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Post-Tensioned & Cable Stay Bridges: Diagnosing & Remediating Corrosive Conditions

April 2018

Ideas in motion.

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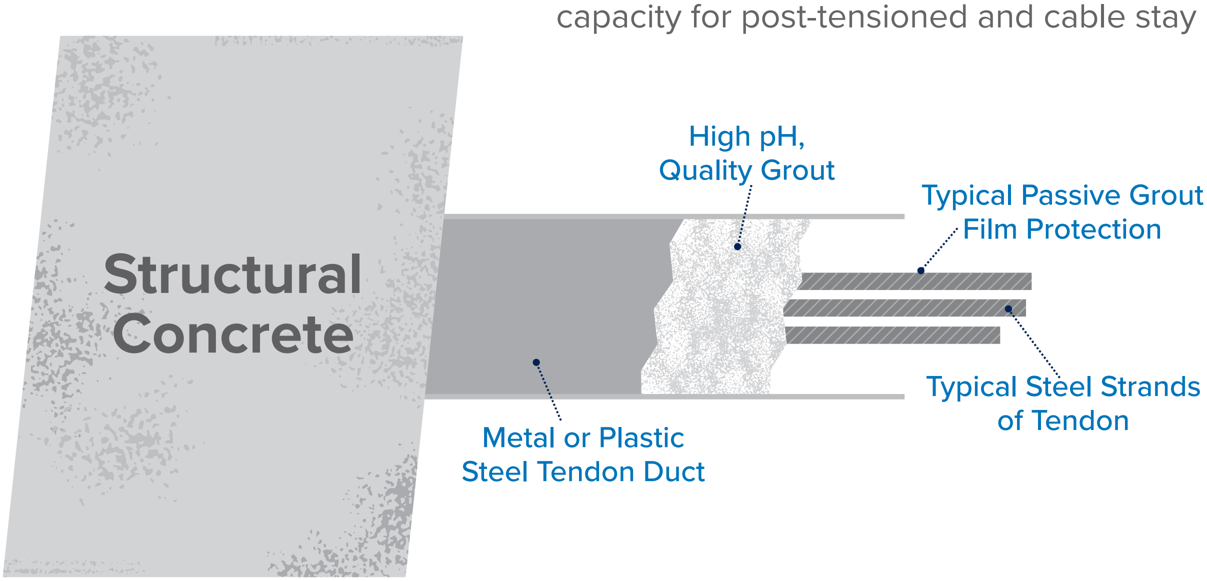
Post-Tensioned & Cable Stay Bridges: Diagnosing & Remediating Corrosive Conditions

Lurking beneath the surface of otherwise visibly sound concrete bridges lies a potentially significant disease-causing corrosion and deterioration. If left untreated, it can lead to a shorter-than-planned effective service life and reduced load carrying capacity for post-tensioned and cable stay bridges.



Typical Interior Post-Tensioned Steel Tendon Detail

This tendon duct has no grout. Note that there is rust on the duct interior and the steel tendon strands. (Photo courtesy of VSL)

This image shows a duct with exposed tendons in the duct interior. Note the mineral and water deposits. (Photo courtesy of VSL)

Soft grout can be seen at the anchor of the steel tendon pictured here. (Photo courtesy of VSL)

The Culprits of Corrosion

In most post-tensioned (PT) and cable stay (CS) bridges, the stressed steel tendons are designed to be surrounded by cementitious grout. This provides a layer of protection from corrosion by forming an alkali film on the tendons.

To prevent the steel that is surrounded by concrete or grout from corroding, the cementitious material must consist of a high pH of 12.5 or above. High pH levels allow the cementitious material to form an alkaline (passive) film on the surface of the steel which provides the primary protection from corrosion. If the pH of the cementitious material placed around steel is below 11, or falls below 11 over time, the alkaline film may deteriorate, exposing the steel to corrosive contaminants. Contaminants may consist of water, chlorides, sulfates, admixtures and other materials. If the level of chlorides and sulfates exceeds threshold limits, corrosion of the steel may initiate.

The best condition for protecting the steel is a balanced water/cement ratio grout that exhibits a high pH. However, many of these structures were built without current knowledge of pre-package grouts and proper duct venting procedures. High water/cement ratios were used on numerous bridges constructed before 2003.

Once the concrete or grout has deteriorated, there are a number of ways that corrosion of the steel tendons can occur. They include:

Pumping: During the pumping operation, bleed water, admixtures and fine particles separate from the main body of the grout and accumulate at the leading edge of the grout flow, creating a condition called "wicking." This condition usually is caused by the high pressure created during the pumping operation which increases the flow speed of the grout. This mass of poor quality, low pH grout tends to settle and cure at high points and anchorages of the tendon ducts and stay cables. As the hydration process takes place, the water evaporates leaving significant voids. These tendon duct and stay cable void locations are at a high risk of corrosion due to the lower pH of the grout.

