PERFORMANCE EVALUATION OF UHPC FIELD CAST CONNECTIONS FOR HOOPER ROAD BRIDGE PROJECT

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ABSTRACT

A project overview and a performance evaluation of the field cast UHPC connections for the Hooper Road Bridge after four years of service are presented. The original intent and observed performance of the link-slab, pier to column, transverse deck panel, and hidden composite field cast UHPC connections are illustrated, assessed, and discussed. The fundamentals of the technology, materials properties, original project design criteria, ABC requirements, and benefits for using UHPC as a field cast connection material are included.

The various types of UHPC connections are performing well and are either meeting or exceeding the original design assumptions. The absence of cracking, scaling, reflective cracking, joint leakage or other deterioration within the UHPC supports that the material is performing as expected. In contrast, multiple random cracking was revealed in the precast deck panels beside, parallel and perpendicular to the UHPC connections throughout the entire structure. This visual performance evaluation is consistent with similar observations as noticed on more than 60 bridge inspections across North America over the last decade.

INTRODUCTION

Ultra-High Performance Concrete (UHPC) has been utilized in new and retrofit bridge construction across North America in various applications such as precast bridge elements, field cast connections, overlays, pier jacketing, and seismic retrofit for the past 20 years. Its unique characteristics of ultra-high strength, short bond development length and durability offer a great solution for the use as field cast UHPC connections for precast concrete bridge elements.

The use of precast High Performance Concrete (HPC) deck panels is a common method to speed up construction and to alleviate user inconvenience during initial construction or rehabilitation; however connecting the precast system is a source for premature failure, leakage, and potential maintenance. Utilizing field cast UHPC with precast bridge elements can significantly extend the usage life of critical bridge structures and reduce the maintenance requirements due to its durability performance. Its short bond development length allows for simpler connections with reduced rebar congestion and narrow joints compared to other conventional grouting methods. During the construction or rehabilitation, UHPC facilitates Accelerated Bridge Construction (ABC), speeds up the construction cycle, and minimizes traffic delays to the general public.

THE UHPC TECHNOLOGY

As per the ACI 239 Committee (1), "Ultra-High Performance Concrete (UHPC) is a cementitious, concrete material that has a minimum specified compressive strength of 22,000 psi (150 MPa) with specified durability, tensile ductility, and toughness requirements; fibers are generally included to achieve specified requirements". Some jurisdictions (Canada & Switzerland) specify a minimum compressive strength of 17,400 psi (120 MPa) (2). The material matrix is typically manufactured from combining fine materials such as sand (< 400 microns), ground quartz, Portland cement, and silica fume with steel fibers (13 mm x 0.2 mm diameter) in a high dosage rate of 2% by volume. Durability properties are at least one order of magnitude better than most durable HPC and its long-term performance has been monitored since 1995 (3).

When compared to conventional concrete or HPC, UHPC is its own class of advanced cementitious material due to its higher compressive strength, tensile ductility, bond development, and enhanced durability properties. These unique properties are a direct result of the low permeability pore structure and the addition of fibers. UHPC is a family of products with different formulations that are used for different applications such as highway bridges, pedestrian bridges, bridge overlays, field-cast connections, security and architectural facades. UHPC formulations vary in raw material ingredient dosages, fiber types and curing regimes and are now available from multiple suppliers.

FIELD CAST UHPC APPLICATIONS FOR BRIDGES

UHPC field connections for precast bridge elements are very popular for ABC, rehabilitation and new construction in North America. This innovative solution has been utilized in North American bridges since 2006 and over 250 bridges are in service (4).

Field cast UHPC connections are to connect full depth precast deck panels, side-by-side box girders, side-by-side Deck Bulb-Tees, live-load continuity connections, precast approach slabs to abutments, curbs to decks, piles to abutments, columns to pier caps and in the haunches to provide horizontal shear for composite construction (5). Field cast UHPC has also been utilized for pier repairs and retrofit projects across to enhance the structural and durability properties of an existing structure through jacketing, seismic retrofit, and encasement construction techniques (6).

