FULL DEPTH PRECAST POST-TENSIONED DECK SLABS FOR A BRIDGE OVER SMITHWICK CREEK IN MARTIN COUNTY, NORTH CAROLINA

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ABSTRACT

This paper discusses the planning, design, and construction of a full depth precast deck panel bridge in Martin County, North Carolina. The paper traces the evolution of the project from its initial planning stage, examining the reasons behind choosing this unique superstructure type, through the design and fabrication of the panels, and finally the placement and finishing of the superstructure. Photographs documenting all phases of construction are presented, and the cost of this structure type is compared a more conventional bridge type of the same length.

The most vital engineering feature of this bridge is the design and the facilitating of the post-tensioning and grouting operation. The paper discusses the design and detailing challenges of the slabs and fully documents the post-tensioning operation. Finally, the paper scrutinizes the design and detailing choices made, with a special emphasis on constructability and durability concerns. The paper also highlights some lessons learned and discusses how this type of structure fits into the Department's future plans for accelerated construction projects.

Keywords:
Precast, Post-tensioned, Deck panels, Grouting, Composite, Accelerated construction

Bridge Replacement projects are increasingly a large part of North Carolina's overall transportation program. North Carolina has over 13,000 bridges to maintain -- the third highest number of bridges on the state's system, topped only by Texas and California. As with many other states facing high growth, replacing these structures as they age has proven to be a difficult balancing act between cost, safety and inconvenience to the traveling public. The ability to replace bridges quickly and efficiently has never been more important, as many of our structures are facing the end of their service life just as the state's roads are as heavily used as ever. In addition, as recently as a generation ago, considerations such as right of way costs, in-stream moratoriums, effects of 'Supertruck' loads, safety and traveler convenience were of a much smaller scale. Today, these issues combined with an increase in the amount of car and truck traffic has made the choice of bridge types and traffic control options critical to the success of a project.

To address this need, NCDOT has committed itself to finding innovative ways of solving these issues. Over the last several years NCDOT has used the FHWA's Innovative Bridge Research and Construction (IBRC) program to develop new details and strategies for bridge replacement projects. This program provides Federal funds to demonstrate the efficacy of innovative materials or accelerated construction techniques. This project was chosen to be NCDOT's entry for the 2005 program, for which the state received $400,000 from FHWA.

This project utilized full depth precast post-tensioned deck panels on steel plate girders to span Smithwick Creek. This technique provides another "tool in the toolbox," for accelerated construction options for NCDOT's planning and design engineers.

Project Description

The project chosen for this new bridge type was a bridge replacement just south of Williamston on the central east coast of North Carolina. The bridge is located on Secondary Road SR 1523 over Smithwick Creek in Martin County. The location has a current year ADT of 500 and a design year (2025) Average Daily Traffic (ADT) of 900. The detour for the project is approximately 3.2 miles. The bridge will carry two 11-foot lanes with 3-foot shoulders for a clear roadway width of 28 feet [Fig. 1]. The length of the single span bridge is 90'-3", and it is skewed 15 degrees.

The original plan for this structure was a 33" precast prestressed box beam with a concrete overlay. The bridge was to be constructed from the bank so that no temporary work bridges or other falsework would be placed in the stream.

While this site was not an ideal location to fully utilize the benefits of this bridge type, it was chosen for several reasons. First is that with the low traffic count, any possible delays or poor quality issues would have relatively low impact on the traveling public. Secondly, the location of the structure is reasonably close to the design office, making it easier to monitor the progress and to troubleshoot construction problems. These reasons, along with a project schedule that fit IBRC requirements, made this site a suitable location for a trial project.

