PERFORMANCE OF DECK-LEVEL CONNECTIONS BETWEEN PRECAST CONCRETE COMPONENTS – CONCEPT AND EARLY RESULTS

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ABSTRACT

The growing demand for accelerated construction of highway bridges has focused significant attention on the constructability and long-term performance of the connections between prefabricated bridge components. An ongoing research program at the Federal Highway Administration's Turner-Fairbank Highway Research Center is aiming to advance the state-of-the-art for Prefabricated Bridge Elements and Systems (PBES) connections. One phase of this study is focusing on the deck-level connections frequently deployed between precast concrete deck panels or between adjacent predecked members. This phase is systematically investigating the range of parameters which are frequently considered during the design of these connections, including shear key shape, reinforcement type, grout type, and precast surface preparation. The testing is focused on the structural performance of full-scale deck specimens loaded in four-point bending with midspan connection details. Constructability, early age grout behaviors, connection performance under cyclic loading, and ultimate capacity are being investigated. At least 60 specimens will be tested, with the results providing a comparison of performance in terms of design parameters.

Keywords: Accelerated Construction, Bridge, Concrete, Connections, Grout, UHPC

INTRODUCTION

The growing demand for accelerated construction of highway bridges has focused significant attention on the constructability and long-term performance of the connections between prefabricated bridge components. An ongoing research program at the Federal Highway Administration's Turner-Fairbank Highway Research Center is aiming to advance the state-of-the-art for Prefabricated Bridge Elements and Systems (PBES) connections. Deck-level connections between precast concrete deck panels and between decked girders are commonly deployed in accelerated bridge construction projects. Given their location within the bridge, these connections are both critical to the performance of the superstructure and susceptible to degradation from traffic and environmental loadings.

One common type of deck-level connection includes discrete reinforcement combined with a field-cast concrete or grout. A wide variety of designs have been deployed in recent decades, and a variety of performances have been observed. This study is focused on systematically assessing the performance of these types of connections through full-scale structural testing. Concurrently, characterization of the materials behaviors will allow for clearer understanding of the mechanical performance of the connection system[1]. Overall, owners will be provided with quantitative measures which can be engaged during connection design and will afford increased awareness of anticipated performance.

TESTING PROGRAM

The testing program is structured in two phases: deck-level connections phase and bond characterization phase. The deck-level connection phase facilitates the assessment of the structural performance of the connections, including grout bond to precast concrete, cracking/splitting of cast-in-place and precast materials, and bond performance of discrete reinforcement. The bond characterization phase facilitates the systematic assessment of the bond strength at the interface between the cast-in-place and the precast materials. The following section describes each phase in more detail.

DECK-LEVEL CONNECTIONS PHASE

The deck-level connection test specimens consist of two precast concrete deck panels (approximately 5 feet long by 28 inches wide by 6 inches thick) joined together by a cast-in-place connection. Typical deck panels with grouted connections are shown in Fig. 1.

Fig. 1 Casting of deck–level connection specimens: Non-shrink grout connections with 8”, 12” and 15” non-contact bar laps are shown.

The variables followed in this phase are summarized below:

1. Grout type: non-shrink grout, magnesium phosphate grout, epoxy grout, and ultra-high performance concrete (UHPC)

2. Lap design**:** *Reinforcing Bar Lap Lengths*: 5.5, 8, 12, and 15 inches; *Lap type:* Contact (true lap splice) or non-contact

3. Longitudinal Reinforcement: mild steel, glass fiber reinforced polymer (GFRP), epoxy coated, and headed bar.

4. Transverse reinforcement: none, one #4 bar, two #4 bars, or two #5 bars.

5. Shear key: triangular or trapezoidal (shown in Fig. 2), formed with either wood or steel

6. Surface preparation: power wash, sandblast, exposed aggregate (shown in Fig. 2), and epoxy bonding agents.

Fig. 2 Trapezoidal shear key with exposed aggregate surface.

The test setup for these deck-level connection specimens consists of a four point bending configuration that generates one-way bending with a constant moment on the connection. A photograph of the test setup is provided in Fig. 3.

Fig. 3 Deck-level connection specimen test setup.

The testing of each deck-level connection specimen is divided into two phases. The first phase is focused on assessing the initial cracking behaviors of the test specimen in the vicinity of the connection. The second phase assesses the fatigue performance of the connection. The loading protocols are described below.

