PROJECT

Rodanthe "Jug Handle" Bridge: Ensuring a Reliable Connection to the Southern Outer Banks

by Jeremy Keene, RK&K

This aerial photo looking north along the 2.5-mile-long Rodanthe "Jug Handle" Bridge was taken in May 2022 before the bridge was opened. The Atlantic Ocean is on the right. All Photos and Figures: RK&K.

The new $145 million, 2.5-mile-long "Jug Handle" bridge replaces a battered stretch of roadway from the Pea Island National Wildlife Refuge to the town of Rodanthe, N.C., by spanning westward over the Pamlico Sound. Situated on Hatteras Island in the picturesque Outer Banks of North Carolina, Rodanthe is a popular destination for vacationers, kiteboarders, and fishers. Most of these visitors travel to the Outer Banks by way of North Carolina Highway 12 (NC 12), a two-lane roadway that sits just above sea level. NC 12 is the only land access and is designated as a hurricane evacuation route. The stretch of NC 12 just north of Rodanthe is referred to by the locals as the "S" curves and is often flooded by hurricanes, nor'easters, and non-storm-related tidal events. Breaches of the dunes that separate the roadway from the Atlantic Ocean are common, and when the road is inundated with sand and water, it can be closed for prolonged periods. The roadway requires nearly constant clearing of sand and maintenance of the protective dunes to remain open.

Seeking a solution to alleviate these challenges, the North Carolina Department of Transportation (NCDOT) issued a request for proposal (RFP) to replace the roadway with a bridge designed for a 100-year service life and 105-mph winds.

There is a potential for large waves to impact the bridge if a breach of the barrier island occurs. Historical data and design storms indicated the potential for waves to reach an elevation of 17 ft above sea level. Any portion of the structure below that elevation needed to be designed for these forces.

As part of the initial preparation for design, the design team compiled a two-dimensional profile of the subsurface soil conditions and scour zones along the bridge profile from the boring information. A thorough review of this profile and the RFP requirements allowed the team to divide the bridge into five separate regions for design. The south approach, south curve, tangent, north curve, and north approach spans were investigated separately with respect to span layouts, superstructure design, scour profiles, and substructure design.

The new structure is designed to survive hurricane waves and collisions with empty barges, and it can remain in service with

profile

RODANTHE "JUG HANDLE" BRIDGE / DARE COUNTY, NORTH CAROLINA

BRIDGE DESIGN ENGINEER: RK&K, Raleigh, N.C.

CONSTRUCTION ENGINEER: Flatiron, Broomfield, Colo.

PRIME CONTRACTOR: Flatiron, Morrisville, N.C.

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

An overhead gantry working from an advancing rail system parallel to the outside edge of the bridge after it lifts a prestressed concrete cylinder pile from a vehicle on the completed portion of the bridge and moves it ahead to be installed. The 54-in.-diameter prestressed concrete cylinder piles, with lengths up to 165 ft, were used for the foundations of the bridge's main spans.

a breach of the barrier island resulting in scour up to 52 ft below sea level. To achieve the 100-year service life, the bridge has stainless steel reinforcing bars in most cast-in-place elements, epoxy-coated reinforcement in the parapets, additional cover on the reinforcement, additional corrosion inhibitors in all of the concrete, and stainless steel for any exposed hardware, including anchor bolts and bridge-mounted signposts.

Why Precast Concrete?

