Design-Build Replacement Bridge for St. George Island Protects the Environment and Ensures Durability

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A 4.1 mile (6.6 km) long, precast, prestressed concrete replacement bridge, belonging to the Florida Department of Transportation (FDOT), was built to provide mainland access to the barrier island of St. George in the Gulf of Mexico. The $73.4 million bridge is needed to accommodate sensitive environmental restrictions and must provide a 75-year service life with quality production and erection processes for a 10-year warranty from the design-build team. At the time of construction, the two-lane St. George Island Bridge was the single largest design-build project undertaken by the FDOT, and when completed in 2004, the 1180 ft (360 m) long, five-span continuous channel span was the longest spliced girder crossing in the United States. In this article, the authors discuss the major advantages of the design-build approach, the innovative concepts used in the project – including spun-cast cylindrical piles, a new precast concrete bent cap-to-pile connection, stay-in-place precast concrete footing forms, and bulb tee girders – and how precast concrete design ingenuity led to rapid construction and maximum span lengths while protecting the marine ecosystem.

Five miles (8 km) offshore of the eastern Florida Panhandle, the beautiful barrier island of St. George stretches itself narrowly for over 28 miles (45 km) in the warm waters of the Gulf of Mexico (see Site Map, Fig. 1). Sheltering the coastline near the town of Eastpoint, St. George

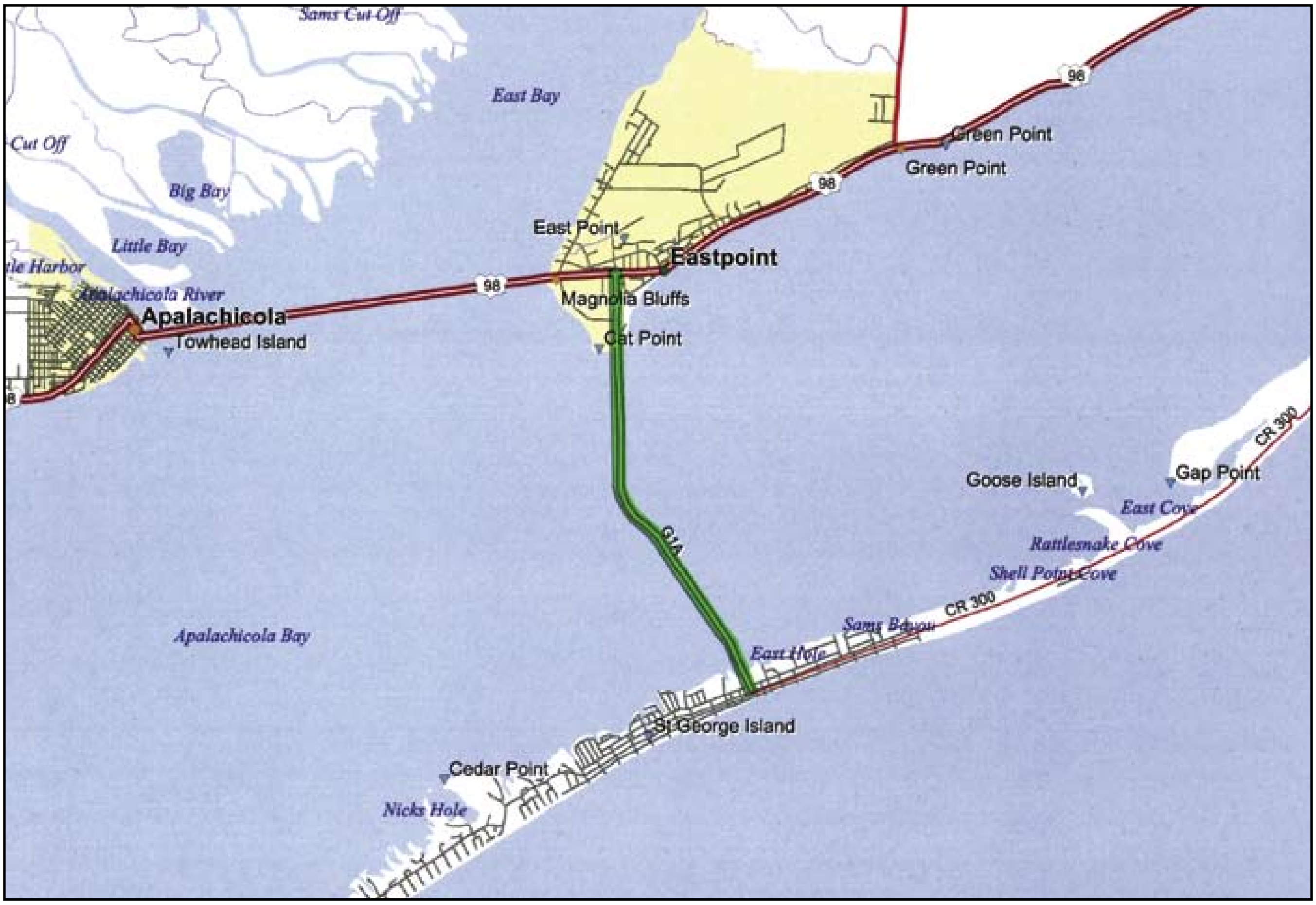

Fig. 1. Site map of St. George Island shows its location about 5 miles (8 km) south of the Florida Panhandle in the Apalachicola Bay, an area known for its oyster production and marine estuary.

Island is home to about 1000 residents and is known for its multitude of natural resources, and recreational and leisure amenities. About 2000 acres (800 ha) of the island's eastern tip is a state park, and St. George Sound and Apalachicola Bay are part of the U.S. National Marine Estuary, the second largest of its kind in the country.

In this article, the authors explain the decisions made concerning the design and construction of the new St. George Island Replacement Bridge over an environmentally sensitive marine estuary that supports Florida's renowned oyster industry. Rapid delivery of the completed bridge was facilitated through a relatively new contractual system that generated several innovative precast/prestressed concrete construction products and processes and delivered a 10-year bridge durability warranty backed up by the project's design-build (DB) team.

ENVIRONMENTAL STEWARDSHIP

St. George Island and the Apalachicola Bay environs support important and endangered natural resources; once on the edge of extinction, the recently reintroduced red wolf now hunts on state land beyond the island's spectacular white dunes and sandy beaches. Fed by the alluvial waters discharged from Florida's Apalachicola River, the nutrient-rich Apalachicola Bay, lying between the mainland and St. George Island, is habitat to 90 percent of Florida's oyster production and many federally-protected species (see Sidebar, "In Deference to Oysters," pp. 61).

St. George Island borders and shelters the habitat for some of the most productive oyster reefs in the United States; these important natural resources were the inspiration for the stewardship for the environment exercised by the Florida Department of Transportation (FDOT) in their prudent assessment of various bridge designs for construction.

Because the St. George Island Replacement Bridge crosses one of the most valuable marine estuaries in North America, the owner, the FDOT, needed a bridge system that could be built with environmentally friendly construction methods as well as providing extended service life and reduced construction schedule. Since Apalachicola Bay sustains significant natural resources, the FDOT sought out on-site erection procedures that would minimize adverse impacts over the water.

ORIGINAL BRIDGES BUILT IN 1960s

The existing bridges that provided vehicular access south from the Florida mainland to St. George Island were built in the early 1960s. The only island access from 1965 to 1999 was provided by Route SR 300 via a pair of bridges and a small island causeway on Bird Island (see Fig. 2).

A 7120 ft (2170 m) long northern bridge originally connected the mainland to the causeway, with a 6000 ft (1830 m)

Fig. 2. Aerial photo shows St. George Island at the bottom of the frame and looks northward toward the small Bird Island causeway and onward to the Florida mainland. The new replacement bridge was constructed to the west (on the left above) of the old bridge.

long southern bridge connecting the St. George Island to the causeway across the Intracoastal Waterway (ICWW). The old bridges were considered functionally obsolete, due to their narrow width, and were structurally deficient.

Table 1. Project timeline.

