

Assessing New Techniques for Evaluating Post-Tensioned Buildings

by A.H. Rahman and G. Pernica

Many buildings with unbonded post-tensioned systems require expensive repairs owing to corrosion of the tendons. This Update presents the findings from a study recently conducted by IRC, in partnership with Canada Mortgage and Housing Corporation (CMHC), on the effectiveness of three new techniques for assessing the condition of these tendons.

Unbonded post-tensioned (PT) systems are popular with developers of multi-storey office and residential buildings as they reduce costs by allowing thinner slabs and faster construction. In many of these buildings, some only ten years old, expensive repairs have been necessary because of premature corrosion of the tendons. This corrosion can occur and continue without any visible signs of deterioration. For safety reasons, it is important to be able to evaluate the condition of the tendons, but there has always been a shortage of reliable and affordable techniques.

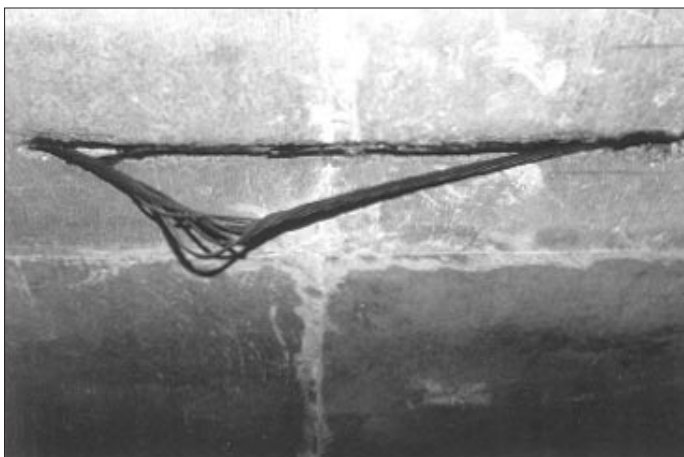


Figure 1. A post-tensioned tendon erupts through the structural slab. Photo courtesy Vanco Structural Services Inc.

Difficulties in Evaluating PT Structures

In-situ evaluation of unbonded tendons in a PT building is technically challenging. The half-cell potential test for detecting areas of active corrosion is ineffective as the tendons are electrically insulated by plastic sheaths or paper wraps.

The screwdriver test, as it is commonly called, which is widely used to detect broken wires in seven-wire tendons, has several limitations. First, the absence of standards governing the hardness, size and profile of the screwdriver head, and the force applied to drive the head, often results in inconsistent conclusions. Second, friction between the wires, particularly in corroded segments of the tendon, can prevent detection of a break that is not within a short distance of the test point. And finally, this test is destructive, as concrete must be removed to gain access to the tendon.

New Evaluation Techniques

Several techniques for evaluating the condition of PT tendons have been proposed and developed over the last few years. Three of these were investigated by IRC to determine their effectiveness in achieving their stated goals.

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Acoustic Continuous Monitoring

This technique is designed to report the time and location of tendon/wire rupture by detecting the sound emanating from the rupture. This is done with an array of accelerometers attached to the structure and connected to an on-site data-acquisition system. The continuously active system is triggered to record an acoustic event only when the signal strength of the accelerometers exceeds a preset adjustable threshold. All recorded events are processed and analyzed by proprietary software to distinguish the ones that are, in fact, ruptures, and to locate the rupture and identify the tendon. The software has an artificial learning network that filters out spurious events. A final screening of the reported tendon ruptures is also done manually by a trained operator.

Extensive field tests were conducted to determine the accuracy, sensitivity and reliability of the technique. A system was installed to monitor an 1800-m² slab in a post-tensioned building. Actual events were caused artificially by cutting individual wires in several tendons. Artificial impacts were applied to the slab and columns to determine whether the technique was able to distinguish impacts from tendon ruptures. In addition to these artificially created events, spontaneous wire ruptures reported by the system in this building and two others over a one-year period were verified.

