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Crack control of a steel and concrete composite plate girder with prefabricated slabs under hogging moments

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Abstract

In this research, an experimental test on a full-scale model of a steel and concrete composite plate girder with prefabricated slabs under hogging moments was cautiously conducted and observed in order to study crack control. Details of prefabricated slab transverse joints were determined from previous research. The test specimen was an overhanging simple support beam, in total 28 m long. Through the four-point flexural test, the behaviour of the composite girder under hogging moments was observed. From the test results, crack development, crack widths and strain of the composite section before and after cracking were observed. Initial cracking load and crack spacing were viewed and the relations between crack spacing and transverse reinforcement spacing were studied. Moreover, the composite section behaviour of the precast deck with loop joints was confirmed. Test results were analyzed by design equations in each code for crack control. The flexural stiffness of the composite section after cracking is compared with that of the proposals in EUROCODE 4-2 and discussed.

Keywords: Steel and concrete composite plate girder; Prefabricated slab; Loop joint; Hogging moment; Crack control; Crack width; Crack spacing; Flexural stiffness of composite section; Eurocode 4-2

1. Introduction

Steel and concrete composite bridges are very attractive solutions for short and medium span bridges. However, for steel and concrete composite continuous bridges, when a concrete slab is in tension and a lower flange of a steel girder is in compression under hogging moments, there are shortcomings in view of durability and strength. Especially, concrete cracking affects the durability and service life of bridges. Therefore, crack control is an important issue in steel and composite continuous bridges. There are two approaches for dealing with concrete cracking in composite bridges: one is to prevent cracking using prestressing methods and the other is to allow the formation of cracks but limit their widths to acceptable values. Prestressing methods, however, are inconvenient and doubtful due to prestress losses by the long-term behaviour of concrete. Therefore, it is considered that the control of crack width without prestressing is the more economical and interesting solution.

Randl and Johnson [1] found that the first transverse cracks that occur in lightly reinforced concrete slabs forming tension flanges of composite beams were significantly wider than is predicted by existing methods. They showed that a reinforcement ratio of 0.9% is sufficient to ensure that bars do not yield when the first crack forms, and it was suggested that 0.9% is sufficient to control initial cracking in composite main girders only when small-diameter bars are used. In the study of Navarro and Lebet [2], the mechanical behaviour

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of steel–concrete composite bridges under non-monotonic service loading was presented. In their study, it could be observed that the reinforcement ratio and longitudinal bar diameter do not significantly influence the crack widths. Since the crack spacing is equal to the transverse reinforcement spacing, crack widths are not influenced by a decrease of the transmission length induced by reducing the longitudinal reinforcement bar diameter. Therefore, reducing the longitudinal reinforcement bar diameter is not an effective method for diminishing crack widths.

Ramm and Elz [3] mentioned that local weakening of the tensile capacity of a concrete slab can lead to an early occurrence of cracks and can cause decreased need of minimum reinforcement. In the case of composite beams, such local weakening can be caused by shear connectors or transverse reinforcement. This can lead not only to an earlier development of cracks, but also can influence the crack spacing. Thus, the development of cracking in slabs as part of composite beams is decisively influenced by the transverse reinforcement.

A precast concrete deck could be very attractive because the system can ensure the quality of concrete decks, improve working environments for the workers, and reduce man hours outdoors and traffic disruption. A shorter construction time could be an important factor in choosing precast deck bridges. A precast deck bridge has two types of connection: shear connection between steel girder and precast deck, and transverse joint between precast panels. Shim and Chang [4] suggested a design basis for longitudinal prestress of continuous composite bridges with full-depth precast decks having female-to-female joints through experimental and analytical studies.

Recently, Ryu et al. [5] carried out experimental works on the mechanical behaviour of precast concrete elements with loop joints. From the observation of crack distribution, crack widths, ductility and ultimate strength considering variable diameters of reinforcements and joint widths of cast-in-place parts, they suggested details of precast elements with loop joints.

However, in order to apply precast decks to continuous composite bridges, the tensile behaviour of precast decks or transverse joints between slabs in hogging moment regions should be confirmed in view of serviceability and durability. Particularly, stiffness of the composite section during cracking should be evaluated precisely, because it is very important to estimate crack widths, deflection and stress ranges applied to structural members under service loads. In this paper, an experimental test on a full-scale model of a steel and concrete composite plate girder with prefabricated slabs under hogging moments was cautiously conducted and observed in order to study crack control. Details of prefabricated slab transverse joints were determined from previous research [5]. The test specimen was an overhanging simple support beam, in total 28 m long. Through the four-point flexural test, the behaviour of the composite girder under hogging moments was observed. The test results showed crack development, crack widths and strain of the composite section before and after cracking. Initial cracking load and crack spacing were observed and the relations between crack spacing and transverse reinforcement spacing were studied. Moreover, the composite section behaviour of the precast deck with loop joints was confirmed. Test results were analyzed by design equations in each code for crack control. The flexural stiffness of the composite section after cracking is compared with that of the proposals in EUROCODE 4-2 and discussed.

2. Static test

2.1. Test specimen

The testing was carried out with the four-point flexural bending test. The span of the overhanging cantilever part is 11 m on either side. The length of mid-span simply supported is 6 m. Fig. 1 illustrates the composite plate girder section and elevation. This specimen is an effective one-girder full-scale model of a bridge designed by current Korean highway standard specifications. The bridge is a first rate three span continuous composite plate girder and four lane highway bridge (Fig. 2) having a width of 12.145 m.

In the test specimen, the precast deck panel was 260 mm thick and had three shear pockets for stud shear connectors (Fig. 1(b)). Details of transverse loop joints in precast decks were determined from previous research [5]. The longitudinal reinforcement ratio was 2.0%, which is a limitation for bridge slabs under hogging moments in Korean Highway Standard Specification [6]. 22 mm stud shear connectors were welded at 680 mm spacing for a full shear connection.

Vertical stiffeners were welded in supports, loading points and among those to prevent shear buckling failure and crippling of the web before flexural failure (Fig. 1(c)). Also, to prevent lateral torsional buckling of the overhanging beam, lateral bracings were installed at each end of the overhanging beam to allow vertical deflection but lateral displacement and rotation.

2.2. Fabrication procedure

First, the prefabricated slabs were placed on a steel plate girder. Then, shear pockets were filled with mortar for achieving composite action. Transverse reinforcements were arranged in loop joints and then filled with expansive concrete to connect precast decks longitudinally. A composite plate girder was completed as shown in Fig. 3.

2.3. Loading and measurements

The test specimen was an overhanging simply supported beam using roller supports (Fig. 4). A concentrated load was applied at each edge of the beam (Fig. 1(c)). A closed-loop