Marine Trestles for the Hampton Roads Bridge-Tunnel Expansion

by Kenneth J. Wright, HDR Inc.

In the spring of 2019, the Virginia Department of Transportation (VDOT) awarded a $3.3 billion design-build contract to widen a 10-mile segment of Interstate 64 (I-64), addressing decades of traffic congestion in coastal Virginia. I-64 is the key connector from Richmond and the Interstate 95 corridor into the Hampton Roads region of Virginia, including Norfolk, Chesapeake, and Virginia Beach, and ultimately provides connections to the Outer Banks region of North Carolina. The portion of I-64 covered under this design-build contract extends between the cities of Hampton and Norfolk, crossing the James River with the main shipping channel between the Virginia harbor and the lower reaches of the Chesapeake Bay. The interstate is being widened from two full-time general-purpose lanes in each direction to two full-time general-purpose lanes, one full-time managed lane, and one part-time managed lane (used during high-volume traffic periods) in each direction.

Marine Trestle Designs

The 3.5-mile harbor crossing consists of two marine trestles: the north trestle connects Hampton to the north artificial island, and the south trestle connects the south artificial island to Norfolk. The two artificial islands, which were originally constructed as end points for the Hampton Roads Bridge Tunnel in the 1950s, are connected by 1.5-mile-long tunnels under the main shipping channel. The new north trestle is approximately 3400 ft long and consists of two four-lane structures, one eastbound and one westbound. The new south trestle is approximately 5900 ft long and consists of an eight-lane bridge on a curved alignment for much of the crossing that splits into three separate branches that feed traffic to the tunnels. These new structures will replace the existing two-lane trestles originally constructed in the 1950s and 1970s.

Resilience of the New Trestles

Because the marine trestles cross open water in a near-ocean environment and I-64 is a hurricane evacuation route out of the Tidewater area, resilience was a top prioirty for this project. Therefore, several design strategies were implemented to ensure resilient, serviceable structures. The bridge designs implemented the American Association

The widening of a 10-mile segment of Interstate 64 addresses traffic congestion in coastal Virginia. The north and south trestles are described in this article. Figure: Hampton Roads Connector Partners.

Project Scope: More than Just a Tunnel

Scope
- New, twin 2-lane bored tunnels
- 5 bridges replaced
- 20 bridges rehabilitated or widened
- 1 mile of interstate widening in Hampton
- 4 miles of interstate widening in Norfolk
- 2 general-purpose lanes (free) plus HREL lane & drivable shoulder in each direction

profile

HAMPTON ROADS BRIDGE-TUNNEL EXPANSION / HAMPTON ROADS, VIRGINIA

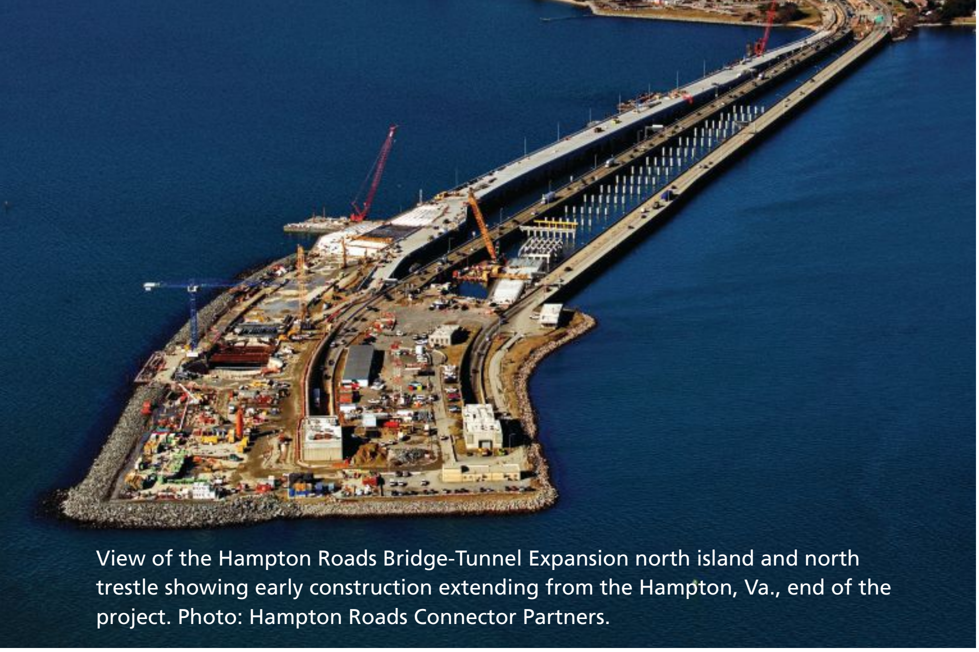
MARINE TRESTLE DESIGN ENGINEER: HDR Inc., Virginia Beach, Va.

