Multi-Span Lateral Slide Laboratory Investigation: Phase II

tech transfer summary

December 2022

RESEARCH PROJECT TITLE
Multi-Span Lateral Slide Laboratory Investigation: Phase II

SPONSORS
Iowa Department of Transportation
(InTrans Project 22-786)

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

Iowa State University
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HR-3037

This project investigated how soon a bridge can be opened to traffic or construction loading using noncontact lap-spliced reinforcing steel bar and ultra-high performance concrete or a hybrid composite synthetic concrete for the closure joints between the super- and sub-structure with slide-in bridge construction.

Project Background

One form of accelerated bridge construction (ABC)—slide-in bridge construction (SIBC)—is completed by constructing the bridge superstructure adjacent to the final alignment on temporary works, typically adjacent to the existing bridge being replaced. Upon completion, the superstructure is slid onto the permanent substructure.

Once the slide is complete, closure joints between the bridge super- and sub-structure are cast to establish continuity. The time to complete the joint and the time-dependent cure of the fill materials establish when the bridge can be opened to traffic or construction loading.

Research Objective, Focus, and Scope

The objective of this project was to investigate the performance of the ultra-high performance concrete (UHPC) closure joint reinforced with noncontact lap-spliced reinforcing steel bar, with a specific focus on determining when a noncontact lap splice has sufficient strength to either open a bridge or expose it to construction loading.

In addition, the research was conducted to explore and compare an alternative material, hybrid composite synthetic concrete (HCSC), that may be able to provide sufficient early-age capacity at less overall cost than UHPC when used as the closure-joint material.

Closure joint between super- and sub-structure during the construction of a multi-span bridge using SIBC on IA 1 over Old Man's Creek southwest of Iowa City

Problem Statement

While Phase I of this project included observation and monitoring of slide-in construction and proved the efficacy of SIBC, one significant question remained: At what point could the bridge be subjected to construction loads or vehicular loads without compromising the strength and performance of the UHPC closure joint between the bridge pier diaphragm and the pier cap?

Research Description/Summary

Task 1: Summarize Phase I findings and complete literature review

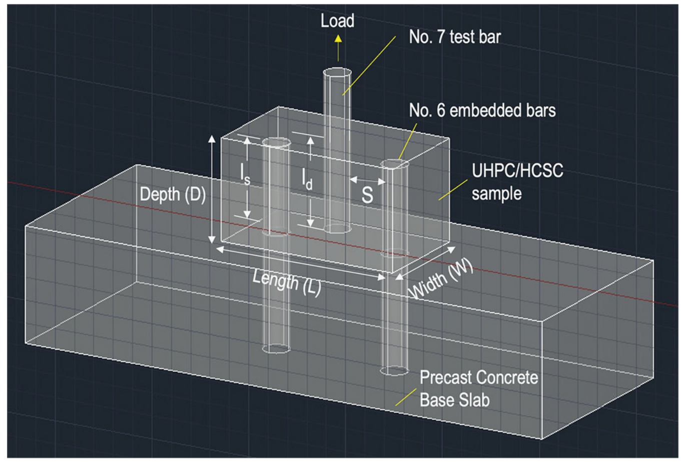
Task 2: Conduct time-dependent noncontact lap-splice strength tests

Task 3: Complete data analysis and develop recommendations

To complete the research goals, a literature review was first conducted to collect and summarize the published information related to the performance of UHPC or HCSC closure joints reinforced with noncontact lap-spliced rebar. Material properties, which are detailed in the final report for this project, were also tested and compared.

Laboratory work was performed on 96 samples in four noncontact lap-splice connection designs with different rebar development lengths and joint filling materials. These test specimens were made by casting UHPC or HCSC blocks atop a precast concrete slab.

Direct tension pull-out tests for the four configurations were completed with Design 1 aimed to mimic the closure joint that was used to connect the bridge pier diaphragm and pier cap of the Phase I three-span, 300 ft long, steel girder bridge on IA 1 southwest of Iowa City.



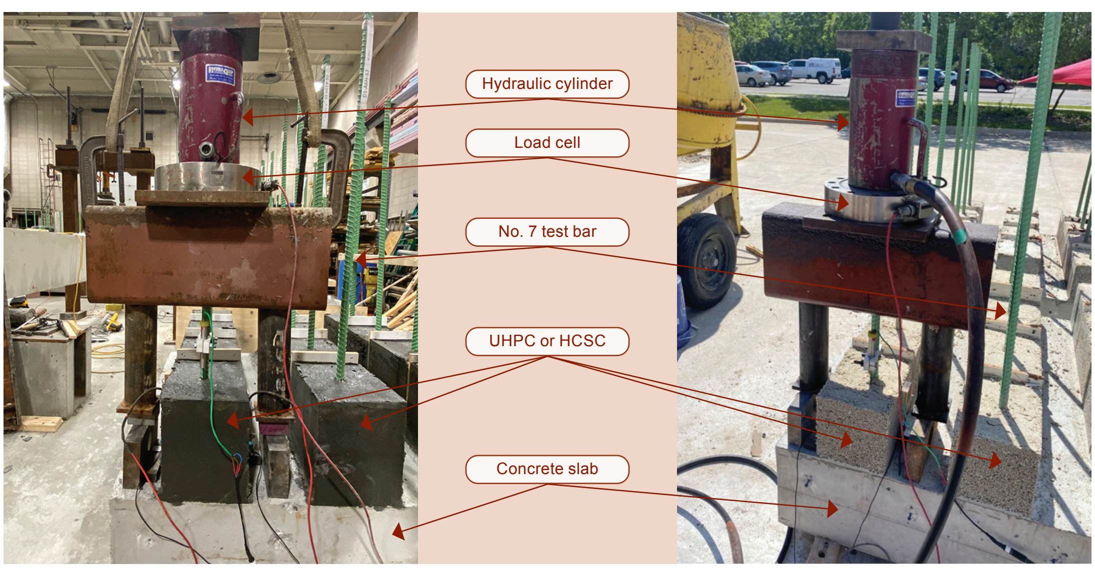
Specimen design for direct tension pull-out tests (with four design specifications detailed in the table)

