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Experimental study on double composite action in the negative flexural region of two-span continuous composite box girder

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ABSTRACT

In the negative flexural region of continuous composite girder, cracking of concrete slab results in a reduction in the sectional stiffness and may affect the durability of reinforcement. Double composite action defined as attaching additional concrete to steel bottom flange to improve local buckling strength can be a way to increase the sectional stiffness. It has many advantages for construction while disadvantages also exist. In this case, two continuous composite girders, both of which had two 9 m long spans with 300 mm extension at each edge support and were 0.55 m high, were designed to study the mechanical properties in concrete crack, formation of sectional plastic hinge, load-carrying capacity, etc. One was a conventional composite girder named CCG and the other one was designed with double composite action in the negative flexural region named DCG. Moreover, evaluations of concrete crack width, based on different design codes, and cracking moment were compared with test results and agreed with each other. It indicated double composite action made concrete crack development slower in service load stage. The evaluation of sectional bending–carrying capacity of CCG in the negative flexural region based on the mechanical model with full plastic section of Euro Code 4 and an analogous method was found to evaluate that of DCG. The evaluation results coincided with test results proved the summation which can be drawn from test results.

1. Introduction

Steel and concrete composite box girder can be an attractive form for medium span bridges due to the advantage of combining the two construction materials. However, regarding the negative flexural region of continuous composite bridges, concrete cracks and local buckling of lower steel flanges are critical to the strength and durability of bridges.

The concrete cracks which cause stiffness degradation make the structural mechanical behavior strongly nonlinear even in low stress levels. So far, there have been two main principals dealing with crack: one is to prevent cracking and the other is to limit the maximum crack width within an acceptable value. Based on several measures in design practice created from these principals, many researches were conducted to discuss the mechanical behavior of negative flexural region. Experiment studies on prefabricated concrete slabs were studied by Chang-Su Shim, Hyung-Keun, etc., mentioning that cracks concentrated at the cast interface of joints between decks even in negative flexural region [1–3]. Experiment studies on prestressed concrete slabs in negative flexural region were studied by Shiming Chen in whose experiment the ultimate moment resistance of negative flexural region was governed by local buckling though full plasticity was developed at mid-span section [4]. Also inelastic behavior of negative flexural region was studied by other researchers [5].

Concerning the studies above in another perspective, they all based on conventional composite section. Double composite section has additional concrete on bottom flange. Steven L. Stroh and Rajan Sen introduced that inclusion of the double composite action provided several beneficial features: saving steel, a "braced effect" let the steel stress reduction factor unnecessary, a compact section is reasonably achieved in the negative flexural region, the redistribution of moments becomes favorable, cross frames may be reduced because of bracing of bottom flange of the girder by bottom slab [6]. Nevertheless, the additional time of concrete casting and additional dead load on sub structure can be viewed as typical drawbacks [6]. As to double composite box girder, bottom concrete slab can be placed directly in steel box girder, without requirement for additional forms. Although a compact section in negative flexural region can be easily formed with double composite action, crack may appear in advance because of height descending of neutral axis, influencing bridge durability.

The global mechanical behavior of composite girder with double composite action was concerned by some previous researches [7,8]. However, studies focused on its negative flexural region are rarely mentioned. So the detailed mechanical behavior of double composite action needs to be studied further. In this case, an experiment has been designed to investigate the related crack development, sectional stress distribution, deflection, reinforcement stress, load carrying

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capacity, etc. In this experiment, two continuous composite box girders with span layout of 2×9 m were designed and manufactured. One was a specimen with double composite action in negative flexural region; the other one was a conventional continuous composite girder.

2. Experimental works

2.1. Test specimens

As introduced above, two continuous composite girders were manufactured and tested to study the mechanical behavior of double composite action in negative flexural region. The conventional one labeled with CCG has the same dimensional size and configuration with the one labeled with DCG except without bottom concrete. The main characteristics and nominal dimensions of the test specimens are shown in Fig. 1 and Table 1.

As shown in Fig. 1, the total length of each girder was 18.6 m. Each span was 9 m with a 300 mm extent portion overhang at each edge support. A 1400 mm wide, 80 mm thick and 18,600 mm long concrete deck slab was connected to steel top flange by shear studs, and the haunch underneath concrete deck slab was 20 mm thick.

The section of steel girder was a tub. It was 450 mm high, 800 mm wide at top side and 600 mm wide at bottom side. Cross frames made of angel bars were installed along the girders, with longitudinal 1000 mm spacing. The thickness of top flange, bottom flange and web were 6 mm, 8 mm and 4 mm respectively. And the longitudinal stiffeners were 5 mm thick while the transverse stiffeners were 6 mm thick. At the support areas, all support stiffeners were 10 mm thick.

