Accelerated Bridge Construction Using Precast Piers

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ABSTRACT

The Route 70 over Manasquan River project utilized a unique precast pier system to construct a replacement bridge. The precast system consisted of post-tensioned, architectural, HPC pier columns, caps and cofferdams. The method of construction maintained traffic, satisfied environmental requirements and produced a signature bridge over 700 days ahead of schedule.

INTRODUCTION

It has long been a goal of the Federal Highway Administration (FHWA) and the New Jersey Department of Transportation (NJDOT) to implement a "Get in, get out, stay out" approach to bridge and highway construction projects[1]. One of the primary methods of implementing this strategy is to employ prefabricated bridge elements and systems. Using precast concrete substructures can have a tremendous impact on a bridge construction schedule through time saved in establishing a work zone, forming, placing reinforcement, placing concrete, stripping formwork and curing; all of which can be accomplished off site and in parallel with other construction operations[2].

Since the existing Route 70 over Manasquan River bridge was structurally deficient and functionally obsolete, the NJDOT programmed it for replacement. In January 2001, NJDOT challenged its design consultant, Arora and Associates, P.C., to provide a design that would allow for the accelerated construction of the project. It was also important to maintain traffic while constructing the project with a minimum of environmental disturbances. To meet the project needs a precast pier solution was developed. By using precast concrete substructure components, including: cofferdams, columns and pier caps connected by post-tensioning, the bridge construction was accelerated with the piers being constructed at a rate of 19 working days per pier.

THE PROJECT

BACKGROUND - The Route 70 over Manasquan River Bridge (Structure No. 1511-150) crosses a navigable waterway and is considered a gateway to both Monmouth and Ocean Counties in the coastal region of the State of New Jersey. The bridge serves vehicular, pedestrian and marine traffic at this crossing. The original bridge was constructed in 1936 and was 625-ft long with a single leaf bascule span over the navigation channel (see Figure 1).

Figure 1. Existing bridge elevation.

The bridge was in poor condition due to a number of substandard elements. The pile bents were deteriorated at the waterline, the abutments had experienced movement and the deck exhibited cracks, spalling and efflorescence. The movable span had also been retrofitted with a sprinkler system to keep it cool and prevent it from becoming stuck during the summer. The bridge had a sufficiency rating of 20.6 out of 100. It also did not meet current geometric standards and only provided 11-ft travel lanes. Due to its low vertical underclearance of 15-ft, the bridge had to be opened on demand to allow for the passage of marine traffic, which impeded the flow of vehicular traffic along the Route 70 corridor.

PROPOSED IMPROVEMENTS - The proposed replacement bridge is the centerpiece of a $52 million project that will carry the dualized section of Route 70 across the Manasquan River (see Figure 2).

Figure 2. Architectural rendering of the proposed replacement bridge.

The project will meet the long-term regional vehicular and marine transportation needs along the Route 70 corridor and the Manasquan River. In addition to these considerations, the NJDOT and FHWA have a goal of eliminating movable bridges, where possible, to minimize traffic delays, facilitate the passage of emergency response vehicles, reduce annual operating and maintenance costs and to provide for a more reliable transportation infrastructure.

The bridge section will have a 2'-8" median, one 4'-8" inside shoulder, two 12-ft lanes and one 10-ft outside shoulder in each direction. 6'-0" sidewalks and 1'-4" parapets will be included on each side of the bridge. The project will widen the bridge from 56'-10" to 94'-8" and shift the centerline of Route 70 by 28'-10" (see Figure 3). The 724-ft long, fixed bridge will consist of twin structures, each having two three-span continuous superstructure units (119'-120.25'-120.25') comprised of bulb tee girders at 8'-0" spacing. The superstructure will be supported on two abutments and five architecturally treated in-water pier lines with pile foundations. With this span arrangement, the ten proposed pier foundations (5 EB and 5 WB) could be constructed adjacent to the existing bridge foundations. Increasing the bridge underclearance to 25-ft, widening the navigation channel from 50-ft to 75-ft and shifting the centerline of channel 15-ft towards the centerline of the river will also accommodate marine traffic needs.

