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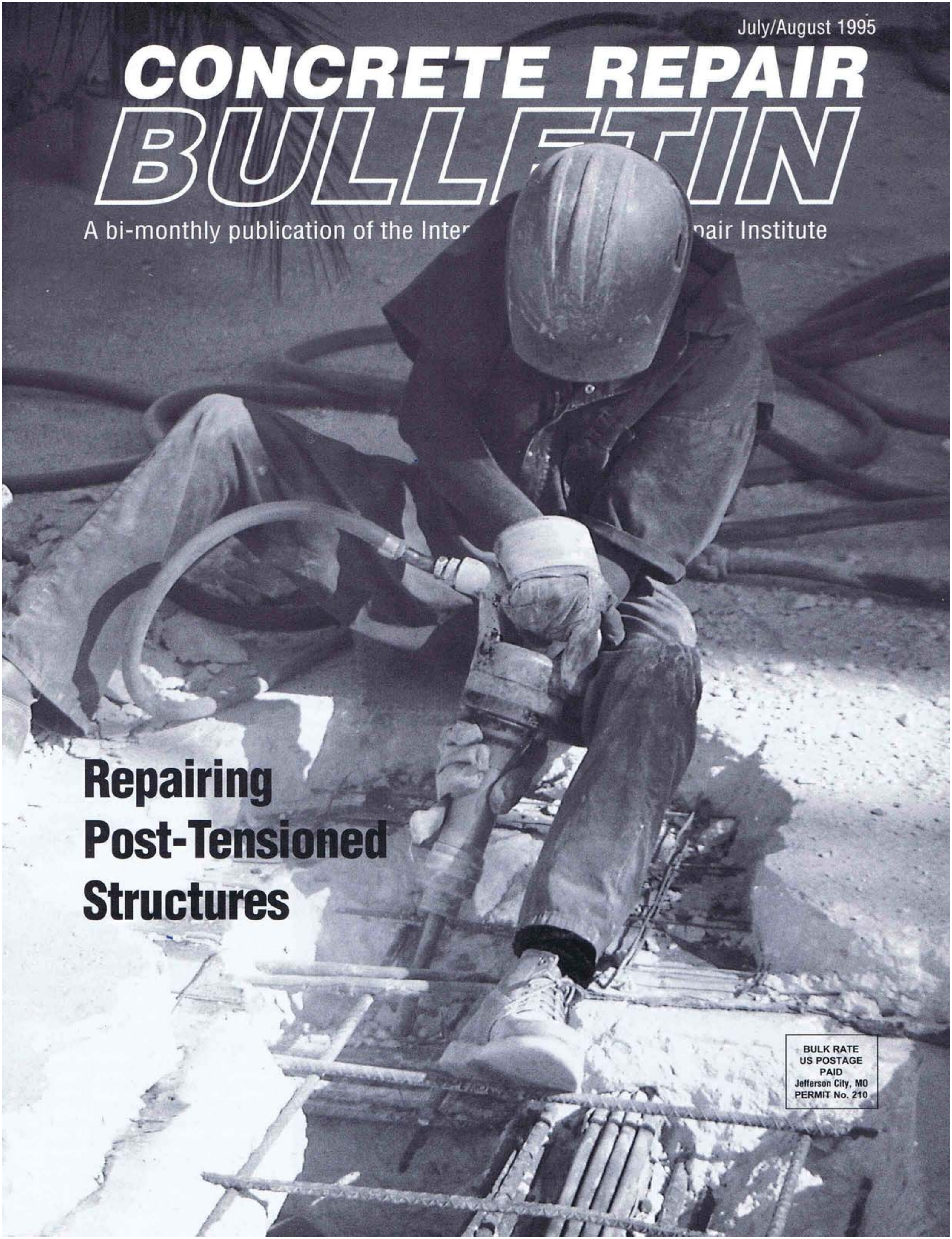


Repairing Post-Tensioned Structures

Evaluating Unbonded Post-Tensioned Slabs

Jeff Small

In recent years, the awareness of durability problems associated with unbonded post-tensioned slabs has grown. Reduced service life results from water contacting the prestressing steel which leads to corrosion and ultimately to failure of the steel strand. Evaluations are conducted to assess slab durability and structural safety, and, should damage exist, to determine the cause and extent of damage. Once the evaluation has been completed, repair options are reviewed to determine which would be most beneficial to the owner.