Cracking Phase

The loading protocol for this phase is intended to facilitate identification of initial cyclic cracking. A total of 100,000 cycles are applied to the specimens in incrementing steps using loads at different percent levels of the theoretical cracking load. A total of 10 steps, each step containing 5,000 cycles, with loads incrementing from 30% to 120% of the theoretical cracking load (6.2 kips) are first applied to the specimen. Then, another group of 50,000 cycles at 120% of theoretical cracking load is applied. The entire cracking protocol is executed for each specimen regardless when “first” crack is identified. Note that the theoretical cracking load, 6.2 kips, is based on the design compressive strength of the precast concrete and the geometry of the test setup and specimen. After the completion of the 80%, 100%, and 120% increments, the loading is paused and the panel is visually inspected for cracking. The cracking phase loading protocol is illustrated by Fig. **4**.

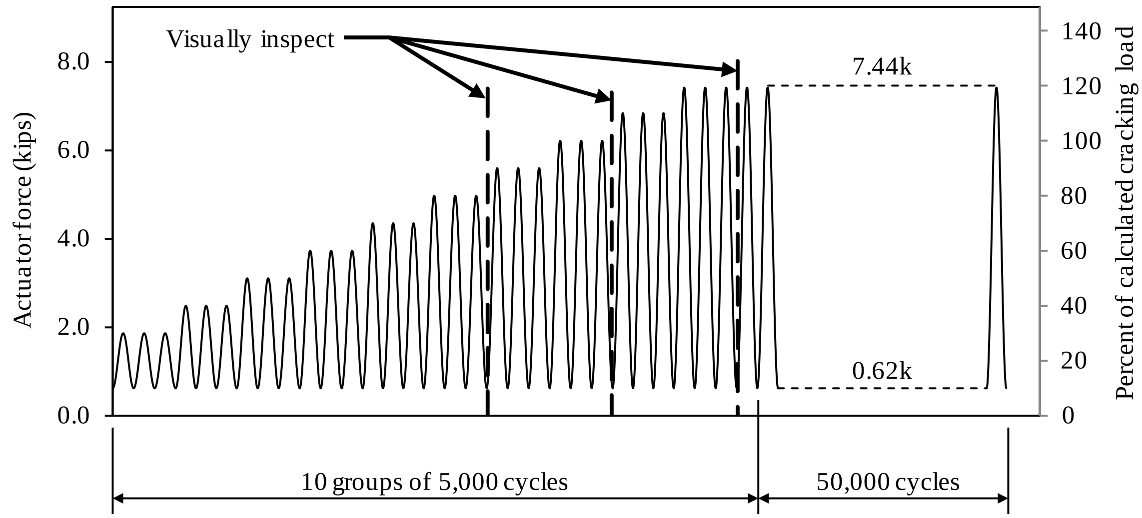


Fig. 4 Panel test loading protocol – Cracking Phase

Fatigue Phase

The loading protocol for this phase is intended to cause further damage to the connection without causing metal fatigue failure of reinforcing bars. The application of identical loading to each specimen will allow for the differentiation of connection performance levels between the varieties of specimens tested. Precursor testing indicated that this loading scheme generated high stresses in the connection while remaining just below the load range which would cause metal fatigue failure in mild steel reinforcement.

The fatigue phase begins with 20,000 cycles that act as transition between the maximum load in the cracking phase and the 2 million fatigue cycles. The transition cycles are divided in 4 groups (5,000 cycles/group) that "ramp up" from the maximum load applied during the cracking phase to a load of 10.89 kips that is used during a majority of the fatigue cycles. The 10.89 kip load corresponds to a calculated stress range of 20 ksi in the reinforcement. The loading protocol then continues with fatigue loading which consists of a group of 100,000 cycles that is repeated 20 times. The cycle group consists of 1,000 "overload" cycles (17.63 kips) followed by 99,000 fatigue cycles (10.89 kips). The overload cycles correspond to a calculated stress range in the reinforcement of 60% of the nominal yield strength. At the conclusion of fatigue phase, each specimen is monotonically loaded to failure. The fatigue phase loading protocol is illustrated by Fig. **5**.

