ASSESSMENT AND RESTORATION OF POST-TENSIONED PARKING RAMP STRUCTURES

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The use of unbonded post-tensioned (PT) reinforcement in concrete parking ramp structures has been popular for many decades. The use of PT reinforcement in these structures greatly reduces the amount of cracking and possible leakage to the structure and also allows economical long-term construction. The construction boom of parking structures in the U.S. began in the 1960s, which also coincided with the beginning of the heavy use of deicing products. Many of these early PT structures are in deteriorated condition, with varying degrees of damage to the systems themselves.

BRIEF HISTORY OF POST-TENSIONED TENDONS FOR PARKING RAMP STRUCTURES

PAPER-WRAPPED WIRE TENDONS

The early unbonded PT systems used high-strength stress-relieved steel wires, bars, or strands. These consisted of parallel 0.25 in. (6 mm) diameter wires bundled together, greased (sometimes by hand), and spiral-wrapped with kraft paper to form a sheath. This system was referred to as button-headed and was the typical system used in the 1950s in the U.S. (refer to Fig. 1).

During the 1950s, the industry's general perception was that the concrete in which the PT reinforcement was embedded provided high-quality, impermeable corrosion protection for the post-tensioning system. The purpose of the sheathing with the kraft paper was primarily to act as a bond breaker, preventing the concrete from coming into contact with the wires of the tendons, thereby allowing them to move freely in the slab when the tendons were tensioned. The kraft paper also held the grease in place on the wires during shipping, handling, and concrete placement. The function of the grease was primarily to lubricate the tendon to allow for lower friction losses during tensioning. Some of the reported vulnerabilities (Nehil 1991) of this PT system are as follows:

- At the dead-end anchorages, the paper wrap was discontinued for around 3 ft (0.9 m), the wires were then flared out through a spreader plate, and the bare plate and wires were buried within the concrete. Typically, the minimum concrete cover over the wires and plate was 0.75 in. (19 mm). Because the dead end anchor did not have to move during stressing, it was considered acceptable for the wires of the tendon to be neither greased nor wrapped for this considerable distance extending from the spreader plate. These bare wires became susceptible to premature corrosion failure as chlorides contaminated the concrete surrounding the wires and the plate.
- At the live-end anchorages (Fig. 1), the detailing is susceptible to premature corrosion deterioration. Once the wires of the post-tensioning tendon pass through the bulkhead plate they are no longer greased and wrapped. The bulkhead bearing plate, the shim plates, the stressing washer, and the wires of the post-tensioning tendon were often simply embedded in a concrete pour strip, placed after the tendons were stressed, to encase the anchorage hardware. Again, this unprotected hardware was susceptible to chloride-induced corrosion damage; and
- At the intermediate anchorages (Fig. 2 and 3), the problems encountered in the end point anchorages were further compounded by the fact that the construction joint over the bearing plate was frequently not sealed to prevent leaking of water and chlorides through the construction joint. Corrosion of the upper surface of the bearing plate characteristically would cause corrosion-induced spalling directly over the

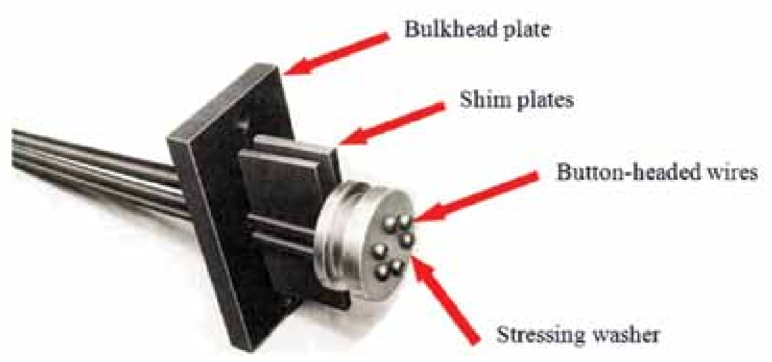

Fig. 1: Schematic of button-head post-tensioned system (live-end anchorage) (after PTI [1976])

anchorage. Corrosion of the bearing plate, shim plates, and post-tensioning wires was promoted by this constant supply of water, chloride, and oxygen adjacent to the joint.

The corrosion performance of paper-wrapped button-headed wire tendons has had many problems, particularly in the past 25 to 30 years. The paper wrapping inevitably provides minimal protection against moisture and chloride ion intrusion. The paper was easily damaged during concrete placement, which was exacerbated by inadequate cover, low quality concrete, and concrete cracking (refer to Fig. 4).

