THE EVOLUTION OF PRE-CAST SEGMENTAL BRIDGE CONSTRUCTION IN THE STATE OF FLORIDA
Staying on course in our "New Direction"

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ABSTRACT

Over the past eight years, the Florida Department of Transportation (FDOT) has made sweeping changes in the design and construction practices of pre-cast post-tensioned concrete structures. These changes were necessary upon the discovery that many of the post-tensioned structures in the FDOT's inventory had experienced major durability and structural deficiencies in relatively short periods of time.

The DOT requested a comprehensive study be developed to investigate these deficiencies and propose possible solutions. That study was performed by Corven Engineering Inc. and is entitled New Directions for Florida Post-Tensioned Bridges. Among its many findings was the suggested implementation of new procedures and policies for the construction of all post-tensioned, pre-cast structures statewide. The FDOT began implementing these measures on various projects statewide and attempted to build upon their successes.

The evolution of segmental bridge construction in Florida, as a result of the New Directions study, has brought significant cost and time impacts at the construction project level during these early stages. However, there is no doubt that as a result of these changes, a better product is being produced than was ten years ago. Many of these changes were needed additions to a troubled industry within The State of Florida and it is important that they continue to be studied and improved upon as we move forward.

KEYWORDS:

Florida department of transportation, Pre-cast segmental bridge, Post-tensioning tendons, Post-tensioning grout, New directions for Florida post-tensioned bridges, Borescope tendon inspection, Segmental duct couplers,

INTRODUCTION

The State of Florida has a long history in the construction of post-tensioned and specifically segmental box girder bridges. Florida has always been viewed as a nationwide leader in the United States Segmental Bridge Industry. Florida's first experience with segmental bridge construction occurred in the early 1980's with the construction of the Long Key Bridge and Seven Mile Bridge, both located in the Florida Keys. Furthermore, these two projects were the first segmental bridges in the United States erected utilizing the span by span method. Florida remains a leader in segmental bridge construction. Currently there are numerous segmental bridges in service in the state of Florida, nine of which having been built in the last decade. Currently there is one segmental structure under construction, and more in the works. Florida's reputation as a leader in the segmental bridge industry has led many other states and transportation agencies to adopt the Florida Department of Transportation's (FDOT) construction procedures and specifications. For this reason it is important that the ongoing changes that Florida is making are analyzed and continually improved upon to ensure that the standards of quality and durability are met and passed along to other entities seeking guidance.

A TROUBLED INDUSTRY

Pre-cast segmental bridge construction grew in popularity in the FDOT throughout the 1980's. There were several high profile segmental bridges constructed including the Seven Mile Bridge in the Florida Keys, I-595/US 441 Interchange in Ft. Lauderdale and the new Sunshine Skyway Bridge spanning Tampa Bay to name a few. These projects saw very little problems or concerns in the area of maintenance throughout this time period as projects continued to be developed and constructed. The first signs of problems with segmental bridges were seen in 1996 when during routing maintenance inspections, some minor problems were discovered. These problems did not amount to major issues when first discovered and they were deemed to be isolated. The State of Florida began to take notice more intently when a series of major deficiencies were discovered in structures across the state in a relatively short period time. These discoveries, occurring on different projects in different locations in the state, revealed a pattern of durability and safety concerns that began to resonate through the segmental construction industry. The following are examples of the major discoveries that were found during FDOT inspections.

I-595/I-75 Interchange (Broward County, FL)
-Discovery of water leaking through numerous epoxied joints.
-A 300 foot post-tensioned tendon with no grout present.

Niles Channel Bridge (Florida Keys)
-A longitudinal post-tensioned tendon completely failed due to corrosion at one of the anchor locations.

Mid-Bay Bridge (Okaloosa County, FL)
-Failure of 2 post-tensioned tendons due to corrosion of the strand between the anchor locations (Figure 1).

Sunshine Skyway Bridge (Pinellas County, FL)
-Failure of 1 vertical post-tensioned tendon in one of the piers due to corrosion of strand.