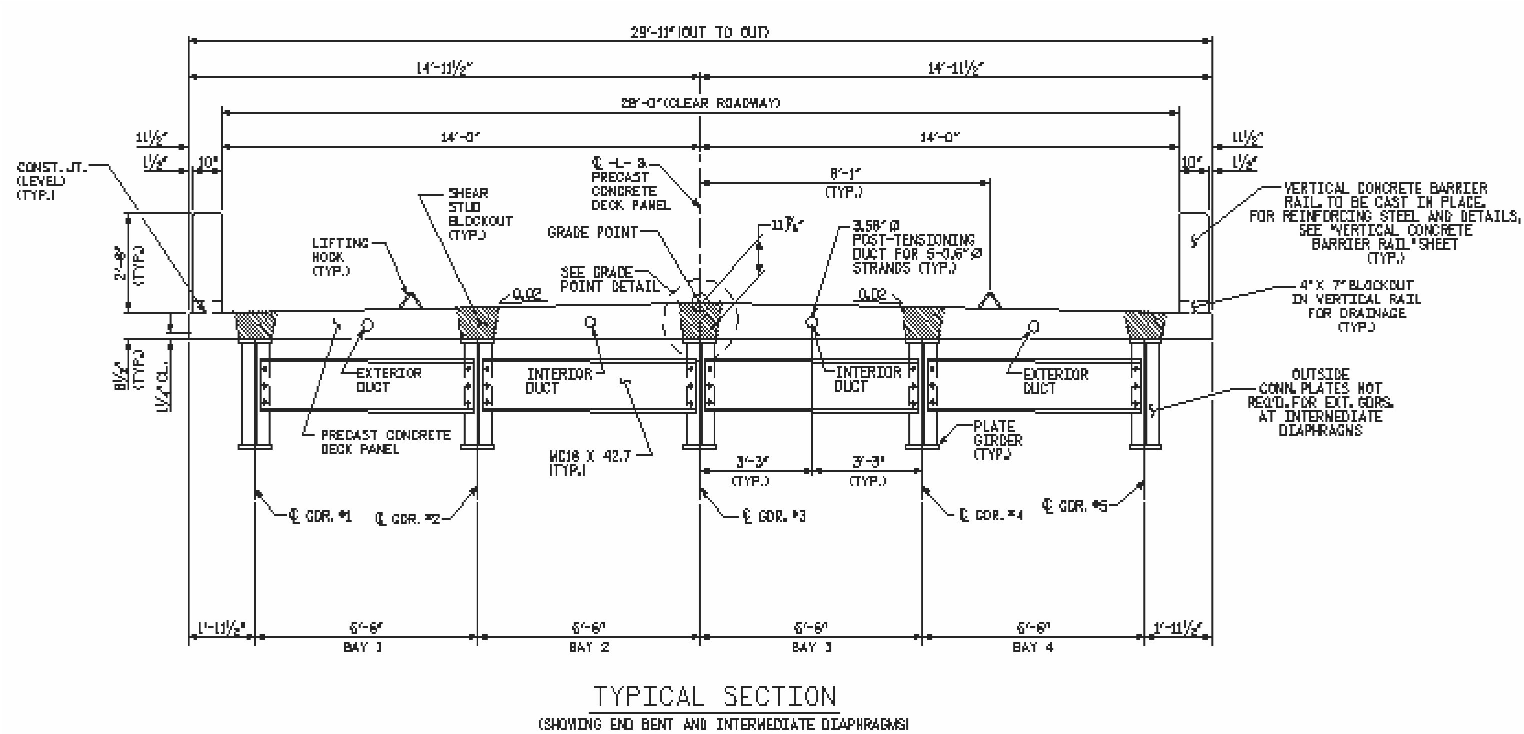

Figure 1 --Bridge Typical Section

Design and Detailing

The first decision facing the Design team of Emily Murray, PE and Madonna Rorie, PE was the number and size of the panels and supporting beams. Steel plate girders were chosen as supporting elements to keep the structure depth to a minimum and because the field-applied deck connectors could be easily attached. Since the out-to-out bridge width was only 29'-11", the panels could easily be made full-width [Fig. 2]. The designers chose a panel length of 8' to facilitate shipping and placement, meaning there would be a total of 11 panels. Since there was a normal crown on the bridge, the panels were designed to be a minimum thickness of 8 1/2" at the outside edges, increasing to 11 7/8" at the center. The bridge had a constant longitudinal roadway grade of 0.3 %, so the panels were designed to be completely flat on the bottom and to rest directly on the girder top flange.

The panels included a transverse grout-filled shear key [Fig. 4] between adjacent panels, which were also longitudinally post-tensioned. The amount of post-tensioning was initially determined to be similar to what is detailed for our common prestressed voided slabs. Early in the design process, 4 ducts each with 4 – 0.5" strands per duct were detailed. The ducts were 1" x 3" oval plastic ducts with a flat anchorage. This duct size could also accommodate 3- 0.6" strands in lieu of 4-0.5", and were determined to be commercially available.

