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Investigation & Mitigation of Corroding Unbonded Post-Tension Tendons

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ABSTRACT

Unbonded post-tension (PT) tendons have been used for many years to reinforce concrete structures. Generally, these structures have performed well except where unbonded PT tendons have suffered from corrosion due to moisture penetration or protective grease deficiencies.

Like other technologies, unbonded PT systems have evolved and improved over the years from “paper-wrap” to “push-through” to “heat sealed” to “extruded” to “fully encapsulated” systems. Consideration should be given to the type of system when selecting the appropriate evaluation and corrosion mitigation methods for these systems.

Evaluation of unbonded post-tensioned structures is important to determine the current condition and to determine if corrosion and deterioration is likely to occur. If broken tendons or corrosive conditions are identified, a suitable mitigation strategy should be implemented such that the structural integrity can be maintained, and the service life of the structure can be met or extended.

This paper will discuss the types of unbonded PT structures which exist, evaluation techniques which can be used to identify the presence of corrosion, and mitigation methods which have been developed to mitigate corrosion of unbonded PT tendons. Project case studies will be presented to demonstrate the applicability and effectiveness of these techniques.

Key words: post-tension (PT), evaluation, drying, tendon, cable, corrosion, testing, tension, magnetic.

INTRODUCTION

Unbonded post-tensioned reinforcement in concrete structures has been used for many years in elevated slabs (parking garages and residential or commercial buildings), residential foundations, walls, and columns and more recently in bridge structures. The use of unbonded post-tensioned reinforcing allows for unique and cost-effective design and construction that include: 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 psi (1861.6 MPa) as compared to a piece of standard rebar with a tensile strength of 60,000 psi (413.7 MPa). Tendons typically have a diameter of 0.5 to 0.6 in (12.7 to 15.2 mm), are composed of seven tightly wound strands, and are stressed to a force of about 33,000 pounds (146.8 kN).

There are several different types of unbonded post-tension systems used in structures. The first systems installed consisted of greased strands surrounded by a paper wrap. The technology subsequently progressed to greased unbonded post-tensioned cables “heat sealed” and “pushed through” ducts. These early systems have been found to be susceptible to corrosion as water, moisture and chlorides have been able to penetrate the protective layer and in some cases the sheathing was cut short leaving strands with no protection at these locations. Today, post-tension tendons are manufactured with an extruded plastic sheath tightly molded to the cable to provide superior corrosion protection. In aggressive environments, fully encapsulated systems are now used where fixed-end anchorages come pre-installed and are designed to be watertight, with the live-end anchor being installed following strict engineering specifications using coated anchors, tubes, seals and caps filled with approved PT grease to ensure that the entire tendon system is watertight. Grouted tendons are not included in the scope of this document.

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.

Figure 1: Examples of post-tension tendon failure due to corrosion.

PROBLEM - CORROSION

Unbonded Post-tensioned tendons may corrode for a number of reasons even though they are protected by the plastic duct. This is primarily due to voids in the protective grease which allows moisture to accumulate adjacent to the post-tension tendon. Corrosion may go undetected for years until eventually significant structural deterioration leading to loss in structural capacity and eventually extensive and costly repairs will result. Increasingly, however, instances 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-seventies, isolated instances of corrosion deterioration of unbonded post-¬tension cables were reported with increased frequency.

Since the mid-eighties, 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 and condensation on interior cables due to the climatic difference; and in 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 grouting of bonded cables.

With 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 corrosion pits and at the base of the pits 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 critical 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. These include:

- 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 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.