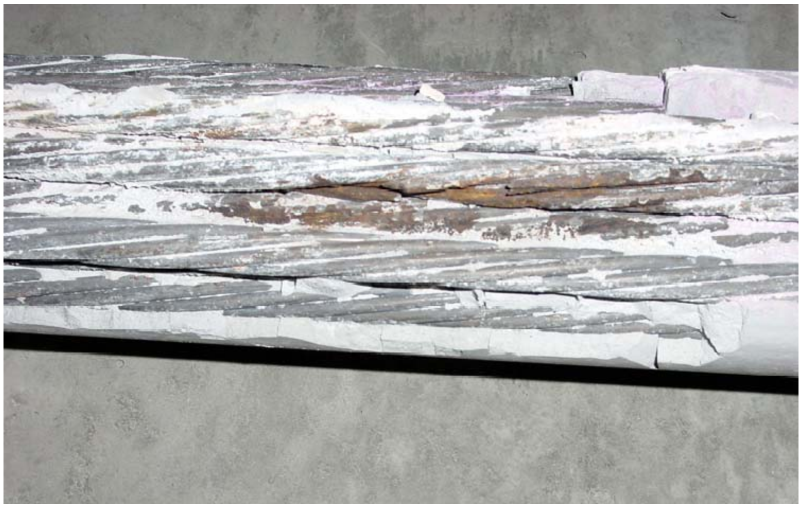

Figure 1 – Corroded post-tensioned tendon, Mid Bay Bridge

Based on the information gathered from these inspections and investigations into these failures, it was determined that there existed systemic problems with these structures. Also, it was determined that these problems were caused, in part, by certain construction practices. The durability and viability of these structures was now in question in response to these serious problems. One of the major advantages to pre-cast segmental construction had been its minimal long term maintenance requirements as compared to other types of structures. However, now facing enormous maintenance problems and potentially catastrophic failures in the bridges support structure, the industry was facing a crisis. It needed to fix the perception that these bridges were a maintenance liability and also ensure that the corrective measures did not make them economically obsolete.

In 1999 the FDOT began to address some of these problems by instituting some new requirements of segmental construction projects. One of the new requirements was requiring the use of manufactured pre-bagged grout in lieu of a standard portland cement and water mixture that had been used up until this point. The manufactured pre-bagged grout is used to alleviate concerns with material quality and consistency that existed with water and cement mixtures. Also the pre-bagged grout was produced with additives that made it more conducive to high pressure tendon grouting. An advantageous property of the manufactured grout material is that in its liquid state, it maintains thixotropic properties. This means that while stationary, the fluid material retains a gel-like consistency. However, when agitated by mixing or pumping through the tendon ducts, the material becomes more flowable and is able to fill all of the annular spaces. This characteristic is very important when injecting into very long tendons with many elevation and curvature changes to ensure the tendons are filled completely.

Another property that the manufactured pre-bagged grout shows is that it has virtually zero bleed water after final set. Bleed water is excess water that is left over, after the grout has hardened, that remains trapped in the encapsulated tendon. If allowed to remain inside the tendon over time there is potential that the water can become corrosive. This could ultimately impact the steel post-tensioned cables inside the duct. Furthermore, the bleed water tends to be more prevalent near the anchor locations which are the most critical parts of the tendon. Bleed water is unfortunately a common characteristic of standard portland cement and water mixtures and is thought to be a contributing factor to the problems existing in the bridges mentioned earlier. The manufactured pre-bagged grout has properties and additives that intend to eliminate bleed water. To ensure this; the FDOT has mandated that every batch of grout mixed for pressure grouting operations has to be tested for bleed water. The test, called the wick induced bleed test, entails filling a graduated cylinder with the mixed grout and inserting a piece of strand in to it while the grout is still fluid. After the grout sets, there should be no excess water remaining in the cylinder. Any water leftover is bleed water.

