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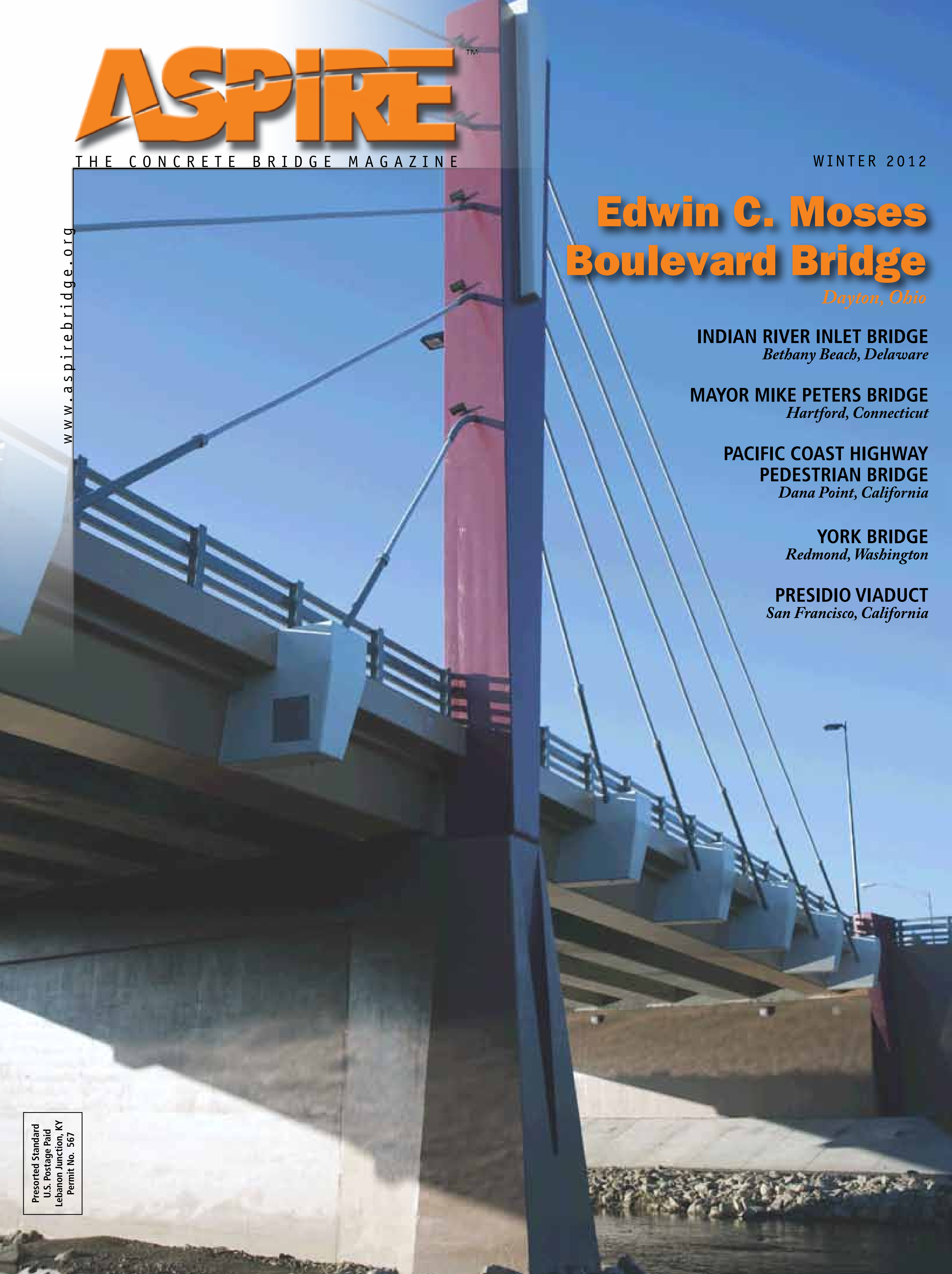
WINTER 2012