Corrosion potential

The procedure and discussion presented below focus primarily on post-tensioning tendons which use a plastic sheath. A tendon is composed of the prestressing steel strand, grease coating, and plastic sheath. The three different types of tendons which use plastic sheaths are: lapped and heat-sealed, push-through, and extruded.

Generally, heat-sealed and extruded sheaths fit tightly to the strand while the push-through sheath exhibits a loose fit. Due to the small amount of grease used in the push-through sheath coupled with its loose fit, voids are created where water can accumulate against the steel strand. This fact has made the push-through type generally more susceptible to corrosion damage; however, the other types of tendons are not always trouble-free.

The reduced durability of post-tensioned slabs has generally been a result of poor construction practices, poor design details, or unintentional exposure to a corrosive environment. During the construction phase, there are many opportunities for water to contaminate the prestressing steel. This contamination could occur during storage at the manufacturing plant or on site, during transportation of the materials to site, or immediately prior to concrete placement. Other construction deficiencies affecting durability are poor placement tolerances (tendons too close to the surface), damage to the sheathing during any stage of work, and poor or insufficient waterproofing.

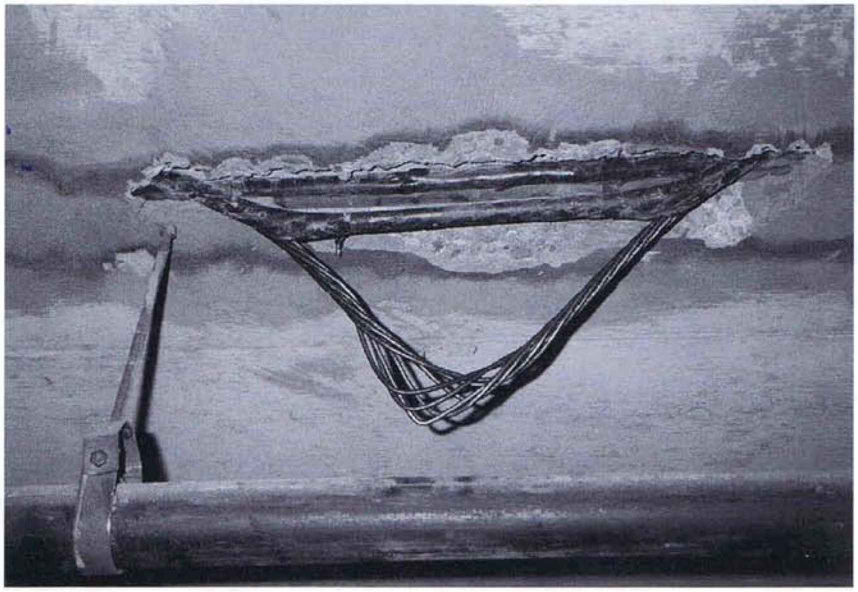
After construction is completed, water can enter the post-tensioning system through inadequately protected anchorages, through cracks in the concrete, or through the concrete pore structure. Although a number of measures can be taken during the design stage to mitigate cracking, significant cracking is often observed where these measures are absent. Another common oversight in design details is the lack of waterproofing at anchor zones which are particularly vulnerable to moisture penetration. The majority of corrosion damage observed results from water entering through the stressing ends of the anchors.

Corrosion damage

Corrosion of the prestressing steel typically begins as galvanic corrosion, where rust is produced as a product of the reaction between water and oxygen. Localized attack of the steel can produce pits on the surface where the rate of corrosion can be greater than general corrosion at adjacent sites. This localized attack can significantly reduce the cross section and therefore the strength of the strand.

Stressed high-strength steels are also susceptible to stress-corrosion cracking, which is typified by the propagation of a cracks in individual wires with little loss of metal. Higher stress levels result in more rapid crack growth. Hydrogen, which is produced from galvanic corrosion, can be absorbed onto the surface of the crack making it easier to propagate. In the majority of cases, strand failure has been a result of brittle fracture and not from a loss of cross section.

The consequence of corrosion damage is a reduction in the structural capacity of the slab from loss of cross-section or from brittle fracture



Strand eruption through a slab soffit.

of the strand. Strands erupting from a slab or projecting from a slab edge from sudden brittle fracture pose an additional threat to public safety. However, eruption is a relatively rare occurrence—most failures occur without external evidence. This point is significant since a high percentage of internal strand failures can go unnoticed. As extensive damage can exist without any external indicators, post-tensioned slabs exposed to a corrosive environment should be periodically reviewed by a qualified and experienced engineer.