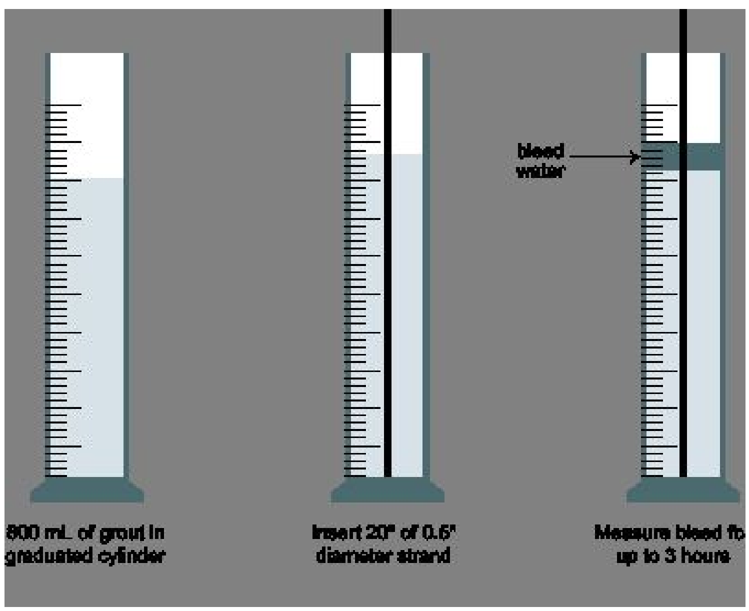

Figure 2 – Wick Induced Bleed Test

Another of the initial steps taken to improve project quality was to institute a preliminary training program for all workers involved with the construction. This requirement was for both the contractors' personnel and the inspection staff. This training program began with a training video produced by the FDOT that showed the basic steps and procedures for properly performing grouting operations. Also, the FDOT worked closely with the American Segmental Bridge Institute (ASBI) to formulate a nationwide grout training certification for workers involved with segmental bridge construction. The ASBI certification is currently the only nationally standardized training course that specifically deals with the grouting of post-tensioned tendons. This certification remains a requirement for contractor and inspection personnel for all FDOT segmental projects. These changes were the first steps in a series of major improvements that the segmental bridge industry was about to face as the need for the industry to evolve was becoming apparent.

FLORIDA'S NEW DIRECTION

In the follow up to the discovery of major durability and quality issues, the Florida Department of Transportation acted quickly to reverse this growing trend surrounding segmental bridge structures. The FDOT commissioned a study to investigate all aspects of segmental bridge technology and to determine the source of the problems discovered during post-construction maintenance inspections. The study's purpose was to examine past practices and also to provide a future pathway to improve the design, construction, and inspection of post-tensioned segmental bridges. In 2002 the study entitled *New Directions for Florida's Post-Tensioned Bridges* was produced by Corven Engineering, Inc. of Tallahassee, FL. This study was an in-depth analysis of all aspects of segmental bridge design, construction and inspection. The goal of this study was to provide a guide to the industry on how to ensure the highest levels of quality for future projects and identify ways to improve the industry. New policies were clearly needed to ensure that pre-cast segmental structures would not become obsolete due to these newly discovered quality concerns. Based on the *New Directions* study, the FDOT began instituting major policy and procedural changes immediately. The changes implemented as a result of the *New Directions* study affect all aspects of the segmental industry including design and construction. The suggestions were to implement redundant corrosion protection measures in constructing segmental bridges to ensure there would not be a repeat of what was seen in the past.

The construction of pre-cast post-tensioned structures was where the major impacts were felt as a result of *New Directions*. Many aspects of segmental bridge construction were changed all with the goal of increasing quality and durability. One of the first steps was changing the FDOT specifications related to segmental bridges and post-tensioning. The new specifications introduced strict requirements on contractor personnel, equipment, materials, procedures and methods. The new specification, specifically for post-tensioned tendon grouting, is very prescriptive in nature. The exact procedures for material testing and grouting are defined in the specification leaving very little room for innovation or contractor nuance. Consequently it also increased costs associated with those aspects of the construction. FDOT's response to *New Direction*s has also affected the post-tensioning suppliers with new, more stringent, requirements for material properties and material testing, eliminating some of the existing standard practices that have been in place previously.

A major goal for all of the changes to the Florida pre-cast segmental industry is to improve the overall quality of structures produced. As was discovered through routine bridge inspections, consistent quality was not being achieved. Consequently there were potentially catastrophic problems exposed. One of the growing fears throughout the implementation stages of this process was the inevitable affect on construction costs. Many of the measures brought about by *New Directions* were completely new to the industry and added significant costs at the outset. One of the main goals for the industry, in partnership with the FDOT, was to continually analyze and provide feedback as the new measures were introduced at the construction project level. The majority of the changes made were necessary and vast improvements on past practices. However, the goal all along for the FDOT and the industry as a whole is to maintain a balance with these changes to ensure that pre-cast segmental bridges can remain competitive in a low-bid world. Although many of these changes have been in place for over seven years the industry has not yet fully adapted.

