Benefits of Ultra-High Performance Concrete for the Rehabilitation of the Pulaski Skyway

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Abstract:

Ultra-High Performance Concrete (UHPC) is currently being employed to facilitate the redecking of the four-lane, 3.5-mile long Pulaski Skyway. The $400 million project is part of a series of projects to completely rehabilitate this monumental structure, which was built in 1932 and is listed on the National Register of Historic Places. The Skyway carries about 70,000 vehicles per day and is a critical link in the Greater New York City transportation network.

Because of the critical nature of the Skyway to the region's transportation, and the narrowness of the structure making it difficult to perform maintenance without impacting traffic, the New Jersey Department of Transportation wanted to ensure that the new bridge deck would have a service life of 75-years with little maintenance required during that time period. Consequently, plant-cast concrete deck panels with stainless steel reinforcing bars and field-cast UHPC panel closure joints was selected as the redecking system.

This paper will discuss the decisions made during the design of the Pulaski Skyway redecking project regarding the deck system that was chosen, and will present in detail the reasons behind the selection of UHPC for the project and the benefits that it provides to the project schedule, budget, and durability.

Keywords:

Ultra-High Performance Concrete (UHPC), Precast Deck Panels, Connections, Pulaski Skyway, Accelerated Bridge Construction (ABC),

1. Introduction

The Pulaski Skyway is a three and one-half mile (5.6 km) long viaduct located in northern New Jersey that serves as a direct link to New York City via the Holland Tunnel. The Skyway first opened to traffic on Thanksgiving Day, November 23, 1932. Originally designed in 1927 to sustain an estimated volume of 5,500 vehicles per day, it has seen a significant increase in usage over its lifetime leading to a current sustained volume of 70,000 vehicles per day.

In 1932 when the Skyway originally opened as "Route 1 Extension," it was the single largest highway construction project undertaken in the United States and at the time was described as "the greatest highway project in the United States today." This was the first roadway project where public time-saving was used to justify dramatic capital expenditures. Public time-saving has since become a major consideration for most large scale construction projects and is once again a main focus of the Pulaski Skyway, this time for the rehabilitation of the 80-year-old bridge, leading to the use of Accelerated Bridge Construction (ABC) methods.

