UHPC IN NON-PRESTRESSED REINFORCED CONCRETE (RC) CONTINUOUS GIRDER SECTIONS FOR BRIDGE ELEMENTS

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Abstract:

Research was being conducted to evaluate the use of ultra-high performance concrete (UHPC) versus high strength self-consolidating concrete (HS-SCC) in end girder connections of bridges. With its high compressive and tensile strengths, durability and chemical resistance, UHPC can be used to reduce high transfer stresses. The test matrix in this investigation consisted of two beams connected with a cold joint, a 6-in. (152 mm) wide joint cast using UHPC versus a more traditional HS-SCC and a monolithically casted control for reference. The flexural performance of the joint under four point loading with a high flexural moment was evaluated. The additional variables include: rebar detailing (straight lap) within the joints, the effect of surface preparation (i.e., smooth, roughened, and sand blasted) within the beam interface where the joint was to be developed, and yielding of reinforcement in the joint casted with UHPC versus HS-SCC. Favorable findings would accelerate the use of UHPC on a larger scale and will allow for the use of smaller joint widths, the use of longer spans for bridge girders, and the use of different detailing to help reduce the transfer stresses.

Keywords: Ultra-High Performance Concrete, High-Strength Concrete, Joints, Rebar Detailing, Surface Preparation, and Bridge End-Girder-Connections.

1. Introduction

Connections are one of the most critical components of bridges. They are subjected to very high transfer stresses and are often considered weak links in bridge structures. Connections often lead to failure of the structure because, in most scenarios, cast-in-place concrete, which is not very effective in transferring and sustaining structural loads, is used.

With high binder ratio and no coarse aggregate, ultra-high performance concrete (UHPC) has been used in bridge deck connections with successful results and has proven to be a material with multiple applications. The steel fibers that are used with UHPC have attributes like high compressive strength and durability that can prolong the life of structures when used in connections.

The objective of this research was to use UHPC in place of high-strength SCC (HS-SCC) in end girder connections and evaluate its performance when subjected to a high moment load, which is the worst-case scenario in terms of real structural loading. The other objectives were to use a straight-lap detail in the connection and three different types of surface preparations (no preparation, roughening and sandblasting) for the beam-joint interface.

2. Background

Using UHPC in joints is not a new practice. UHPC has been successfully used in field-cast deck-level connections, significant research has been done in this region by Graybeal, B. (2010), for FHWA with much success. UHPC has been successfully used in bridge elements in USA, Canada, Europe, Australia and Japan (Perry, 2010). End-to-end connections in girders are subjected to critical stresses and are often neglected in design and execution. Using UHPC in connections would reduce the load on these connections and their improve ductility and service life. Research has been conducted in deck-level connections using different joint details like straight-lap, hairpin etc. For this research, a straight-lap joint was used as it proved to be simple and economical and performed better.

Figures 1 & 2. Specimen during testing, straight-lap reinforcement detail in the joint

UHPC is characterized by its high compressive and tensile strengths, durability, ductility, and chemical resistance, resistance to weathering and low permeability. Coarse aggregate is not used in UHPC. A high binder ratio and low water cement ratio are typical features of the UHPC.

3. Experimental program

3.1. Test Matrix

The test matrix consisted of 8 beams, 2 controls, 3 HS-SCC joint beams and 3 UHPC joint beams. The specimens were 84-in. (2,134 mm) in length, and each one contained a 6-in. (152 mm) joint. The control specimen, B-1-C-N-N, was cast monolithically without a joint. The remaining beam specimens with straight-lap reinforcement details were cast with conventional concrete (CC) and their joints were filled with HS-SCC and UHPC. The joint detail consisted of rebars lapped for 6 -in. (152 mm) of length as shown in Figure 2. One of the surface preparations involved a roughened surface where 0.25-in. (6.4 mm) thickness of the concrete layer was removed. Sand blasting was undertaken until an exposed aggregate finish was visible.

