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"Design-build of a Temporary Bascule Bridge with Steel Piers"

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DESIGN-BUILD OF A TEMPORARY BASCULE BRIDGE WITH STEEL PIERS

By

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ABSTRACT

In January 1999, a design-build contract was issued for the design, construction, three year maintenance and operation, and removal of a temporary bascule bridge and fixed approach spans to carry four lanes of S.R. 702 across the Intracoastal Waterway between the City of West Palm Beach and the Town of Palm Beach in Florida.

The temporary bridge was needed to provide continued traffic flow over the Intracoastal Waterway during design and construction of a permanent bridge to replace a heavily deteriorated arch span bridge. The 1929 arch span bridge was in danger of collapsing due to marine borer infestation of support piling. Also included in the design-build contract was the removal of arch spandrel sand fill to relieve the loads on the foundations of these spans. The scheduling of this design-build project was important due to the declaration of emergency issued because of the condition of the foundations of the arch spans.

The project was approximately 1 kilometer (3,300 feet) long, including the 600-meter (1,970 foot) temporary bridge, and 400 meter (1,310 foot) approach roadway work. The bridge carried two lanes of traffic eastbound and two lanes westbound over the Intracoastal Waterway. At least two lanes of traffic were maintained during construction, and marine traffic was only interrupted during two 48 hour periods for installation of the four rolling lift bascule leaves. The existing mechanical drive machinery was moved with the existing steel bascule leaves, and a new PLC operating system was installed to maintain simultaneous operation of the existing bascule span and the new temporary bascule span during maintenance of traffic staging.

Lichtenstein lead the design team and was responsible for the fast-track design of fixed approach spans on steel bent caps, founded on steel pipe piles, and the design of new open framed steel bascule piers to support the relocated existing rolling lift bascule leaves and a temporary bridge control house. The construction materials and bent configurations were contractor chosen to provide his best bid based on a combination of low material costs, speed of construction, low maintenance, high salvage value, and low demolition costs. The open framed steel bascule pier was an innovation of the design team to meet the contractor requirements of quick construction (by prefabricating components); maximizing salvage value of the materials; and speedy and inexpensive removal of the components upon demolition of the structure. The prefabricated bascule pier framing was also designed as a stay-in-place pile driving template to ensure that piles were installed within the tolerances required by the moving leaves.

The open framed steel bascule piers, prefabricated off-site, consist of 660 mm (26 inch) diameter steel pipe sleeves and 310 mm (12 inch) wide-flanged bracing. 610 mm (24 inch) diameter pipe piles were driven through the sleeves after setting the frames in place and using the frames as a pile driving template. Prefabricated steel beams were installed on the piles to support the flat tread castings which were relocated from the existing rolling lift bascule bridge. The existing rolling lift bascule leaves were then floated onto the new steel piers using the lift of the tide and the available draft of a barge.

The temporary bridge was designed, built, and opened to four lanes of traffic within one year of the contract award.

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PROJECT BACKGROUND

In 1929, a 14 span reinforced concrete filled spandrel arch bridge with a swing span center span was constructed to carry two lanes of S.R. 702 over the Intracoastal Waterway between the City of West Palm Beach and the Town of Palm Beach in Florida. The arch spans were founded on timber piles. In 1959, two new lanes were added by constructing a reinforced concrete tee-beam structure next to the original 1929 structure. At this time, the swing span was replaced by a rolling lift bascule span, and the new bridge was built with identical bascule leaves. This resulted in a twin double leaf rolling lift bascule bridge. The 1959 structure was founded on prestressed concrete piles. The new structure was designed with piles battered in one direction only, away from the original 1929 structure to the original 1929 structure.

During the 1997 routine underwater inspection of the parallel bridges, extensive marine borer damage was discovered in the timber piles supporting the 1929 structure. The deterioration was so extensive that the load carrying capacity of the structure was questioned. The Florida Department of Transportation instrumented and load tested the structure in February 1998 and August 1998. During the second load test, permanent deflection was measured at one of the piers of the 1929 structure, and the two lanes carried by this bridge were permanently closed to traffic. As the newer structure depended on the older structure for its lateral stability, the entire structure was in danger of collapsing.