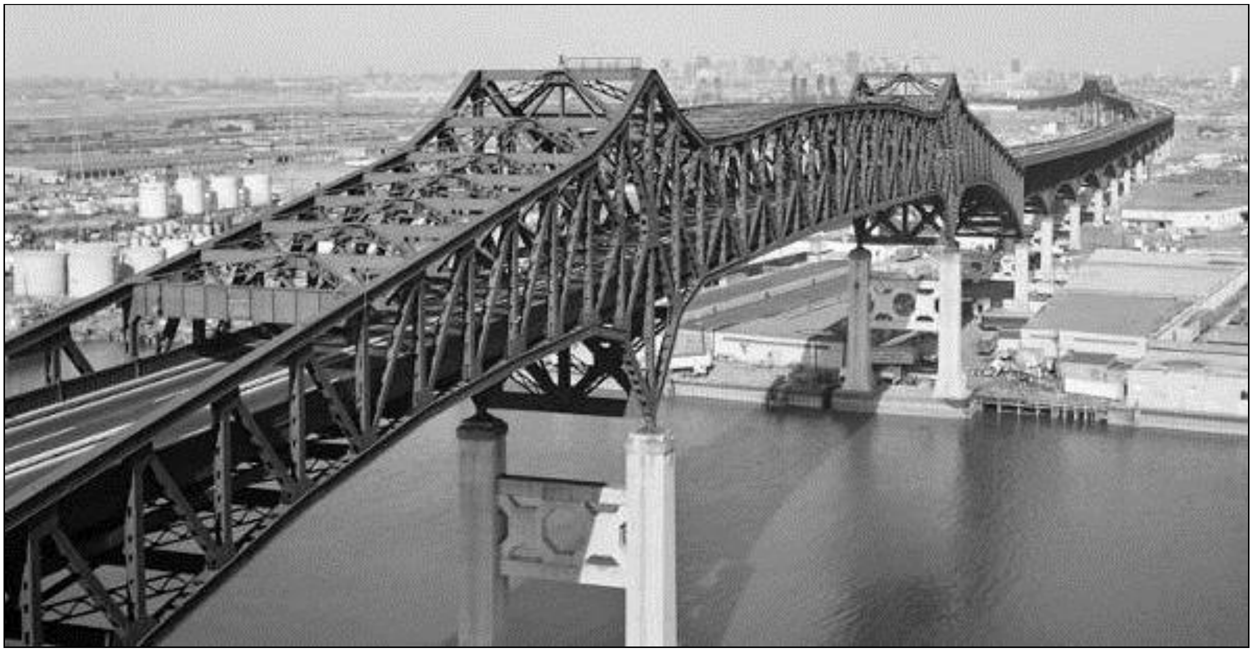

Figure 1. Partial Elevated View of the Pulaski Skyway

A series of projects is being undertaken by the New Jersey Department of Transportation (NJDOT) to completely rehabilitate the Pulaski Skyway, shown in Figure 1, which is listed on the National Register of Historic Places. The objectives of this rehabilitation project include not only public time-saving by minimizing disruption to traffic during construction, but also include providing a 75-year design live with minimal maintenance. Because the Skyway is very narrow with minimal shoulders, any prolonged lane closure for future maintenance will have major consequences on the traffic on the Skyway and also in the region in general. Therefore, the current design should minimize the need for any such maintenance over the design life. One of the current rehabilitation projects involves the complete redecking of this four-lane structure, replacing over 14 lane-miles (22.5 lane-km), or about one-million square feet (93,000 m^2) of deck. NJDOT has planned for this work to take place over a 24-month time period, which equates to about 10,000 square feet (930 m^2) of deck to be replaced per week.

2. Selection of Deck Replacement System

In order to meet this aggressive schedule and also meet the design life criteria, the designers considered several different deck systems. NJDOT also wanted to add capacity to the supporting steel structure where possible by reducing the weight of the replacement deck. Therefore, a traditional cast-in-place deck system was eliminated due to the long cure times and the limitations that would impose on construction staging as well as the limited availability of cast-in-place lightweight concrete in New Jersey. Instead, the designers focused on precast deck systems. The following deck systems were considered:

- Filled Grid Deck
- Inverset Precast Deck and Stringer System
- Precast Post-Tensioned Full-Depth Deck Panels
- Precast Full-Depth Panels with Cast-in-Place (CIP) Joints

- Precast Exodermic Deck Panels with CIP Joints

The filled grid deck, despite being known for longevity, did not present any significant weight savings, and generally had no advantage over the Exodermic grid deck system, and so was eliminated. The Inverset deck system was interesting for potential weight savings, but it would be challenging to fit the Skyway's non-uniform framing plan and it is not conducive to future redecking. Therefore, it was also eliminated.

After some detailed investigation, the post-tensioned full-depth deck panel option was also eliminated. It was initially thought to be a good option that would produce a highly durable deck system with weight savings provided by light weight concrete. The compression forces created by the post-tensioning would help prevent cracks from appearing, particularly in the cast-in-place joints between precast panels which are typically otherwise subject to cracking. However, it was discovered through analysis that the post-tensioning creep and shrinkage introduced out-of-plane bending forces on the original floor beam members, in excess of the members' capacities. The system would have required complicated field connections to deal with this issue, and so it was eliminated from consideration.

This left the remaining options of precast full-depth panels and precast Exodermic deck panels, which are unfilled steel grid deck panels cast composite with a reinforced concrete slab, each with cast-in-place panel joints. Both of these systems had properties that would be advantageous for the design including light weight through the use of precast lightweight concrete, simplicity of precast operations, and flexibility to adapt to an existing structure with constantly changing floor beam and stringer arrangements and multiple curves. Thus both systems were selected to be used on the Pulaski Skyway.

