11th International Conference on Short and Medium Span Bridges
Toronto, Ontario, Canada
July 19 – 22, 2022

POST-TENSIONING INVESTIGATION IN PRECAST SEGMENTAL BRIDGES

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Abstract: Post-tensioned precast concrete segmental construction has been widely used and can be very economical when access to the site is restricted, especially due to environmental and/or traffic constraints. It is also chosen for its aesthetic appeal.

Post-tensioning tendons are the key structural elements in segmental bridges. In segmental bridges, there are typically a significant number of post-tensioning tendons in the top slab of the girder which are more susceptible to corrosion from chloride contamination than post-tensioned bridges cast on falsework which typically have the post-tensioning in the webs. Segmental bridges also have more anchorage locations that are susceptible to chloride contamination as each segment has its own set of anchorages located near the top surface of the deck. Compared to precast segments, the closure pours have poor quality and deserve more attentions. Proper and complete investigations of the tendons provide better understanding and knowledge of the condition of the tendons, which structural engineers can rely on to make well-informed engineering judgement and determine an applicable rehabilitation strategy where necessary to achieve long term service life for the structure.

This paper will describe various non-destructive testing and destructive testing methods to evaluate the condition of post-tensioning tendons and present some case studies including the Burnhamthorpe Road West Bridges over the Credit River, in the City of Mississauga.

1 POST-TENSIONING GROUT PROBLEMS

In precast segmental bridges the grout provides a high pH environment for passivating and protecting prestressing steel against corrosion. These steel strands are at an increased risk of corrosion and failure when there are defects in the installed grout (Figure 1). The most common grout problems (defects) include (Liao & Wong, 2017):

- Voids – Incomplete filling of the ducts with grout can result in water leakage into the voids prior to hardening of the grout. These voids are usually a result of grout bleed, where excess water in the grout floats to the top of the grout. This results in a pocket of water or a void, if the water later dissipates. Grout bleed was a common occurrence in the early application of PT structures with cement – water grouts and typically ranged between 3 and 5% of total grout volume. These voids often appear at the high point of draped PT strands (Figure 1).

- Variations in grout properties – Grouts in close proximity to the strand can develop 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 and sulfates) can also effect the rate and extent of corrosion. As shown in Figure 2, excess water when used with prepackaged grouts can also result in segregation forming a layer of porous and/or soft grout with a different chemical composition compared to good-quality grout. Excess water in cement/water grouts results in the presence of a soft, chalky, porous upper layer of grout in addition to the voids caused by bleed, as mentioned previously. It has been verified that variations in grout properties can hasten corrosion initiation without the need for other environmental contaminants.

- Chloride contaminated grout - The effect of chlorides to initiate corrosion is well known. Chloride contamination occurs in a number of ways, including exposure to chlorides in the environment, such as seawater salt spray coming in contact with the steel strands or accumulating in the ducts during construction

- Chlorides may accumulate over time if the structure is exposed to seawater or deicing salt. Susceptible areas include grout voids and tendons near joints or cracks in the structure.

- Grouts can be contaminated through the use of mixing water containing chloride. In some cases, the cement products themselves may contain chlorides.

