Structural behavior of lap-spliced joints in UHPC bridge deck slabs

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Abstract:

Ultra High Performance Concrete (UHPC) is a superior structural material with high strength and durability. The main objective of this study is to investigate behavior of the lap-spliced reinforced joints in UHPC. The lap-spliced joint type has simple details but it is expected to be highly effective method of joints in UHPC structure because of the high bond stress of UHPC. The static test was performed to verify the effect of the joint in the UHPC bridge deck slab. The major parameter considered in experimental plan was lap-spliced length and the strength of UHPC. Test results show that the minimum lap-spliced length which behaved similar to the continued reinforcement test specimen in strength and ductility was 150 mm (5.91 in.).

Keywords: UHPC, lap splice, deck joint, precast, bending test

1. Introduction

Ultra High Performance Concrete (hereafter ‘UHPC’) is one of the materials expected to be highly useful in the future construction industry. These expectations have gradually turned into reality (Graybeal, 2008; Kim et al., 2012; Resplendino, 2008). An increasing number of studies and results allow us to look at UHPC beyond the abstract concept defined by the numerical performance UHPC achieves as a construction material with high strength and durability. They also enable us to overcome typical limitations in concrete structures, thereby generating innovative design and construction methods. This study has experimentally investigated the static behavior of the flexural members and determined the minimum lap-spliced length as one of the simplest forms of joint by installing the lap-spliced joint suitable for thin members, including the bridge deck. Flexural members used in this study are copied from the UHPC deck precast segment.

2. Background

Reflecting the recent technical trends of accelerated construction, the precast method has been applied in a growing number of cases. Consequently, extensive studies of the joint have been also conducted. There have been reports on many cases that are based on different bond properties between individual materials. The case of the precast joint using UHPC as a fill material in the existing steel-reinforced concrete structure has been studied by Perry and Seibert (2012). In addition, the experimental study for interface behavior of the glass fiber-reinforced plastic composite beam, whose compressive section is filled with UHPC has been conducted (Raafat and Donna, 2012). Graybeal et al. (2012) also have carried out a test to assess connectability of precast deck panels using the section details as parameters.

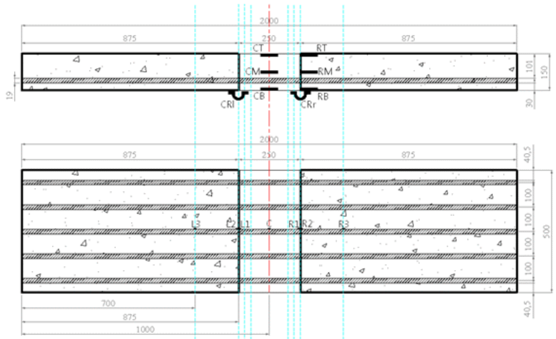
3. Testing Methods

3.1. Dimensions of Test Members

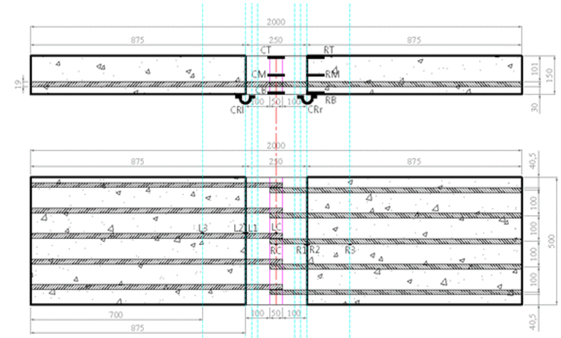
With the same dimensions and section details, a total of 10 test members were created considering the lap-spliced length and UHPC strength as major parameters. When it comes to the dimension, the test member has a length of 2000 mm (78.7 in.), a width of 500 m (19.7 in.) and a height of 150 mm (5.91 in.) with a 250 mm (9.84 in.) wide joint in the center part. The test members were fabricated based on block placement in which UHPC is cast in the joint after the curing of UHPC in the precast part. The dimensions and details of the test member are presented in Table 1. According to this table, A indicates the specimen in which cast-in-place joint has been subjected to steam curing. The compressive strength of this specimen is 184.0 MPa (26.7 ksi). On the other hand, B shows the specimen in which cast-in-place joint was dry-air cured in the winter season. In this case, the compressive strength is 138.6 MPa (20.1 ksi). The Arabic number indicates the lap-spliced length. A-0 and B-0 are arranged in a continuous manner without any joints even though they have joints. The dimensions of each test member are shown in Figure 1. The yielding strength and diameter of steel rebar was 400 MPa (26.7 ksi), 19.1 mm (0.75 in.), respectively.