Selection of design-build team	April 1999
Notice to proceed	July 1999
Begin pile fabrication	November 1999
Complete initial design and permitting	December 1999
Begin test pile program	December 1999
Begin construction	January 2000
Complete test pile program	February 2000
Begin girder fabrication	September 2000
Begin cap fabrication	November 2000
Complete cap fabrication	July 2001
Complete pile fabrication	June 2002
Complete girder fabrication	July 2003
Complete construction	February 2004
Complete demolition Final acceptance	July 2004

The southern bridge had both low and high-level approach spans and crossed the ICWW with a continuous three-span unit comprised of four variable depth steel plate girders for a total bridge width of 28.25 ft (8.61 m). Low-level approaches were supported by four AASHTO Type II girders and high-level approaches used four AASHTO Type III girders. The northern bridge was of low-level trestle construction similar to the southern bridge. It was imperative that FDOT replace these structures for several reasons.

These two original bridges and causeway were in need of repair after decades of exposure to the harsh marine environment. Major corrosive deterioration of the piles in the splash zone required a substantial amount of costly recurring bridge maintenance, but more critically, the old bridges were no longer structurally adequate to resist ship impact loads in the ICWW. The FDOT made the decision to replace the bridges to St. George Island in 1998.

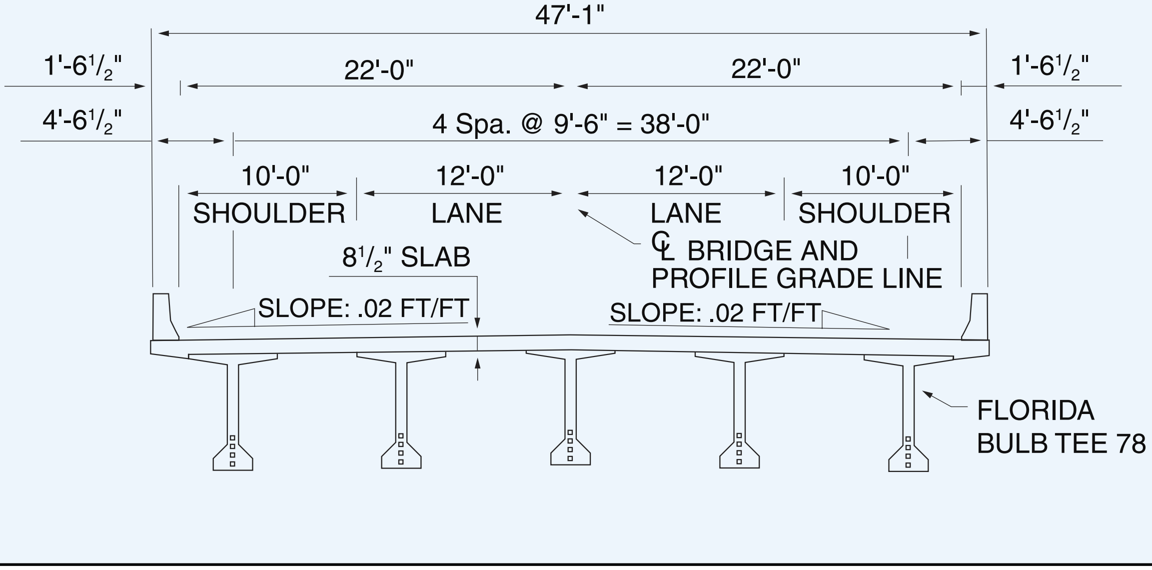

Fig. 3. Typical section of high level portion of St. George Island replacement bridge. Note: 1 ft = 0.305 m; 1 in. = 25.4 mm.

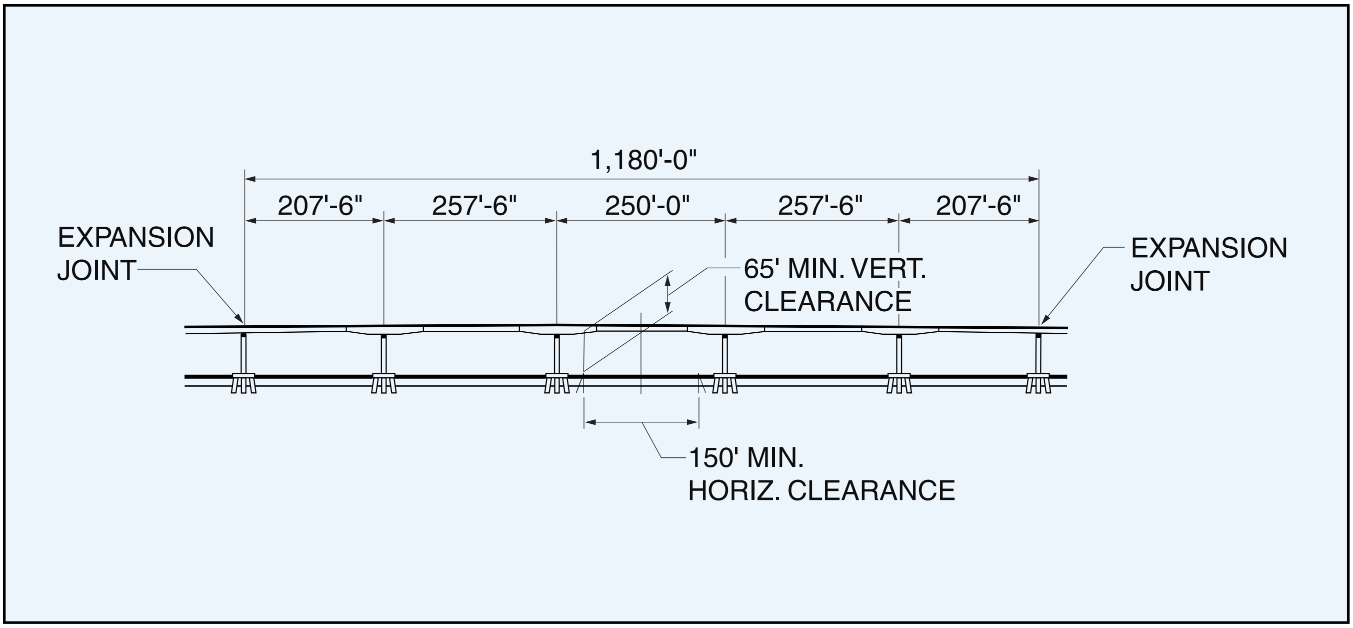

Fig. 4. Five-span channel unit elevation drawing. Note: 1 ft = 0.305 m; 1 in. = 25.4 mm.

Begun in 1999 and completed in 2004 at a cost of $73.4 million, the new 4.1 mile (6.6 km) long bridge replaced the two original bridges and the mid-bay causeway on Bird Island (see Tables 1 and 2 for project schedule and cost breakdown). With an overall length of 21,541.8 ft (6566 m), the new bridge carries two lanes of traffic with 10 ft (3.0 m) shoulders on each side for a total bridge width of 47.08 ft (14.3 m) including barriers (see Fig. 3).

The low-level approaches include 136 spans with typical span lengths of 125 ft (38.1 m), and are supported on pile bents using precast concrete caps. The superstructure consists of a cast-in-place concrete deck supported on four, 78 in. (1980 mm) deep precast, prestressed concrete bulb tee girders. There are 12, high-level approach spans on either side of the main channel, each 140 or 141 ft (42.7 or 42.9 m) long. These spans transition from four to five 78 in. (1980 mm) deep bulb tee girder support systems (see Tables 3 and 4 for product and span data).

The five-span main channel unit features various span configurations that range from 207.5 to 257.5 ft (63.2 to 78.5 m) long and total 1180 ft (360 m) in length (see Figs. 4 and 5). The high-level approaches and the main channel unit substructures are cast-in-place concrete piers. The bridge foundation typically uses spun-cast, 54 in. (1370 mm) diameter precast, prestressed concrete cylinder piles. The main channel unit, with precast, prestressed concrete haunched spliced girders, is believed to be the longest spliced girder crossing in the United States.

Table 2. Detailed project cost data.

Item	Cost, dollars
Mobilization	7.0 million
Approach roadway	4.0 million
Precast, prestressed concrete piling	16.0 million
Foundations and substructure	12.0 million
Precast concrete bent caps	3.0 million
Precast, prestressed concrete girders	11.0 million
Bridge superstructure	10.0 million
Design and construction engineering	7.4 million
Demolition of existing structure	1.0 million
Miscellaneous	2.0 million
Total	73.4 million

Table 3. Number and dimensions of precast/prestressed concrete components used in St. George Island Replacement Bridge.