BRIDGE LOAD RATINGS: SAEED Associates Chartered, Springfield, Va.

PRIME CONTRACTOR: Hampton Roads Connector Partners—a joint venture between Dragados USA, VINCI Construction Grands Projets, Flatiron Constructors, and Dodin Campenon Bernard

CONCRETE SUPPLIER: Commercial Ready Mix Products Inc., Chesapeake, Va.

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


View of the Hampton Roads Bridge-Tunnel Expansion north island and north trestle showing early construction extending from the Hampton, Va., end of the project. Photo: Hampton Roads Connector Partners.

of State Highway and Transportation Officials' *Guide Specification for Bridges Vulnerable to Coastal Storms*,[1] which provides a robust design for water forces based on a metocean hydraulic analysis (that is, analysis of the combined effects of meteorological and oceanographic conditions). This analysis factored in previous large storms experienced in the area. The water forces used to design the new structures were greater and more conservative than those used for the design of the existing bridges in the 1950s and 1970s.

A key strategy that the design-build team implemented to optimize the design and increase resiliency on this designated hurricane evacuation route was to raise the profiles of the main portion of the trestles by an average of 6 to 8 ft so that the bottoms of the beams were set above the maximum expected water levels, including the VDOT requirement to design for a 2-ft rise in sea level. This strategy reduced lateral design forces on the piers and eliminated lateral water forces on the prestressed concrete beams; it also avoided uplift on the superstructure and the need to vent air trapped between the beams during high-water events. The design also elevated the concrete girders above the splash zone—a factor that had contributed to serious deterioration in the existing trestle beams.

Deck Design

The cast-in-place concrete decks for the new trestles are designed to achieve a 100-year service life. A significant factor in achieving this longevity is the use of stainless steel reinforcement in the decks with 2.5-in. concrete cover at the top of deck and 2-in. cover at the bottom. The selection of stainless steel reinforcement instead of traditional reinforcement greatly reduces the likelihood that deck rehabilitation will be needed in the future.

Additionally, the low-permeability deck concrete slows the ingress of chlorides. VDOT specified that the chloride permeability of concrete at an age of 28 days shall not exceed 1000 coulombs and that the water/binder rates be between 0.35 and 0.42 to help promote the targeted characteristics. Contractors typically achieve the prescribed results by using supplementary cementitious materials and water-reducing admixtures.

These technical improvements are especially significant in the corridor, where existing capacity is strained and the newly constructed lanes will generate toll revenue. By prolonging the life of the deck and postponing the need for rehabilitation, traffic volumes will be able to benefit from the additional lanes for decades. Because the crossing currently serves nearly 100,000 vehicles per day, any lane closures greatly affect corridor throughput.

Beam Designs

VDOT's technical requirements for the project stipulated that the prestressed concrete beams use one of the following two reinforcement systems:

- Stainless steel strands with stirrups and bulb (bottom flange) confinement reinforcement of stainless steel using a standard 1.5-in. cover on reinforcement

Stainless steel reinforcement is visible in the connection between the precast concrete bent cap and cylinder pile before concrete placement. Photo: Virginia Department of Transportation.