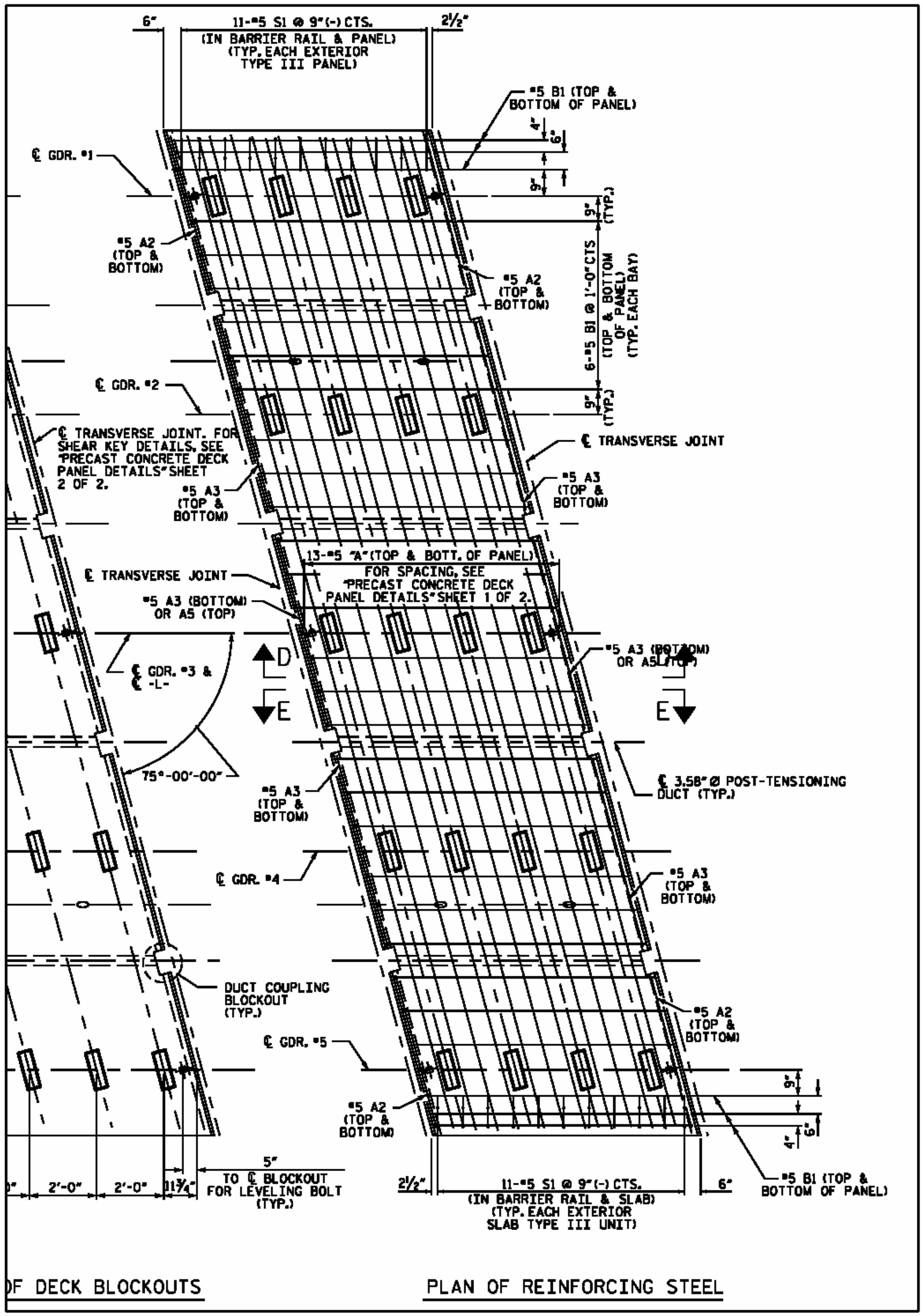

Figure 2 –Panel Reinforcing and Post-Tensioning duct layout

For a project with this many precast pieces and grouted joints, rideability was a concern. A common bridge type in North Carolina for small stream crossings is precast prestressed voided slab units post tensioned together and topped with a minimum 2” thick asphalt wearing surface. Based on some of the state’s previous IBRC experiences with precast units and accelerated construction, the design and construction engineers felt confident that the precast units could be fitted together with enough precision that no overlay would be needed. Instead, the panels were constructed with an extra ½” of cover. The specifications would require a minimum of ¼” to a maximum of ½” to be ground off in the field.

Figure 3 -- Panel resting directly on Leveling bolts and girder top flange

Reinforcement for the panels were based on two criteria: the stresses due to dead and live loads from AASHTO, similar to the procedure used for cast-in-place decks, and stresses induced by fabrication, shipping and final placement. For simplicity and ease of construction, the designers preferred to reinforce the slabs using mild reinforcing steel rather than prestressing steel, and the combination of a narrow panel width and careful location of the slab lifting loops enabled the designers to accomplish this. The required 28 day concrete strength of the panel was determined to be 6500 psi.

Each panel is designed to be supported on six 1-in diameter leveling bolts, which allow for easy raising and lowering of the panel for improved vertical alignment. The panels are supported by the bolts until all post-tensioning is completed [Fig.3]. To make the girders composite with the panels, shear studs were field welded to the girder top flange through a full-depth blockout in the panel, which was subsequently grouted. The number and spacing of the shear studs were determined using current American

Association for State Highway Transportation Officials (AASHTO) Standard Specification equations for cast-in-place slabs; no special considerations were given to the fact that the panels were precast and post-tensioned. To increase the spacing of the studs and the stud blockouts, the size of the studs were increased from the standard 0.75-in diameter x 4-in stud to a 1-in x 6-in stud. The shear stud blockout was made larger at the deck surface than the girder surface to provide as much room as possible to the shear stud gun, and the designers contacted stud gun manufacturers to make sure the clearances would work.

