ALL-PRECAST CONSTRUCTION SPEEDS CRITICAL BRIDGE REPLACEMENT PROJECT

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ABSTRACT

In the winter of 2008, the North Carolina Department of Transportation replaced seven aging timber bridges along NC 12 on Ocracoke Island, a remote site on NC's Outer Banks. Due to funding restrictions and low traffic volumes during the winter, it was decided to substantially replace all of the bridges during a single 2 1/2 month road closure. Six of the bridges were replaced with prestressed AASHTO voided slab structures (the seventh structure being replaced with a pipe culvert). To allow construction within this limited time period, the bridges were designed almost entirely of precast concrete components. There was a substantial bonus for early completion, so the contractor, Carolina Bridge Company, Inc., decided to cast the parapets onto the exterior voided slab units at the prestressing plant. This eliminated the field placement and grouting of 234 precast parapet segments, substantially speeding construction. The Ocracoke bridge replacement project was successfully completed 30 days ahead of its demanding schedule.

Keywords: Precast, Prestressed, Bridge, Parapet, Railing, Ocracoke, Voided Slab, Cored Slab, Accelerated Construction, Lightweight Concrete

INTRODUCTION

The Village of Ocracoke is one of the most remote settlements on North Carolina's famous Outer Banks. The only town on its namesake island, this scenic port is situated at the south end of the narrow island, where it was established at a natural harbor which was later deepened by the US Navy during World War II. Interestingly, this harbor once attracted Ocracoke's most infamous resident, pirate Edward Teach (aka Blackbeard). Today it attracts tourists for its fishing, beaches, and the Cape Hatteras National Seashore (Figure 1).

The village is separated by 14 miles (22.5 km) of two-lane NC 12 from the free ferry access to Hatteras Island, its only convenient connection to the mainland. The seven aging timber bridges along this route required replacement, and this presented many challenges to the North Carolina Department of Transportation (NCDOT).

