

## PRECAST SOLUTIONS FOR DESIGN-BUILD OF THE INDIAN RIVER INLET BRIDGE

Hohsing Lee, PE, AECOM, Sacramento, CA

### ABSTRACT

*With its recent completion under a design-build contract, the Indian River Inlet Bridge replaces an existing structure which was affected by severe scouring. Located in the Delaware Seashore State Park, the replacement bridge with a total length of 2,600 feet is part of the Delaware SR1 Highway across the Indian River Inlet. The bridge is located within yards of the Atlantic Ocean and is subject to a very corrosive marine environment.*

*The project includes the design and construction of a 1750 feet long cable stayed main bridge with a center span of 950 feet, as well as the approach structures utilizing 70" deep precast Bulb-T girders.*

*The cable-stayed concrete superstructure consists of a deck slab supported by prestressed floor beams which frame into two edge girders. Each edge girder is supported by a plane of cables in a semi-harped configuration. To achieve some cost savings and accelerate the construction, a significant portion of the bridge is constructed on falsework utilizing precast floor beams. Only the central two-thirds of the main span are erected in traditional cast-in-place construction with a form traveler.*

*This paper describes the background of the project and provides an insight into the design, fabrication, and erection of the precast components in the project.*

**Keywords:** Precast, Segmental, Cable-stayed, Post-tensioning, Design-build, Form-traveler

## INTRODUCTION

The Indian River Inlet “Charles W. Cullen” Bridge, crossing the Indian River Inlet on State Road (SR-1) in Dewey Beach, Delaware, was recently completed and opened to traffic in 2012. The Delaware Department of Transportation (DelDOT) selected the design-build team Skanska USA Civil Southeast and AECOM in the fall of 2008. This \$150 million signature bridge replaced an existing structure which was affected by severe scouring, and it is the fifth bridge over the inlet in just over 60 years. The history of scour of the previous bridges over the inlet led DelDOT to restrict placement of any piers in the inlet. A key design requirement by DelDOT was to provide a 900-ft horizontal clearance opening at the inlet without obstruction to accommodate the potential future widening of the inlet. Additionally, DelDOT mandated use of a concrete superstructure which is highly resistant to corrosion for the aggressive marine environment of the Atlantic Ocean. An aerial photo of the new replacement bridge and the existing bridge is shown in Figure 1.



Fig. 1 Aerial Photo of Project Site

The primary objective of this paper is to present the design and construction of precast concrete components used for this project. Due to the advantages of speed of construction, cost effectiveness, and superior quality, the winning design-build team utilized precast prestressed concrete elements to construct the Indian River Inlet replacement bridge. This included the transverse precast floor beams for a significant portion of the cable-stayed spans, precast Bulb-T girders for the approach superstructure, and precast prestressed concrete piles for all bridge foundations.

## PROJECT DESCRIPTION

The Indian River Inlet Bridge Project involved the design and construction of a 2,600 feet long replacement bridge structure. The approach structures each have four spans with an overall length between expansion joints of 425 feet. The approach deck sections consist of precast prestressed Bulb-T girders, each 106'-3" in length. The main bridge of the concrete cable-stayed structure is 1,750 feet in length with two flanking spans, each 400 feet long. The overall depth of the superstructure is 6 feet, which complements the relative low-level structure profile over the Inlet. The height of the pylons is approximately 236'-6" above top of pile caps and 190'-6" above deck level. A minimum of 45 feet vertical clearance is provided over the future 800-ft inlet channel. The general plan and elevation of the structure is illustrated in Figure 2.