INITIAL PROJECT IMPLEMENTATION

After the publication of the *New Directions* study, the FDOT began implementation of a select few of the new requirements on some of the recently begun projects in the state. Among the projects chosen to act as “pilot” projects for these new measures were the *Hathaway Bridge Replacement Project* in Panama City, FL (2000 – 2004), and the *Ringling Causeway Bridge Replacement Project* in Sarasota, Florida (2001 – 2003. These projects utilized the design build contract delivery system which made them ideal candidates to implement the new requirements after the contracts had been let. The Hathaway Bridge and the Ringling Bridge were both pre-cast segmental bridges erected using the balanced cantilever method. Both projects had longitudinal and transverse internal post-tensioning in the superstructure. In both cases the projects had already been bid prior to the FDOT‘s decision to implement some of the new segmental bridge requirements. Because the decision to use the new requirements was made after the bidding, the FDOT negotiated a supplemental agreement to amend each project to include some of these new requirements. For the Ringling Causeway Bridge Project, the FDOT and Construction Engineering and Inspection firm (CEI) RS&H CS, INC negotiated a $2,000,000.00 supplemental agreement with the design build team of *PCL Civil Constructors and JMI (Earthtech).* For the Hathaway Project an agreement was reached in the amount of $1,500,000.00 between the FDOT and the design build Team of *Granite/Rizanni De Eccher, (A Joint Venture) and HNTB.* CEI services for this project were also provided by RS&H CS, INC. By making the decision to pay these premium costs to implement a few of the new requirements, the FDOT has shown its dedication to aggressively pursue ways to improve this industry.

One of the new requirements that were adopted by both the Ringling Project and the Hathaway project was to mandate double faced epoxy for all segment joints. This means that when two segments are mated together during erection, both faces of the adjoining segments will have epoxy applied to them. Prior to this change, epoxy was typically applied to only one segment face during erection. The purpose of epoxied joints on a segmental bridge is to provide a water tight seal between the joints throughout the life of the bridge. This seal ensures that water cannot penetrate the bridge deck and intrude on the post-tensioned tendons. By applying epoxy to both faces, there is added protection to ensure that the seal will be complete and effective. This requirement, which would become permanent in FDOT segmental bridge construction, added a level of quality to the final product, but it also added costs. Initially it doubles the amount of epoxy material needed to erect the structure versus single face epoxy. Also, it has an effect on contractor's production rates during segment erection. By requiring epoxy on both faces during erection it increased the time of one erection cycle or it required added manpower to accomplish the added work.

Another requirement negotiated into both contracts was related to the field grouting performed by the contractor. The FDOT wrote a comprehensive developmental specification to mandate new grouting procedural requirements. These new requirements were much more detailed and much more stringent than had been in place previously. Among the new procedures that had not been used in segmental bridge construction prior to the Ringling and Hathaway Projects was an emphasis on grouting pressures and redundant procedures. The new specifications required that each tendon be grouted full at a target injection rate and injection pressure. Also, upon completion of grouting, the tendons are to be re-pressurized to expose any area where the tendon could be leaking grout. As a final step the procedures called for the contractor to re-open the grouted tendon after ten (10) minutes under pressure to expel any air and water that may have been trapped in the tendon's high point. These steps were intended to ensure that the tendons would be fully grouted. These steps were a significant change from past procedural requirements which were not nearly as rigorous.

One final requirement in the grouting process was added to once again ensure the tendons are fully grouted. Approximately eighteen to twenty four hours after completion of tendon grouting all anchor heads were required to be visually inspected by using a fiber-optic borescope to ensure that tendons had been fully grouted. This is achieved by drilling a hole in to the grouted tendons, at the location of the grout tubes, and inserting a fiber optic scope inside the anchor head (Figure 3). This allows the inspector to view the area behind the anchor, and also inside the grout cap, to ensure that no voids exist in these critical areas. If a void is discovered as a result of this inspection, the area can be filled with grout or flowable epoxy and a potential serious problem can be eliminated. The borescope inspection is an extremely important addition to the post-tensioning requirements and added minimal expense to the overall project. With this procedure it can be visually verified and documented that the grouted tendon has been fully encapsulated. The post-grouting borescope inspection has become a permanent addition to the FDOT segmental bridge specifications and is now a routine procedure in the segment erection cycle.

Figure 3 – Borescope inspection

One of the major effects of these on-site field changes were felt, once again, in the contractor's production levels. Because of the built-in wait time required by the new procedures, the production rates were significantly affected. In addition, the individuals performing the work had to adapt to these changes both on the contractor side and the inspection side. It was a real challenge at the beginning of the process to change the thinking of everyone involved who had been accustomed to the "old way" of performing the work. Ultimately the implementation of these procedures was a success due to the commitment of all parties. Although some alterations in the details of these procedures have been made based on field performance and project feedback, this part of the specification also remains in the FDOT specifications today.