Product	Number	Total length, lineal ft
14 in. square prestressed concrete piles	202	11,000
24 in. square prestressed concrete piles	14	1015
54 in. diameter spun cast cylinder piles	644	47,900
Spliced girder haunch segments	20	2350
Spliced girder end and drop-in segments	25	3600
78 in. bulb tee girders	684	103,272
Precast concrete bent caps	134	5762
Precast concrete waterline footing forms	30	NA

Note: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

Fig. 5. St. George Island replacement bridge under construction prior to post-tensioning operations in the main channel span over the Intracoastal Waterway.

DESIGN-BUILD TEAM APPROACH

At the beginning of the St. George Replacement Bridge Project in 1999, this was the single largest DB project ever undertaken by the FDOT. FDOT decided to use the DB method of project delivery to provide contractors with as much flexibility as possible and to open the new bridge access to St. George Island as soon as possible.

In a typical design-bid-build process, the owner solicits letters of interest from qualified engineering firms and a short list, normally three to five firms, is compiled. Written technical proposals and/or oral presentations are submitted to the owner, the firms are ranked, hours and fees are negotiated with the selected firm, a contract is signed, and design begins.

Table 4. Number of spans, span configuration, overall length, and deck area of St. George Island Replacement Bridge.

Number of spans	Length, ft
8	125.0
1	130.0
1	120.0
22	125.0
5	141.0
7	140.0
1	207.5
1	257.5
1	250.0
1	257.5
1	207.5
12	140.0
68	125.0
2	118.81
18	125.0
2	129.58
14	125.0
Total number of spans: 165	
Overall bridge length: 21,541.8 ft	
Total bridge length: 21,541.8 ft	
Total deck area: 1,014,260 sq ft	

Note: 1 ft = 0.3048 m; 1 sq ft = 0.0929 m^2.

In typical design-bid-build contracts, with the design completed including secured environmental permits, the FDOT would issue the plans for bid from contractors. The construction contract is normally awarded based upon the lowest bid. For this project, the authors estimate that the time required from conception to bid would have taken about 30 months, and would have resulted in a delay of the construction start date until February 2001.

With the DB process, on the other hand, the FDOT substantially reduced the time to deliver the bridge. Timing was important to the FDOT due to restrictions for receiving federal transportation funding. FDOT solicited letters of interest from DB teams in August 1998. Four teams were short listed.

A criteria package outlined specific requirements for the construction of the new bridge, including a corridor for placement of the structure, a typical bridge section, horizontal and vertical clearances at the ICCW, and important environmental procedures. Written proposals were submitted and oral presentations were made in March 1999 (see Table 1 for project timeline).

The bid proposals included about 30 percent complete plans for the new bridge and the roadway approaches; enough design detail had to be provided for FDOT to have a clear understanding of the concepts. More importantly, the contractor had to calculate take-off quantities accurately enough to properly prepare bids and determine the construction schedule. The winning DB team obtained the best score on the technical proposal, had the lowest bid price (approximately $3 million less than the second and third place bidders), and construction was able to start 15 months ahead of a design-bid-build process.

The DB approach reduces the total contract time for other reasons. These include concurrent design, construction, and soils exploration. Additionally, DB provides the engineer the opportunity to design the project to take maximum advantage of the strengths of the contractor. In other words, the engineer can design the project most efficiently for the specific contractor's preferred means and methods.

The winning DB team selected several precast/prestressed concrete components to construct the St. George Island replacement bridge, based on the advantages of durability, speed of construction, cost effectiveness, and environmental compliance. The project's proposed schedule included about 10 months for survey, geotechnical investigations, design, and permitting of the bridge prior to commencement of a load test program for the foundations.

The DB team consisted of Boh Bros. Construction Co., LLC, of New Orleans, Louisiana; Jacobs Civil, Inc., of Tampa, Florida; and Gulf Coast Pre-Stress, Inc., of Pass Christian, Mississippi (see Sidebar 2, "Precaster and Contractor Face the Unimaginable Devastation of Hurricane Katrina" on pp. 69). Several subconsultants assisted in the design process, providing survey, post-tensioning installation, geotechnical engineering, and environmental services.

After partial completion of the load test program (just 12

In Deference to Oysters

The Apalachicola Bay, one of the most productive estuaries in the northern hemisphere, remains one of the few waters in the Gulf of Mexico where oysters are tonged by hand, as they have been for generations. The wide and shallow waters of Apalachicola Bay constitute a 210 square mile (540 km^2) estuary of major economic and ecological importance to the region as the bay generates more than 90 percent of Florida's oysters and 10 percent of the nationwide supply. Oysters grow rapidly in these warm, pristine waters, reaching a marketable size in less than two years.Tongers, traditionally called "oystermen," harvest oysters from small wooden boats, 20 to 23 ft (6.1 to 7.0 m) long, bringing the mollusks to the surface with long, fork-like tongs. Once on board, oysters are sorted by size as they must be 3 in. (76 mm) in length to be legally harvested. The FDOT obtained environmental permits for construction of the St. George Island Bridge Replacement Project by ensuring the Florida Department of Natural Resources that not only would the oysters in the path of the new bridge be relocated out of harm's way, but the structure would be built with environmentally friendly construction, using off-site fabrication of precast concrete for the bridge components.

Additional environmental enhancements on the project included: Bird Island improvements, including causeway shoring; relay of at-risk oysters; creation of an artificial fishing reef; and stormwater improvements to local streets on St. George Island and in the neighboring towns of Eastpoint and Apalachicola.

— by Tommy Speights
FDOT District 3 Information Director

months after the notice to proceed), the installation of permanent test piles used to confirm driving criteria and to establish pile production length began. The total test pile program lasted four months. It should be noted that prior to submittal of bids, the competing DB teams were provided with only 12 soil boring logs for the entire 4.1 mile (6.6 km) length of the St. George Island Bridge corridor, upon which all preliminary geotechnical design was based. Over 100 additional borings were required to complete the geotechnical evaluation that would normally have preceded construction procurement.

The total proposed schedule to complete design, permitting, and construction of the new bridge was 52 months. Compared to other approaches, the DB contract is open to more flexibility in construction means and methods. The DB approach allowed the designers to work hand-in-hand with the contractor and precaster to develop concepts and construction techniques that work best for the particular contractor, and this concerted effort led to the most economical and environmentally sound design for the owner.

FIRST MAJOR USE OF LRFD BRIDGE SPECIFICATIONS IN FLORIDA

The St. George Island Bridge was the first major bridge in Florida to use the then new AASHTO LRFD Bridge Design Specifications.[1] FDOT had not fully adopted the LRFD Bridge Design Specifications at the time of the bridge planning in 1999, but the FDOT still allowed the individual teams bidding for the DB job to determine which design specification to use. Jacobs Civil, Inc. chose to use the LRFD Specifications for several reasons.

First, the LRFD Specifications provide a more accurate estimate of the live load distribution factor for both moment and shear and also use a more realistic live load model. The resulting design of the prestressed concrete girders actually required an additional one to three prestressing strands when compared to a design based on the AASHTO Standard Specifications for Highway Bridges.[2]

Second, the increased compression in the concrete resulting from these extra prestressing strands produced a more durable design and should translate into a longer service life for the girders.

Third, although not specifically disallowed by the Standard Specifications, LRFD outlines procedures for the use of strut-and-tie methods of reinforced concrete design, which served to be a useful tool, particularly in the footings of the high-level approach spans.

Finally, the deck design using LFRD provided a means of saving a significant amount of reinforcing steel. An estimated 425,000 lb (192,780 kg) of reinforcement was saved by using the LRFD Traditional Method of deck design when compared to a deck designed using the Standard Specifications.

