building blocks

Repair of Unbonded Single-Strand Tendons

By Gail S. Kelley

Unbonded single-strand (monostrand) post-tensioning tendons have been used as concrete reinforcement in North America since the 1950s. Unfortunately, the concrete industry did not really understand the importance of corrosion protection until the late 1970s. Although many of the post-tensioned structures built in the 1960s and 1970s continue to perform satisfactorily, many others, particularly those in aggressive environments, have required extensive repairs.

Over the years, there have been significant improvements in both tendon components and tendon installation procedures. ACI 423.6, *Specification for Unbonded Single Strand Tendons*, now provides performance criteria for the components of unbonded single strand tendons, as well as recommendations for their fabrication and installation. In particular, ACI 423.6 requires that encapsulated tendons be used in structures that may be exposed to deicing chemicals, seawater, brackish water, salt spray, or salt-laden air. When installed correctly, encapsulation systems provide watertight protection to the post-tensioning strand.

Tendon repairs may be necessary even when tendon components and installation procedures comply with current recommendations and requirements, however. Tendons may be accidentally cut when penetrations are made by other trades. Tendons may also be intentionally cut for renovations such as new stairways.

This article provides a brief overview of unbonded post-tensioning repair. The repair procedures are essentially the same whether the strand has corroded or has been cut. The objective is generally to splice the strand so that it can be retensioned.

Fixed-end anchorages. Anchor on the left is non-encapsulated. Anchor on the right is encapsulated.

Tendon Components

ACI 318 defines an unbonded tendon as the complete assembly consisting of anchorages, prestressing steel with coating, and sheathing. The prestressing steel used for monostrand tendons in building construction is usually ½-inch diameter, seven-wire, 270 ksi strand. The standard anchorage consists of a rectangular cast-iron plate and a two-piece wedge.

When a tendon is less than 120 feet, it is typically only stressed from one end. The anchorage at one end (the fixed-end anchorage) is attached when the tendon is fabricated. The anchorage plate for the other end (the stressing-end anchorage) is nailed to the edge form, along with a plastic pocket former that creates a recess for the anchorage. The tendon is rolled out on the formwork and the strand is pushed through the stressing-end anchorage before the concrete is placed. After the concrete has reached the strength required for post-tensioning, wedges are placed in the stressing-end anchorage and the strand is stressed to 80% of its ultimate strength. When the strand is subsequently released, the wedges are pulled into the anchorage plate until they lock the stressed strand in place.

If a tendon has been stressed properly, the elongation will be approximately 8 inches per 100 feet. Once the elongation has been verified, the strand extending through the anchorage is cut off about ½ inch past the wedges and the stressing pocket is grouted. If the tendon is encapsulated, a cap is placed over the wedges and strand tail before the pocket is grouted.

Splice chucks in a partial-depth overhead access hole.

Splice chucks in full-depth access hole. Anchors on the right are fixed-end anchors for partial-length tendons.

Repair Hardware

The two basic types of hardware used in repairs are barrel couplers, also called splice chucks, and in-line stressing couplers, also called by their trade name, lok-couplers. A splice chuck simply connects two pieces of strand together. The most commonly used splice chuck consists of a short metal pipe with a set of wedges at each end. The existing strand is inserted into one end of the metal pipe; the new strand is inserted into the other end. When the tendon is restressed, the wedges at the each end of the coupler join the two pieces of strand.

An in-line stressing coupler also connects two pieces of strand, but instead of being anchored within the coupler, the strands continue and extend through wedges at the other end of the coupler. The stressing procedure for an in-line stressing coupler is the same as for a stressing-end anchorage.

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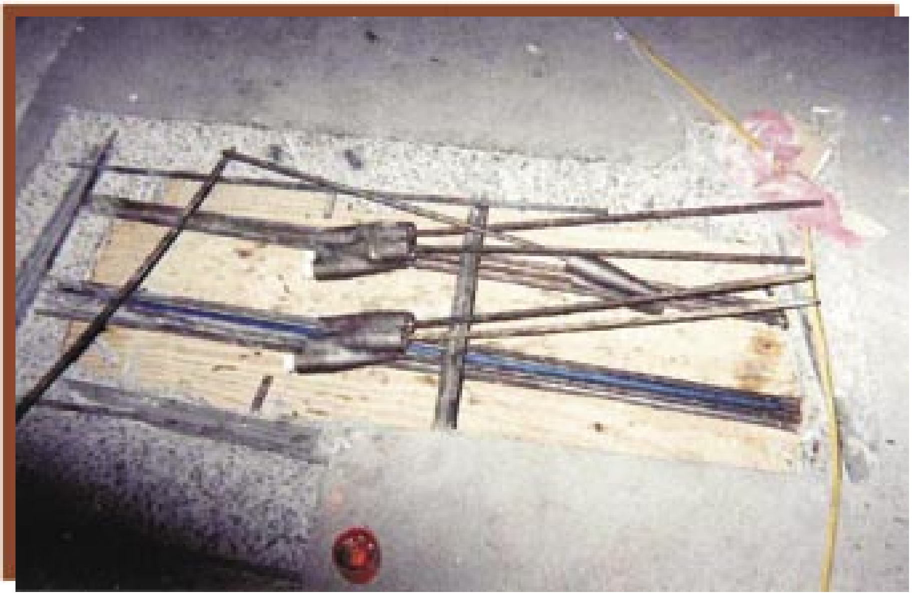
Structural Systems Used in Post-Tensioning