In September 1998, the State issued a Declaration of Emergency that allowed a design-build contract to be issued in January 1999 for the design, construction, three year maintenance and operation, and removal of a temporary bascule bridge and fixed approach spans to carry four lanes across the Intracoastal Waterway. Also, to relieve the loads on the filled spandrel arches, the contract included the removal of sand fill from the arch spans.

The design-build team lead by PCL Civil Constructors, Inc., of Coral Springs, was low bidder at approximately \$11 million dollars. Lichtenstein Consulting Engineers, Inc., of Fort Lauderdale, was the lead design engineer, and was responsible for all structural, mechanical, and electrical engineering for the fixed and movable spans. Stanley Consultants, Inc., of West Palm Beach, was the subconsultant responsible for roadway, highway, and maintenance of traffic design. Nodarse & Associates, Inc., of West Palm Beach, was responsible for geotechnical exploration and analysis.

DESIGN TEAM OBJECTIVE

To complete the project under budget, the design team worked with the Contractor to develop structural systems that would minimize construction time and construction costs. To minimize construction time, systems were designed to allow simultaneous on-site construction and off-site fabrication. Economical and easily erected construction types were designed for the fixed approach spans. To reduce construction costs by maximizing salvage value, components were designed which could be re-used after removal from the bridge. Use of the steel components helped to keep construction costs low by reducing demolition and disposal costs. The salvage value of the components also reduced disposal costs. No concrete was used in the bascule span piers, so the difficult task of demolishing concrete bascule piers was avoided; no disposal of concrete is required upon demolition of the bascule piers.

Design features used to meet the objectives included:

- Steel pipe piles designed for fixed approach bents and bascule piers. The preferred size of the pipe piles was chosen by the Contractor to ensure that the piles had maximum value to them after demolition of the bridge. The pipe piles had great bending strength, so the use of battered piles was avoided, except where the channel was the deepest.
- Rolled steel beams designed for the fixed approach span superstructure and the intermediate bent caps. The steel bent caps were designed so that they could later be separated at the field splice and used as construction crane bents on future projects. See Figure 1. Sizes were selected that were in the Contractor's inventory, or could be easily purchased with no lead time.
- Steel bascule piers designed to maximize salvage value and minimize demolition and disposal costs. The steel truss system designed to carry vertical and horizontal loads enabled the Contractor to fabricate the system off site while on-site construction proceeded. The steel frame was designed to be used initially during construction as a pile driving template and then in service for the bracing and horizontal load carrying system of the bascule piers. The system works by distributing vertical and horizontal loads from the most severely loaded piles to adjacent piles through the bracing system. See Figure 2. Component sizes for the bracing and load distribution system, consisting of wide flange steel sections, were selected from the Contractor's inventory, or were most readily available and could be easily purchased with no lead time.
- By using the frame as a pile driving template, the contractor ensured that the piles would be driven in the design location, within the tolerances required by the rolling lift bascule spans. See Figure 3.

BASCULE PIER DESIGN AND ANALYSIS

The design of the bascule piers was governed by the AASHTO "Specifications for Movable Bridges", AASHTO "Standard Specifications for Highway Bridges", AASHTO "Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges", and the parameters specified in the "Design and Construction Criteria for Design Build Services" of the Request for Proposal documents. The design loads included:

- Ship impact on the bascule piers: 1334 kN (300,000 pounds) transverse load, 667 kN (150,000 pounds) longitudinal load, applied independently.
- Scour at the bascule piers: 1.83 M (6 feet), based on the 10 year scour event. Based on the FDOT "Structures Design Guidelines" 50% maximum scour (0.9 M (3 feet)) to be combined with maximum ship impact.
- ♦ Wind on superstructure: 2.87 kPa (60 psf), bridge closed (down), 1.44 kPa (30 psf), bridge open.
- Dead load of the bascule span superstructure: 2713 kN (610,000 pounds) per leaf.
- Live load: HS 20
- The above loads were applied using six AASHTO "Standard Specifications for Highway Bridges" load combinations, two load combinations that included ship impact in accordance with the "Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges", and an additional load combination including dead load impact at the bumper blocks.

To resist the vertical loads, and avoid the costs and time associated with concrete casting and demolition, the steel pipe pile foundation, consisting of 610 mm (24 inch) diameter piles, was extended out of the water, up to the main supports of the rolling lift flat tread castings. Each flat tread casting was supported on two wide flanged steel beams (W 920 x 381 (W 36 x 256)) welded together, side-by-side. The width and strength of this double beam provided the lateral tolerances needed to float the bascule leafs onto the castings and also position the beams directly on top of the driven steel piles.

