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# Post-Tensioning Technologies

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# JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION  
AND PURDUE UNIVERSITY



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## JOINT TRANSPORTATION RESEARCH PROGRAM

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<b>16. Abstract</b> <p>Post-tensioned bridge construction has become increasingly popular and financially competitive with traditional prestressed concrete and steel plate girder bridges. Unfortunately, Indiana has experienced several construction-related problems in the few post-tensioned structures built, some of which have caused significant long-term durability concerns. Indiana's problems have generally been attributed to a lack of a standard set of specifications for post-tensioned construction as well as inexperience and inadequate training of contractors and inspectors. These types of issues, however, were once more prevalent throughout the industry and much work has been accomplished in recent years to address these issues. This research program had two primary objectives: (1) to improve the quality of post-tensioned bridge construction in Indiana and (2) to provide the State with more confidence when using this type of construction. First, past problems related to post-tensioned construction were identified, and for each, case studies were conducted. Each case study includes an overview of the bridge, a summary of the problems related to post-tensioning, and possible sources and remedies to those problems. Next, a standard post-tensioning construction specification was developed. The specification addresses problems specific to Indiana which were found in the case studies and common problems experienced in the industry as a whole. Specifically, the specification addresses industry standards of practice, requirements for certification and experience of personnel, and proper testing and sampling procedures. In addition, specific recommendations are provided for training programs and certification of INDOT construction personnel to ensure they are properly trained to inspect post-tensioned construction.</p>			
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## EXECUTIVE SUMMARY

### POST-TENSIONING TECHNOLOGIES

#### Introduction

Post-tensioned bridge design and construction can result in very efficient use of construction materials; the post-tensioning system can be designed to keep nearly all structural concrete under compression under service loads, where it is most effective. Additionally, post-tensioned construction can facilitate longer spans, curved girders, and if designed and constructed properly, improved durability. For these reasons, post-tensioned bridge construction has become more popular and financially more competitive with traditional prestressed concrete and steel plate girder bridges.

Unfortunately, Indiana has experienced several construction-related problems in the few post-tensioned structures built, some of which have caused significant long-term durability concerns. Indiana's problems have generally been attributed to a lack of a standard set of specifications for post-tensioned construction as well as inexperience and inadequate training of contractors and inspectors. These types of issues, however, were once more prevalent throughout the industry and much work has been accomplished in recent years to address them. In particular, courses have been developed by the industry, and standard provisions have been created to familiarize and standardize the design and construction community with common construction techniques and standards of practice.

This research program had two primary objectives: (1) to improve the quality of post-tensioned bridge construction in Indiana and (2) to provide the State with more confidence when using this type of construction. First, past problems related to post-tensioned construction were identified, and for each, case studies were conducted. Each case study included an overview of the bridge, a summary of the problems related to post-tensioning, and possible sources and remedies to those problems. Next, a standard post-tensioning construction specification was developed. The specification addresses problems specific to Indiana, which were found in the case studies, and common problems experienced in the industry as a whole. Specifically, the specification addresses industry standards of practice, requirements for certification and experience of personnel, and proper testing and sampling procedures. In addition, specific recommendations are provided for training programs and certification of INDOT construction personnel to ensure they are properly trained to inspect post-tensioned construction.

#### Findings

From the case studies, it was determined that most of the problems encountered could be alleviated through additional experience by both the contractor and construction inspectors as well as knowledge of proper post-tensioning procedures. Though the increase in experience will only come over time, a requirement for certification training for contractor foremen, grouting personnel, and construction inspectors should be employed. The Post-Tensioning Institute (PTI) offers training certification for both bonded and unbonded post-tensioned construction, and these courses are a requirement of several departments of transportation for construction foremen as well as inspectors. The "Level 1&2 Bonded PT Field Specialist" is a general program for all bonded post-tensioned construction and should be required, at the very least, for all contractor foremen and

construction inspectors. Also, the American Segmental Bridge Institute (ASBI) offers training specific to grouting and awards an "ASBI Certified Grouting Technician" certificate upon successful completion of the program. Due to the importance of grout in tendons, all personnel involved in the grouting process, including construction inspectors, should have received this training.

In addition to contractor inexperience, many of the problems encountered could be attributed to both inadequate and inconsistent special provisions related to post-tensioning. The post-tensioning provision currently used by INDOT is not current with standard post-tensioning practices. As a result, an updated provision is needed.

#### Implementation

A unique special provision was developed to provide uniformity and consistency in post-tensioned construction for the State of Indiana. The new provision includes several modifications and additions to the previous INDOT provision, and the layout was changed to be in accordance with other INDOT Recurring Special Provisions. This updated special provision incorporates new standards for materials and construction and references recently released specifications by PTI and ASBI that are becoming commonplace among state DOT specifications. The reference specifications include the "Guide Specification for Grouted Post-Tensioning" and the "Specification for Grouting of Post-Tensioned Structures." The recommended provision references industry specifications and only modifies or adds provisions specific to Indiana or includes provisions that are more restrictive or explicit than those of the reference specifications. Because of this format, updating the special provision is a relatively simple task.

Required training and certification of inspectors monitoring post-tensioned projects in Indiana are recommended. The training and certification is similar to that required by construction foremen and personnel outlined in the recommended special provision. Inspectors present during any post-tensioned construction should have the PTI Certification of "Level 1 Bonded PT—Field Installation." This certification requires attendance of a three-day workshop conducted by PTI and successful completion of an exam administered at the conclusion of the workshop. This certification workshop provides an overview of standards of practice and proper safety regarding all bonded post-tensioned construction. In addition to the PTI certification, inspectors present during any grouting operations or grout material testing related to post-tensioned construction should have an "ASBI Grouting Training Certificate." This certificate requires attendance of a two-day workshop provided by ASBI and successful completion of an exam. Similar in nature to the PTI certifications, this program and certificate is specific to the standards of practice for proper grouting and grout material testing.

