

# **Cable Impregnation for Post-Tension Grouting Problems**

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## **ABSTRACT**

Thousands of bridge structures utilize grouted high-strength, post-tension strands. Problems with grouting techniques and grout materials has resulted in bridges with deficient grout including voids, segregated grout, chloride contaminated grout and soft grout. These problems have promoted corrosion and failure of post-tension tendons, some within 6 to 17 years of service. The Florida Department of Transportation (FDOT) has spent more than \$55 million (USD) repairing 11 post-tension bridges to date.

A cost-effective corrosion mitigation technique has been developed to minimize the corrosion of post-tension bridges which have grouting issues.

This paper describes the development and implementation of this technique including application to grouted tendons of the Ringling Bridge (Sarasota, FL) and the I-95 / I-295 Interchange in Jacksonville, FL.

Keywords: post-tension, bonded, grout, tendon, corrosion, corrosion protection, cable impregnation

## **INTRODUCTION**

Post-tensioned (PT) concrete bridges are susceptible to corrosion if the post-tensioned tendons are not sufficiently protected from corrosion.

## **CAUSES OF POST-TENSIONING CORROSION**

Post-tensioning steel is susceptible to corrosion when it is exposed to corrosive conditions. Some of the conditions which may result in corrosion include:

- Voids in grout due to incomplete grouting and grout leaks
- Voids in grout due to grout bleed (may be caused by high water cement ratio)
- Presence of moisture/water and oxygen in grout voids
- Segregated grout
- Soft and putty grout
- Chloride contaminated grout
- High sulfate content in grout

- Concentrated chloride and sulfate content in localized areas, such as the interface between grout and voids or the interface between segregated and non-segregated grout.
- Contact between grouts with dissimilar properties (original grout and repairs/re-grouting)
- Contact between dissimilar metals



Figure 1. Corrosion evident in voids in a tendon duct near anchorage. (Florida Department of Transportation)



Figure 2. Failed tendon due to corrosion near anchor plate. (Florida Department of Transportation)



Figure 3. Failed tendon due to corrosion at interface between original Portland cement grout and new grout in re-grouted voids (Virginia Department of Transportation)

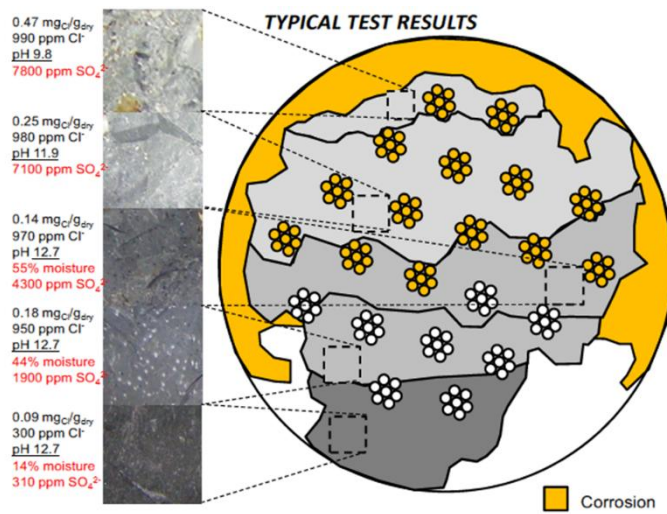


Figure 4. Post-Tension Tendon corrosion due to grout segregation. (Florida Department of Transportation)



Figure 5. Voids between wires, high water cement ratio grout and presence of chlorides does not provide adequate corrosion protection to the PT tendon.

Prior to the early 2000's, conventional Portland cement grout was typically used for filling Post-Tension ducts. It is common to find voids in grouted tendons in bridges where conventional Portland cement grout was used. Typical Portland cement grout will experience 3 to 5% bleed (by volume) and the bleed water will rise to the high points of the grouted section. After the bleed water evaporates or is absorbed into the structure, voids will remain in the grouted section. For a 50m long tendon, 4% bleed will result in 2m of voids. Bleed water accumulation also results in very porous, poor quality cement grout with very high water/cement ratio material at the interface between the grout and the bleed water. Water soluble corrosive ions such as chloride and sulfate, dissolve in the bleed water resulting in higher chloride and sulfate concentrations in these localized areas. As a result, these areas will generally be the first sites of corrosion.