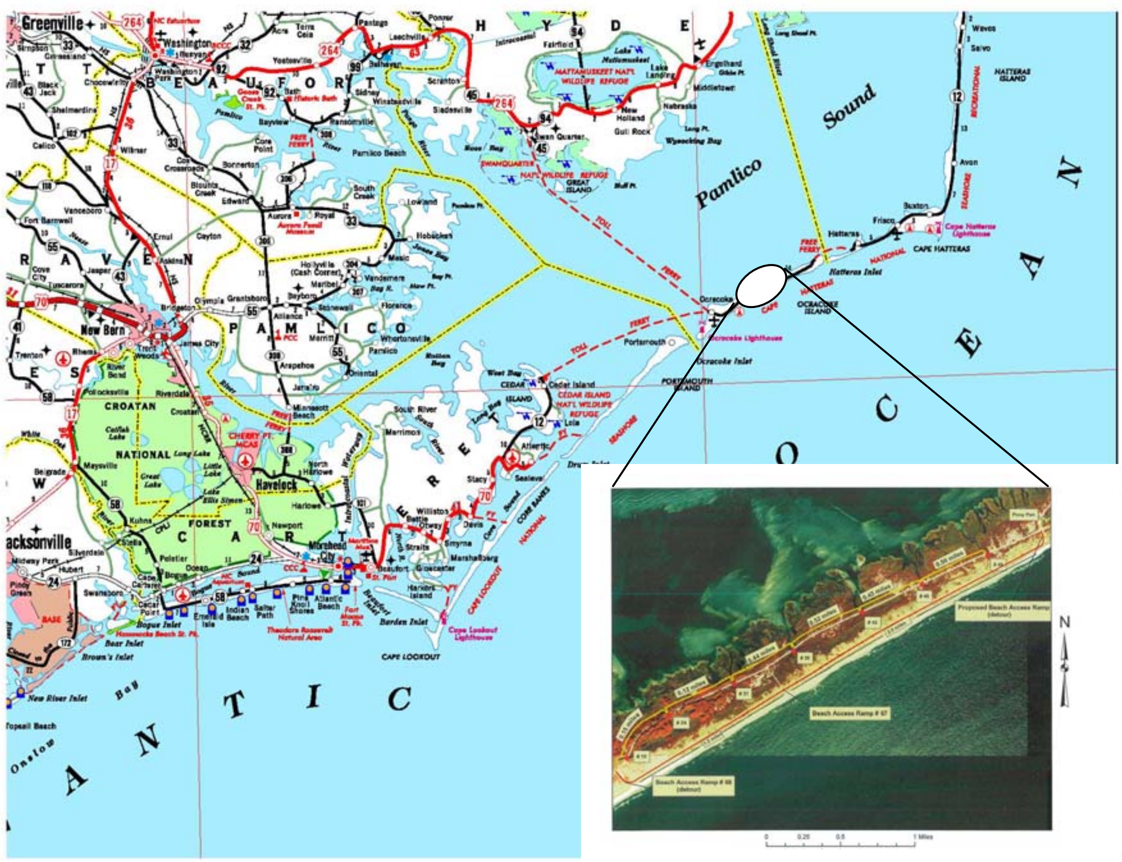

Figure 1: Location map

BACKGROUND

The funding source for the replacement bridges was the North Carolina Moving Ahead program, which stipulated that construction be completed within a specific two-year period. Staged construction was considered in order to maintain a single lane of traffic during construction, but the geometry of the existing bridges precluded this option. Closing even a single lane of traffic during the summer tourist season was highly undesirable as well. After considering many options, and with the input of the local residents and business owners, it was decided to attempt replacing all seven bridges by closing the road completely for a single 10-week period during the winter (the nadir of the tourist season). During the closure a detour along the beach was available for four-wheel drive vehicles only. Other vehicles could access the island via two toll ferries from the mainland, which dock in Ocracoke Village. These ferries have transit times of approximately 2 ½ hours, representing a major inconvenience to islanders and visitors. The National Park Service required that the beach detour be removed by March 15 to avoid disturbance of sea turtles during egg-laying season, further restricting the construction window for this project.

With this short construction period in mind, NCDOT and its design consultants prepared the contract plans for six bridges using all precast concrete components, including piles, pile caps, voided slab span units, and parapets. (The seventh bridge was replaced with a pipe culvert). The precast bridge components were to be installed on-site and connected by grouting. Aside from the rapid construction possible with precast components, the corrosion resistance of plant-produced high strength concrete was another advantage of the chosen system, as compared to structural steel or cast-in-place concrete. All of the streams crossed by these bridges are brackish tidal creeks, and present a corrosive environment. For this reason, the plans and special provisions required the inclusion of silica fume (for decreased permeability) and calcium nitrite (a corrosion-inhibitor) in the precast concrete. For repetition in design and fabrication, all six of the proposed bridges were designed using combinations of 35’ (10.66 m) and 50’ (15.24m) spans.

The construction schedule was also set up in a manner to minimize the duration of the roadway closure. Although closure of the roadway was not permitted until January 2, 2008, the construction contract was awarded to Carolina Bridge Company on July 17, 2007 to facilitate early fabrication of the many precast members required for the project. Staging of materials and equipment to the island began in early November, 2007 and pile driving through the existing roadways was done in advance of the roadway closure. In this manner, 29% of all piling for the project was in place before closure of NC 12, enabling crews to immediately begin installing pile caps. The schedule also called for the roadway to be re-opened prior to the installation of incidental items such as the asphalt wearing surfaces and metal pedestrian/bicycle railing. These items were to be installed under temporary lane closures. Finally, substantial financial incentives/disincentives were provided for opening the roadway on schedule (“Intermediate Contract Time No. 1” in the contract). These consisted of a $10,000 per day incentive for early completion (limited to $100,000), $10,000 per day penalty for late completion, and a $250,000 lump sum bonus for meeting or beating the schedule.

DESIGN

Upon award of the contract, Carolina Bridge employed Alpha & Omega Group (A&O) to design a contractor-proposed alternate parapet as a means to reduce construction time. The contract plans specified the parapet as precast sections most of which were 10' (3.05 m) in length. (Figure 2) Each section was to be set in place on a mortar bed, and then connected by grouting to reinforcing steel projecting from the slabs. The contractor proposed instead to cast the parapets directly onto the exterior slab units at the precasting plant, after transfer of prestressing force to the units and removal from the forms. By eliminating the handling, grouting, and curing of 234 parapet segments he hoped to ensure completion on or ahead of the required schedule. Other benefits of the alternate parapet design included fewer joints in the parapet, elimination of field connections, better detail at skewed joints, and a more positive bond between the parapet and the voided slab unit. The parapet change was proposed at no additional cost to the State.