While these recommended requirements provide minimum training for inspectors, it is desirable for inspectors to have more advanced certifications from these programs. These advanced certifications, however, have significant experience requirements. This experience may not be feasible for inspectors in Indiana due to the infrequent use of post-tensioned construction, but it would be advantageous to use inspectors that have training as well as experience in this type of construction to monitor these projects.

It is recommended that the special provision as well as the inspector requirements be adopted by INDOT. From these measures, the reliability of post-tensioned construction in Indiana can be improved and provide added confidence to the successful deployment of this bridge technology.

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## 1. INTRODUCTION

Post-tensioned bridge design and construction can result in very efficient use of construction materials; the post-tensioning system can be designed to keep nearly all structural concrete under compression under service loads, where it is most effective. Additionally, post-tensioned construction can facilitate longer spans, curved girders, and if designed and constructed properly, improved durability. For those reasons, post-tensioned bridge construction has become more popular and financially more competitive with traditional prestressed concrete and steel plate girder bridges.

Post-tensioned construction can be very useful but, as with any bridge system for which the participants lack experience and expertise, can result in difficulties. Many state departments of transportation have considerable experience in post-tensioned bridge construction, namely California, Texas, and Florida. On the other hand, Indiana has limited experience and only recently has considered expanded use of this construction type. Unfortunately, Indiana has experienced several construction-related problems in the few post-tensioned structures built, some of which have caused significant long-term durability concerns.

Indiana's problems have generally been attributed to a lack of a standard set of specifications for post-tensioned construction as well as inexperience and inadequate training of contractors and inspectors. These types of issues, however, were once more prevalent throughout the industry and much work has been accomplished in recent years to address these issues. In particular, courses have been developed by the industry, and standard provisions have been created to familiarize and standardize the design and construction community with common construction techniques and standards of practice.

## 2. OBJECTIVE

This research program had two primary objectives: (1) to improve the quality of post-tensioned bridge construction in Indiana and (2) to provide the State with more confidence when using this type of construction. First, past problems related to post-tensioned construction were identified, and for each, case studies were conducted. Each case study includes an overview of the bridge, a summary of the problems related to post-tensioning, and possible sources and remedies to those problems. Next, a standard post-tensioning construction specification was developed. The specification addresses problems specific to Indiana, which were found in the case studies, and common problems experienced in the industry as a whole. Specifically, the specification addresses industry standards of practice, requirements for certification and experience of personnel, and proper testing and sampling procedures. In addition, specific recommendations are provided for training programs and certification of INDOT construction personnel to ensure

they are properly trained to inspect post-tensioned construction.

## 3. CASE STUDIES OF PROJECTS AND RELATED SPECIAL PROVISIONS

To evaluate problems INDOT has experienced with post-tensioned construction, several case studies were conducted. Each of the case studies includes an overview of the particular bridge, a summary of problems related to post-tensioning, and a review of possible sources and remedies to those problems. Three bridge construction projects were selected for case studies: US 231 over the Wabash River, Bridge No. 13 at the Borman Interchange, and the I-70 Indianapolis Airport Interchange Bridges. The bridges varied in construction type, cast-in-place and precast, and girder type, I-beam and box girder. Also, the problems experienced during construction varied from grouting and material problems to time-dependent construction problems. The case studies for these bridges follow.

### 3.1 US 231 over the Wabash River (231-79-07531)

#### *Overview of the Bridge and Specifications*

This bridge structure, completed in 1995, consists of two separate bridges and carries US 231 over the Wabash River in Lafayette, IN. The identical structures are composed of four three-span continuous girders with individual span lengths of approximately 175 ft. Each superstructure width is 44 ft-2 in. from outside to outside of coping. Figure 2.1 shows a partial perspective view of the bridges.

The bridges were constructed using hybrid pre- and post-tensioned 90-in. deep Indiana bulb tee sections. Each superstructure span consists of four bulb tee beams, and each precast beam spans between supports (175 ft). Beams were post-tensioned to create a three-span continuous girder. Figure 2.2 shows a cross-sectional view.

#### *Summary of Issues Related to Post-Tensioning*

During construction, no reported problems related to post-tensioning were experienced. During inspections by INDOT personnel in 2002 and 2003, however, several longitudinal cracks were discovered on the bottom surface of several beams. Beginning in 2004, Wiss, Janney, Elstner and Associates (WJE) began an investigation into the cause of these cracks (1). Later, in 2009, Janssen and Spaans Engineering (JSE) further investigated the extent and cause of the cracks (2,3). Both investigations resulted in detailed reports, and this section summarizes the findings.

The initial investigation by WJE was conducted after an INDOT inspector noted a 20-ft long longitudinal crack along the bottom of a beam during a routine inspection in 2002. During a follow-up inspection in 2003, the INDOT district engineer verified the crack

