Illinois's First Precast Deck Panel Bridge with UHPC Joint

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ABSTRACT

As a part of the $450 million Circle Interchange Project in Chicago, the existing Peoria Street Bridge over I-290 and the Chicago Transit Authority (CTA) is being replaced with a 3-span, continuous, galvanized steel plate girder bridge. The bridge is providing the main access to the CTA station among three adjacent stations. Therefore, constructing the new bridge in a shorter time is one of the main design considerations.

Full-depth precast deck systems have been gaining popularity as an Accelerated Bridge Construction (ABC) method. As stated in the FHWA's ABC website, use of full depth precast deck is the most popular ABC method. Utilizing the superior characteristics of Ultra High Performance Concrete (UHPC) enables the simplification of the precast panel fabrication and installation processes. This simplified design provides the owner with improved tolerances, reduced risk, increased speed of construction, an overall cost savings in construction in some cases and a more durable, longer lasting bridge deck solution. With these reasons, Illinois's first Precast Deck Panel Bridge with UHPC joints is proposed for this bridge.

In this paper, the mechanical properties for UHPC and research on UHPC joints for precast deck panels are reviewed. The design procedure for precast deck panels with UHPC joints and UHPC joint details are presented. Other non-conventional design such as semi-integral abutment on tall wall is also presented.

Keywords: Accelerated Bridge Construction, Precast Deck Panel, ABC, UHPC, Semi-Integral Abutment.

INTRODUCTION

Accelerated Bridge Construction (ABC) using prefabricated bridge components and systems has many advantages over conventional cast-in-place construction. Prefabrication speeds up construction and increases the quality of concrete members by fabricating in a controlled plant environment with reduced dependency on the weather. Prefabrication also increases construction safety by avoiding forming, rebar placement, concrete placement and curing at the bridge sites. The reduction in the duration of traffic closures and a reduced negative impact on the environmental are other benefits for using ABC.

Utilizing the superior characteristics of Ultra High Performance Concrete (UHPC) enables the simplification of the precast panel fabrication and installation process. This simplified design provides the owner with improved tolerances, reduced risk, increased speed of construction, an overall cost savings in construction in some cases and a more durable, longer lasting bridge deck solution.

As a part of the $450 million Circle Interchange Project, the existing Peoria Street bridge over I-290 and Chicago Transit Authority (CTA) is being replaced with a 3-span, continuous, steel plate girder bridge with a total length of 273’-0” and bridge width of 56’-4”. Three alternatives were proposed to Illinois Department of Transportation (IDOT) for consideration: 1) Precast deck panels with post-tensioning; 2) Precast deck panels with UHPC joints; and 3) AccelBridge System.. IDOT decided to select the new generation deck system: precast deck panels with UHPC joints.

In this paper, the mechanical properties for UHPC and research on UHPC joints for precast deck panels are reviewed. The design procedure for precast deck panels with UHPC joints and UHPC joint details are presented. Other non-conventional design such as semi-integral abutment on tall wall is also presented.

FULL DEPTH PRECAST DECK PANELS

One of the largest and specific challenges facing bridge owners is the long-term durability of bridge decks which receive continuous impact loading from trucks and changing environmental conditions, especially the use of salts and de-icing chemicals in cold regions. The years of continuous flexural and thermal stresses create long-term deterioration and maintenance issues for bridge decks. While Cast-In-Place (CIP) concrete decks and corrosion resistant reinforcing steel such as epoxy coated rebar could extend the deck life, it creates high user inconvenience and is problematic for bridge deck replacement in high traffic areas. The use of precast deck panels is a common method to speed construction and address the user’s inconvenience.

Full-depth precast panel systems have many other advantages over CIP decks, some of the advantages include shorter construction times, high-quality plant production under tight tolerances, low permeability, less variation in volume caused by shrinkage and temperature changes during initial curing, and lower maintenance costs.

The use of full-depth precast concrete deck panels in highway bridges in the United States started as early as 1965[1]. In 2001 the FHWA launched a new initiative called Accelerated Bridge Construction (ABC). As of 2011, more than 60 projects using precast deck panels have been successfully completed[2].

Illinois built its first precast deck panel bridge on Illinois Route 29 over Sugar Creek, in 2000. This was a deck replacement project. The precast deck panels were full depth, 195mm (7.68”) thickness and were post-tensioned longitudinally. A 60mm (2.36”) Microsilica Concrete Overlay was place on top of the panels. The deck has performed well. The latest NBIS inspection rates the deck as an 8, very good condition and no problems are noted.