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Bethany Beach, Delaware

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PROJECT

Indian River Inlet Bridge–Surviving the Storms

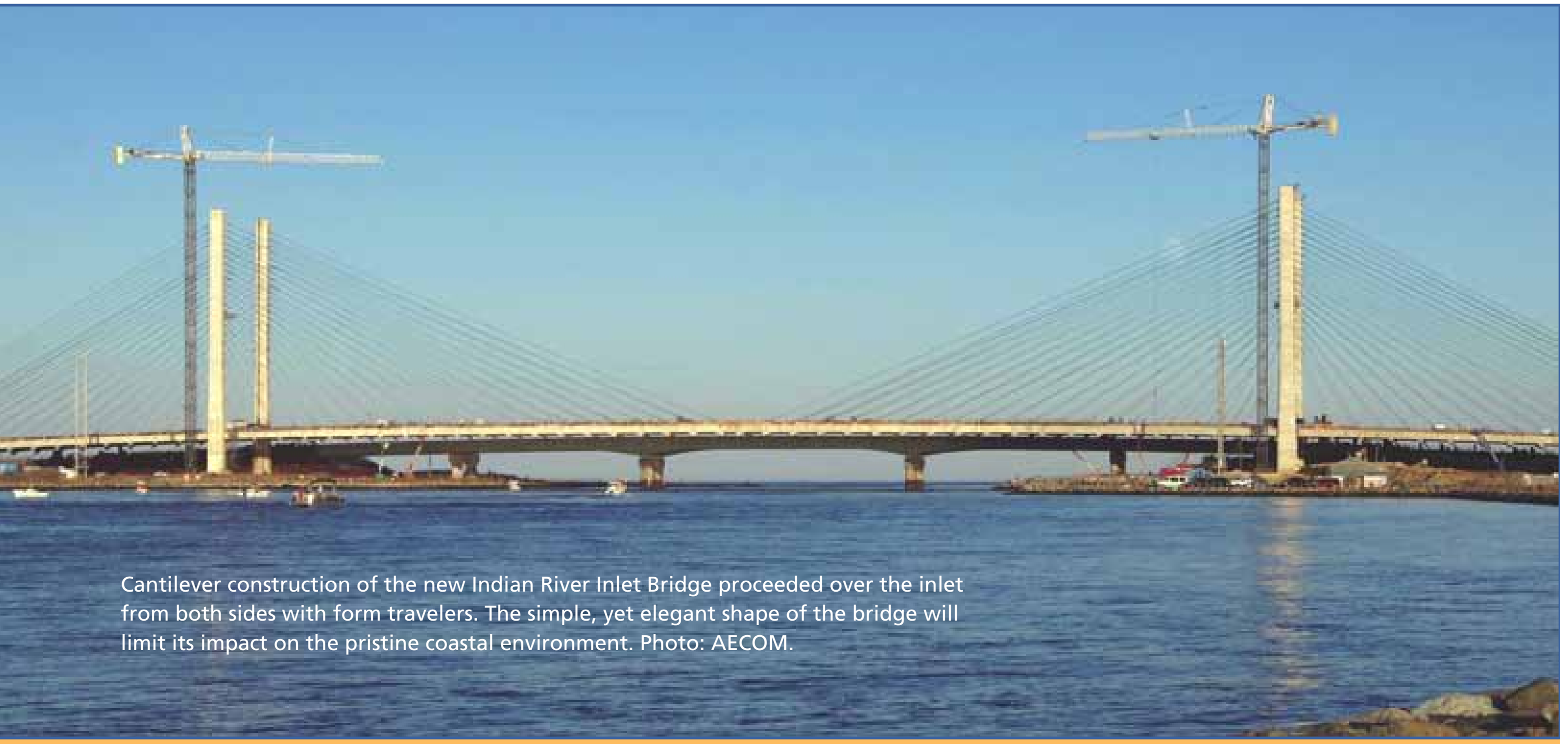
by Eric T. Nelson, AECOM

Cable-stayed design spans treacherous inlet with history of extreme scour

In the last week of August 2011, Hurricane Irene roared up the east coast of the United States leaving billions of dollars in property damage in its wake. Directly in its path was the ongoing construction for the new Indian River Inlet Bridge in Delaware. With this site being just yards from the Atlantic Ocean, this will not be the last such storm that the new bridge will have to withstand. In fact, bridging this inlet has proven very difficult over the years.