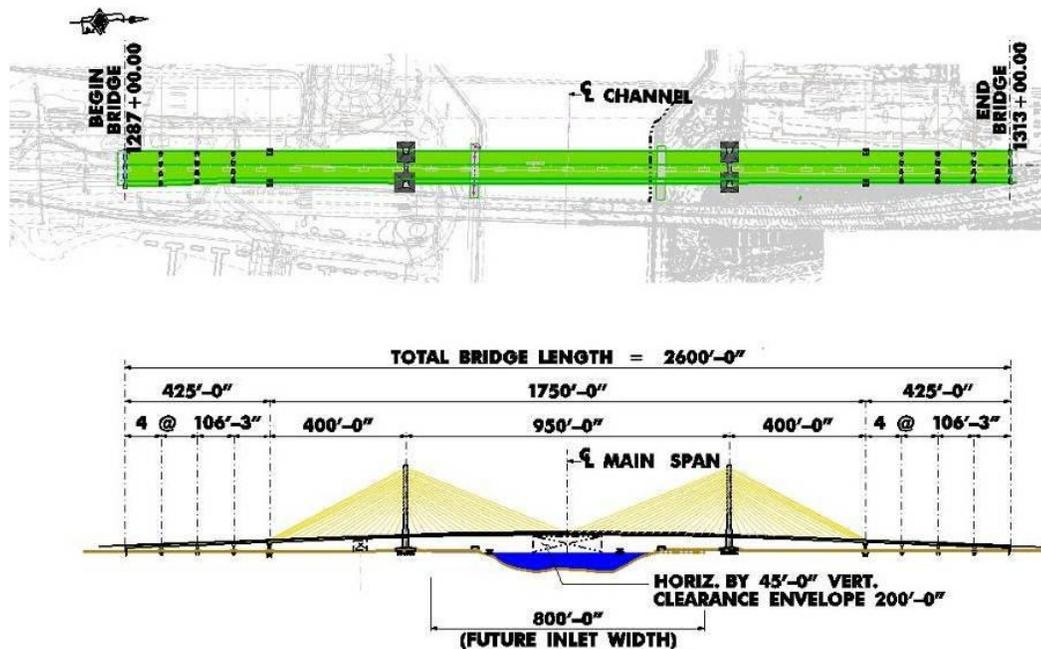


Fig. 2 General Plan & Elevation

The superstructure rises from the abutments at a 4% grade and transitions into a 1,250 foot vertical curve, symmetrical about the centerline of the main span. The bridge roadway cross sections for the approaches and cable-stayed structure provide four traffic lanes, two shoulders and a 12'-0" sidewalk for pedestrians and bicyclists on the east side of the bridge. Figure 3 illustrates the roadway cross section for the main span structure, which includes the location of the sand bypass system.



## **KEY DESIGN CONSIDERATIONS**

The main span cable-stay structure and the approach structures of the Indian River Inlet Bridge were designed for all of the required loadings and limit state combinations in the AASHTO LRFD Bridge Design Specifications, Fourth Edition, 2007 and subsequent interim specifications through 2008. These provisions were supplemented by the Post-Tensioning Institute Recommendations for Stay Cable Design, Testing and Installation, Fifth Edition, 2007, as well as project specific design requirements in the Project Performance Specifications.

### **100 YEAR DESIGN LIFE**

The project specifications for the replacement of Indian River Inlet Bridge called for a 100-year design life which is longer than the 75-year design life as stipulated in the AASHTO LRFD Bridge Design Specifications. To achieve the specified 100 year design service life, several lines of corrosion defenses were proposed which included the use of high performance/low permeability concrete in both superstructure and substructure to reduce chloride penetration, 2-inch concrete cover in the deck, 1” minimum polymer concrete deck overlay, all epoxy coated reinforcing steel, transverse and longitudinal compression in the deck resulting from cable stayed forces and post-tensioning, limit number of expansion joints greatly enhance the durability and maintainability of the structure, and state-of-the-art corrosion protection for cable stay components.

### **GEOTECHNICAL**

Four general soil strata were identified at the site through the geotechnical soil explorations. Stratum I (Upper Sand) consists of loose to dense, fine to coarse sands. The thickness of Stratum I is generally similar on the south and north sides of the inlet, and ranges from approximately 30 feet to 40 feet. This first layer generally offers some resistance to vertical loads, but it is prone to scour. Stratum II (Clay) primarily consists of very soft to medium stiff, highly plastic clay. The thickness of Stratum II ranges from approximately 54 to 60 feet on the south side, and from approximately 10 to 30 feet on the north side, typically thinning towards the north. These soils serve as the principal resisting strata for laterally loaded deep foundations under the scoured condition, but are subject to settlement and could lead to some downdrag loads on the piles. Stratum III (Lower Sand and Gravel) consists of medium dense to very dense fine to coarse sands and gravels, with thickness varying considerably from 30 to 45 feet in the south side of the inlet to 80 to 100 feet in the north. These soils form the principal bearing strata for the deep foundation tips supporting the new structure. Stratum IV (Clay & Sand) consists of loose to medium dense clay and sand which form an intermediate bearing stratum considering an equivalent footing representing large pile groups underlying Pylons 5 and 6. The subsurface profile of the site is shown in Figure 5.