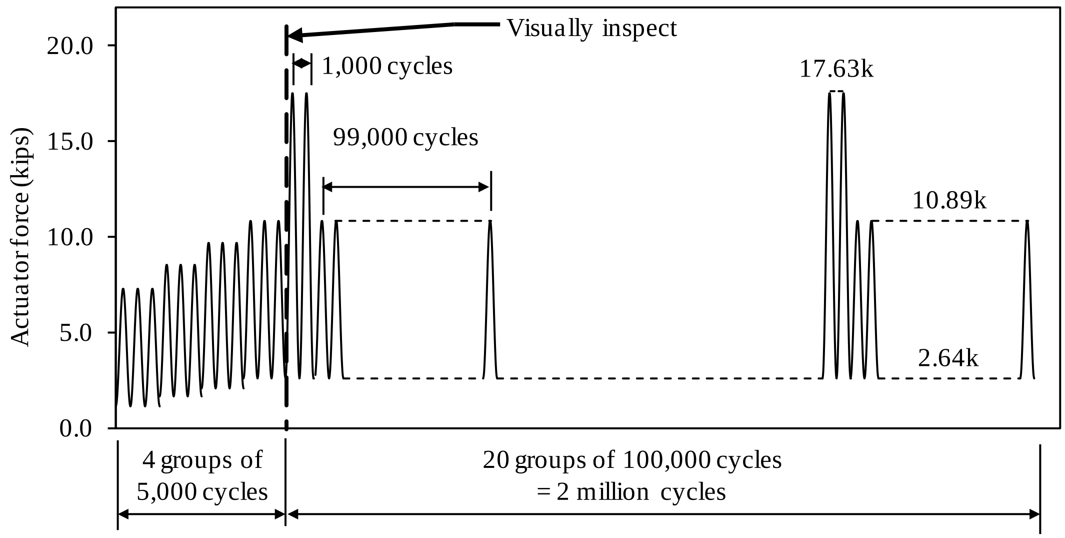


Fig. 5 Panel test loading protocol – fatigue phase

The deck-level connection specimens are instrumented to capture the structural response. The purpose of the selected instrumentation is to determine when the first cyclic cracking occurs, monitor the deflection of the connection at center line, and assess how the stiffness of the specimen changes throughout the cyclic load application. Each deck-level connection specimen includes three LVDT's and three strain gages that are affixed to the specimen. Two LVDT's are installed to measure opening across the bonded interface, while the third one is installed vertically on the transverse center line of the grout connection to measure the midspan deflection. Two strain gages are installed at the interface of the connection (both faces) to identify first cracking, and one strain gage is installed on the bottom face of the specimen to measure concrete strain. Fig. 6 shows some of this instrumentation of a test specimen.

A B C

Fig. 6 Deck-level connection specimen instrumentation: A) – two horizontal LVDT's at the connection interface (both faces); B) – one vertical LVDT at the center of the connection; C) – two strain gages at the interface (both faces).

To date, 23 deck-level connection specimens have been tested and the data analysis is underway.

BOND CHARACTERIZATION PHASE

The main objective of this phase is to evaluate interface bond performance through standardized or standardizable test methods. The tests all focus on the bond performance of grout-type materials cast against precast concrete. The following tests are being conducted: slant shear test, splitting tensile test and flexural strength test. These bond tests are variations of the tests covered by ASTM C882, ASTM C496 and ASTM C78, respectively. Fig. 7 provides photographs of these three tests. Note that the precast and field-cast portions of each small scale test specimen were cast concurrently with the associated pieces of specific deck-level connection specimens, thus allowing for correlation between the two testing scales.

A B C

Fig. 7 : Bond characterization specimens testing: A) slant shear test; B) splitting tensile test; C) flexural strength test.

These bond characterization specimens are built in two steps. First, when precast deck panels are being cast, the “concrete half” of the specimens are also cast as shown in Fig. 8. Once these specimens are appropriately cured, the bond surface is prepared accordingly to the test matrix (e.g., power wash, sand blast, exposed aggregate, etc.). Then the “grout half” of the composite specimens are cast concurrently with particular deck-level connection specimens as shown in Fig. 9.