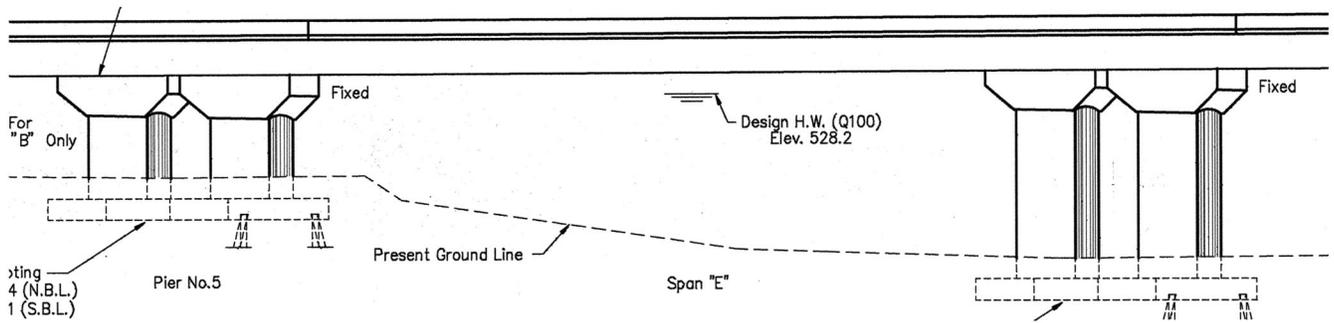


Figure 2.1 Perspective view of US 231 over the Wabash River.

and noted additional hairline cracks along the bottom of other beams. The intent of the WJE investigation was to inspect the beams using non-destructive techniques to evaluate the condition of the beams using exploratory openings, if necessary. Finally, recommendations for follow-up actions were to be made.

First, ground penetrating radar was used to verify the location of the draped tendon. Next, impact-echo was used to identify the extent of grouting in the tendon. Exploratory openings were made to calibrate and verify the findings obtained from the impact-echo. In addition, portions of the tendon for which testing indicated lack of grout were examined using exploratory openings. This initial investigation focused on regions with visual external longitudinal cracking.

The results of the initial investigation revealed significant voids in two tendons; one tendon was nearly completely void of grout while the other tendon had intermittent lengths of incomplete grouting. Though significant portions of the tendon were ungrouted, the prestressing steel appeared to be in good condition with no visible corrosion product apparent at the exploratory openings. WJE concluded that the longitudinal cracking resulted from water collecting in the ungrouted duct and freezing during the winter.

Due to the small number of inspected beams, WJE recommended further investigation using both non-destructive techniques and exploratory openings to produce, at the very least, a larger sampling of the bridge.

In 2009, JSE further investigated the cracking of the beams. JSE used similar methods for the investigation, though they also employed the use of a videoscope to visually explore the voids, and with the help of Dywidag Systems International (DSI), JSE used a volumeter machine capable of measuring void volume. In all, JSE investigated nearly 30% of the beams.

In summary, JSE reported "the bridge is in satisfactory condition with minor defects with the exception of the mid span cracking" in the same beam which originally raised concern with INDOT (2,3). This beam contained significant grout voids in the tendon which were at least 90 ft in length. For this beam, there was evidence that a blockage occurred during grouting that was never remedied and resulted in the void. Specifically, a center void existed which suggests the contractors attempted to grout from the opposite end of the duct after the initial blockage occurred. Additionally, several other tendons contained channel voids in the grout at least 30 ft in length. These channel

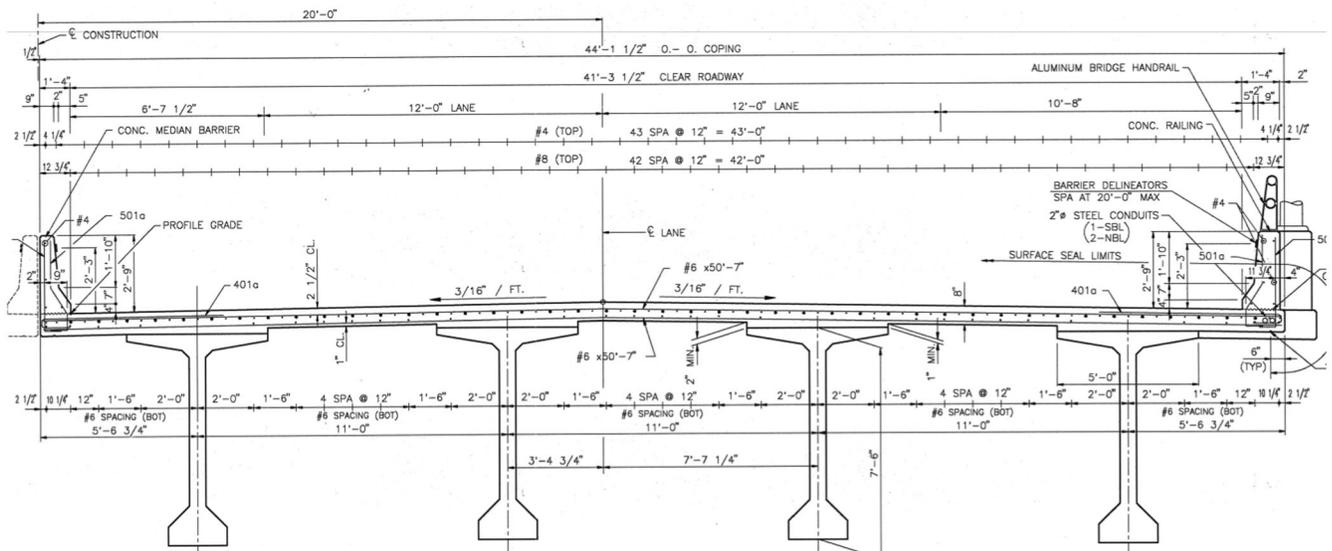


Figure 2.2 Cross-sectional view of US 231 over the Wabash River.

voids, however, did not expose the prestressing steel and resulted in no discernible corrosion damage to the prestressing steel beyond minor surface oxidation. It was noted that the beams for this bridge did not contain low-point vents for the tendons, which could have allowed water to collect during construction and resulted in the cracking due to freezing.

