Innovative Corrosion Evaluation System for Unbonded Post-Tensioned Cables

By Garth Fallis, J. Christopher Ball, and Andrew Moad

Unbonded post-tensioned reinforcement has been used for many years in concrete structures, such as in elevated slabs (parking garages and residential or commercial buildings), residential foundations, walls, and columns. The use of unbonded post-tensioned reinforcing allows for unique and cost-effective design and construction, including thinner concrete sections, longer spans between supports, stiffer walls to resist lateral loads, and stiffer foundations to resist the effects of shrinking and swelling soils.

Unbonded post-tensioned reinforcing is accomplished by placing high-strength steel tendons or bars into a sheathing or duct, allowing it to move as the tensioning force is applied after the concrete cures. The steel elongates as it is tensioned, and it is locked into place using an anchoring component that forms a mechanical connection and maintains the force in the strand for the life of the structure.

A typical steel tendon used for post-tensioning has a tensile strength of 270,000 lb/in.^{2} (1860 MPa) as compared with a piece of standard reinforcing steel with a tensile strength of 60,000 psi (415 MPa). Tendons, which typically have a diameter of 1/2 in. (1.3 cm), are composed of seven tightly wound strands and are stressed using a force of approximately 33,000 lb (15,000 kg).

There are several different types of unbonded post-tension systems currently in use. The first systems installed consisted of greased strands surrounded by a paper wrap. The technology subsequently progressed to greased unbonded post-tensioned cables pushed through plastic ducts. These early system have been found to be susceptible to corrosion, as water and moisture have been able to penetrate the protective layer. Today, post-tension tendons are manufactured with an extruded plastic sheath tightly molded to the cable to provide superior corrosion protection.

Broken strands or entire tendons have been found during the investigation of many of the older types of unbonded post-tensioned structures. As the tendons are integral structural members, the loss of strands and tendons can significantly affect the structural capacity of the structure.

Post-tensioned tendon anchor and grout pocket protruding from parking garage façade after failure

Failed post-tensioned tendon that erupted from slab soffit

Failed strand from post-tensioned tendon

Void space in greased unbonded push-through, post-tensioned system

Problem: Corrosion

Unbonded post-tensioned tendons may corrode for a number of reasons, even though they are encapsulated by a plastic duct. This is primarily due to voids in the protective grease, which allow moisture to accumulate adjacent to the post-tensioned tendon. Corrosion may go undetected for years until eventually significant structural deterioration, leading to a loss in structural capacity and, eventually, extensive and costly repairs. Increasingly, however, cases have been reported where corroded (failed) cables have erupted from the concrete, thus also posing a risk of damage or injury from ejecting cables, falling concrete, and/or dislodged claddings.

From the mid- to late-1970s, isolated instances of corrosion deterioration of unbonded post-tensioned cables were reported with increased frequency. Since the mid-1980s, corrosion-related deterioration of poorly greased and inadequately protected cables in structures has also been well documented and continues today. The seriousness of corrosion-induced failures of unbonded post-tensioned structures is illustrated by the fact that strands can fail silently and this failure can go unnoticed. These undetected broken cables can significantly and unknowingly reduce structural capacity. A dramatic illustration of this was demonstrated by the fatal collapse of the Berlin Congress Hall in 1980.

Corrosion of unbonded post-tensioned cables appears in a large variety of situations. Some of these include unprotected structures, such as parking structures exposed to the weather; interior protected apartment and office structures, where cable wetness and cable corrosion have been identified due to leakage from unsealed anchorages or moisture during construction; buildings in hot, humid environments, where cool air-conditioned interiors can facilitate elevated humidity on interior cables due to climatic difference; and portions of structures with partial exterior exposure, such as balconies and roof slabs.

There are three main forms of corrosion in unbonded post-tensioned cables: uniform corrosion, localized or pitting corrosion, and stress-induced corrosion.

With uniform corrosion, the surface of the steel is attacked evenly and the thickness of a section is uniformly decreased. This generally occurs when unprotected steel is exposed to the environment, perhaps during shipping or storage, or prior to the grouting of bonded cables.

In pitting corrosion of unbonded post-tensioning, the metal does not corrode uniformly, but rather deep pits are produced at distinct locations. This may lead to sudden brittle failure after only negligible overall corrosion. The time from construction to tendon failure may therefore be quite short.

