PROJECT

Economy and Durability Achieved through Precast Concrete—the New Marc Basnight Bridge

by Domenic Coletti, R. Dominick Amico, Nicholas Burdette, and Mohit Garg, HDR

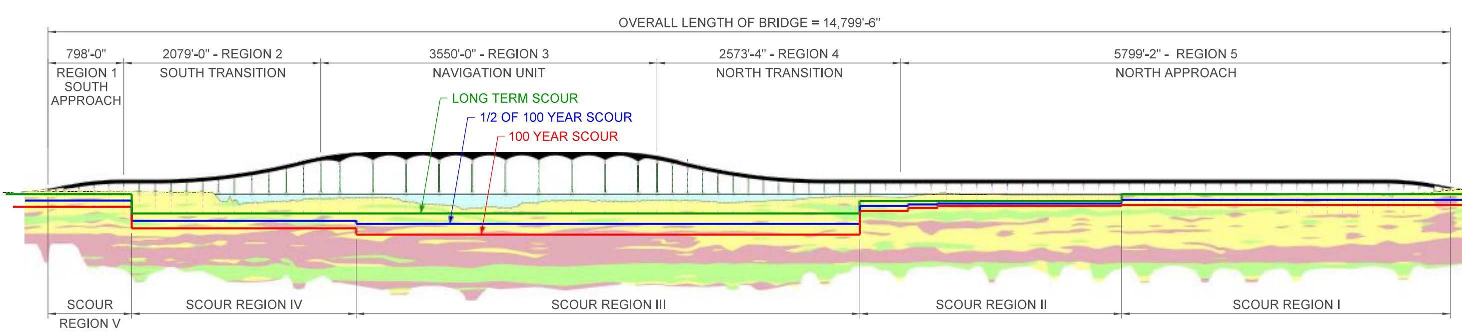
The new $252 million, 2.8-mile-long Marc Basnight Bridge carries traffic for North Carolina Highway 12, a hurricane evacuation route. The structure spans the remote Oregon Inlet of North Carolina's Outer Banks. The inlet is considered by some to be the most dangerous on the East Coast due to treacherous currents, constantly shifting bathymetry, and the potential for violent storms.

The new bridge replaces the Herbert C. Bonner Bridge, which had been designed for a 30-year service life and was a source of consternation for more than 55 years, requiring nearly continuous repairs after its completion in 1963. The Basnight Bridge is designed for a 100-year service life and to resist up to 84 ft of scour, 105 mph winds, and vessel collision forces.

Early in the design process, structural and geotechnical engineering teams for the Basnight Bridge created a color-coded longitudinal plot of the project illustrating the subsurface conditions, scour profile, vessel collision zones, and navigation clearance zones. Examination of this plot allowed the project to be partitioned into five regions: north approach spans, north transition spans, navigation unit, south transition spans, and south approach spans. These regions corresponded to both the scour profile and the vertical geometry of the bridge. Vessel collision forces, a primary loading consideration for the deep foundations of the bridge, also varied along the length of the bridge, with smaller forces in the north and south approach spans, larger forces in the north and south transition spans, and the largest forces in the navigation unit.

The vessel collision forces varied along the length of the bridge for a number of reasons. First, the vessel collision design vessel, the dredge Atchafalaya, was only considered as operating within the navigation zone; in other regions of the bridge, only the American Association of State Highway and Transportation Officials (AASHTO) minimum impact vessel (an empty hopper barge) was considered.

Also, the current (velocities) varied along the length of the bridge; the design



Longitudinal profile of the Marc Basnight Bridge, showing subsurface conditions, scour depths, structure height, and design regions. All Photos and Figures: HDR.

profile

MARC BASNIGHT BRIDGE / DARE COUNTY, NORTH CAROLINA

BRIDGE DESIGN ENGINEER: HDR, Raleigh, N.C.

CONSTRUCTION ENGINEERING: Corven Engineering Inc., Tallahassee, Fla.

PRIME CONTRACTOR: PCL Civil Constructors, Raleigh, N.C.

PRECASTER: Coastal Precast Systems LLC, Chesapeake, Va.—a PCI-certified producer

POST-TENSIONING CONTRACTOR: Schwager Davis Inc., San Jose, Calif.

OTHER SUPPLIERS: Segmental formwork: Ninive Casseforme, Garbagnate Monastero, Italy; segment lifters: HCR Bridge Machinery, Kuala Lumpur, Malaysia

Simple precast concrete elements, such as these Florida I-beam girders and pile bents, were combined to accommodate a curved horizontal alignment in the south approach spans.

collision velocities were generally faster (with larger vessel collision forces) in the main part of Oregon Inlet and slower (with smaller vessel collision forces) near the ends of the bridge.