The new bridge will be the fifth bridge constructed across the inlet in just over 60 years. The first three bridges were battered by storms and extreme tides at the site, and the current bridge built in 1965 is now in jeopardy from severe scour and erosion of the inlet bed, with some scour holes near the foundations approaching 105 ft deep.

The Delaware Department of Transportation (DelDOT) has continued to monitor the condition of the existing bridge closely, while construction of the new replacement bridge began in late 2008 under a design-build contract. The history of problems with extreme tides and scour of the previous bridges over the inlet led DelDOT to mandate that all piers for the new bridge had to be placed outside of the inlet. Additionally, DelDOT imposed a 900-ft horizontal clearance requirement to accommodate for the potential future widening of the



Cantilever construction of the new Indian River Inlet Bridge proceeded over the inlet from both sides with form travelers. The simple, yet elegant shape of the bridge will limit its impact on the pristine coastal environment. Photo: AECOM.

profile

INDIAN RIVER INLET BRIDGE / BETHANY BEACH, DELAWARE

DESIGN-BUILD TEAM: Skanska USA Civil Southeast, Virginia Beach, Va.—AECOM, Glen Allen, Va.

CONTRACTOR: Skanska USA Civil Southeast, Virginia Beach, Va.

BRIDGE DESIGN ENGINEER: AECOM, Glen Allen, Va., and International Bridge Technologies Inc., San Diego, Calif.

CONSTRUCTION ENGINEERING: AECOM, Hong Kong, China (Erection Analysis) and Finley Engineering Group Inc., Tallahassee, Fla. (Falsework)

CONSTRUCTION ENGINERING INSPECTION: Parson Brinckerhoff, New York, N.Y.

STAY CABLE AND POST-TENSIONING CONTRACTOR: Freyssinet USA, Sterling, Va.

PRECAST CONCRETE PRODUCER: Bayshore Concrete Products Corporation, Cape Charles, Va., a PCI-certified producer

Use of precast and cast-in-place concrete over land sped construction.

inlet from the current 500 ft to 800 ft. These two criteria resulted in a bridge solution that consists of a three-span, cable-stayed bridge with two twin-pylons, a center span over the inlet of 950 ft, and two side spans of 400 ft each. The total length of the new bridge is 2600 ft, which includes the cable-stayed main spans and flanking 425-ft-long approach units on both ends.

The bridge site lies on a barrier island bounded by the Atlantic Ocean on the east and Indian River Bay on the west. This barrier island is part of the 2825-acre Delaware Seashore State Park. The Indian River Inlet Bridge is on State Route 1 (SR 1) that lies on the barrier island, connecting the towns of Rehoboth Beach to the north and Bethany Beach to the south of the Indian River Inlet. Dunes and beaches dominate the landscape to the east of SR 1, while tidal marshes and wetlands are located to the west.

The bridge roadway for the approaches and cable-stayed structures carries four lanes of traffic with shoulders and a 12-ft-wide sidewalk for pedestrians and bicyclists. The out-to-out widths of the approach and cable-stayed spans are 93 ft 3 in. and 106 ft 2 in., respectively.

The use of precast concrete floor beams and cast-in-place construction on falsework for the portions of the bridge over land significantly sped construction because work could be completed simultaneously on several different fronts. Photo: AECOM.