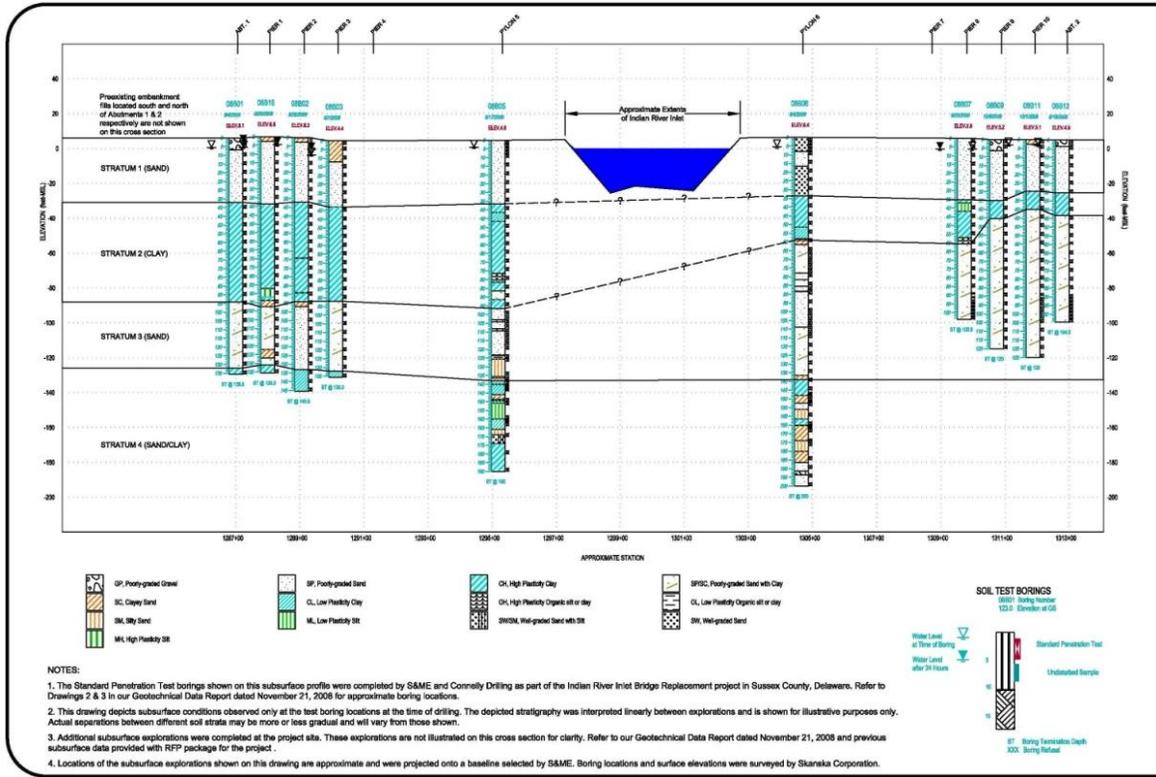


Fig. 5 Subsurface Profile of Bridge Site

**SCOUR**

Scour is a key issue that complicated the design and construction. Both the main span cable-stay structure and approach span structures were designed to account for the occurrence of scour without the benefit of any scour mitigation measures. The total scour depths considered in the design were 30-feet and 35-feet at both abutments and all piers and pylons for the Design Flood (100-year return period) and Check Flood (500 year return period) events, respectively. The storm currents have erosion potential to remove all soil to a depth of 30 to 35 feet. Foundation elements must be capable of supporting storm loads with no lateral support to this depth.

**DESIGN OF CABLE-STAYED TRANSVERSE PRECAST FLOOR BEAMS**

Because the vertical bridge profile is relatively low and the much of the bridge is accessible from the ground, the design-build team chose to precast the floor beams as much as possible in order to remove this operation from the critical path of construction. It also reduced the amount of concreting operations performed on-site. Precast floor beams were used in the back spans and about 200-feet of the main span that is accessible by land, with exception of the pylon pier table areas and ballast regions near the transition piers, which were cast in place.

The minimum compressive strength of the precast floor beam was specified as 6500 psi at 28 days. The depth of precast floor beams varies from 5'-9" (maximum) to 4'-9½" (minimum) with a 98 ft overall length, weighting about 50 tons. There are two transverse floor beams spaced at 12-ft centers for a typical 24-ft long deck segment, as shown in Figure 6. The reason for using 12-ft spacing rather than a more conventional 24 ft spacing was because the deck thickness can be minimized to 8 ½" with a 12-ft beam spacing. A deck thickness of 11" or 12" would have been required for 24-ft beam spacing. This strategy resulted in an overall savings in structural self weight and lower demands on the foundations.

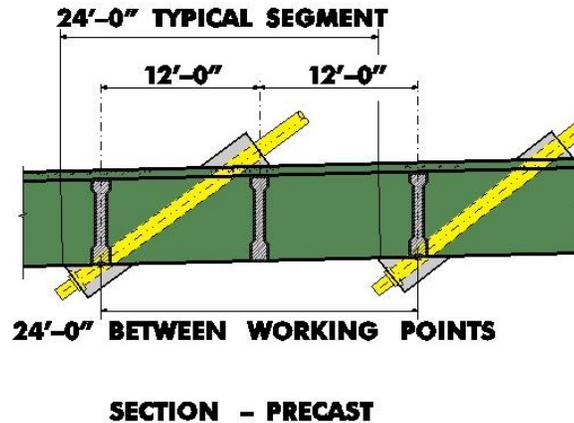


Fig. 6 Precast Floor Beam Layout

Each floor beam consists of a standard prestressed concrete I girder shape, but modified with a web thickness and truncated top flange, as shown in Figure 7. The floor beams were designed as prestressed concrete elements, each beam was pretensioned with enough initial prestressing to control stresses and provide an adequate factor of safety for lateral stability during the lifting of the beam. Also, each beam has two transverse post-tensioning tendons which were designed to carry the dead load and live loads imposed on the floor beams and to ensure that the floor beams and deck slabs were pre-compressed between edge girders for all loads.



