

Evaluating Unbonded Post-Tensioned Structures

By Gail S. Kelley, P.E.



Fig. 1: Repair to a two-way flat plate parking structure built in 1971. Two-way structures built during the 1960s and 1970s often used a “basket-weave” tendon layout; tendons were distributed in both directions. Current practice is to band the tendons in one direction

For any concrete repair project to be successful, the team undertaking the evaluation and repair must have a clear understanding of the repair objectives. It is also helpful to know something about the history of the structure, including which version of ACI 318 was in force at the time of construction—ACI 318 requirements affecting durability such as air entrainment, minimum concrete cover, and minimum reinforcement have changed over the years. When evaluating a post-tensioned structure, there are a number of additional considerations; depending on the type of structure, where it is located, and when it was built, repair recommendations may be quite different. Although there are general guidelines for the evaluation and repair of post-tensioned structures, each project will be different. It is strongly recommended that the individuals involved in evaluation and repair also have experience in the design and construction of post-tensioned structures. A repair project done by individuals without the proper qualifications may be quite expensive but ultimately of little value.

Types of Post-Tensioning

There are two types of post-tensioning tendons: bonded and unbonded. In North America, almost all post-tensioned buildings are now being constructed with unbonded tendons consisting of seven-wire strands that are greased and covered with an extruded plastic sheathing. The anchorages are cast-iron plates with a recess that holds a two-piece wedge. Current Post-Tensioning Institute (PTI) and American Concrete Institute (ACI) Committee 423 specifications require that tendons in aggressive environments be completely encapsulated, so that there is no exposed strand.

Post-tensioning systems have changed quite a bit over time, partly because of the corrosion problems experienced with early systems. Early post-tensioning systems included button-headed parallel wires greased and wrapped with reinforced kraft paper, as well as seven-wire strand wrapped with paper or covered with various types of plastic sheathing. Some early systems for one-way slab and beam structures used bonded post-tensioned bars or wires in the beams, in conjunction with unbonded strands in the slab; there were also some systems that used bonded wires in both the beams and the slab. Most repair projects, however, involve unbonded wire or strand tendons.

Evaluation Guidelines

Although unbonded post-tensioning tendon repair requires both experience and appropriate equipment, the repairs themselves will generally be straightforward. The type of repair required will usually depend on the location and extent of the deterioration, and whether there is access along the length of the tendon and access to the anchorages.

The more difficult task is to accurately determine the extent of corrosion damage to the tendons and to develop a rational repair strategy. In most projects, the repair recommendations must take the owner’s objectives and expectations into consideration. As in other types of structures, much of the observed deterioration may be cosmetic rather than structurally significant, or the deterioration may not be structurally significant over the desired life of the structure. On the other hand, there may be a considerable amount of structurally significant deterioration that will not be found by a visual evaluation.

Evaluation of Tendon Corrosion

The objective of a structural evaluation is to identify deterioration and distress and, if possible, determine the cause or causes. When evaluating nonprestressed concrete structures, corrosion damage can be estimated reasonably well by examining rust-stained and spalled areas. It is assumed that the reinforcement is in good condition where the concrete is not stained, spalled, or delaminated. The same logic may be applied to the reinforcing bars in a post-tensioned structure, but is less helpful in evaluating the condition of the tendons.

The causes and visible effects of deterioration in structures post-tensioned with unbonded tendons are significantly different from those in nonprestressed structures or structures with other types of prestressing systems. Unbonded tendons are isolated from the surrounding concrete except at the anchorages, so chlorides and moisture in the concrete may not affect them. At the same time, however, the high pH of the surrounding concrete does not provide any corrosion protection to the prestressing steel. Measures taken to repair and protect the surrounding concrete may not prevent continued deterioration of the prestressing steel where corrosion has started.

If prestressing steel is completely coated with a corrosion-inhibiting substance, corrosion will probably not occur. The coatings used in early post-tensioning systems typically did not provide adequate corrosion protection, however. The tendon fabrication process usually results in a length of exposed strand at both ends of the tendon; in early systems, voids inside the sheathing allowed moisture to migrate into the tendons while they were stored on site and after they had been installed.