HOOPER ROAD BRIDGE PROJECT OVERVIEW

Existing Structure

With a total length of 150’, the 3-span, 2 lane Hooper Road bridge over NYS Route 17C in Union, NY was originally constructed in 1964 (Fig.1). Hooper Road is an urban, arterial road that accommodates large traffic volumes (ADT 10,000) and is a critical link between the local community and the City of Binghamton, NY. Years of continuous impact loading from vehicles and continuous exposure to deicing salts resulted in serve deterioration of the bridge.

Fig.1: Hooper Rd. Bridge Prior Rehabilitation

Fig.2: Leaky Joints (7)

Fig.3: Deteriorated Pedestal (7)

Leaky and failed joints (Fig.2) resulted in a widespread deterioration of the bearing pedestals (Fig.3) and piers (7). The pier concrete was also cracked and delaminated; whereas areas of the deck showed additional deterioration. In 2013, the condition of the bridge structure was assessed at a rating of 4.45 and an FSR of 68.3 determining that rehabilitation of the bridge is required (7).

Rehabilitation Options

The primary objectives were to restore the bridge condition using cost effective techniques while minimizing the life cycle cost of the maintenance and repair. The secondary objectives were to utilize construction techniques to minimize traffic to Hooper Road and to minimize impacts to NYS Route 17C during construction.

In total, four rehabilitation alternatives were considered using either conventional construction techniques or ABC methods. The conventional construction would require bridge rehabilitation in halves where one lane of traffic on Hooper Road always remains open to traffic and would impact traffic for 4 to 5 months during construction. The two potential alternatives using conventional construction techniques were either a deck replacement or a superstructure replacement. The ABC methods would use prefabricated bridge elements and a total road closure resulting in a traffic impact of 2 to 4 weeks. The two potential alternatives utilizing ABC were either superstructure replacement or a complete bridge replacement.

Preferred Alternative

As the preferred alternative, an ABC superstructure replacement with full depth precast deck panels, new steel girders, precast pier caps and precast approach slabs was selected (7). The owner specified a 21-day Hooper Road closure with only two open lanes for NYS Route 17C and liquidated damages of $5,000/day. This option was considered to have reduced user costs and was strongly favored by the public due to the short-term closure.

Completed ABC Project

The Hooper Bridge rehabilitation project was designed by McFarland Johnson in 2013 and executed by Economy Paving in 2014. Field cast UHPC was utilized for the precast pier cap to existing columns connection, for the link slab connections, panel to beam connections and for the precast deck panel connections. The ABC was completed within 21 days without any liquidated damages at a construction cost of $1,600,000. Overall, the project was well received by the community and received a lot of positive feedback.

BRIDGE INSPECTION

The first round of field visits and visual condition survey was conducted on more than 40 bridge structures with field cast UHPC connections in 2012 where the findings of six of these bridges have been published (8).

In November 2018, a second round of a total of 20 New York State bridges with field cast UHPC connections including the Hooper Road bridge (Fig. 4) were visited and visually inspected. The weather conditions were cold, snowy and changeable between wet and dry for several days leading up to the field visits with temperatures around the freezing point. Even though these conditions seem not favorable for the inspectors, the continuous wetting of the bridge deck for several days provided favorable inspection conditions for leakage and crack detection. Several of the recently inspected bridges, each with varying types of typical field cast UHPC connections have been recently published (9).

The main focus of this paper is to present the results of the visual inspection and the four year performance evaluation of the four ABC field cast UHPC connections of Hooper Road over NYS Route 17C in Union, NY: a) precast pier cap to existing columns connection, b) link slab connections, c) transverse precast deck panel connections, and d) hidden composite connection between precast deck panel and steel girder.

Fig. 4: Hooper Road Bridge Inspection

PRECAST PIER CAP TO EXISTING COLUMNS UHPC CONNECTION

Background

The original bid documents only specified field cast UHPC for the precast deck panel connections and slabs. The contractor (Economy Paving Company) had previously used UHPC on other bridge deck projects and felt that the project schedule was a little bit too aggressive. Upon contract award, the contractor turned his attention to the specified connection for the new precast pier caps to the existing pier columns (Fig. 5).