MONOSTRAND UNBONDED TENDONS

In the 1960s, the use of the seven-wire strand became more common. The first strand systems were paper-wrapped and easier to install and stress than the button-headed systems. By the mid-1970s, however, the use of plastic sheathing with grease was the system primarily used in parking ramp structures. There are three sheathing types: push-through or stuffed, heat-sealed, and extruded systems.

In the push-through system, the coated strand was pushed into a preformed plastic tube. The push-through heat-sealed plastic sheathings were loose-fitting, and the extruded type was tight-fitting. Both the push-through and the heat-sealed sheathing left a large void around the tendon where the unfilled, or partially filled, annular space was susceptible to moisture intrusion. In addition, the lap weld was poorly performed on many occasions and would open during handling and installation; this allowed moisture to penetrate and the grease to leak out. The loss of grease, or coating, made the strand more susceptible to corrosion damage as well as increased the friction during stressing (refer to Fig. 5).

In recent times, the predominant system in the U.S. is the extruded sheathing system. This system eliminates the lapped joint problem in the sheathing and results in a watertight covering that tightly encases the grease with no voids.

The 1985 Post-Tensioning Institute Guide Specifications marked the first time industry standards were applied for the sheathing and coating used in unbonded PT systems. The totally encapsulated systems were developed for the corrosion protection of the tendons and anchorages to maintain a complete water-tight system. The specification included minimum thickness requirements for the sheathing, along with performance requirements for the strand coating (grease), and minimum required coating coverage rates.

DETERIORATION MECHANISMS

The most frequently encountered types of deterioration in PT ramp structures include the

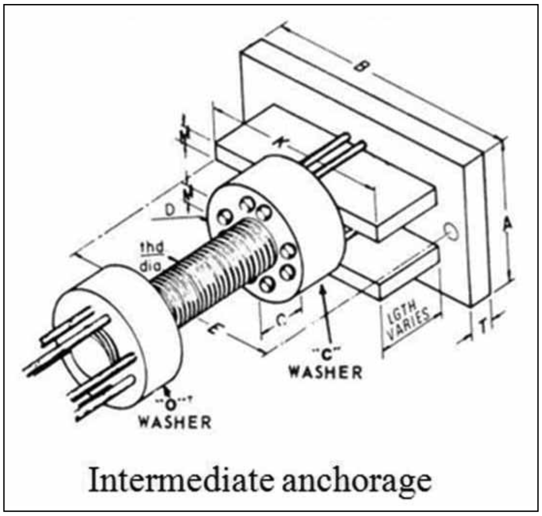

Fig. 2: Schematic view of a typical intermediate anchorage (after Nehil [1991])

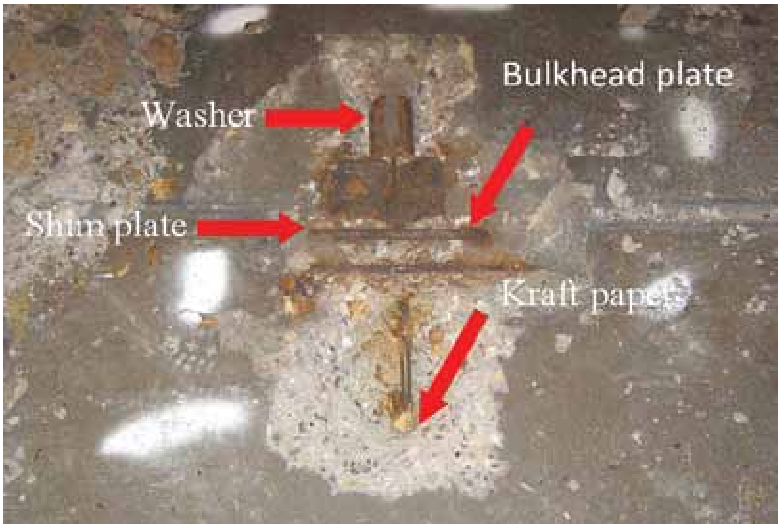

Fig. 3: Overview of an intermediate anchor for a button-headed system

Fig. 4: Emulsified PT coating (grease) from a paper-wrapped system

Fig. 5: Exposed strand with severe corrosion and wire section loss for a push-through system

Fig. 6: Post-tensioning tendon failure due to corrosion

corrosion of the reinforcement, freezing-and-thawing damage, and material-related degradation. These conditions frequently occur in combination and result in scaling of the driving surface, spalls, and delaminations of both the driving surface and slab soffit. In addition, leakage of water through joints and cracks results in spalling of concrete on beams. The walls and columns suffering the distress from leakage are also continually exposed to the splashing and spray of salt-contaminated water. Concrete degradation, particularly in its advanced stages, is seldom due to a single mechanism; in harsh climates, significant deterioration can result from the combined effects of freezing and thawing along with the heavy use of deicing products.