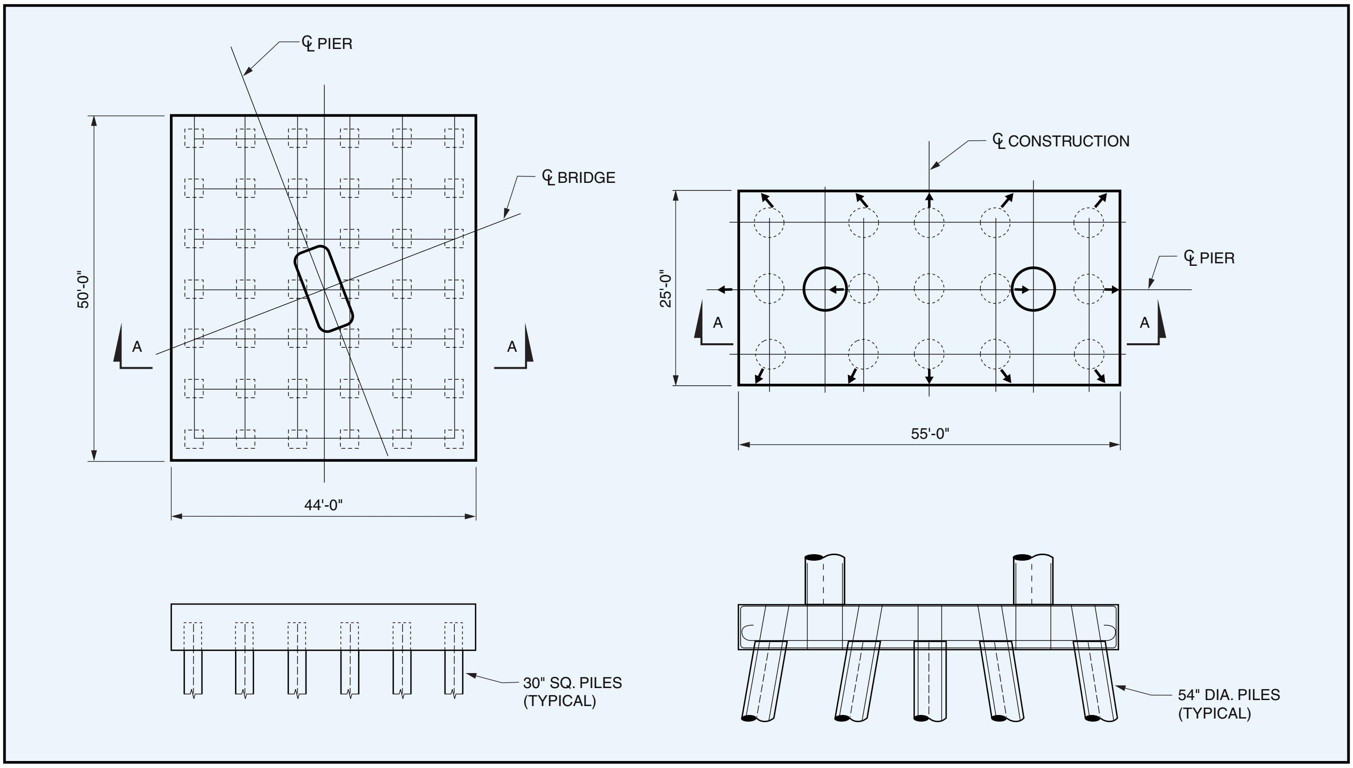

Fig. 6. Comparison between footings using 30 in. (760 mm) square and 54 in. (1370 mm) diameter precast, prestressed concrete piles.

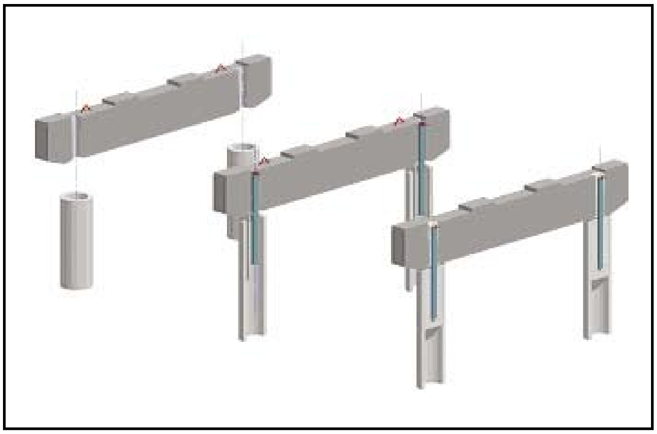

Fig. 7. Innovative pile-to-precast concrete bent cap connection using steel pipe.

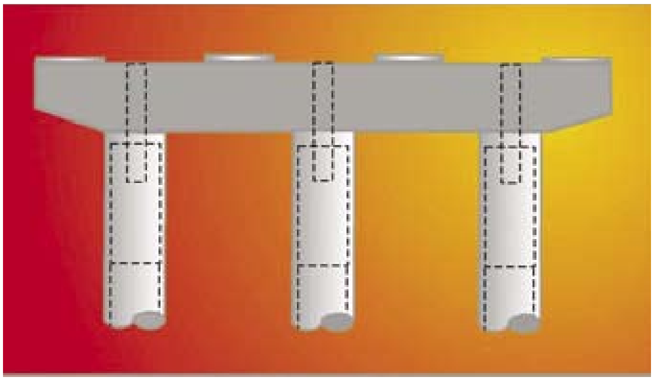

Fig. 8. Schematic shows positioning of steel pipe in the pile-to-bent cap connection.

FDOT would not allow the use of the LRFD Empirical Deck Design Method on this structure, which would have saved an additional estimated 1,750,000 lb (793,780 kg) of reinforcing steel over the LRFD Traditional Method.

FIVE MAJOR BENEFITS OF THE WINNING PRECAST DESIGN

There were five significant benefits in durability, speed of construction, protection of the bay environment, cost savings, and maximum span lengths provided through the selection of a precast/prestressed concrete system for use on the St. George Island Replacement Bridge. The key benefits of the winning design are listed below and discussed in more detail with respect to fabrication, erection, and environmental protection in latter sections of this article.

1. Ten-Year Bridge Service Warranty for FDOT — Enhanced product quality and the durability of precast concrete products for the selected bridge system were critical for two reasons. First, this was the first major bridge designed in Florida based upon the AASHTO LRFD Bridge Design Specifications that calls for a 75-year life span. Secondly, the DB team provided the FDOT with a ten-year, "bumper-to-bumper" warranty on the bridge, backed up by a bond. The warranty covers all aspects of the structure, so the DB team was contracted to ensure that there would be no need to provide scheduled repairs to the bridge during the first ten years of operation.

2. Larger Piles Meant Less Adverse Impact on the Bay — While seldom used for previous bridge projects in Florida, larger, 54 in. (1370 mm) diameter spun-cast cylinder piles —

rather than conventional square precast concrete piles — were selected for use on the St. George Island Bridge to accelerate construction while at the same time limiting adverse impact to the natural habitat. The greater strength of the larger piles for the foundation directly reduced the number of required piles for the project (see Fig. 6).

Fewer piles directly translated into less construction-induced impact to the environmentally sensitive bay bottom and a reduction in construction time for the bridge foundation. Additionally, the much larger moment of inertia of the cylinder piles provided substantially greater resistance to the design-controlling lateral forces of potential ship collisions.

3. Precast Concrete Bent Caps and New Connection Eased Production — Fabrication and erection were further facilitated by specifying the use of precast concrete bent caps for the 134 low-level trestle bents. Precast concrete bent caps eliminated the need to erect forms in the field, install reinforcing steel cages, and place and cure cast-in-place concrete over open bay waters, miles from shore. Use of precast concrete bent caps meant less over-water construction, and therefore, minimized potential damage to the oyster-rich Apalachicola Bay.

Although precast concrete bent caps are not new, an innovative pile-to-bent cap connection scheme was designed to enable the transfer of moment between the pile and cap. In the new connection system used on this project, use of a steel pipe—in lieu of a conventional steel reinforcing cage—eliminated typical fabrication, storage, and handling problems and considerably simplified the erection at the bridge site (see Figs. 7 and 8). To the authors' knowledge, this is the first time this pipe connection was used in Florida to connect a precast concrete cap. The first use of a pipe to enhance the moment capacity, particularly for vessel collision load, was at the Evans Crary Bridge in Stuart, Florida, in 2000.

Note that this pipe connection was developed by Henry T. Bollmann and was tested by Moussa A. Issa at the FDOT Structures Research Center on February 25, 1999.[3] The project report can be obtained from the FDOT Structures Research website.

4. Stay-in-Place Footing Forms Cut Labor Time — Waterline footing forms, a seldom used precast concrete system, were employed on this project to eliminate the need to erect conventional forms, place seal concrete, and remove and clean forms for the foundations of the 30 high-level piers. Precast concrete in waterline footing forms provided the bottom and sides for the footings, which were left in place and supported by the previously driven cylinder piles. These footing forms facilitated erection by reducing the amount of construction required in and over the Apalachicola Bay Estuary that would have been required by cast-in-place concrete formwork installation, removal, and cleaning.