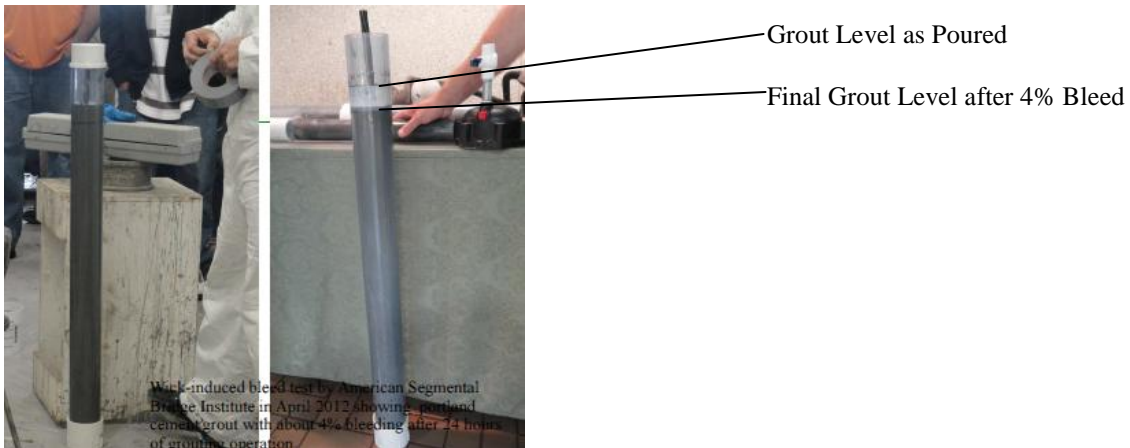


Figure 6. Comparison of non-bleed prepackaged grout (left) vs conventional Portland cement grout (right) with about 4% bleed.

Voids due to grout bleed have been greatly reduced as a result of the development and introduction of prepackaged thixotropic grouts. These grouts are less sensitive to bleed compared to conventional Portland cement grout but they can segregate and in some cases bleed. Prepackaged grouts can also produce pockets of soft grout (grout that does not harden and remains soft). The presence of segregated and soft grout has been reported in localized areas, such as anchor zones, tendon high points and between strands. Florida Department of Transportation defined soft grout as grout which can be penetrated by more than 1/16" by an awl with 10 to 15 pounds of force (Florida Department of Transportation 2013). Soft grout is often located adjacent to voids or in areas where there is a high probability of voids. It is often corrosive with high concentrations of sulfate, chloride and moisture (Figure 4). Significant corrosion has been found on post-tension strands which are in contact with soft grout (Figure 7).



Figure 7. Corrosion of post-tension tendons in soft grout (Florida Department of Transportation 2013)

## **POST-TENSION IMPREGNATION**

### Interstitial Space

The Post-Tension Impregnation system utilizes the interstitial spaces between the wires of PT strands to transport a ultra-low viscosity impregnation material along the length of the strands. As impregnation material travels along and wets out the length of the strand, the impregnation material is then available to impregnate into the grout surrounding the strand. The impregnation material forms a corrosion resistant film on any exposed steel surfaces and reduces the permeability of the grout surrounding the strand.