CORROSION-INDUCED DETERIORATION

The floor surfaces of a parking ramp structure are the most susceptible to chloride contamination. Deicing products tracked into the structure or directly applied to the surface during winter months tend to accumulate on the surface and accelerate the infiltration of the chloride ions into the concrete. Similar conditions are produced in coastal areas due to the salt spray and high humidity conditions with similar results. This exposure to chlorides may be worsened by poor drainage layouts, standing water or ponding, and clogged drains. Spalling and delamination of concrete, due to corrosion of embedded reinforcement, are typical forms of deterioration. Spalling can occur on the slab surface or the underside. Freezing-and-thawing cycles, vehicular action, and additional corrosion tend to further accelerate the rate of spall development.

Cross-sectional loss of prestressing tendons due to corrosion has a significant impact on the load-carrying capacity and integrity of the parking ramp structure itself. Release of the post-tensioning force due to tendon failure sometimes causes the tendon to break the surface of the slab (refer to Fig. 6).

Corrosion of the PT tendons typically occurs at the most vulnerable regions of the PT system—at the construction joints, expansion joints, and at random cracks. This condition is characteristic of older facilities with paper-wrapped, push-through, and heat-sealed systems. Structures without an encapsulated system are extremely vulnerable to tendon corrosion at leaking joints. Additionally, if the sheathing is damaged, moisture can enter the sheathing and infiltrate other locations by following the tendon profile, causing damage. In some extreme circumstances, the moisture collects at low points in the tendon and during freezing-and-thawing cycles, the sheathing breaks, causing leakage of the PT protective coating, making these areas very vulnerable to corrosion. Furthermore, the end anchorages require protection from corrosion. The anchor pocket is often filled with nonshrink, nonmetallic grout. This grout lends itself to shrinking over time and falls out, causing an anchor to be susceptible to moisture intrusion. If this condition is left unattended, corrosion may form, subsequently releasing the post-tensioning, resulting in a tendon eruption.

CRACKING

Cracking in concrete occurs as a consequence of the development of tensile stresses. Cracking can take place in plastic as well as hardened concrete. Cracking also indicates concealed problems in concrete that could be due to design or construction deficiencies. In some cases, cracking can be resultant to the restraint and concrete volume changes. Localized loss of prestressing forces due to PT deterioration or failure of the anchorages may also result in cracking. In extreme cases, the frequent water leakage through cracks forms leaching deposits.

FREEZING-AND-THAWING CYCLES

The concrete floor surfaces in parking ramp structures are susceptible to freezing-and-thawing deterioration, particularly when concrete is not properly air-entrained in a saturated environment or in areas with poor drainage layouts where ponding can occur. The most common form of surface deterioration is scaling, which is characterized by the progressive exposure of the coarse aggregate after the disintegration of the sand/cement paste.

JOINT DISTRESS

Expansion joints and construction joints in parking ramp structures provide a practical limit on structure dimensions. These systems provide an important role to minimize volumetric changes in a particular location as well as to control the size of concrete placements. All joints must be properly designed, installed, and maintained to reduce premature deterioration of underlying systems. The ongoing leakage through a failed and unmaintained joint system in a parking ramp structure creates serious concerns for ensuring corrosion-induced and freezing-and-thawing-related distress on interior levels.

EVALUATING POST-TENSIONED PARKING RAMP STRUCTURES

The initial step in the restoration and maintenance of a PT parking ramp structure begins with a comprehensive condition assessment of the facility. The condition assessment requires an in-depth review of existing conditions by visual observations of each structural component, supplemented by materials and nondestructive testing. The International Concrete Repair Institute (ICRI) *Technical Guideline* No. 210.2-2002 (formerly No. 03736) presents a step-by-step methodology to evaluate unbonded PT structures. A selected section of the ICRI recommendations are given as follows:

DOCUMENT REVIEW

The first step in preparing for the condition assessment is to collect and review plans, specifications, and miscellaneous information regarding the parking ramp structure, including the history of maintenance on the facility.

VISUAL EXAMINATION

During this portion of the assessment, deterioration in members is identified and recorded in the field sheets using a task item notation. The deterioration noted needs to be documented by means of photographs. The following items need to be recorded:

- The size, location, and depth of spalling and scaling on floor surfaces, beams, columns, ceilings, and bumper walls;
- Cracks, crack patterns, types, widths, and lengths;
- The location and condition of the expansion and construction joint systems;
- The location and condition of drains;
- Locations of exploratory openings; and
- Locations for material testing including the locations for nondestructive evaluations.