5. Bulb Tee Extends Span Lengths —The main channel unit over the ICWW set a new standard for spliced girder construction with a 1180 ft (360 m) long system, believed to be the longest of its type to date. This project was the first adaptation of spliced Florida bulb tee design in a five-span unit in Florida. The superstructure of the bridge consisted of precast, prestressed concrete girders with a cast-in-place concrete deck. Using the 78 in. (1980 mm) deep bulb tee girders, the span lengths were optimized for creating the maximum possible span length for a given number of girders in a span (see Fig. 10).

Fig. 9. Erection of precast concrete bent pile caps at the bridge construction site.

FOUNDATION, SUBSTRUCTURE, AND SUPERSTRUCTURE

Foundation

Design Based on Twelve Soil Borings — Use of the spun-cast cylinder piles provided the DB team with other schedule-enhancing benefits. For the proposal, the firms competing for this project were provided with only 12 soil borings upon which to base their foundation designs. This meant that a complete geotechnical investigation had to be performed after the award of the project and prior to designing the foundations; production pile lengths then could not be determined until *after* completion of the load test investigations.

Reduction in Number of Piles — A bridge of this type would typically be constructed using square, precast, prestressed concrete piles. However, as mentioned previously, the use of high capacity 54 in. (1370 mm) diameter cylinder piles significantly reduced the number of piles required for all

Fig. 10. Erection of 78 in. (1980 mm) deep Florida bulb tee girder.

Fig. 11. Potential ship impact forces controlled the design of the Intracoastal Waterway, or main channel section, of the bridge.

of the bridge foundations and thus minimized the probability of adverse impacts to the bay environs.

For example, the main piers in the ICWW had to be designed to resist a substantial ship impact force. Had the foundation been constructed using conventional 30 × 30 in. (760 × 760 mm) square piles, 42 piles would have been required. Use of the larger, 54 in. (1370 mm) diameter cylinder piles meant that only 15 piles were required, an overall reduction of more than 60 percent in manufacturing and pile driving activities needed for a conventional design (see Fig. 6). Although lateral ship impact forces governed the design of bridge foundations for the high-level portion of the bridge, similar reductions in the number of piles were realized for the bents.

Early Pile Fabrication and Stockpiling — Since the spun-cast cylinder piles are manufactured in 8 and 16 ft (2.4 and 4.9 m) sections and then joined together through the use of post-tensioning tendons, pile section fabrication could begin immediately after the award of the project. Pile sections were then stockpiled in the Gulf Coast Pre-Stress, Inc. yard at Pass Christian, Mississippi, until such time as the specific pile lengths could be determined for each bent or bent location.

Fig. 12. As viewed from the bridge foundation, five lines of prestressed concrete girders were designed for the St. George Island Bridge high level and main channel sections.

For marine applications, FDOT requires piles to provide a minimum concrete cover of 3 in. (76 mm) over reinforcing steel on both the interior and exterior walls of the pile. In order to meet FDOT Standards, pile wall thicknesses were increased from the past practice of 5.0 in. (127 mm) to 8.125 in. (205 mm) in the DB team proposal. This concrete cover, coupled with the very dense concrete of the spinning fabrication process, resulted in a pile that is very resistant to chloride intrusion. It is anticipated that these piles will provide a useful service life in excess of 100 years in the very corrosive marine environment of Apalachicola Bay.

Pile Demonstration Test — To demonstrate the ability to fabricate and install this new pile section prior to submission of the proposal, the precaster manufactured a pile with the greater specified wall thickness. The contractor successfully drove the pile in soils that were similar to those represented in the 12 preliminary soil borings, giving confidence to the fabricator, contractor, and the FDOT that this new pile section would prove structurally sound and drivable in the soil strata encountered in Apalachicola Bay.

The end bents used 24 in. (610 mm) square prestressed concrete piles because their installation required the use of a lighter product due to limitations in the lifting radius and reach of the contractor's crane. A total of 644 cylinder piles and 14, 24 × 24 in. (610 × 610 mm) square prestressed concrete piles were installed on this project (see Table 3).

Stay-in-Place Precast Concrete Footing Forms — In addition to the use of the cylinder piles, another innovative scheme used to accelerate the construction process was the use of precast stay-in-place concrete forms for the waterline footings. Typically, waterline footings require the installation of a substantial amount of reusable forms for the bottom and side walls of the pile cap. After the forms are installed, a weak, non-structural concrete, called seal concrete, is placed in the bottom of the forms.

For this project, precast concrete waterline footings were designed so that the bottom of the cap was below the mean low water level. Precast concrete stay-in-place footing forms are not considered a structural element, but were used to facilitate speed of construction and minimize over-water construction. Use of these precast concrete forms eliminated the need to develop a system of removable forms capable of supporting the heavy, deep cap.

Substructure

Ship Impact Forces — The 30 piers in the high-level portion of the bridge were founded on the 54 in. (1370 mm) diameter cylinder piles with conventional, cast-in-place waterline footings (see Fig. 11). The columns and caps for these piers were also of cast-in-place concrete. The piers in the ship impact zone utilized waterline pile caps supported on cylinder piles, with impact resistance varying from very large values adjacent to the shipping channel, to minimal resistances requirements in the low level portion founded in shallow waters.

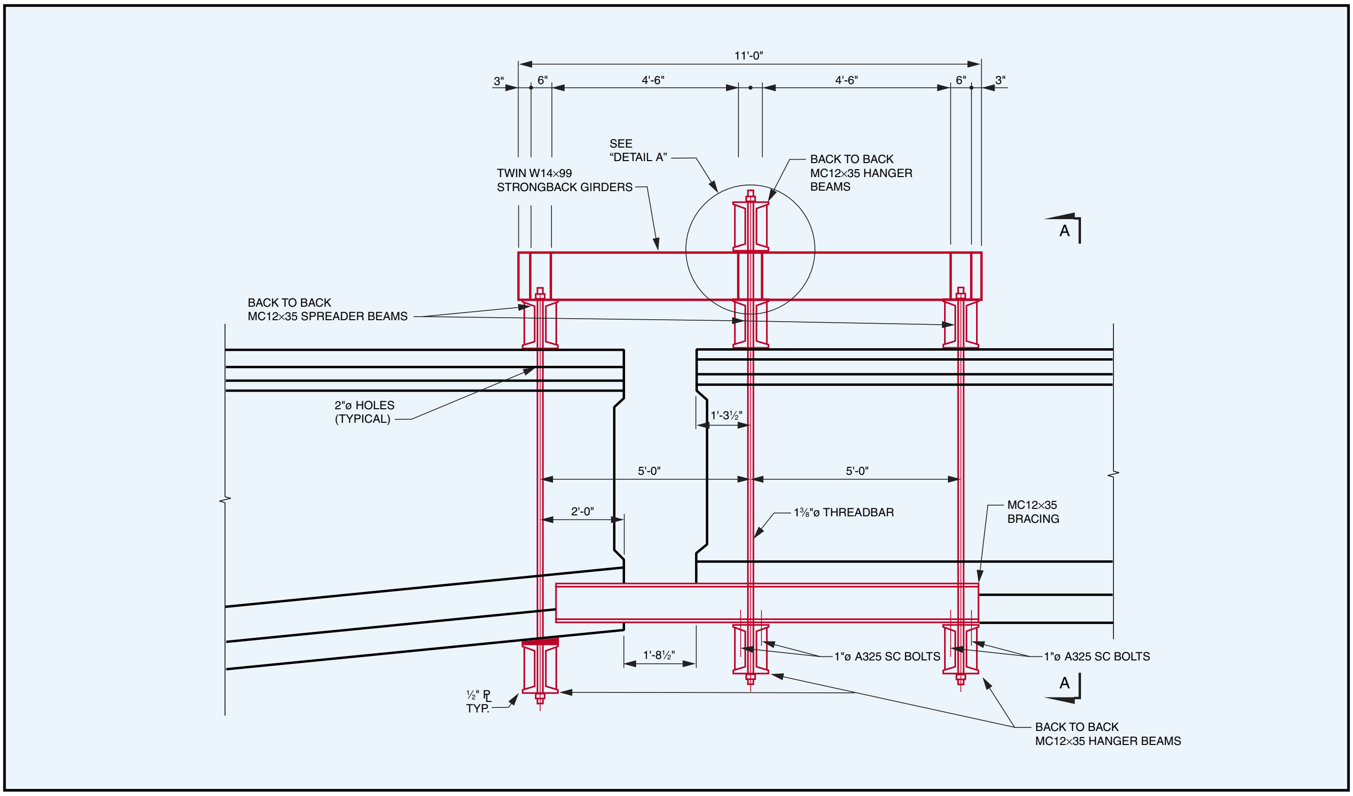

Fig. 13. Elevation detail of temporary shoring strongback. Note: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

The remaining low-level trestle portion of the bridge consisted of pile bents using 54 in. (1370 mm) diameter cylinder piles and precast concrete bent caps. The DB team had originally hoped for a two-pile precast concrete bent cap system for application on the entire bridge, but soil conditions required the use of three piles at the majority of the bents.