Fig. 7 Precast Floor Beam Section

Due to the differences in behavior of the structure for dead load and live load cases, the methods of analyses were different. The treatment for the dead load case needed to include all locked-in stresses in the floor beam imposed by the various stages of construction. Rigorous step-by-step time-dependent analyses, including the changes of the composite section, were performed utilizing the program Tango. The combined effects of creep, shrinkage and differential shrinkage of concrete, and relaxation of prestressing steel were carefully studied. To minimize long term creep and shrinkage effects, each precast floor beam was specified to have a minimum age of 90 days before its continuity was made with the cast-in-place deck slab. Also, stressing of the transverse post-tensioning was completed in two stages to achieve an efficient design and balance the structure load. First, the bottom tendon which was comprised of 19-0.6" diameter strands was stressed after the placement of the CIP edge girder. Then, the top tendon with 13-0.6" diameter strands was stressed after the 12-ft tributary composite deck was cast in place and had attained the required strength. The mean creep and shrinkage coefficients, and coefficients varying about from the mean within 90% confidence limits were calculated in accordance with the provisions of the CEB-FIP 90 Model Code.

In the case of live loads, these loads were developed from a finite element model. The program SAP2000 was used to create a refined 3D local model for the cable stayed superstructure. The edge girders and floor beams were modeled as frame elements and the deck was modeled as shell elements. The cable stays were treated as elastic spring supports which were computed from the length, cross sectional area and modulus of the cable. A general view of the local model and a plot of the resulting live load stresses are shown in Figure 8.

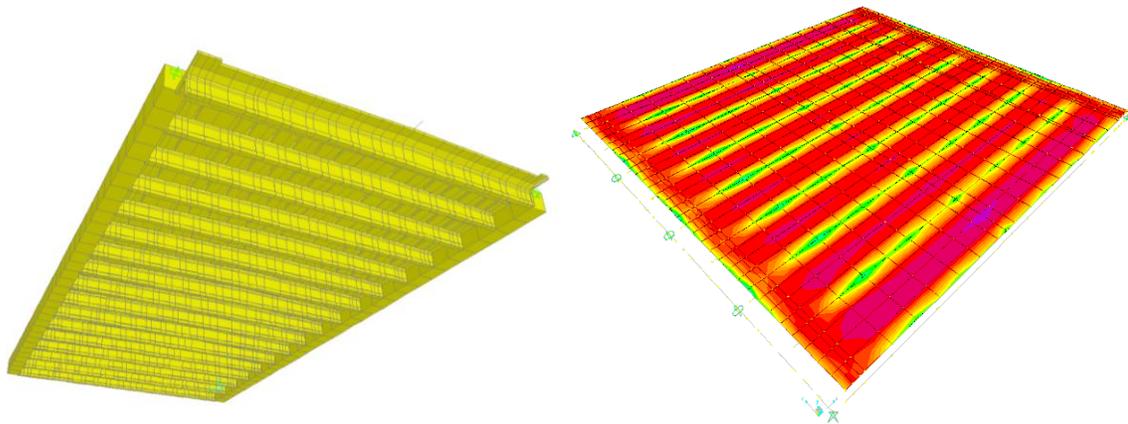


Fig. 8 SAP2000 Local Model with Live Load Stresses

The precast floor beam was designed to satisfy the allowable stresses for "fully prestressed" components in the *AASHTO LRFD Bridge Design Specification* and a 'no tension' stress limit for an additional Service Limit State Combination consisting of the sum of effective prestress, permanent loads and the long term effects from creep, shrinkage and relaxation.

## DESIGN OF BRIDGE FOUNDATIONS

Foundations were a clearly critical component to the successful implementation and completion of this project. Several foundation types were considered to address the many geotechnical challenges, including the severe scour and consolidation (downdrag and settlement). The design-build team selected 36-inch-square, precast, prestressed concrete driven piles for the foundation due to previous successful experience on a similar project. The 36-inch precast piles are voided with a 22½ inch circular cut out. Concrete piles were designed based on a 28-day concrete compressive strength ( $f'_c$ ) of 8,500 psi, with 6,500 psi minimum strength at the time of prestress transfer. The maximum pile lengths are about 100 feet without any splicing. The maximum allowable stress in the piles was limited to approximately 33% of  $f'_c$  or 1,273 tons on a 6.24-square foot-cross section.