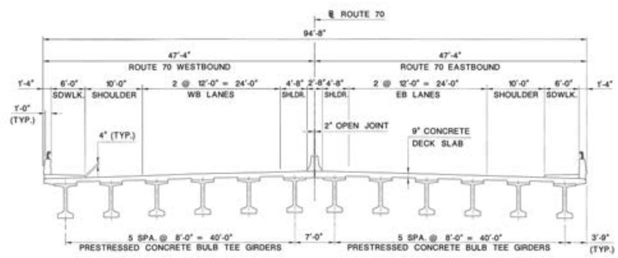

Figure 3. Superstructure cross section.

In addition to the bridge replacement and roadway widening, the project included many other elements. A new bridge fender system and a public fishing pier were designed using Fiber Reinforced Polymer (FRP) composite piles and lumber. Retaining walls, noise walls, bulkheads, ramps, traffic signals, water quality stormwater management retention basins and manufactured treatment devices (MTDs), highway lighting, ITS improvements and utility relocations were also included.

TRAFFIC CONTROL - Route 70 is a heavily traveled regional corridor with a Two-Way A.D.T. (2005) of 32,300 vehicles. Since it is also a coastal evacuation route, NJDOT required that two lanes of traffic be maintained in each direction during construction. To address the maintenance and protection of traffic needs and minimize the amount of right of way required, the project would be constructed in stages.

After performing a partial demolition of the existing bridge, the eastbound bridge structure would be constructed approximately 3-ft from the south fascia of the existing bridge. Traffic would then be transferred onto the newly constructed eastbound structure. Traffic would be maintained in four 10'-11" wide temporary lanes, which would utilize the entire bridge deck surface including the sidewalk and shoulder areas. Pedestrian traffic would be maintained on a temporary structure cantilevered off the south fascia of the eastbound structure. Demolition of the existing structure could then be performed, followed by the construction of the westbound half of the bridge. A final stage would then be required to remove the temporary sidewalk, shift traffic into its final lane configuration, and construct the eastbound sidewalk (see Figure 4).

Figure 4. Traffic has been shifted onto the newly completed eastbound half of the bridge and the existing bridge is being demolished.

ENVIRONMENTAL - In-water work restrictions were stipulated in the environmental permits issued by the United States Army Corps of Engineers in their Nationwide Permit 23 and the New Jersey Department of Environmental Protection in their CAFRA and Waterfront Development Permits. To protect winter flounder and anadromous (alewife) fish during migration and spawning runs, a timing restriction of January 1st to April 30th was imposed to prohibit in-water construction activities and to reduce the possibility of increased turbidity.

During the subsurface investigation, arsenic, beryllium and salt laden soils were found in the riverbed sediments. Therefore, it was desirable to develop a pier design that would minimize the bridge footprint in the riverbed and limit the amount of riverbed sediments that would need to be excavated.

PIER AESTHETICS AND PRECAST SOLUTION - Arora studied the project aesthetic issues with its architectural subconsultant H2L2 Architects/Planners, LLP and the NJDOT Bureau of Landscape and Urban Design. Traditional solid-shaft and multi-column pier types constructed on plinths were evaluated against more creative architectural concepts[3]. The preferred alternative, which resulted from the architectural study, was to use V-shaped piers, with eased edges and punctured by symmetrical, sloped geometric voids. The large simple shapes would visually reinforce the pier's weight-carrying ability and provide a dramatic appearance from the water and the shoreline[4] (see Figure 5).