An additional requirement that the FDOT wanted to add to the segmental bridge construction is the concept of a segment to segment duct coupler. This requirement was included as part of the Ringling Bridge Project negotiated change. The couplers that the FDOT provided for the Contractor to use were the Lia-Seal® couplers which were developed by Freyssinet LLC (Figure 4). These couplers consist of two identical pieces with one piece cast into each half of a match cast pair of segments. The coupler pieces were cast into the segments during pre-casting operations and a third sealing part was added for erection. These couplers were utilized in each of the top slab post-tensioned tendons for this project as an experiment to test the feasibility of the coupler concept.

This concept had never been used previously in segmental bridge construction but was seen as an important addition for future projects. This was the first attempt at providing this coupled connection and this project served as a springboard to further implementation. This coupler functioned, for the most part, as it was intended. However, there were instances of grout leaking and crossover that were still experienced during this project. The definitive cause of these problems and the effect, if any, on the erection geometry will never be known.

In future projects the FDOT would re-visit this coupler requirement to pursue the ultimate goal of standardizing their use for all projects. The design and feasibility of segmental couplers would continue to be investigated as well. Currently the FDOT requires a mechanical coupling device for all internal post tensioned tendons that cross over a joint. This requirement is being addressed on current projects as the industry is in the process of developing an effective coupler to meet its intended purpose.

Figure 4 – Freyssinet Lia-Seal Coupler

THE POST-TENSIONING SYSTEM

Many of the changes implemented by the FDOT based on the New Directions Study involved rewriting the specifications related to post-tensioning and grouting of segmental bridges. One of the new specification requirements which has had major impacts on a construction project level is the requirement of a pre-approved comprehensive post-tensioning system to be used for all tendons in the structure. This means every component of the post-tensioning tendon must be part of an integrated system and must go through extensive testing prior to its acceptance. Although most of the components of the systems have been use in the past, the requirement for them to be fully assembled and pre-tested as a whole had not been in place previously. A separate system is required for each size, type and location of post-tensioned tendon in the bridge structure. The intent of the specification is that suppliers would develop and test the systems independent of any specific project and ultimately gain approval according to various requirements spelled out in the specification. This would enable a contractor to choose a system that would suit their needs when it came time to bid and eventually construct the project.

TESTING REQUIRMENTS

The post-tensioning systems that are to be available for use on FDOT projects will need to undergo extensive testing by the manufacturer. Written into the FDOT's segmental bridge specifications, are the requirements for both individual components of these systems along with the requirements for the systems as a whole. The FDOT specifications now require that all post-tensioning duct be made of plastic or galvanized steel where necessary in deviation blocks. For internal post tensioning ducts only corrugated plastic can be used and it must be certified to meet the requirements of International Federation of Structural Concrete (FIB) Technical Reports for load and wear resistance. In addition these ducts must be tested for a minimum bending radius according to testing procedures outlined in FIB. External post-tensioning ducts must meet separate material requirements as certified by the supplier. All external post-tensioning ducts must be made from High Density Poly-ethylene (HDPE) material. They must meet standards for the Oxidative Induction Time (OIT) according to ASTM D 3895 and they must also meet pressure requirements according to ASTM D 3035 "Standard Specifications for Polyethylene (PE) Plastic Pipe." All duct connections, along with grout tubes and fittings, and permanent grout caps must be individually certified to meet specific standards and specifications.

Along with the requirements of the individual components each comprehensive post-tensioning system must be tested as a whole to meet specific guidelines. As was stated earlier, each size and type of post-tensioning tendon requires a specific system, which in turn requires specific testing. The main goal of the testing is to certify that the systems provide a near air-tight seal when fully assembled. All systems must be initially conditioned to maintain 150 psi pressure for three hours. After three hours the system must maintain 150 psi internal pressure for 5 minutes and not lose more than 15 psi during that time. To satisfy these testing specifications, manufacturers seeking FDOT system approval must create mock ups and sample system assemblies in order to accomplish the intended results.

These steps were all to be accomplished prior to system approval in a laboratory environment. There were further requirements enacted that must be met at the project site as well. The post-tensioning systems need to be proven, through the practice of pressure testing, at the site prior to their being filled with grout. A pressure test is to be performed on the duct system in the casting yard prior to the concrete being cast for the segment. For this test the duct must be pressurized to 1.5 psi and the pressure cannot decrease more than 10% in one minute. Furthermore, another pressure test is to be performed immediately prior to the tendons being grouted. For this test the system is to be pressurized to 50 psi and the loss cannot be greater than 15 psi. For both of these tests it is very difficult to achieve passing results. It has been discovered through many attempts that the ducts, and especially the grout tubes and valves, cannot hold the kind of air pressures that are required. All of the systems must pass similar tests in laboratory conditions in order to be approved for use; however in project site conditions it is far different. These requirements remain in the specifications and the project personnel try their best to meet their intended goals. However, it is well known throughout the industry that these requirements are not achievable with the materials used on projects today. Field personnel try to find a suitable middle ground to attempt to achieve the intended goal of the requirements while maintaining levels of constructability. This requirement will continue to be altered and improved upon based on continuous feedback from the industry.