For the numerous joints and blockouts in the finished deck, we chose to use a combination of cementitious grout and concrete. For the transverse joints and small blockouts such as for the leveling bolts, lifting devices and anchor hardware, standard non-shrink, non-chloride grout was specified. For the large blockouts for shear studs and the duct couplings, we felt that class AA concrete (4500 psi 28 day strength) with coarse aggregate gradation of 78m would prove to be stronger and more durable.

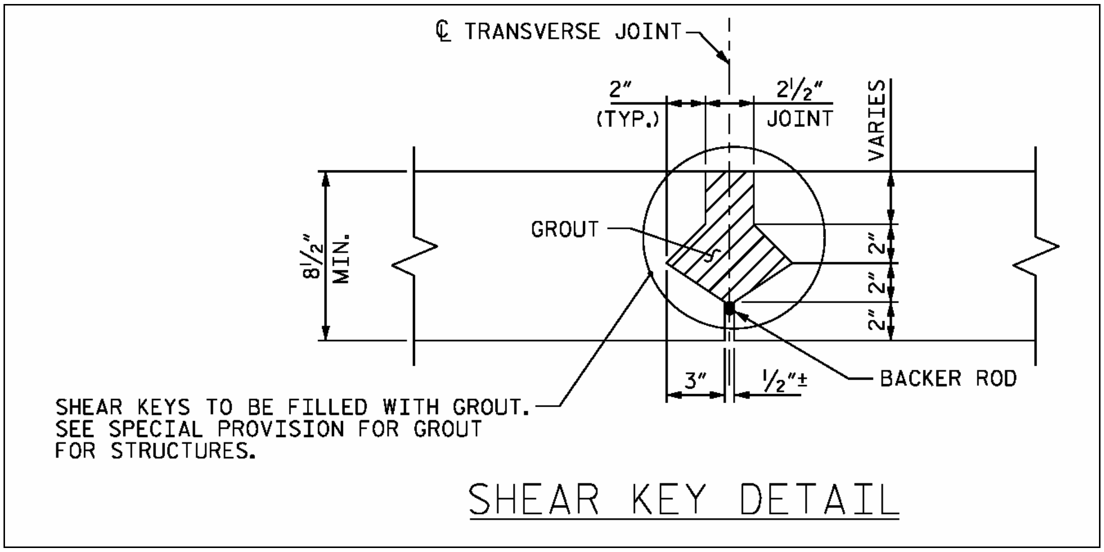

Figure 4—Transverse Shear Key Detail

Feedback from industry

Once the panel dimensions and sizes were set, we solicited feedback from several sources outside NCDOT: Gary Pueschel of DSI America and Rodney Money, PE of TY Lin. As DSI Eastern Sales Manager, Gary was able to give us valuable information on post-tensioning hardware and operations. Rodney Money had design experience on a similar project of a larger scale on the 16th street bridge in Cabell County, West Virginia.

An early design decision that Gary helped us with concerned the grouting of the post tensioning. Although NCDOT has used grouted post-tensioning on several large bridge projects, there was some discussion on the merits of grouting the post-tensioning for a small project. Some felt that grouting the post-tensioning (P/T) ducts would make inspection difficult and would eliminate the possibility of replacing corroded strands or adding future strands. Discussion with Gary and some of the NCDOT Bridge

Maintenance engineers helped the design team conclude that properly grouted strands provided the most superior corrosion protection, and that future post-tensioning operations performed by maintenance personnel would be impractical.

Gary and Rodney directed us to information key to detailing the panel so that there were adequate clearances for the ductwork, grout caps, and other assorted hardware associated with the grouting and post-tensioning procedures. We used information provided by DYWIDAG catalogs (and others) to ensure the panels were provided with the proper clearances and reinforcing for ductwork.

For feedback on panel fabrication, we solicited help from our local Georgia/Carolinas Precast Prestressed Concrete Institute (G/C PCI) chapter, with whom NCDOT engineers regularly meet. With the help of that committee we were able to transmit some proposed details of the precast panels. The G/C PCI members were helpful in critiquing all aspects of the panel design and details, and were able to give us specific comments on the most economic details.

Coordination with G/C PCI and with Gary led us to change our duct and strand detailing. As a direct result of experiences from constructing Charleston South Carolina's massive Cooper River bridge, both Gary and Richard Potts of Standard Concrete convinced us to use a standard round duct in lieu of the 1-in x 3-in flat oval duct we originally detailed. Although the flat duct would seem ideal for use in thin slabs, both men reported that contractors had experienced difficulty threading the strands through the flat duct. Several references also encouraged us to increase the amount of post-tensioning in the slabs to the PCI recommended value of about 200 psi across the joint. The final plans called for a total of 20 -- 0.6-in post-tensioning strands (5 strands per duct).