The full-depth precast panels were chosen as the primary deck system and will be used for the majority of the Skyway roadway. The Exodermic deck was chosen for two specific sections of the bridge. The first section is near a center on/off ramp where the design called for the roadway to be widened. This widening will be performed to provide more space for acceleration and deceleration lanes that were lacking in the original configuration. The extra weight savings of the Exodermic deck panels cast with light weight concrete enables this area to be widened without adding any extra weight to the supporting structure, as compared to the existing deck weight.

The second region where Exodermic panels are being used is on the east end of the bridge where the deck being replaced is in excess of 16 inches (400 mm) thick. In addition to deck replacement, the number of deck joints is being reduced in this area to reduce future maintenance needs, which led to concerns about the capacity of the existing columns under seismic loads. The selection of Exodermic deck panels, even without lightweight concrete for this section, reduced the deck weight significantly enough to eliminate the column concerns.

While the selected deck systems provided the required schedule and weight advantages, they did not necessarily meet the demanding durability requirements based on traditional construction techniques, especially when compared against the precast post-tensioned deck system. Therefore, two specific design decisions were made to boost the long-term durability of the deck systems. First, stainless steel reinforcing was selected for all of the precast full-depth deck panels. While the initial intention was to use stainless steel reinforcing bars everywhere, it did not make sense to use it in the Exodermic panels since those panels incorporated galvanized steel grids, and the rebar sat directly on top of the grid. These materials not only have different long-term corrosion resistance but there would be the potential for galvanic corrosion due to contact between dissimilar metals. Therefore, galvanized reinforcing bars were used in the Exodermic panels.

While the selection of stainless and galvanized reinforcing bars significantly reduced any concerns of deck panel corrosion within the panels themselves, an "Achilles' heel" remained in these deck systems in the form of the panel joints. Precast deck panels, including Exodermic deck panels, are typically joined together with cast-in-place concrete. Since the Pulaski deck was designed to be composite with the stringers, full rebar development is required between adjacent panels. Consequently, these joints would be quite wide if using lap splices, or would be time consuming to construct if using mechanical splices. And if using traditional concrete in the joints, any time savings gained by using precast panels would be lost waiting for the joints to cure. Finally, since precast concrete typically has higher quality control and higher strength than traditional cast-in-place concrete, the panel joints become the weakest points in the deck system where cracking and reinforcing bar corrosion typically begins.

In order to realize all of the time and durability advantages of precast panels with stainless and galvanized reinforcing bars, the designers chose to use Ultra-High Performance Concrete (UHPC) for the panel joints.

3. Benefits of UHPC for the Pulaski Skyway

UHPC is a very high-strength fiber reinforced concrete, with compressive strengths that typically reach about 22,000 psi (150 MPa). UHPC for precast concrete panel closure pours is a relatively new application in the United States. However, it has undergone extensive research and testing by the Federal Highway Administration (FHWA) and has been implemented numerous times to-date by the New York State Department of Transportation. The high strength of UHPC enables it to fully develop reinforcing bars with minimal embedment depth. Panel joints can, therefore, be as narrow as 5-inches (127 mm) to fully develop and lap splice #5 (#16 metric) reinforcing bars. This is fully explained in the FHWA TechNote publication "Design and Construction of Field-Cast UHPC Connections."

UHPC also confers other benefits to precast deck systems, in the form of a fast cure time, high flowability, and high durability. The following bullets briefly explain these key benefits. As the purpose of this paper is not to present all the technical properties of UHPC, the reader is encouraged to refer to the above mentioned FHWA TechNote for more detailed data. Consider the following unique properties of UHPC:

- High strength – as noted above, the extremely high strength of UHPC results in very short rebar lap and development lengths.
- Fast cure time – UHPC typically reaches strengths of about 14,000 psi (100 MPa) within 24 to 48 hours. This is usually enough strength to meet all design objectives, including reinforcing bar development, so the UHPC can be loaded with design loads after this time.
- Highly flowable – Uncured UHPC is highly flowable and will readily fill tight spaces, so much so that it is important to tightly seal forms, and sloped pours require top forming. This fluidity is useful for potentially congested areas such as panel joints, where two sets of rebar and possibly even shear studs are all fighting for the same space. It can also be used to fill haunches underneath precast panels with haunch thicknesses as low as 5/8 inch (15 mm), limited only by the length of the steel fibers in the UHPC.