Figure 1: Voiding of PT Grout at Anchorage

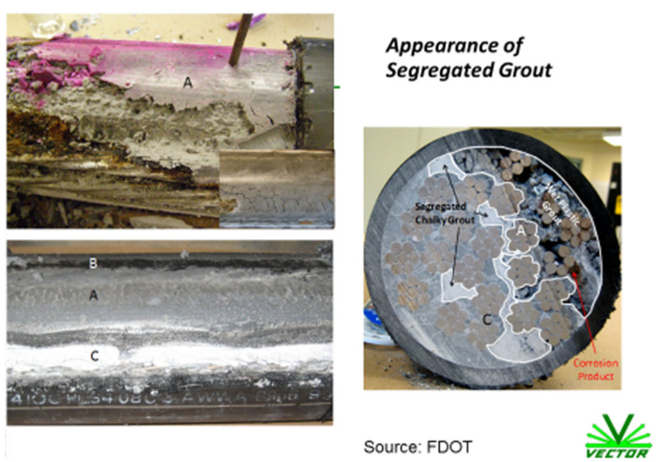
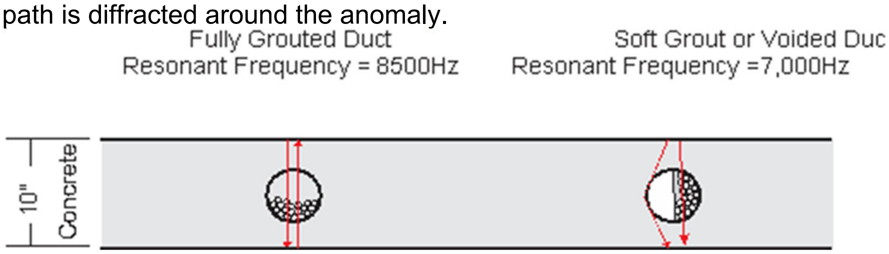
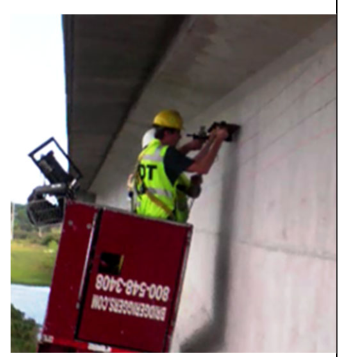


Figure 2: Segregation of PT Grout

2 INVESTIGATION OF GROUTED PT-STRANDS

There are several testing methods that can be used for investigating grouted PT tendons.

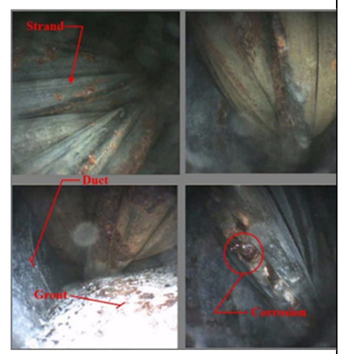
Surface Visual Inspection The visual inspection will focus on identifying cracking, rust staining, spalling, and efflorescence along the tendons. These factors are strong visual indicators of corrosion activity and other forms of concrete deterioration. The distribution and quantity of damaged areas will be recorded along with photographic documentation.	
Test Pit and Visual Inspection Inspect and record the conditions of the duct, grout and strands. Collect grout samples for chemical tests such as chloride, sulfate, and carbonation tests.	
Ground Penetrating Radar Ground penetrating radar (GPR) is a very quick and reliable non-destructive testing (NDT) method capable of identifying the steel reinforcing layout and concrete cover. GPR can be surveyed over an entire reinforced concrete structure to locate the steel reinforcement's position, spacing, depth of cover, and concrete thickness.	
NDT Ultrasonic/ Sonic Impact Echo Void Detection Ultrasonic/Sonic Impact echo is a non-destructive test that uses a projectile impact to create a compressional wave that propagates through the concrete thickness and the energy input is reflected back through the concrete from the back surface of the web/flange. This energy is trapped between the two surfaces and resonates at a frequency that is a function of the compressional wave velocity and concrete thickness. When anomalies are along the wave path such as soft grout or air voids (typical velocities – soft grout 4,000 feet/sec; air 1,000 feet/sec; concrete 14,000 feet/sec) it results in a longer travel path because the sonic ray path is diffracted around the anomaly.  	

Small Opening for Further Investigation

An auto shutoff drill will be used to drill holes at the selected duct locations, the drill will automatically shut off when contacting metal, which avoids damaging the tendons. Small openings of ¾ inch in diameter are created to verify the NDT ultrasonic/sonic impact echo results. When voids are found, a borescope inspection device is inserted to visually inspect the voids and strands. The drilled holes are also the inlets and outlets for the air testing.

