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Experimental study on static and fatigue strength of loop joints

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Abstract

In order to investigate the stiffness and strength of the loop joints, experimental studies were conducted. Two types of loading tests were performed which are static loading tests and fatigue loading tests. The test variables are the diameter of the loop bars and the width of the loop joint. Cracking, ultimate behaviour, ductility and fatigue behaviour of the loop joints were observed and compared with the behavior of RC beams without joints. From the test results, the mechanical behaviour of the loop joints was confirmed similar to that of ordinary RC beams without joints if the joint widths were enough in terms of development length concept for the anchorage of hook reinforcement. It was investigated that the overlapping section within the loop joint has similar or rather good mechanical characteristics to the RC beam section without joints. However, it is necessary to notice that a reduction of stiffness and strength could be occurring at the casting interface region in the loop joint RC members, especially with inadequate narrow joint widths. The design concept of the development length for the anchorage of hook reinforcement for the design of details of loop joints is recommended. Consequently, details of the loop joints were suggested and based on the fatigue test results, a S–N curve for the loop joints was proposed.

Keywords: Loop joints; Reinforced concrete beams; Stiffness and strength; Cracking; Ultimate behaviour; Ductility; Fatigue behaviour; Joint width; Development length

1. Introduction

The application of precast deck systems on bridges may provide numerous benefits such as fast construction, reduction of labor costs and securing of quality. However, in order to take full advantage of these merits, there is a need to have insight into and sufficient understanding of the structural joints that may constitute vulnerable points. Research has thus been continuously pursued on the characteristics and features of the joints in order to enhance the effectiveness of precast decks [2,3,7–10,12,13].

Joints of precast deck bridges can be distinguished as joints between decks and joints between deck and girder. In the case of a composite bridge, the joint between the deck and the girder appears in the form of a joint generally using a shear pocket in order to create composite action through a stud shear connection. Much research has already been devoted to this class of joint [7,13].

Joints between decks can be designed with prestressing introduced at the joints or with cast in place concrete used at the joints. Basically, the mechanical behaviour of the joint in terms of stiffness and strength is needed to be investigated. Moreover, the joint must be highly durable. Many serviceability problems such as cracking and water leakage at transverse joints were reported in several bridges [5]. Therefore, studies focusing on the strength, stiffness and serviceability at the joints must be conducted.

As the first step of research aiming to develop precast decks with loop joints [12], which are believed to be potentially competitive for newly-built bridges, this paper investigates the flexural behaviour of reinforced concrete beams with loop joints through 3-point and 4-point loading tests. The test variables are the diameter of the loop bars and the width of the loop joint. To investigate the stiffness and strength under service load and ultimate load, experimental work was analyzed in

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Table 1
Mix proportions of concrete

Strength (kgf/cm^2)	Aggregate max. size (mm)	Slump (mm)	W/C	S/a	Air (%)	Proportion by unit weight (kgf/cm^3)			
						Water	Cement	Fine aggregate	Coarse aggregate
400	25	15	31.7	41.5	4.5 ± 1.5	165	520	685	973

detail. Cracking behavior was observed through the crack load, crack width and crack distribution, and the ultimate behavior was evaluated by means of the yield load, ultimate load and ductility. These results were compared with the behavior of RC beams without joints.

Additionally, bridge decks being structures subjected to repeated loading such as traffic loads, investigation should be performed to evaluate the behavior of joints under fatigue load as well as their performance. This paper investigates experimentally the fatigue behavior and strength of loop joints with regard to the diameter of loop bar, loop joint width and applied load ranges. The test results were analyzed to evaluate the current domestic design code for fatigue of reinforcement bars and serviceability under repeated loading.

2. Experimental work

2.1. Details of loop joints

Currently, specific rules for details of loop joints do not exist in Korea [11]. Furthermore, foreign codes for these details cannot be found. Conservatively, the development length concept for the anchorage of hook reinforcement was used for the design of details of loop joints. Using the development length for a deformed bar in tension terminating in a standard hook in the ACI code [1], details of loop joints could be determined. The hooked bar anchorage provisions give the total hooked bar embedment length as shown in Fig. 1. The development length l_{dh} is measured from the critical section to the outside end (or edge) of the hook. l_{dh} shall not be less than the smaller of $8d_b$ and 150 mm. Also, the internal diameter of the hook reinforcement, D shall be greater than $6d_b$ for the reinforcement diameter, 10 mm to 25 mm.

From the ACI code, joint width, B as shown in Fig. 2, can be determined as 220 mm for 13 mm reinforcement bar, 250 mm for 16 mm reinforcement bar and 300 mm for 19 mm reinforcement.

In the German code, DIN 1045 [4], hook anchorage length shall not be less than 1.5 times the internal diameter of the loop rebar or 200 mm. From DIN 1045, joint width, B as shown in Fig. 2, can be determined as 250 mm for 13 mm reinforcement bar, 300 mm for 16 mm reinforcement bar and 350 mm for 19 mm reinforcement. The required joint width by the DIN code is more conservative than the joint width by the ACI code.

2.2. Material properties

The concrete used in this study is ready-mixed concrete with a design strength of 40 MPa. Table 1 shows mix proportions

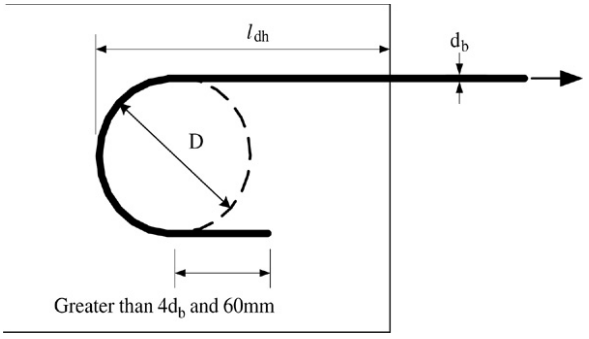

Fig. 1. 180 degree standard hook.

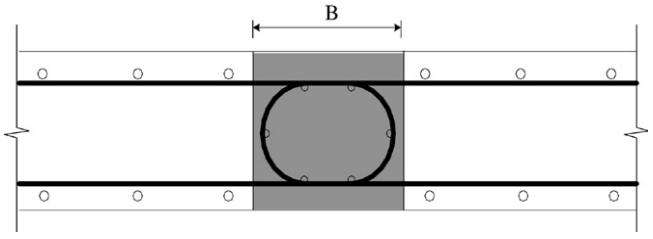

Fig. 2. Details of loop joints.

Table 2
Material strength (7 days strength, units: MPa)

(Units: MPa)	RC beam	Transverse joint*	Transverse joint**
Strength (MPa)	36	29	57

Transverse joint*: for 4-point load test specimens; Transverse joint**: for 3-point load test specimens.

of the concrete. The reinforcement used for the specimens is a deformed bar with yield strength of 400 MPa with diameters of 13, 16 and 19 mm. The expansive concrete cast in the joints incorporates a CSA type expansion agent in an amount corresponding to about 10% of the cement weight. Table 2 presents the material strengths obtained as the mean value of the measurements performed several times for each of the specimens of concrete used in the beam member and casting of the joints.

2.3. Test members and variables

Two types of loading tests were performed which are static loading tests and fatigue loading tests. For the static loading test, four-point loading tests were conducted to observe the flexural behaviour of loop joints under pure bending and three-