Advantages of Precast Concrete

Precast concrete elements were chosen as the optimum design solution for several reasons. First, each of the structure's regions lent itself to a tailored design approach, allowing for widespread use and detailing of repetitive elements in different configurations. Also, concrete resists corrosion from the saltwater environment, making it a durable material that extends the structure's service life and reduces maintenance.

Furthermore, broad use of prefabricated concrete elements and modular construction techniques was a practical and economical option given the project's remote location. Precasting Florida I-beam (FIB) girders, box-girder segments, bent caps, columns, and piles under controlled conditions at an off-site precast concrete facility resulted in the production of high-quality, extremely durable concrete components. These levels of quality and durability would have been difficult to achieve if the concrete had been cast in the harsh marine environment of the Oregon Inlet. Off-site fabrication was also less expensive than delivering and placing cast-in-place (CIP) concrete at the remote project site.

Additionally, because the use of precast concrete elements minimized field construction work from barges and work trestles, construction was faster and safer and had less impact on the environment than other options. It is estimated that 24 working months were saved because of the use of precast concrete.

Substructures and Foundations

The north and south approach spans represent approximately half of the total bridge length. Foundations in these regions consist of precast concrete pile bents, with three or four vertical 54-in.-diameter precast concrete cylinder piles for each bent. The cylinder piles connect directly to innovative precast concrete bent caps via reinforced CIP concrete infill. This infill extends 30 ft into the hollow piles to provide stiffness in cases of severe scour, transfers both moment and axial loads to each pile, and provides strength locally to prevent vehicle-collision damage to the pile wall.

The north and south transition spans represent approximately one-quarter of the total bridge length. Foundations in the transition regions include six to sixteen battered 36-in.-square precast concrete piles with a CIP waterline pile cap. The bents for the transition regions are match-cast, precast concrete solid 5-ft or 6-ft square, post-tensioned columns in a two-column bent arrangement with column heights up to 50 ft, supporting a precast concrete bent cap.

The 11-span navigation unit extends 3550 ft and includes 12 substructure bents. Foundations in this region include 18 to 30 battered 36-in.-square precast concrete piles, with square and octagonal CIP waterline pile caps. On top of the pile cap, a precast, post-tensioned, match-cast 16 ft by 11 ft hollow-box concrete column supports a rectangular precast concrete column cap.

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: A 14,800-ft-long bridge consisting of 71 spans of precast, prestressed Florida I-beam (FIB) girders (span lengths up to 182 ft) and 11 spans of variable-depth, post-tensioned segmental concrete box girders (span lengths up to 350 ft)

STRUCTURAL COMPONENTS: Two-hundred eighty-five 96-in.-deep FIB girders (46,379 ft total) and eighteen 45-in.-deep FIB girders (1508 ft total), both with 9-in.-thick sand-lightweight concrete decks; 238 single-cell precast concrete variable-depth (9 ft 0 in. to 19 ft 0 in.) segments in a 3550-ft-long continuous, post-tensioned box-girder unit; 44 pile bents with precast concrete bent caps and precast, prestressed concrete 54-in.-diameter cylinder piles; 25 two-column bents and 12 single-column bents with precast concrete caps supported on CIP pile caps and precast, prestressed concrete 36-in.-square piles

BRIDGE CONSTRUCTION COST: $252 million (total project cost), approximately $350/ft^2

AWARDS: American Road and Transportation Builders Globe Award in the >$100 Million projects category; Deep Foundations Institute Outstanding Project Award

Lateral resistance was a major element of the foundation designs. Multiple refined soil-structure interaction analysis models were performed for every bent on the bridge, considering pier stiffnesses, vehicle collisions, and various scour depths from no-scour to full-scour conditions. Design of the navigation unit included individual FB-MultiPier software bent models and a global three-dimensional LARSA model of the entire 3550-ft unit with superstructure and substructure. (The design process used for the piers is described in a related Concrete Bridge Technology article in this issue of *ASPIRE*®.)