Research and experience indicate that the most critical location in a full-depth precast deck system is the transverse joint between panels. Transverse joints are subject to shear and to tensile stresses in the longitudinal direction. The integrity of transverse joints is essential for structural performance and durability.

There are three approaches to provide the continuity between precast deck panels:

- Post-tensioning
- UHPC
- AccelBridge system (Jacking and External Post-Tensioning)

The majority of bridges with full-depth precast decks constructed over the last 30 years utilize longitudinal post-tensioning (PT) to ensure long-term joint performance. The use of post-tensioning across the joints has been used as a method to ensure the deck effectively remains structurally monolithic while performing under the constant pounding of truck wheel loads and seasonal conditions, more specifically; to ensure the joint does not deteriorate or leak. While post-tensioning can resolve most of the performance issues, it is not without potential problems. It is expensive, requires specific expertise and equipment for installation, and it has potential for corrosion. Transverse closure pours at abutments and longitudinal closure pours for wider bridges are typically required, which will lengthen bridge deck construction time. Furthermore, the analysis is complex in terms of the correct post-tensioning forces, creep losses, and grout properties.

The typical transverse joint detail with longitudinal post-tensioning is shown in Fig. 1. The post tensioning duct coupler is installed at the transverse joint. The in-span longitudinal post-tensioning anchorage is presented in Fig. 2. A closure pour is typically required to protect the anchorage. If the bridge is over 40-ft wide, a longitudinal closure pour is typically provided as shown in Fig. 3.

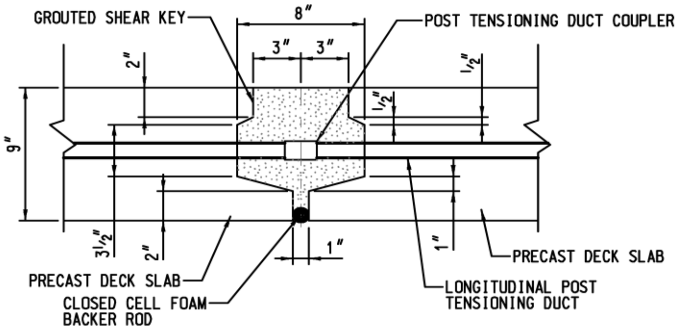


Fig. 1 Transverse Joint Detail with Post-Tensioning[3]

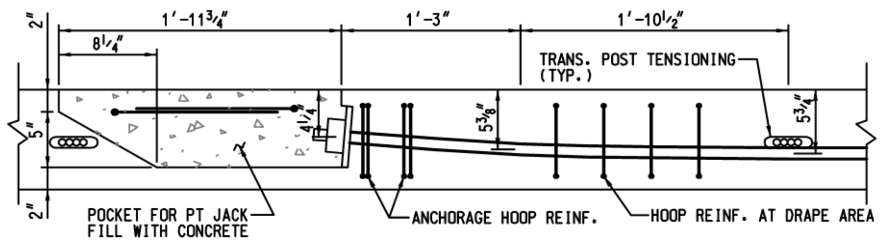


Fig. 2 In-Span Longitudinal Post-Tensioning Anchorage[3]