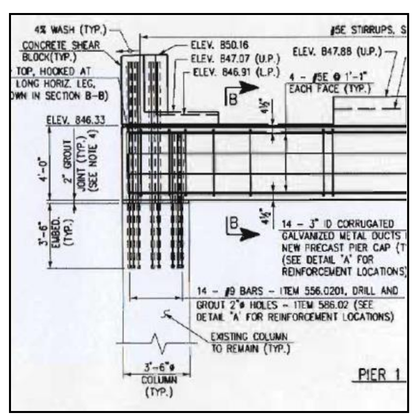

Fig.5: Originally Specified Pier Cap Connection

The originally specified detail of the precast pier cap required fourteen 3 in (75 mm) ducts for each column which would match new 2 in (50 mm) diameter holes that were to be drilled to a depth of 3 ft 6 in (1.07 m) in the existing columns. A total of 84 holes would be required. The contractor was very concerned that the existing rebar cage was not exactly located where it was specified on the original drawings. It was also deemed quite challenging to locate the existing rebar when drilling the new holes and to match these drilled locations with the ducts cast in the new precast pier caps (6).

UHPC Connection & Installation

Since UHPC was already specified for other portions of this project, the contractor saw an opportunity to propose a field cast UHPC connection for the precast pier caps to existing columns. Rebars from the existing columns were exposed to create continuity with new rebars extending from the underside of the new precast pier caps (Fig. 6). Due to the short development length of #9 (nominal area 1 in^2 or 654 mm^2) dowels in UHPC, it was determined that an 11 in (280 mm) development length was sufficient to achieve the required load transfer.

Fig. 6: Rebar Connection

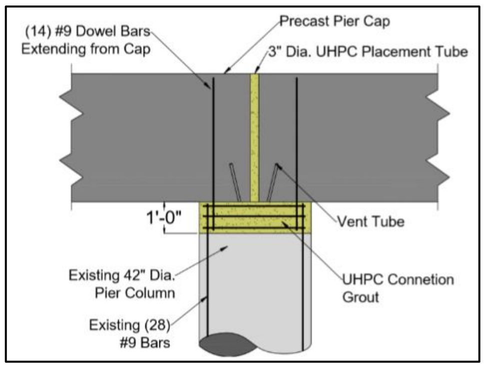

Fig.7: UHPC Placement (10)

Fig.8: Completed Connection

The existing rebars on the outer edge of the existing columns were exposed and cut to allow the 11 in (280 mm) splice. By leaving a concrete pedestal at the center of the existing columns, steel shims were used for final height adjustments and to provide spacing for the UHPC material flowing down the central placement duct. The precast cap had rebars extending downward the same distance.

Actually, the rebar extensions from the precast element were threaded dowels making the precast element flat and easier to handle during fabrication, transportation and erection. Once the new pier cap was lowered on the concrete pedestal of the existing columns, the rebar extensions were threaded into the precast cap and UHPC was poured around the rebar trough a 3 in (75 mm) diameter grouting duct at each column location. Two small bleeding ducts ensured no voids in the completed connection (Fig. 7). Heated blankets and monitoring thermal couples were used to minimize the curing time and allow a faster construction.

This field cast UHPC connection (Fig. 8) saved two days on the construction schedule and allowed easy adjustments to set the elevation and place the new precast pier caps. It also eliminated the uncertainty of misalignments and the individual grouting of 84 ducts.

Performance Evaluation

A visual inspection of the precast pier cap to existing column connection showed no evidence of any reflective cracking within the UHPC for both pier caps after four years in service (Fig.9). Upon closer inspection vertical cracks were noticed in the existing concrete column and the precast pier cap but seem to disappear within the UHPC connection (Fig. 10). The authors believe that micro and non-visible to the eye cracks are present in the UHPC connection and that they are spread across multiple micro cracks which are bridged by the fibers in the UHPC matrix. This appears to be very similar when testing precast panels with UHPC connections under flexural cycling loading, where single structural cracks in conventional concrete precast panels tended to become multiple, tightly spaced cracks in the field-cast UHPC (11).