Table 1. Test Matrix

Sl.no.	Nomenclature	Beam	Joint Type	Surface Prep.	Joint Detail
1	B-1-C-N-N	CC	NO-JOINT	Smooth/as-cast	Straight
2	B-2-C-N-S	CC	NO-JOINT	Smooth/as-cast	Straight
3	B-5-H-N-S	CC	HS-SCC	Smooth/as-cast	Straight
4	B-8-H-R-S	CC	HS-SCC	Rough	Straight
5	B-11-H-S-S	CC	HS-SCC	Sand blasted	Straight
6	B-14-U-N-S	CC	UHPC	Smooth/as-cast	Straight
7	B-17-U-R-S	CC	UHPC	Rough	Straight
8	B-20-U-S-S	CC	UHPC	Sand blasted	Straight

The mix designs used for CC, HS-SCC, and UHPC are presented in the Tables 2, 3 and 4, respectively. The reinforcement details are given in Figures 2, 3, & 4. The CC mix was cast using ready-mix-concrete. The HS/SCC mix used was designed at Missouri S&T for use in the Highway 50 Bridge (Myers, et.al. 2014). The UHPC-modified mix (Meng, W., et al., 2016) was designed for use at Missouri S&T. All the materials were cured by using wet burlap for three days.

The HS-SCC mix was designed to give a compressive strength of 10 ksi (69 MPa), and the UHPC was designed to give a compressive strength of 18 ksi (124 MPa). UHPC is characterized by an absence of coarse aggregate, which enables a better particle packing density and higher strength. Steel fibers (diameter-0.008-in. (0.2 mm), length-0.5-in. (12.7 mm), tensile strength-313 ksi (2158 Mpa)) are used with UHPC to increase the tensile strength, which is key factor in UHPC's success.

Table 2. Conventional Concrete (CC) Mix Design

Material	Amount kg/m^3 (lb/yd^3)
Portland Cement Type I/II	364 (614)
1" Concrete Stone	1002 (1689)
Missouri River Sand	906 (1527)
Water	120 (202)
Water/CM	0.33

Table 3. High Strength/ self-consolidating concrete (HS-SCC) Mix Design

Material	Amount kg/m^3 (lb/yd^3)
Portland Cement Type I/II	504 (850)
Missouri River Sand	850 (1433)
3/8" Crushed Stone	795 (1340)
High Range Water Reducer	57 (96)
Water	166 (280)
W/CM	0.33

Table 4. Ultra-High Strength Concrete (UHPC) Mix Design

Material	Amount kg/m^3 (lb/yd^3)
Portland Cement Type III	504 (850)
Silica Fume	41 (70)
GGBS	535 (902)
Missouri River Sand	708 (1194)
Masonry Sand	310 (523)
High Range Water Reducer	70 (117)
Steel Fibers	156 (263)
Water	146 (246)
W/CM	0.13

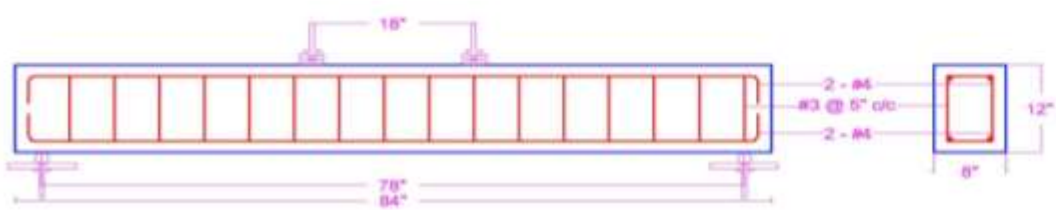

Figure 3. Reinforcement Detail of Control

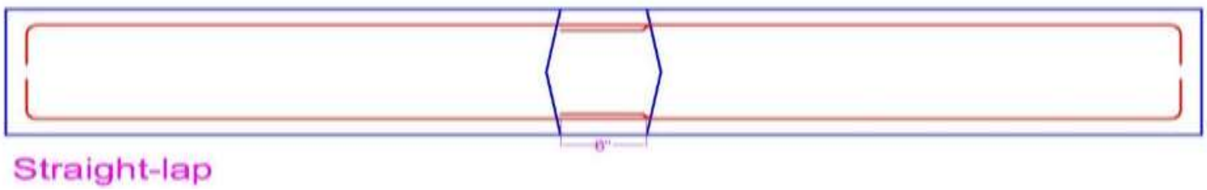

Figure 4. Reinforcement detail of joint for all specimens

3.2. Test Method

The specimens were tested for failure in flexure using four-point loading. The points of loading were 9-in. off the center of the specimen on either side, as shown in Figure 5. The load deflections at the center and quarter span were measured along with crack propagation. The results of these tests are given in the following sections. Though the joints in bridges are not subjected to high moments, the incentive behind applying a high moment was to recreate a worst-case scenario in the joint. A load rate of 0.02-in./min was applied until the specimen reached failure (crushing of concrete in compression zone, slippage of rebar, and drop in peak load by 20%, or rebar rupture).

