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GROUTED POST-TENSIONING TENDON EVALUATION

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The corrosion of post-tensioning (PT) tendons leading to wire/tendon break or, if not identified and repaired, to bridge collapse is a serious problem for bridge owners. Water bleeding and grout segregation from conventional portland cement grout and improper grout practice have created pockets of voids and water/moisture in many bridges. Water or sufficient moisture presence and corrosive ion concentration has caused corrosion in tendons. Some improper repairs have even accelerated corrosion of post-tensioning tendons. The key is to understand the conditions of post-tensioning and causes of its deterioration.

This paper first discusses the causes of post-tensioning corrosion, then introduces post-tensioning evaluation techniques and process. The PT evaluation of a bridge in British Columbia was completed recently and will be presented as a case study.

The evaluation techniques include nondestructive testing (NDT) and destructive testing. NDT includes locating tendons with ground-penetrating radar (GPR), detecting grout voids with impact echo, drilling holes for air testing, moisture testing, and borescoping to inspect the tendon conditions. Destructive testing includes excavating the cover concrete to expose the tendons for visual inspection and taking a grout sample for lab testing. The evaluation process starts from locating tendons, detecting voids, narrowing down the hot spots for borescope and then narrowing down hot spots further for destructive testing.

KEYWORDS

corrosion; grout; post-tensioning tendon; voids.

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INTRODUCTION

Prestressed concrete bridge construction offers a wide range of engineering solutions and variety of aesthetic opportunities. A properly constructed post-tensioned (PT) concrete bridge can be very durable due to reduced cracking and multiple layers of protection. Corrosion protection of post-tensioned tendons is essential for structural integrity and long-term durability.

However, over the years, PT tendon failures have been found due to corrosion. Understanding the causes of the PT corrosion and evaluating the existing conditions are the key to address PT corrosion.

This paper first discusses the corrosion problems of grouted post-tensioning, then presents various PT evaluation techniques from the simple visual inspection to advanced nondestructive void detection with ultrasonic impact echo technology.

CAUSES OF POST-TENSIONING PROBLEMS

Post-tensioning problems are primarily grout problems. Bonded post-tensioned structures are at increased risk of corrosion and failure of the tendons when there are defects in the installed grout. The most common grout problems (defects) include:

1. *Grout voids and strand interstitial space*

   Grout may not be able to completely fill in the interstitial space between wires and between strands, especially conventional portland cement/water grout. Commonly, voids are a result of grout bleed, where excess water floats to the top of the grout through the interstitial spaces between wires and between strands, resulting in a pocket of water or a void if the water was re-absorbed into the grout, which in turn makes the top layer of the grout have a high water-cement ratio (w/c) resulting in porous, white and chalky grout. Grout bleeding is a normal occurrence and typically ranges between 3 and 5% of total grout volume if standard cement/water grout used. Voids may also be created as a result of incomplete filling of the ducts or grout leakage, which may occur prior to hardening of the grout.

2. *Variations in grout properties*

   Grout is intended to provide a uniform, protective environment around post-tensioning strands. Variations in grout properties create variations in corrosion potentials, which can initiate and sustain corrosion. A variation in properties such as pH, density, porosity, and chemical composition (for example chlorides sulfates) can result in corrosion.

   Excess water used with prepackaged grouts can result in segregation and creation of a section of porous and/or soft grout with a different chemical composition than solid grout. Excess water in cement/water grouts can result in the presence of a soft, chalky, porous upper layer of grout in addition to the voids caused by the bleeding mentioned earlier. These conditions can hasten corrosion initiation without the need for other environmental contaminants.

3. *Soft grout*

   Soft grout is grout that does not harden and cure, and appears soft. The Florida Department of Transportation defined that grout is soft when penetration by an awl with 10 to 15 lb (44 to 67 N) of force is more than 1/16 in. (1.6 mm).[1] A high water/moisture content promotes grout deficiency.[2] The causes of high water/moisture content can be excessive water added during grout mixing and pre-exposure to a high level of humidity. And wick-induced bleeding and grout segregation may cause localized deficient grout with high water/moisture content.

4. *Local concentration of sulfate and chloride content*

   A high concentration of sulfate and chloride contents can be accumulated in deficient grout locally without external source due to grout segregation. Local concentrations of chloride and sulfate have an adverse effect on PT steel corrosion development in the case of low-level chlorides. Corrosion occurs when sulfate ion concentration is greater than 0.07% by weight of grout power.[2]

Other factors including dissimilar metal and chemical contaminations may also cause PT corrosion.

PTI has done tremendous work to improve grouting specification. The majority of problems can be avoided by enforcing PTI M55.1-12, Specification for Grouting of PT Structures,[3] to make sure of the proper material selection and adequate qualification of grouting crew. PTI/ASBI M50.3, Specification for Grouted Post-Tensioning, requires the foreman of each grouting crew to be certified as **PTI Level 2 Bonded PT Field Specialist** and **ASBI Certified Grouting Technician.** In addition, at least 25% of each crew are required to be certified in **PTI Level 1 Bonded PT – Field Installation.**

POST-TENSIONING EVALUATION TECHNIQUES

Post-tensioning evaluation techniques vary from simple visual inspection to advanced ultrasonic impact echo void detection, which can be used alone as well as in a combination to have a more complete evaluation.

