Unique and Effective Sampling Method Saves Money and Time

Bridge Post-Tensioning Inspection, Assessment and Evaluation Project

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Figure 1: Cline Avenue Bridge Structures

After nearly 20 years of serving northwest Indiana near Gary, the Cline Avenue Bridges had begun to show signs of their age. But not all changes in the bridges' appearance were typical of a 20-year-old overpass. Inspectors for the Indiana Department of Transportation (INDOT) had observed unusual patterns of cracking, spalling and efflorescence in the bridge. Recent National Bridge Inspection Standard (NBIS) inspection efforts identified significant longitudinal and transverse cracking in the bridge deck, as well as cracking in the webs and diaphragms.

In addition to the observed cracking, INDOT – like many state DOTs – had grown concerned about the condition of the post-tensioning (PT) tendons within its bridges and the quality of the protective grout. Since the late 1990s, when Florida DOT inspectors found significant grout voids and broken tendons within some of its bridges, the segmental bridge industry has worked to improve the quality of grouting in new bridge construction. These improvements include a new grout specification by the Post-Tensioning Institute (PTI) and a technician certification program administered by the American Segmental Bridge Institute (ASBI). Given this heightened awareness of tendon condition and grouting quality, INDOT wanted to be certain that the PT system in the five Cline Avenue structures were performing as expected.

In 2003, INDOT embarked on a program to assess the condition of the Cline Avenue Bridges. A specialized team to inspect, assess, analyze and evaluate the structures' performance was formed. A critical component of the inspection effort required the balance of experience and field leadership between the project engineer – Frost Engineering & Consulting -- and VSL – a leader in post-tensioning--to perform the post-tensioning inspection portion of the bridge inspection. In addition, with a creative statistical and systematic approach to performing the testing, inspection, analysis and evaluation, the team saved INDOT more than nine million dollars in testing and inspection costs with a commensurate reduction in project duration and focused "hot spot" inspection and testing effort.

Tackling the Big Bridge

The Cline Avenue Bridges are predominately cast-in-place, post-tensioned multiple cell box girder bridges spanning the Indiana Harbor Canal along Indiana State Route 912. The mainline bridge has a 6,520-foot length consisting of two parallel structures, each measuring nearly 35 feet wide. Four connecting ramps, with post-tensioning construction, are also part of this structure that stands 100 feet over the canal. With 53,000 cubic feet of concrete and 7.5 million feet of post-tensioning, the Cline Avenue Bridges presented a monumental inspection and evaluation undertaking.

In a typical bridge inspection, every post-tensioning tendon would be visually inspected. The estimated cost for a complete visual tendon inspection for these structures was estimated between twelve and fifteen million dollars, which was not economically feasible. Using the team's extensive capabilities, including VSL's experience on the Massachusetts Central Artery/Tunnel project, an approach to investigate the very large amount of post-tensioning tendons was identified. A sampling method, as established by the American National Standards Institute (ANSI), was selected. This method calls for testing a smaller statistical sampling of the PT tendons on the project to determine whether the entire structure passes or fails its inspection. Using this proven guideline approach provided the team with a high degree of confidence that the inspection findings would be representative of the condition of the post-tensioning system in the entire bridge.

The Sampling Method

The ANSI statistical sampling method is primarily used in the manufacturing industry. In the manufacturing process, a plant does not inspect every item it produces. Instead, the plant uses a statistical sampling method and tests only a portion of its product in a given lot. If the sample passes inspection, the lot is determined to pass. However, if the lot fails inspection, 100 percent of the lot must be inspected.

Cline Avenue Bridge Inspection Team

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Inspection Contractor
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NDT Consultant and Materials Testing
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Figure 3: Crew inspecting and recording the condition of the grout and strand using a video borescope

For the Cline Avenue Bridge project, the inspection team defined a statistical sample pool, which consisted of the mainline structure and the ramps, by referencing the ANSI guideline *American National Standard, Sampling Procedures and Tables for Inspection by Attributes* as published by the American Society for Quality Control (1993). The team used construction plans for a quantity take-off for the total number of tendons in the structure. The approximate total number of tendons is 1,079, which corresponds to the lot size range of 500 to 1,200 in the ANSI guidelines. Following ANSI guidelines, the team determined the sample size to be 80 tendons, based on this lot size and the bridge's particular conditions.

Figure 5: Crew drilling inspection hole into tendon duct

Next, the team had to establish the acceptable and rejectable thresholds, which ultimately define a passing or failing lot. In order to find the thresholds, an Acceptable Quality Level (AQL) had to be established. According to the ANSI guidelines, "The AQL is the maximum percent non-conforming … that, for the purposes of sampling inspection, can be considered satisfactory as a process average." Although derived from a complex mathematical equation, the AQL can be thought of as the maximum percentage of failures within a sample lot that corresponds with the overall acceptability of a given product. In the case of the Cline Avenue Bridge, the product is the installed post-tensioning tendons. The AQL designated for the bridge's installed post-tensioning tendons was 2.5. This number indicates that if about 2.5 percent or less of the tendons had failed for one reason or another, the remaining sample pool (and therefore the entire structure or the acceptable lot) being represented is still satisfactory. That is, it passes the inspection.