In the author's experience, regarding the recording of information during an assessment, it is easier to evaluate the top of a floor slab and the underside of a slab on different sheets using a task item legend with different color coding, particularly when extensive deterioration is encountered.

TESTING

In conjunction with the walk-through examination, it is necessary to perform materials and nondestructive testing to supplement the results of the visual observations. The testing assists in verifying the extent of deterioration and in evaluating the condition of the existing structure. The selection of the types, location, and amount of testing should be consistent with the size of the structure so that the results are statistically meaningful. The following tests are recommended by ICRI:

Instrumental Testing

- Acoustic testing/hammer sounding;
- Impact-echo;
- Impulse response;
- Covermeter;
- Ground-penetrating radar;
- X-ray;
- Rebound hammer;
- Corrosion potential testing; and
- Acoustic monitoring

Exploratory Investigation

- High-point/low-point inspections;
- Anchor inspection;
- Lift-off testing;
- Strand extraction;
- Screwdriver penetration test;
- In-place strand tension test;
- Grease inspection and testing;
- Borescope;
- Corrosion potential evaluation;
- Core sampling; and
- Load test

Material Testing

- Compressive strength;
- Petrographic examination;

- Chloride content;
- Carbonation; and
- Metallurgical and physical examination of the prestressing steel strand

REPAIR RECOMMENDATIONS

The restoration of PT parking ramp structures requires the use of several repair methods to address existing deterioration of structural members as well as to provide effective protection in extending the service life of the repaired structure. Once the condition assessment is performed, the repair implementation consists of using the findings of the assessment to select appropriate repair schemes, repair materials, and methods. With respect to concrete repairs, there is a significant amount of literature on concrete repair methods and materials that has been published during the past years. The design and execution of post-tensioned repairs require an in-depth understanding of the structural system by an experienced personnel to provide appropriate shoring and bracing during the repair sequencing, keeping in mind that the effects of tendon detensioning can be experienced along its entire length. The majority of the repairs in a PT parking ramp structure are centered at the floor slab due to the deterioration mechanisms described earlier. Repairs to beams are less common. The following repair strategies are typically followed by design professionals specialized in the post-tensioned field:

Fig. 7: Center stressing splice for monostrand system

Fig. 8: Monostrand to wire system splice (after VanOcker [2005])

PARTIAL TENDON REPLACEMENT

The technique of partial tendon replacement is recommended in slab tendons where the corrosion or deterioration is localized. Representative areas for this repair are high points of tendons and construction joints. The affected section of the tendon is replaced by a new section attached to the existing tendon by couplers (refer to Fig. 7). In the case of a button-headed system, the repair follows a similar procedure, using threaded rods, wire splices, and a combination of button-headed hardware with monostrand replacement tendons. Successful repairs using the combined system have been reported (VanOcker 2005) (refer to Fig. 8).

COMPLETE TENDON REPLACEMENT

In areas where multiple failures of the same and adjacent tendons occur, complete tendon replacement should be considered. In this approach, the existing deteriorated tendon is removed or abandoned and a new tendon installed. For monostrand systems, strand replacement eliminates tendon components that may have hidden corrosion and may fail. Additional information for the repair of post-tensioned structures can be found in the ICRI *Technical Guideline* No. 320.4-2006 (formerly No. 03743).

DESIGN FOR MAINTENANCE

Once the concrete repairs are performed, special attention needs to be provided to the waterproofing details in order to protect the post-tensioning system from the environment. A comprehensive maintenance plan needs to be outlined to address, minimally, the following:

JOINTS AND CRACKS

Periodic replacement of joint sealant in construction joints, control joints, and cracks is recommended.

EXPANSION JOINTS

Expansion joints are prone to leakage if not properly maintained. In PT systems, the maintenance of expansion joints is vital, particularly where strands are anchored at expansion joints.

SEALERS AND WATERPROOFING MEMBRANES

The application of concrete-penetrating sealers makes the concrete less permeable. This aids in preventing chloride ions, moisture, and water to infiltrate the concrete; however, it cannot completely screen out the chloride ion or moisture like a traffic topping membrane. A heavy-duty traffic topping membrane reduces the oxygen supply and moisture that supports corrosion and assists in extending the service life of slabs. A membrane can effectively bridge active cracks and is suitable for floor systems with extensive through-slab cracks. It is recommended to at least apply a strip of the traffic topping membrane over construction joints to reduce the intrusion of chloride ions.

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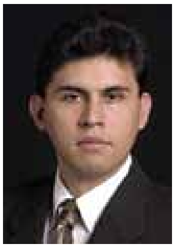

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