Cable-Stayed Spans

The cable-stayed superstructure consists of cast-in-place concrete edge girders with both precast and cast-in-place concrete transverse floor beams, and a cast-in-place concrete deck. The cable system consists of 19 stays on each side of the four pylon towers to form two vertical planes of stays supporting the edge girders (152 stays in total). The stay cables consist of 0.62-in.-diameter, seven-wire, low-relaxation strands, and have 19 to 61 strands per cable. For improved corrosion resistance, each strand is coated with wax and encapsulated inside high-density polyethylene (HDPE) sheathing. Additionally, the strand-bundled stays are protected by an outside HDPE pipe, with the surface textured by a double helical fillet to reduce rain- and wind-induced vibrations. The stay cables are anchored in the edge girders and pylons in a modified fan pattern.

With the bridge being relatively close to the ground, the effects of concrete creep and shrinkage are mitigated by having only one permanent longitudinal connection of the superstructure to the substructure. At the north pylon, elastomeric bearings transfer longitudinal forces from the deck to the pylon. Bearings are located on each

Visual Sensitivity

Providing a context-sensitive design solution was one of the principal considerations for the design-build team. The design theme selected for the bridge was to provide unobtrusive views of the Atlantic Ocean and not overpower the beach communities near the site with a massive structure. The resort communities near the bridge have expressed great appreciation for the simple, yet elegant shape of the bridge and its minimal impact on the pristine coastal environment. The 248-ft-tall pylons are the tallest structures in this flat coastal region, but their slenderness combined with blue, outer cable-stay pipes evokes a nautical theme replicating tall masts of sailing ships. The low profile of the superstructure is only 6 ft deep and provides open vistas of the Atlantic Ocean and Indian River Bay. Boaters, as well as people living in the area have commented that the bridge is unique and has enhanced the oceanfront.

THREE-SPAN, CABLE-STAYED CONCRETE BRIDGE WITH FOUR-SPANS OF PRECAST, PRESTRESSED CONCRETE GIRDER APPROACH UNITS AT BOTH ENDS / DELAWARE DEPARTMENT OF TRANSPORTATION, OWNER

CAST-IN-PLACE CONCRETE SUPPLIER: Thoro-Goods Concrete Company, Millsboro, Del.

REINFORCING STEEL SUPPLIER: CMC Rebar, Wilmington, Del.

FORM TRAVELERS: Strukturas, Langesund, Norway

BRIDGE DESCRIPTION: A 2600-ft-long, three-span, cable-stayed, cast-in-place and precast concrete bridge with span lengths of 400, 950, and 400 ft with two sets of cast-in-place concrete pylons and fanned stays. Four approach spans of 106 ft 3 in. each at both ends of the bridge use bulb-tee beams with composite concrete deck. The substructures are cast-in-place concrete piers for the approach spans and the main spans. All substructures are supported by precast, prestressed concrete piles.

BRIDGE CONSTRUCTION COST: $150 million

The stays are anchored in the white structural steel anchorage boxes in the pylons. The anchorage boxes take advantage of the high-tensile capacity of structural steel to resist the large horizontal tension resulting from the cable stays, while the vertical compression from the stays is handled by the concrete. Photo: AECOM.

Low permeability concrete and epoxy-coated reinforcement were used to achieve a 100-year service life.

longitudinal face of the pylon, so that they are acting only in compression. At the south pylon, the deck is free to move relative to the pylon. During construction, the bearings at both pylons were fixed so the spans were not totally free to move. Only after the closure in the main span was cast were the bearings at the south pylon released.

Each of the two continuous edge girders is 6 ft deep and 5 ft wide, and for the majority of the deck, the edge girders are centered on the vertical planes of the supporting stay cables. However, in order to avoid the edge girder framing into the pylons, the edge girder is configured to deviate around the pylons. This allows the edge girder to be aligned with the pylons in the regions where the stay cables are anchored, while still allowing the deck to move longitudinally at the free pylon.