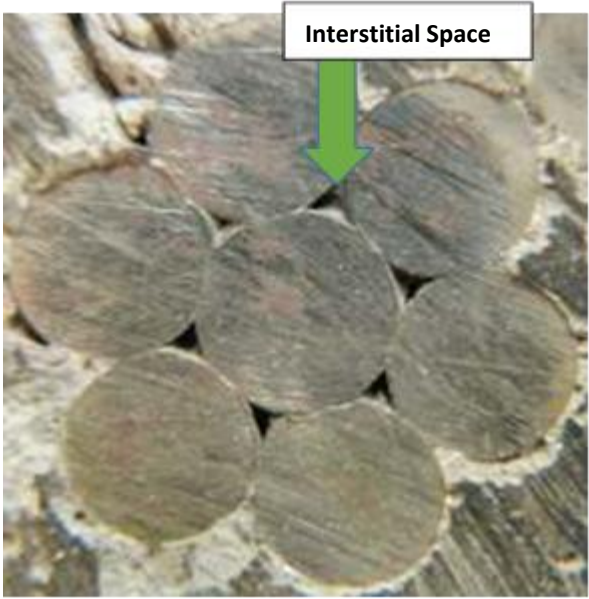


Figure 8. The interstitial spaces between the wires of a seven wire post-tension strand.

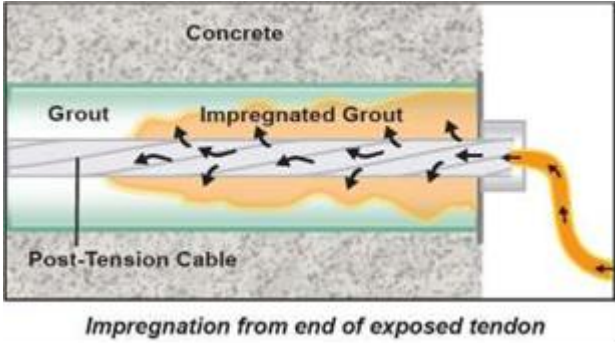


Figure 9a. Schematic diagram showing Post-Tension Impregnation from the end of a tendon.

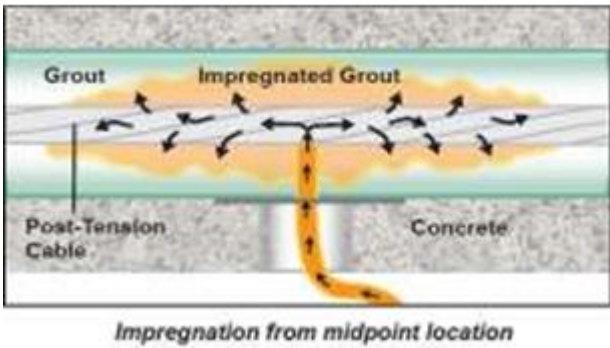


Figure 9b. Schematic diagram showing Post-Tension Impregnation from a mid-point location along the length of a tendon.

### Laboratory Testing:

- Two types of laboratory tests were performed:
1. Tests to confirm the corrosion protection capability of the impregnation material, and
  2. Tests to confirm the ability of the impregnation material to flow along the length of the strand and to penetrate the surrounding grout / concrete.

Prior to completing field projects, the corrosion protection properties of the post-tension impregnation material were evaluated. Laboratory tests to simulate a worst case scenario were conducted on steel plate samples which received no surface preparation. Impregnation material was applied to one-half of each steel plate. The samples were then exposed to a periodic salt water spray. The figure below shows treated and untreated sections of a steel plate after 30 days salt spray exposure. The treated portion of the steel surface was very well protected compared to the untreated portion. This test was repeated with the exposure of treated and untreated sections of steel plate to seawater spray and sulfate spray with similar results.



Untreated Control

Section treated with Impregnation  
Material

Figure 10. Steel plate after 30 day exposure to salt spray.

After successful completion the tests on steel plate samples, a similar test was completed using treated and untreated sections of post-tension strand samples. The figure below shows treated and untreated sections of post-tension strand after salt spray exposure. This test showed the treated strand to be much more resistant to corrosion.



Figure 11. Post-tension strand after exposure to salt spray test.

In addition to the above tests, samples with sections of strand embedded in pre-packaged post-tension grout were also prepared. These samples were exposed to potentiostatic testing to force the tendon sample to corrode by applying a voltage between the tendon sample and a counter-electrode. Impregnated and untreated samples were tested and the results were compared to each other. Figure 12 shows impregnated and untreated samples prior to potentiostatic testing. Figure 13 shows a sample undergoing potentiostatic testing and Figure 14 compares the performance of impregnated and untreated strand embedded in grout. Impregnation was extremely beneficial and reduced the current induced by the potentiostatic testing by over 90%.