PROJECT EFFECTS

The first project that required the use of a pre-approved post-tensioned system was the *Ernest Lyons Bridge replacement* in Stuart, FL (2004-2007). This project was a design build pre-cast segmental bridge using the span-by-span erection method. The new design and construction requirements mentioned earlier were also included for this project. The added requirement for pre approved post-tensioning systems proved to be one the most difficult challenges thus far. The design build team consisted of PCL Civil Constructors Inc and Parsons Transportation Group and the CEI services were provided by RS&H CS, INC. The post-tensioning supplier subcontracted for the project was VSL Inc.

The post-tensioning system requirement was part of the updated specification prepared for this project and was therefore included in the contract documents. The main problem that was initially identified was that at the time the project was advertised and ultimately bid, there were no approved post-tensioning systems in existence according to FDOT's specified parameters. Since this requirement had not existed in any prior project, the industry had not begun the process of compiling these packaged systems and presenting them for the necessary approval process. Secondarily, all of the details for the requirements of these proposed systems had not been fully investigated by the FDOT's approving authority. Fortunately for the ultimate success of the project, this was a design build pre-cast segmental bridge. Being design-build meant that the project needed to be fully designed by the design build team while under contract time. This resulted in a significant design phase at the beginning of this project in which no construction would occur. Therefore the majority of the development, testing, and eventual approval of the systems could occur without effecting project time, which was of great benefit to the design build team and the FDOT.

RESEARCH AND DEVELOPMENT

As the impacts of this new requirement were first being realized, the contractor began exploring these requirements with their post-tensioning supplier to determine the exact nature of this specification. The revised project specifications provide specific material requirements and testing procedures as outlined earlier. The main intent of the testing of these systems is that they provide a sealed, water tight duct system so as to ensure water cannot intrude into the tendons and that grout cannot leak out. In order to achieve this, the individual components of the system need to be assembled in a lab environment and tested according to the stringent requirements spelled out in the specifications. Secondarily, the system needed to be successfully used in a field setting at the project level. This means that the system is required to be easily assembled and durable enough to withstand the rigors of a construction project. As testing proceeded there began a growing concern as to whether the system approval would delay the project construction. Another concern was a growing list of costs that the contractor was incurring that had not been fully anticipated when the project was bid. The majority of these costs were associated with the research and the testing necessary to develop and ultimately approve these post-tensioning systems. Other material costs were incurred due to multiple derivations of a specific item as testing revealed the best solutions for meeting these requirements. Although the contractor was aware of the requirement for the pre approved post-tensioning system, the intent of the specifications as they were written was that the system would be in place prior to project letting. Also, it was not intended that the Design Build Team would be compensated for these costs to develop the systems.

Since The Ernest Lyons Bridge was the first project to utilize this concept and no such approved systems existed in the industry, there were understandable set backs in the approval process. There were further complications in the fact that the approval for the system has to be provided by the FDOT state structures office and not at the project level. This caused a conflict between the parties involved as the priorities differed among them. Those on the project level were most interested in the successful construction of the bridge on time and on budget and more focused on a system that would meet the needs of this specific project. The FDOT's approval authority was interested in a more global priority of developing a successful post-tensioning system available to be used in the future, and to establish the precedent that the approved system must be in place prior to construction. Their goal was system that could be used for all projects and therefore needed to be adaptable beyond this particular one. As the system development progressed, and time became more of a critical issue, these conflicting priorities became more evident.

PROJECT SUCCESS

Following months of development and rigorous testing performed by the design build team and their post-tensioning supplier all necessary systems to construct the bridge were approved and implemented. Thanks to the effort of the project personnel and those in the approval authority, the development process did not cause significant delay to the construction schedule. Upon final approval of the new systems, the design build team identified a number of expenses which it deemed to be unforeseen at time of bid. In examining the process and the progress that was achieved, the FDOT and the design build team reached a negotiated settlement of $300,000.00 to reimburse these extra expenses.