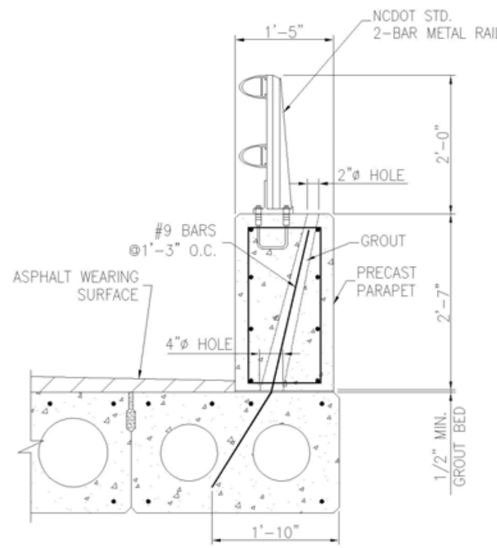

Figure 2: Contract parapet design

After preliminary discussions with NCDOT, A&O abandoned the contractor's original concept of using a standard three-bar metal railing on a shortened parapet, as it did not meet the code vehicle impact requirements (TL-3 Criteria from AASHTO LRFD Code). Several parapet configurations were then considered, (Figure 3) with the goal of minimizing the combined shipping and lifting weight of the 50' (15.24m) exterior slab unit with parapet attached (the heaviest piece to be handled on the project). Options considered included (1) a rectangular parapet with longitudinal circular voids, (2) a concrete post-and-beam parapet with a web wall at the traffic face, and (3) a parapet with a bulb at the top and a tapered outside face. Ultimately a rectangular parapet fabricated from sand lightweight concrete was selected. Compressive strength of the concrete at 28 days (f'c) was 5000 psi (34.5 MPa) and the design unit weight was 120 pcf (1920 kg/m).