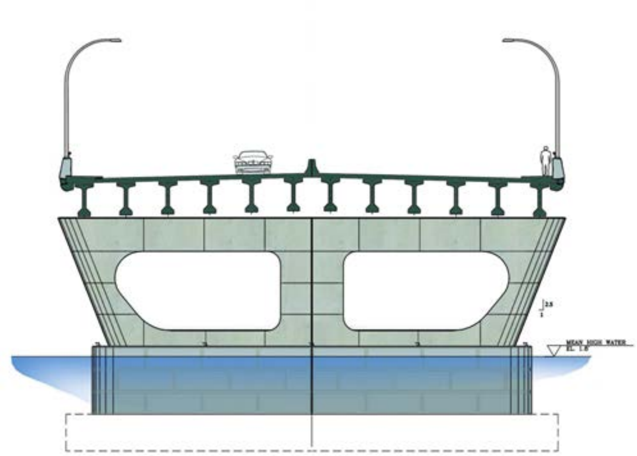

Figure 5. Initial architectural recommendation for the proposed piers.

The NJDOT requested that the architectural pier design concept be studied for design development and challenged the design team to utilize precast concrete and minimize the duration of the in-water construction activities. The process resulted in an architectural pier design with each pier being supported at the waterline on a simulated masonry faced plinth and having a pair of prismatic vertical columns at the centerline of the bridge and inclined tapered columns sloping outward towards the bridge fascias. A cap beam would then connect the tops of the columns. In the final condition the piers would appear uplifting with two symmetrical trapezoidal openings (see Figure 6).

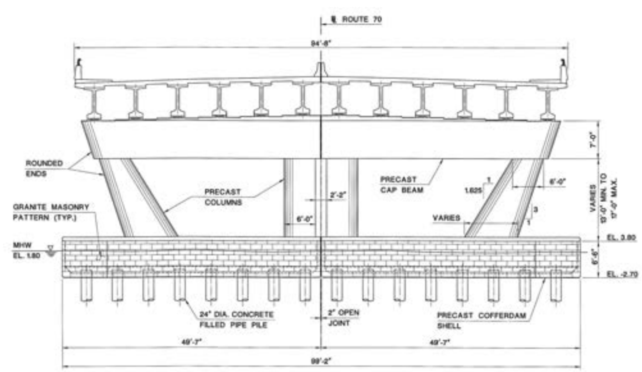

Figure 6. Final precast pier configuration.

The pier structural system consisted of precast concrete cofferdam shells, columns and cap beams connected through post-tensioning. 8,000 psi HPC was used for all of the precast bridge elements for added strength and durability. In addition to the distinctive pier treatment, the parapets, sidewalks, retaining walls and noise walls also received architectural treatments.

PILE FOUNDATIONS - The foundations utilized 24-inch diameter concrete-filled steel pipe piles driven to an estimated pile tip elevation of –110. For the eastbound and westbound structures, groups of 37 piles were used at the fixed piers, 26 piles were used at the continuity piers and 32 piles were used at the expansion piers. To construct the foundations, the contractor chose to drive pilot piles with a template around the perimeter of each pile group (see Figure 7). These piles were used to construct a temporary frame to support the precast cofferdam sections.

Figure 7. Perimeter piles driven with a template.

The remaining piles for each footing were then driven through openings in the floor slab of the cofferdam shell. A vibratory hammer was used to advance the piles 60-ft through the upper riverbed muck layer, and an impact hammer was used to drive the piles the remaining 50-ft to the estimated tip elevation. After a 7-day setup period, each test pile was restruck to verify they had achieved the minimum 800 kip ultimate pile driving resistance. By utilizing the setup characteristics of the sandy subsurface layers, the required pile capacities were developed without the necessity of driving to a lower stratum.

FOOTINGS - The typical footing size for each half of each pier was 30-ft wide by 49.5-ft long. Rather than constructing the footings inside traditional braced steel sheeting cofferdams below the riverbed, they were constructed at the waterline within precast concrete cofferdam shells. The cofferdam shells provided driving templates for the piles, served as architecturally treated formwork for the footings and minimized disturbances to the riverbed. The precast concrete cofferdams offered significant cost and schedule advantages over traditional cofferdams.