Visual inspection

The visual inspection focuses on identifying cracking, rust staining, spalling, and efflorescence (Fig. 1 and 2). These factors are strong visual indicators of corrosion activity and other forms of concrete deterioration. Cracking along the tendons can be a result of PT corrosion, as well as freezing and expanding of the water in the grout void.

Locating tendons with ground-penetrating radar (GPR)

Ground-penetrating radar (GPR) is a very quick and reliable nondestructive testing (NDT) method capable of identifying the tendon locations, layout, and concrete cover to the tendons.

Sonic/ultrasonic impact echo to detect grout void

This technique has been proven effective in locating voids and soft grout in post-tensioning grout (Fig. 3). A stress wave is created on the surface of the structure by a metal projectile and the resonant frequency is measured. Sonic/ultrasonic testing can detect a range of anomalies including voids, soft grout, soft grout layer surrounding hard grout, duct corrosion, and honeycombed concrete.

Borescope inspection

Once potential voids are identified with minimum destruction, small holes can be drilled and borescope inspection can be employed to evaluate the strand and grout conditions inside the ducts.

The borescope provides the unique ability to visually inspect extremely small and difficult-to-access areas. It

Fig. 1—Deteriorated beam exhibiting cracking, rust staining, spalling, and efflorescence.

is capable of capturing video and still images along with recording audio from the inspector.

Excavation for physical inspection and sample collection

After the borescope inspection, large openings can be made in selected locations to physically inspect the grout and tendon. Grout samples can be collected for lab testing.

Moisture testing

Moisture testing inside the tendon duct can be performed by passing a inert gas to measure the moisture level and verify the air communications of the tendon along its length, which identifies the possibility of moisture/water migration along the tendon and determines the feasibility of some corrosion mitigation techniques along the tendon length. Moisture tests may also provide indication of water presence inside the tendon sheath. Moisture content higher than 0.7% usually indicates high probability of PT corrosion.[4]

Lab testing

Lab tests include chloride content, sulfate content, and petrographic analysis to evaluate grout quality.

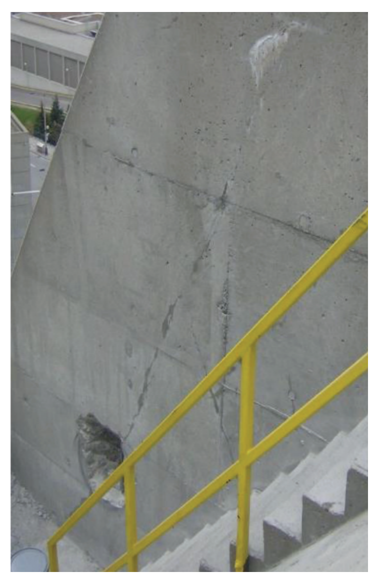

Fig. 2—Concrete showing efflorescence and cracking.

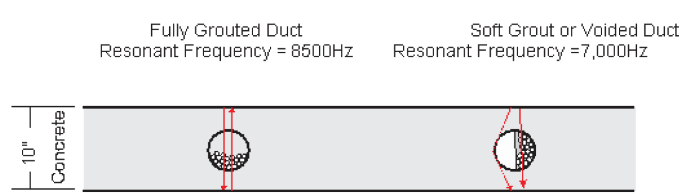

Fig. 3—Sonic/ultrasonic impact echo to detect grout void.

CASE STUDY

Post-tensioning evaluation was recently performed on a bridge in British Columbia. The bridge, constructed in 1993, was suspected of having grout issues in its PT ducts. Reports submitted by the inspector during construction of the bridge indicated that the contractor had trouble properly filling at least one of the ducts with grout from the center of the main span. The contractor then attempted to finish grouting the duct by placing grout from each end of the beam. Based on this inspector's report, the bridge owner wanted to see if grout issues did exist and to evaluate the current condition of the PT system in the main span.

The evaluation included:

- Visual inspection and sounding;
- GPR;
- Electrical continuity;
- Corrosion potential;
- Impact echo;
- Borescope inspection;
- Large openings for physical inspection and grout sample collection; and
- Laboratory testing:
  - Chloride concentration;
  - Grout pH; and
  - Petrographic analysis.

GPR was used to locate the tendons (Fig. 4), and then sonic/ultrasonic impact echo testing was performed to identify potential voids and soft grout areas. Two substantial possible voids of approximately 25 to 30 ft (7.6 to 9.1 m) were identified in one duct (Fig. 5). Small 3/4 in. (19 mm) holes were drilled to verify the presence of the voids, which found the voids were 28 and 33 ft (8.5 and 10 m), respectively.

