PROJECT

Innovative Post-Tensioned Concrete Slab Superstructure Elevates New Landmark Florida Bridge

by Rafal Wuttrich and George C. Patton, H&H

Aerial view of the completed State Route 80/ Southern Boulevard Bridge. Photo: Johnson Brothers Corp.

The Southern Boulevard Bridge is the southernmost of three drawbridges that connect West Palm Beach, Fla., across Lake Worth Lagoon and the Atlantic Intracoastal Waterway, to the barrier island town of Palm Beach. This bridge has served as an important transportation link since its original construction in 1950. After conducting a project development and environment study, the Florida Department of Transportation (FDOT) concluded that the existing drawbridge needed replacement to address the poor structural condition from corrosive deterioration and the substandard roadway section. The new drawbridge serves one of Florida's most influential communities, so it was important that it be a landmark structure consistent with the Royal Park and Flagler Memorial drawbridges to the north.

The new two-lane structure is 948 ft long and consists of a 228-ft-long, double-leaf rolling bascule main span with five 72-ft-long approach spans on each side. The overall width of the bridge varies from approximately 60 ft for the east approach spans and the moveable span to 72 ft for the west approach spans. The additional width for the west approach spans accommodates a left turn lane. The new bridge was constructed on the same straight alignment as the existing bridge, while traffic was maintained on a temporary bridge, with a vertical lift span, on an offset alignment. The design and construction of the approach

profile

STATE ROUTE 80/SOUTHERN BOULEVARD BRIDGE, PALM BEACH/WEST PALM BEACH, FLORIDA

BRIDGE DESIGN ENGINEER: H&H, Tampa, Fla. (specialty construction engineer and approach-span redesign engineer of record)

OTHER CONSULTANT: Primary engineer of record: AECOM, Tampa, Fla.

PRIME CONTRACTOR: Johnson Brothers Corp., a Southland Company, Orlando, Fla.

CONCRETE SUPPLIER: Titan Florida LLC, Deerfield Beach, Fla.

PRECASTER: Capitals for approach span support: Johnson Brothers Corp., a Southland Company, Orlando, Fla.

POST-TENSIONING CONTRACTOR: Freyssinet USA, Sterling, Va.

The completed east approach spans with the drawbridge visible in the background. Photo: H&H.

span superstructures are highlighted in this article.