Evaluation program

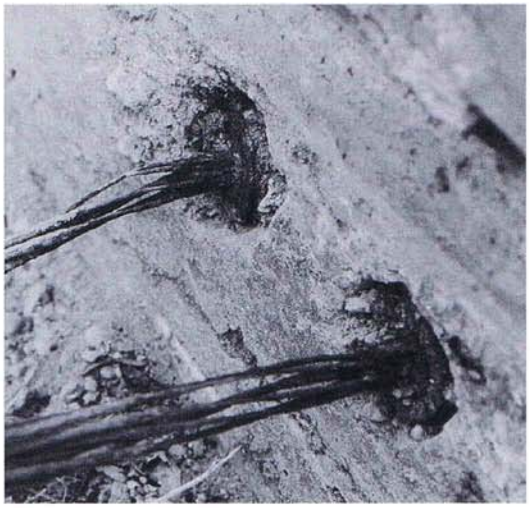
The first stage in the evaluation program is to qualify the potential for a particular slab or area of slab to have corrosion damage. Available drawings are reviewed to determine the layout and type of post-tensioning tendons and sheaths. The live, intermediate, and dead end anchor locations are confirmed.

During visual review of the slab, obvious signs of strand failure are observed. Failures can be manifested by a strand segment protruding out of the slab at its edge or by a loop of strand extending through the any of the slab surfaces. Spalled concrete associated with an underlying tendon can indicate potential distress of the strand. Both the accumulation of corrosion products and the freezing of sufficient water within the sheath can lead to spalling. By cutting the sheathing, the interior condition can be viewed. This often reveals the cause of the spalling. Delamination caused by corrosion of supplemental bonded reinforcing can also provide water access to tendons.

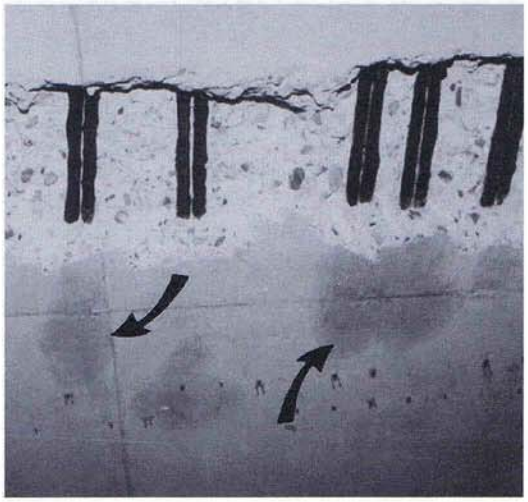
Grease stains on the slab soffit should be noted. These stains do not necessarily confirm strand damage, but they do indicate defects in the protective sheath. An opening in the sheath could allow water to enter the void created by the loss of grease.

The condition of the grout pockets can provide additional information. Poor quality grout or the absence of grout indicate a slab that is more vulnerable to moisture penetration. An unfilled anchor recess below grade is a strong indicator of potential corrosion damage.

Signs of water leakage should be recorded, as water can contact the tendon through slab cracks. The condition of expansion joints should be checked. Failed joints will allow moisture access to the post-tensioning system. Leakage through slab/foundation wall construction joints indicates that water is present at the anchorages. Leaking of this joint has often been associated with a lack of slab edge waterproofing, resulting in strand corrosion.



Top: *Buried anchors exposed for inspection.*



Above: *Grease stains on soffit indicating a damaged sheath.*

Protection systems on the slabs and slab edges should be confirmed. Landscaping on buried slabs should be selectively removed to expose the protective system for evaluation. Often waterproofing has been installed on the deck but not continued down the edges where the anchors are located. Again, this is a critical deficiency that should be confirmed.

Drainage of the surrounding site should also be qualified. Water entry through the anchors is contingent upon water being available at the anchor zones. Water draining toward or ponding against the slab edge should be noted. Selected tendons anchored where waterproofing is absent should be examined. Landscaping materials, such as grass and topsoil tend to trap moisture against the slab, increasing the potential for corrosion damage.

All observed defects are recorded on sketches of the slab surface and slab soffit. The defect map aids in the selection of inspection recesses where the tendons will be exposed for review.

Strand examination

A number of selected strands are exposed for examination, since external evidence of strand deterioration is infrequent. The need to expose strands is particularly significant for slabs which display the indicators of moisture penetration. The drawing and visual review data are used in conjunction with a knowledge of mechanisms of moisture ingress to identify high risk locations.