For the cable-stayed spans, there are two separate pylon towers on each side of the inlet. The foundation of each pylon tower 5W & 6 E&W is comprised of 42 vertical precast piles spaced at 2.9 diameter center-to-center. Pylon tower 5E is supported by 49 vertical precast piles due to eccentric loading conditions since the footing had to be offset to avoid an existing sheetpile wall. The pile cap for each pylon tower is approximately 50-foot by 60-foot rectangular footing. Each pylon foundation was required to support axial compressive loads of approximately 26,600 kips under the Strength I loading condition. A general view of the pile supports for the pylon towers is shown in Fig. 9 below.

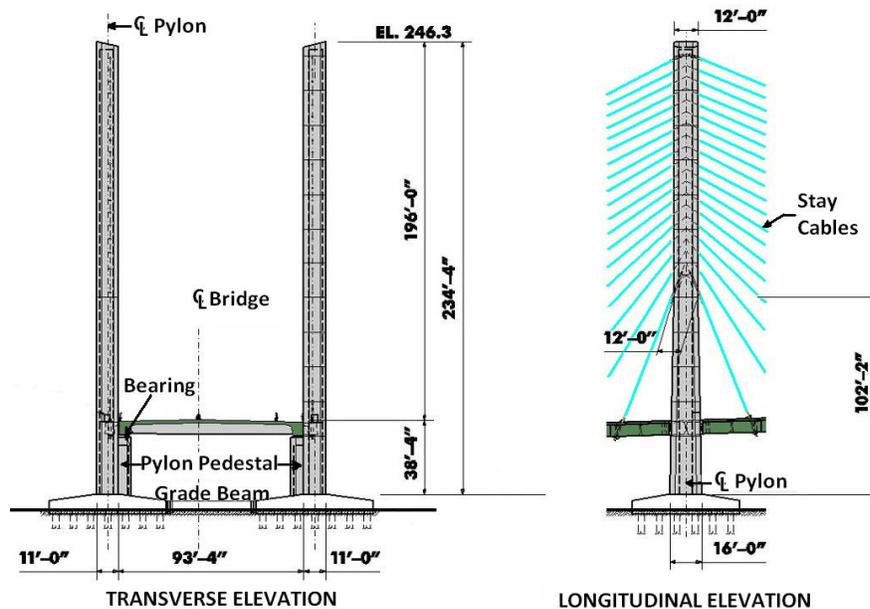


Fig. 9 Overview of Pylon Foundation

The supporting precast piles carried the loads through a combination of skin friction between the soil and pile, and bearing at the tip of pile. The 36-inch precast piles can provide up to 1,800 tons of ultimate bearing capacity. Also the large bending capacity of these piles

allowed them to be designed as vertical piles without having to batter them to resist horizontal loads. These piles allowed the main span to be 950-feet in length, which exceeded the 900-ft horizontal clearance requirement. Transition piers at the land end of the main spans have two piers supported by six-pile groups, each.

The pile foundations for the approach span piers and abutments are similar to that of the main span foundations. The approach structure consists of two abutments and six piers. Each abutment is founded on a single row of eight prestressed concrete piles. The piles were designed to provide support for the approach span Bulb-T girders and roadway approach slabs. An elevation view of Abutment 1 as presented in the design drawings is shown in Figure 10.

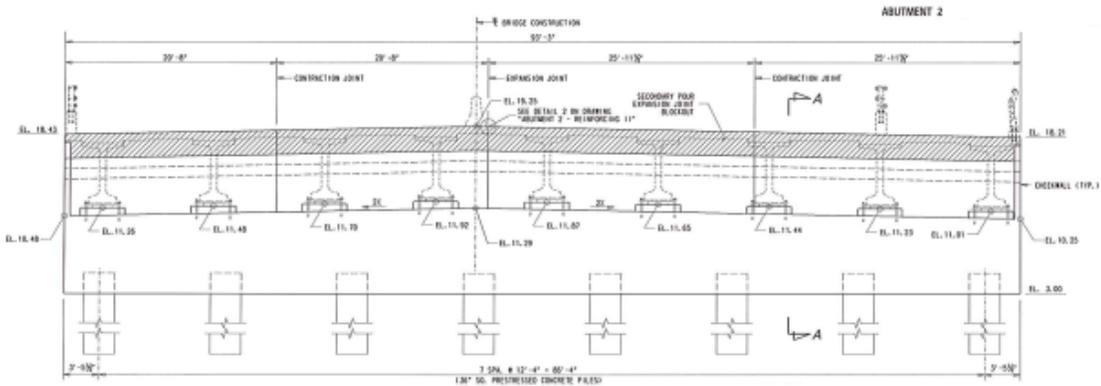


Fig. 10 Elevation View of Abutment 1

Each approach pier is a multiple column bent composed of four 4'-0" diameter circular columns. All of the approach pier columns are founded on 5'-0" thick footings that are supported by three prestressed concrete piles. A drawing elevation view of a typical approach pier with its foundation is shown in Figure 11.