Condition Surveys

Evaluation of a post-tensioned structure should include a condition survey, a review of the design drawings and drawings from previous repairs, and materials testing. The condition survey will typically consist of a delamination survey, a crack survey, and documentation of anything that appears to be atypical.

The delamination survey is used to estimate the extent and distribution of corrosion damage to the reinforcing systems. Surveying the concrete surrounding the tendon anchorages is particularly important. Delaminations and spalling at the anchorages can allow moisture and contaminants to penetrate through the wedges; corrosion of the wedges and the strand within the wedges can cause failure of the anchorage and thus the tendon. Delaminations can also allow moisture and contaminants to penetrate any unsheathed strand that may exist in front of the anchorage. Delaminations

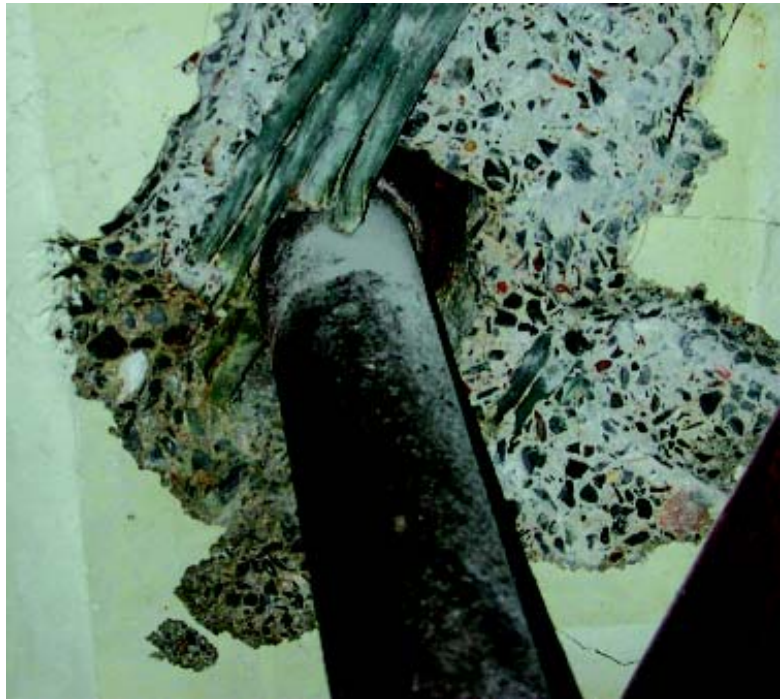


Fig. 2: Tendons that have been damaged during building renovations, such as new pipe penetrations, may be difficult to find. Often, the area where they were damaged will have been patched back or otherwise covered up



Fig. 3: Water leaking from an open construction joint at a slab/wall joint has severely corroded all of the anchors in this band. Several of the anchorages have failed. Drip pans have been installed along the length of the joint

elsewhere along the tendon paths should also be examined closely, especially those near columns, since these will coincide with the high point of the tendon profiles (the point where the concrete cover over the tendons is lowest).

The crack survey is used in conjunction with the delamination survey to determine whether there is a pattern to the deterioration. Much of the cracking in post-tensioned slabs is due either to restraint