Specifications and Provisions

North Carolina's previous experience with grouting and post-tensioning operations taught us the importance of good specifications to the success of a project. While we had used one particular in-house specification successfully on other projects, we were aware that there has been a national debate on proper grout types and procedures, and we wanted to ensure that we used the most current specification. For this, we found that the FHWA's "Post-Tensioning Tendon Installation and Grouting Manual" [http://www.fhwa.dot.gov/BRIDGE/pt/pttoc.cfm] was an invaluable resource, and careful attention was given to updating our specification to the latest recommendations. Perhaps the most important items stressed on the FHWA site were specifying the correct grout for the post-tensioning strands and to grout as soon as practical (within 15 calendar days) of placing the strands. The grout was required to be a pre-packaged product "specifically formulated for grouting highly stressed steel."

Specifications for the precast slab units were another important component of the project and draft copies were provided to the G/C PCI members for comments. To ensure the panels would be fabricated to the highest possible quality, the specifications required that the panels be fabricated at a B4 certified plant. Allowable tolerances were also tightened up, especially for the location of the ducts, which were allowed to be located no more than ¼” from the plan dimension in any direction. Once fully fabricated, the panels were required to be assembled in the yard and match marked. The ductwork was required to be ‘proven’ by aligning the ducts and sending a torpedo through the length of the ducts.

Figure 5 -- Panel and blockout formwork during fabrication

Project let to contract

This project was scheduled to be let on August 15, 2006. To alleviate contractor concerns with the unusual nature of the project, the Department held a mandatory pre-bid meeting for all potential bidders on August 8, 2006 at the Resident Engineer’s office in Williamston, NC. It was hoped that the meeting would serve two purposes: First, it would give the potential bidders a chance to ask questions about the project to reduce uncertainty and increase the number of competitive bids. Second, it would give the designers some feedback on aspects of the plans and specifications that may be incorrect or unclear, so that the contract documents could be corrected prior to letting.

The pre-bid conference was a success, with nine contractors attending and eight ultimately bidding on the project. Atwell Construction won the contract with a winning bid of $710,973.77, which corresponded to a $153.80 per sq ft cost. This is about 55% higher than our average cost of $99 per sq ft. One of the strategies for this IBRC project was to work out some of the design, fabrication and construction issues on a structure whose schedule was not particularly critical, so while the project’s schedule was shortened, it was not accelerated nearly as aggressively as it could have been.

Figure 6 -- Finished panel waiting to be shipped

Fabrication

Standard Concrete Products (SCP) of Savannah, Georgia were contracted to fabricate the full-depth precast panels. Due to the skew and unique dimensions of the panels, the formwork was custom made [Fig 5]. As SCP prepared to submit their working drawings, a problem with clearances was discovered. The location of the two exterior P/T ducts were in a relatively thin section of the slab, due to the normal crown of the top surface. The anchorage and anchorage plates to be used were too large to maintain proper clearances at the height shown in the plans. This came as a surprise to our detailers, who had actually used dimensions from DYWIDAG's own catalogue to ensure that clearances would be sufficient. When we forwarded this information to DYWIDAG, they explained the problem—we had been referencing a catalog that included post-tensioning hardware not available in North America. For the internal ducts we were able to choose a suitable anchorage system with minor modifications to the panel reinforcing and duct location. For the two external ducts, to maintain the panel fabrication schedule it was decided to request DSI America to custom-design and fabricate the anchorage plates. DSI America was able to achieve that quickly with minimal extra cost to the department. From that point on, fabrication of the panels proceeded without incident and in accordance with the schedule [Fig.6].

Figure 7 -- Panel placement

Bridge Construction

Since the structure was a single span bridge, the construction of the end bents and the placement of the plate girders was accomplished similar to a standard cast-in-place decked bridge. Due to depth constraints, 33-in deep plate girders were used in lieu of rolled beams, as the plate girder could be optimized to allow for a more shallow girder than would have been practical for a rolled beam.

The panels were delivered to the site early May 2 –3, 2007 [Fig.7]. Each panel was delivered one truck at a time, three the first day and eight the next day. The panels, each weighing 30 kips, were placed from the stream banks behind the end bents.

Placement of the panels revealed several design and detailing issues. Many bridges of this type utilize a ½-in to 1-in grout bed on the girder to help support the panels and to account for construction and girder camber tolerances. The slight skew, short span and the ability to control the camber of the plate girders encouraged the designers to set the panels directly on the girder top flange. It was thought that this would speed construction and simplify the panel placement. To reduce friction between the flange and panel during tensioning, we gave the contractor the option to use roofing felt on the top flange.