Figure 12. Impregnated and untreated samples prior to potentiostatic testing.





Figure 13. A sample undergoing potentiostatic testing.

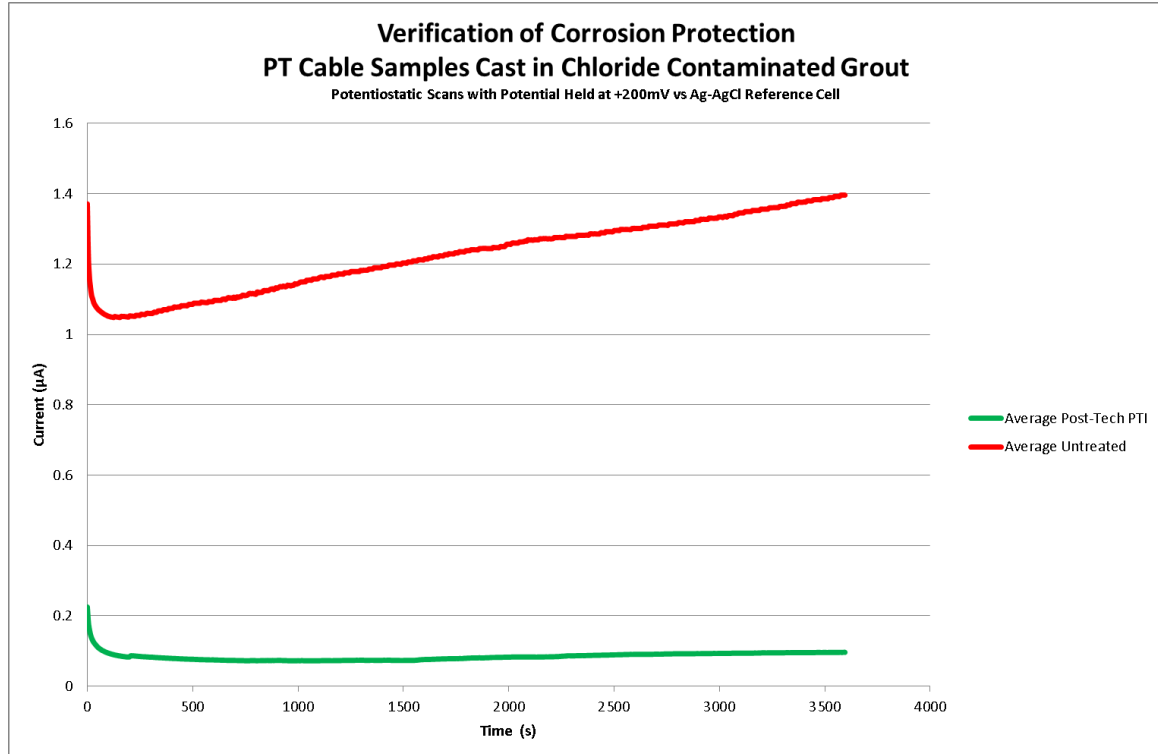


Figure 14. Results of potentiostatic testing of impregnated and untreated post-tension strand samples.

In addition to testing the ability of the impregnation material to mitigate corrosion, the ability of the impregnation process to impregnate bridge tendons was completed on bridge tendon specimens provided by FDOT. The tendon specimens provided to Vector were sections of external tendons which had been removed from a bridge in Florida. Each specimen was 4.5" diameter and contained nineteen, 0.5" diameter strands. The specimens were between 3 and 4 feet in length.



Figure 15. End view of one FDOT tendon specimen as received.



Figure 16.  
(Left) Impregnation being completed from the end of a prepared specimen.  
(Right) Impregnation being completed from the midpoint of a specimen.

The specimens were prepared and impregnated in the lab. Impregnation was completed from the end of one tendon specimen. The other specimen was impregnated from the midpoint.