Stress-induced corrosion cracking produces pits at the base where microcracks may originate. Once a crack has started, the stress concentrations result in the formation of larger cracks, which may propagate causing a sudden failure. In some cases, hydrogen embrittlement appears to be involved. In any case, corrosion of a tendon under stress will likely produce a sudden and sometimes volatile failure.

Cause: Moisture

It is accepted that, for corrosion of steel to occur, both water (in liquid or gaseous state) and oxygen must be present. As oxygen is generally always present, moisture is the external factor in promoting corrosion in unbonded post-tension cables. Because of the often poorly greased and loose-fitting nature of push-through and heat-sealed ducts/tendons, the presence of moisture in the voids surrounding and along unbonded cables is fairly common.

Moisture can enter the cable ducts in various ways:

- Water may have entered into the ducts during construction if cables were left out in the weather before being installed or from exposure to rain after the cables are installed but the anchorages were not yet grouted.
- Cracks in the concrete slab may allow water to leak through imperfections in the duct. This is most prevalent in roof slabs and parking structures.
- Water may enter through the anchorage points if these are not protected from the weather. This is especially prevalent where the anchorages are below grade and are susceptible to moisture in the soil.

Evaluation

As previously mentioned, corrosion of poorly greased, highly stressed, unbonded post-tensioned cables can reduce the structural capacity and lead to costly repairs. This, along with the cost-effective methods of corrosion mitigation now available, underlines the importance of timely identification and treatment.

Existing methods typically used to evaluate corrosion of steel in concrete structures such as half cell corrosion potentials and corrosion rate testing are not practical to use on these types of unbonded post-tensioned structures due to the presence of the non-conductive plastic ducts. In response to the need to determine the probability of corrosion activity within unbonded post-tensioned cables, the Post-Tech* PT Corrosion Evaluation Method was developed.

The PT corrosion evaluation test is a nondestructive test used to identify cables exposed to corrosive environments by measuring the moisture condition inside a cable sheath. Thus, the corrosion evaluation test is used to identify cables that are of high risk of corrosion.

In older structures, the corrosion-evaluation process can identify cables with a high probability of corrosion deterioration. This is achieved using previously correlated corrosion evaluation results with the corrosion condition of cables randomly removed for visual inspection; thus, providing a statistical overview of the condition of the wet and dry cables in a concrete structure. When also correlated with screwdriver penetration testing, optimum condition evaluations can be achieved. In the absence of a direct means of corrosion condition measurement, the corrosion-evaluation process thus permits cost-effective quantification of the corrosion condition of the cables in a structure.

The PT corrosion evaluation process works by injecting ultra-dry air under very low pressure and