The placement of the panels exposed a problem, however: at certain spots, especially near the middle of the girders, a space of ¾-in to 1-in was clearly visible at the shear stud blockout between the flange and the bottom of the panel. At other places, especially at the ends, the panels did rest tightly against the top flange. The temporary leveling bolts were lowered as much as possible, but there was concern that some crushing of the transverse joints might occur, since the transverse joints were extremely tight-fitting [Fig. 8] and there was concern that there might be some binding of the joints while individual panels were lowered. In addition, the shear stud blockouts were at some places slightly out of line relative to the top flange of the girder, due to slight horizontal girder misplacement. This left small, approximately 1 square inch blockout areas that extended beyond the top flange.

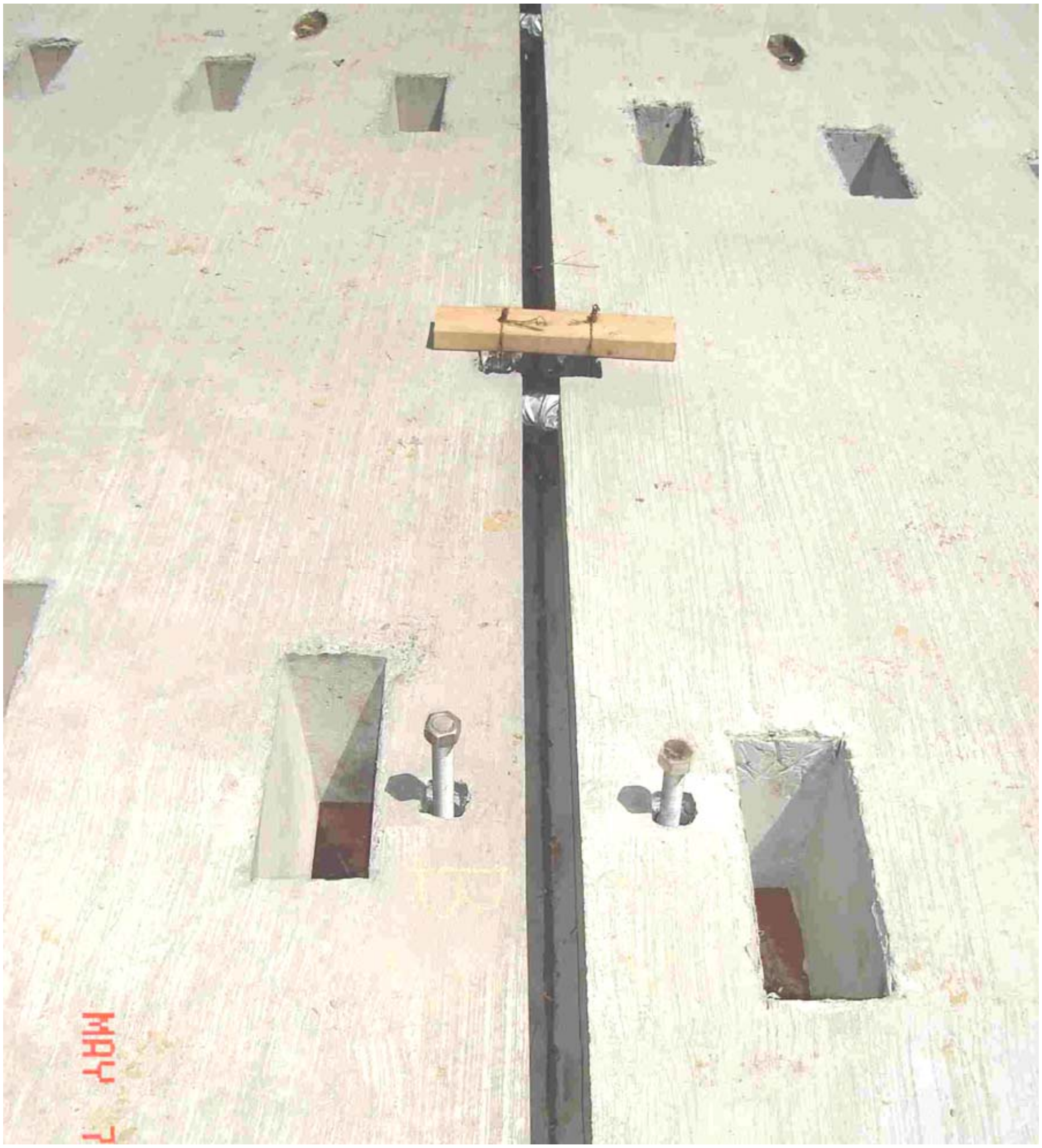

Figure 8 -- Transverse joint in panel ready to be grouted. The wooden block is helping to support the duct coupling.

The design office, along with the bridge construction engineer, agreed on a small modification to the plans. Instead of installing the shear studs and filling the entire blockout with class AA concrete, it was decided to install ½-in wide styrofoam into the space between the flange and the panel, to serve as grout “formwork”. The contractor would then add a 1 ½-in to 2-in lift of high strength grout, wait until it hardened, and then fill the rest of the space with the class AA concrete. This work would be performed after grouting and post-tensioning and before placing the shear studs.