JSE also concluded that, other than the most problematic tendon, the longitudinal cracking could not be conclusively attributed to the grouting quality. There were a number of other problems linked to manufacturing quality such as insufficient concrete cover and inadequate consolidation of concrete around the ducts. The beam with the largest-width cracks was found to be the only one with a lengthy portion of ungrouted tendon. Nevertheless, JSE (2,3) recommended that the rest of the bridge girders be investigated for voids and remedied using vacuum and vacuum assisted grouting. Small voids in the tendons, while not exposing the prestressing steel, could affect the long-term integrity of the bridge. JSE also recommended all cracks with widths larger than or equal to 0.007 in. be epoxy injected.

#### Possible Sources of Problems

For this structure, the sources of problems related to post-tensioning are straightforward. The main issue, incomplete grouting, likely arose from numerous sources. First, proper grouting procedures such as when and in what order to close the vents likely were not followed. If these were followed, evidence of incomplete grouting during construction would have been obvious. The absence of low-point vents would have made it difficult to follow the path of the grout as it flowed through the duct. The lack of these vents would have also allowed water to collect prior to grouting and altered the water-to-cement ratio of the grout, though there is no direct evidence of this being the case. The lack of vents also likely led to water collecting and freezing in the duct, possibly contributing to the longitudinal cracks later found in the beams.

The submission of and adherence to a grouting plan for this project would have helped to eliminate some of these problems. For one, the grouting plan should include an estimate of the amount of grout to be injected into each tendon. Due to the very large voids found in the duct, these estimates would likely have shown that incomplete grouting was taking place. The investigations found that the voids in the problem duct likely arose from a blockage during grouting that was

never addressed. It is unclear if the contractors were aware of this blockage, but a grouting plan would ensure that the contractors would be prepared in the event of a blockage.

A combination of incomplete specifications, contractor inexperience, and inspector inexperience led to the problems in this bridge. Current construction specifications are more thorough and should help to alleviate many of the problems encountered. In addition, certification requirements for both the contractor foreman and construction inspectors should help to address the lack of experience of the personnel.

### 3.2 I-70 Indianapolis Airport Interchange Bridges (170-69-08519 and -08516)

#### Overview of the Bridge and Specifications

The airport interchange bridges, completed in 2005, are two similar bridges near the Indianapolis International Airport and span over various roadways including I-70. Both bridges are cast-in-place, continuous, post-tensioned concrete box girders. The larger structure is a four-span continuous bridge with spans ranging from 175 to 220 ft with varying skew angles. The smaller structure is a two-span continuous bridge with equal spans of 170 ft with varying skew angles. The larger bridge carries two lanes of traffic while the smaller bridge carries only one lane. Both bridges were built on a slight horizontal curve. Figure 2.3 shows an elevation view of the larger bridge.

The cast-in-place bridges were constructed on temporary falsework. The bridges were also cast in stages: first the bottom slab, then the web and diaphragm walls, and finally the top slab. The top slab was post-tensioned transversely. Figure 2.4 shows a cross-sectional view of the larger bridge.

#### Summary of Issues Related to Post-Tensioning

Compared to the previous case study, these bridge structures exhibited many fewer construction issues related to post-tensioning. The one significant issue that occurred was shortly after stressing of the transverse post-tensioned tendons in the top slab. Some anchor regions were observed to fail within hours of stressing. Though the concrete cylinder tests achieved the appropriate strength, it was determined there was an issue with the concrete mix used in the slab. As a result, all remaining stressed tendons were temporarily removed, the top slab and anchor regions were repaired, and the tendons were prestressed.

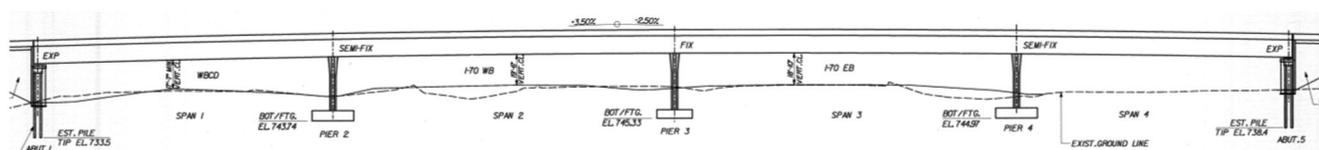


Figure 2.3 Elevation view of the I-70 airport interchange bridge.