As shown in Fig. 2, in the negative flexural region, there were two layers of longitudinal reinforcements Φ8 (the diameter of reinforcement is 8 mm) and the spacing of stirrups Φ6 was 80 mm. Two rows of studs of which the shank diameter was 13 mm and stud height was 80 mm were uniformly welded on each steel top flange. The transverse spacing was 80 mm and the longitudinal spacing was 120 mm. As to DCG girder, in the negative flexural region, an approximately 640 mm wide, 95 mm thick and 3000 mm long concrete slab was connected to bottom flange by the same size shear studs. These studs were arranged into 4 rows and uniformly welded on bottom flange. The transverse spacing was 150 mm while the longitudinal spacing was 120 mm. Moreover, the longitudinal stiffeners of bottom flange embedded in bottom concrete slab were designed with holes to play a role in connecting steel and concrete.

The measured thicknesses of the steel plates are also given in Table 1.

The sequence of concrete casting on these two girders based on the real construction of a continuous composite girder for considering the construction process effect.

Table 1
Measured dimensions of the specimens (mm).

	Top flg.	Bot flg.	Web	Tran. Stf.	Hori. stf.	Main reinforcement	Stirrup
Design value	6.00	8.00	4.00	6.00	5.00	Φ8	Φ6
CCG	5.50	7.98	4.12	5.78	5.30	–	–
DCG	5.76	7.90	4.26	6.28	5.52	–	–

2.2. Material properties

The concrete material properties of both girders were tested on 7-day, 28-day and test day. The uniaxial compressive strength tests based on 150 mm cubic test specimens. The uniaxial tensile strength and Young's modulus tests based on 40×40×160 mm specimens and 100×100×300 mm specimens, respectively. Table 2 gives the test results. In Table 2, because of specimen initial imperfection, some data are not listed.

The mean tensile properties of samples cut from webs, top flanges, bottom flanges and stiffeners of the steel girders are summarized in

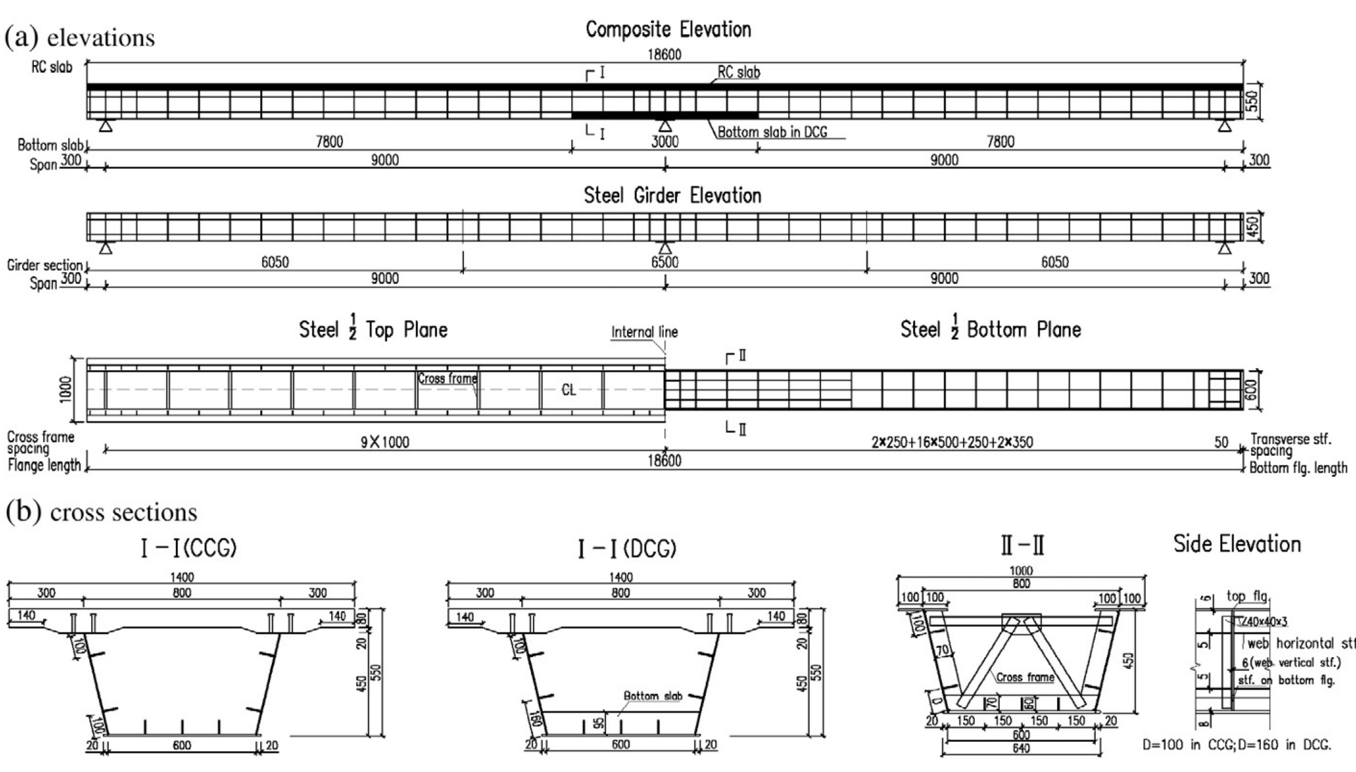

Fig. 1. Elevations and cross sections of experiment girders (mm).