Borescope Inspection

The borescope provides the unique ability to visually inspect extremely small and difficult to access areas. It is capable of capturing video and still images along with recording audio from the inspector. The borescope has an overall length of 3 meters, diameter of 4 mm, and a 360^{o} articulating head. The 3 meter cable length is made of stainless steel braid providing the necessary durability to the system for difficult and harsh environments. The cable is also able to penetrate into various liquids without harm to the device.



Water/Moisture or Air test

Air test can be performed to 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. Air tests may also provide indication of water presence inside the tendon sheath.

3 BRIDGE DESCRIPTION

The Burnhamthorpe Road West bridges are twin 5-sapn precast segmental post-tensioned box girder bridges built in the late 1970s. The structures have a West-East orientation in the City of Mississauga, Ontario. Each bridge carries 2 lanes of traffic across the Credit River with a total crossing length of 393m and a maximum clearance of 17.8m. The deck of each bridge has a travel width of 7.8m and an overall width of 10.85m.

With an AADT of 34,750 the crossing is heavily used with truck volumes accounting for 10 to 25% of the total traffic. The speed limit at this location is 60 km/hr. There is no load limit posted at this site. The structures underwent rehabilitation in 2008.

Figure 3: Bridge Aerial View

4 METHODOLOGY

The PT investigation utilized various methods to locate, identify and assess the condition of the tendons. The scope of investigation was limited to perform testing of as many cables as possible within the allowable road closures. The general procedure was as follows:

1. Locate, identify and mark out cable ducts using ground penetrating radar (GPR).
2. Visual inspection for the concrete along the tendons
3. Scan identified cable ducts with a sonic/ultrasonic impact echo test system to determine if any voids in the duct exist.
4. Drill verification holes into cable ducts to support results of impact echo scans.
5. Perform borescope inspection through the holes if voids are found.
6. Perform air test or moisture test through the holes if voids are found.

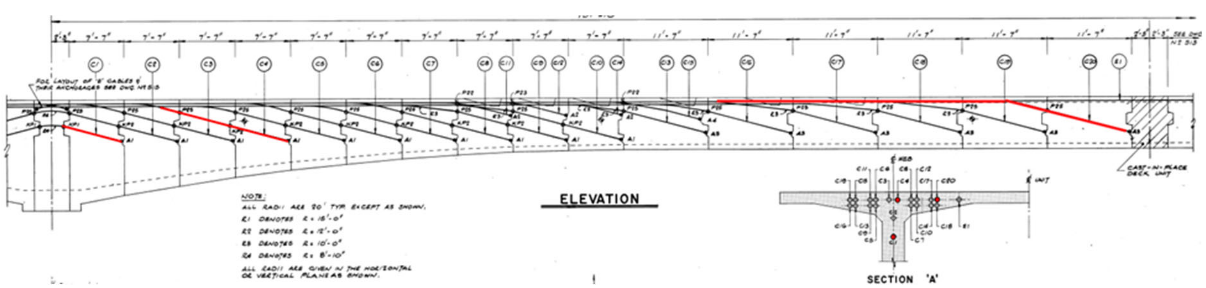


Figure 4: Typical Elevation View of The Burnhamthorpe Bridges

5 NONDESTRUCTIVE TESTING MEASUREMENTS

The nondestructive testing for void detection in the grout consists of two elements: ground penetrating radar (GPR) to locate the duct and sonic/ultrasonic impact echo testing to detect voided or soft tendon grout.

Ground Penetrating Radar (GPR)

GPR data was acquired using a digital 2700 MHz antenna. The GPR method uses a pulsed electromagnetic signal that is transmitted to, and reflected by, a target (in this case the metal PT strands inside the plastic ducts) back to the point of transmission. The electromagnetic wave transmission and reflection is dependent on the electrical properties (dielectric constant and electrical conductivity) of the material(s) being investigated. These electrical properties determine the velocity and reflection characteristics of the electromagnetic waves used to locate and determine the approximate depth of the ducts and reinforcing bars. The GPR system transmits and receives reflected pulsed electromagnetic signals obtained from a 2700 MHz antenna controlled by a miniaturized handheld radar control unit which displays, archives and provides data playback. The approximate center line of each tendon duct is marked on the concrete surface with different color keel (wax crayon)/ or chalk with 1-foot sonic/ultrasonic test interval points.