- Durability for long service life – UHPC is inherently durable. It has extremely low permeability, as demonstrated by chloride ion permeability test (AASHTO T259) results of less than 0.10 lb/yd³ (0.06 kg/m³). This impermeability means very little water will ever penetrate the material to cause corrosion.

UHPC is being employed in three specific situations on the Pulaski Skyway. It is being used for the transverse panel-to-panel joints throughout the project. It is also being used to fill the shear connections and haunches between the panels and the steel framing. Finally, it is being used to fill the longitudinal joint at the median of the bridge. Each of these three uses will be described and the benefits conferred by UHPC in each situation will be detailed.

3.1. Transverse Panel Joints

The majority of transverse panel-to-panel joints on the project are 8 inches (200 mm) wide, as shown in Figure 2. For the Exodermic panels, the typical joint width is 10 inches (250 mm) with some joints as narrow as 5 inches (125 mm).

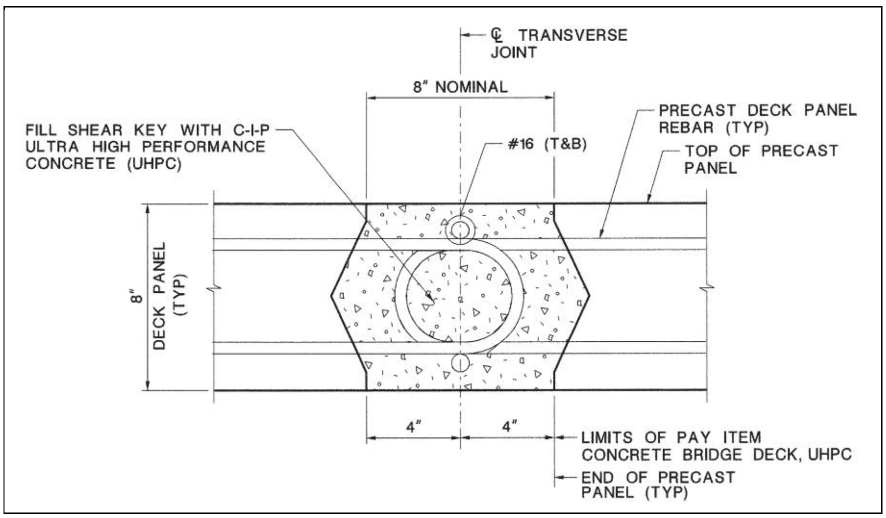

Figure 2. Typical Transverse Joint

The first benefit of UHPC for the Pulaski Skyway transverse joints should now be evident – the high strength of UHPC results in short reinforcing bar development and lap splice lengths, which enables the use of very narrow panel joints. This maximizes the amount of precast concrete deck and minimizes the amount of cast in place material, which results in time savings. Furthermore, the fast cure time means that in as little as 24 hours after pouring the joints, the panels can be put in service, either for construction loads or for service loads. The high flowability of UHPC means that there is a very low risk of unconsolidated material or air pockets in the joints, which, especially for the Exodermic panels, can get somewhat crowded. Finally, the high durability of UHPC combined with the high strength means that the deck panels are more likely to crack and see reinforcing bar corrosion than the joints are, giving long-term confidence in their performance. This ensures that all of the durability measures incorporated into the precast panels themselves will be fully realized and not compromised by the panel joints.

3.2. Haunches and Shear Connections

The typical full-depth precast concrete panel used for the new Pulaski Skyway deck has rectangular shear pockets to facilitate the connection between the panels and the shear studs, so that the panels will act compositely with the underlying steel framing. The Exodermic panels are also connected to the stringers and floor beams, although rather than using rectangular block-outs, the entire length of underlying stringers and floor beams are blocked out (but the panel steel grid still spans over the steel members, maintaining panel integrity during panel erection). Figures 3 and 4 show the two panel layouts. Since the text in the details is difficult to read, the important thing to understand from these figures is the layout of the shear pockets in the precast panels (Figure 3) and the stringer and floor beam block-outs in the Exodermic panels (Figure 4).