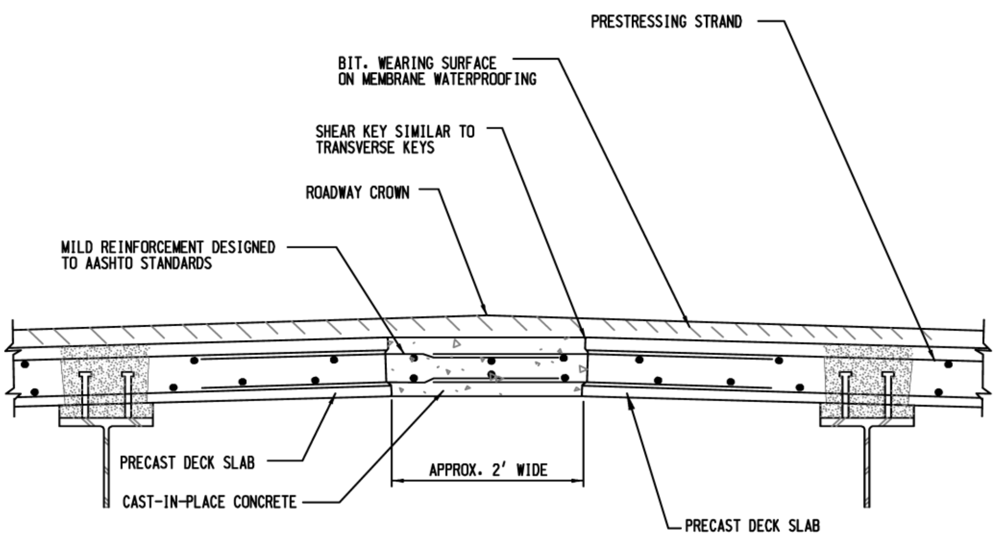


Fig. 3 Longitudinal Closure Pour[3]

Using reinforced transverse joints with UHPC can achieve joint durability without longitudinal post-tensioning. UHPC joints can replace the time consuming work of coupling PT ducts and installing PT strands. The old generation UHPC joint detail is shown in Fig. 4.

The mechanical properties for UHPC and the benefits for using UHPC joints will be discussed in the following section.

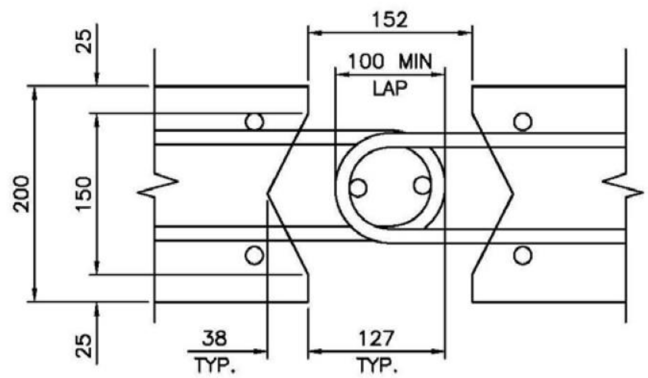


Fig. 4 UHPC Joint Detail[4] (Metric Units: mm)

AccelBridge system is a patented full depth precast deck system invented by Eddie He. The principle of AccelBridge is to introduce deck longitudinal compression by jacking the deck against the girder. In such a way, the deck can achieve zero-tension without using any post-tensioning[5]. As opposed to conventional post-tensioning inside deck panels, AccelBridge system applies external post-tensioning thru the girders to provide the compression in the deck panel joints.

The main advantages of AccelBridge are durability and minimum maintenance. The PT couplers at the grouted transverse joints are the weak link in the typical full depth precast deck system with internal post-tensioning. Any cracking / leaking in the joint will potential cause PT corrosion. AccelBridge provides the needed deck longitudinal compression without PT; thus eliminating any concern of PT corrosion. Also, AccelBridge system uses match cast epoxy joint between panels, which has been proven to be more durable than grouted joints based on the history of segmental bridges[5].

UHPC and UHPC JOINTS

UHPC is a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio less than 0.25, and a high percentage of discontinuous internal fiber reinforcement. The mechanical properties of UHPC include compressive strength greater than 21.7 ksi (150 MPa) and sustained postcracking tensile strength greater than 0.72 ksi (5 MPa). Ultra-high performance concrete has a discontinuous pore structure that reduces liquid ingress, significantly enhancing durability as compared to conventional and high-performance concretes[6].

Tensile Stress-Strain Response of UHPC is shown in Fig. 5. The post-cracking behavior of UHPC is almost plastic as opposed to strain softening experienced by conventional concrete as shown in Fig. 6.