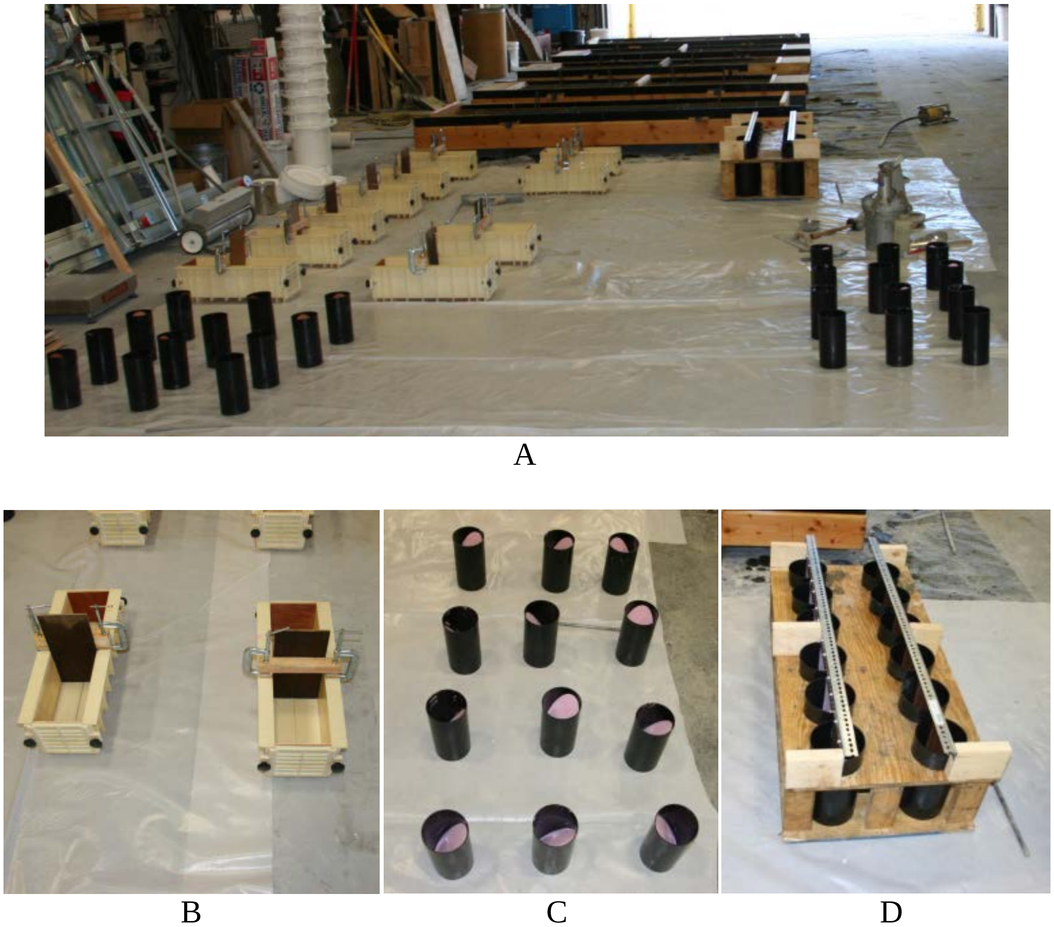
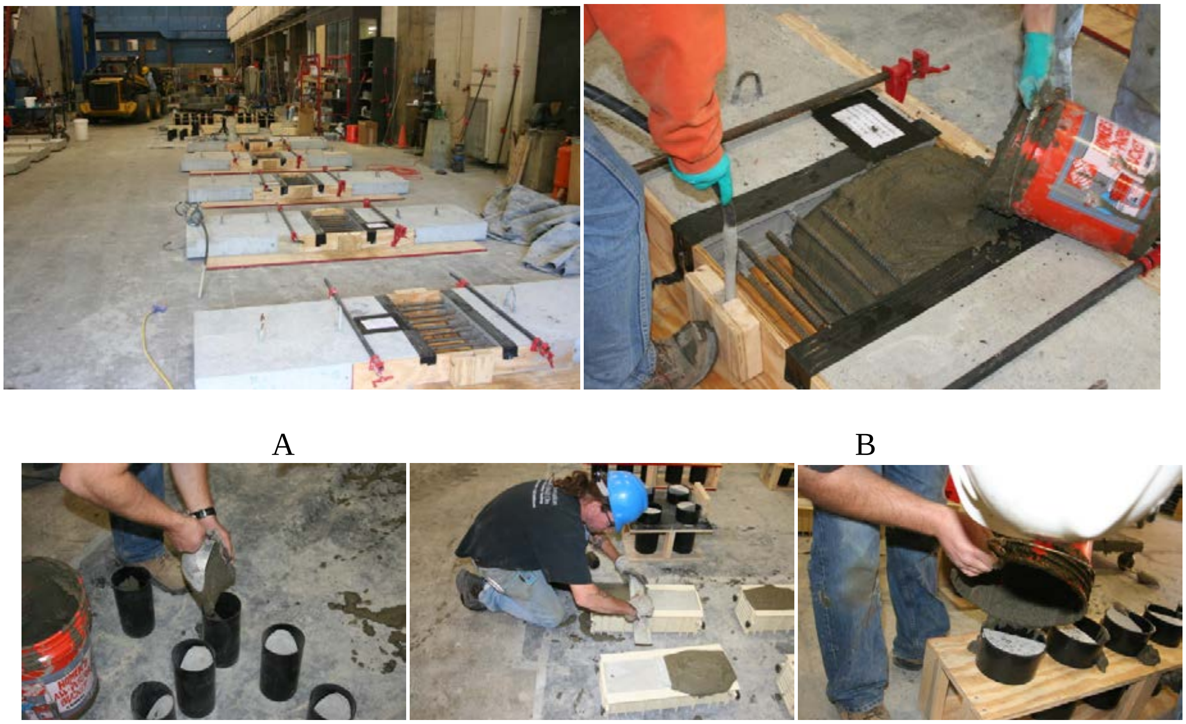