To resist the horizontal loads, a steel truss system was designed. The horizontal and diagonal members consisted of steel W 310 x 107 (W 12 x 72) members. The vertical members consisted of 660 mm (26 inch) diameter steel pipe pile sleeves. These were selected in conjunction with the Contractor to provide maximum salvage value and ease in procuring the shapes.

The east bascule pier was modeled three dimensionally as a finite member model using STAAD Professional software. The channel bottom was deepest at the east bascule pier so unsupported pile lengths were critical at this pier. See Figure 4. The joints were modeled with 75% rigidity, except for the connections at the bottom of the frame sleeves to the piles, which were modeled with 10% rigidity. The bottom truss connections were not required to transmit vertical loads into the pile foundation. All vertical loads were transmitted from the truss system to the piles at the top connection. In order to maximize the stiffness of the horizontal load resisting system, the truss depth was made as deep as possible. This resulted in a truss depth of 6.5 M (21.3 feet), which put the bottom truss chord at the channel bottom in the shallowest area.

The resulting pile loads and required tip elevations published in the design drawings are shown in the following table.

PUBLISHED MAXIMUM PILE LOADS FOR CONSTRUCTION					
PILE No.	COMPRESSIVE LOAD, kN (KIPS)	UPLIFT LOAD, kN (KIPS)	LATERAL FORCE, kN (KIPS)	MIN. TIP ELEVATION, M (FEET)	
13	1150 (256)	N/A	25 (5.6)	-14.3 (-46.9)	
1, 25	1000 (225)	N/A	20 (4.5)	-14.3 (-46.9)	
6, 7, 14, 15, 18, 19, 26, 27	1000 (225)	N/A	20 (4.5)	-14.3 (-46.9)	
8, 16, 20, 28	1000 (225)	125 (28)	25 (5.6)	-14.3 (-46.9)	
4, 32	500 (112)	350 (79)	15 (3.4)	-19.0 (-62.3)	
2, 3, 30, 31	500 (112)	200 (45)	15 (3.4)	-15.0 (-49.2)	
10, 12, 22, 24	500 (112)	200 (45)	30 (6.7)	-15.0 (-49.2)	
9, 11, 21, 23	500 (112)	200 (45)	30 (6.7)	-15.0 (-49.2)	
33, 34	500 (112)	N/A	30 (6.7)	-14.5 (-47.6)	

The loading combination of (dead load + stream force + wind) resulted in maximum pile compressive loads. The loading combination of (dead load + transverse ship impact + stream force) resulted in maximum pile uplift loads and lateral pile loads. Because the piers were designed for a rolling lift bascule, the dead load was positioned for maximum effects. The maximum effects were obtained with the leaf in the full open position. The actual maximum loads resulting from the analysis are summarized below:

LOAD COMBINATION	COMPRESSIVE LOAD, kN (KIPS)	UPLIFT LOAD kN (KIPS)	LATERAL FORCE kN (KIPS)
(DL + SF + W)	1360 (306)	331 (74.4)	32 (7.1)
(DL + Ship + SF)	1214 (273)	445 (100)	67 (15)

The above maximum loads did not occur simultaneously at the same piles.

DESIGN AND FABRICATION DETAILS

If vertical loads due to rolling of the bascule leafs and horizontal loads due to wind and vessel collision could not be shared between piles, individual piles would be overstressed. In the absence

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of a conventional heavy and rigid concrete footing to transfer these loads, particular attention was given to the design of load distribution elements of the steel framing system. These included the support of the bascule flat tread casting, the top-of-pile-to-frame connection, and the bottom-of-pile-sleeve-to-pile connection.

As previously described, each bascule girder was supported on a set of double W920 X 381's (W36 x 256) welded together, side-by-side. These double wide-flange beams provided over 620 mm (24 inches) of horizontal space to position the flat tread casting. See Figures 5 and 6. This provided the field adjustment needed to float the rolling lift bascule leafs onto the flat tread castings. The driven piles were capped with a steel cap plate and double W920 X 381's (W36 x 256) placed on top of the cap plate. To provide strength and properly support the castings within the required mechanical tolerances for flatness, and provide as much shop fabrication as possible, the existing flat tread castings were cleaned and shop bolted to a steel W360 x 314 (W14 x 211). This assembly was then brought to the field and bolted to the top flanges of the double W920 X 381's (W36 x 256).

