Construction and Building Materials 144 (2017) 462–474

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental investigation of composite beams reinforced with GFRP I-beam and steel bars

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HIGHLIGHTS

- GFRP I-beam is encased in concrete to reinforce the concrete beam.
- Flexural behaviour of I-beam in composite beam is assessed.
- Tensile steel bars are used to improve the ductility of the composite beam reinforced with I-beam.
- Location of I-beam affects the ultimate load of the composite beam.

ARTICLE INFO

Article history:
Received 7 October 2016
Received in revised form 5 March 2017
Accepted 28 March 2017

Keywords:
Composite beams
GFRP
I-beam
Ductility
Flexural behaviour

ABSTRACT

This paper presents results of an experimental study on the flexural behaviour of a composite beam, which is reinforced with longitudinal tensile steel bars as well as glass fibre reinforced polymer (GFRP) pultruded I-beam encased in concrete. Five beam specimens, including one traditional reinforced concrete (RC) beam and four composite beams, were cast and tested under four-point bending. The variables involved in the composite beams include the type of longitudinal tensile bars (steel bars and GFRP bars) and the location of the I-beam in the cross-section (middle and a shift of 30 mm towards the tension region). The test results presented in this study show that the proposed composite beams have a very ductile response due to the existence of the tensile steel bars, and the yield point of the composite beam is controlled by the tensile steel bars. The ultimate load of the proposed composite beam in this study is higher than the traditional RC beam in this study, and the ultimate load is governed by the encased I-beam. When GFRP bars were used to replace the tensile steel bars to reinforce the composite beams, the brittle failure of GFRP bars caused lack of ductility of the beam members, and both the stiffness and ultimate load were reduced significantly. Compared with steel bars, the slip between the concrete and the I-beam was also increased when GFRP bars were used. The different location of the I-beam has little effect on the flexural response.

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1. Introduction

Fibre Reinforced Polymer (FRP) is increasingly used in civil engineering construction in the last two decades because of the excellent properties of corrosion resistance as well as high strength-to-weight ratio. Extensive research studies have been conducted on using FRP to retrofit existing structures [1–4]. On the other hand, FRP composites (such as FRP bars and FRP pultruded profiles) are also exploited as a kind of standard construction product in new construction [5–8]. Due to the advantages of convenient installation and the customized cross-sections (e.g. I-beam, square tube or circular tube), the application of the FRP pultruded profiles have been extensively explored in recent years.

The FRP pultruded profiles are suitable for use as all FRP structures such as building floor, cooling towers and offshore platforms [9–11]. Moreover, it can be used in combination with other materials to develop composite structures. A few studies were carried out to use the GFRP I-beam to reinforce the beam specimens, thus forming a composite structural member. Two types of representative composite beams are shown in Fig. 1. The composite beam with Cross-section A (Fig. 1a) is composed of a concrete block on the top and an I-beam at the bottom [12]. In this case, the concrete is intended for compression and the I-beam for tension. Nevertheless, the disadvantage of instability at the web could not be ignored during the loading. In addition, the fire performance of such composite beam is poor since the I-beam is exposed to air without

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http://dx.doi.org/10.1016/j.conbuildmat.2017.03.217
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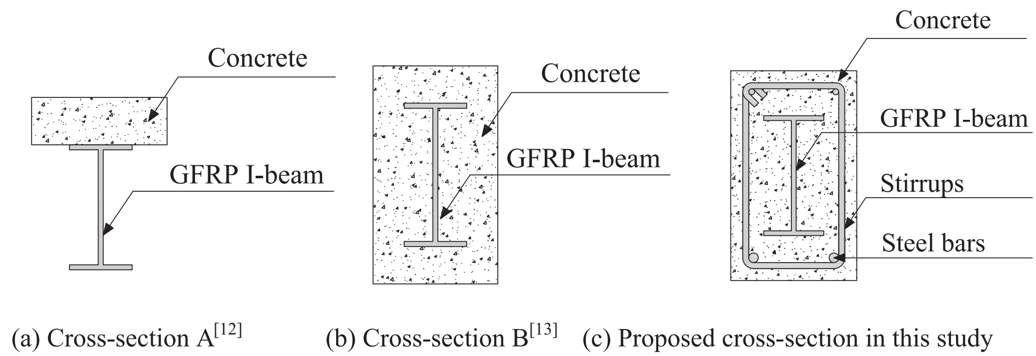

Fig. 1. Cross-sections of composite beams.