The transverse floor beams are typically spaced at 12-ft on center and the cable support points are located every 24-ft along the longitudinal edge girder corresponding to the length of each cantilever segment. The cable stays align with alternate floor beams except near the transition pier in the back spans where the stays are grouped closer together. The use of a closer floor beam spacing than has been used conventionally for this type of cable-stayed bridge, allowed the deck thickness to be only 8½ in. for the majority of the bridge, with a 10½-in. thickness only in the highly compressed regions near the pylons. This resulted in a significant savings in concrete weight and thus less demand on the stays and pylon foundations. Additionally, the closer floor beam spacing allowed easier deck form placement and removal.

A combination of both precast and cast-in-place concrete floor beams was used. Precast, pretensioned concrete floor beams were used in the side spans and the portion of the main span that is accessible by land, while the floor beams in the main span over the inlet used cast-in-place concrete. Since much of the bridge is easily accessible by land, it was beneficial to precast as many floor beams as possible to remove this operation from the critical path of construction. It also resulted in one less concreting operation to be performed on-site, which saved both time and money. The precast floor beams are roughly I-shaped, 5 ft 9 in. deep at the crown point of the deck and approximately 4 ft 9 in. deep at the edge girders. The webs are 10 in. thick with 1-ft 10-in.-wide flanges. The top flange is 9 in. deep and the bottom flange is 1 ft 0½ in. deep. The ends of the precast floor beams are flush with the edge girder. Reinforcement extends from the floor beams into the edge girders. The cast-in-place concrete floor beams are rectangular with a width of 11 in.

Internal post-tensioning tendons were used in all of the transverse floor beams, and in portions of the edge girders and

Sustainability

Given the proximity of the Indian River Inlet Bridge to the Atlantic Ocean, the ability of the structure to withstand the corrosive marine environment was a high priority and DelDOT dictated that the new bridge be designed for a 100-year service life. Development of a project-specific corrosion control plan was required by the design-build performance specifications and intended to ensure that the specified service life for each structural component is achieved.

DelDOT also specified that high-performance, low permeability concrete be used in both the superstructure and substructure elements with a maximum allowable permeability of 1500 coulombs. Epoxy-coated reinforcement was used for the entire structure with a minimum concrete cover of 2 in. from all surfaces. Additionally, to mitigate potential alkali-silica reactivity, the cementitious materials used in the concrete mixes included 35 to 60% ground-granulated blast-furnace slag.

Finally, a polyester polymer concrete (PPC) overlay with a high molecular weight methacrylate resin prime coat will be applied to the top of the deck along the riding surfaces and pedestrian walkway of the main-span, cable-stayed portion of the bridge. The PPC baseline target thickness is 1-in.-average thickness and ¾-in.-minimum thickness.

The use of epoxy-coated reinforcement throughout the structure along with several other anti-corrosion measures will help the new Indian River Inlet Bridge achieve a planned 100-year service life in the corrosive marine environment near the Atlantic Ocean. Photo: AECOM.

Precast, pretensioned and post-tensioned concrete floor beams are supported by the edge girders with reinforcement that extends from the beams into the girders. Photo: AECOM.

deck. Anchors for the floor beams are located in the edge girders. All of the tendons on the bridge comprise 0.6-in.-diameter, seven-wire, low-relaxation strands in corrugated, high-density polypropylene (HDPP) plastic ducts. The tendon sizes range from four-strand tendons in the deck and up to 31-strand tendons in the edge girders.

Pylons

Each pylon consists of two, cast-in-place reinforced concrete hollow towers. In the longitudinal direction, the towers have a constant width of 11 ft. In the transverse direction, the pylon towers taper from 16 ft at their base to 12 ft at the top. The towers are approximately 248 ft tall above the ground level. The inside wall thickness of the tower on the side toward the deck is 2 ft 6 in., while the outside wall thickness is 1 ft 6 in. This results in the center of gravity of the tower section falling within 3 in. of the centerline of the stay cables, thereby minimizing the eccentric loading of the towers. Structural steel anchorage boxes are used to anchor the stays in the towers and transfer longitudinal tension across the section.

