PROJECT

Harbor River Bridge Replacement

by Lynda Monroe, Infrastructure Consulting & Engineering PLLC

As the only means for vehicular transportation from the mainland to Harbor Island, Hunting Island, and Fripp Island, the Harbor River Bridge (U.S. Route 21 over Harbor River) in Beaufort County, S.C., is an important transportation link. The original swing-span bridge over a tidal waterway and navigable channel was in poor condition and required replacement. The design-build project to replace the original structure was awarded in August 2017. The new structure, which opened to traffic in April 2021, is a high-level, 3340-ft-long fixed-span bridge that provides uninterrupted access for shrimping and sailing vessels along the river below, as well as safety improvements for motorists crossing the bridge.

The complex bridge is designed to withstand hurricane-force winds, seismic events, vessel collisions, and significant long-term scour. Preserving the pristine environmental setting and satisfying environmental permit constraints were other design concerns.

The size of the replacement bridge makes it a focal point for the local community and completely transforms the landscape of the surrounding area. The structure spans a significant distance over environmentally sensitive salt marshes and a tidal river from St. Helena Island to Harbor Island. The layout of the bridge was established to satisfy the required vertical clearance over the 90-ft-wide navigational channel (65-ft minimum vertical clearance from the mean higher high-tide elevation to the low chord), and to meet the existing roadway using a maximum grade of 4%. The total bridge length is 3340 ft, and the maximum height is approximately 120 ft from the top of the deck to the bottom of the river at its highest point.

The new 3340-ft-long Harbor River Bridge carries U.S. Route 21 over environmentally sensitive habitat. Photo: Kaze Aerial Production.

profile

HARBOR RIVER BRIDGE REPLACEMENT / BEAUFORT COUNTY, SOUTH CAROLINA

BRIDGE DESIGN ENGINEER: Infrastructure Consulting & Engineering PLLC, West Columbia, S.C.

OTHER CONSULTANTS: Geotechnical engineer of record: GeoEngineer Inc., Charleston, S.C.; bridge hydraulic design: Taylor Engineering Inc., Jacksonville, Fla.; geotechnical investigation: Terracon Consultants Inc., St. Louis, Mo., Mid-Atlantic Drilling Inc., Wilmington, N.C., and Catlin Engineers, and Scientists, Charleston, S.C.; materials testing: Insight Group LLC, Charleston, S.C.

PRIME CONTRACTOR: United Infrastructure Group Inc., Great Falls, S.C.

CONCRETE SUPPLIER: Low Country Concrete Inc., Beaufort, S.C.

PRECASTER: Prestressed concrete piles and beams: Standard Concrete Products, Savannah, Ga.—a PCI-certified producer

OTHER MATERIAL SUPPLIERS: Reinforcing bar: Harris Rebar, Catawba, S.C.; compression seal expansion joints, anchor bolts, tie rods: Georgetown Mill Supplies, Georgetown, S.C.; laminated bearing pads: New South Construction Supply, Charlotte, N.C.