Figure 5: Tendon Locations Detected and Marked on the Wall

<u>Sonic/ultrasonic Measurements</u>

The testing performed falls under ASTM C1383 "Test Method for Measurement P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method". Sonic/ultrasonic and impact echo/resonant (multiple reflections) frequency measurements were obtained using a projectile impact energy source, a hand-held four-sensor array and a portable computer to archive and provide a quality control field display of data. Sensors were spaced 2, 8, 14 and 20 inches from the energy impact point for all testing. Continuous sonic/ultrasonic data were obtained for each tendon by positioning the energy source at one end of the array and incrementing the array every foot.

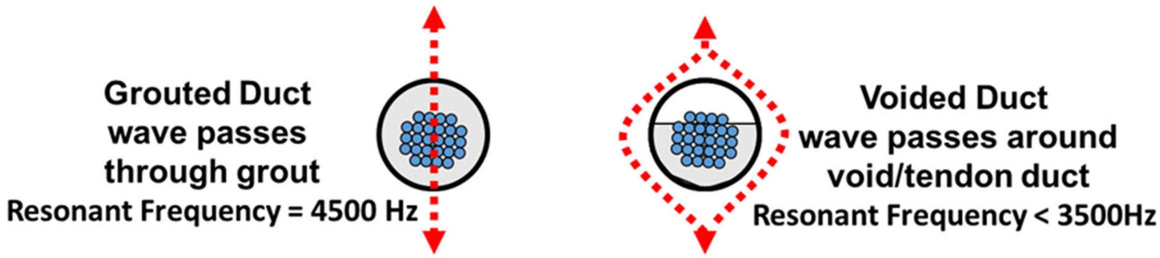


Figure 6: Sonic Wave Paths for fully Grouted and Voided Ducts

Figure 7: Sonic/ultrasonic Measurements

A PC (personal computer) is used to process, display and archive the data. A compressed inert gas supply system provides a consistent energy source for a hand-held impact projectile energy source. The projectile impact produces stress waves that are detected by an array of 4 sensors, each spaced 6 inches apart. Each sensor measures the amplitude of the stress wave in time (time-domain plot). The sensor array is placed at the marked 1-foot intervals along the duct. Time domain data are used to measure the compressional and shear wave velocity values (strength of deck concrete and evaluate for weak concrete that will affect impact echo data) and the frequency domain data is the resonant frequency (thickness) of the concrete elements being tested.

There are three primary data characteristics detected by the impact echo testing

- Fully grouted duct: Thickness frequency in the range of 4.1 to 5 KHz with no spurious resonant frequencies
- Fully grouted duct with brittle / fractured / weak grout, possible thin (<1/4 inch) voids or honey combed deck concrete: Thickness frequencies in the range of 3.5 to 4.0 KHz with spurious resonant frequencies
- Duct suspected of having soft grout or a void : No Full thickness frequency or a thickness frequency of 2.8 to 3.5 kHz spurious frequency.

6 RESULTS

6.1 Visual Inspection

A walkthrough visual inspection inside the box girders was performed, no delaminations and spalling along the tendons were found at the time of inspection.

Figure 8: Shear Key

Exterior inspection was performed, spalls were found at the closure strips between the segments, and at the anchor pockets of the transverse tendons on the hammer head piers.

Figure 9: Exterior Inspection: Corrosion & Spalling at Closure Strip, Spalling at Transverse Anchor pocket

6.2 Sonic/ultrasonic Impact Echo Scanning

In total 12 cables throughout the two structures were scanned. All cables were scanned at 12” intervals starting at the end anchors. See Figure 10 below. The scanning length was restricted to lengths where the cable was within the concrete structure but not inline with adjacent cables.