Figure 9 -- Once the transverse joints are grouted, the panels will be ready for tensioning

Grouting and Post-tensioning

Prior to any grouting of the blockouts, the transverse joints needed to be grouted and the panels post-tensioned together [Fig.9]. Epoxy was applied to the face of all the transverse joints, and the joints were grouted using a bucket and a trowel. Once the grout in the joints reached a strength of 1000 psi, post-tensioning could begin [Fig 10].

Grouting operations started immediately after tensioning, on May 17th, which exposed a problem with our specification. Our specification required a flow cone test, in which grout is placed into a funnel of a specific size and shape, and the rate at which the grout flows out is measured with a stopwatch. It is a very important test for grouted post-tensioning, since it ensures the grout will be able to flow easily through the entire length of the duct. This test had been used on several NC projects prior to this, and the specification stated that department personnel would run the test. However, as the grouting procedure was about to start, the Department’s flow cone could not be found, and some of the construction personnel were told not to bother with the test. The construction engineers were concerned that holding up the grouting subcontractor to locate a flow cone would result in a costly claim. Discussions with the grouting subcontractor revealed that he normally performs his own flow cone test, and that if he had known he would have brought his own.

The night before grouting was to begin, the department's only flow cone was located at a Division office 100 miles away, and DOT personnel were able to bring it to the jobsite about 45 minutes before grouting was to begin. The grout easily passed the flow cone test on the first attempt, and the project was able to immediately proceed. The pump was attached to the end of the duct, and it took about 15 minutes for the grout to flow the entire length.

Figure 10 – The Portable jack can easily pull all five 0.6" strands

The rest of the project proceeded without much incident. After the grouting and post-tensioning, the 48 rows of shear studs were installed in rows of three, for a total of 144 studs per girder. Styrofoam was installed between the flange and the panel, and both the cementitious lift of grout and the class AA concrete were placed. The duct coupling blockouts, the anchor hardware blockouts and the lifting hardware blockouts were grouted. Once the Class AA concrete in the shear stud blockouts reached 3000 psi, the leveling bolts were removed and leveling bolt blockouts grouted.

Once all the grouting was completed, the vertical concrete barrier rails were slip-formed, and the approach slab was cast. At the joints between the approach slab and the first panel an armored evazote joint with elastomeric concrete was placed. The final step in the bridge construction after the approach roadway work was completed was the grinding of ½-in of the deck and approach slab.

The bridge was opened to traffic on June 6^{th}, 2007 [Fig.11] .

CONCLUSIONS

NCDOT learned several important lessons during the design and construction of this bridge, lessons that will help us whenever the construction schedule is more sensitive and critical. Any critical analysis of the project must look not only to what we did wrong, but also what we did right, and there were several decisions we made that had positive impacts to the projects. First and foremost, we enlisted the aid of the precasters who would most likely be manufacturing the panels. The panels are necessarily customized and must be fabricated to tight tolerances, and by requesting assistance from the producers we were able to minimize fabrication problems. By familiarizing the fabricators with the project during the design stage, we were able to take away some of the mystery of the project, which ensured that we would get the best possible price.

Similarly, the prebid meeting and a preconstruction meeting we held prior to panel placement was beneficial in both obtaining the best possible price and with avoiding construction issues.

Regarding the details and specifications of the panels and the grouting and P/T procedures, the leveling bolts performed well for panel positioning, and were easy to remove and patch. The specified fabrication tolerances of the panels and the panel hardware were tight but achievable, and the manufactured panels fit together very well. The decision to place the panels on a skew, rather than making them normal to the centerline and trapezoidal at the ends, was a good one for production, handling and economy. Finally, with so many transverse joints and grouted pockets on the riding surface, grinding off ¼-in was an important step to provide a suitably continuous riding surface that was still rough enough to provide good traction and skid resistance.

Of the things that would be done differently, we would probably detail the girder with a grout bed for the panel, or tighten up the specification's required camber tolerances and inspection for steel girders. Also, some of the designers later expressed concern over the details for the shear stud pockets, which showed sheer-sided stud blockouts. There is some concern that when grouted and subjected to numerous traffic cycles, the grout pocket could slip at the blockout/panel interface. For these and other blockouts, some type of mechanical bond (such as a shear key or sawtooth pattern) would provide added resistance at that interface.

For grouting the blockouts, we will revisit the decision to use Class AA concrete for future projects. The concrete was more difficult to work with and took longer to set up. Future visits will give us an indication of the durability of the Class AA concrete patch versus the cementitious grout used in the joints.

For grouting the P/T ducts, the specifications would be modified to state that the grout would be flow tested prior to pumping each duct, instead of testing every 1.5 cubic meters of grout or for every 2 hours of grouting operations. We would also revise the specification to require the grouting contractor to provide his own flow cone and to perform the test under the supervision of Department personnel. Also, given the importance of specialized, limited- supply proprietary hardware to the success of the project, we would take extra care to ensure the availability of specialty hardware.