Table 1. Specification of test members

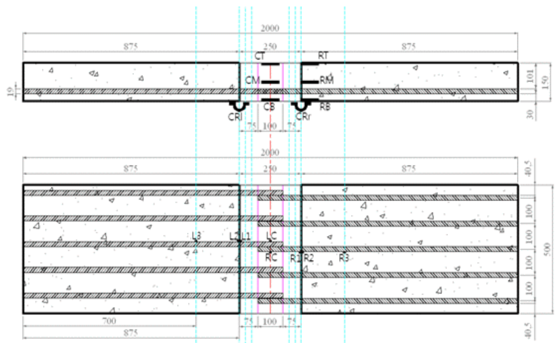
Specimens	Length		Width		Height		Joint width		Lap-spliced length		UHPC strength	
	in	mm	in	mm	in	mm	in	mm	in	mm	ksi	MPa
A-0	78.7	2000	19.7	500	5.91	150	9.84	250	0	0	26.7	184.0
B-0									0	0	20.1	138.6
A-50									1.97	50	26.7	184.0
B-50									1.97	50	20.1	138.6
A-100									3.94	100	26.7	184.0
B-100									3.94	100	20.1	138.6
A-150									5.91	150	26.7	184.0
B-150									5.91	150	20.1	138.6
A-200									7.87	200	26.7	184.0
B-200									7.87	200	20.1	138.6



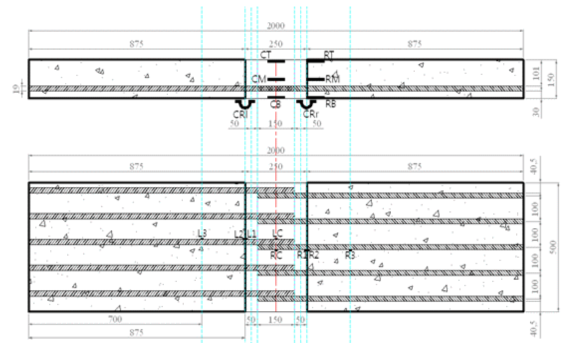
(a) Lap-spliced length 0 mm (0 in.)



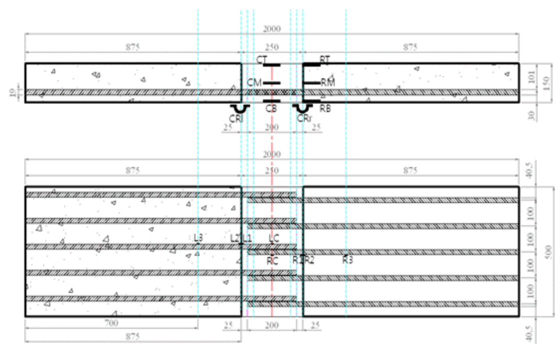
(b) Lap-spliced length 50 mm (1.97 in.)



(c) Lap-spliced length 100 mm (3.94 in.)



(d) Lap-spliced length 150 mm (5.91 in.)



(e) Lap-spliced length 200 mm (7.87 in.)