Ship Impact Zone and Span Lengths — Span lengths for the main channel unit and the high-level approach spans were selected to minimize the effects of ship impact loading on the cost of the bridge, primarily the foundation costs. The ship impact zone is about 4175 ft (1273 m) in length and centered on, and normal to, the ICCW. The high-level portion of the structure is about 4933 ft (1504 m) in length. Based on the skew between the ICWW and the bridge, the limits of the high-level structure are roughly the same as the ship impact zone.

The number of piles required for the high-level units varied from 4 per footing to 15 per footing. The piers consist of two, cast-in-place, 66 in. (1675 mm) diameter columns with a cast-in-place 5.75 ft (1.75 m) wide × 6.0 ft (1.8 m) deep concrete cap. Piers taller than 50 ft (15.24 m) had 4.0 × 6.0 ft (1.2 × 1.8 m) deep struts between the columns located at about mid-height.

New Pile Cap Connection — In the past, precast bent caps were cast upside down to permit the steel reinforcing bar cage to extend from the cap, and the cap consequently was difficult to handle, ship, and place. Additionally, the timing of delivery of ready-mixed concrete for placement in the pile had significant impact on the bridge erection schedule.

The use of precast concrete bent caps in conjunction with cylinder piles is not a new concept; however, the connection scheme between the cylinder pile and the precast concrete cap used on this project is unique. The benefits of this connection are presented in more detail under the “Production” and “Erection” sections. The two major advantages of precast concrete fabrication of bridge bent caps are better quality concrete and more accurate placement of reinforcing steel.

Superstructure

Main Channel Unit — Since span lengths for the channel units and the high-level portions of the project were selected to minimize the design forces from ship impact, these forces are partially a function of the distances of individual substructure units from the centerline of the channel. Increasing the span lengths and reducing the number of piers within the ship impact zone reduced the design forces. The need to minimize the effect of ship impact loads heavily influenced the decision to use a five-span, longitudinally post-tensioned, spliced girder channel unit with spans of 207.5, 257.5, 250, 257.5, and 207.5 ft (63.2, 78.5, 76.2, 78.5, and 63.2 m).

Five lines of girders spaced at 9.5 ft (3.0 m) are used in the main channel unit (see Fig. 12). Typically, the bridge span that crosses the ICWW would have been designed as a three-span system. A new record was set by designing the unit across the ICWW as a five-span, spliced precast concrete system.

The five-span configuration chosen for this project is not the most efficient one with regard to post-tensioning due to the increase in friction and wobble losses in the post-tensioning tendons, as well as the secondary effects associated with the continuous unit. However, the five-span system is the most cost effective configuration with respect to ship impact

Fig. 14. Precast concrete haunch segments with girder depth varying from 6.7 to 12 ft (2.0 to 3.7 m).

forces and the resulting substructure cylinder pile layout. The longer spans around the channel help to reduce the probability of ship impact at the piers.

Other spans within the ship impact zone were typically 140 ft (42.7 m) in length, with some spans as long as 141 ft (43 m). The 78 in. (1980 mm) deep bulb tee girder has a 60 in. (1525 mm) wide top and is very stable during handling. For all of the girders, 0.6 in. (15.2 mm) diameter low relaxation strands were used in the prestressing operations, using a 2 in. (51 mm) strand spacing.

The end segments are 147.81 ft (45.0 m) long. The drop-in segments are 139.08 ft (42.4 m) long in the second and fourth spans and 131.58 ft (40.1 m) long in the center span. The end segments and the drop-in segments are 2 in. (51 mm) wider than the typical beams, allowing the fabricator to use the same side forms used for the approach spans.

The pier segments, also known as the haunched segments (see Fig. 14), ranged in depth from 6.7 to 12.0 ft (2.0 to 3.7 m). The web depth varied, keeping the top and bottom flange shapes constant for the length of the beam, except for a 5 ft (1.5 m) long section directly over the pier. By keeping the flanges the same depth, the weight of the pier segments was minimized.

The erection sequence consisted of setting the pier segments on the piles and temporary shoring supported on the pier footing. The shoring also included vertical hold-downs to balance the moments when end and drop-in segments were erected.

The end segments were erected on the end piers and suspended from the haunch segments by means of strongbacks (see Fig. 13). The drop-in spans for the second and fourth spans were then erected, suspended by strongbacks with lateral end restrainers from the pier segments. Finally, the center span drop-in segment was erected on the pier segments using strongbacks with lateral end restrainers. Post-tensioning ducts in the girders were then spliced between the segments. A cast-in-place concrete pour was placed between each of the segments.

After the closure pours had cured, two of the four post-tensioning tendons were stressed. This first stage of post-tensioning created continuous girders; the first two post-tensioning ducts were then grouted and the temporary restraints removed. When the grout had cured, the cast-in-place concrete deck was placed in a specified sequence. Once the deck had cured properly, the last two post-tensioning tendons were stressed and grouted.

APPROACH SPANS

The high-level approach span lengths were selected by weighing the cost of additional girders to obtain fewer substructure units in consideration of the increased cost of those units.

Typically, the span length for the low-level trestle portion of the bridge was 125 ft (38.1 m), but ranged from 118.81 to 130.0 ft (36.2 to 39.6 m). Four girders spaced at 12.67 ft (3.86 m) were used to support the cast-in-place concrete deck. The total deck area for the St. George Island Replacement Bridge was 1,014,260 sq ft (94,225 m^2).

BRIDGE ALIGNMENT

Bridge Orientation Designed to Protect Environment

The DB team selected an alignment that diverges westerly from the existing bridge at the southern end of the bridge (see Fig. 2). The low-level approaches provide 12.0 ft (3.7 m) of vertical clearance above mean high water. The bridge crosses the ICCW approximately 6275 ft (1913 m) from the south end of the bridge, near St. George Island. This span provides a minimum vertical clearance of 65.0 ft (20 m).

The bridge crosses the ICCW about 1600 ft (490 m) west of the existing bridge, at an approximate skew of 28.5 degrees, providing a minimum horizontal clearance of 150 ft (45.7 m). As an aid to local fishing boats, a secondary boat access with 25 ft (7.6 m) of vertical clearance has been provided about 16,100 ft (4910 m) from the south end of the bridge.

Minimum radii for the horizontal curves at each end of the bridge were selected to eliminate right-of-way impacts on the mainland, at the northern terminus. One of the determining factors for the selected alignment was the attempt to minimize bridge construction over the oyster beds. Although this impact could not be totally eliminated, the selected alignment provided for the minimal impact to the prime oyster growing areas. Oysters in the path of the new bridge foundation were "relayed" or harvested and redeposited to areas away from any impacts from bridge construction activities.

PRODUCTION

Concrete Design

Typically, concrete strengths used for bridge design in 1999, in the state of Florida, ranged from 5500 to 6500 psi (38 to 44.8 MPa) for prestressed concrete products. To increase the efficiency of the structural components used on this project, higher concrete strengths were specified. The piles for the project required 7000 psi (48.3 MPa) concrete, and the concrete strength for all the girders was specified at 8500 psi (58.6 MPa). Since this project, the Florida bridge industry has generally used the 8500 psi (58.6 MPa) concrete for Florida Bulb Tee girders in project contracts. Concrete used for the precast pier caps was required to attain a strength of 5500 psi (38 MPa).