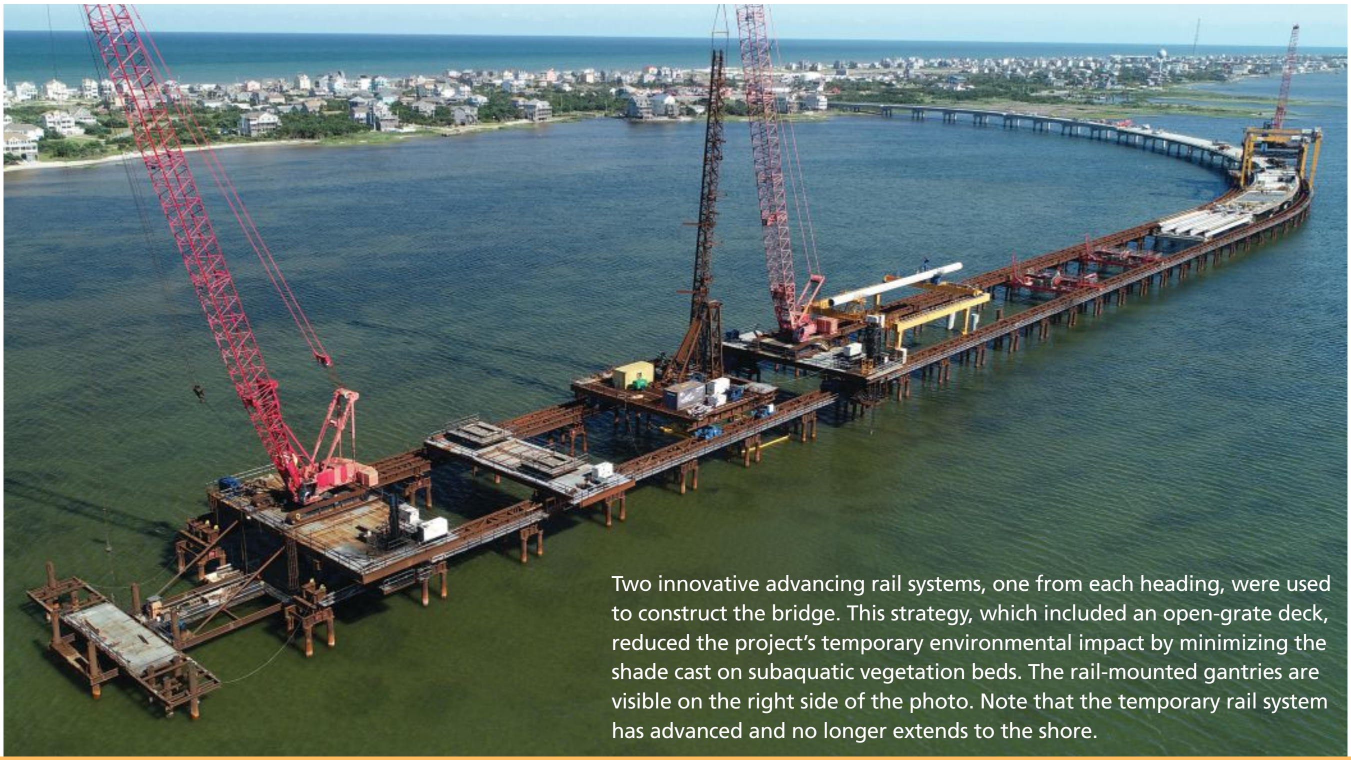
Given the harsh saltwater environment, the designers quickly decided to use precast concrete bridge components. Concrete's corrosion resistance in a saltwater environment reduces long-term maintenance costs and extends the life of the bridge. NCDOT's requirements for corrosion-inhibiting additives in the concrete mixture further enhance the concrete's resistance to corrosion.

Additionally, the design-build team aimed to use similar bridge components in all design regions to simplify detailing and streamline the precasting process. Widespread use of precast concrete components was advantageous given the bridge's remote location. All piles, Florida I-beam (FIB) girders, voided-slab units, deck panels, and concrete sheet piles were fabricated at a controlled precasting facility off site, which increased the quality of the products.

The use of precast concrete components sped up construction of the bridge. On-time delivery of the precast concrete components enabled the contractor to build simultaneously from the north and south headings, doubling the work area and accelerating the construction schedule.

Substructure

All superstructure units are supported on precast, prestressed concrete pile bents



Two innovative advancing rail systems, one from each heading, were used to construct the bridge. This strategy, which included an open-grate deck, reduced the project's temporary environmental impact by minimizing the shade cast on subaquatic vegetation beds. The rail-mounted gantries are visible on the right side of the photo. Note that the temporary rail system has advanced and no longer extends to the shore.

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION, OWNER

OTHER EQUIPMENT SUPPLIER: Gantries, pile-tripping frame, custom rail bogies: DEAL, Italy

BRIDGE DESCRIPTION: A 12,987-ft-long bridge consisting of 10 spans of precast, prestressed concrete voided-slab units with spans up to 60 ft, and 97 spans of precast, prestressed concrete Florida I-beam girders with spans up to 137 ft

STRUCTURAL COMPONENTS: 45- and 72-in.-deep prestressed concrete Florida I-beam girders; 8400 ft of 24-in.-deep prestressed concrete voided slabs; 445,925 ft^2 of 5-in.-thick precast, prestressed concrete deck panels; 3940 ft of 30-in.-square prestressed concrete piles; 42,525 ft of 54-in.-diameter precast concrete cylinder piles; 156,290 ft^3 of cast-in-place concrete pile caps