VIRGINIA DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: North marine trestle: Two 4-lane, approximately 3400-ft-long structures. South marine trestle: One 8-lane, approximately 5900-ft-long bridge split into three branches that feed traffic into the tunnels.

STRUCTURAL COMPONENTS: Transition zones (approximately 500 ft from abutments to the main portions of the trestles) consisting primarily of 29-in.-deep prestressed concrete bulb-tee (PCBT-29) beams, with a few spans using PCBT-37 beams; PCBT-85 beams for the main portions of all trestles; carbon-fiber-reinforced-polymer (CFRP) prestressing strands; martensitic microcomposite formable steel bars for stirrups and bulb confinement bars; cast-in-place bridge deck is 9 or 9½ in. thick, depending on beam spacings, and is reinforced with stainless steel bars; precast concrete bent-cap segments installed in sections with closure pours; 54-in.-diameter prestressed concrete piles for bents; bed-cast cylinder piles with CFRP prestressing strands

PROJECT COST: $3.3 billion for construction and $3.9 billion for the entire scope of work for the design-build contract

The new eight-lane south trestle is constructed in phases to maintain traffic on the existing trestles. Photo: Virginia Department of Transportation.

- Carbon-fiber-reinforced-polymer (CFRP) strands with martensitic microcomposite formable steel bars (commercially known as "MMFX") for the stirrups and bulb confinement bars, requiring a 2.5-in. minimum cover to the reinforcement

The design-build team chose the CFRP strand option for the marine trestle prestressed concrete beams. VDOT did not require a service-life assessment, given that the specific systems for the beams and piles stipulated in the technical requirements—noncorrosive reinforcement systems, low-permeability concrete, increased reinforcing bar cover as appropriate, and limits on tension in the concrete sections—provided a sufficient level of confidence in the service life of the components without necessitating the effort to prove the desired 100-year service life via modeling.

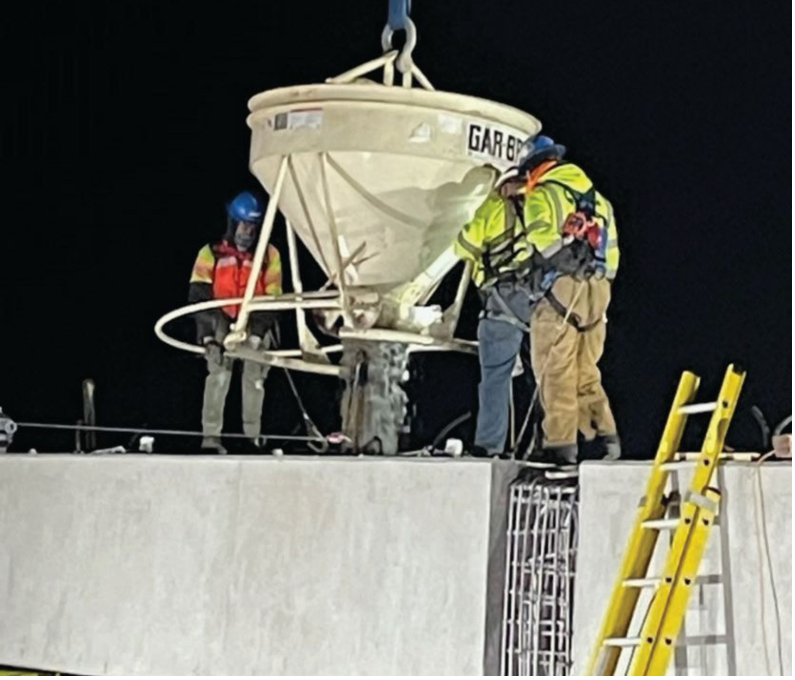
The concrete for the precast, prestressed concrete beams was VDOT Class A5 with a 28-day strength of 10,000 psi. The prestressed concrete bulb-tee beams ranged from 29 to 85 in. in depth, with spans up to 125 ft between bents. Relative to the existing bridges' 50- and 75-ft spans, these longer spans simplified future maintenance and inspection by reducing the number of piers in the water.