Superstructure

The superstructure of most of the bridge (the north and south approach spans and the north and south transition spans) consists of a conventionally formed 9-in.-thick CIP sand-lightweight concrete (sand-LWC) deck supported by precast, prestressed concrete FIB girders. Stainless steel reinforcement is used in the deck to enhance corrosion resistance. The deck of the FIB spans was constructed using sand-LWC to reduce dead load on the girders, allowing the girders to span longer distances at the same girder spacing. This reduced both the total number of required spans and, more importantly, the total number of bents and foundations, thereby lowering costs substantially. The sand-LWC deck was not treated differently with regard to durability or corrosion protection; the North Carolina Department of Transportation permitted the use of sand-LWC in the deck without additional corrosion protection provisions.

Most of the bridge has a roadway cross section with two 12-ft-wide lanes and two 8-ft-wide shoulders, with a total out-to-out deck width of 42 ft 7 in. The most common span configuration features a four-girder cross section and a span length of 160 ft 10 in. In the south transition region, a number of spans feature a six-girder cross section and spans up to 182 ft, the longest simple-span prestressed concrete girders in North Carolina. The FIB girders are designed as simple spans for dead load and live load, but they are detailed as continuous for live load and are supported on steel-laminated elastomeric bearing pads with stainless steel sole plates and anchor bolts. In some cases, where designed to allow redistribution of vessel collision loads to adjacent bents, reinforced concrete shear keys are provided.

The use of precast concrete pile bents and vertical cylinder pile foundations minimizes the project's permanent impact on environmentally sensitive seagrass beds in the north approach spans.

To minimize the need for future dredging to accommodate Oregon Inlet's highly dynamic bathymetry, the design provides for a 2400-ft-wide "navigation zone." All spans within this zone provide at least 200 ft of

AESTHETICS **COMMENTARY**

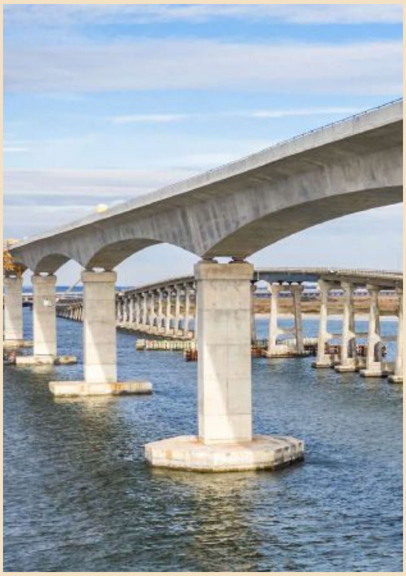
by Frederick Gottemoeller

For observers on the shore, long, relatively low bridges over water have an unfortunate aesthetic impact. Absent the bridge, water-level observers may have 180 degrees or more of seascape to admire, along with sunrises or sunsets and long-distance views of dramatic weather events. However, when a typical short-span causeway is viewed from shore at the usual oblique angles, the pile bents line up one behind the other to form a visual wall, cutting the visible water surface in half and destroying the sweeping, wide-angle exposures otherwise available.

The Marc Basnight Bridge impressively applies modern foundation technologies to the challenging conditions of the Oregon Inlet. Most of the major construction decisions emanated from those conditions, including the decisions to double the spans, raise the bridge height, and use haunched girders over approximately 25% of the bridge's length. A happy consequence of those choices is that the bridge's long spans and high clearances eliminate the most objectionable feature of typical causeway bridges—the way they block views of the water from the shore. With the new structure, long water-level views of the inlet are visible through the bridge.

The haunched girders also engage viewers by providing information about how the bridge works. The girders are thickest over the piers, where the forces are the highest. Finally, the disc bearings and their pedestals raise the girders above the piers just enough to provide a glimpse of sky between the tops of the piers and the bottoms of the girders, so that the girders appear to be floating in midair.

The aesthetic consequences of decisions made for technical reasons will make the Basnight Bridge a



valued improvement to the Oregon Inlet seascape. With this example in front of them, perhaps other transportation agencies will now consider significantly longer spans and higher clearances for other water crossings with high scenic values, even if the technical issues are not as difficult as those faced in the Basnight project.

An innovative "leapfrog" approach to work-trestle construction for the north approach spans reduced the project's temporary environmental impact associated with shading of seagrass beds.

horizontal clearance and 70 ft of vertical clearance. By simply moving the navigation lights and buoys, the span identified for ship passage can be easily changed to accommodate migration of the natural channel. The resulting 3550-ft-long navigation unit consists of nine 350-ft-long main spans and two 200-ft-long end spans. The unit is a single, continuous post-tensioned concrete segmental structure with 238 single-cell precast concrete box-girder segments supported on post-tensioned precast concrete columns; this is one of the longest continuous precast, balanced-cantilever segmental concrete box-girder units in the United States. The variable-depth segmental superstructure provides a solution that is both aesthetically pleasing and economical.