The technique successfully reported the majority of the deliberate wire cuts. Those cuts not reported were missed because the system was triggered prematurely by the noise from the grinder used to cut the wires. In real-life situations, this would not be a problem, as spontaneous wire ruptures are not preceded by such a noise. From the monitoring of the three buildings, 24 out of 29 reported wire ruptures were confirmed by exposing the affected tendon; three reported ruptures could not be verified because of poor access to the reported location. A small fraction of the artificial impacts were reported by the technique to be wire ruptures.

Based on these field-test results and the scientific soundness of the technique's working principles, IRC researchers are confident that the technique is capable of detecting and locating spontaneous wire ruptures in PT structures. While the technique is unlikely to miss actual wire ruptures, there is a small likelihood that it

will falsely report some events that are not, in fact, ruptures. The technique is virtually non-destructive, as no chipping or drilling into the concrete is required to install the monitoring system.

While the acoustic continuous monitoring technique obviously cannot be used to identify already broken tendons, once installed in a new building, or in an old building in which tendon damage has been identified by other techniques, it could eliminate the necessity of further evaluations by other techniques. By providing a continuous log of tendon ruptures, this technique could help establish the rate of deterioration of the building, thus assisting the owner to assess its remaining economic service life and to choose the more cost-effective option — repair or demolition.

Corrosion Prediction by Moisture Measurement

This technique estimates the probable degree of corrosion of tendons based on the measured moisture content of the air inside the plastic sheaths of the tendons. Dry air is pumped into the sheath through a nipple, forcing air out of the sheath. This expelled air is collected through another nipple located some distance away, and its moisture content determined by means of a standard relative humidity and temperature gauge. The tendon is then graded according to its moisture content, and this process repeated for all tendons deemed to require investigation. A small number of these tendons (considered to be representative of building moisture conditions) are then extracted, and their corrosion condition visually inspected and graded. The relationship between the degree of corrosion and the moisture grades for the extracted tendons is determined and used to statistically project the probable degree of corrosion for the rest of the tendons.

The corrosion process requires both moisture and oxygen. As some oxygen is usually present inside the sheath, the detection of moisture confirms the potential for corrosion. However, the extent of the corrosion cannot be determined merely through knowledge of the moisture content; the duration of the moist condition and the presence of other elements within the sheath are also significant factors. As well, the absence of moisture at the time of the investigation does not necessarily mean that the tendon has never been wet. These

limitations are largely overcome by correlating the moisture content of extracted tendons with their visually determined corrosion grade. Establishing the accuracy of this relationship is therefore crucial to assuring the effectiveness of the technique. This accuracy is highly dependent on the representativeness of the extracted set of tendons.

The current IRC evaluation focused on the verification of a relationship that was derived for an actual floor slab. Additional tendons were extracted from the floor slab and the observed degree of corrosion compared with that predicted by the technique. The comparison showed that

- 1) if the number of tendons extracted is based solely on a percentage of the moisture-tested tendon population, the sample set can be too small to provide a meaningful relationship, and
- 2) the number of tendons extracted should not be less than 15.

However, extracting tendons on a percentage basis would be adequate for typical PT slabs, which contain hundreds of tendons, thus providing a large enough sample.

One limitation of this technique is that it cannot be used to evaluate paper-wrapped tendons or tendons with extruded plastic sheaths as neither of these types of tendon contain enough space for airflow. Only the “stuffed” type of tendon with loosely fitted plastic sheaths can be evaluated. The technique requires that access holes be made to the tendon sheath, either by drilling or by chipping through the concrete cover, usually on the soffit of the slab. This procedure is somewhat disruptive to building functions and has the potential to damage a tendon by nicking one or more of its wires. The extraction of tendons to correlate the measured wetness grades with the observed grades of corrosion is also a destructive and expensive operation.

In spite of its disruptiveness to building functions and its destructiveness to the concrete member, the technique has the potential to be cost-effective, especially when a large number of tendons are to be investigated. Even if the projected degree of corrosion for member tendons is somewhat inaccurate, knowing the wetness conditions within tendon sheaths may still be helpful in assessing the tendons’ potential for corrosion and in deciding whether protective measures such as

moisture removal (gas purging) and grease injection would be beneficial.