Fig. 9: Precast Pier Cap/Column Connection

Fig. 10: Vertical Cracks in Column & Pier Cap

UHPC LINK SLAB CONNECTION

Background

Link slabs connections are located above the interior supports of multiple, simple span bridge structures and are designed to resist tensile forces due to the negative moment from live-load on the structure. The intent of the connection is to eliminate the need for strip seals or other traditional joint systems by creating a durable structural element spanning between the adjacent bridge decks (12). This prevents ingress of water and maintenance of the joint is eliminated (13). The Hooper Bridge was designed (Fig.11) and installed with two link slabs (Fig. 12).

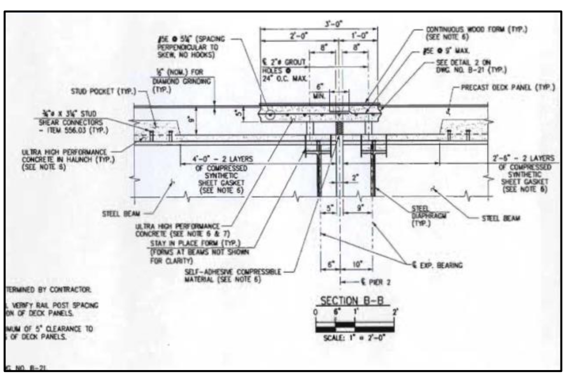

Fig.11: UHPC Link Slab Design

Fig.12: Installed UHPC Link Slab

Performance Evaluation

The visual inspection showed no evidence of reflective cracking in field cast UHPC link slabs above both piers (Fig. 13). No leakage through the UHPC link slab was noticed. Water draining down the side of the deck at the piers was seen causing some surface rust staining of the steel fibers. Only one longitudinal crack parallel to the link slab connection was noticed in the precast deck panel above the South Pier (Fig. 14) which may have been caused due to the negative moment over the pier of the bridge structure. This indicates that the UHPC link slab maybe too stiff and stronger than the adjacent panel and thereby inducing too much tensile stress into the conventional concrete precast panel.

Fig. 13: North Pier Link Slab

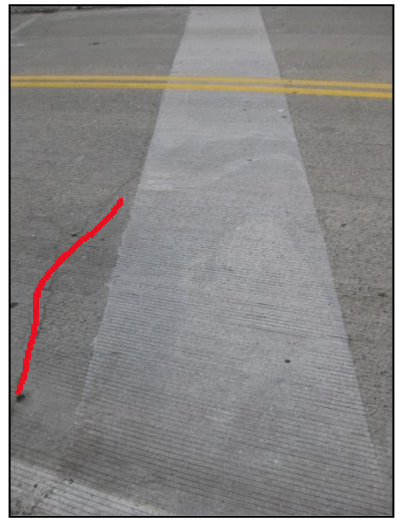

Fig.14: South Pier Link Slab

UHPC PRECAST DECK PANEL CONNECTIONS

Background

Adjacent Lab Splice Deck Panels Connections

The precast bridge deck panels use rebar projecting from each panel into the space between the panels which is filled with UHPC to form the connection. This connection transfers moment, shear, and tensile forces across the joint using short, straight rebar spaced at intervals typical to conventional deck design. The width of the connection is based on the rebar development and lap-splice lengths plus construction tolerance and is between 6 and 8 inches (152 and 203 mm) (12).

The Hooper Road Bridge utilized field cast UHPC connections in the transverse direction between the precast deck panels as well as between the approach slabs (Fig. 15).

Deck Panel to Girder Composite Connection

The Hooper Road project utilized a hidden-pocket composite connection where a continuous pocket is created above the girder line and then filled with field cast UHPC. The composite action is generated through the transfer of forces between the girder, with Nelson-studs and deck panel through UHPC (12). A total of four steel girder lines across three spans were made composite with the precast deck panels (Fig. 16).