Concrete Pile Designs

The design-build team chose 54-in.-diameter, prestressed concrete cylinder piles for the marine trestle bents. The piles were bed cast (wet cast) and had a design 28-day concrete strength of 8000 psi. This was a change from the bid design using 30-in.-square battered precast, prestressed concrete piles. The larger cylinder piles provided greater lateral stiffness, and they could be installed vertically, which made it easier to drive them in the open water of the harbor, and provided a safer situation for the pile-driving crew.

The contractor chose to perform a static load testing program for the piles to optimize the required pile lengths and observe drivability performance. The subsurface investigations indicated that the bearing layer ranged from relatively loose to densely packed Yorktown Formation sands, with variable pockets of fine-grained soils and shell fragments. Four static load tests and six dynamic load tests with restrikes were

The new north trestle is constructed as two separate four-lane structures. Photo: Virginia Department of Transportation.



Concrete is placed for the connection between the 54-in.-diameter cylinder pile and a precast concrete bent-cap segment. The stainless steel reinforcement in the bent-cap closure joint is visible. Photo: Hampton Roads Connector Partners.

Concrete is placed at a closure pour between two precast concrete bent-cap segments. The design-build team used the alternative technical concept of precast concrete bent-cap segments spliced in the field to facilitate staged construction. Photo: Hampton Roads Connector Partners.

performed to confirm the pile depths. Optimizing the pile depth controlled the pile lengths, helped limit driving stresses, and avoided overstressing the piles. VDOT's special provision for cylinder piles in the contract required a minimum prestress after losses of 1000 psi. However, there was precedent to prestress to a lower level on large piles. This was supported by a wave equation analysis of the piles as informed by the pile-driving analysis results from the test-pile monitoring during driving.

The piles were designed using CFRP strands and CFRP spiral confinement bars. The final pile design was based on 700 to 800 psi of effective prestress after losses.

Precast Concrete Bent Cap Designs

The marine trestle piers were pile bents (bent caps placed on a single line of piles). Precast concrete bent caps were chosen for two primary reasons. First, forming the required number of caps over water would be very labor intensive. Second, many of the bent caps were very long and/or had to be constructed in stages to match the overall construction phasing. Although VDOT does not routinely use precast concrete components in this manner, the approach was approved as an alternative technical concept during the procurement stage. The safety and environmental advantages of precast concrete production were attractive, given that most of the fabrication occurred on land instead of over water.

By design, maximum segment lengths of the bent caps were approximately 45 ft. This maximum length was determined based on the crane lifting capacity. However, during construction, some additional segments were added to better accommodate changes to the construction staging on site and equipment constraints. The bent-cap concrete had a 28-day design compressive strength of 6000 psi.