The pylon towers at each location are only connected together across the deck at the footing level by a grade beam. The cross strut conventionally used to connect twin pylon towers together for stability above the deck level was eliminated. The lack of this strut significantly expedited the speed and cost-efficiency of the construction. Elimination of the cross strut resulted from a combination of two factors:

1. Judicious design that minimized the p-delta effect resulting from the centerline of the stay cables being only slightly eccentric to the center of gravity of the tower section.
2. Improved aerodynamic characteristics of the tower cross section by using a slender shape with rounded corners.

The pylons are founded on 10-ft-thick, cast-in-place concrete footings, which are supported by 42 prestressed concrete piles. Each 36-in.-square pile is 100 ft long and has a capacity of 1800 tons.

Approach Spans

Each 425-ft-long approach unit at each end of the bridge comprises four 106-ft 3-in.-long spans. These consist of 70-in.-deep precast, prestressed concrete bulb-tee girders. The girders are composite with an 8½-in.-thick concrete deck. The spans are made continuous for live load by casting the beam ends integral within a diaphragm and placing the deck continuous over the top. Eight prestressing strands and nonprestressed reinforcement extend from the ends of the beams into the diaphragms.

The Indian River Inlet Bridge has a 950-ft-long main span and two side spans of 400 ft each. Photo: Skanska USA Civil Southeast.

Construction Sequence

The site for the Indian River Inlet Bridge presented a unique advantage seldom seen in long-span, cable-stayed construction in that more than half of the deck is accessible from the ground. This presented an opportunity to construct a significant portion of the deck on falsework. This is clearly preferred, as it is both less expensive and significantly faster than traditional form traveler construction. The entire 400-ft-long side spans and approximately 182 ft of the main span on both sides of the inlet—a total of 364 ft of the main span—were built entirely on falsework before any stays were installed. The first seven pairs of stays were then installed, and then only with the eighth stay was one-way incremental, cantilever erection started over the inlet with the form traveler. During construction with the form traveler, the stays were added incrementally; with the side span stay installed first and then the stay on the main span side installed as the form traveler advanced. The falsework was sequentially removed as the stays were installed.

As Hurricane Irene approached in August 2011, cantilever construction over the inlet was well underway. With the heavy form traveler on the tip of the cantilever, the structure was in a very vulnerable state. Anxiety was already high on the site as the most powerful earthquake to strike the east coast of the United States in 67 years had just rattled nerves the week before. However, a post-earthquake inspection of the bridge revealed that all was well. Pre-installed 2½-in.-diameter, post-tensioning, hurricane tie-down bars were engaged to help stabilize the structure during the storm and everyone was then evacuated from the site. There were two tie-down bars at the ends of all four cantilevers. The bars were anchored to 36-in.-diameter steel pipe piles and stressed to 123 kips on the side-span cantilevers and to 161 kips for the main span cantilevers. The eye of the hurricane passed almost directly over the bridge with winds approaching 80 mph. In a testament to the robustness of the design and to the dedicated professionalism of the people constructing the bridge, Hurricane Irene passed through causing no damage to the bridge.

Closure on the main span was completed in October 2011 and the new bridge is scheduled to open for traffic in early 2012. While Hurricane Irene won't be the last storm to ravage the area, the citizens of Delaware can now be confident that the new Indian River Inlet Bridge will survive the storms and provide safe travel for them over the inlet for many decades to come.

Boat traffic was uninterrupted as cantilever construction of the bridge extended out over the Indian River Inlet. Photo: AECOM.

Eric T. Nelson, is a lead bridge design engineer with AECOM in Nashville, Tenn.

For additional photographs or information on this or other projects, visit www.aspirebridge.org and open Current Issue.

Views from above and below the pier table showing the edge girder deviated around the pylon towers to permit longitudinal movement of the deck. Post-tensioning anchorages have been placed at the sides of the floor beam not accessible from the outside face of the edge girder. Photos: AECOM.