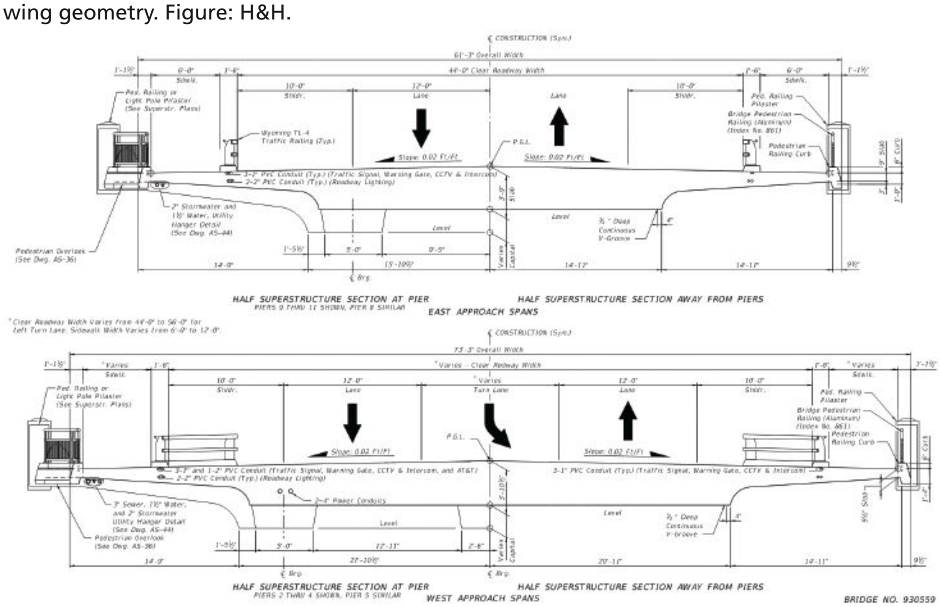
Design Constraints and Considerations

The new bridge had to meet current U.S. Coast Guard navigation requirements, including navigation clearances of 125 ft horizontal and 21 ft vertical. Those new clearances were, respectively, 45 ft and 11 ft greater than the horizontal and vertical clearances of the existing bridge. To achieve the increased clearances, the roadway vertical profile had to be raised by using steeper, 5% grades. The vertical profile was constrained by the adjacent intersection with Flagler Drive, only 100 ft west of the west bridge end. Even with a higher profile, the approach spans' lowest members are less than 12 ft above mean high water, which is the minimum height required by FDOT *Structures Design Guidelines* to minimize exposure of the superstructure to salt water. The new approach spans are also below the maximum wave crest elevation of 18.5 ft, which subjects the superstructure to wave loading during major coastal storm events. To achieve the 75-year design life considering the profile constraints, the superstructure included a combination of 3-in. bottom cover and FDOT Class V concrete with a 6.5-ksi 28-day minimum compressive strength, Type II (MH) cement, fly ash, and silica fume.

For this site, FDOT recognized the advantages of using continuous, cast-in-place concrete slabs—longitudinally and transversely post-tensioned—rather than conventional precast, prestressed concrete girders. The slab cross section is similar to that of a typical segmental concrete box girder, with long, slender cantilever wings on each side, but with a shallow solid core instead of an open trapezoidal core. The wings are approximately 15 ft long and 9.5 in. deep at the cantilevered end, and they taper at a slope of 1:16. The core for the west approach spans is approximately 42 ft wide, with a maximum depth of 3.88 ft at the center, while the core for the east approach spans is approximately 30 ft wide, with a maximum depth of 3.75 ft at the center. The slabs include integral tapered capitals at the piers that align with the pier columns. The advantages of the solid slab compared with conventional precast, prestressed concrete girders at this site include the following:

- A shallower structure depth that maximizes clearance above the salt water.
- A more durable structure with less surface area exposed to salt water.
- A shallower profile that significantly reduces wave forces, which improves the likelihood the bridge will survive a major coastal storm event. (The slab was

Typical cross sections of the approach spans. The west approach span is 12 ft wider than the rest of the bridge to accommodate a left-turn lane. Both sections share a common wing geometry. Figure: H&H.



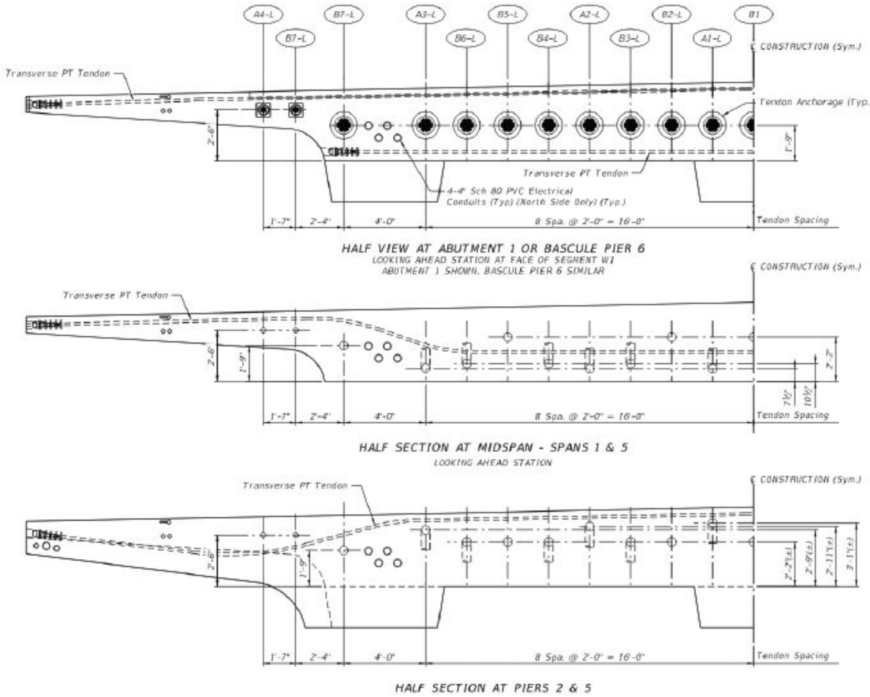
FLORIDA DEPARTMENT OF TRANSPORTATION, DISTRICT 4, OWNER

OTHER MATERIAL SUPPLIERS: Falsework fabrication: Wheelblast Inc., Zephyrhills, Fla.; formwork design and fabrication: EFCO, Orlando, Fla.