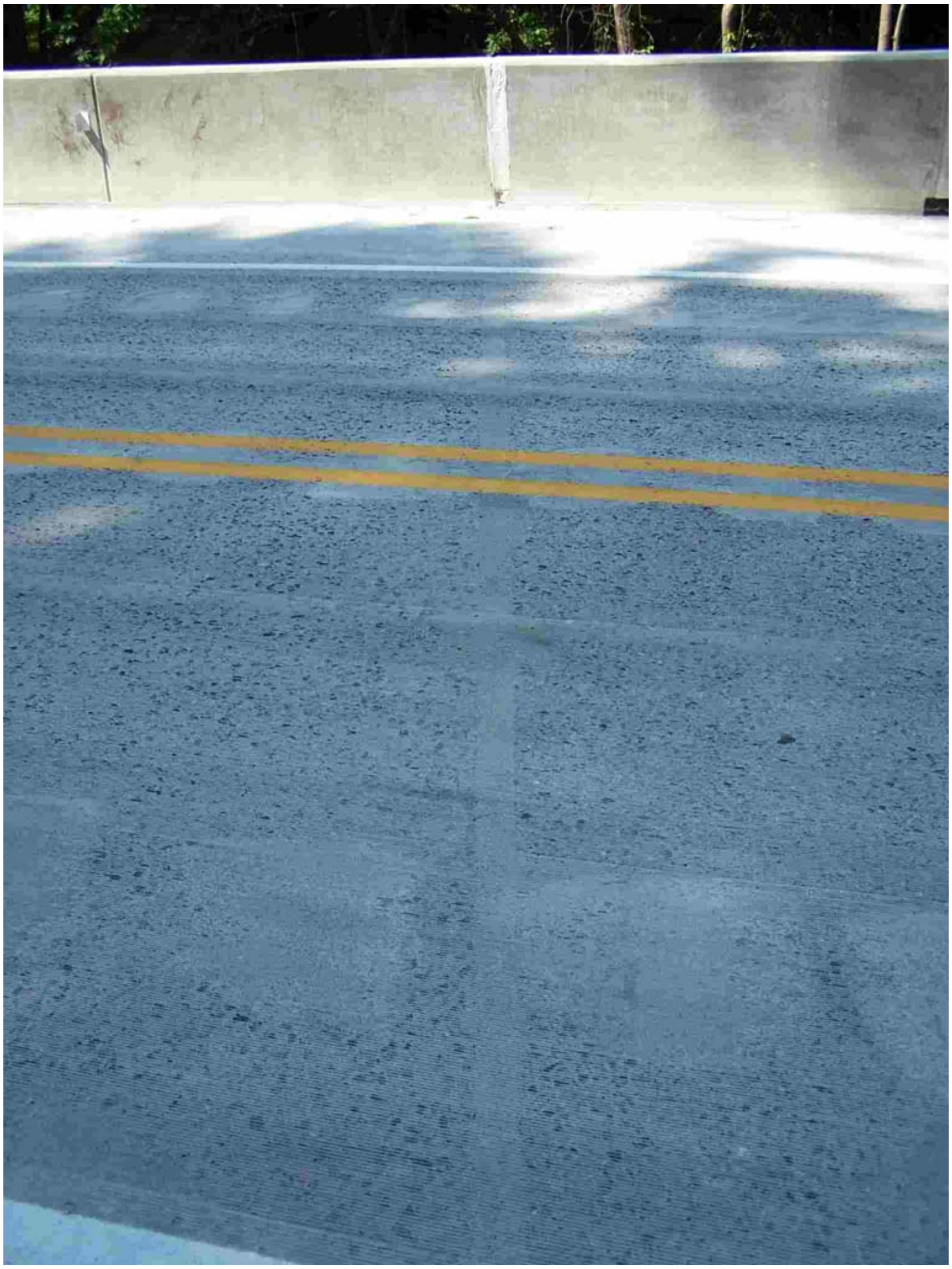

Figure 11 -- Finished deck under traffic. Grinding is completed and grouted areas are only slightly noticeable.

Faster, Faster

This project successfully showed that this type of bridge construction could be built in North Carolina using the contractors, fabricators, suppliers, and department personnel available to us. It has yet to be proven that this can be accomplished under pressure, under an aggressive schedule in a difficult setting. Upon reflection, there are several ways to have made this a faster project:

- *More precast elements* -- Instead of slip forming, the rails could have been precast and either bolted to the deck or even cast monolithically.
- *A+B scheduling* – To achieve the truly accelerated schedule this bridge type promises, some type of incentive/disincentive clauses are needed in the contract.
- *More demanding Delivery requirements*—require certain key elements such as panels, studs, and post-tensioning and grouting equipment to be on hand prior to closing traffic on the existing bridge.

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