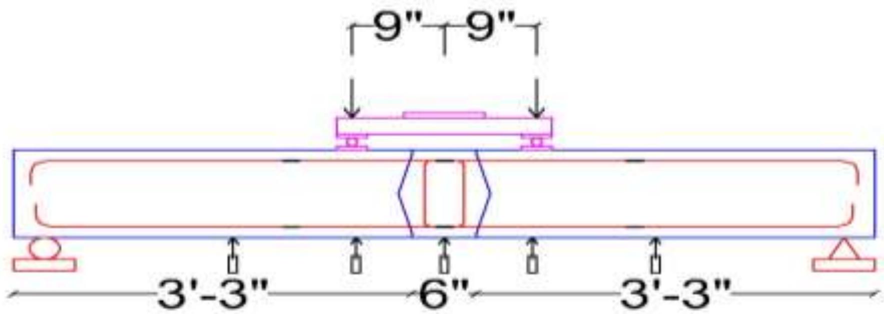

Figure 5. Test setup

4. Results and Discussion

The HS-SCC joint beams did not perform as expected (as compared to the controls) as specimens failed due to slippage in the joint region before the beams fully engaged in flexure. The UHPC joint beams performed similar to the controls and were even more ductile. The failure was due to the crushing of concrete in the compression region rather than slippage as was the case in the HS-SCC joint beams. Table 5 summarizes the peak load and deflection results from the experimental program.

Table 5. Test Results (Conversion: 1 Kip→4.4 KN, 1 inch→25.4 mm)

Nomenclature	Joint Detail	Joint Filler	Surface	Load (Kips)	Deflection (inches)
B-1-C-N-N	Control	-	NO-JOINT	31.0	0.8
B-2-C-N-S	Straight-lap	CC	Smooth	12.7	0.2
B-5-H-N-S		HS-SCC	Smooth	7.5	0.2
B-8-H-R-S		HS-SCC	Rough	6.8	0.1
B-11-H-S-S		HS-SCC	Sand blasted	9.2	0.2
B-14-U-N-S		UHPC	Smooth	30.3	2.0
B-17-U-R-S		UHPC	Rough	30.6	1.6
B-20-U-S-S		UHPC	Sand blasted	30.4	1.5

The control reached a peak load of 31 kips (138 KN) which exceeded the predicted design strength of 24.8 kips (110 kN). Beams with HS-SCC joint beams that had different surface preparations reached a peak load of only 12.7 kips (56 KN), while the UHPC joint beams performed exceptionally well with a peak load of 30.6 kips (~ 31kips/138 KN). The deflection results also indicate that the UHPC (~2-in./51 mm) is a far better joint filler than HS-SCC (~0.2-in./5 mm).

The control specimen B-1-C-N-N failed due to crushing of the concrete in the compression zone. Similar behavior was seen in the UHPC joint beams (crushing in the beam region outside the joint) with the rebar along the beams' joint interfaces rupturing in some cases. No failure in UHPC was observed). The HS-SCC joint beams failed due to slippage of the rebar in the joint region, which might be the reason for the low flexural capacity of the HS-SCC joint beams. The effect of surface preparation was insignificant except for roughening which improved the capacity by a small amount.

As the results indicated, the ductility of UHPC beams was much higher than that of the controls or HS-SCC beams, which can be seen in Figures 5, 6 and 7. Figure 9, 10, and 11 show that the crack propagation in UHPC joint beams was similar to the control. The flexural cracks started from the tensile zone and propagated to compression zone, resulting in crushing of the concrete in the compression zone. The testing was stopped after the load dropped by 20% of the peak load or if slippage was observed.