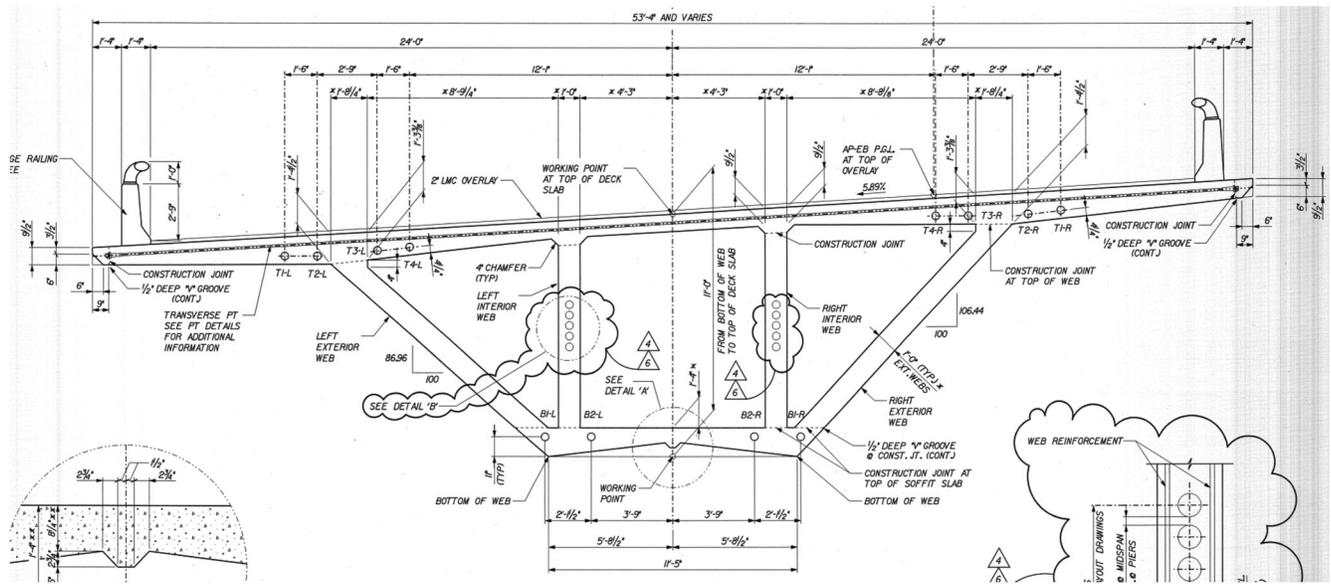


Figure 2.4 Cross-sectional view of the I-70 airport interchange bridge.

Possible Sources of Problems

The failure of the anchors was likely due to a concrete mix error and not the fault of the contractor or the specification. The concrete cylinders were tested, and they satisfied the specified strength requirements. The cylinder tests may have shown evidence of inadequate concrete, however. Any evidence could have highlighted the problem earlier and prevented the initial stressing of the tendons which resulted in failure of concrete in the top slab, creating a potentially dangerous situation.

3.3 Bridge No. 13 at the Borman Interchange (165-266-08637)

Overview of the Bridge and Specifications

Bridge Number 13 at the Borman Interchange, completed in 2009, is two adjacent bridge structures built as a replacement for Interstate 65 at the interchange of Interstate 65 and Interstate 80/94. The bridge consists of two separate structures carrying Interstate 65 over the interchange lanes. The project was constructed in two phases. First, the northbound bridge was constructed with a span length of approximately 240 ft and a skew of 53 degrees. The northbound bridge consists of two 12-ft

lanes and two 14-ft shoulders. Next, the southbound bridge was constructed with a variable span length of approximately 191 to 237 ft and a variable skew of 52 to 58 degrees. The southbound bridge consists of two-12 ft lanes, a variable width ramp lane, and two 12-ft shoulders. Figure 2.5 shows a partial elevation view of the twin bridges.

The bridges were constructed using hybrid pre- and post-tensioned 102-in. Indiana bulb tee sections. The northbound structure consists of seven girder lines, and the southbound structure consists of nine girder lines. Using temporary supports, the bridges were erected as three pre-tensioned spans ranging from 44 to 130 ft and then post-tensioned to form a continuous single-span structure. The post-tensioning was designed to be completed in phases, before and after deck placement, to provide proper counteracting forces. Each beam has six tendons. Figure 2.6 shows a cross-sectional view of the northbound bridge.

Summary of Issues Related to Post-Tensioning

The first construction phase, which was associated with the northbound bridge, experienced many problems related to post-tensioning. First, the bulb tee beams were designed using semi-lightweight concrete with a density of 130 pcf, but the end-third segments

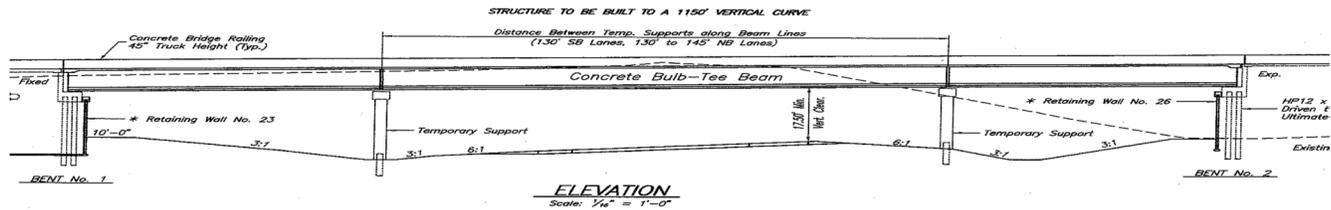


Figure 2.5 Partial elevation view of northbound portion of bridge no. 13.

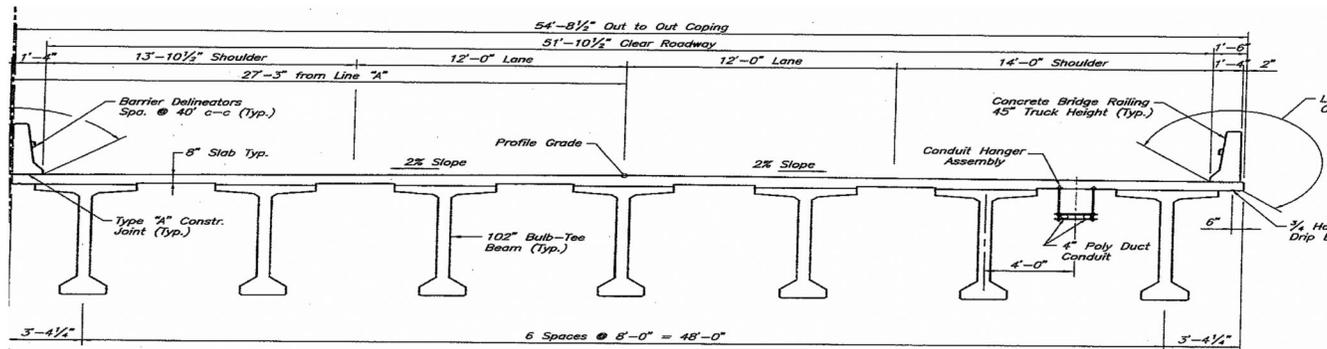


Figure 2.6 Cross-sectional view of northbound portion of bridge no. 13.

were cast using 135 pcf concrete because the design engineers had not seen the shop drawings before casting began. Once the problem was discovered, the design engineers were able to increase the stressing forces to account for the increased weight because they were initially designed with additional capacity for contingencies. Once the contractor returned the stressing records, however, it was evident that the contractor used the initially-intended tendon stressing values. The stressing was redone to achieve proper stress levels.