BRIDGE DESCRIPTION: 948-ft-long bridge with 228-ft-long, double-leaf rolling-bascule moveable span and 360-ft-long, five-span continuous concrete approach units on each side (72 ft per span)

STRUCTURAL COMPONENTS: Approach spans: longitudinally and transversely post-tensioned concrete slab superstructure on reinforced concrete piers with drilled shaft foundations

BRIDGE CONSTRUCTION COST: $93 million (estimated total contract value for construction of the main span, the approach spans, tide-relief bridge, and associated roadway work)



Half sections of the west approach spans showing longitudinal and transverse post-tensioning. Figure: H&H.

the only alternative that could reasonably meet an "extremely critical" importance level and "service immediate" performance level at the strength limit state as described in the American Association of State Highway and Transportation Officials' *AASHTO Guide Specifications for Bridges Vulnerable to Coastal Storms*.[1])

- A greater amount of prestressing force, designed to provide net compression across the construction joints under service loading, and bonded reinforcing steel across the construction joints for crack control.
- Improved aesthetics with a visually slender superstructure, clean and uncluttered soffit, no dark shadows between beams, and full aesthetic integration with substructure.

The approach spans were originally designed to be built using the incremental launching construction method, with 36-ft-long segments (equal to half of one span) cast on temporary casting beds in the first and last spans of the bridge and then jacked uphill toward the bascule pier on launching beams. The contractor saw an advantage in constructing 72-ft-long segments (the length of a one span) cast on falsework over water. The contractor proposed this change as a contractor savings initiative (CSI). Although the CSI required a large amount of temporary falsework, it offered the following advantages:

- It maintained all major design features, criteria, and restrictions in the contract documents.
- It reduced the amount of longitudinal post-tensioning through more-efficient design and replacement of bar tendons with more-efficient strand tendons.
- It eliminated the casting beds, including approximately ninety-five 30-in.-diameter driven steel pipe piles, the casting bed concrete slab, and steel beams.
- It eliminated temporary intermediate pile bents and corresponding lateral bracing.
- It eliminated incremental launching equipment and structures.
- It simplified segment formwork.
- It reduced the number of transverse post-tensioning tendons with modified duct routing to achieve greater efficiency.
- It moved construction staging further from active traffic.
- It will reduce future maintenance requirements by having fewer transverse construction joints and post-tensioning hardware.
- It employed a more commonly used construction method.

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

The civic scene in Palm Beach, Fla., was influenced by Addison Mizner, Florida's leading architect of the 1920s. His Spanish Mediterranean revival style became the architectural signature of the place, creating the ambience that truly transformed the landscape of South Florida. In other words, he was a hard act to follow. Nevertheless, the designers of the Southern Boulevard Bridge were asked to do just that—and they had to do it in the few feet available between the deck of the highway grade and the crests of the salt waves below. They rose to the challenge with both innovative aesthetic features and innovative engineering.

Examining the aesthetic features from the top down, we see that the overlooks offer comfortable locations to pause, rest, and take in the civic scene, while the railing is transparent to drivers and pedestrians alike. Looking below the roadway, the structural system is clear, simple, and shaped to reflect the forces on it. The soffit is flat and reflective, with no dark recesses to harbor birds or debris. The pier columns have a pilaster on their outer faces that reduces their visual mass and makes them look thinner. The column tops flare to accept the bearings, and that flare continues into the slab to visually spread the bearing reaction into the slab. The column pilasters continue onto the slab as brackets that reinforce the overlooks. Even though there is a clear joint between the piers and the slab, they look as if they were conceived as a single shape.