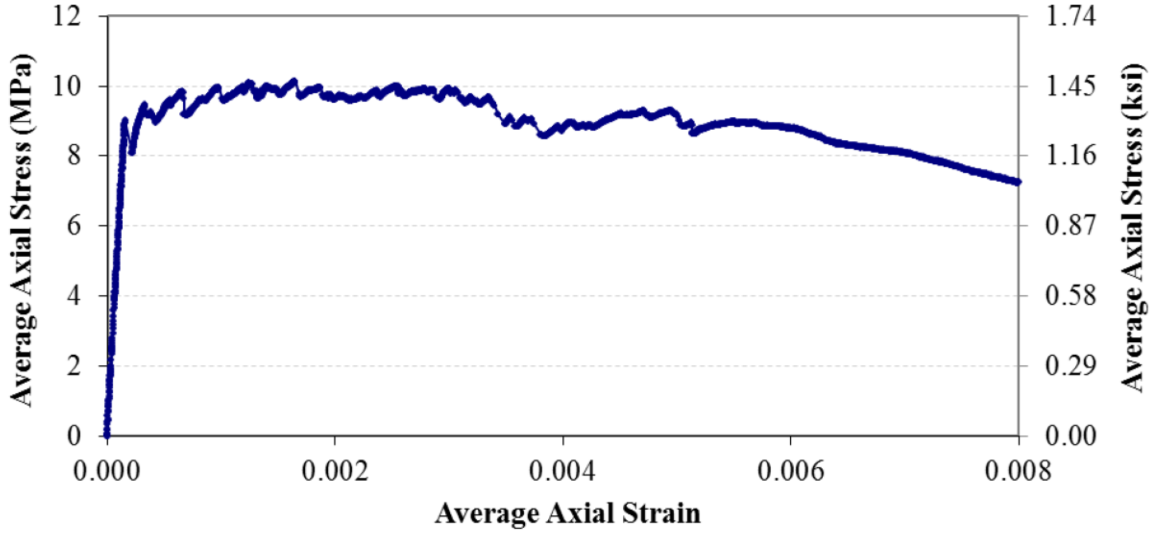


Fig. 5 Tensile Stress-Strain Response of UHPC[7]

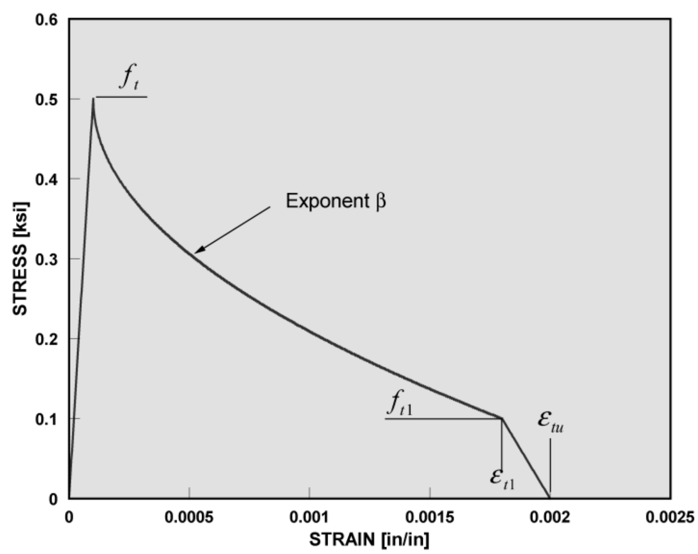


Fig. 6 Tensile Stress-Strain Response of Conventional Concrete

The research on UHPC started in Europe in the early 90's to explore new possibilities in advanced concrete technologies. At the end of the 90's, ten years of research produced a completely innovative material offering technological performances that had never been seen before. The mechanical and durability properties of UHPC make it an ideal candidate for use in developing new solutions to pressing concerns about highway infrastructure deterioration, repair, and replacement. Since 2000, when UHPC became commercially available in the United States, a series of research projects has demonstrated the capabilities of the material. A handful of state departments of transportation have deployed UHPC components within their infrastructure, and many more are actively considering the use of UHPC[6].

UHPC is being considered for use in a wide variety of highway infrastructure applications. The high compressive and tensile strengths allow for the redesign and optimization of structural elements. In the United States, UHPC has been used in prestressed concrete girder simple-span bridges, precast concrete deck panels, and field-cast connections between prefabricated bridge components. Fig. 7 shows the first UHPC highway bridge constructed in the United States[6].

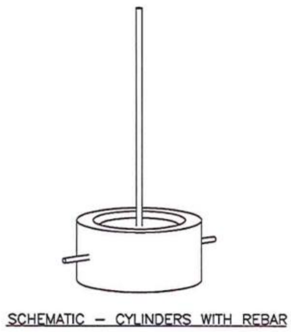
Fig. 7 The First UHPC Prestressed I-girder Bridge in US[6]

In 2009, the first highway bridge using UHPC joints between full-depth deck panels was constructed in the United States. Since then, 17 bridges of its kind have been built in US. As of 2013, there are six states that have built precast deck panel bridges with UHPC joints.

UHPC joints are filled with UHPC and reinforcing steel is lapped across the joint. The lap length of reinforcing steel is based on the pull out test as shown in Fig. 8.