The initial post-tensioning consisted of stressing five of the six tendons. The five stressed tendons were grouted, and then due to cold weather, construction of the entire bridge was halted. Before construction was halted, the prestressing steel in the sixth duct was inserted but not stressed. This tendon could not be stressed at this time because the deck needed to be placed prior to stressing. Again, due to weather, the deck did not get placed. Over winter, the tendon remained in the duct without any corrosion protection.

During the winter, the beams experienced lateral sweep. The exact cause of the sweep was not determined, though many factors likely contributed. First, the temporary supports were erected on different base conditions. One temporary support was erected on solid ground, while the other support was erected on fill, and consequently, the different support conditions likely led to differential settlement. Also, during placement of the wet splice, the girders were observed to have shifted. This movement provided an unintended horizontal eccentricity that, during stressing, resulted in a visually noticeable sweep of the beams. Most importantly, the beams were left stressed for a significant time without the deck in place, which would have provided significant lateral stiffness. Thermal effects may have also influenced the lateral sweep because the sweep tended towards the east for the north-south oriented bridge.

When construction resumed after winter, the lateral sweep was noticed, and the design engineer was consulted. The engineer conducted detailed surveys, though these could not be compared to previous surveys because none were conducted. During stressing of the final tendon, however, failure of the wedges occurred and strands were ejected from the ducts. After inspection, the anchorages were noted to be contaminated

with dust and corrosion, and the wedges failed due to corrosion. New wedges were used, and construction continued. However, the same strand was used that was left in the duct over winter.

The construction of the southbound bridge exhibited many fewer problems and is not discussed in this review.

#### Possible Sources of Problems

After discussion with the design engineers, United Consulting, and review of the problems, several sources of problems related to post-tensioning were determined. Most importantly, though the contractors and Engineer were familiar with post-tensioning, the INDOT inspector knew very little about post-tensioning operations. The INDOT inspector is the last line for quality control of construction, and knowledge of all construction aspects is necessary. It is important that all INDOT inspectors overseeing post-tensioning work be required to attend appropriate training classes related to post-tensioning already in place by organizations such as the American Segmental Bridge Institute (ASBI) and the Post-Tensioning Institute (PTI).

In the initial construction phases, communication issues caused many of the problems. The shop drawings incorrectly stated the weight of the concrete, but the design engineers were not shown the drawings before casting commenced. Even though modifications to tendon stressing levels were made, the contractor was found to have used the initial values. As a result, stressing had to be performed again. Though instructions for stressing of tendons are provided to the contractor, the submission of a detailed stressing plan by the contractor for verification by the Engineer should be provided. This plan should include updated values reflecting the modulus of elasticity stated on the mill certificates for the different heats of prestressing steel. This submission would ensure the contractor and Engineer are coordinated for the stressing operations. Also, a representative of the Engineer should be on-site before and during stressing to monitor the operations.

Another issue was that monitoring of falsework was not included in the Specifications. The Engineer limited the allowable settlement of the top of the falsework to 3/8 in., and the design for the falsework was to

be according to the Special Provision “Temporary Supports” and submitted to INDOT for approval. During construction, half of the falsework was built on fill while the other half was built on solid ground. It is not known if the settlements were within tolerance, though they were very likely differential at the least due to the different ground conditions. It is also not known if the different base conditions for the falsework were approved by INDOT. In any case, improved communication between all parties involved could have averted this problem. Monitoring of temporary supports is of significant importance.

Surveys of the beam erection by the contractor were either not conducted or not recorded. Though this is generally not a requirement, it is good practice to ensure proper placement of girders and to have a record of such. Furthermore, proper planning for weather conditions was evidently not performed because construction was halted at a very inopportune time in the construction sequence. The deck was not in place, and the beams had little lateral support for several winter months. If the construction necessarily had to be halted during this time, either INDOT or the Engineer should have been consulted to determine any deleterious effects of this break in construction such as creep or lateral instability of the beams. Remedies such as not stressing the tendons in the first place or increasing temporary lateral support could have been employed to counter these effects.

Regardless of the time-dependent effects on the stressed beams, poor care was given to the protection of the prestressing steel. The subsequent issues should be prefaced by the fact that there was no direct evidence of corrosion damage to the prestressing steel. Nevertheless, protection of prestressing steel is known to be very important, and the deficiencies of that protection on this project are outlined below. First, five of the six tendons were stressed and grouted, and the prestressing steel was inserted in the sixth tendon duct at the same time. Placement of any of the prestressing steel should not have been allowed to occur without assurance that stressing and grouting could be completed within a reasonable time frame, which is generally 20 days for moderate weather and humidity conditions. Though this is now standard practice, the less restrictive specification at the time of this construction project required a corrosion inhibitor to be used when the time frame exceeded 20 days. However, there is no evidence any inhibitor was used, and it is not known why the prestressing steel was allowed to remain unprotected in the ducts for many months. After construction was halted, the prestressing steel in the sixth tendon should have simply been removed.

Failure of the wedges in the sixth tendon could have easily been avoided. Simple visual inspection of the entire tendon before stressing would have revealed corroded and damaged wedges, which for safety and practical reasons should never be used. Regardless of when the strand is inserted in the duct, wedges should only be placed in the anchorage immediately prior to stressing and should be protected from corrosion wherever they are stored.