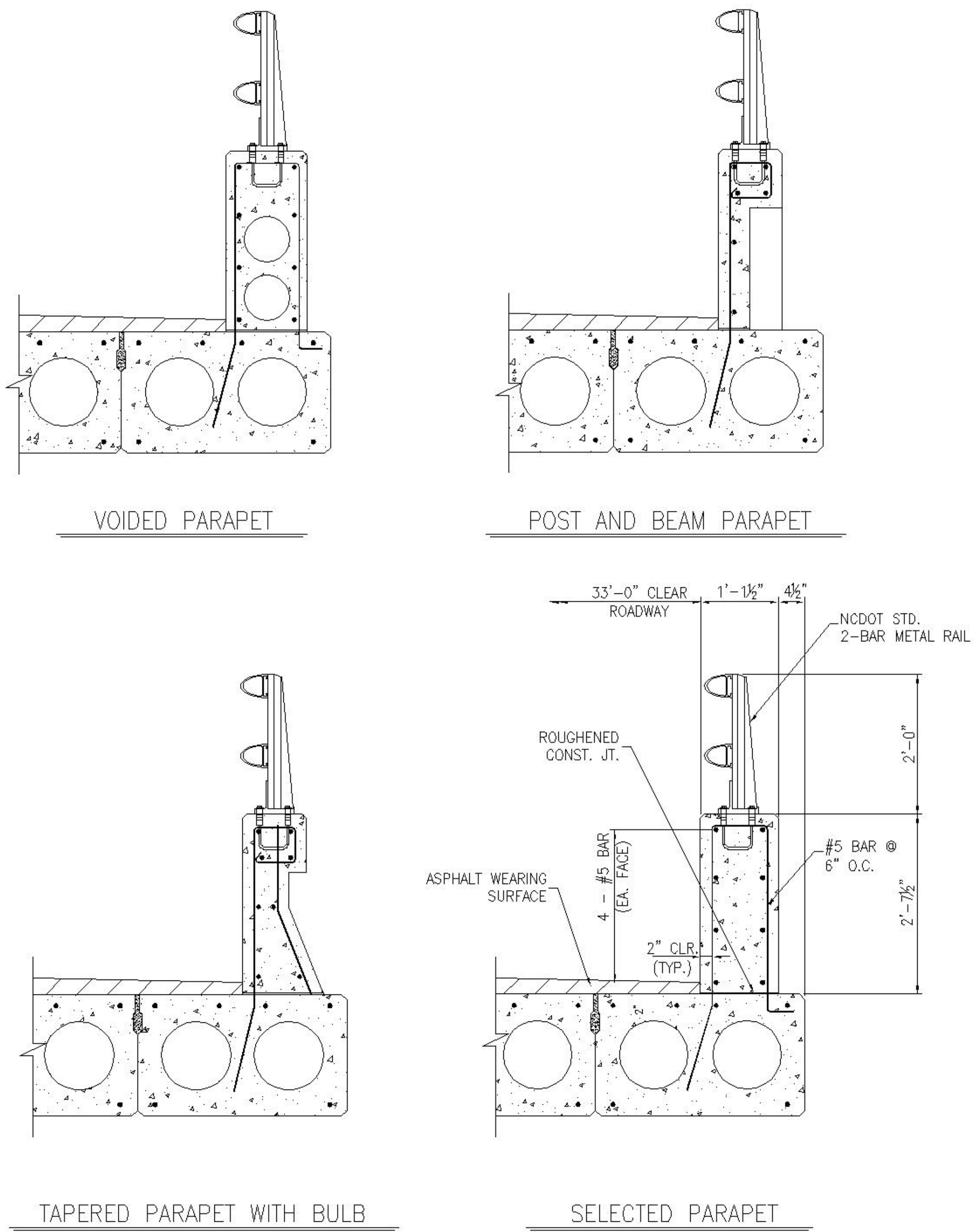

Figure 3: Parapet options considered

From the beginning the Department of Transportation cooperated with the contractor and his engineer, and even encouraged the design modification. Nonetheless, this being a new technique, a thorough review of the proposal was conducted by NCDOT before approval. A&O produced structural calculations and drawings for the parapet, as well as a re-design of the exterior slab unit for NCDOT review.

Parapet thickness and reinforcing were determined using the AASHTO Load Factor Design method. The design transverse loading was a 54,000 lb. (240 kN) horizontal load applied at 24” (610 mm) above the roadway surface (LRFD TL-3 Criteria). Shear force controlled the thickness of the parapet section and a 1’-1 ½” (343 mm) thickness was selected. (Shear strength was one of the few code requirements where the use of lightweight concrete affected the design with a 0.85 reduction factor being applied.) To resist moment at the base of the parapet, #5 vertical reinforcing bars were provided, spaced at 6” (152 mm) on centers along the parapet. The above parapet design was then analyzed using the yield line analysis method from the AASHTO LRFD Code, and found to be adequate.

In addition to structural design of the parapet itself, the exterior prestressed slab section also required a design check. The exterior slab section supported a larger share of the dead load under the alternate parapet design, due to the change in construction sequence. Normally, slab sections are erected and tied together with grouted shear keys and transverse post-tensioning strands before the parapet is installed; the dead load of the parapet is thus distributed to several or all of the slab units in the cross section. However, with the alternate parapet design proposed, the entire parapet weight is applied to the exterior slab unit. The prestressed slab design was checked using this assumption for both the 35’ (10.66 m) and 50’ (15.24m). The analysis indicated that for the 35’ (10.66m) span units the original (contract) design was adequate [13 - ½” (12.70mm) low relaxation strands required.] However, the 50’ (15.24m) span units required the addition of 2 - ½” (12.70mm) low relaxation strands [24 strands in the original design, 26 strands with the alternate parapet] and an increase in concrete strength (f'_c) from 5000 psi (34.5 MPa)to 6000 psi (41.4 MPa).

Another consideration was the camber and deflection of the exterior slab units. Due to the difference in dead loading mentioned above, both Carolina Bridge and A&O were concerned that there would be differential deflection between the exterior and interior units, causing fit-up problems during construction. A secondary concern was long-term differential deflections. In considering these issues, camber and deflection multipliers for the 50’ (15.24m) span were calculated based on “A Rational Method for Estimating Camber and Deflection in Precast Prestressed Members” (PCI Journal, Volume 22, No. 1). It was determined that the differential settlement was tolerable: although the exterior slab had a greater (downward) deflection due to the parapet weight, this deflection was more than compensated for by the increase in (upward) camber due to the additional prestressing force provided. The camber analysis was relatively insensitive to long term effects, since both the deflection and camber were increased by multipliers which were in the same numerical range, effectively cancelling each other out. In the end, the sole concern was that the holes for the transverse posttensioning strand would align properly during erection, so the strand hole diameter was increased slightly on the exterior slab unit to allow for any slight misalignments. Any elevation difference at the top surface of the slab units would be eliminated by the subsequent placement of the asphalt wearing surface. During plant and field fit-up, no alignment problems were noted, and the difference in in-place camber between interior and exterior units was approximately the same as the camber variation between the otherwise identical interior units.

Once the design was substantially complete, it was submitted to the NCDOT Structure Design Unit for approval, along with typical parapet cross section drawings. Upon preliminary approval, the Department submitted the design to the Federal Highway Administration (FHWA) for approval as an equivalent crash-tested rail. The responsible NCDOT resident engineer's office was also consulted, and provided useful comments on constructability of the parapet.