All vertical loads were distributed and shared between piles through the connection of the pile sleeves and frame to the top of the piles. The loads were transferred through a curved bar welded to both the pile and the pile sleeve. See Figure 7. The inside curvature of the bar was made to match the outside diameter of the steel pipe piles. The width of the curved bar was 45 mm (1.75 inches). This equals the maximum gap between the pile and the pile sleeve, plus the thickness of the sleeve (10 mm (3/8 inch)), plus 10 mm (3/8 inch)). This was done in case the pile was installed against one side of the pile sleeve, rather than centered in the sleeve. Each connection was designed to minimize the amount of welding required to transfer the loads from the pile into the frame. Thus, some connections used more than one curved bar in the connection. The bars were placed symmetrically around the circumference of the pile.

The connection of the bottom of the frame to the piles was designed to transfer only horizontal loads. This could be accomplished by bearing of the pile on the inside face of the pile sleeve, but to reduce the movement at the bottom of the frame, the connection was designed with bolts passing through the pile sleeve of the frame to the pile, but not through the pile. See Figure 8. Once the piles were driven to the required elevation, through the sleeves of the frame, the bolts at the bottom of the sleeves only needed to be tightened to bear against the sides of the pile. No specific torque was required. This simple connection would also facilitate demolition of the piers once the permanent bridge was completed.

The critical position for loads on the bascule piers was with the rolling bascule leaf fully open. If the loads were not shared between piles in this critical position, the pile under the main bascule girders would be highly overstressed. In order to share the loads with other piles, a longitudinal (parallel to traffic) "A-frame" arrangement was used with diagonal truss members extending from the top of the overloaded pile to the bottom of the front and rear trusses. See Figure 9. This worked to transfer loads to two piles that were lightly stressed under this load condition.

FINAL QUANTITIES

The final weight of the entire east bascule pier was approximately 1286 kN (289,000 pounds), not including the piles. The weight of the two east bascule leafs supported by this pier was approximately 5427 kN (1,220,000 pounds). This resulted in a ratio of the mass of the substructure to the mass of the superstructure of 0.24. The final weight of the entire west bascule pier was approximately 1450 kN (326,000 pounds), not including the piles. The weight of the two west bascule leafs supported by this pier was approximately 5427 kN (1,220,000 pounds), not including the piles. The weight of the two west bascule leafs supported by this pier was approximately 5427 kN (1,220,000 pounds). This resulted in a ratio of the mass of the substructure to the mass of the superstructure of 0.27. The steel frames could have been optimized further to reduce the weight of steel used, but due to schedule demands, there was no time for optimization. Additionally, the diagonal and horizontal members chosen for the trusses were chosen by the Contractor because they were in his inventory or could easily be obtained. Lighter members may have been more difficult to obtain under the tight constraints of the schedule. Besides the direct cost advantages, there were the advantages previously discussed such as the ability to fabricate the frame off-site while on-site construction progressed. Once the frames were delivered to the site, construction progressed very quickly on the remaining portions of the bascule piers above water.

Two concrete bascule piers would have required approximately 1758 CM (2300 cubic yards) of concrete. These would have cost approximately \$713,000 to install, and approximately another \$420,000 to demolish and dispose of the debris. The total estimated cost to construct, demolish and dispose of concrete bascule piers would have been \$1,133,000, not including piles. Concrete piers would have required similar quantity of piles. The piles would have been shorter, as they would not have extended out of the water. On the other hand, more piles would have been needed for concrete piers due to the heavy weight of concrete. The costs associated with the time required to cast and cure concrete piers has not been accounted for here.

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FIGURE 1: Typical elevation of intermediate bent cap. Note steel cap can be separated at the field splice and used as a crane bent cap.

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FIGURE 2: Front elevation west bascule pier.



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FIGURE 3: Plan view of bascule frame and pile driving template.

FIGURE 4: 3-dimensional STAAD model of east bascule pier.





FIGURE 5: Elevation of tread casting support beam.

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FIGURE 6: Section through flat tread casting support beams.





FIGURE 7: Plan view of connection of pile to top of pile sleeve and frame.

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FIGURE 9: Elevation of longitudinal "A-frame" under last position of roll.