Electromagnetic Pulse Technique

This technique was developed to estimate the loss of cross-sectional area (LCA) at a defect (such as a corrosion pit or a wire break) in a tendon, and to establish the location of such a defect along the tendon. An electromagnetic pulse is sent into a tendon from one of its ends. The pulse is reflected back from any anomalies (e.g., corrosion pits and wire breaks) or from the steel/air interface at the other end of the tendon. The transmitter, which also acts as a receiver, captures the reflected waves. The waves are recorded for a selected time interval and displayed on a video screen. Numerous pulses (128 or more) are transmitted into each tendon, with each new waveform added to those previously collected. The average waveform is calculated, displayed and carefully examined before being stored in a computer.

The stored waveforms are then analyzed and the properties of individual reflections (which comprise the waveform) determined. Analyzed reflections are translated into an estimated LCA by a proprietary method, and defects classified into different categories based on the estimated LCA. The distance of the defect from the transmitting end of the tendon is calculated from the arrival time of the reflection, and the severity of the defect from the duration, amplitude and shape of the reflection.

The effectiveness of this technique in achieving its objectives was investigated by conducting extensive field tests on 86 tendons in three buildings. Its accuracy and resolution were determined by comparing the reported LCA and defect location with those obtained from a visual inspection of 17 tendons with artificially inflicted defects, and 69 tendons with natural defects. The reporting consistency of the technique was investigated by testing 31 tendons on two separate occasions. Changes were made to 10 of the 31 tendons following the first investigation, without the knowledge of the operator. Tests were also conducted to determine whether the technique is influenced by real-life environmental conditions. These tests included putting water in the tendon sheath, wetting the surrounding concrete, creating electrical fields by placing a live electrical conduit across the tendon on

the slab soffit and inserting metallic contacts between tendons. The researchers also investigated known blind spots of the technique, i.e., the parts of the tendon where defects would remain undetected.

The test results clearly showed that the electromagnetic pulse technique is not effective in detecting defects or measuring the LCA in unbonded post-tensioned tendons. It was unable to detect 49 out of 68 actual defects with an LCA of more than 6%, including some that involved the complete failure of a tendon. Fifteen of the remaining 19 defects were detected with respect to location only, with their LCA underestimated in most cases. In addition, the technique reported 158 defects that were not found when the tendons were visually inspected — 83 of these non-existent defects were reported on 29 tendons that were, in fact, completely devoid of defects.

There was also a lack of consistency in reporting defects: 10 new defects were reported and one previously reported defect was not reported in the repeat investigation of 8 tendons that had not been altered in any way following the first investigation.

Tests to examine the influence of environmental factors showed that this technique was affected by electrical wires attached to the slab as well as by direct contact with other tendons or non-prestressed steel.

The study demonstrated that the electromagnetic pulse technique was not an effective method for investigating the condition of unbonded PT tendons.

Concluding Remarks

The acoustic monitoring technique was found to be reliable for capturing tendon ruptures. Obviously, it cannot be used to detect existing tendon defects.

The corrosion prediction by moisture measurement technique was found useful in providing an overview of the wetness conditions within tendon sheaths and a statistical estimate of the degree of tendon corrosion, if the extracted tendons are chosen judiciously.

The electromagnetic pulse technique, which attempted to detect and locate existing defects, was found to be ineffective.

The investigation showed that there is still a need to develop effective techniques for assessing and locating corrosion damage in post-tensioned tendons — in particular, techniques that directly measure the residual force in a tendon *in situ*.

In the meantime, the widely used screw-driver test should be standardized to improve its consistency and reliability. In addition, guidelines on evaluating post-tensioned buildings are needed by building owners and professional engineers. IRC is currently developing such guidelines in collaboration with Canada Mortgage and Housing Corporation and professional engineers.

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