For the Cline Avenue Bridge sample size, ANSI guidelines state that five or less non-conforming samples (tendons) still allow for the lot to be accepted, while six or more non-conforming samples (tendons) call for the lot to be rejected. If the lot is rejected, further sampling shall be performed to provide assurance of the state of the structure.

The Inspection

Inspection of the Cline Avenue Bridge's post-tensioning began in March of 2004 after plan review, defining the scope of work and preparation of contingency plans. The field effort identified the probable void locations throughout the structure's mainline segments and ramps to distribute the sampling population appropriately. Such areas consisted of high points, areas approaching and leaving the high points, and couplers.

Using non-destructive ground-penetrating radar (GPR) and field layout drawings, the team of VSL and CTL Group (Skokie, IL), the non-destructive and materials testing firm, located mild steel and ducts for the post-tensioning tendons. This was a necessary step to investigate and identify high-potential void locations for the post-tensioning tendons, which could lead to significant corrosion of the tendons. An inductive probe was used to identify the location of the metal duct during drilling operations. Once the tendons were exposed, the level of corrosion, section loss, void length and void volume was documented and recorded. Recording of the inspection was possible through a video borescope, which detailed the condition of the tendons and also the void length. Video recordings were also collected for future reference. The grout was tested at some, but not all of the locations. Where the testing was performed, documentation was collected and reported. As part of the inspection and testing effort, additional tests were completed to test for the levels of chloride in accordance with ASTM testing.

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Table 1 Summary of Findings – PT coupler data is not included

	Pass/Fail Initial Test	Total # Tendons	# Tendons Inspected	# Voids	#Voids with Exposed Strand	# Voids with Corroded Strand
Mainline	Pass	840	80	2	0	0
Ramp A	Fail	87	87	2	2	0
Ramp B	Fail	24	24	6	1	0
Ramp C	Fail	72	72	21	5	0
Ramp D	Pass	40	14	2	0	0

Soon after the testing of the 80 tendons in the tendon sample, the team realized the sample would fail the inspection based on initial findings. According to the project action plan set-up through the use of ANSI, inspection of 100 percent of the bridge's tendons would be the next step – a process INDOT had hoped would be unnecessary from the beginning of the evaluation. The team completed a re-evaluation of the data and since most of the failures were occurring in ramp C, the team proposed an alternate to re-testing 100 percent of the post-tensioning tendons.

Figure 4a: Example of corrosion – Duct Void

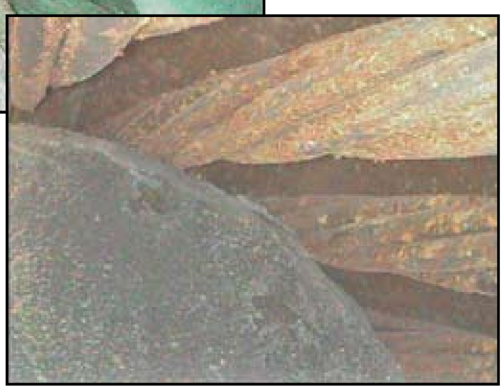

Figure 4b: Example of Level 1–2 Corrosion

ANSI guidelines allow for various scenarios of sampling to be performed in order to most accurately reflect the quality of the product being sampled. In an effort to better match the initial findings with the overall status of the bridge, relying on a one-lot sample was no longer the ideal scenario since most of the failures were occurring in one area. Based on this observation, the team divided the bridge into five separate lots (the mainline and ramps A, B, C and D), and treated each lot as an individual inspection. The extended sampling effort allowed for a consistent approach in identifying and determining the valid and useful data.

When the five-lot sample was tested, the mainline and ramp D passed inspection. However, samplings from ramps A, B and C failed inspection. Following ANSI guidelines, the team then performed a 100-percent inspection of the post-tensioning tendons in these ramps. Because these ramps were smaller structures, a 100-percent inspection was more feasible than performing a 100-percent inspection on the entire bridge.

When the team performed the 100-percent inspection of ramps A, B and C, one more lot was added to the inspection. During the inspection testing effort, one of the goals was to identify the sensitive links of the structure and ensure these components were secure and offered a reasonably high level of performance and capacity. One of the key components of these post-tensioning systems is the performance of the couplers. As a measure of safety, the Team decided to focus in on the coupler location and assess each relative to potential for corrosion and decay. As such, the team also inspected 100 percent of the couplers in the entire bridge. Each coupler was a sample lot. The couplers passed with a minimum fair condition state.