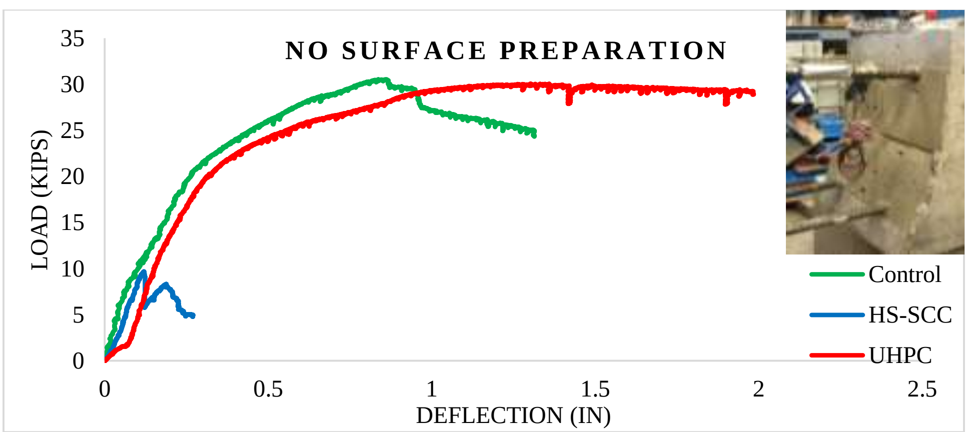

Figure 6: Load versus deflection plot for No surface preparation

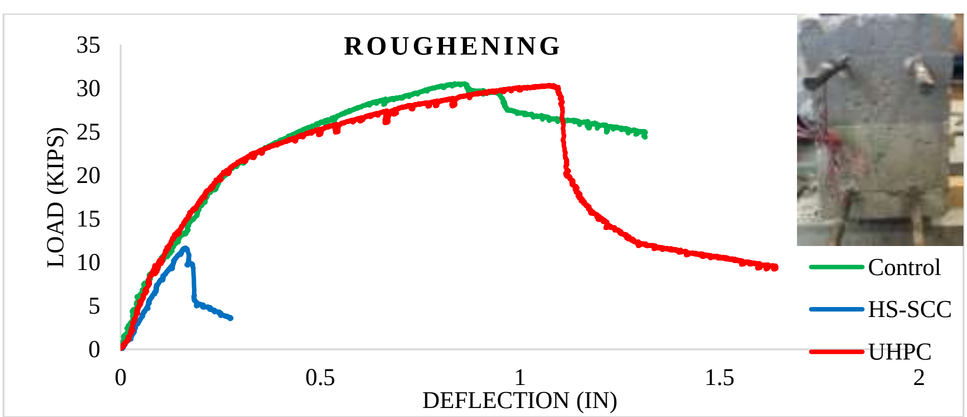

Figure 7: Load versus deflection plot for Rough surface preparation

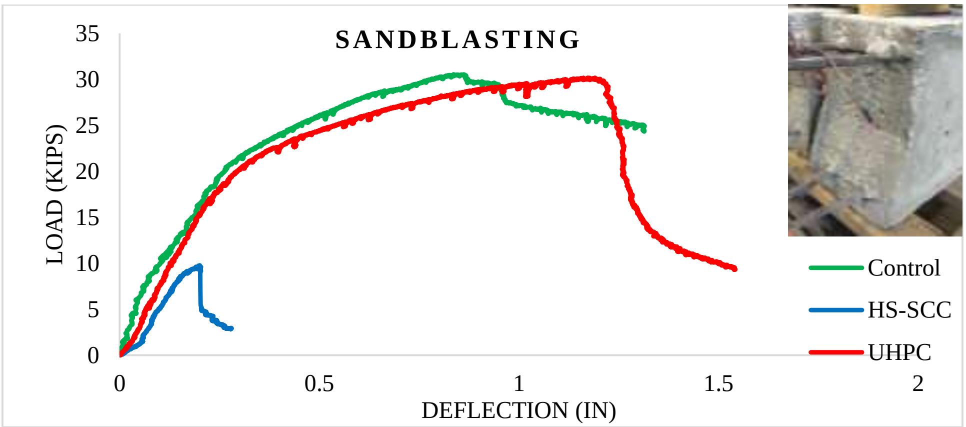

Figure 8: Load versus deflection plot for Sand blasted surface preparation

The higher ductility exhibited by the UHPC joint beams is a good indicator for longer sustainability and service life of the bridge structures. The steel fibers used in UHPC increase the tensile strength of concrete, which enhances the concrete's performance as can be seen through this experimental program. Figures 8, 9, and 10 present the specimens after failure and show how closely the UHPC joint beam (Fig. 11) behaves like the control (Fig. 9) when compared to the HS-SCC (Fig 10). The UHPC joint fully engaged the beams, while the HS-SCC joint slipped very early on during loading, resulting in low loads.