These frequencies are used to develop a sequence of images that collectively reviewed identify anomalous locations. See Figure 11 below for a sample of frequency reading. These readings were interpreted by a geophysicist prior to verification drilling. No lost, spurious or low frequencies were identified in any of the scan locations suggesting the absence of voids inside the tendon ducts.

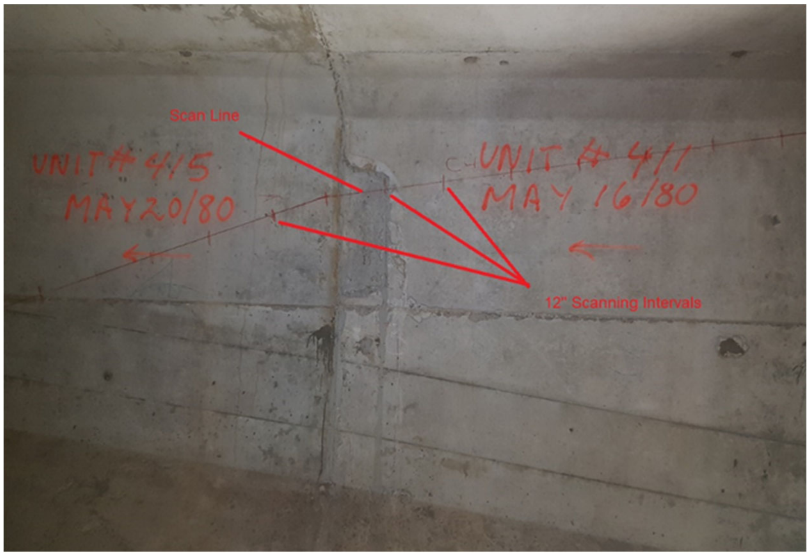


Figure 10: Scan Line with 12” Intervals

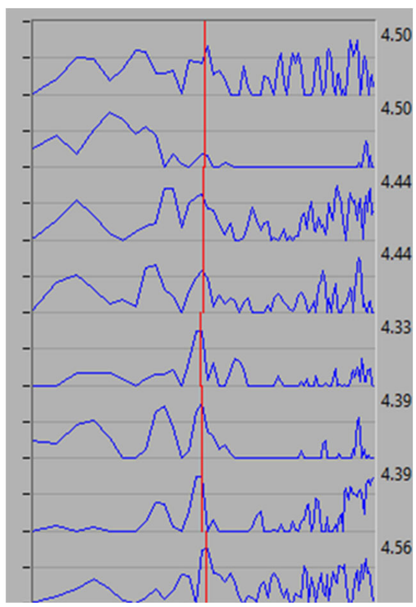


Figure 11: Typical Sonic Impact-Echo Frequency Record

6.3 Verification Drill Holes

Two locations were selected for verification drill holes. As the scanning data did not suggest any anomalies, locations for drilling were selected to represent high potential of void spaces, such as high point, transition areas between girder walls and ceilings, etc. Where possible, all drill holes targeted the top of each duct to maximize the potential to identify void spaces.

All drill holes penetrated the cable duct and solid grout was found behind the duct. No presence of moisture was identified in any of the drill holes. Individual wires were visible in the drill holes at three locations and showed no sign of corrosion.

The drill hole length was generally 7-9 inches in depth allowing review of the drill hole without any special instrumentation. Air communication was not attempted due to the lack of voids.

7 SUMMARY OF FINDINGS

No delamination and spalling along the tendon inside the box girders was found. Exterior inspection was performed, spalls were found at the closure strips between the segments, and at the anchor pockets of the transverse tendons on the hammer head piers.

Non-destructive testing with Sonic/Ultrasonic Impact Echo technology was performed for 12 tendons and no voids were found. Limited destructive testing with verification hole drilling was performed for 2 tendons. No voids were found and the strands appeared in good condition

Based on the findings from the PT investigation it was determined that the grout inside the ducts is sound and the PT strands are in good condition and did not require repair.

References

Liao, H. & Wong, E. 2015. Post-Tensioning Tendon Corrosion Evaluation and Mitigation. *Transportation Association of Canada*. St John's, Canada.