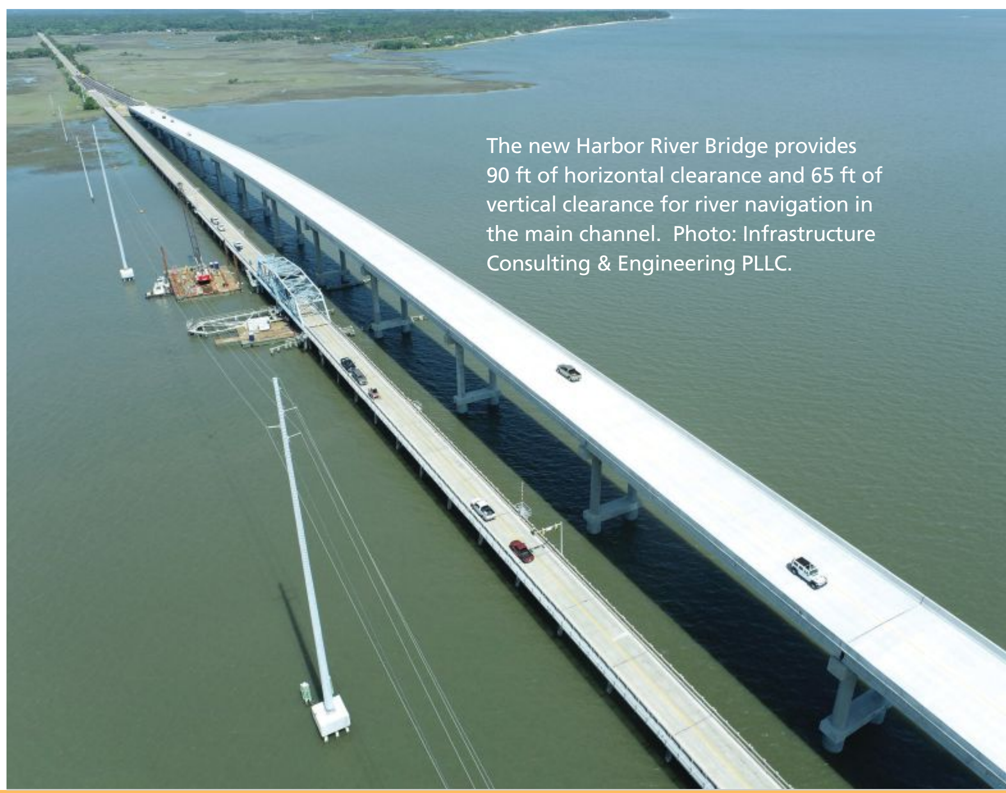
The new Harbor River Bridge is constructed from temporary causeways and by using sectional barges. Photo: Infrastructure Consulting & Engineering PLLC.

The original bridge was extremely narrow and created a safety hazard for motorists. Dangers associated with narrow lanes and shoulders were exacerbated by the volume of wide recreational and camping vehicles traveling to and from nearby Hunting Island. Two such vehicles passing each other on the bridge created a nerve-racking experience. The typical section of the replacement bridge, which features 12-ft-wide lanes and 10-ft-wide shoulders, provides a more comfortable and safer driving experience. The replacement structure has improved the health, safety, and welfare of the community and the traveling public. Additionally, the high-level crossing allows vessels to pass under the bridge without interruption, eliminating delays associated with opening the swing span of the original low-level bridge.

Complex Design Challenges

Two-dimensional modeling of the tidal river and the contributing water currents indicated a significant amount of scour could occur under certain conditions. At some of the tallest bents, the total scour depth was predicted to be approximately 30 ft below the bottom of channel. To address this scour potential, the design team used the 100-year scour profile to design the interior bents for all strength and service limit states, while completely neglecting the contribution of soils above the predicted scour level, to ensure that the new bridge will not be negatively affected by scour over its full 75-year design life (based on the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1]).

Because the Harbor River Bridge is the only means of vehicular access to



The new Harbor River Bridge provides 90 ft of horizontal clearance and 65 ft of vertical clearance for river navigation in the main channel. Photo: Infrastructure Consulting & Engineering PLLC.

SOUTH CAROLINA DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: 3340-ft-long, 20-span bridge featuring two 12-ft-wide lanes with 10-ft-wide shoulders in each direction, and providing 90 ft of horizontal clearance and 65 ft of vertical clearance for river navigation in the main channel

STRUCTURAL COMPONENTS: 100 Modified Florida BT-78 prestressed concrete beams spanning up to 167.5 ft, cast-in-place reinforced concrete deck, 8-ft-diameter drilled shafts, and 24-in. prestressed concrete piles. Reinforced concrete struts are provided between columns in the river for vessel-impact loads.

BRIDGE CONSTRUCTION COST: $54.7 million

AWARDS: Design-Build Institute of America National Award of Merit; American Council of Engineering Companies (ACEC) Engineering Excellence – National Recognition Award; ACEC of South Carolina National Award, Engineering Excellence, and Engineering Excellence – State Honor Award

Contractor sets the prestressed concrete beams as deck placement continues on another bridge unit. Photo: Infrastructure Consulting & Engineering PLLC.

three barrier islands, the South Carolina Department of Transportation (SCDOT) placed high importance on the longevity of the structure. The design criteria therefore required a seismic pushover analysis (Seismic Design Category C), and the substructure was also required to resist vessel impact in the form of multiple scenarios of loaded barges and towboats traveling at different speeds and tidal conditions. To address these extreme event loading scenarios and ensure that all seismic design requirements were satisfied, the design team used an analysis and design software package to create multiple models of the entire bridge. Seismic detailing techniques, as defined in SCDOT's *Seismic Design Specifications for Highway Bridges*,[2] include butt-welded column and shaft reinforcing bar hoops, shear keys, and minimum bent-cap shelf widths.