Approach spans used 24-in.-deep prestressed concrete voided slabs on bents with 30-in.-square prestressed concrete piles.

with cast-in-place (CIP) concrete bent caps. The north and south approach span regions are supported by five vertical, 30-in.-square prestressed concrete piles embedded into a reinforced CIP concrete cap. The south curve, tangent, and north curve regions are supported by three 54-in.-diameter prestressed concrete cylinder piles. The exterior piles are battered transversely away from the centerline of the bridge at a 1:12 ratio while the center pile is vertical. These driven piles have a CIP concrete plug and cap connection that transfers moment and axial loads to the piles while providing a robust impact zone for the design vessel-collision forces and other lateral forces.

Several measures were taken to enhance the corrosion protection of the CIP substructure components. Stainless steel reinforcement was used with increased concrete cover for the cap and shear keys. Calcium nitrite corrosion inhibitor was added to both the precast and CIP concrete components to help achieve the 100-year service life requirements.

Lateral force resistance was a significant challenge for the substructure design. Several soil-structure interaction models were developed, and an analysis was performed for each of the design segments that considered the stiffness of the bents, vessel collisions, wave forces, and other external forces on the structure. Various models in the finite element analysis program FB-MultiPier also considered the full-scour and no-scour conditions and the applicable loads for the investigated cases. (For details on the analysis of barge collisions with bridges, see the Concrete Bridge Technology article in the Summer 2019 issue of *ASPIRE*®).

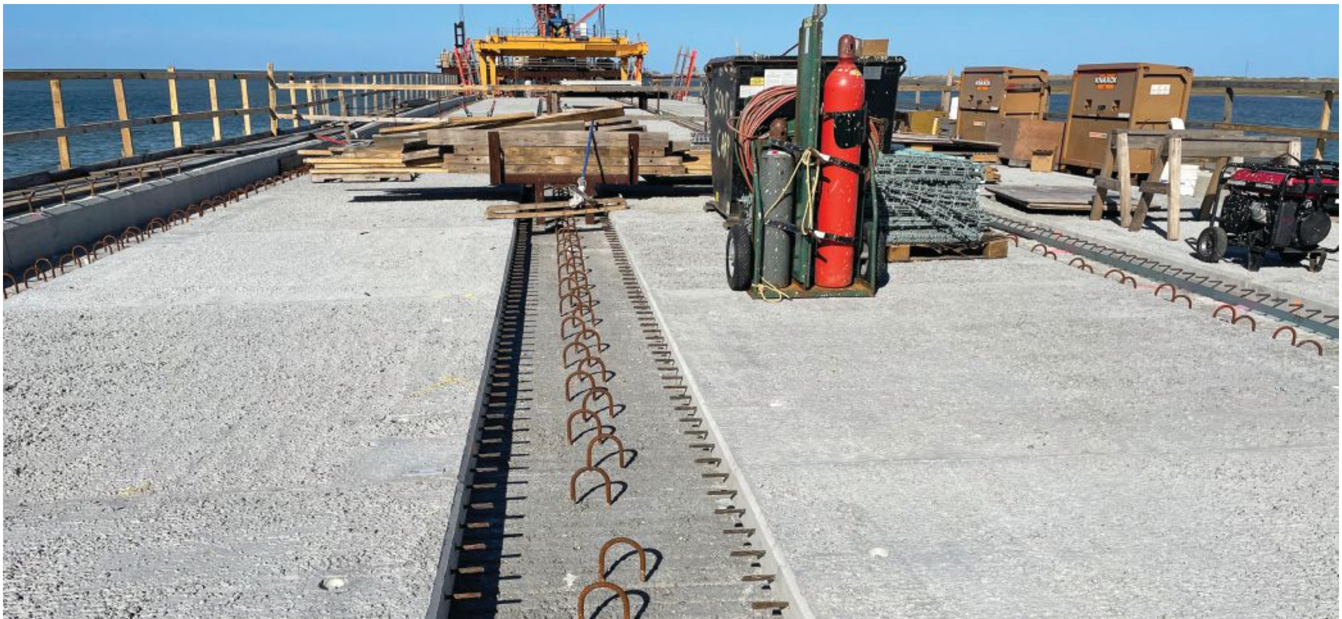
Superstructure

The bridge's typical section consists of two 12-ft-wide travel lanes and two 8-ft-wide outside shoulders. A concrete parapet with a two-bar metal rail protects the traveling public from the waters of the Pamlico Sound. The resulting out-to-out width of the bridge is 42 ft 7 in. North and south approach spans have superstructures that include a series of 24-in.-deep precast concrete voided-slab units that are post-tensioned together transversely and topped with a CIP concrete wearing surface. These voided-slab units are anchored on each end to the substructure with two 1-in.-diameter stainless steel anchor bolts and a hold-down plate to prevent the slabs from lifting off as a result of wave forces.