Table 1
Configuration of specimens.

Group	Specimen	Top bars			Bottom bars			Stirrups			GFRP I-beam (mm)	Location of I-beam (mm)
		Material	Diameter (mm)	Number of bars	Material	Diameter (mm)	Number of bars	Material	Diameter (mm)	Spacing (mm)[a]		
Reference	RC	Steel	10	2	Steel	16	4	Steel	10	60 or 80	–	–
Group S	S0.57M	Steel	10	2	Steel	16	2	Steel	10	60 or 80	200 × 100 × 10	Middle
	S0.57B	Steel	10	2	Steel	16	2	Steel	10	60 or 80	200 × 100 × 10	30 below middle
Group F	F0.46 M	Steel	10	2	GFRP	12	3	Steel	10	60 or 80	200 × 100 × 10	Middle
	F0.46B	Steel	10	2	GFRP	12	3	Steel	10	60 or 80	200 × 100 × 10	30 below middle

[a] The stirrups were spaced at 60 mm in the shear span and 80 mm in the pure bending region.

the protection of the concrete cover. The other type of composite beam with Cross-section B (Fig. 1b) was proposed by encasing the I-beam in the middle of the cross-section [13]. Compared with the composite beams with Cross-section A, the stability and the fire performance are improved in this type of composite beams. Nevertheless, both FRP and concrete are poor in ductility, thus causing a brittle failure of this type of composite beam.

In order to improve the flexural response of the composite beam reinforced with the I-beam, a type of the composite beam is proposed in this study. As shown in Fig. 1c, the composite beam is reinforced with the I-beam and the longitudinal tensile steel bars, and the I-beam is encased in concrete. The encased I-beam is contributed to the improvement of the flexural strength and the corrosion resistance of the beam members. The tensile steel bars used in this composite beam aim to ensure enough bending stiffness and the ductility of the composite beams. The concept of incorporating FRP and steel materials together to enhance the ductility of structure has been proven to be effective by both experimental and numerical approaches [14–20]. Steel stirrups are employed to confine the concrete and enhance the shear strength of the beam members.

The advantages of this type of composite beams are apparent when compared with the existing composite beams reinforced with steel I-section or GFRP I-beam. Compared with the common composite beam reinforced with steel I-section, although the configurations of both are similar, the self-weight of the proposed composite beam is reduced and the corrosion resistance is improved due to the existence of the I-beam. Compared with the composite beam reinforced with GFRP I-beam as shown in Fig. 1a or b, the advantages of this type of composite beam include: (a) the fire performance can be improved because the I-beam is protected by the surrounding concrete; (b) the stability of the I-beam is improved because it is encased in concrete; and (c) the ductility can be improved due to the application of the tensile steel bars. In addition, this type of composite beam also has significant advantages in practical applications, such as: (a) all the materials are standard building materials without special treatment like drilling holes, riveting or welding; and (b) ease for connection to columns due to the presence of the inside steel bars.

This paper aims to investigate the flexural behaviour of this type of composite beams. A total of five beam specimens, including one traditional RC beam and four composite beams, were cast and tested under four-point bending. The ultimate load, bending stiffness and failure modes of the beam specimens were studied. Finally, the flexural strength provided by the I-beam and the slip between the I-beam and concrete were discussed to evaluate the effect of the I-beam in such composite beams.

2. Experimental program

2.1. Beam specimens

A total of five beam specimens were cast and tested in this experimental study, and the details of the specimens and the configurations of the cross-section are shown in Table 1 and Fig. 2, respectively. All the specimens had an overall length of 2040 mm and a cross-section of 350 × 200 mm. The label of the reference specimen is RC. For the remaining four specimens, the label of the specimens represents the type of tensile bars and the location of the I-beam. The first letter (S/F) in the label indicates the type of longitudinal tensile bars used in the specimen, steel bars (S) or GFRP bars (F). The letter followed by a number which indicates the reinforcement ratio of the specimens in percent, and the last letter M/B (middle/bottom) in the label is the location of the I-beam. For instance, Specimen S0.57B indicates the specimen

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