5. Conclusions

- Beams with UHPC in the connections performed similar to beams without joints.
- The HS-SCC did not perform as expected with low capacity and ductility
- The UHPC joint beams were more ductile than the control and HS/SCC beams due to the steel fibers used in the UHPC.
- Roughening of the surface improved the flexural capacity slightly. The overall effect of the surface preparation of the beam's joint interface was insignificant.
- The UHPC beams failed with crushing of the concrete in the compression zone (similar to the control).
- The HS-SCC beams failed with slippage of the rebar in the joint region which is not desirable.
- The straight-lap detail used with the UHPC is simple, economical, and easy to maneuver and resulted in good performance due to sufficient lap length.
- No cracks were formed in the UHPC joint, while horizontal cracks were observed in the HS-SCC joint beams through the tensile region indicating slippage as the type of failure.
- The flexural crack propagation (Fig.11) through the UHPC beams indicates that the beams were fully engaged in the mechanism, resulting in a better performance of the structure.

6. Future Work:

Successful results in this research have led to further research in this area. The future research being done in this area includes

- Using hairpin detail in the joint with lap length of 3.9 inches (99mm) with UHPC versus HS/SCC with three different beam surface preparations.
- Using anchored-rebar detail in the joint with lap length of 3.4 inches (89mm) with UHPC versus HS-SCC with three different beam surface preparations.
- Using typical MoDOT prestressed end-girder detail in a Non-prestressed modified detail using UHPC in the joint instead of typical MoDOT-B (deck) mix to evaluate use of UHPC with MoDOT detail.
- This research focused on connections in high-moment regions, one of the aspects that could be further studied are connections in pure shear (to better study effect of surface preparation) and connections in shear and bending.

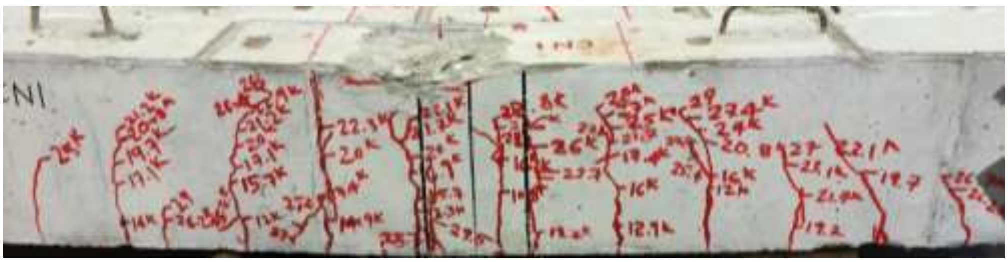

Figure 9: Control beam after failure

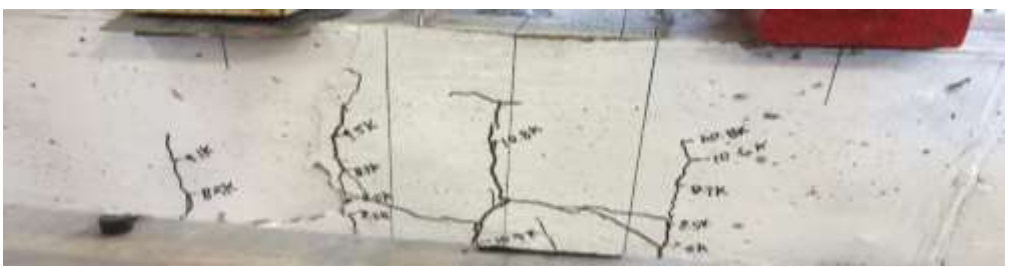

Figure 10: HS-SCC joint beam after failure

Figure 11: UHPC joint beam after failure

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