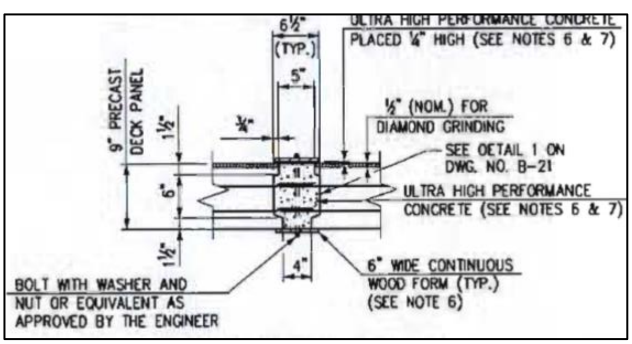

Fig. 15: Deck Panel Connection

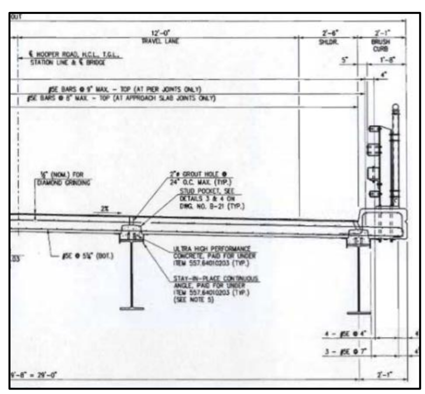

Fig. 16: Hidden Composite Connection

Performance Evaluation

The visual inspection on top of the bridge deck (Fig. 17) showed no cracking within the transverse field cast UHPC connections. The precast deck panels revealed multiple random cracking beside (Fig. 18), parallel (Fig. 19) and perpendicular to the UHPC connections throughout the entire structure. No leakage below the deck along the UHPC connections was observed. All galvanized channels originally used for forming the UHPC connections showed no rust stains, therefore no leakage is evident (Fig. 20). Water draining down the side of the deck panels were seen causing some surface rust staining of the steel fibers (Fig. 21). Any of the observed deteriorations are not related to field cast UHPC connections.

Fig. 17: Bridge Deck Surface

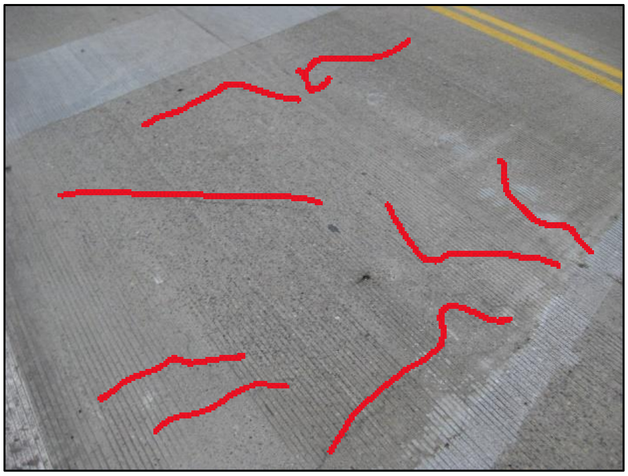

Fig. 18: Multiple Random Cracking in Precast Panel

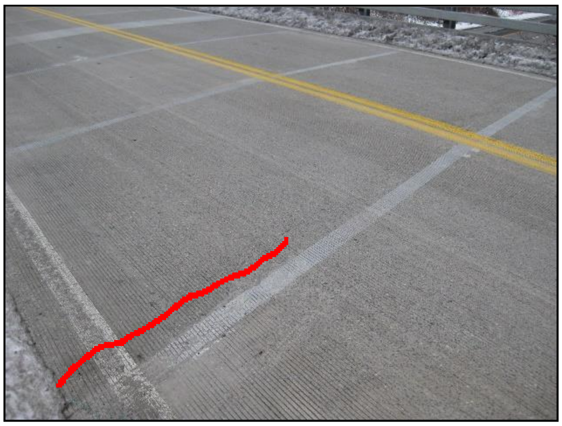

Fig. 19: Parallel Cracks to UHPC Connection

Fig. 20: Bridge Deck Underside

Fig 21: Transverse Joint

OTHER DETERIORATION MECHANISMS

Other bridge components appear to have started to deteriorate. This was especially noticed with the multiple cracks in the precast deck panels with some appearing to be full depth cracks with leakage (Fig. 22). This will allow future deicing salts to penetrate the concrete deck panels attacking the steel reinforcement. In addition, the expansion joints at the abutments appear to be starting to deteriorate (Fig. 23).