The negotiated settlement of $300,000.00 signified another step in completing the process of post-tensioning system implementation and ultimately streamlining the process. In the overall scheme of things this price was insignificant when compared to the project contract value of approximately $46,000,000.00. Paying a premium cost that amounted to less than 1% of the contract amount was deemed a great success to those involved in the process. Although the interpretation of the specifications and the assumptions made at the time of project bidding were up to debate, those at the project level considered it a valuable investment for an improved overall structure. The PT systems used on this project were rigorously tested and improved upon when faults were discovered. When combined with the other changes made to procedures and requirements for segmental bridges, these comprehensive approved systems add to the higher levels of quality that are now being achieved.

The end result of the Ernest Lyons Bridge Project was a successfully constructed bridge that was completed ahead of time with minimal cost over runs. The project was also awarded The Florida Transportation Builders Association (FTBA) award for Best in Construction – Major Bridge – for 2007. Furthermore, the FDOT now had a published list of approved post-tensioning systems for use on future projects both here in Florida and throughout the world.

THE NEXT STEP

In the wake of the success of the Ernest Lyons Project the next pre-cast segmental project was advertised for bid. This project would act as the next step in the implementation process of the changes brought about by *New Directions*. For the first time all changes to specifications, procedures, and requirements, as recommended by *New Directions*, would be implemented. Some of the details of this project would, however, make this step in the process more difficult.

The *I-95/I-295/SR-9A North Interchange Improvement Project* (North I) (2007 – Present) in Jacksonville, FL would consist of a pre-cast segmental bridge erected using the balanced cantilever method. Unlike the projects mentioned earlier, this would be a conventional Design-Bid-Build contract. The contractor for this project is Superior Construction Company, Inc, the Project Designer is PB Americas, and CEI services are provided by RS&H CS Inc. Although the success of the Ernest Lyons Bridge Project produced a list of systems approved for use, they would not be used for this project for the following reasons.

The North I project design uses the balanced cantilever construction method. This is a method where segments are erected on alternating sides of the pier and are post-tensioned to each other as the cantilever extends out on either side. This type of construction uses a majority of the post-tensioning that is internal to the concrete structure. Unlike the systems approved for the Ernest Lyons Project which were for external post-tensioning. This type of post-tensioning requires different hardware components and also requires different testing requirements. Although there was some preliminary testing done by multiple suppliers prior to the project letting, both at time of advertising and at time of bid there were no published available external post-tensioning systems approved by the FDOT. To further complicate matters, the winning bidder for the North I project chose a different Post-tensioning supplier than the one used on the Ernest Lyons Bridge Project.

The use of internal post tensioning that accompanies balanced cantilever construction brings about another characteristic that had been used, but not contractually required before. The FDOT specifications now require that a mechanically coupling device must be used for every tendon that crosses a segment joint. Since the first experimental use on the Ringling Causeway Project in 2001, the coupler has been included as a contractual requirement for internal post-tensioning tendons; however a balanced cantilever structure had not been built with this specification requirement in that time frame. Therefore, the North I project would be the first in the Nation to contractually require the use of segmental couplers. Subsequently, the post-tensioning suppliers in the industry did not have an approved coupler that could be used for this project.

COUPLERS

The coupler requirement was an important aspect that arose from the *New Directions* Study. As part of the strategy to protect post-tensioned tendons over the life of the structure the segment to segment coupler was deemed a necessary added level of protection. Since the tendon at the location of the joint has a finite section that is unprotected by duct material, this mechanical coupling device would provide an additional layer of protection should water penetrate the epoxied joint. By providing a water tight seal across this segment interface, it also ensures that grout will not leak out while it is being filled during pressure grouting operations. Preventing grout from leaking during grouting operations is very important to the structure's quality. Without a seal across the joint, grout can leak out of the tendon being filled and into an adjacent tendon that is not intended to be filled. This is referred to as "crossover" and it can occur without the field staff being aware of it. This can cause major problems when it comes time to install post-tensioning strand into that duct. If it is discovered to be blocked with hardened grout, the duct must be cleared out by penetrating the top deck of the structure. This operation is very time consuming and also it is deleterious to the quality of the structure since a new intrusion into the deck has been introduced.

Along with providing a layer of tendon corrosion protection, and eliminating crossover, the coupler serves other purposes as well. It acts to fix and center duct sections in the formwork during pre-casting of segments. Post tensioning ducts shifting during casting has often been an issue with segmental bridge construction in the past. The ducts often get stepped on and they can get struck by falling concrete or by concrete vibrators during placement. If a duct gets shifted during this time it may not be noticed until after the concrete has set. If this happens it can cause major problems during segment erection.