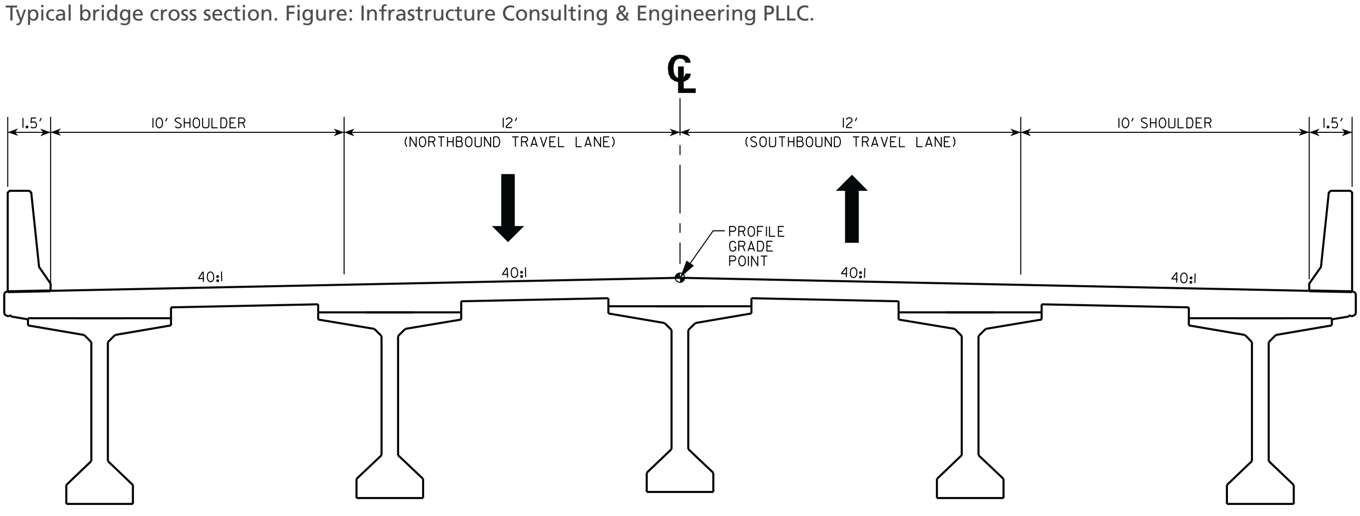
Geotechnical borings taken from the site indicated a high probability of liquefaction during a seismic event. Liquefaction occurs when saturated or partially saturated soil loses shear strength in response to an applied stress, such as ground motion from an earthquake. To mitigate the effects of liquefaction, the design team included a ground-improvement program consisting of driven piles and earthquake drains in the bridge embankments. The piles were designed to meet the settlement performance criteria under the static conditions per the SCDOT *Geotechnical Design Manual*.[3] The earthquake drains—prefabricated vertical drains made of a perforated pipe wrapped with a geotextile filter fabric—were incorporated to prevent liquefaction of the soils surrounding the piles under the design seismic events. These drains have a high-flow capacity that provides a shortened drainage path for the rapid reduction of earthquake-induced stresses in the soil during a seismic event. Seismic models of the bridge also included liquefied cases to ensure that the interior bents could accommodate the predicted loss of soil support.

To address multiple vessel-impact scenarios, the design team used nonlinear finite element analysis software to accurately distribute the massive loads to adjacent bents and fully capture the effects of soil-structure interaction below the groundline. Large reinforced concrete struts (4.5 × 8.5 ft in cross section) were placed at the bottom of the columns within the navigational channel to ensure adequate distribution of vessel-impact loads to adjacent columns and drilled shafts. A fender system was also required in the main channel span to address vessel-impact risks.

Cost-Saving Strategies

The design-build contractor and engineer developed 10 alternative technical concepts (ATCs) for the project to reduce construction and maintenance costs while meeting all of the SCDOT design criteria for the structure. One ATC eliminated the need for closed drainage systems to carry runoff from the bridge deck. These systems often clog, requiring constant

Typical bridge cross section. Figure: Infrastructure Consulting & Engineering PLLC.