FDOT requires that concrete located in the splash zone of extremely aggressive marine environments include silica fume to reduce chloride penetration. By using the spun-cast cylinder piles, the precaster was able to economically place silica fume only in those pile segments located within the splash zone. The cylinder piles were fabricated with only the top two segments containing silica fume, which reduced the material cost of the piles.

The concrete compressive strength for all of the cast-in-place, structural components was specified at 5500 psi (38 MPa), with the exception of the concrete used in the closure pours for the spliced girders; this concrete required a strength of 8500 psi (58.6 MPa).

Piles Fabricated Prior to Load Test Results

Prior to completing the test pile program and the permitting process for the bridge project, fabrication of precast concrete components for the various parts of the structure began at Gulf Coast Pre-Stress Inc. facilities, in Pass Christian, Mississippi. Time was saved because fabrication of these precast concrete elements could begin prior to completing the load testing (see Figs. 15 and 16).

Because of the size of the St. George Island Bridge Replacement Project, it was very important to use construction components that could be fabricated in advance of construction and could easily be joined together once production lengths were established. The precaster selected and scheduled the early manufacture of bridge components that could be built before the survey, geotechnical investigation, design, and load testing were completed.

Pile sections were fabricated using the Cen-Vi-Ro process. In this process, a very low slump concrete is placed in a spinning form and externally vibrated. A roller is then used to compact the concrete and screed it to the proper thickness. Finally, the rotational speed of the form is increased, further consolidating the concrete by means of centrifugal force. Steel wires were used for spiral reinforcement in the pile sections and longitudinal tendon ducts were formed in the walls for placement of the post-tensioning strands.

Once production lengths were determined from the load tests, the appropriate number of sections were retrieved and joined together at the precaster's plant. Two post-tensioning strands were threaded through each of the voids in the piles and an epoxy was placed on the pile faces. Then, the tendons were partially tensioned.

Once the epoxy had achieved a prescribed strength, the strands were fully stressed. This two-step process ensured that the epoxy served as a leveling agent to achieve uniform pressure transfer between the pile segments. Voids were grouted using pre-approved, pre-bagged grout to provide a fully bonded post-tensioned system.

New Pile Cap Connection Design Saves Time and Money

Although mild reinforcing steel is an effective means of making a fixed connection, fabrication and handling of traditional precast concrete caps proved somewhat difficult. Conventional precast concrete caps must be cast and shipped to the project site upside down to accommodate the projecting reinforcement.

Fig. 15. Manufacture of spun-cast cylindrical piles at Gulf Coast Pre-Stress, Inc. facilities.

After delivery to the bridge site, the caps must then be turned over, with special care to avoid bending the reinforcing steel, and erected on the piles. The DB team on the St. George Island Replacement Bridge Project developed a new connection method so that the caps could be fabricated, stored, handled, transported, and erected in their final upright orientation.

Instead of a conventional steel reinforcing bar cage, the pile caps were cast with a vertical square tapered void where the piles would be located. The caps were erected on a grout bed on top of the cylinder piles. A structural steel pipe was then dropped through the void and suspended in the opening (see Figs. 7 and 8). Concrete would later be placed in the upper portion of the pile and in the void in the cap, completing the connection in the field.

Special attention had to be given to the cap design regarding the placement of reinforcing steel around the void and in the method of suspending the pipe from the cap, while providing proper cover to the reinforcement and the pipe. This connection procedure allowed the caps to be fabricated, shipped, and

Fig. 16. Because of the size of the project, it was important to fabricate precast concrete elements in advance of construction.

Fig. 17. Erection of precast concrete stay-in-place footing forms saved erection time.

Fig. 18. Precast concrete footing forms were fabricated to account for the battered piles through the use of circular openings.

set upright. Additionally, concrete placement for the connection could occur sometime after the cap placement, providing flexibility in the concrete delivery schedule.

ERECTION

Boh Bros. Construction Co., LLC of New Orleans, Louisiana, had successfully constructed several projects in the past using cylinder piles for the foundation. Use of the cylinder piles provided several attractive features when compared to square piles. The cylinder piles are capable of supporting substantially higher loads for a specific soils system; a smaller number of piles were driven in both the low-level approaches and those areas where ship impact loads are low, and increased in the areas where ship impact becomes substantial.

The use of precast concrete cylinder piles provided an excellent means of ensuring that the connection between the piles and the footings in the ship impact zone was completely fixed. Complete fixity of the piles in the pile cap greatly enhances the performance of the foundation system if the bridge is subjected to ship collision forces. Fixity was accomplished by placing a cylindrical reinforcing cage in the pile and then placing concrete to a depth of 10 ft (3.0 m) below the top of the pile. The top of the pile projected 1.92 ft (0.6 m) above the bottom of the pile cap. The cage projected into the footing to provide full development of the reinforcing steel.

Precast Concrete Stay-in-Place Footing Forms Accelerate Erection

Precast concrete footings were fabricated to account for the battered piles by use of oval openings in the footings (see Figs. 17 and 18). Each form was built for a specific footing, based on field-measured pile locations. The forms were supported by a steel system resting on the tops of the piles.

Once forms were placed, the gaps between the piles and the form were sealed. The form was then dewatered and reinforcing steel was installed in the form. After the footing concrete was placed, the forms remained in place to provide an additional layer of protection for the footing reinforcement. Boh Bros. saved considerable time by not having to construct conventional, removable formwork.

Precast Concrete Bent Cap Offers Many Erection Advantages

For the contractor, the one component that most enhanced the speed of construction was the use of a precast concrete bent cap, which offered multiple advantages over cast-in-place caps (see Fig. 9).

First, there was no need for the contractor to erect conventional formwork in the field, install reinforcing cages, place concrete, and remove and clean forms afterward. With a prefabricated unit, the cap is simply delivered by barge to the work site, erected, and connected to the piles.

Second, the potential for damage and accidental pollution to the marine environment, which would accompany any delivery of ready-mixed concrete over the water, was substantially reduced.

Third, because of the plant controls used in precast concrete fabrication methods, the precast concrete member is of higher quality than that of field cast concrete bridge caps.

While precast pile caps used in conjunction with cylinder piles — or any type of pile — is not new, the development of a different connection between the caps and the cylinder piles substantially eased fabrication, shipping, and installation of the caps.

The typical procedure for erecting bent caps for this project proceeded as follows:

1. Piles were driven and cut off at the proper elevation.
2. The mud line inside the pile was verified to allow for 10 ft (3.0 m) of concrete placement below the top of the pile.
3. If required, mud was removed from inside the pile.
4. Non-structural concrete was placed in the cylinder pile, acting as a form and sealing the bottom of the pile void.
5. Plastic shims were placed on top of the piles.
6. Non-shrink grout was placed on top of the pile.
7. The cap was set immediately.
8. The gap between the bottom of the cap and the top of the pile was visually inspected to ensure that it was fully filled with grout.

Using this procedure, the contractor was able to set four caps in half of a day. A follow-up operation installed the pipes in the cap voids and placed concrete in the piles and cap voids; this operation also proceeded at the rate of four caps in half a day. The ease and speed of the pile cap installation meant the contractor used fewer personnel working over the water for the bent construction. As the overhead cost and insurance for contractors working over water is significantly higher than work performed on land, fewer workers and reduced erection time saved money for the contractor and the owner.

Shoring System Eliminates Temporary Piles

The shoring system for a typical three-span spliced girder system normally uses a temporary tower located under the closure pour between the end segment and the haunch girder and strongbacks connecting the drop-in segment to the haunch girder. The strongbacks, with lateral restraint, would then create hinges at the closure pours, while the temporary towers would provide stability by resisting both the vertical reaction to the end segment and the uplift forces resulting from the drop-in segment.

To eliminate the cost and delay associated with a conventional temporary tower, an alternate shoring system that utilized the permanent foundation was used for the St. George Island Bridge main channel unit. Temporary shoring towers were installed on both sides of each interior pier (see Fig. 19). Each tower was able to resist uplift forces and thus create the stability required during construction, and the strongbacks provided the connection between the constant depth segments and the haunch segments. This shoring system eliminated the need to drive temporary piles, saving the contractor time and money.