A borescope was then inserted into the holes to evaluate the conditions of the tendon and grout (Fig. 6). Throughout the voids, corrosion product was observed along the strands. There were no observed broken tendons. It appeared that the wires near the grout had more severe corrosion than those further away from the grout. At each end of the voids, the grout was white, which is typically due to a high w/c at the grout surface because bleeding water from the grout traveled along the interstitial spaces between wires to the high point and created a layer of grout with high w/c at high points. The grout can be seen filling the duct and encasing the strands gradually. This transition typically occurred over only a couple of feet.

Once void detection and borescope testing were completed, locations were selected to create large openings so that grout samples from inside the duct could be collected for laboratory testing (Fig. 7). The cover concrete was removed using a concrete grinder wheel and chipping hammer. Then the galvanized ducts were opened using a chisel. Once the duct was opened, a chisel was used to collect grout samples for petrographic and chloride testing. After sampling and photo documentation of the

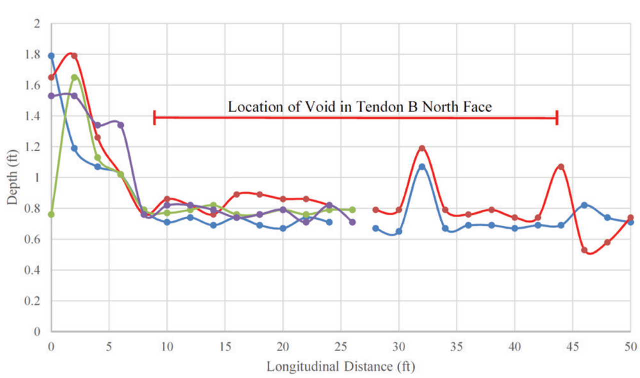

Fig. 4—Sonic/ultrasonic impact echo testing identified potential voids and soft grout areas.

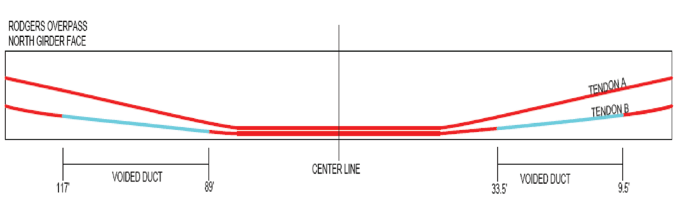

Fig. 5—Potential voids and soft grout areas.

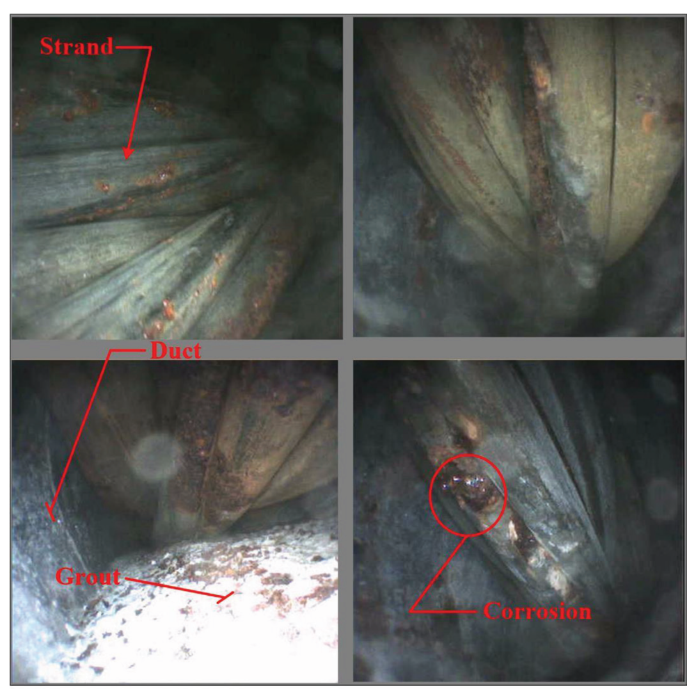

Fig. 6—Boroscope images confirming voids and corroded PT strands.

Fig. 7—Inspection opening in voided area.

opening, the metal duct was closed and the cover concrete was replaced with a fast-setting vertical patch material.

Air communication testing was then performed using the drilled holes and the large excavated opening. This verified the existence of the air communications, which makes some PT corrosion mitigation technology feasible for this bridge, such as PT impregnation.

Finally, lab tests were performed to determine the grout quality, which found the chloride content was low and had no carbonation. Petrographic analysis revealed that the w/c was approximately 0.33, calcium hydroxide was abundant, and the air content of the grout was in the range of 1 to 3%.

CONCLUSIONS

Many factors contribute to PT corrosion problems. The majority of problems can be avoided by enforcing the M55.1-12 specification to ensure proper material selection and the adequate qualification of grouting crew. This paper has described the technologies and techniques to evaluate PT corrosion. Once the problems are identified, a corrosion mitigation solution can be designed.

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