Testing confirmed the ability of the impregnation material to travel along the length of the specimen, to soak into the grout surrounding the strands and to pass from strand to strand across the cross section of the tendon.

#### Field Verification:

Field work has been completed on structures for Manitoba Infrastructure and Transportation (Canada) and Florida Department of Transportation (USA) to verify the performance of the impregnation system on bridge structures.

The post-tension impregnation field verification completed for Florida Department of Transportation was completed on post-tensioned tendons of a FDOT bridge in Jacksonville, FL. This bridge was chosen because “soft grout” had been found during inspection of some of the tendons. Tendons with and without soft grout were chosen to determine if the presence of soft grout would create any difficulties.



Figure 17. Street view of FDOT bridge



Figure 18. Interior view of FDOT bridge showing post-tensioned cables and anchorages

Procedure:

A number of tendons were impregnated from the end anchorage location. In order to complete this work, the grout caps and grout within the cap was removed to expose the anchor plate and the end of the 1/2" diameter strands. After the strand ends were exposed, the caps were re-installed and used for impregnation.



Figure 19. From Left to Right: Before removal of anchor cap, view of grout at anchorage after anchor cap was removed, and exposed anchor plate and strand ends after removal of grout

Figure 20. Post-Tension Impregnation System set up from an anchorage location

Prior to completing impregnation, the moisture content of the strands was tested to ensure the strands, voids and grout was not saturated with water. Testing confirmed the moisture content of the grout was well below saturation and the pores of the grout would not be filled with water. As a result, drying of the strands and surrounding grout was not required prior to impregnation.

Impregnation was initiated and low pressure was maintained until impregnation material appeared at the far end of the tendon, 255 ft. (78m) from the point of impregnation.

As impregnation was being completed, impregnation material typically appeared at the far end of one or two strands initially and then impregnation material would appear at the far end of more and more strands until the impregnation material was flowing out the far end of all strands of a particular tendon. After material was flowing out the far end of all strands of a tendon, the impregnation process was stopped, the quantity of impregnation material used was recorded and the impregnation hoses were removed.



Figure 21. Post-Tension Impregnation Material leaking from the far end of 2 strands of a tendon (255 ft from point of impregnation)



Figure 22. Post-Tension Impregnation Material present at far end of tendon on left. No impregnation material present on adjacent tendon (right).

### Tendon Openings:

To verify the performance of the impregnation system, six openings were made in one of the impregnated tendons after impregnation was completed. The openings were spaced along the length of the tendon and each opening was approximately 6-8 inches long.

The plastic duct was cut and removed to expose the grout inside. A grinder was used to partially cut through the duct. Final cutting through the remaining thickness of the plastic duct was completed using a Dremel. The duct pieces were typically removed using a hammer and screwdriver.



Figure 23. Removal of plastic duct after cutting

After the duct was removed, the grout was carefully removed using hand tools to expose the PT strands and to verify the strands were impregnated.



Figure 24. Chipping grout to expose strands and observe the level of saturation



Figure 25. Post-Tension Impregnation material clearly visible in the strands as well as in the surrounding grout



## **SUMMARY:**

Post-tensioned tendons are critical reinforcing elements which are susceptible to corrosion, and must be properly grouted and protected to perform properly. Post-tension grout problems including voids, moisture/water in ducts, porous grout, segregated grout, soft grout, carbonated grout and chloride contaminated grout can lead to corrosion and failure of PT tendons.

Laboratory testing has verified the corrosion protection properties of the Post-Tension Impregnation material developed for this application.

The Florida DOT bridge project demonstrated the impregnation material's capability to penetrate the full length of bonded post-tensioned tendons with a span of more than 250 feet (over 75m). Impregnation was completed from the end of most tendons. One tendon was impregnated from the midpoint of the tendon to verify this technique could be used on other structures where the ends of the tendon are not readily accessible.

PT impregnation can provide corrosion protection to post-tensioned tendons with grout deficiencies to extend the service life of post-tensioned bridge structures.