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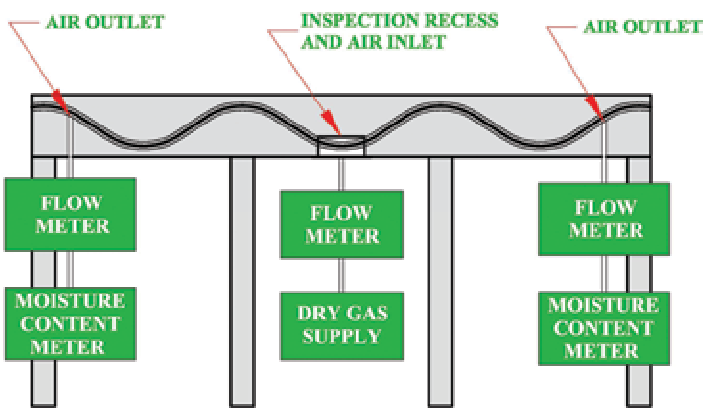
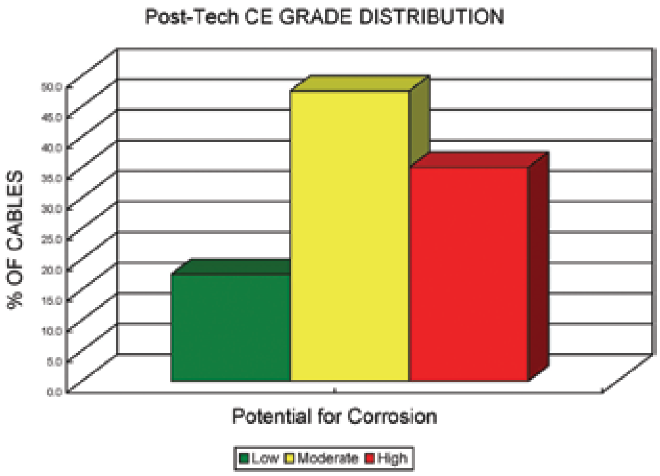
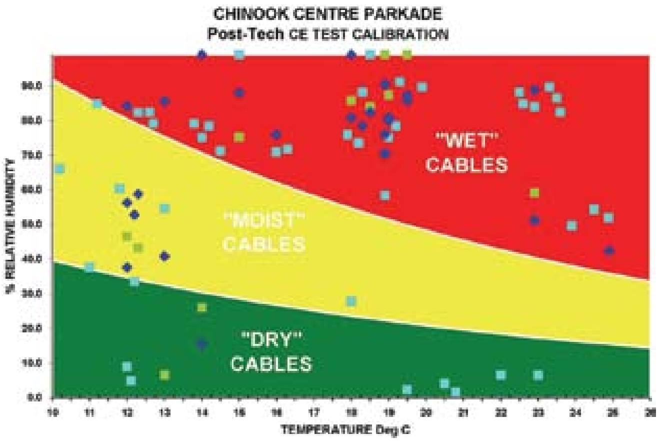
**Post-Tech is a trademark of Vector Corrosion Technologies*



PT corrosion-evaluation system setup

Taking readings for the PT corrosion evaluation





Graphical examples of PT corrosion evaluation test results

Table 1

	Corrosion potential	PT corrosion evaluation
Low probability of corrosion	> –200 mV	< 0.003 kg/kg
Moderate probability of corrosion	–200 to –350	0.003 to 0.007
High probability of corrosion	< –350 mV	> 0.007 kg/kg

flow into the post-tensioned cable duct at a central location. At an exit port near the end of the cable, the air is directed through the PT corrosion evaluation testing unit, which verifies the flow rate and determines the moisture content of the air within the cable duct. This information is then analyzed and processed to determine the potential for corrosion in that cable. Information is tabulated for all cables tested to provide an overall picture of the condition of the structure.

The corrosion evaluation process of determining the probability of corrosion by using the measurement of an indirect parameter, in this case moisture condition, is analogous to the determination of the probability of corrosion of reinforcing steel using the Half Cell Corrosion Potential Survey, (ASTM 876) where the potential difference between reinforcing steel and a copper-copper sulphate half cell is measured and related to the probability for corrosion. In both cases, there is a range of measurements that indicates a lower probability of corrosion (less than –200 mV for corrosion potential measurement and less than a moisture content of .003 kg/kg with the PT corrosion evaluation process). Other comparative levels are shown in Table 1.

The PT corrosion evaluation moisture content ranges and the correlation of the probabilities for corrosion were determined by the National Research Council of Canada in conjunction with G. Livan.[1]

Solution

There are several solutions to address the concern of moisture in unbonded post-tensioned cables. Removing and replacing the cable, monitoring the cable and replacing broken ones during future inspections, or drying the cables using the Post-Tech PT Cable Drying System.

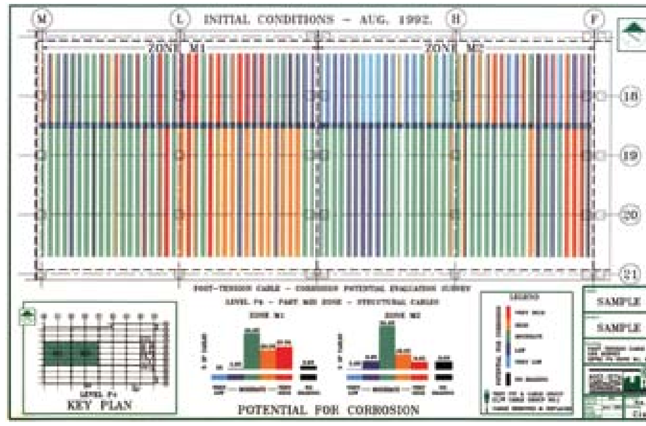
The cable-drying system uses the same process as the corrosion-evaluation system in that ultra-dry air is blown through the cables but, in this case, for an extended period of time. The extended drying period is required to allow moist air (and any bulk water) to be removed from voids, between the wires of the cable, and from emulsified grease. This process may take 4 to 6 weeks, and is determined by taking corrosion-evaluation measurements before, during, and after the drying is complete.