Getting all of that to work in an extremely thin structure, and then building it over water, required numerous engineering innovations. The designers and contractors are to be congratulated on the ingenuity that resulted.

It's probably a stretch to say that Addison Mizner himself would have been proud of the Southern Boulevard Bridge, but I think he well might have been.

Spans 1 and 2 before concrete placement. Photo: Florida Department of Transportation.

Post-Tensioned Slab

The structure is post-tensioned using 0.6-in.-diameter low-relaxation strands in both longitudinal and transverse directions. The following post-tensioning systems were used:

- Primary longitudinal 29- and 30-strand tendons located in the slab core:
  - The primary tendons in the core perform much of the work of carrying the weight of the cantilever wings to the piers, which are located within the core section.
  - East approach: 10 five-span tendons and two groups of 5 two-span tendons. (The shorter two-span tendons were used to accommodate the casting sequence, described later.)
  - West approach: 13 five-span tendons and two groups of 6 two-span tendons.
- Secondary longitudinal 7-strand tendons located in the slab wings:
  - The secondary tendons in the wings provide the necessary supplemental longitudinal precompression of the wings.
  - East and west approaches: 2 five-span tendons and 2 two-span tendons.
- Four-strand transverse tendons (per five-span approach unit):
  - 128 draped tendons over the full width of the slabs, anchored at the wing tips.
  - 50 straight tendons over the width of the core near the bottom of the slab, anchored at the edges of the core.

Modified Span-by-Span Slab Construction

The slab placement sequence was developed to minimize the amount of falsework and to optimize the longitudinal post-tensioning. Placing the full five-span unit at one time would have been prohibitively expensive because of the extensive amount of falsework required. Therefore, an innovative span-by-span construction scheme was proposed to allow reuse of the falsework and formwork. After the substructure construction was complete, each five-span superstructure unit was constructed in three major stages:

- Stage 1: Construct the two-span unit near the abutment.
- Stage 2: Construct the two-span unit near the bascule pier.
- Stage 3: Construct the center closure span.

The first two stages included only the portion of the total post-tensioning required to support the self-weight of the two-span continuous slabs, and the corresponding temporary construction loads—including staging of construction equipment on the previously constructed unit. After the center closure span was placed, full-length continuity tendons were installed to create the continuous five-span unit. This construction scheme resulted in offsetting moments that significantly reduced the total amount of longitudinal post-tensioning.

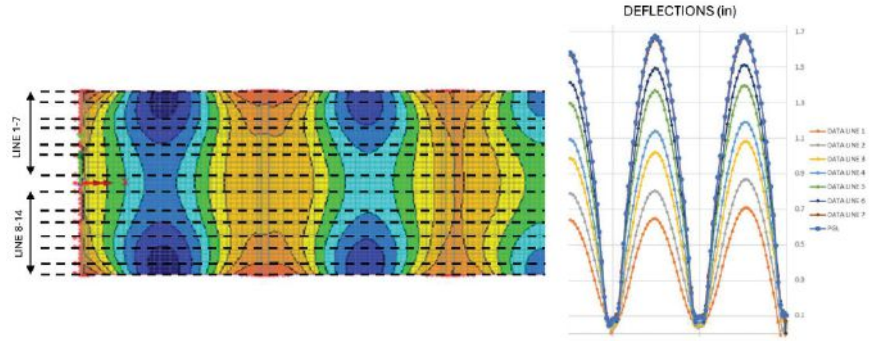
Modular Falsework Design

The falsework consisted of a series of longitudinal steel beams that spanned from pier to pier. W36x262 beams were used for the heavier core sections, and W36x150 beams were used for the lighter slab wings. For the core section, the beams were supported on top of the abutment footings and on HP14x117 columns that were supported on top of the waterline footings at the intermediate piers, anchored to the pier columns for stability. For the cantilevered wings, the beams were supported on steel towers, consisting of HP14x117 columns with cross bracing, supported on driven temporary steel pipe piles. The columns were designed to accommodate the variation in height at each pier with a series of bolted column extensions.