Precast concrete segments were match-cast under controlled conditions at an off-site precast concrete facility, which resulted in high-quality, durable components.

Segments for the variable-depth, balanced-cantilever segmental box-girder superstructure were delivered by barge. In general, the north and south transition spans and the navigation span regions of the bridge were accessible by barge. Segments for the north and south approach spans regions were delivered either overland or in shallow water because barge access was not possible. The balanced-cantilever construction of the box-girder spans did require the use of temporary shoring towers to accommodate out-of-balance loading as segments were erected on either side of the piers.

The application of the balanced-cantilever construction method permitted the 350-ft-long spans. The superstructure segments range in height from 9 ft 0 in. at the midspan to 19 ft 0 in. at the interior piers. Longitudinal post-tensioning consists of 18- or 22-strand cantilever tendons and either 12-, 16-, or 20-strand continuity tendons encased in plastic ducts and high-strength grout. The cantilever tendons were installed in the top of the segment as each segment was erected. These tendons provide negative moment capacity for the box girder in the cantilever condition during erection as well as negative moment capacity in the completed multispan continuous-span structure. Once the closure pour was made at midspan, the continuity tendons were installed in the bottom of the segments. These tendons provide positive moment capacity in the completed continuous multispan structure. One pair of contingency ducts is provided for each cantilever. Segments are transversely post-tensioned using four-strand tendons spaced at 3 ft 6 in. All tendons are comprised of 0.6-in.-diameter, 270-ksi low-relaxation prestressing strands. The diaphragms use vertical 1¾-in.-diameter, 150-ksi deformed post-tensioning bars to resist vertical splitting induced by the longitudinal post-tensioning.

The superstructure is supported by two disc bearings at each pier, and the entire 3550-ft-long navigation unit is longitudinally restrained at the two middle piers. Bearings at other piers are designed to slide longitudinally to relieve thermal, creep, and shrinkage stresses. The construction sequence included midspan jacking prior to closure of the center span to counteract long-term creep and shrinkage effects

Creative pile templates were used to control the geometry during installation of battered 36-in.-square piles that were at least 130 ft long.

Balanced-cantilever erection of precast concrete segments in the 350-ft-long spans of the high-level navigation unit. Falsework towers, crane and materials barges, and two segment erectors (green and yellow hoists on ends of nearly completed cantilevers) are visible. The long spans allow the migration of the natural channel, and there is no need to constantly dredge to maintain a navigation channel.

on the two fixed piers (see the related Concrete Bridge Technology article in this issue of *ASPIRE*.)

Corrosion Protection

The 100-year design service life for the Basnight Bridge was achieved by incorporating a number of design and construction features, many of which were prescribed in the North Carolina Department of Transportation (NCDOT) request for proposals for the design-build project. NCDOT required concrete that would greatly enhance the durability and longevity of all concrete elements of the bridge, including the extensive use of fly ash or ground granulated blast-furnace slag and silica fume, a low water-cementitious materials ratio, and the use of a calcium nitrite corrosion-inhibiting admixture. In addition, stainless steel reinforcement was used for all CIP concrete except the barrier rails, which used epoxy-coated reinforcement. Stainless steel post-tensioning bars were used for post-tensioning applications below the splash zone, defined as 12 ft above the mean high-water level. Furthermore, stringent design criteria, such as a zero-tension stress requirement for prestressed concrete members under service load conditions, augmented the level of corrosion protection provided through material and construction requirements.

Conclusion

The Marc Basnight Bridge is a monumental structure built in a challenging marine environment and designed to achieve a 100-year service life with minimal maintenance. The extensive use of precast concrete elements—including 3.4 miles of precast concrete cylinder piles, 12 miles of precast concrete square piles, 0.58 miles of precast concrete bent caps, 0.3 miles of precast concrete columns, 8.75 miles of precast concrete FIB girders, and 0.67 miles of precast concrete segmental box girders—greatly enhanced the quality and durability of the structure, while simultaneously facilitating faster, safer, and more economical construction. In total, over 25 miles of precast concrete structural elements were used in the construction of the bridge; this represented over two-thirds of the 90,000 yd^3 of concrete in the structure, of which approximately 18,000 yd^3 was sand-LWC. The contractor's bid was $215.7 million, which was approximately $25 million below NCDOT's estimate. The new bridge opened to traffic on February 25, 2019, with a dedication ceremony held on April 2.

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