The next task for the designer was to submit a revision to the contract plans. The standard procedure for contractor-proposed alternate designs is to issue revisions to each affected plan sheet. However, revising the approximately 70 sheets necessary would have been both time- and cost-prohibitive. NCDOT agreed to accept instead two new plan sheets per bridge (12 sheets total) detailing the revised parapet and voided slab strand patterns. The contractor's engineer produced these plan sheets and they were issued to all plan holders. Upon completion of the project, the resident engineer will produce "as-built" plans, with notes added to affected sheets, directing the reader to the supplemental drawings.

NCDOT's normal practice is to review shop drawings "in-house," whether the project was designed by NCDOT or by a consultant. However, due to the short time available for review Carolina Bridge agreed to have A&O review the shop drawings, at the contractor's expense, concurrently with NCDOT. During the review, communications between the Structure Design Unit of NCDOT, A&O, Carolina Bridge, and the fabricator were informal and frequent, keeping all parties up-to-date with the plan modifications which were occurring frequently.

CONSTRUCTION

The 240 voided slab units, as well as over 200 - 12" (305 mm) and 16" (407 mm) square prestressed piles, were fabricated by Bayshore Concrete Products Corporation at Chesapeake, VA. Precast reinforced bent caps were fabricated by Florence Concrete Products, Inc., Florence, SC. After the slab units were cast using conventional methods, the exterior units were moved to an unused casting bed for placing of the parapets. Parapet forms were supported independently of the slab unit. In this way, the forms would remain level even as the slab deflected due to the weight of the plastic concrete, ensuring a straight finished product. Mock erection and match-marking of each span is standard practice (Figure 4), but in this case two spans at a time were erected in sequence to further check the parapet alignment between spans. The contractor made several trips to the prestressing plant during fabrication to inspect the quality and alignment of the parapets.

Figure 4: Mock erection at prestressing plant

Meanwhile, construction was well underway at the project site, proceeding from north to south. Once the roadway was closed on January 2, the pile driving crew could work uninterrupted. Following closely behind, a second crew installed precast caps on the piles (Figure 5). Frequently, the two crews were working simultaneously on a single bridge, and both crews used the existing timber structures as a working platform (Figure 6). As conditions (primarily temperature) permitted, a third crew followed, mixing and pumping the grout to permanently connect the piles and caps. Once this grout had cured and the remaining timber structure was removed, the superstructure slab units were installed span by span (Figure 7).

Figure 5: Precast cap segment being placed between sections of existing deck.

Figure 6: Substructure cap segments being placed by crane in foreground while piles are driven on the same bridge (background).

Figure 7: Field erection of precast slab and parapet.

As each span was placed, the crane moved out onto the new span to place the units for the next span. In this way, each structure was constructed "top down" as required by the contract documents. Finally, the slab units were posttensioned transversely and shear keys were cast between the slab units to lock the units together permanently. At this point, the bridges were substantially complete and suitable for traffic under temporary conditions (Figure 8).

Figure 8. All precast sections in place, bridge ready for traffic.

CONCLUSION

The six bridges and one pipe culvert were installed and ready for traffic by February 15, 2008 and Carolina Bridge was credited with completion of Intermediate Contract Time No. 1 thirty days ahead of schedule. Thus the contractor earned the maximum bonus plus incentive payment of $350,000. Since the project was ahead of schedule, NCDOT elected to have the contractor perform paving and metal rail installation before opening the road. This allowed the remaining work to proceed more quickly and safely and provided a smoother roadway upon opening of the road. Even with this additional work, NC 12 was reopened and the beach detour discontinued on March 5, 2008, ten days ahead of schedule. Shoulder construction, guardrail, and a final 1” (25mm) lift of asphalt surfacing were then installed under temporary lane closures, completing the project.

In a progress report, Pablo Hernandez, Assistant Resident Engineer for the NCDOT summed up the project this way: “Overall the progress and quality of work to date is outstanding. To remove six bridges and replace them with concrete structures, along with a twin culvert, in approximately 6 weeks is a remarkable accomplishment.” The dedication and cooperation of the entire project team resulted in a “win-win” situation on this unique bridge replacement project.

PROJECT CREDITS

Owner: North Carolina Department of Transportation
Designer: Mulkey Engineers & Consultants / Simpson Engineers & Associates
Contractor: Carolina Bridge Company, Inc.
Alternate Parapet Design: Alpha & Omega Group, Inc.
Voided Slab and Pile Fabrication: Bayshore Concrete Products Corporation
Precast Cap Fabrication: Florence Concrete Product