The falsework beams, diaphragms, and formwork system for each span were preassembled and floated into position on a barge. Next, a lifting system on top of the piers, consisting of strongback beams, hydraulic jacks, and threaded bars, was used to lift the spans to their specified heights. The falsework beams were then bolted to the falsework columns. The process was reversed to lower the falsework and float it to the next span to be constructed. Two spans of falsework were used in stages 1 and 2, and one span of falsework was used in stage 3. Each falsework component was used multiple times (between two and six times) during the construction. This modular approach provided significant savings in the cost of the falsework.

Completed spans 1 and 2 support a concrete pump truck used for concrete placement on spans 4 and 5. Photo: Florida Department of Transportation.

View of a typical formwork system supported by the steel falsework. Shoring posts are individually adjusted to provide three-dimensional camber. Photo: Florida Department of Transportation.



Typical slab deflection data from three-dimensional finite-element analysis. Deflection contours for half of the five-span unit are shown on the left. Deflection data for half of the five-span unit are shown on the right. The deflection data are used to set formwork elevations to achieve the final deck profile. Figure: H&H.

Geometry Control

Post-tensioned segmental concrete structures require detailed construction engineering and planning to achieve correct final vertical roadway geometry upon completion. Due to the nearly square superstructure (span-to-width ratio), significant weight, and relatively shallow depth, the slabs used for this project created geometric-control conditions unlike those typically found in segmental concrete box-girder construction, as the structure behavior is three-dimensional. The project team performed three-dimensional structural deformation analysis, including time-dependent concrete effects, longitudinal and transverse post-tensioning force effects, and flexibility of the formwork and falsework supports. The "fresh concrete" stage was modeled using a fictitious low-modulus-of-elasticity material to calculate deflection of the falsework. The "fresh concrete" deflections were superimposed with those of the hardened post-tensioned concrete slab to provide a single set of transverse and longitudinal camber input points.

Each of the east approach spans required 224 adjustable shoring posts supported on top of the falsework beams that support the formwork, while each of the west approach spans required 256 shoring posts. Top elevations of the shoring posts provided camber adjustment points for the formwork. Calculations also included required cambered screed clearances to the top of the top mat of reinforcement at key locations to offset deflections occurring during concrete placement. Top-of-deck elevations were recorded after concrete placement, post-tensioning, and form removal to provide ongoing camber validation and adjustment in the following spans where necessary. The calculations proved sufficiently accurate so that only minor diamond grinding of the roadway was required after completion.

Aesthetics

The use of post-tensioned, cast-in-place concrete permitted the designers to develop a unique custom visual form for this project. The long cantilever wings resulted in a slender fascia and permitted the piers to be tucked in away from the edges, which gives the impression of a lighter and more graceful structure. The shallow slab and smooth underside provide a clean and uncluttered appearance with no dark shadows, which makes the underside seem open and bright, despite the limited height above the water. The slab fully integrates with the piers, providing visual continuity. Tapered capitals below the slab core and cantilever ribs below the slab wings align with the tapered cruciform shape of pier columns and diaphragms between the pier columns. The tapered edges of the thickened slab core harmoniously align with the outside face of the pier columns. The wider west approach spans use the same pier shapes as the narrower east approach spans but with three columns instead of two. The front face of the abutments and back face of the bascule piers include matching pier shapes integrated into the walls. Steel post and beam traffic railings and custom aluminum pedestrian picket railings maximize viewing opportunities of the waterway for motorists and pedestrians. Semicircular overlooks integrated into the cantilever wings at each pier provide respite for pedestrians to take in the natural environment. The octagonal domed control house and trellis structures are inspired by architectural themes throughout the historic town of Palm Beach.

Conclusion

The use of a longitudinally and transversely post-tensioned concrete slab superstructure for the Southern Boulevard Bridge was an innovative solution to address the site-specific geometric constraints. The result is a durable and resilient structure suitable for an aggressive saltwater environment where there is a high risk of significant wave forces from major coastal storms. The CSI for the approach-span superstructure and the supporting specialty engineering were instrumental in the construction of the new landmark drawbridge. The first falsework component was erected in November 2019, the final post-tensioning operation was completed in May 2021, and the bridge was opened to traffic in September 2022.

Reference

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

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