Sectional barges were used for construction access and to place the prestressed concrete beams. The prestressed concrete beams and piles were delivered to the project site either by barge or truck. Photo: United Infrastructure Group Inc.

maintenance, and also add significant initial construction costs to the project. Given the overall length of the bridge, the predicted hydraulic spread could not be contained within acceptable limits if a normal 2.0% crown section was used. Consequently, the design team proposed using a crowned section with a slightly steeper 2.5% cross slope to keep the spread within acceptable limits, thereby eliminating the need for any closed drainage systems on the bridge.

Mass Concrete Elements

The project criteria specified that drilled shafts with a diameter of 6 ft or greater were to be considered "mass concrete" elements; such elements require special concrete mixture proportions, special placement parameters, temperature monitoring and control, and testing to ensure the structural integrity of the shafts. Nine interior bents located within the limits of the channel required two 8-ft-diameter drilled shafts each. Therefore, provisions for accommodating mass concrete were required. To limit the maximum temperature difference from the inside to the outside of the shaft to less than 35°F (as required by the project specifications), the design included the placement of cooling tubes within these drilled shafts and the development of special concrete mixture proportions. Computer simulations of the curing process were developed and compared with the actual thermal behavior of the concrete placed in a test shaft. The team used the results to calibrate the computer model and make refinements to concrete placement techniques before constructing the production shafts. This approach ensured that the shafts were not exposed to high temperatures that might result in excessive internal tensile strains and microcracking of the concrete.

Environmental Considerations

On this project, it was critical to protect the natural resources associated with the Harbor River. The design team elected to use prestressed concrete beams to eliminate the long-term maintenance costs associated with structural steel in a marine environment. The team chose a beam type that could accommodate long spans—modified Florida BT-78 beams—to minimize the number of substructure elements required and help meet the environmental commitments. The beams are 78 in. deep, are spaced at 10 ft 1¾ in. on center, and span a maximum of 167 ft 6 in.

To further minimize work in the salt marshes, footings supported by 24-in. prestressed concrete piles were selected for the interior bents outside of the channel limits. Crews constructed these marsh bents from temporary causeways, using sectional barges that could be removed without long-term damage to the marsh ecosystem. Floating barges were used for much of the bridge construction access. Crews used either trucks or barges to deliver the prestressed concrete piles and beams to the site, depending on their location in the final structure.

The design team committed to monitoring the bald eagle nest in the vicinity of the project, implementing best management practices regarding sea turtles and manatees, and removing portions of existing embankments for environmental mitigation. Additional environmental commitments, conditions, and regulatory obligations involved compensatory mitigation (fish habitat mitigation), shellfish restoration, and marine mammal monitoring during demolition blasting. The project team also initiated a robust environmental compliance monitoring plan that would protect the unique and sensitive natural surroundings.

Conclusion

The original Harbor River Bridge was too narrow, in poor condition, and a safety hazard for motorists traveling to and from Harbor Island, Hunting Island, and Fripp Island. The design team faced multiple challenges when designing the replacement, including increased scour potential, seismic design and vessel-collision loads, embankment liquefaction, and environmental constraints. To compensate for coastal conditions and to increase the structure's longevity, the team used resources such as the 100-year scour profile and impact-scenario software to determine the most enduring design. Given the important coastal habitat, the team also made many environmental commitments, such as monitoring a bald eagle's nest and implementing the best management practices for sea turtles and manatees, to minimize the structure's impact on the local ecosystem. The design team provided SCDOT with design submittals that were on-time, efficient, and of high quality. This process led to successful completion of the bridge five months ahead of schedule.

References

1. American Association of State Highway and Transportation Officials (AASHTO). 2017. *AASHTO LRFD Bridge Design Specifications,* 8th ed. Washington, DC: AASHTO.

2. South Carolina Department of Transportation (SCDOT). 2008. *Seismic Design Specifications for Highway Bridges*. Columbia, SC: SCDOT. https://www.scdot.org/business/pdf/structural-design/specs_2008.pdf.

3. SCDOT. 2018. *Geotechnical Design Manual*, version 2.0. Columbia, SC: SCDOT.

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