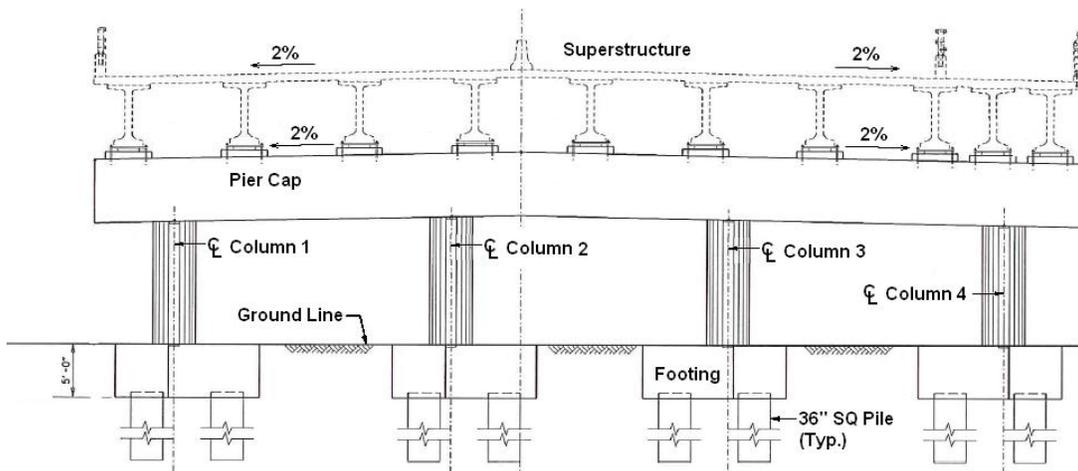


Fig. 11 Elevation View of Typical Approach Pier & Foundation

Preliminary drivability analyses were performed to confirm that the design pile section could be installed to the required ultimate bearing capacity without being overstressed. Pre-drilling of the piles through the upper dense and clay layers was required to help reduce the driving resistance. Consideration was given in the foundation design due to the effect of the large downdrag from the unconsolidated clay layer in Stratum II. The foundations were also designed for the scoured condition which removed all soil to this depth with no lateral support. One of the benefits of using voided piles was that the connection with the footing caps allowed for a completely fixed connection. The fixity was accomplished by inserting steel reinforcing column cages (24-#11 bars) and then securing them in place at the top of the pile with a secondary concrete pour back. The rebar extended 10-feet into the voided pile and 4-feet into the footing cap. A detail of the pile connection is shown in Fig. 12.

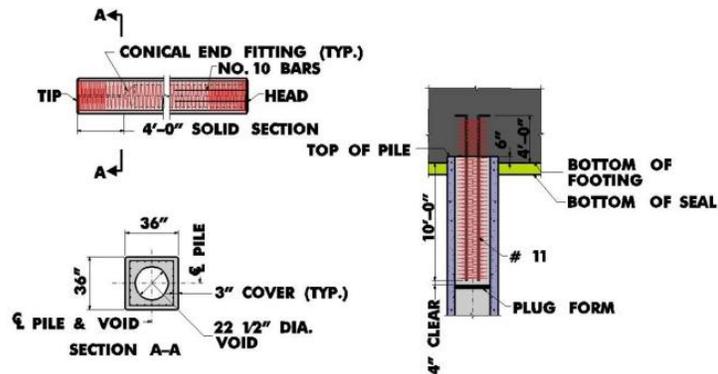


Fig. 12 36-inch Pile Fixity Connection

The design team used the program FB-Multiplier to analyze the foundations for the various load combinations, which accounted for soil-structure interaction and lateral load effects. This program combines non-linear structural finite element analysis with non-linear static soil models for the structure and foundation system. The pile foundations were analyzed for both scoured and unscoured conditions, and the structural capacities of the prestressed piles were evaluated within the program for the combined effect of axial force and moment. A screen plot of the FB-MultiPier file for the foundation under the scoured condition at Pylon 5 is shown in Figure 13.