The couplers act to prevent this by the way they are installed prior to casting. The pieces are attached to the formwork and to the match cast segment and the ducts are then secured in between. As seen in Figure 5, the yellow coupler piece (left side) is secured to the match cast face and the orange coupler piece (right side) is attached to the formwork bulkhead. The plastic duct is securely locked in to the coupler pieces which prevent them from shifting. This ensures that ducts are centered properly and that they will not deviate from this position during concrete placement operations. The coupler is intended to all but eliminate this as a concern.

Figure 5 – Ducts prior to pre-casting

What makes the development of these couplers difficult to achieve is that in providing the protection outlined above these couplers cannot inhibit the face to face mating of the two adjoining segments during erection as this can cause serious problems with the structure. What also must be realized when developing these couplers is the amount of pieces needed for the structure. The Jacksonville North Interchange Bridge, which has a length of only 2,654 feet, has approximately 2500 sets of couplers required for the entire structure. As is seen in Figure 6, there is little room for them in the deck cross section and they are most often adjacent to each other. With that amount of couplers required, and them needing to be properly aligned there are many opportunities for potential problems.

Figure 6 – Pier segment with multiple duct couplers

Coupler development has proven to be the most challenging part of the system approval process for this project. With some pre-project work done by the post-tensioning supplier and a template established from the prior project the system implementation went quite quickly. Due to the phasing of the project and some unrelated project delays, the supplier ended up with adequate time to develop and gain approval on the majority of the needed systems. The one remaining obstacle was the coupler. The coupler chosen for use on this project was developed by General Technologies Inc. (GTI). The system utilizes two plastic "coupler" pieces with a rubber gasket in between to provide the seal. For this system to function the seal cannot act as a barrier to segment erection, but also must be firm enough to serve its intended purpose of a water tight seal. The initial rubber gasket proposed for this system was found to be too firm and rigid when the coupler pieces were mated together. This was discovered in field testing performed at the project casting yard. It was found through testing that the amount of pressure required to completely compress the seal was far more than will be applied across the faces of the two adjoining segments when post-tensioned together. This gasket could potentially have acted like a shim between the segments and caused major problems during segment erection.

Currently the GTI coupler system is being utilized during the segment pre-casting phase of the North Interchange Project and thus far the couplers have been very successful in their performance. A joint decision was made between the contractor, the supplier, and the FDOT to utilize this coupler even though the system has not been fully approved. Upon receipt of the new rubber gasket, more testing will be performed to ensure the design will function properly. Ultimately this entire coupler assembly will be field tested when segment erection begins. Based on the results of all the work the suppliers have done and the successful implementation in to the construction process, the goal will be to have an approved coupler to accompany the approved system at the conclusion of this project.

Once again, this project began with difficult requirements and an unknown timeframe as to the availability of the necessary systems. Through diligent work from the suppliers and cooperation from project personnel there is the potential to complete this project with the exact goals that the FDOT intended. Thus far, the process of post-tensioning system implementation has not affected the project schedule. Additionally to this point the contractor has not requested any additional compensation due to the development, testing or implementation of the new post-tensioning system. There are no other pre-cast segmental projects in the world that use a segment to segment duct coupler as part of the erection system. If this project can demonstrate the successful use of this coupler for a major segmental bridge, it could provide a guide to others in the industry to adopt many of these same concepts.

CONCLUSION

When analyzing where the pre-cast segmental bridge industry is today, it can be definitively concluded that the level of quality and durability in the finished product has increased significantly. All of the changes that have been enacted based on the *New Directions* study were aimed at accomplishing that feat. An important aspect of this transition to higher quality results is that the production of these structures did not cease. It would have been a feasible solution to propose a moratorium on pre-cast segmental bridge construction while these major issues were investigated. However, the FDOT chose to implement these measures on the fly by introducing them into active projects. This decision, which cost the FDOT significant sums of money, proved to be an effective solution. By doing this the FDOT was able to perform real life research on active projects and analyze the effectiveness of their solutions. As new projects were turned out the FDOT was able to introduce more measures until the complete transition to the new requirements was complete.

With the first phases of the new requirement implementation complete the look is toward the future. All eyes are on Florida once again as new technologies are being developed, such as the new segment coupler system on the Jacksonville North Interchange Project. If proven successful other entities world wide will begin to take note and implement these technologies for their projects. The overall goal of the pre-cast segmental bridge industry as a whole is the improve quality and durability in the final product. Furthermore, the intent of these improvements is that pre-cast segmental bridges will remain a viable competitive option for construction in the future. As higher levels of quality are achieved and the evolution of pre-cast segmental bridges continues, this will remain a strong industry for years to come.

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