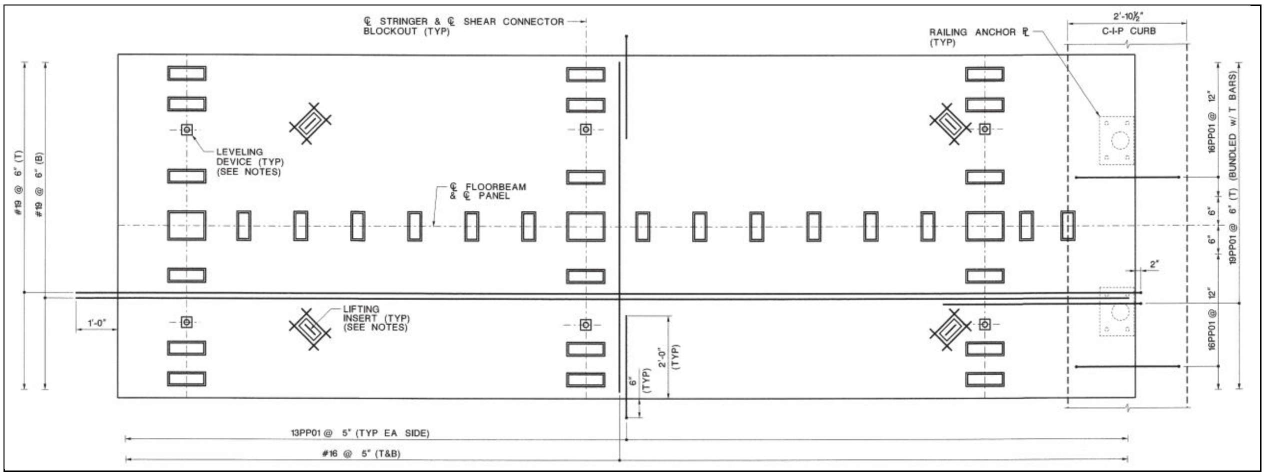

Figure 3. Typical Precast Panel Detail

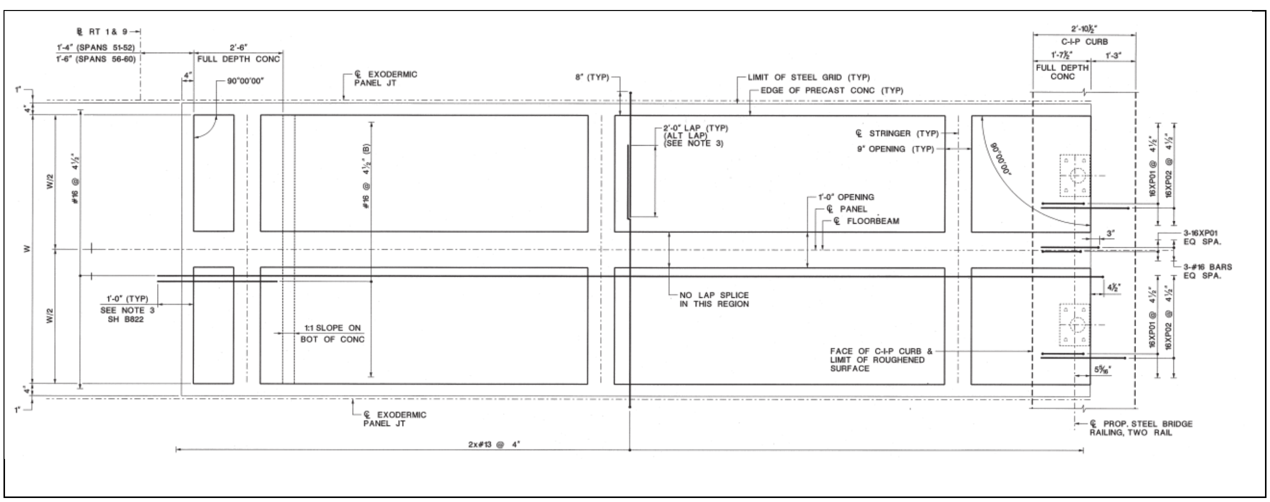

Figure 4. Typical Exodermic Panel Detail

The haunches are beneath the panel between the pockets for the typical precast panel but integral with the continuous block-outs for the Exodermic panels. These haunches and shear pockets were not originally designed to be UHPC, as can be seen in Figure 5 which indicates two different grouts, Type A and Type B. However, the contractor elected to use UHPC in order to combine the pocket with the haunch as well as with the transverse joints into a single pour.