Inspection holes are chipped to expose strands at these high risk locations. Enough concrete is removed to expose a complete wrap of the helical wires of the strands. The hole should be wide enough to allow the strands to be easily accessed. The sheath is cut back to view the strand. The presence of water and corrosion products and the condition and quantity of grease are noted.

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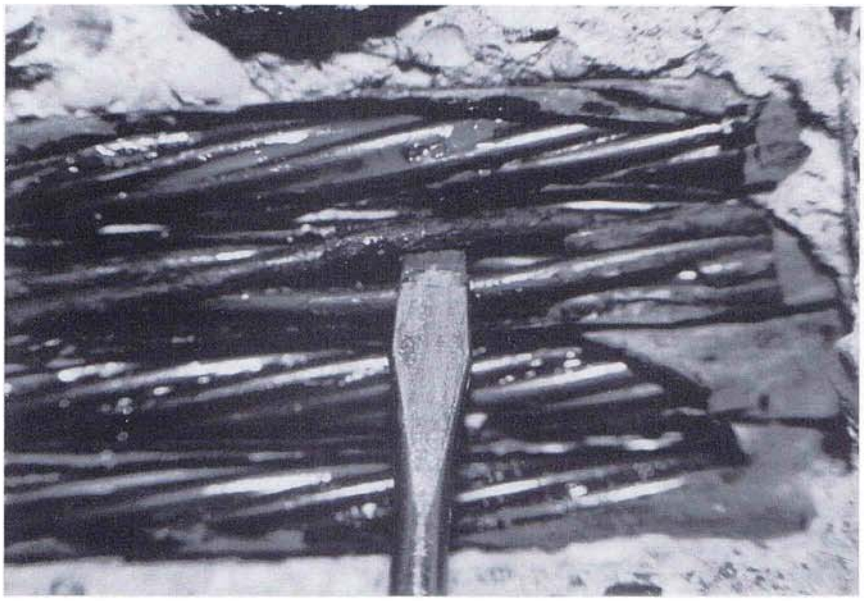

Trying to wedge apart the individual wires of the strand is one way to check for breakage.

There are several ways to check strands for breakage. The most reliable method is to attempt to wedge apart the individual wires of the strand. Another technique—deflecting the exposed strand with a prybar—has not been reliable. Strands which are readily deflected have been cut, and seemingly tight strands have been broken. Occasionally, the data provided by wedging the wires apart has proved to be misleading, but this is the exception, not the general rule.

The author is not aware of any electronic or acoustic test techniques which have been used to reliably confirm the presence of *existing* corrosion or breakage. A method has been used to assess the potential for corrosion damage of stuffed or heat-sealed tendons. With this method, dried air or an inert gas is injected into the sheath at one end of the tendon. The humidity of the exhausted air is then measured at the other end. The amount of moisture extracted is correlated to the corrosion potential. Unfortunately, this method cannot detect failed strands.

Examination holes provide valuable information on the condition of the strand. However, because the percentage of the total strand length visible at an examination recess is extremely small, the level of confidence is dependent largely upon the accuracy with which the highest risk locations were identified. A strand observed to be in good condition at a probe site may be corroded at another location along its length. Unfortunately, because the system is unbonded, it is the worst condition along the strand which governs.

The level of confidence may be improved by removing some strands for full-length inspection. This should be done on slabs having high risk factors even though no evidence of corrosion damage is uncovered at the probe sites. This situation generally occurs in installations with extruded tendons. When removing strands, care must be exercised to prevent contamination of the strands. By placing strands onto plastic sheets, contamination may be prevented.

A slab is generally divided into areas according to the potential for moisture to penetrate into the post-tensioning system. Conditions observed at the inspection recesses in each area are extrapolated over that section only. For example, a slab was examined where there was 80% breakage of tendons running north/south while perpendicular tendons displayed only 3% breakage. In this instance, the north/south tendon live-end anchorages were located against backfill where water was ponding and the slab edge was unprotected. Alternately, east/west tendons were relatively well protected.

Finally, structural analysis of the slab can be conducted to assess safety. This will lead to conclusions regarding shoring requirements and remedial work. Before scheduling of repairs is determined, the feasibility of a phased approach should be reviewed.

Summary

Judgements regarding the overall fitness of the post-tensioning system are, of practical necessity, based on extrapolation from a limited number of inspection points. Therefore, the reliability of the evaluation process is highly dependent upon the engineer's ability to correctly identify and properly inspect those locations having high risk potential.❒

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