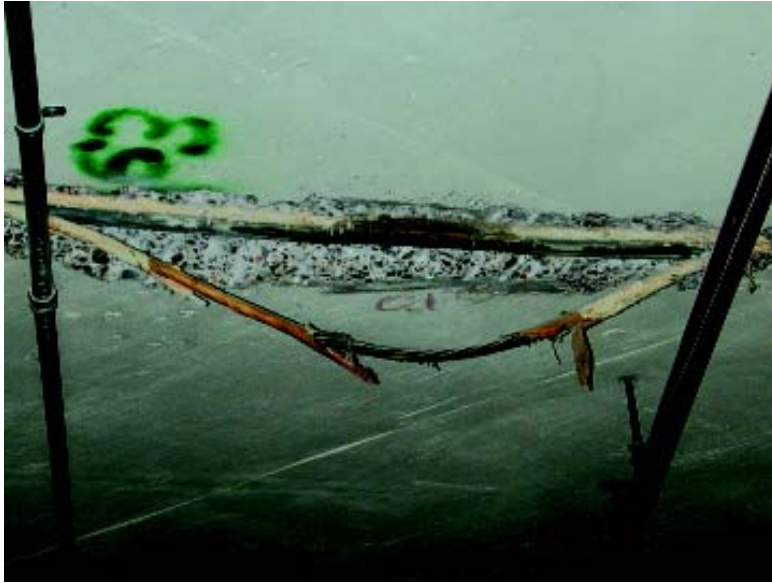


Fig. 4: Paper-wrapped tendon that had broken through the slab at a low point when the anchorage released

of shrinkage or restraint of volume change due to temperature changes. Other causes of cracking include corrosion of the reinforcing bars and improper detailing of the reinforcement at tendon anchorages. These cracks can pose a serviceability problem due to leakage and leaching, but they are not usually a structural problem. On occasion, however, cracks can be a sign of severe structural distress. The approximate width and length of the cracks should be documented and any leakage, efflorescence, or rust stains should be noted.

If a tendon is properly protected by a coating such as grease and the sheathing is intact, it may not be affected by delamination or cracking in the surrounding concrete. Corrosion of the reinforcing bars can cause spalling, however, which exposes the tendon to vehicular traffic. The tendon sheathing is not intended to withstand direct contact with traffic and is easily abraded. The corrosion-inhibiting coating will be compromised once the sheathing is breached, and corrosion will start as soon as water gets to the steel.

Tendon Damage

The most obvious sign of tendon damage is a loop of strand sticking out of the slab. When a strand is stressed during construction, the steel elongates. If the strand subsequently breaks or the anchorage fails, this elongation is released, and an energy wave travels down the tendon as the strand returns to its original, unstressed length. In areas where the concrete cover over the tendon is low and the tendon curvature is high, the released energy may be enough to split the concrete. Tendons are most likely to loop out at a high or low point at the end opposite where the anchorage failed or the

break occurred. If the concrete around the anchorages was badly consolidated or the anchorage pockets were not grouted, a broken tendon may exit at the slab edge rather than create a loop. This type of failure is extremely rare, though; often, there will not even be any cracking at the grout plug.

Evaluation of Cracking and Staining

Vertical cracks in beams and slab cracks perpendicular to the direction of the span may be another indication of broken tendons. A structural analysis of the original design, including anticipated losses of precompression due to restraint, can indicate whether such cracking could be expected under normal loading. A significant discrepancy between the calculated service load stresses and the observed cracking may indicate there has been a loss of prestress due to broken tendons. In general, if there are areas with significant cracking and there is no reasonable explanation based on what can be observed visually, it is advisable to chip out some of the anchorages or do other exploratory openings.

Evaluation of the tendon anchorages requires experience and is somewhat subjective, though. Rust may have developed on the anchorage casting, on the wedges before they were installed, or before the anchorage pocket was grouted. Small rust spots near anchorage pockets are typically due to the nails used to attach the stressing-end anchorages to the formwork. Although these may be aesthetically objectionable, they are not of any significance to the anchorage. Nevertheless, all rust staining at anchorages should be investigated. Other signs of deterioration, such as shrinkage or cracking of the grout in the anchorage pockets, in combination with rust staining, can indicate possible corrosion at the anchorage, but these too need to be evaluated with care. If the anchorage pocket was filled with a high-shrinkage material such as masonry cement, it is very likely that the grout will be cracked. But if the anchorage pocket was not exposed to water, there may not be any deterioration. If there is rust on the end of the strand tail but water has not penetrated into the wedges, the anchorage can usually be considered satisfactory, provided it will be waterproofed to prevent future deterioration. If there is rust on the face of the anchorage but no rust on the nails, it is likely that the rust occurred before the anchor was installed.