The south curve of the bridge is a more traditional bridge design, with four prestressed concrete, 45-in.-deep FIB girders at 12 ft 6 in. spacing with 5-in.-thick precast, prestressed concrete deck panels overlayed with a 5.5-in.-thick CIP concrete deck surface. All reinforcement in the CIP deck is stainless steel, which provides additional corrosion resistance to achieve the 100-year service life requirement. The use of 45 in. FIB girders allowed the team to optimize the span lengths for the tighter radius section while maintaining a similar girder spacing to the tangent and north curve sections of the bridge. In addition, the south curve span arrangement crosses over a historic sunken barge in the Pamlico Sound.

In areas where the low chord of the superstructure is above the maximum design wave height, the superstructure-to-substructure connections were designed to eliminate steel anchor bolts by using reinforced concrete shear keys. The design of the shear keys and diaphragms ensures all transverse and longitudinal forces are transferred efficiently between the superstructure and substructure components. Stainless steel, 2-in.-diameter anchor bolts and stainless steel bearing plates are employed in areas where the low chord elevation of the superstructure is below the maximum design wave height.

A close-up of the 5-in.-thick prestressed concrete deck panels on Florida I-beams. The roughened surfaces and stirrups protruding from the beams provide the shear interface between the cast-in-place deck and precast concrete components necessary for the composite action of the superstructure.



Prestressed concrete 5-in.-thick deck panels were used extensively in the main spans of the bridge. Large shear keys on the cast-in-place concrete caps allow the girders to resist wave loads. The panels are supported by prestressed concrete Florida I-beam girders, which are supported by precast, prestressed concrete pile bents with cast-in-place concrete bent caps. The exterior girders have a curb section cast on the top flange, which will support the deck screed. A portion of the advancing rail system that runs parallel to the bridge is visible in the foreground.

The tangent and north curve sections of the bridge also have 5-in.-thick precast, prestressed concrete deck panels and a 5.5-in. CIP concrete wearing surface. These spans are supported by four 72-in.-deep FIB girders spaced at 12 ft 11 in. For the exterior girders of the tangent spans, a precast concrete curb was used to reduce overhang falsework and support the screed rail during casting of the CIP bridge deck. Similar to the south curve, the span lengths of the tangent and north curve spans were optimized to take advantage of the full capacity of the FIB girders.

The design team optimized the design of the bridge components and provided an economical and constructible structure for the client by modeling the typical four-span continuous unit in FB-MultiPier. This model provided an accurate structural response for the bridge for use in optimizing the design.

Construction Methods

Construction means and methods for this structure were carefully thought out. With tidal water depths averaging between 2 and 4 ft throughout the length of the bridge alignment, working from barges or the ground was not feasible. Because this area is adjacent to the Pea Island National Wildlife Refuge and contains subaquatic vegetation throughout the project footprint, the project team had to meet stringent rules and regulations related to environmental impacts. The requirement to maximize sunlight in the areas under work trestles also limited the possibilities of working platforms. These restrictions led the team to develop a construction method that would exceed the environmental requirements. An advancing rail system parallel to the outside edge of the permanent bridge superstructure was used to build the bridge. Gantries that moved along the 1600 ft advancing rail lines carried the precast concrete bridge components and other materials for installation. The use of precast concrete components with this gantry system reduced construction times and allowed the contractor to build one span per week at the north and south headings under optimal conditions.

Conclusion

The Rodanthe "Jug Handle" Bridge is a significant structure that was constructed in a harsh marine environment under strict construction tolerances and designed to reach a 100-year service life. To significantly enhance the quality and performance of the structure, the project used a broad array of precast concrete components, including 0.78 miles of 30-in.-square precast concrete piles, 8.00 miles of 54-in. precast concrete cylinder piles, 9.34 miles of precast concrete FIB girders, and 445,925 ft^2 of precast concrete deck panels. The use of precast concrete components in conjunction with the advancing rail system for construction enabled the contractor to construct the bridge economically. The contractor's bid was $145.3 million. A dedication ceremony and community day was held on April 9, 2022, with the new bridge opened to traffic on July 28, 2022. A

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