The contract plans detailed the architectural and dimensional requirements for the cofferdams and provided nominal reinforcement for shipping and handling of the units. The cofferdams were faced with a #1104 random cut stone pattern and coated with a clear epoxy waterproofing seal coat. This gave the pier footings the appearance of being faced with wet granite masonry at the waterline. The contract documents allowed the contractor to introduce joints and fabricate smaller sections to facilitate casting, shipping and erection. He also had the responsibility of selecting his own method of temporary support for the cofferdams. The cofferdams were fabricated in sections varying in length from 7.2-ft to 14.5-ft. They were then trucked to the site and loaded onto barge platforms (see Figure 8).

Figure 8. Cofferdam section delivered to the project site and fitted with lifting beams.

The sections were hoisted into place and connected with couplers consisting of 1¼" anchor bolts, 4" structural tubing and 1" threaded rods (see Figure 9).

Figure 9. Precast cofferdam section being hoisted into place.

The remaining work for each footing was to:

- Seal the annular spaces around the pile heads,
- Place tremie concrete,
- Dewater the cofferdam,
- Cut the piles off 6-inches above the floor slab,

- Support the cofferdam on the pile heads,
- Concrete the piles, and
- Make a mass pour of footing structural concrete (see Figure 10).

Figure 10. Work being performed inside a cofferdam. Piles are being filled with concrete.

PIER COLUMNS AND CAPS - The pier columns were designed to be constructed from hollow segmental units connected by post-tensioning strands extending from anchorages cast in the footings to tie points in the cap beams. Precast manufacturers were consulted during the design phase to determine a preferred segment height for fabrication and shipping. 4-ft high segments with a 9-inch wall thickness were selected. However, the contract plans allowed the contractor to modify the segment heights for his convenience and method of construction. During the shop drawing development process, the contractor chose to fabricate the columns as complete units of approximately 16-ft in length rather than the 4-ft segments shown on the plans; however, the architectural appearance of the columns was not altered. Using complete column units cut the column erection sequence down to a single step.

7-ft deep by 5-ft wide hollow prestressed concrete box beams were designed for the cap beams. Since the cap beams had rounded exterior ends, the contractor was given the option of precasting the beams as complete units or casting the rounded ends in place after the beams had been erected. The precast option was selected.

The precast pier column and cap components were then fabricated offsite, delivered via trucks and loaded onto barges (see Figure 11).

Figure 11. Precast pier columns and a cap beam are being prepared for erection.

The post-tensioning design was based on using ½" diameter ASTM A416 seven wire, Grade 270, low relaxation strands. The contractor proposed substituting 1¾" diameter, ASTM A775, Grade 150, threadbar for the specified strands. Since the threadbar was an equivalent system and easier to install in the sloping outer columns, the requested substitution was allowed.

The contractor had mobilized a number of large land-based and barge-mounted cranes, which provided flexibility in handling the larger concrete members. Working from barge platforms, the individual pier components were hoisted into place and connected using the post-tensioning threadbar. The erection of the pier column and cap beam components was accomplished in a matter of hours for each operation, and the architectural form of the piers quickly took shape. (see Figure 12 and Figure 13).

Figure 12. The first precast pier columns.

Figure 13. The precast columns and cap beam have been erected to complete the first pier.

GIRDERS - The bridge was designed to accommodate either Prestressed Concrete Economic Fabrication (PCEF) Bulb Tee girders or New England Bulb Tee girders. The contract plans were detailed using the PCEF XB 71 47 section, which is the section that was ultimately supplied by the contractor. The existing bridge was used as a working platform during Stage 1 to set the girders for the eastbound structure. During Stage 2 the newly constructed eastbound structure was used to set the girders for the westbound structure. Galvanized steel intermediate diaphragms were used to quickly secure the girders at the time of erection. CIP continuity diaphragms were later constructed at the piers (see Figure 14).

Figure 14. PCEF Bulb Tee girders.