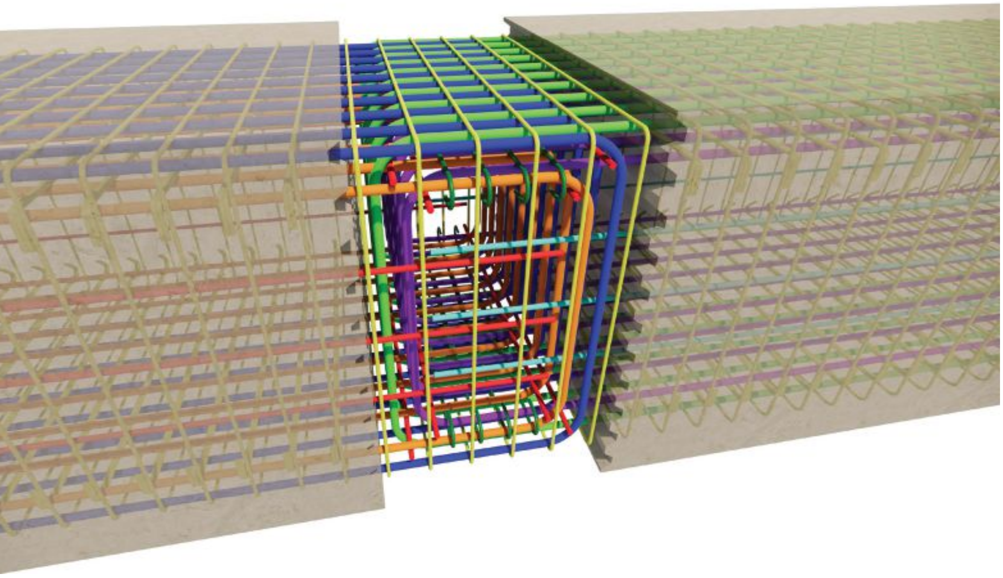
All reinforcement in the bent caps was stainless steel to optimize the service life of the caps. The design-build team had concerns regarding the availability of large bar sizes in stainless steel, so most of the caps were designed to use no. 9 bars for the main reinforcement. The smaller bar sizes and the limited cap depth led to the use of two layers of flexural reinforcement in the caps.

An important aspect of the precast concrete bent-cap design was to develop a closure-joint detail between bent-cap segments that was repeatable. The team chose to develop a connection that relied on noncontact lap splices between the U-bars within the 2-ft 8-in.-wide closure joint. This feature of the bent-cap splice was a critical element for VDOT's conditional approval of the alternative technical concept, and VDOT evaluated it closely as the design was finalized.

The goal of this connection was to shorten the length of forming required in the field to make the closure joint. The design team believes that this was the first implementation of this concept in the United States. The limit on the bar sizes used led to nested U-bars in the closure joint. The concept was designed based on the assumption that all flexural steel was fully stressed to 60 ksi, which provided for maximum flexibility in locating the splices of the bent-cap segments and did not require a large number of unique designs. Standardizing a fixed number of cap/splice designs benefited the project by allowing modular construction with typical elements, thus reducing constructability issues and gaining efficiency during precasting.

Most of the bent-cap splices were located near the inflection points between adjacent piles, rather than at points of higher flexural stress. This arrangement provided an additional factor of safety against cracking at the splices. The team used strut-and-tie modeling to verify the efficacy of the noncontact lap splice in the closure joint.

The reinforced pile plug connecting the concrete cylinder piles to the bent caps also required significant design and detailing consideration. The voids in the bent caps were fabricated with horizontal corrugations to ensure a positive shear connection



Three-dimensional isometric rendering of the reinforcement in the closure joint between two precast concrete bent-cap segments. The concept of noncontact splices of the nested U-bars was the result of an alternative technical concept evaluated and accepted by the Virginia Department of Transportation. Figure: HDR Inc.

between the cap and the piles. The reinforcement cage was detailed to provide a minimum gap between the plug reinforcement and the wall of the precast concrete cap to within the specified pile placement tolerance of 3 in. Additionally, the reinforcement in the precast concrete caps was carefully detailed to provide the required cap strength while leaving the pile plug opening clear for the reinforcement cage to fit.

Conclusion

The marine trestles were carefully designed to provide the desired service life. Advances in the design codes will provide a more resilient structure. Significant use of precast concrete components added value to this mega-project, yielding both improved efficiency and construction safety. The use of corrosion-resistant reinforcement, careful design to limit tensile stresses in the concrete, and the use of low-permeability concrete were critical to achieving the desired result: durable new bridges that are expected to last 100 years and will serve the residents of Virginia for generations to come.

Reference

1. American Association of State Highway and Transportation Officials (AASHTO). 2008. *Guide Specification for Bridges Vulnerable to Coastal Storms*. Washington, DC: AASHTO.

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This article was written in consultation with the Virginia Department of Transportation Hampton Roads District.