The high strength of UHPC in the pockets gave the designers and contractor some added flexibility over shear stud placement. Since minimum shear stud spacing criteria are typically based on local failure of the concrete around the stud, the extremely high strength of the UHPC meant that the designers could accept tighter spacing of shear studs when conditions required it.

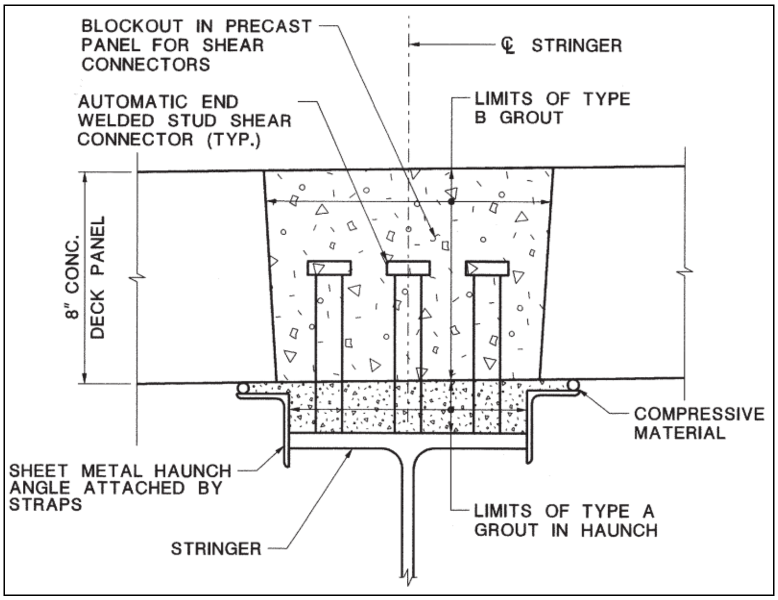

Figure 5. Typical Shear Pocket Detail

Similar to the transverse joints, the fast cure time means the panels can be put in service in as little as 24 hours. The high flowability of the UHPC was critical for the haunches, which were as thin as 5/8 inch (15 mm). In order to confirm this would not be a problem, a mockup was created with 5/8 inch (15 mm) haunches to confirm the UHPC would fully fill the haunch, and it was successful. Finally, the high durability and low permeability of the UHPC ensures that the shear pockets and block-outs, just like the transverse joints, will never become weak points in the precast deck systems.

3.3. Longitudinal Joint at Median

In order to maintain partial traffic during the redecking operation, only half of the Skyway was permitted to be closed at any time. Therefore, the presence of the existing southbound roadway carrying two lanes of traffic was a constriction for construction of the new northbound deck, which also had to be configured to carry two lanes of traffic when completed so that the existing southbound deck could be replaced with traffic on the northbound side. Figure 6 shows the general situation for the first half of construction when the northbound lanes are redecked.

Figure 6. Temporary Lane Arrangement for Northbound Redecking

This arrangement meant that very little open space was available between the existing southbound deck and the new northbound deck for the extension of rebar necessary to make the two halves continuous in the final condition. In fact, this open space was typically only 10 inches to 12 inches (250 mm to 300 mm) wide.

As a result, the high strength of UHPC was critical for this application. The designers detailed 6 inch (150 mm) long rebar hooks extending out of the edge of the northbound precast panels along the median. This provided more than enough extension to ensure that these bars would be fully developed in the UHPC median concrete. Later, the southbound precast panels, which will have the advantage of a 3 foot (0.9 m) typical open median, will have straight rebar extending out of the panels along the median with a typical 12 inch (300 mm) extension. Lastly, a set of straight reinforcing bars, 2'-8" (0.8 m) long will be placed in the median, lapping the rebar extending from both northbound and southbound panels, as shown in Figure 7. Thanks to the high strength of the UHPC, this rebar will have fully developed lap splices to the rebar extending from each panel, thereby ensuring that the rebar that extends transversely across the bridge is continuous between both edges of the bridge and across the median. Without UHPC, the only other way this could be accomplished would be to install mechanical couplers on every rebar extending out of every panel in the median area – a costly and timely operation.