CONSTRUCTION SCHEDULE - The construction contract was awarded in December 2005 to George Harms Construction Co., Inc. Since in-water construction operations were prohibited from January 1 through June 30, every effort was made to maximize each in-water construction season. An added difficulty was that cold weather concrete provisions would be in effect if the pier construction extended into the winter months. Therefore, the substructures and superstructure of the first half of the bridge had to be completed as quickly as possible so that traffic could be shifted onto the new structure and in-water construction activities could begin at the start of the following in-water construction season.

To achieve this, the contractor operated on a six-day workweek and employed several crews, which moved from one pier location to the next, performing the same tasks for each pier. Once an element of a pier was constructed the crew performed the same series of tasks on the next pier, and this was done for each step in the pier construction process (see Figure 15).

Figure 15. Crews working on multiple piers.

The eastbound pier construction activities occurred between July 1, 2006 and October 23, 2006. Since the five eastbound piers were being constructed concurrently, the contractor's goal was to optimize the construction of all five piers rather than any single pier. The construction duration for the individual piers ranged from 69 to 86 working days (WD) with an average duration of 78 WD per pier. However, these construction durations all contained some float. The total duration of the eastbound pier construction was 96 WD, so the rate at which the five eastbound piers were completed was approximately 19 WD per pier. The schedule for the construction of the eastbound piers 1 through 5 is illustrated in Figure 16.

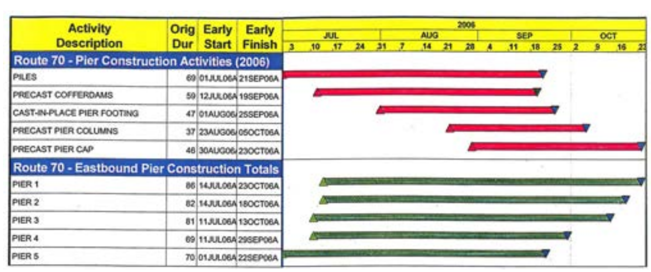

Figure 16. Construction schedules for the eastbound precast pier operations and the durations of Piers 1EB through 5EB.

The westbound pier construction activities occurred between August 24, 2007 and November 27, 2007. As on the eastbound structure, the contractor's goal was to optimize the construction of all five piers rather than any single pier. The construction duration for the individual piers ranged from 53 to 67 WD with an average duration of 61 WD per pier. The contractor was still bound by the same in-water environmental permit and cold weather concrete provisions that were present for the eastbound construction. The work was further complicated by the in-water demolition of the existing bridge, which could not begin until July 1, 2007. This resulted in a late start and late finish of the westbound pier construction activities. To make up for this, the contractor was able to reduce the average time of construction for each pier from 78 WD on the eastbound structure to 61 WD on the westbound structure. The total duration of the eastbound pier construction was 93 WD, which was an improvement of 3 WD, but the rate of pier completion remained approximately 19 WD per pier. Since the contractor was able to replicate this rate of pier completion, it is reasonable to conclude that this construction rate could be achieved on other projects. The schedule for the construction of the westbound piers 1 through 5 is illustrated in Figure 17.

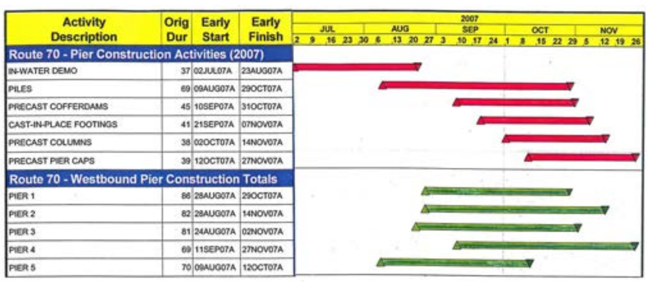

Figure 17. Construction schedules for the westbound precast pier operations and the durations of Piers 1WB through 5WB.