The specifications for this project were relatively complete and were not the primary cause of problems. The problems associated with this bridge structure were primarily related to contractor and inspector inexperience. Also, the lack of communication between the contractor and design engineer contributed to the problems experienced. For the most part, these issues were corrected as evidenced by the reported success of the second phase of this project.

### 3.4 Summary and Conclusion of Case Studies

Considering these case studies, the issues that have arisen in post-tensioned projects constructed in Indiana are quite varied. These construction problems, however, appear to have become fewer and less severe as all parties, including INDOT, have gained more experience with post-tensioned construction. The bridge with the most problems, US 231 over the Wabash River, was constructed much earlier than the other bridges. The problems with this bridge were caused by a combination of insufficient specifications as well as contractor and inspector inexperience. Even for that bridge, the consultants hired to perform the investigation noted that the problems were concentrated in the portions of the bridge constructed early in the project, and the construction practices improved during the span of that project.

For the more recent projects, the construction issues, though post-tensioned related, were not caused explicitly by the use of post-tensioned construction. For Bridge No. 13 at the Borman Interchange, most of the construction issues were the result of poor communication between the contractor and design engineer as well as weather and time conditions that were not properly accounted for during the construction process. On the other hand, several issues arose as the result of bad construction practices that were inconsistent with the specification at that time, though these issues did not result in any unresolvable long-term problems. A few of these issues included exposing the strand and wedges to corrosion given the amount of time they were exposed to the environment. For the I-70 Airport Interchange bridges, the issues encountered were material related, though these problems were somewhat accounted for in the post-tensioning specifications.

In summary, the conclusions for the case studies are as follows. Most of the problems encountered could be alleviated through additional experience by both the contractor and construction inspectors as well as knowledge of proper post-tensioning procedures. Though the increase in experience will only come over time, a requirement for certification training for contractor foremen, grouting personnel, and construction inspectors should be employed. The Post-Tensioning Institute offers training certification for both bonded and unbonded post-tensioned construction, and these courses are a requirement of several departments of transportation for construction foremen as well as inspectors. The “Level 1&2 Bonded PT Field Specialist” is a general program for all bonded post-

tensioned construction and should be required, at the very least, for all construction inspectors and contractor foremen. Also, the American Segmental Bridge Institute offers a training certification specific to grouting and awards an “ASBI Certified Grouting Technician” certificate upon successful completion of the program. Due to the importance of grout in tendons, all personnel involved in the grouting process, including construction inspectors, should have this certification.

Lastly, the current post-tensioning provision used by INDOT is not current with standard post-tensioning practices. A new recommended provision, developed by revising the previous provision employed by INDOT, will be presented in the next section.

#### 4. DEVELOPMENT OF A UNIQUE SPECIAL PROVISION

A special provision was developed to provide uniformity and consistency in post-tensioned construction for the State of Indiana. This new specification includes several modifications as well as additions to the current INDOT provision. The layout was also changed to be in accordance with other INDOT Recurring Special Provisions. The provision incorporates new standards for materials and construction and references recently released specifications by PTI and ASBI that are becoming commonplace among state DOT specifications. The reference specifications include the “Guide Specification for Grouted Post-Tensioning” (4) and the “Specification for Grouting of Post-Tensioned Structures” (5). The provision only includes modifications of and additions to these specifications specific to INDOT or includes provisions that are more restrictive or explicit than those of the reference specifications.

##### 4.1 Notable Changes

Notable changes from the past provisions are summarized.

###### 1. Layout

The layout of the special provision was designed to be consistent with existing INDOT Recurring Special Provisions. The provision begins with the Description and General Design Requirements and continues with Submittals and Construction Documents. The provision then includes more specific material and construction specifications.

###### 2. Prestressing System Design and Scheme

The prestressed system must be designed and constructed in accordance with PTI/ASBI M50.3-12 “Guide Specification for Grouted Post-Tensioning” (3). This Specification outlines material requirements, installation and construction requirements, and provides options for tendon protection levels. The recommended special provision requires that the prestress system shall be designed for “Protection Level 2.” This protection level is designed for moderately corrosive environments and, in general, requires plastic duct and construction methods to ensure leak-proof connections.

###### 3. Submittals

Submittals are also grouped together. While some construction submittals are listed throughout the special provision, the most important submittals are summarized in the “Submittals and Construction Documents” section. Of particular note are submittals for a duct pressure test and a grouting plan and report. These submittals and reports were either nonexistent or insufficient in the previous provisions.

###### 4. Grout and Material Testing

Only Class C pre-packaged grout is to be used, and up-to-date laboratory tests are prescribed including set time, grout strength, permeability, volume change, fluidity, bleed, and wet density. A grout trial batch and report, to be approved prior to grouting, is required, and production tests during grouting are to be conducted.

###### 5. Personnel Qualifications

Personnel qualifications for post-tensioned related construction are grouped together. Significant updates to requirements for foreman and specialists for both grouting and stressing are provided.

###### 6. Duct Construction Practices

Locations of grout duct inlets and outlets are specified, notably an outlet beyond the high point in the direction of grouting. Recent practice has shown this outlet is very important for eliminating grout voids in the duct. Prior to concrete casting, a duct pressure test must be conducted. The values included in the special provision are standard practice according to PTI, and higher pressures, which are required by some departments of transportation, are considered unnecessary. These values are based on the assumption that internal ducts are used. If external ducts are used, the special provision requires that the Engineer be consulted for proper test procedures and pressures.