Bridge Post-Tensioning Improvements

Although the concrete was considered high performance, because its 28-day design compressive strength was 8500 psi (58.6 MPa), the true performance and durability of the main channel unit was realized in the post-tensioning and grouting operations. Recent corrosion problems documented in post-tensioned bridges in Florida have resulted in many improvements to these critical operations. While this project was let prior to the improved Florida post-tensioned specifications, which deployed five improvement strategies, this project did include many improvements in the construction of the main channel unit including:

- Using a pre-approved post-tensioning system (Part of Strategy 1 — Enhanced PT Systems);
- Ensuring four levels of protection (Part of Strategy 1 — Enhanced PT Systems);
- Conducting duct pressure testing (Part of Strategy 2 — Fully Grouted Tendons);
- Requiring certified grouters and inspectors (Part of Strategy 2 — Fully Grouted Tendons);
- Using low point grout injection (Part of Strategy 2

Precaster and Contractor Face the Unimaginable Devastation of Hurricane Katrina

Television coverage and news stories cannot come close to depicting the horrific devastation left in the wake of the furies of Hurricane Katrina on the coastal facilities of Boh Bros. Construction Co., LLC in New Orleans, Louisiana, and Gulf Coast Pre-Stress Inc., whose plant facilities are located in the Gulf Coast town of Pass Christian, Mississippi.

Boh Bros. had damage to equipment and found one of their barges had been swept from their moorings and grounded inland by Katrina's unprecedented winds and tidal surge. However, Boh Bros. immediately began to fulfill federal emergency contracts to assist others devastated by the hurricane, including the Louisiana DOT Design-Build contract to temporarily repair I-10 over Lake Pontchartrain.

Devastation was felt by all that inhabited the Gulf Coast region.

Getty Images

Due to Katrina, Gulf Coast Pre-Stress offices and production facilities were submerged under 25 ft (7.6 m) of seawater in late August 2005. Most of the electrical and production equipment was destroyed and must be replaced. Many of the 150 precast plant workers lost their homes and are now being housed in used late model mobile homes provided by Gulf Coast, since emergency housing was not available. While Biloxi, Mississippi, and other larger coastal towns received broad media coverage after the hurricane and can hope for eventual rebuilding and restoration, many are concerned that small coastal towns, like Pass Christian, may not fully recover from the horrific leveling force of Mother Nature's fury.

— by Don Theobald, Vice President of Engineering, Gulf Coast Pre-Stress Inc., Pass Christian, Mississippi and Ed Scheuermann, Project Director, Boh Bros. Construction Co., LLC, New Orleans, Louisiana

Fig. 19. Temporary shoring towers eliminated the need to drive temporary piles at the bridge piers.

— Fully Grouted Tendons);

- Requiring post-grouting inspection (Part of Strategy 2 — Fully Grouted Tendons);
- Ensuring deck joints were not over anchorage (Part of Strategy 4 — Water Tight Bridges); and
- Installing four tendons per beam (Strategy 5 — Multiple Tendon Paths).

FDOT Strategy 3 — Anchorage Protection, which requires permanent grout caps, was not deployed on this project.

Post-Tensioning and Grouting

The post-tensioning consisted of four tendons stressed in two stages. Each tendon was comprised of 15 — 0.6 in. (15.2 mm) diameter strands that were stressed at both ends. Two tendons were stressed on the non-composite section, while the remaining two tendons were stressed after the deck was placed and had attained the required strength. Prior to the installation of the tendons, the duct was flushed with lime-treated water that had been tested for chlorides and oils. Once the chloride levels were below 250 parts per million (250 mg/L), oil-free compressed air was blown through the tendon to remove any excess water and the installation of the tendons commenced.

Fig. 20. The overall length of the spliced girder unit, 1180 ft (360 m), complicated the installation of the post-tensioning tendons.

The overall length of the spliced girder unit, 1180 ft (360 m), complicated the installation of the tendons. The contractor determined that pushing the strands through the duct would be extremely time consuming and could also damage the duct. The tendons were installed by pulling the entire tendon through the duct at one time. This was accomplished by first using compressed air to blow a wire through the duct. All 15 strands were then cut to length and placed on the approach spans (see Figs. 20 and 21). The strands were welded to a swivel plate that was pulled through the duct using the wire.

After stressing, and prior to the grouting operation, the ducts were pressure tested by blowing compressed air into the duct. The duct was pressurized to 100 psi (0.7 MPa) and held for five minutes. The maximum allowable pressure loss over the five-minute period was 10 psi (0.07 MPa). Typically, relatively minor leaks around the anchorages were noticed. After sealing those leaks, the ducts generally were able to meet the allowable pressure loss criteria.

After successful pressure testing, the grouting operation was performed with grout pumped from the low-point injection port. Despite the length of the ducts, each tendon could be grouted from one injection point without exceeding the maximum allowable pumping pressure of 145 psi (1.0 MPa). Grout efflux tests were performed for each tendon at both the inlet and outlet ports. After successful testing of the outlet port grout, each grout outlet was "burped" to ensure that leaks and entrapped air were not present in the tendon; this was done by sealing all outlets, elevating the pressure to 75 psi (0.5 MPa), and waiting two minutes to determine if any leaks were present.

After sealing any existing leaks, the pressure was bled to 5 psi (0.03 MPa) and held for 10 minutes to allow any entrapped air to flow to the high points. After the 10-minute period, grout was subsequently discharged down the beam at each high point to remove the entrapped air. The process was completed by locking a pressure of 30 psi (0.2 MPa) into the tendon. This was a key component provided by the post-tensioning vendor, Dywidag Systems International USA, Inc., in the contractor's shop drawing submittal process.

CONCLUDING REMARKS

Use of the DB approach in Florida allowed the total St. George Island Replacement Bridge project schedule to be reduced substantially, as the geotechnical investigation, test pile program, environmental permitting process, and preliminary designs began in concert as soon as the notice to proceed was issued by the FDOT. The DB contractual system ensured a direct relationship between the contractor and the design team whereby field problems were resolved rapidly and the use of several innovative construction products and processes was facilitated. Because of the shear magnitude of this structure, it was critical that the precast concrete components — the cylinder piles, bent caps, footing forms, and prestressed concrete girders — were able to be fabricated in advance of construction with members that could be easily joined together in the finished product.

The precast/prestressed concrete components will provide superior durability in the aggressive marine environment of the Gulf of Mexico. The new bridge is constructed entirely of durable materials to satisfy both the owner's needs for low maintenance and long structural life and to limit any warranty costs that must be borne by the DB team (see Fig. 22). Time-saving precast concrete system designs for the early fabrication and stock piling of foundation systems, fewer piles, an innovative pile cap connection and installation process, use of stay-in-place concrete footings, and a simplified temporary shoring system all worked to reduce costs and, importantly, minimized the potential for adverse ecological impacts.

In terms of the FDOT's commitment to protect the oyster resources and fragile environment in Apalachicola Bay, precast concrete construction provided the best bridge construction system possible as most of the individual structural components were fabricated off-site, thereby greatly limiting construction activities over the water. Furthermore, by using larger capacity spun-cast cylinder piles, the magnitude of impact from the pile driving activities was reduced by 35 percent compared to typical bridge construction. As national and international natural resources grow more scarce, as the worldwide list of endangered species grows, and as public knowledge of the need for environmental stewardship increases, the future bodes well for the minimal site disruption afforded by prefabricated precast concrete products and efficient erection operations.

In awarding the St. George Island Bridge Replacement Project the prestigious Harry H. Edwards Award, the PCI Jury commented:

"This is quite a unique structure, with quite an impressive length. The system provides an economical design that also speeds construction. It has taken advantage of all the possibilities of precast concrete, including its durability for a marine environment. It offers a wonderful combination of many innovative ideas that optimize design and economy. It shows that precast concrete was a natural choice for this bridge."

Fig. 21. Installation of post-tensioning tendons.

CREDITS

Owner: Florida Department of Transportation, District Three, Chipley, Florida

Design Engineer: Jacobs Civil, Inc., Tampa, Florida

General Contractor: Boh Bros. Construction Co., LLC, New Orleans, Louisiana

Precaster: Gulf Coast Pre-Stress Company Inc., Pass Christian, Mississippi

Specialty Engineer: Hugh D. Ronald, P.E., Orlando, Florida

Post-Tensioning Supplier: Dywidag Systems International USA, Inc., Bolingbrook, Illinois.

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2. AASHTO, *Standard Specifications for Highway Bridges*, 16th Edition, American Association of State Highway and Transportation Officials, Washington, DC, 1996.
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Fig. 22. The St. George Island Replacement Bridge was completed in 2004.