Fatigue tests were also performed as shown in Fig. 9. Other field-cast UHPC connection tests for the transverse and longitudinal connections between precast deck panels were presented and discussed in FHWA Publication No. FHWA-HRT-11-023[8].

Pull-out Testing



Types of Bars Tested	Diameter of Bars (mm)	Embedment Length (mm)	Failure Type
Black Steel	13	75	Bar Rupture
	16	100	Bar Rupture
	19	150	Bar Rupture
Epoxy Steel	13	75	Bar Rupture
	16	100	Bar Rupture
	19	150	Bar Rupture
Galvanized Steel	13	75	Bar Rupture
	16	100	Bar Rupture
	19	150	Bar Rupture
GFRP	16	100	Delamination between Epoxy Skin and Bar
	19	150	Delamination between Epoxy Skin and Bar

Fig. 8 Pull Out Test of Different Types of Reinforcement in UHPC[9]

Cyclic Loading (Fatigue):

2000 to 16,000 Pounds
For 8,900,0000 cycles
2000 to 21,300 pounds
For 5,200,000 cycles

"No Leakage through the Joint"

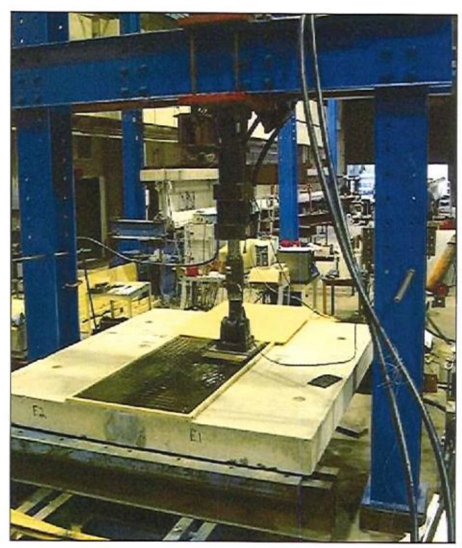


Fig. 9 Fatigue Test of UHPC for Joint Fill[9]

The initial unit cost for full depth precast deck panels with UHPC joints is higher than CIP concrete decks, which is typical for Prefabricated Bridge Elements and Systems (PBES) used for ABC. If the cost savings for user convenience could be quantified, the unit price for precast deck panels would be lower.

Full depth precast deck panels with UHPC joints requires less construction tolerance than precast deck panels with internal post-tensioning because PT ducts have to be lined up precisely at each panel.

PEORIA STREET BRIDGE

As a part of the $450 million Circle Interchange Project, the existing Peoria Street Bridge over I-290 and the CTA is being replaced to accommodate the widening of I-290. The new bridge is a 3-span, continuous, galvanized steel plate girder bridge with a total length of 273’-0” and bridge width of 56’-4”. During the preliminary bridge type study, three alternatives were proposed by TranSystems: 1) Precast deck panels with post-tensioning; 2) Precast deck panels with Ultra High Performance Concrete (UHPC) joints; and 3) AccelBridge system ; were proposed to IDOT for consideration. IDOT decided to select the new generation deck system: full-depth precast deck panels with UHPC joints.

A plan view of precast deck panel layout is shown in Fig. 10. There are 52 deck panels in total and a longitudinal UHPC joint is provided to accommodate the 56-ft wide bridge. Twenty different deck panels are required due to the complex bridge layout such as CTA train station entrance to the west, CTA staircase to the east, and light poles and drainage scuppers. All the transverse and longitudinal joints are filled with UHPC. The shear stud pockets are filled with non-shrink grout.