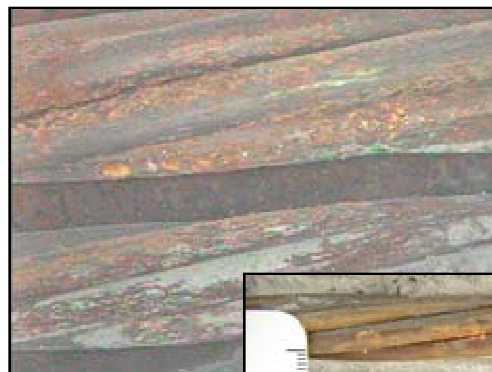

Figure 4c: Example of Level 4 – 5 Corrosion

Figure 4d: Example of Level 5 – 6 Corrosion at Coupler

After review of each inspection, VSL placed epoxy in the borescope hole to protect the tendons from air and moisture intrusion. Whenever the field team found a void in the tendon inside the duct, action steps for repairs were taken but only after full inspection, documentation and assessment of the tendon condition was completed. VSL used the vacuum grouting technique to fill the void. In this technique, a vacuum pump extracted air from the void. Then grout was added to the void.

Figure 2 Hooking up vacuum grouting equipment to a tendon void

Forms were used to record the activity, including void volume, grout volume used to fill and final pressure to secure grout seal. The team observed and documented the strand's condition based on the Precast/Prestressed Concrete Institute (PCI) Journal guideline, *Evaluation of Degree of Rusting on Prestressed Concrete Strand*, May/June 1992.

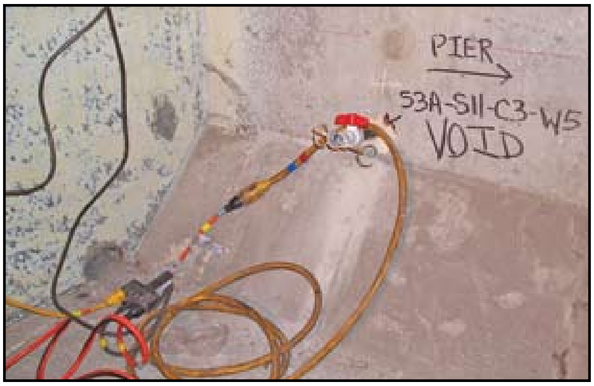

Figure 6: Hooking up vacuum grouting equipment to a tendon void

Inspection Findings

The inspection and testing effort encompassed three specific areas of focus: post-tensioning inspection and testing, crack re-inspection and field finding inspection/testing. The focus of this article is on the post-tensioning aspects of the project.

Table 1 summarizes the findings of the inspection. Ramps A, B, and C failed the statistical sampling test performed in accordance with ANSI. For these sample lots, 100 percent of the tendons were inspected. The table indicates the total number of voids found inside the PT ducts at high points to be 33. Most of the voids had no exposed strands. *Figure 4* shows a tendon void where the strands are completely covered by grout. Of the total number of voids, 8 were large enough to have exposed strands.

The exposed strands exhibited various levels of corrosion (*Figure 4*). The observed level of corrosion was classified according to the corrosion chart in the PCI Journal article, *Evaluation of Degree of Rusting on Prestressed Concrete Strand*. A classification of level 4 or less was considered mild corrosion with no loss of cross-sectional area. Areas with exposed strands and corrosion levels greater than 4 were noted and itemized as areas for future monitoring and inspection efforts.

In addition to the findings represented in Table 1, the team found significant incidence of exposed strand with corrosion level of 5 or higher at the PT couplers in the Mainline and in Ramp C. These areas were also noted and itemized as areas for future monitoring and inspection efforts.

Summary of Concluding Recommendations

The results of the post-tensioning portion of the Cline Avenue Inspection confirm that the post-tensioning system, for the most part, is continuing to perform as originally intended. Although voids were observed at some of the tendon high points, there exists little corrosion and loss of cross-sectional area of the strand for a majority of the strands. The exception is at a few specific points of coupler duct voids and the post-tensioning coupler locations. Results of the sensitive areas and the coupler inspections indicate significant voids with corrosion resulting in some loss of cross-sectional area.

The statistical sampling approach used on this project proved an effective tool, which saved the Indiana DOT significant time and money. The inspection, testing and evaluation team is offering the following concluding recommendations related to post-tensioning system inspection:

Figure 7: Access to the bridge was by 120-foot boom-lift

1. Because of the significant cracks found in the crack mapping and inspection phase of this project, regular inspections of the post-tensioning system will continue.
2. Incorporate the inspection approach, process and findings developed herein into the Bridge Inspector Training program.
3. Incorporate the analysis approach, process and findings developed herein into the evaluation of complex structures through out Indiana.(Please note that a full discussion of the analysis "layering" approach was not discussed in this article. In short, the analysis incorporated a systematic approach to encompass the design drawings, field findings and analyses to develop bridge load ratings.)
4. Incorporate the inspection approach, process and findings developed herein into the remaining Post-Tensioning bridges throughout the INDOT population.▪

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Don Kline, P.E. is currently principal and founder of Kline Engineered Concrete, LLC in Manassas, VA. He serves as voting member of ACI 423, prestressed concrete. This project was completed while Mr. Kline was employed with VSL in Springfield, VA. Don can be reached at ***dkline@klineengineered.com.***

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