Most post-tensioned slabs are either one-way slabs with beams or two-way slabs. One-way slab and beam structures are often used for stand-alone parking structures because the layouts work well with drive aisle and parking stall requirements. The primary structural reinforcement consists of draped tendons in the beams and draped slab tendons running perpendicular to the beams. In most structures, there are also two or three temperature tendons in each bay to control cracking due to drying shrinkage and temperature changes. Temperature tendons run parallel to the beams and are laid flat (without any drape).

Office and residential buildings are typically two-way slabs, sometimes with drop panels or column capitals. To simplify the tendon layout, two-way slabs are typically done as "banded systems." The tendons in one direction are banded over the column lines. The tendons in the other direction are evenly spaced across the bay, usually in groups of two or three. If the column spacing required for the office or residential floors does not allow an efficient parking layout, transfer girders can be used to reduce the number of columns in the levels used for parking. The tendons in a transfer girder are usually stressed in stages as the upper floors are constructed.

In the simplest tendon layouts, all of the tendons run the entire length or width of the building. However, additional partial-length tendons are often required in the exterior bays of both one- and two-way slabs to make up for the reduction in tendon drape. The drape in the exterior bays is reduced because the anchorages must be at the mid-depth of the slab to avoid applying a moment to the slab edge. In addition, increased cover may be required at the low point of the exterior bay for fire protection.



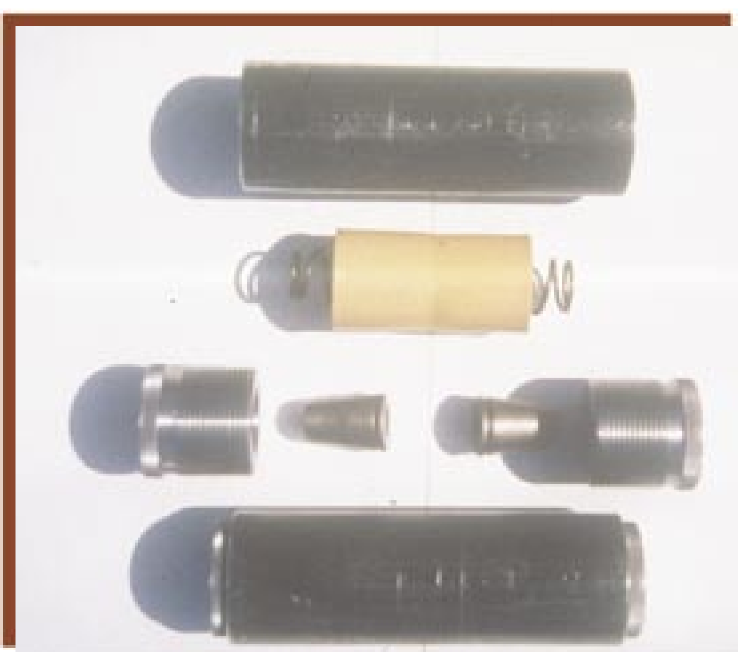
Five tendon repairs with in-line stressing couplers

Project specifications typically require that couplers be located at the quarter-point of the span, because the tendon is usually near the mid-depth of the slab at the quarter-point. Placing the coupler at the mid-depth of the slab provides good cover top and bottom.

Anchorage Replacements

If an anchorage exposed to water or chlorides is not properly protected, the wedges may corrode to the point that they can no longer grip the strand. Anchorages are typically replaced if the wedges have more than surface corrosion because the tendon loses all value as reinforcement if the wedges release the strand.

Anchorage replacements are complicated by the fact that the strand extending through the wedges is cut after the tendon is stressed. A tendon cannot be restressed with only ½ inch of strand tail; a standard stressing jack requires a minimum of 8 inches of strand to grip on.