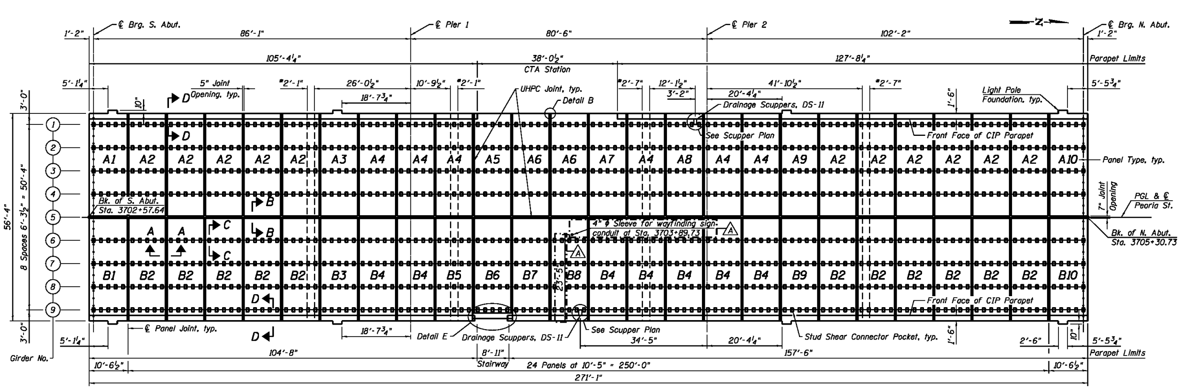


Fig. 10 Plan View of Precast Deck Panel Layout

A typical bridge cross section is presented in Fig. 11. To reduce future maintenance cost, galvanized steel plate girders were used for this project. Small girder spacing at 6’-3 1/2” was provided to meet the minimum vertical clearance over I-290. A latex concrete overlay with scored joints was provided on the top of precast deck panels to meet the aesthetic requirement by University of Illinois at Chicago (UIC).