With many of the early post-tensioning systems, there are likely to be grease stains on the slab soffit, particularly in areas where the concrete cover is low. Although grease stains indicate that there has been a breach in the tendon sheathing, they are not necessarily a sign of distress. If there are also rust stains along the tendon path, however, the

corrosion protection of the tendon may have been compromised. Exterior spans and spans adjacent to expansion joints should be examined closely for staining—if water has migrated into the tendon through the anchorage, it will collect at the first low point of the tendon profile.

Review of the Design Drawings

If the original structural drawings and post-tensioning installation drawings are available, they should be reviewed to identify problems that might be due to design, detailing, or materials selection. The drawings should be compared with the findings of the condition survey to determine whether problems are likely to be widespread or limited to isolated areas. It should be noted, however, that as-built conditions often differ from the design drawings. In post-tensioned structures, the construction sequence may have required that tendons be stressed at locations different from what is shown on the drawings. Switching the fixed and stressing ends of the tendons has no effect on the structural system but may affect on the slab's durability. In general, stressing-end anchorages are more vulnerable to corrosion than fixed-end anchorages; stressing-end anchorages should not be located where there may be leakage. Tendons may also have been stopped short or extended past what is shown on the drawings. This type of change to the tendon layout can have a significant impact on the structural system and may be a cause of distress.

Materials Testing

Materials testing may include compressive testing, petrographic analysis, and chloride ion extraction. The amount of testing required usually depends on the size of the structure, the extent of the deterioration, and the variability in observed conditions. Although materials testing can be useful, often it will only confirm what an experienced engineer can determine from an inspection of the structure, a review of the drawings, and an investigation into the history of the structure. Furthermore, test results can vary considerably, depending on where materials samples are taken. Samples taken from convenient but nonrepresentative locations, such as crane openings, may result in meaningless information and lead to inappropriate repair recommendations.

Summary

A visual condition survey alone will not accurately identify all of the deficiencies in a post-tensioned structure. There may not be any external signs of broken strand; it is possible to have a significant number of broken strands without any obvious distress, especially in two-way construction. In most repairs, the objective is to address the obvious

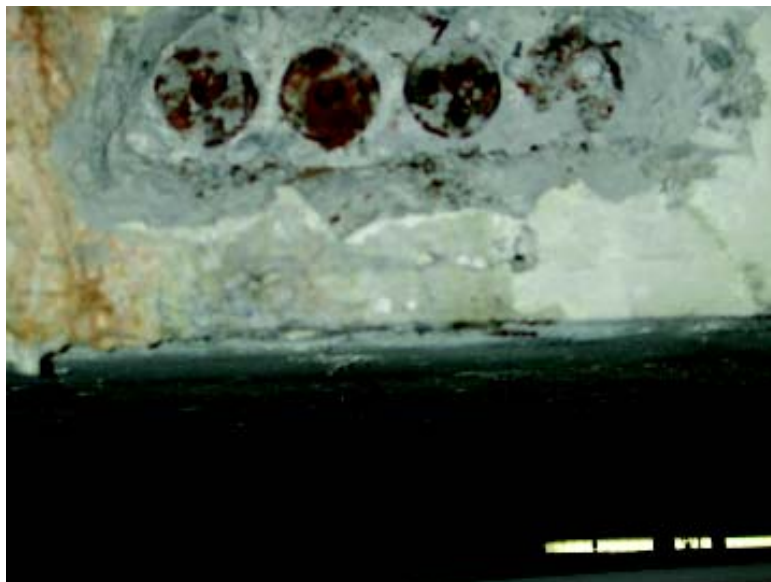


Fig. 5: The anchorage for the tendon in Fig. 4 is the second from the left. Years of water and salts leaking from a planter on the plaza caused the strand within the wedges to corrode to the point where the wedges could no longer grip it

deterioration, eliminate as many of the causes of the deterioration as possible, slow any deterioration that will continue, and determine requirements for monitoring and maintenance.

Information and guidelines for evaluating concrete structures are given in ACI 364.1R, "Guide for Evaluation of Concrete Structures Prior to Rehabilitation," and ACI 437, "Strength Evaluation of Existing Concrete Structures." Additional guidelines and recommendations for post-tensioned structures are given in ACI 423.4, "Corrosion and Repair of Unbonded Single Strand Tendons."

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