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A lab titration process quantifies the chloride content in concrete and grout. (Photo courtesy of SCS)

NOTE: Current Post-Tensioning Institute (PTI) and American Segmental Bridge Institute (ASBI) standards provide for maximum pressure and grout flow speeds. They now take into account the diameter of the duct and the length as well as the drape of the tendon.

Chloride Content: Chloride content within the grout also is a concern. The American Association of State Highway and Transportation Officials (AASHTO) allows a maximum chloride concentration of 0.08% with respect to the mass of the grout. The lower the pH of the grout, the lower the chloride concentration required to initiate corrosion of the steel tendons.

Sulfate Concentration: The sulfate concentration in the grout can be a significant factor with respect to steel tendon corrosion. This has not been a consideration in the grout placement within the tendon duct and stay cable until recent years. Although no threshold level for sulfates has been established for tendon grouting, a concentration of 200 ppm is currently considered safe for the grout mix.

The Perfect Storm

As we have noted, high chloride and sulfate concentrations, low pH and inadequate grouting procedures are all contributing factors to a corrosive environment for steel tendons in PT and CS structures. This perfect storm of corrosive conditions has raised a number of concerns for bridge owners, including:

- Many of the PT and CS bridges built before 2003 are showing deficiencies of the steel tendons and stay cables. This is, in part, due to the lack of adequate grouting materials and construction procedures. Since that time, ASBI and PTI have begun to develop, and continued to refine, the construction, materials and procedures for the grouting of PT and CS structures.

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The Perfect Storm *(Continued)*

This exterior tendon has a large void. Note that the steel tendon is exposed. (Photo courtesy of SCS)

A typical view of external tendons in a post-tensioned structure. (Photo courtesy of SCS)

- The inspection and testing procedures for PT and CS bridges vary considerably from those used for bridges constructed primarily of steel. In most cases, deficiencies in steel structures can be located with minimal invasive testing. Most PT bridges, whether they are constructed with internal or external steel tendons, or stay cables of CS structures do not allow for easy or constant visual monitoring of the steel tendons and stay cables. If a PT or CS structure begins to show visible signs of corrosion in the steel tendon(s), they could be deteriorated beyond their design load carrying capabilities.
- The Federal Highway Administration (FHWA) is working with state Departments of Transportation (DOTs) to develop adequate programs with procedures that address the inspection and testing of PT and CS structures to qualify and quantify their conditions. They are interested in inspecting structures for tendon corrosion, quantifying the rate of corrosion in-situ, documenting the grout quality and its effects on future tendon corrosion, and establishing the remaining service life of their structures for planning considerations.
- Most engineering firms do not have the resources, knowledge, or experience to use the most current procedures to inspect and test bridge tendons and stay cables–the primary structural element on PT and CS structures, respectively–and determine their current conditions.

Is a Formal Repair Program Right for You?

Many DOTs and bridge owners are weighing whether or not to proceed with a formal PT or CS bridge testing program. Burgess & Niple (B&N) can help determine what type of testing program is right for your organization.

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B&N, a nationally recognized bridge engineering and design firm, has teamed with Siva Corrosion Services (SCS) and VSL to provide comprehensive PT or CS inspection, testing, evaluation, and rehabilitation services. For more than 12 years, this team of experts has provided complete bridge inspection services for clients throughout the country. Specifically, numerous arms-length visual inspections, corrosion rate testing, grout sample gathering/testing, boroscoping, and service life prediction have been performed, as well as generation of rehabilitation plans and construction inspection services.

Our bridge experts will help you evaluate your bridges to identify the optimal solution for your project and budget.

Repair Program Benefits

Without the knowledge of what factors are driving deterioration, the solution may not be effective. The goal is not just to identify symptoms, but to determine, treat and cure the underlying disease. With information provided from inspections and testing completed by our team, clients can make data driven, sound decisions with respect to future inspections and rehabilitation procedures. Recommendations may include, but are not limited to:

- Take no action at this time and define future inspection and testing intervals.
- If existing tendon or stay cable grout is in good condition, fill all void locations with new grout to prevent the ingress of contaminants.
- If significant corrosion is found on the steel tendons or stay cables, identify the cause (moisture, high levels of chlorides and/or sulfates, soft/low pH grout). Remedial action may include installation of external post-tensioning or replacement of stay cables.