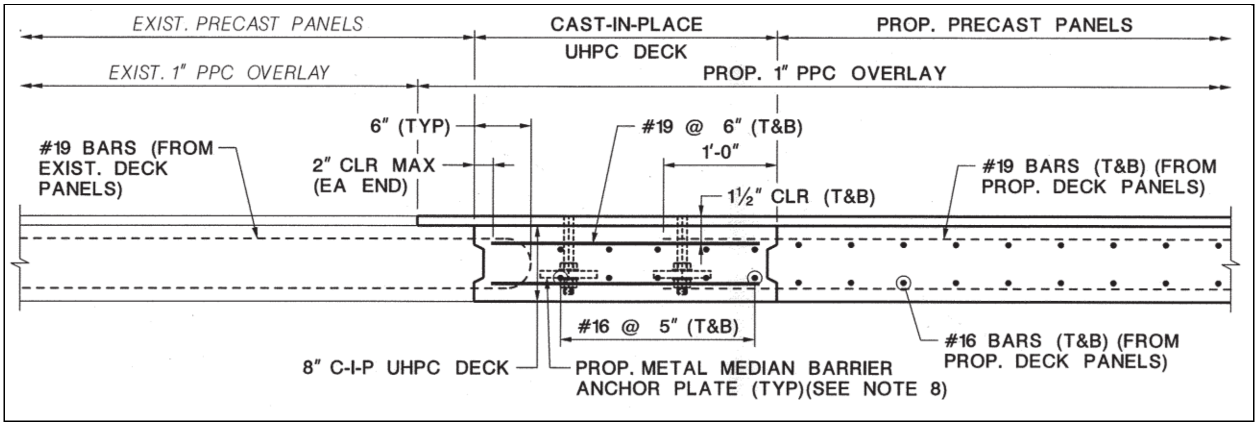

Figure 7. Typical Median Detail

Once again, with the UHPC curing in as little as 24 hours, construction can continue and the median can be loaded rather rapidly. Furthermore, the fluidity of the UHPC eliminates any concern for air pockets or unconsolidated concrete that could be caused by the anchors for the metal median barrier that are to be cast in the median. Finally, as with the transverse panel joints, this continuous longitudinal panel joint will be stronger and more durable than the panels it is connecting, thereby ensuring the long-term durability of the entire deck system.

4. Final Considerations

While using UHPC for the entire deck might have resulted in an even more durable deck system, it would be difficult to justify the cost. With UHPC costing up to ten times that of traditional concrete per cubic yard in place, it is important to employ UHPC where it provides maximum benefit and offsets other costs. In the case of the Pulaski Skyway precast panel deck system, the UHPC eliminates the typical weak spots, and does so in a very compact manner by reducing the joint width to about one-third of what would otherwise be required. Attempting to replicate the durability benefits of the UHPC with an epoxy-based product could easily result in higher cost due to the need for a much larger joint width. Furthermore, the durability of the Skyway deck system as a whole will be enhanced by the application of a polyester polymer concrete overlay.

5. Conclusions

The on-going deck replacement of the Pulaski Skyway makes extensive use of UHPC. The unique properties of UHPC, which include very high strength, fast curing time, high flowability, and high durability, allow the deck to be replaced with a simple, rapidly installed, and durable system, despite challenging conditions and limited space. With UHPC employed for nearly all precast panel connections, the connections are no longer the weak points as they traditionally are, both in terms of strength and durability. Instead, the connections are the strongest and most durable points of the deck system, stronger and more durable than the precast deck panels with shop-cast concrete and corrosion-resistant rebar, all of which is expected to eliminate the need for major deck maintenance over the next 75 years.

6. References

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