###### 7. Grouting Procedures

In general, the recommended special provision follows the PTI Committee M-55.1-12 “Specification for Grouting of Post-Tensioned Structures” (5). The recommended special provision includes a more specific plan for grouting and specifies the general order in which inlets and outlets should be used. The provision also prohibits any flushing of tendons or ducts with water at any time. Though flushing was common practice in the past, especially in the event of blockages and after the use of corrosion inhibitors, experience has shown that excess water remains in the duct no matter the level of effort to remove it. As a result, the excess water leads to the formation of water pockets after grouting or, at the very least, an increased water-to-cement ratio for the final set grout. Either case is detrimental to the long-term reliability of the duct and prestressing steel. In the event of a grout blockage, grouting should continue at the next available duct inlet until one-way grouting is possible with allowable grouting pressures. After the grout sets, invasive tests should be conducted to check for voids, and vacuum-grouting should be performed as necessary.

#### 4.2 Summary of Unique Special Provisions

The recommended provision references industry specifications and only changes or adds provisions

specific to Indiana or includes provisions that are more restrictive or explicit than those of the reference specifications. Because of this format, updating the special provision is a relatively simple task. The referenced standards will be required to be updated to newer editions, and only Indiana-specific additions will be required.

## 5. RECOMMENDED TRAINING FOR INDOT CONSTRUCTION INSPECTORS

In addition to contractor and specification issues, the lack of experience and training of INDOT construction inspectors contributed to the previous post-tensioned construction problems experienced by Indiana. Accordingly, required training and certification of inspectors overseeing post-tensioned projects in Indiana are recommended. The training and certification is similar to that required by construction foremen and personnel outlined in the recommended special provision.

Inspectors present during any post-tensioned construction should have the PTI Certification of “Level 1 Bonded PT—Field Installation.” This certification requires attendance of a three-day workshop provided by PTI and successful completion of an exam administered at the conclusion of the workshop. This certification workshop provides an overview of standards of practice and proper safety regarding all bonded post-tensioned construction. In addition to the PTI certification, inspectors present during any grouting operation or grout material testing related to post-tensioned construction should have an “ASBI Grouting Training Certificate.” This certificate requires attendance of a two-day workshop provided by ASBI and successful completion of an exam. Similar in nature to the PTI certifications, this program and certificate is specific to the standards of practice for proper grouting and grout material testing.

While these recommended requirements provide minimum training for inspectors, it is desirable for inspectors to have more advanced certifications from these programs. Specifically, PTI offers a “Level 2 Bonded PT—Field Specialist” certification that, in addition to the requirements provided above, requires a “minimum of 1500 hours of verifiable field experience, with 500 hours in each of the three categories (installation, stressing, and grouting).” ASBI offers a certification of “Certified Grouting Technician” that, in addition to the requirements provided above, requires “verifiable documentation of three years of experience in construction of grouted post-tensioned structures.” While this experience may not be feasible for inspectors in Indiana due to the infrequent use of post-tensioned construction, it would be advantageous to use inspectors for these projects that have training as well as experience in this type of construction.

It should be noted that these recommendations assume the inspectors are monitoring bonded PT construction. In other cases, PTI offers certification programs such as

“Unbonded PT Inspector” for unbonded construction. Inspectors should receive training in the type of construction they will monitor.

## 6. SUMMARY

Due to problems in Indiana involving post-tensioning, this project was initiated to evaluate problems experienced in past projects and provide recommendations to improve future post-tensioned projects. As part of the evaluation, case studies were conducted of three post-tensioned projects in Indiana that experienced problems. In general, these problems were attributed to a lack of experience of contractors and inspectors as well as the lack of an up-to-date provision for post-tensioned construction. These problems can be remedied through the following.

1. An up-to-date special provision that includes up-to-date specifications developed by the industry. These specifications include current standards of practice which are beginning to be accepted nationwide. In addition, these specifications cover a range of post-tensioned related construction aspects including personnel requirements, tendon stressing, and tendon grouting procedures.
2. Training and certification requirements of construction inspectors. The recommended requirements are similar to those for construction foremen and personnel outlined in the recommended special provision.

Many of the problems experienced by Indiana have been experienced by the industry as a whole. Due to significant issues experienced by other states, the post-tensioning industry has learned much and worked to improve both practice and performance. This form of construction is much more reliable than in the past based on this continuous improvement and can provide significant design advantages. Through the changes recommended here, reliability of post-tensioned construction in Indiana can be improved and provide added confidence to the successful deployment of this bridge technology.

## 7. PROPOSED FUTURE RESEARCH

This report addressed problems of bonded post-tensioning experienced by INDOT, which were also experienced by the industry as a whole. These problems can be addressed by improvements to specifications and construction practices, but issues still exist for bonded post-tensioning. Notably, though there may be confidence when a tendon is thought to be properly grouted and encapsulated, no direct form of inspection exists to verify the condition of the tendon. Efforts to visually inspect post-tensioning tendons results in local damage, which leads to concerns for future reliability due to the exposure of the tendons to the environment, even temporarily. Additionally, inspection to ensure 100% grouting of tendons requires extensive non-invasive inspection and intermittent invasive drilling for calibration, which can lead to the same durability issues.

As a result of these inherent inspection problems, some countries in Europe have recently shifted toward unbonded post-tensioned construction and the use of grease encapsulated strand for corrosion protection. This method of construction can provide the same structural advantages as bonded post-tensioning with significantly improved inspection abilities. Simple methods can be used to verify tendon condition such as visual inspection with videoscopes and evaluation of tendon force with periodic anchor lift-off tests.

Research is needed to develop new materials that can be used to provide improved corrosion protection of prestressing strand while also permitting future inspection capability. There are numerous research possibilities for developing non-destructive test methods for inspection of bonded and unbonded post-tensioned structures.

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## About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: <http://docs.lib.purdue.edu/jtrp>

Further information about JTRP and its current research program is available at: <http://www.purdue.edu/jtrp>

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