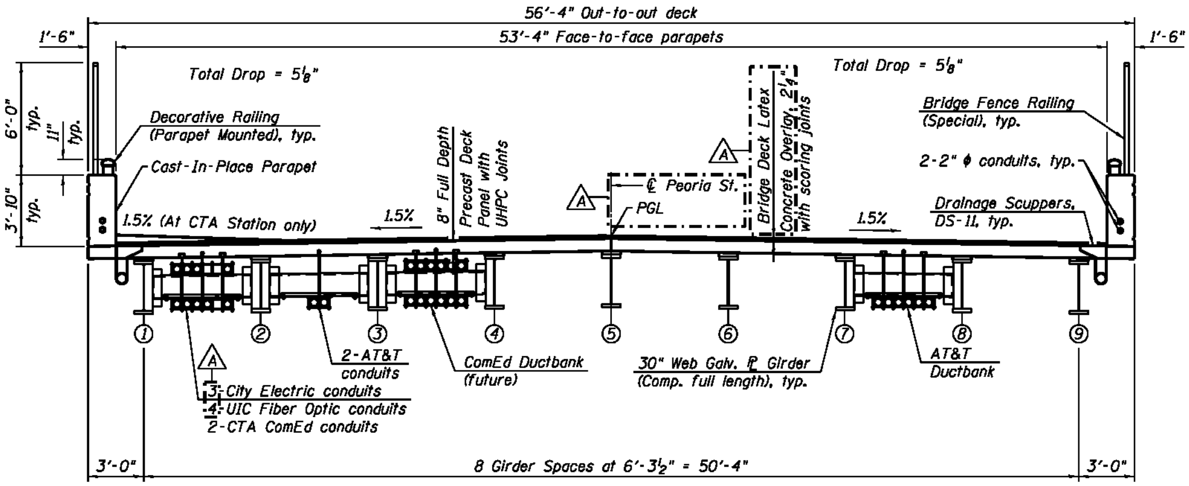


Fig. 11 Typical Section

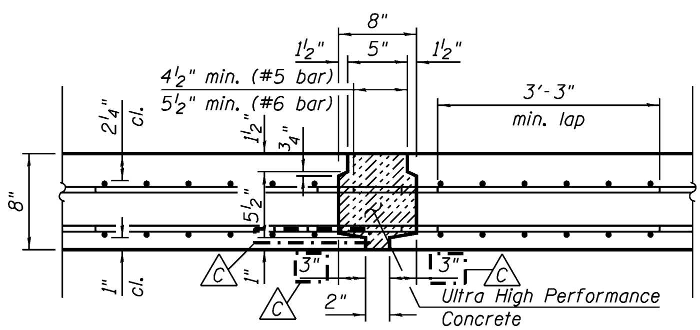


Fig. 12 UHPC Transverse Joint

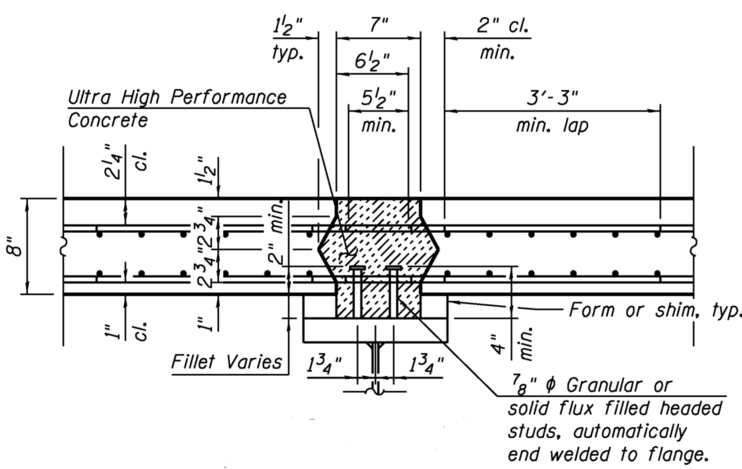


Fig. 13 UHPC Longitudinal Joint

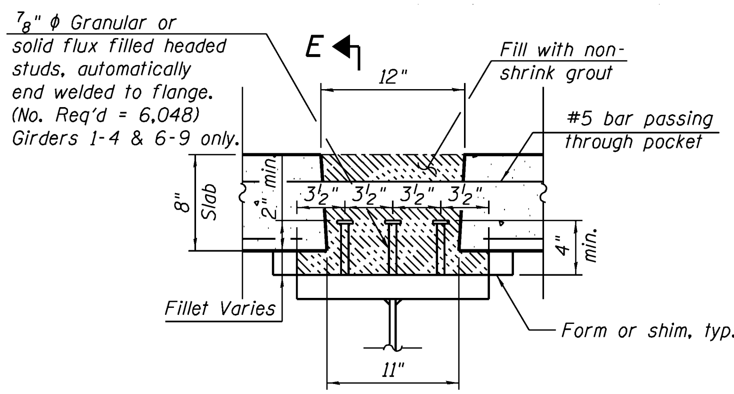


Fig. 14 Shear Stud Pocket

The design of precast deck panels is similar to cast-in-place deck design except for larger girder spacing the prestressed strands would be required. For the Peoria Street Bridge, only mild reinforcement was required. The design of UHPC joints is based on pull out research. The UHPC transverse joint and longitudinal joint details are shown in Fig. 12 and Fig. 13, respectively. The shear stud pocket detail is presented in Fig. 14.

The construction sequence of precast deck panels with UHPC joints is as follows. Stage 1 panels are placed in the positive moment region first followed by panels placed in Stage 2 in the negative moment region.

1. Erect steel girders.
2. Cast abutment diaphragms.
3. Clean surfaces of deck panel shear keys and stud shear connector pockets.
4. Install drainage scuppers.
5. Preset leveling bolts to anticipated height.
6. Form fillets between the top of the girders and the bottom of the deck panels.
7. Erect precast concrete deck panels according to the erection sequence for Stage 1.
8. Adjust leveling devices on deck panels to bring panels to grade.
9. All leveling bolts shall be torqued to approximately the same value (20 percent maximum deviation).
10. Install stud shear connectors in all blockouts.
11. Form and cast transverse and longitudinal UHPC joints for Stage 1.
12. Grout all fillets and stud shear connector pockets along Girders 1-4 and 6-9 with a flowable, non-shrink grout.
13. Repeat steps 7-12 according to the erection sequence for Stage 2.
14. Cast Concrete Superstructure slab at CTA stairway.
15. Cast parapets.
16. Place latex concrete overlay.

OTHER DESIGN CONSIDERATIONS for the PEORIA STREET BRIDGE

For tall wall abutments, a closure pour is typically required for precast deck panel bridges to accommodate the expansion joint installation. To eliminate the expansion joint, semi-integral abutments were used for the Peoria Street Bridge to reduce the future maintenance cost. The backfill below the bottom of backwall is compacted while the backfill above the bottom of backwall is not compacted to accommodate the thermal movement. A detail of the Semi-Integral Abutment Section is shown in Fig. 15.