Specimen design specifications

Design ID	Sample geometry (in.)	Design parameters (in.)	Grouting material
Design 1	L = 12 W = 8.25 D = 10	l_d = 9 l_s = 8 S = 4	UHPC
Design 2	L = 12 W = 8.25 D = 9	l_d = 8 l_s = 7 S = 4	UHPC
Design 3*	L = 12 W = 8.25 D = 6	l_d = 5 l_s = 4 S = 4	UHPC
Design 4	L = 12 W = 8.25 D = 9	l_d = 8 l_s = 7 S = 4	HCSC

*Headed rebar

UHPC samples cast at room temperature



HCSC samples cast outside the structural lab at a temperature of about 80°F

Experimental pull-out test setups with specimens cast on top of precast concrete slabs

The time-dependent pull-out tests that were performed focused on the performance of the material at early age for each design. Each sample was loaded with a pull-out force until failure. The ultimate capacity of each sample was captured and analyzed.

Key Findings

- The UHPC material strength at an age of 12 hrs was insufficient to fully develop the reinforcement bars. At that time, the pull-out force for all three UHPC lap-splice designs (Design 1, Design 2, and Design 3) was less than 10% of the ultimate capacity at full strength. When the UHPC reached one day in age, Design 1 had a greater capacity than Design 2 or 3, and the rebar stress at failure for Design 1 exceeded the bar yield strength of 60 ksi. At 1.5 days, all UHPC connection designs reached the bar yield strength before failure.
- The compressive strength of HCSC quickly increased to near full strength within the first 12 hrs. In fact, the pull-out force (40 kips) required to fail the HCSC connection (Design 4) exceeded the force at which the reinforcement bar yields (36 kips) at 6 hrs.
- The lab test results showed that the confinement condition adjacent to the lap-spliced connection could affect the ultimate capacity. That is, when restraint to splitting failure mode due to continuous joint material adjacent to the point of interest exists, the ultimate capacity trends higher than the alternative. Hence, prediction equations with respect to one- and two-sided restraint situations were established for the estimation of the time-dependent ultimate capacities for each design.

Implementation Readiness and Benefits

ABC offers several advantages to bridge construction projects including reduced impact to the traveling public and increased safety to onsite laborers. The closure pour is the last major step in completing the lateral slide with SIBC, and identifying how soon the joint achieves the necessary strength could allow for additional time savings.

The HCSC samples showed better performance with respect to the ultimate pull-out capacity than the UHPC samples during the earliest stages of material cure (before 1.5 days) when comparing the UHPC samples (Design 1, Design 2, and Design 3) to the HCSC samples (Design 4). HCSC gains strength quicker than the UHPC and could provide a solution for joint fill material if a very accelerated timeline is required (e.g., open bridge to traffic or construction loading in less than 24 hrs).

When this research was completed, the material cost comparison of UHPC to HCSC was nearly 2 to 1. It is expected with time and the additional popularity of UHPC, costs will comparatively decrease. Each material has its respective performance advantages, but in situations where each meets the minimum performance requirements, the material of lesser cost becomes appealing, especially where widespread use is planned.

Considering the cost of both materials, HCSC presents a viable alternative material to UHPC (similar minimum durability and strength properties exist) for short lap construction joints with SIBC and contributes to making SIBC cost competitive to staged construction.

Implementation Recommendations

With respect to the time-dependent performance of the noncontact lap-spliced connections evaluated as part of this research, the following recommendations are offered.

- **When using the development of bar yield strength as the minimum threshold for connection capacity, the connection can be considered for traffic or construction loading 24 hrs after the lap-spliced connection is placed if Design 1 is used, 36 hrs after construction when Designs 2 and 3 are used, and 6 hrs after construction when Design 4 is used.** The depth of connection, total lap length, bar configuration (straight/headed), and cementitious material varied between designs. Note that the capacities in the report are presented without factors of safety, the magnitude of which are left to be decided by the engineer.
- **Earlier age load application can be entertained when two-sided restraint is taken into consideration.** Based on the experimental results, pull-out capacities are affected by the presence of continuous joint material (UHPC or HCSC) and reinforcement adjacent to the bar being evaluated. The capacity requirement for the connection between the bridge super- and sub-structures will be uniquely calculated for each bridge structure. The researchers recommend that the prediction equations in the final report for this project be used to assess when the required capacity is met.
- **For the greatest capacity using UHPC, the researchers recommend Design 1 over Designs 2 and 3.** The ultimate capacities for the Design 1 samples tested at each prescribed point in time were always higher than those for Designs 2 and 3. Design 1 does require greater quantities of UHPC, which is likely to increase placement time and material costs.

- **For connections requiring very high early strength, the researchers recommend HCSC over UHPC.** The researchers further recommend working closely with the material supplier, particularly given the HCSC as mixed for this study had low flowability, which could impact complete fill of a gravity-fed closure pour. Discussion and effort to increase the flowability of the material is advised based on the research team's understanding that HCSC can be made more flowable without affecting the strength and durability attributes of the material.
- **When reduction of the total height of the closure pour connection is necessary, the researchers recommend that headed bars be considered for use given they offer capacities similar to straight rebar in connections of greater height.** Both Designs 2 and 3 were designed based on Federal Highway Administration (FHWA) guidance, and the results showed similar ultimate capacities for each design at each point in time during test completion.