Figure 1. Dimensions and Details of the test members

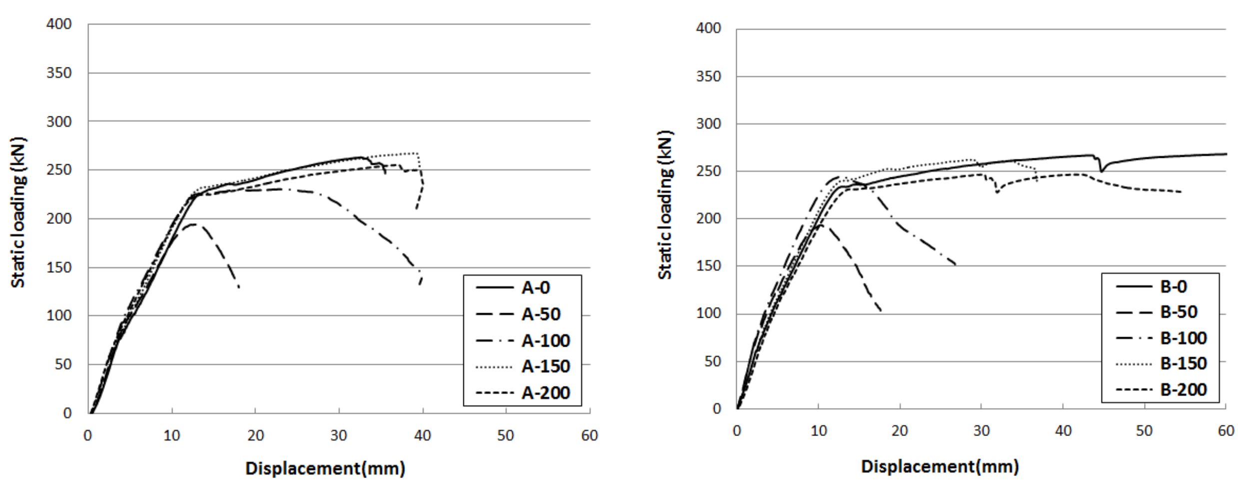
3.2. Static Load Test

The four-point bending test was carried out to cause the maximum bending moment in the joint and investigate the static behavior of the test member with the installation of joint. With possible fractures and safety issues taken into account, support points were placed 100 mm (3.94 in.) inside from the both ends of the test member, and the distance between the two support points was 1.8 m (70.9 in.). This distance was divided into three sections so that the interference of the shear behavior is excluded from the loading locations and the joint can be fully included in the maximum moment section. The section between the two support points was divided into three equal sections of 600 mm (23.6 in.), and the maximum moment occurred at the loading location of the central part of 600 mm (23.6 in.). Therefore, the 250 mm (9.84 in.) wide joint was fully included in the maximum moment section. In the test, the load was loaded at the same time to the two loading locations, whose distance of 600 mm (23.6 in.) was maintained by one hydraulic actuator system and frame. The loading speed was maintained at 0.02 mm/sec (0.0008 in. /sec) using the displacement control method. The test scene is shown in Figure 2.

Figure 2. 4-Points bending test

4. Results

The relation between the load and displacement was measured in the static load test. Figure 3 indicates each test member's relation curves between the load and displacement measured from the start to the end of the static load test. The maximum loads of each test member are listed in Table 2. Figure 4 indicates the relation graphs between the maximum load and lap-spliced length.



(a) Specimens A **(b) Specimens B**

Figure 3. Load-deflection relationship curves

Table 2. Results of maximum loads

Specimens	Bar diameter		Lap-spliced length		UHPC strength		Maximum load	
	in	mm	in	mm	ksi	MPa	kip	kN
A-0	0.75	19.1	0	0	26.7	184.0	59.15	263.13
B-0			0	0	20.1	138.6	60.50	269.13
A-50			1.97	50	26.7	184.0	43.64	194.10
B-50			1.97	50	20.1	138.6	43.47	193.38
A-100			3.94	100	26.7	184.0	51.80	230.40
B-100			3.94	100	20.1	138.6	55.06	244.92
A-150			5.91	150	26.7	184.0	60.13	267.48
B-150			5.91	150	20.1	138.6	58.97	262.29
A-200			7.87	200	26.7	184.0	57.37	255.21
B-200			7.87	200	20.1	138.6	55.46	246.72

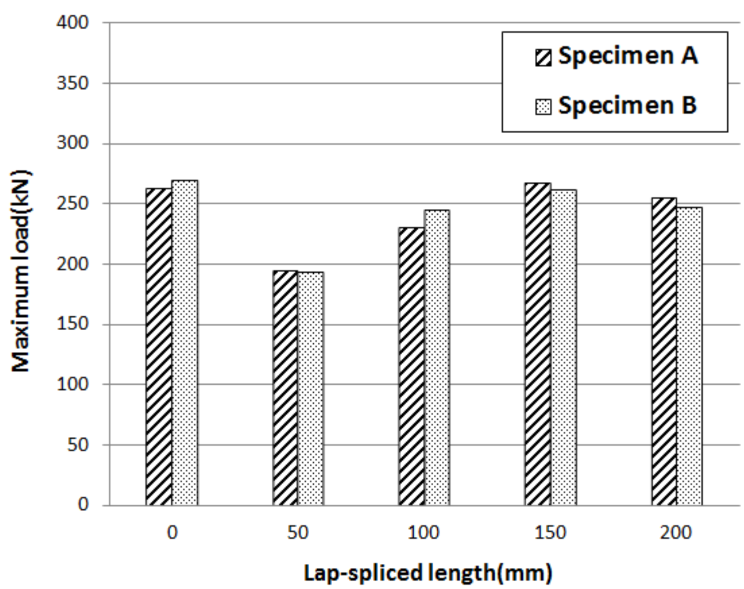
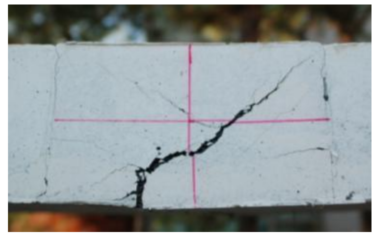