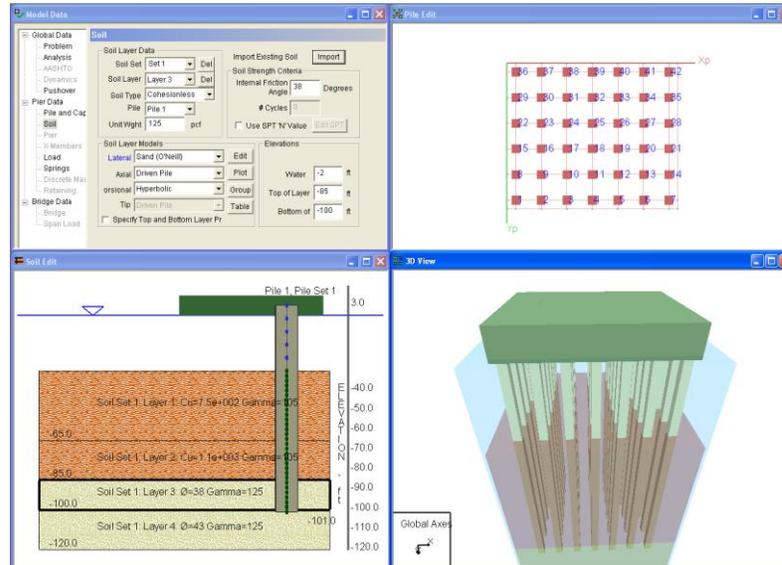


Fig. 13 FB-MultiPier Model for Pylon 5 Foundation (Scoured Case)

### DESIGN OF APPROACH SUPERSTRUCTURE BULB-T GIRDERS

The approach spans on either end of the main cable-stayed bridge consist of four-span continuous units, with each span being 106'-3" in length. The superstructure is composed of ten precast concrete 70" Bulb-T girders (PCBT-70) girders for Spans 1 thru 3 and nine girders for Spans 4 and 8 thru 11. The girders are composite with an 8½" thick concrete deck and are supported by elastomeric bearings at the interior piers and abutments. At the transition piers, the Bulb-T girders are supported by sliding disc bearings.

The girders were designed for the 2-inch concrete cover requirements (resulting in a 8-inch web thickness versus the industry standard of 7-inch) and required a concrete compressive strength of 8,000 psi. Four continuous and uniform spans on each side of the cable stay bridge section were used. The uniform span lengths facilitated repetition and speed of construction. A typical section for the approach spans is shown in Figure 14.

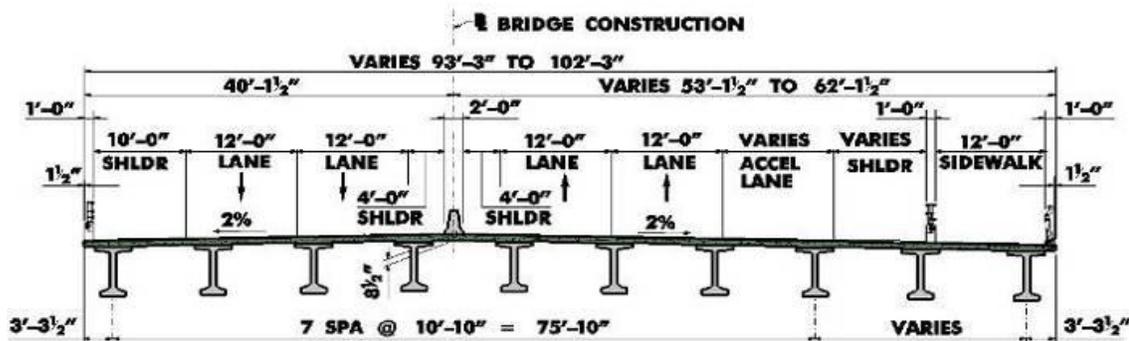


Fig. 14 Typical Section for Approach Spans

The approach structures were designed using LEAP software products: CONSPAN to analyze the prestressed Bulb-T girders and RCPIER to analyze the multi-column pier bents. Similar to the cable-stay spans, the pile foundations for the approach units were also analyzed using the program FB-MultiPier to ensure the structural integrity of the prestressed piles in both the unscoured and scoured conditions.

### **CONSTRUCTION OF PRECAST PRESTRESSD PILE**

A total of 291 precast prestressed concrete production piles, each about 100 feet long, were constructed to support the bridge foundations. Piles were shipped by truck to the site from the Bayshore Concrete Products (BCP) precast yard in Cape Charles, Virginia.

Pile testing was performed as required by the project specifications, which included static load tests, PDA dynamic test piles, and monitoring piles. Prior to beginning the pile driving operations, three static compression and two static tension load tests were performed to verify the pile axial force resistance. The prestressed concrete piles were loaded to 1800 tons in compression and 600 tons in tension. The pile load test apparatus is shown in Figure 15.

The production pile driving criteria was established based on the information obtained during the static load tests along with PDA test pile results which were conducted on two piles at each abutment, pier, and pylon footing. In addition to the specified PDA test piles, several monitoring piles were also dynamically tested as a quality control measure during the production pile driving operation.