Fig. 8 Casting the "concrete half" of bond characterization specimens: A) deck panels and specimens to be casted; B) flexural strength specimens; C) slant shear specimens; D) splitting tensile specimens.



A B

C D E

Fig. 9 Casting the "grout half" of bond characterization specimens: A) deck-level connection specimens and bond characterization specimens to be casted; B) casting of non-shrink grout deck-level connection; C) slant shear specimens; D) flexural strength specimens; E) splitting tensile specimens.

The bond characterization tests are being completed at a variety of ages in order to assess the development of bond properties with time. Specifically, tests are being completed at 1 day and 7 days after grout casting, as well as concurrently with the testing of the associated deck-level connection specimen. Table 1 provides an example of type of test results that the bond characterization phase is generating. For each type of test at each age there are three specimens tested. The table below provided example test results captured at one day and seven days for various prepared surfaces (exposed aggregates, sand blasted + epoxy, sand blasted and power wash) having UHPC as the grout type.

Table 1 Example of test results –bond characterization specimens (UHPC grout): slant shear tests, splitting tensile tests, and flexural strength tests

Surface treatment	Slant shear test		Flexural strength test		Splitting tensile test	
	1 day	7 days	1 day	7 days	1 day	7 days
	Avg. bond strength (psi)	Avg. bond strength (psi)	Avg. bond strength (psi)	Avg. bond strength (psi)	Avg. bond Strength (psi)	Avg. Bond Strength (psi)
Exposed aggregates	4840	5630	430	635	655	820
Sand blasted & epoxy 1†	580	2360	245	475	550	670
Sand blasted	1410	3500	335	165	475	650
Power wash	880	1090	N/A‡	45	470	750

† Epoxy 1 = an epoxy adhesive meeting the requirements of ASTM C881
‡ Specimens not tested due to failure of some specimens under their own weight while handling/demolding.

SUMMARY

This study investigates a range of parameters such as shear key shape, reinforcement type, grout type, and precast surface preparation, which are frequently considered during the design of PBES connections. The study is structured on two phases: deck-level connection phase and bond characterization phase. This paper reports on an ongoing research program wherein 23 of more than 60 deck-level connection specimens have been tested. Further results will be available in Fall 2012. The overall research effort is expected to conclude in 2013. This research should facilitate informed decision making as owners move to implement greater use of bridge prefabrication and encounter choices as to the design of field-cast connection details.

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REFERENCES

1. Swenty, Matthew K. and Benjamin A. Graybeal, "Characterization of Materials used in Precast Bridge Element Connections," *Proceedings*, *PCI National Bridge Conference*, Salt Lake City, Utah, October 2011, 22 pp.