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- Seal all significant cracks, especially on the deck surface to limit contaminant ingress to the steel tendons of PT bridges.
- For external tendons of PT bridges where the plastic tendon duct piping is cracking, remediation may include wrapping the damaged plastic pipe with a waterproof membrane.

Procedures & Protocols

A corrosion rate setup for an interior steel tendon. (Photo courtesy of SCS)

Numerous inspection protocols and testing techniques, refined during evaluations of more than 50 PT and CS bridges, are at our team's disposal to help qualify and quantify the condition of their respective elements.

Since not all PT bridges will exhibit deficient conditions, it is most efficient to start by sampling a portion of the potential testing locations on a bridge. If the areas sampled exhibit deficiencies, then additional testing may be required. To provide guidance on the appropriate number of test locations, we utilize ANSI/ANSQ Z1.4 (American National Standards Institute) statistical sampling protocol. Initial procedures used to assess a structure's condition and guide further testing include an arms-length visual inspection and boroscoping of the tendon ducts at high points, anchors and couplers. The results of these two procedures help guide the team to the optimum locations on the tendons to quantify the rate of corrosion.

The electrochemical, NDT and minimally invasive tools that can be used include, but are not limited to: corrosion rate probes, impact echo, ultrasonic tomography, ground-penetrating radar, electrical capacitance tomography, magnetic flux and infrared camera.

Comparing information obtained from different time periods will provide valuable insight with respect to the potential rate and location of deterioration occurring in the structure from a holistic point of view. All invasive test locations are repaired to a condition equal to or better than the original state.

Conclusion

Each PT or CS bridge has its unique set of issues. All PT and CS bridges should be evaluated by trained and experienced personnel. Of the more than 45 PT bridges inspected and tested by our team for state DOT owners, **over half of the structures exhibited a substantial number of voids and deficiencies in the tendons and anchors**. Additionally, findings included tendons that were never grouted, some tendon grout voids had accumulated water, and corrosion of the steel tendon strands was ongoing. Of the 6 complex CS bridges inspected by our team for state DOT owners, **three of the structures exhibited a substantial number of deficiencies of the stay cables, protective PE piping and anchors.**

Our team of bridge experts has the expertise to help you evaluate your PT and CS bridges, identify potential issues, and develop the optimal solution for your project and budget.

Juneau Douglas post-tensioned bridge over the Gastineau Channel in Juneau, Alaska. (Photo courtesy of SCS)

US 59 post-tensioned bridges over Grand Lake in Delaware County, Oklahoma. (Photo courtesy of SCS)

Our Team

Burgess & Niple: As a Senior Project Manager and a nationally recognized expert in evaluation and repair of post-tensioned concrete and cable-stay bridges, Dallas Montgomery, PE, RLS, has firsthand insight into detecting and establishing programs for PT evaluation projects. He was the Project Manager for partnering agencies SCS and VSL while employed by URS and AECOM. This team, led by Dallas, has inspected and tested:

- 18 PT bridges for the Oklahoma DOT.
- 12 PT bridges for the Indiana DOT (two were PT cable stay structures).
- Three PT bridges for the Indiana Toll Road Concession Company (ITCC).
- Three PT bridges for the Alaska DOT.
- 10 PT bridges for the Ohio DOT.
- The La Plata long span PT cable stay bridge for the Puerto Rico
- Highways & Transportation Authority.
- The Bridge of Honor long span PT cable stay bridge for the West Virginia DOT.
- The William H. Harsha long span PT cable stay bridge for KYTC.
- The IPFW cable stay pedestrian bridge for Indiana DOT.

Dallas also was the project engineer for the construction inspection portion of the 28 span, I-235 South Bound Post-Tensioned Bridge rehabilitation project in Oklahoma City, Oklahoma.

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Our Team (*Continued*)

Siva Corrosion Services (SCS): Siva Venugopalan, President of Siva Corrosion Services, is a member of the FHWA Bridge Preservation Expert Task Group. He has over 27 years of experience in field efforts related to embedded steel corrosion and electrochemical rehabilitation techniques. As part of the team, he has developed a unique testing routine to quantify corrosion problems and extend the service life of post-tensioned and cable stay structures.

VSL: Project Manager Bruce Osborn has over 28 years of post-tensioned and cable stay bridge inspection, testing, new construction and rehabilitation experience. He has an extensive understanding of minimally invasive boroscope testing and utilization of ground penetrating radar equipment of post-tensioned tendons and stay cables structures.

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For more than 100 years, Burgess & Niple has led the development of infrastructure in rural and urban regions. Our success is driven by a passion for advancing the built environment with exceptional concern for quality of life, safety and sustainability. Our work spans the world and ranges from complex urban renewal projects to restoration of historic bridges.

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