Figure 4. Test result of maximum load

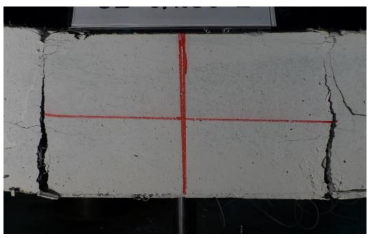
5. Discussion

Despite the high bond properties of UHPC, crack propagation was detected along the interface of the joint at the early stage of loading, as shown in Figure 5. The reason of this crack propagation was due to that UHPC was cast on the smooth surface of the joint produced by the steel form. There were differences in behavior depending on the lap-spliced length of the test members. The test members with the lap-spliced length of larger than 150 mm (5.91 in.) (A-150, A-200, B-150, B-200) showed similar behavior to that of other test members with continuous steel reinforcement. The slip found in lap-spliced joint of such specimens is very little and therefore it is expected not to affect the flexural behavior. The specimens with the lap-spliced length of 100 mm (3.94 in.) (A-100, B-100) behaved in a similar way before reaching the yield point. However, once it goes beyond the yield point, the plastic behavior was detected but limited compared to the test member having the lap-spliced length of longer than 150 mm (5.91 in.), and the maximum load decreased by approximately by 12 %. Test members with the lap-spliced length of 50 mm (1.97 in.) (A-50, B-50) were fractured even before reaching the yield point. Meanwhile, there were few differences depending on the strength of UHPC in the joint. This might be due to characteristics of flexural members; the ultimate behavior of the test members is dominated by the yield strength of steel reinforcement.

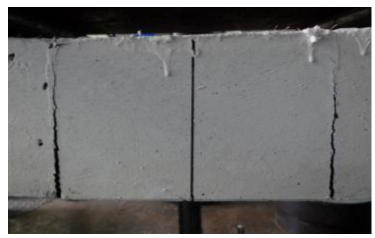
(a) A-0



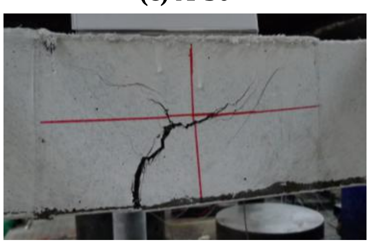
(b) B-0



(c) A-50

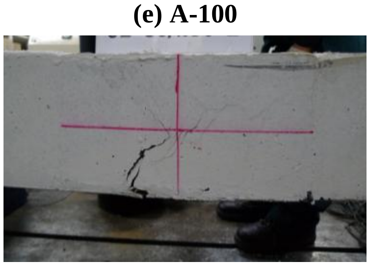


(d) B-50

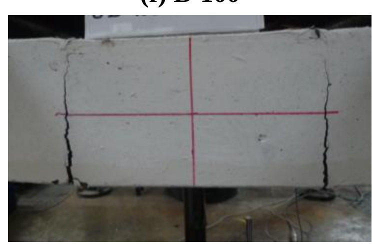


(e) A-100

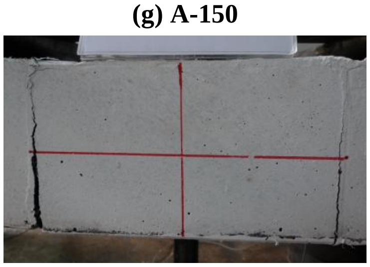
(f) B-100



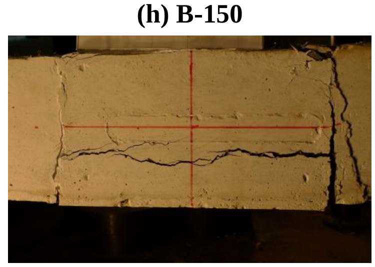
(g) A-150



(h) B-150



(i) A-200



(j) B-200

Figure 5. Failure pattern

6. Conclusions

We performed the test for the lap-spliced joint, which has been viewed as one of the simplest and most effective alternatives, which are suitable for thin members and making the most of the high bond stress of UHPC. We reached the conclusion by experimentally examining the lap-spliced length and the effect of the joint. It demonstrated that it is difficult to use steam curing method to cast-in-place concrete joints. Therefore, the minimum lap-sliced length has been proposed based on the results of the joints in which dry-air curing method was used. In the UHPC joint, the minimum lap-spliced length of 150 mm (5.91 in.) is required to secure continuity similar to that of continuous steel reinforcement. We believe that the conclusion above will be useful and provide basic information to help judge the appropriateness of lap-spliced joint for application of precast method for the UHPC bridge deck. We expect that the lap-spliced joint can be commercialized if the test of connectivity is carried out later taking into account usability and fatigue.

7. References

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