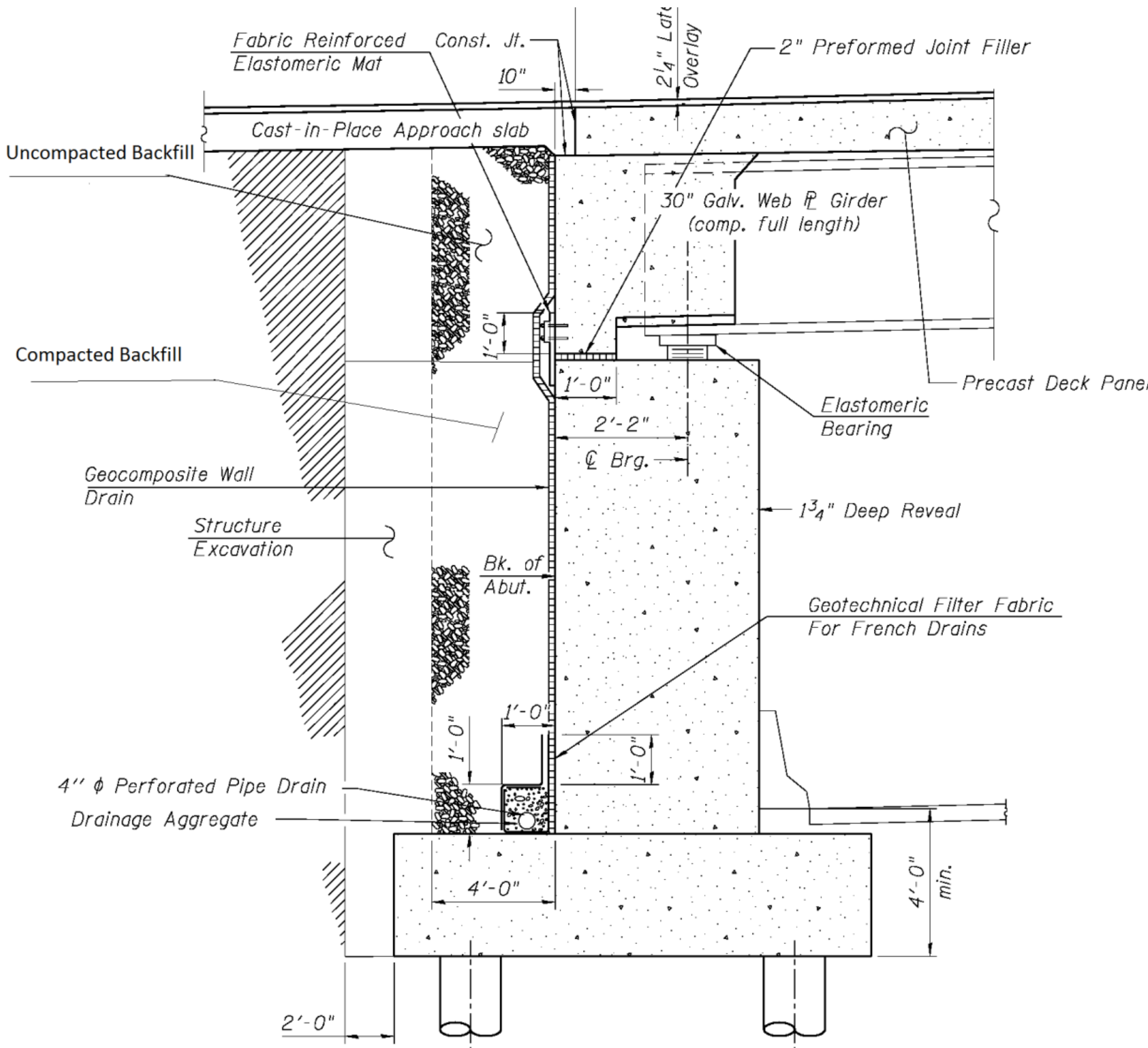


Fig. 15 Semi-Integral Abutment Section

CONCLUSIONS

Accelerated bridge construction using prefabricated bridge components and systems has many advantages over conventional cast-in-place construction. Prefabrication speeds up construction and increases quality of concrete members by fabricating in a controlled plant environment with reduced dependency on weather. Prefabrication also increases construction safety by avoiding forming, rebar placement, concrete placement and curing at bridge sites.

Full-depth precast deck systems have been gaining popularity as an Accelerated Bridge Construction (ABC) method. As stated in FHWA's ABC website, full depth precast deck is the most popular ABC method.

There are four primary characteristics of UHPC that distinguish it from conventional concrete:

- Higher compressive strength.
- Higher tensile strength with ductility.
- Increased durability.
- Higher initial unit cost.

Utilizing the superior characteristics of Ultra High Performance Concrete enables the simplification of the precast panel fabrication and installation processes. This simplified design provides the owner with improved tolerances, reduced risk, increased speed of construction, and overall cost savings in construction in some cases and a more durable, longer lasting bridge deck solution.

The introduction of new methodologies and innovative material technologies facilitates the implementation of new solutions. Precast deck panel with UHPC joints is a new generation bridge deck system.

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