Break-away of a splice chuck showing the pipe, the divider that goes inside (with springs) and the wedges. The wedges are held in place with threaded end caps. An assembled splice chuck is shown below

If the anchorage is at least 3 feet from adjacent tendons and has already failed, it is sometimes possible to chip out the slab edge and reset the anchorage further in. Typically, however, an access hole is made behind the anchorage, the strand is cut, and a new piece of strand that has been pushed through the anchorage is spliced on. The access hole should be at least 3 feet from the anchorage, unless the anchorage has already failed and the strand is fully detensioned. The compressive stresses immediately behind the anchorages of a stressed tendon are extremely high and can result in explosive concrete failures. The coupler does not have to be at the quarter-point; the tendon is at mid-depth behind the anchorage.

Water that has come through the anchorage will collect at the low point of the first span. If there has been significant corrosion at the low point, it is usually advisable to replace the strand to the far quarter-point of the span.

It is sometimes preferable not to detension a tendon while replacing the anchorage. This is particularly true in occupied buildings where there is low cover over the tendons, because the energy released during detensioning can cause the strand to break through the slab at a high or low point. Although this is not a safety threat to the building occupants, ceiling and floor finishes may be damaged. The tendon can be kept under tension by installing a temporary "lock-off" anchor before cutting the strand.

Replacement of Strand Away from an Anchorage

The most common reason for replacement of the strand away from an anchorage is damage because of insufficient cover at a high point in the tendon profile. High points are always located over columns or beams. The strand replacement typically extends from the quarter-point of the span on one side of the column or beam to the quarter-point on the other side. If water has gotten into the sheathing and collected at the low points, the strand may need to be replaced to the far quarter-points.

The new strand is spliced in with a splice chuck at one end and a stressing coupler at the other end. The stressing coupler needs to be positioned so that the stressing nose of the jack can be seated squarely on the wedges. The wedges cannot grip the strand properly unless they are pushed in evenly.

Protection of Couplers

ACI 423.6 requires that couplers be protected with the same coating that is used on the strand. It also requires that couplers be enclosed in a sleeve that allows movement during stressing. To comply with these requirements, couplers are typically placed in a PVC pipe filled with grease.

Although this configuration ensures that the coupler is protected against corrosion, the loss of concrete cross-section may be a concern if a large number of closely spaced splices are required. It may also be difficult to accommodate a large number of splices when there is conduit in the slab. If encapsulation is not required, an alternative method is to leave the access hole open until after the strand is stressed. The coupler will be free to move as the strand elongates, so a sleeve is not required. After the strand is stressed, the exposed strand can be covered with tape or a scrap piece of sheathing. Both splice chucks and stressing couplers will move while the strand is being stressed. The movement needs to be accounted for when positioning the couplers in the access holes.

It should be noted that the ACI 423.6 requirement for protection only applies to splice chucks. ACI 423.6 does not provide any guidance for the protection of stressing couplers.

Evaluating Whether to Repair a Tendon

There are a number of considerations when evaluating whether to repair a tendon. Most tendon repairs involve slab tendons. Because slab tendons have less concrete cover than beam tendons, they are more susceptible to corrosion. However, beam tendons may fail due to anchorage deterioration or may be cut when a new opening is required. If a beam tendon has been damaged or cut, external post-tensioning is often more economical than repairing the existing strand. A typical three-span beam in a parking garage will have nine or ten tendons bundled in groups of three or four. It is often difficult to separate the strands enough to insert a coupler. It may also be difficult to determine which strand corresponds to which anchorage.

It is seldom worthwhile to repair partial-length tendons. In particular, partial-length tendons that only extend through one or two bays have very little effect on the integrity of the slab. These tendons can be identified by measuring the amount of elongation that is lost when the tendon is cut. A partial-length tendon that is 25 feet long will elongate about 2 inches when it is stressed. If it is cut, the strand ends at the cut will be about 2 inches apart.

Likewise, it is seldom worthwhile to repair temperature tendons. The temperature tendons in one-way slab and beam systems are usually designed to provide an average compression of 100 psi between beams, in accordance with ACI 318, Section 7.12.3. However, there has not been any research to show that 100 psi is actually required to prevent objectionable cracking. If corrosion due to increased cracking is a concern, a waterproofing membrane on the slab is more cost-effective than repairing damaged temperature tendons.

Finally, the most important consideration in post-tensioning repair, as in all repairs, is safety. If a repair cannot be done safely, some other means of restoring the structural integrity of the building must be found.▪

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