction time, have been amply observed from laboratory tests and field applications [24,25].

Various off-the-shelf products or custom made systems have been explored for the FRP SIP formwork [12]. For example, Fam and Nelson [10] used corrugated GFRP SIP forms with pin-and-eye panel-to-panel connection for concrete decks. The SIP form eliminated the bottom layer of steel reinforcement. Full-scale tests on prototype decks confirmed the effectiveness of the forms. Safety factors ranging from 3.5 to 4.9 over the design service load were reported for the tested decks. The decks also experienced significant deformability and pseudo-ductility after the initial failure. Nelson and Fam [19] also used another type of SIP form, consisting of flat plate with intermittent T-shaped ribs, in five full-scale bridge decks. The ribs, being embedded inside the concrete, were believed to provide a good mechanical interlock between the concrete and the SIP form. The tested decks reached an ultimate load, 33% higher than that for a conventional reinforced concrete (RC) counterpart, and 7.8 times higher than the design service load.

Gai et al. [18] proposed a hybrid SIP formwork for concrete slabs to enhance slab ductility. The new slab system consisted of a GFRP box section for resisting tensile forces, a moulded GFRP grating for resisting

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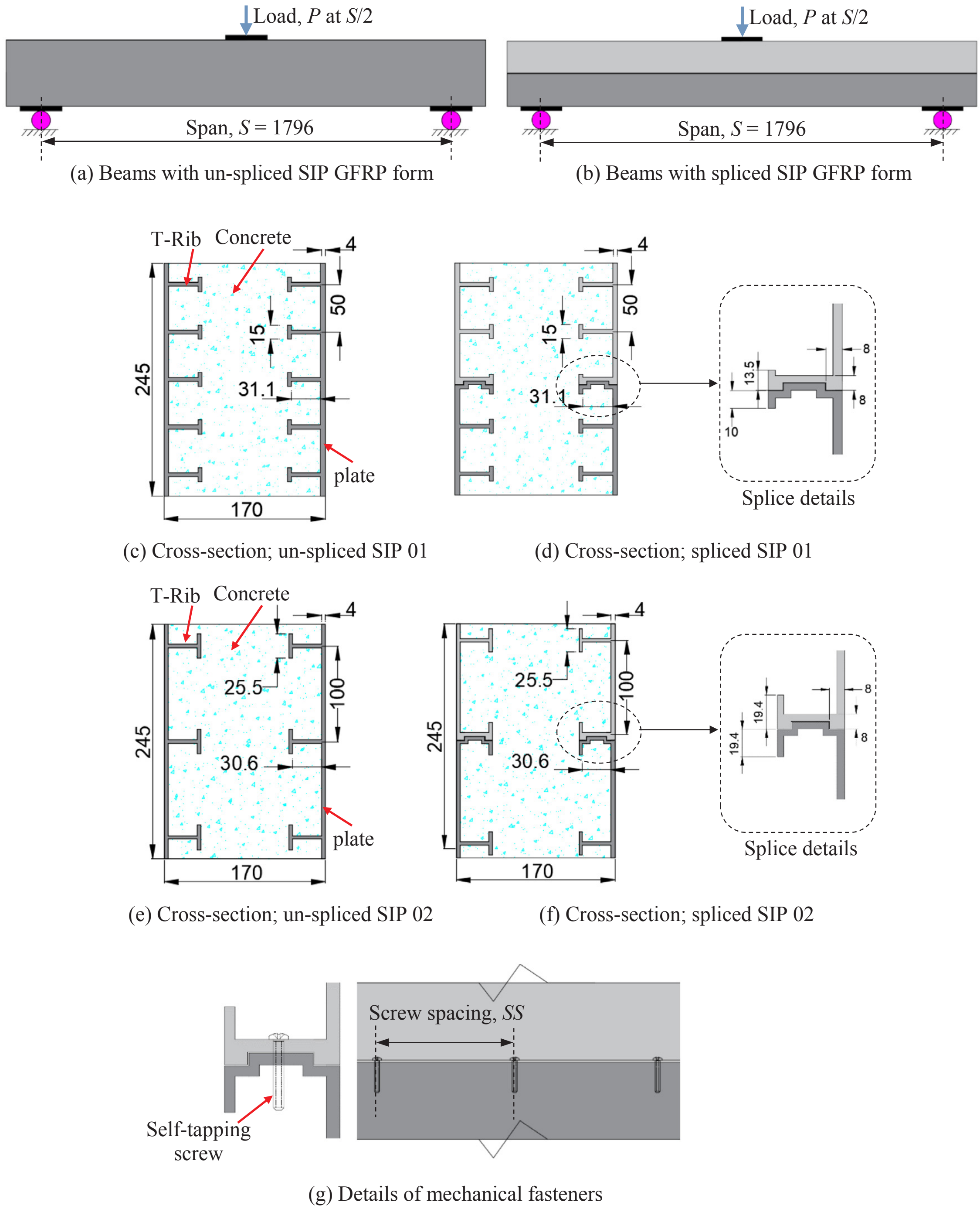

Fig. 1. Geometry of concrete beams reinforced by GFRP SIP form (dimensions in mm).

compressive force, GFRP bars acting as shear connectors between the box and grating, a concrete core in the compression zone (inside the grating), and a foam block inside the GFRP box. Push-out tests on four small slab segments and five-point monotonic tests on six slab specimens confirmed that the proposed system exhibited a sufficient stiffness during construction, and significant ductility at failure.

A new hybrid beam concept has been developed at Queens University [26], with an objective of eliminating all steel reinforcement. The beam consists of concrete and GFRP SIP form at the beam sides, acting as a permanent formwork and reinforcement for shear and bending. To study plate splices, beams with SIP form spliced at mid-height by mechanical fasteners or adhesive bonding were also tested