Fig. 15 Pile Load Test Setup

## PILE DRIVING

Compatibility of the pile driving equipment, the soil conditions and the pile type being driven are all essential elements in achieving the required penetration and capacity. The minimum acceptable hammer energy, in foot-pounds, was taken as at least 250 times the design service load, in tons. It was necessary to pre-drill through the upper hard sand and clay layers in order to achieve the required design tip elevations for the 36-inch square precast piles. The Contractor used an ICE 44-50 vibratory hammer to drive 54" diameter casing that was 50 ft long through Stratum 1 with a penetration of at least a few feet into Stratum 2. Then, the casing was augered out using the drilling rig to an approximate depth of 15 feet above the top of Stratum 3. The 36-inch piles were then set in the casing and driven to the required tip elevations. Piles were lifted with three point pickup. Figure 16 shows that a pile that is being lifted and supported by the Manitowoc 2250 crane.



Fig. 16 Erection of 36" Precast Pile

The pile hammer, as shown in Figure 17, was a JUNNTAN HHK 20S, which is a hydraulic impact hammer with an adjustable stoke of up to 4.9 ft.



Fig. 17 Pile Hammer

Once all of the piles were driven and completed, the piles were trimmed to cutoff elevations which provided a minimum embedment into the footings of 6 inches at the piers and pylons and 2 ft at the abutments. For each pile, the upper 12 feet of the pile void was filled with cast-in-place reinforced concrete detailed with dowel bars extending into the footing to develop a fixed pile connection. A view of the completed driven pile groups in one of pylon footings is shown in Figure 18.



Fig. 18 View of Pylon Foundation with Piles in Place

## CONSTRUCTION OF CABLE-STAYED PRECAST BEAMS

The portion of cable-stayed superstructure accessible by land was constructed on temporary falsework utilizing precast floor beams. The falsework was placed in two parallel rows directly under each edge girder, and this falsework provided support for the precast floor beams that spanned the full width of the bridge. A total of 192 precast floor beams were produced at BCP and delivered to site by truck as shown in Figure 19. Figure 20 shows a floor beams being lifted onto the temporary supports.



Fig. 19 View of Precast Floor Beam on Truck



Fig. 20 Placement of Precast Floor Beam onto Temporary Falsework

Temporary steel diaphragms between the floor beams were installed to stabilize the beams prior to deck placement. Once the floor beams were in place, steel reinforcing cages in edge girders, stay cable formwork tubes, and post-tensioning hardware were first installed, and then the edge girders were cast and monolithically connected with the floor beams. Figure 21 shows the main span precast floor beams in place.



Fig. 21 Overall View of Precast Floor Beams at Main Span



Fig. 22 Installation of Deck Formwork over Floor Beam

Once the edge girders reached sufficient strength, the first stage post-tensioning tendons of the transverse floor beams were stressed and anchored at the exterior face of the edge girders. The next phase of construction consisted of installing forms between the floor beams,

installing deck reinforcement, and then the concrete slab in between the edge girders and floor beams was cast. The final stage post-tensioning tendons of the transverse floor beams were then stressed. Finally, stay cables were stressed to carry the superstructure dead load from the falsework. Figure 22 shows the formwork for the deck slab supported by the precast floor beams and Figure 23 shows a portion of the superstructure supported by the stay cables.



Fig. 23 Superstructure Segments Supported by Stay Cables

### **CONSTRUCTION OF APPROACH SUPERSTRUCTURE BULB-T GIRDERS**

A total of 72 precast Bulb-T girders were produced at Bayshore Concrete Products. Girders were transported to the site, lifted by Manitowoc cranes and placed on elastomeric bearings at the top of the pier cap. Figure 24 shows a Bulb-T girder being lifted into place. After the girders were placed in the correct location, concrete diaphragms were then poured to provide lateral stability.



Fig. 24 Erection of 70 in Deep Bulb-T Girder

Stay-in-place galvanized metal deck forms were used. A standard Bid-Well paving machine was used to provide the proper deck profile during the deck pouring operation. The approach deck concrete mix design included fibers to help prevent premature cracking of the deck during curing. Views of the approach spans during construction are shown in Figures 25 and 26.



Fig. 25 End View of Approach Span



Fig. 26 Approach Spans Under Construction

## CONCLUSION

The extensive use of the precast prestressed concrete components has proven to be very successful for the design and construction of the Indian River Inlet Bridge Replacement Project. It offered the bridge Owner many benefits resulting from the use of the precast components, which included the following:

- Speed of bridge construction arising from the efficient and fast erection of the precast bridge components.
- Protection of the environment surrounding the bridge site due to reduced amount of concreting operations performed on-site.
- Assured concrete product quality due to factory conditions for concreting in the precasting yard.
- Inherent long-term durability of precast concrete construction.
- Cost-effective solution through the acceleration of construction.

## CREDITS

Owner:	Delaware Department of Transportation
Design-Build Team:	Skanska USA Civil Southeast & AECOM
Contractor:	Skanska USA Civil Southeast, Virginia Beach, VA
Bridge Design Engineer:	AECOM, Glen Allen, VA
Precast Concrete Producer:	Bayshore Concrete Products Corporation, Cape Charles, VA