To better understand the efficiency of the precast pier construction a typical precast pier should be compared to a typical cast-in-place (CIP) pier. This comparison should also be made with pier construction schedules considering all construction activities to be on the critical path. For comparison purposes, the same pile foundations were used for each type of pier. An optimum precast pier construction duration was arrived at by starting with the actual schedule for the most efficient pier (Pier 1WB), eliminating the days when no construction activities were occurring, and substituting the most efficient durations for each individual task to eliminate the float. In this way, an optimum precast pier construction duration of 34 WD was arrived at. It was then estimated that a single CIP pier could be constructed in 72 WD. The difference is more pronounced if the 19 WD for the similar pile foundations are deducted. This yields durations of 15 WD and 53 WD for the precast and CIP piers respectively. Excluding the pile driving operations a precast pier can be constructed 3.5 times faster than a CIP pier. The schedules for the typical optimized precast and CIP piers is shown in Figure 18.

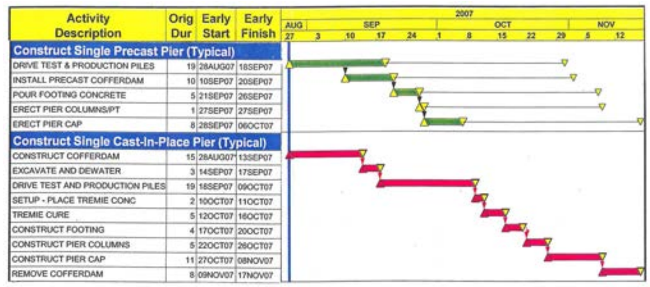

Figure 18. Construction schedules for a typical cast-in-place pier and an optimized precast pier.

The effect of using precast components can also be quantified by comparing the construction duration of five conventional piers to the actual duration of the precast piers. Since the pile driving operations in this illustration take 19 WD and they are the longest duration task, this is the stagger that should be used when considering the overall duration of constructing multiple piers together. Assuming that the contractor could optimize the construction of all five CIP piers, the construction duration would be 148 WD. This is 55 WD longer than the actual westbound precast pier construction duration of 93 WD. If CIP construction had been used, then construction of both the eastbound and westbound structures would have extended into the following calendar year and could have been even further impacted by cold weather. Since the pier construction on this project was on the critical path and the schedule effects are cumulative, it is likely that the contractor would not have been able to beat the baseline construction schedule by two whole construction seasons.

With the implementation of the precast pier system, the contractor was able to begin work on the eastbound superstructure, and the first girders were erected on September 29, 2006 (see Figure 19).

Figure 19. Piers 1EB through 5EB have been completed and the bulb tee girders erected.

This early start on the bridge superstructure allowed the eastbound bridge to be completed on April 10, 2007. Traffic was switched onto the eastbound structure and demolition of the existing bridge superstructure commenced. After the in-water demolition was significantly advanced. Construction on the westbound structure began on August 9, 2007. The westbound piers were then rapidly advanced (see Figure 20). The westbound bridge was opened to traffic on May 7, 2008, and the third and final stage of construction was commenced. Because of the accelerated bridge construction using precast components, the project is approximately 735 calendar days ahead of schedule and is anticipated to be complete in December 2008.

Figure 20. Westbound bridge piers are shown in various stages of completion.

CONCLUSION

The Route 70 over Manasquan River Bridge Replacement Project utilized a precast concrete substructure solution to meet the project needs and facilitate construction of the bridge. The precast concrete components, including the precast pier system, were detailed on the contract plans to allow the contractor and his fabricator to modify the design for maximum economy, which reduced costs to the owner, and the most efficient method of construction could be employed. Over two construction stages, 10 in-water piers were constructed in a total of 189 WD with an average completion rate of approximately 19 WD days per pier. Since this efficient rate of construction was achieved in two separate stages, this type of efficiency can be expected on future projects with multiple in-water piers. As contractors continue to gain experience with precast substructure construction, it is expected that even greater efficiencies will be realized. Once construction of the project is completed, the use of precast substructures will have resulted in a high quality signature bridge being constructed 24 months ahead of schedule.

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