Similar to the corrosion-evaluation comparison to half-cell potentials, the cable-drying system is analogous to electrochemical chloride extraction (ECE) in that the processes are intended to address the major cause of the corrosion activity in the structure (in one, moisture in unbonded post-tensioned structures and in the other case, chloride in conventionally reinforced structures).

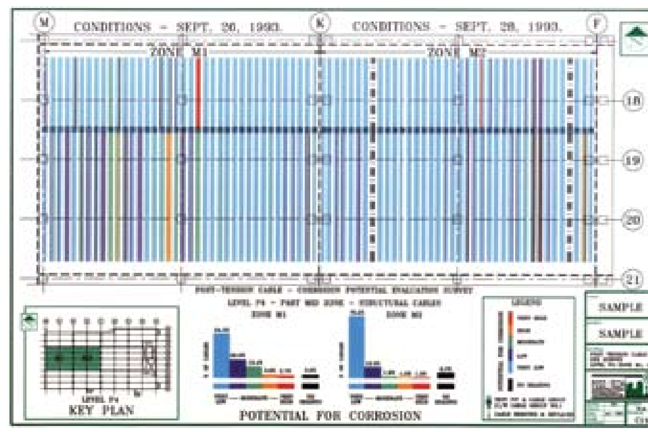
Unbonded post-tensioned tendons are integral structural members, and the loss of strands and tendons can significantly affect the structural capacity of the structure. With these systems, unbonded post-tensioned cables can be evaluated for their potential for corrosion to identify cables at risk of corrosion and failure, potentially saving major damage to structures.

Reference

Livan, G., "Evaluation of the CPE Test Method for the Assessment of the Condition of Unbonded Post-Tensioned Cables in Concrete Structures," and NRC A806-1.C, "Effectiveness of the CPE Method of Evaluating Unbonded Post-Tensioned Tendons—An Evaluation Report," 1997.



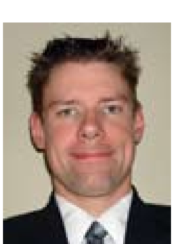
PT corrosion evaluation readings before drying



PT corrosion evaluation readings after drying

***Garth Fallis**, PEng, is Vice President, Construction Technologies, Vector Construction Group, Winnipeg, MB, Canada. Fallis has over 25 years of experience in the concrete rehabilitation industry with Vector, specializing in all areas of concrete repair, protection, corrosion mitigation, and strengthening. Fallis received his BSc in civil engineering at the University of Manitoba, Winnipeg, and is an active member of ICRI, where he serves as a member of the Board of Directors, and ACI, where he is a member of several committees, including ACI Committee 562, Evaluation, Repair, and Rehabilitation of Concrete Buildings, a newly formed committee that is creating a code for concrete rehabilitation.*

***J. Christopher Ball** is Vice President, Sales and Marketing, Vector Corrosion Technologies Inc., Tampa, FL. Ball has over 13 years of construction industry experience, with a specialty in concrete rehabilitation and corrosion-protection systems. He previously held the positions of Senior Market Development Manager and Concrete Repair Product Manager for Master Builders Inc. and Concrete Repair Product Manager for Fosroc Inc. Ball received his BA and MBA in business administration from Bellarmine University, Louisville, KY, and is a member if ICRI, the American Concrete Institute (ACI), and the National Association of Corrosion Engineers (NACE).*



***Andrew Moad** is a Project Manager for Vector Corrosion Technologies Ltd., Toronto, ON, Canada. Moad has over 6 years of cathodic protection and construction experience with Vector, and is now responsible for all post-tension-related projects. He received his BSc and MSc in civil engineering at Queen's University in Kingston, ON, Canada, and is currently a member of ICRI and NACE.*