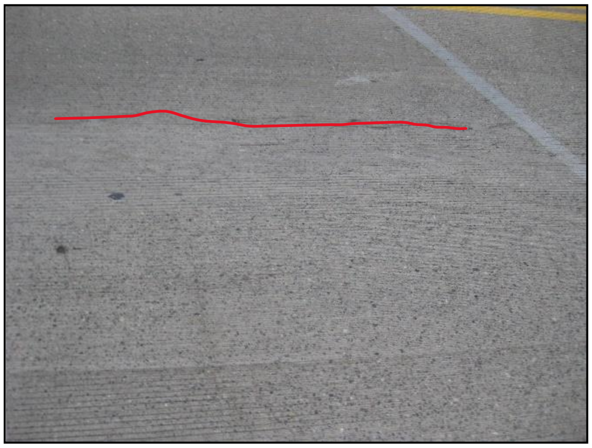

Fig. 22: Longitudinal Crack – Perpendicular to UHPC

Fig. 23: North Abutment Expansion Joint

CONCLUSIONS

Over 250 bridges with UHPC field connections have been constructed in North America since this solution of using field cast UHPC connections for precast bridge elements was first introduced in 2006. UHPC shows very promising results for building better, more resilient, and longer-lasting infrastructure. Field cast UHPC and precast bridge deck systems can minimize traffic impacts and user costs through ABC while providing highly durable and sustainable bridges

The 3-span with 2 lanes at 150' Hooper Road rehabilitation project illustrated that combining field cast UHPC connections with precast elements is an effective method of designing and constructing an ABC project. This ABC project was completed within 21 days without any liquidated damages at a construction cost of $1,600,000. Field cast UHPC was successfully utilized for the precast pier cap to existing columns connection, for the link slab connections, for the precast deck panel connections in the transverse direction, and for the hidden composite deck to steel girder connection. This project also illustrated that exploiting the characteristics and properties of UHPC allows for faster and simpler connection details where a new concept was developed to connect the precast pier cap to the existing columns.

The 2018 bridge inspections showed that the field cast UHPC connections of the Hooper Road Bridge are either meeting or exceeding the original design assumptions. The absence of cracking, scaling, reflective cracking, joint leakage or other deterioration within the UHPC material supports that it is performing as expected by the designers. In contrast, other bridge components were observed to deteriorate. The Hooper Bridge revealed multiple random cracking in the precast deck panels beside, parallel and perpendicular to the UHPC connections throughout the entire structure. The expansion joints also seem to be in the early phases of deterioration.

The visual evaluation of the Hooper Road Bridge provided similar observations as noticed in the inspections of more than 40 bridges in 2012 (8) and of an additional 22 bridges in 2018 (9) with varying types of field cast UHPC connections where some have been in service for over 10 years. This sample size of inspections provides a level of comfort and added assurance to keep constructing bridges with field cast UHPC in the future. Generally, no cracking, scaling, reflective cracking or other deterioration of UHPC were noticed. In contrast, other deterioration mechanisms of other materials were observed on multiple bridges such as: pavement scaling, ASR, cracks in non-UHPC connections, asphalt rutting, longitudinal asphalt cracking, overlay groove wearing, panel cracking in multiple directions, and expansion joint failing.

The precast elements with UHPC field connections provided a solution to the owner to meet the primary goals of restoring the bridge condition using cost effective techniques while having minimal traffic impact to the general public during the construction. The inspections indicate that this solution is performing well, particularly compared to the conventional concrete in the same structure. This indicates that the future maintenance and repair costs will be reduced compared to conventional solutions.

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