



## EFFECTIVENESS OF AN ACOUSTIC CONTINUOUS MONITORING SYSTEM FOR POST-TENSIONED BUILDINGS—AN EVALUATION REPORT

### Introduction

The evaluation of post-tensioned buildings poses a challenge to professional engineers. The tendons are hidden from view and external evidence of their corrosion is seldom apparent. Failure of the tendons can be catastrophic. Therefore, non-destructive techniques that can determine the *in situ* condition of tendons are essential. However, to make rational decisions on whether to repair or rebuild, and to schedule and budget for repairs, techniques that determine the rate of deterioration are also required. In this respect, a technique that can detect and locate the rupture of individual tendon wires can be very useful.

The Institute for Research in Construction was requested by Canada Mortgage and Housing Corporation to investigate some of the more promising techniques proposed to evaluate, repair and protect the condition of unbonded steel cables in post-tensioned buildings. This report presents the evaluation of a proprietary acoustic monitoring system for detecting and locating the rupture of a tendon, or of one or more of its wires.

The working principle behind the technique is that the rupture of a stressed tendon releases substantial energy, creating an acoustic wave that is transmitted into the concrete structure in all directions. Using a continuous monitoring system, the vibration in the concrete caused by a tendon rupture is picked up by an array of piezoelectric accelerometers that are attached to the surface of the concrete member.

To minimize the recording of most trivial events, a “pre-trigger” device is configured to accept only signals possessing certain characteristics. When an acoustic wave exceeds the threshold level of the pre-trigger device, the data acquisition system is activated and waveforms from all slab sensors are recorded for a period of about 150 milliseconds. The system remains busy for at least two seconds recording and writing the collected information into a computer file. If more events occur during this busy interval, they are not recorded.

The threshold level of the pre-trigger device is determined by producing impacts of known characteristics on the slab or, if feasible, by cutting a few wires. As the system also picks up other structural-borne acoustic signals which are comparable in amplitude to tendon ruptures, all recorded events are processed and analyzed by a proprietary on-site computer program, using an “artificial learning network”, to identify actual tendon ruptures and to locate the ruptures within the member. The information collected by the



on-site computer is periodically downloaded to a central computer via phone lines for processing and screening by another computer program that identifies and locates tendon ruptures.

## Research Program

The system was installed in a building in Calgary, Alberta. To determine the monitoring system's capabilities and limitations in a reasonably short period of time, the technique was tested under controlled conditions using artificially induced events, such as cutting tendon wires, striking the structure with hammers and dropping heavy weights onto floors. Tendons were cut using either a noisy hand-held grinder or using a quieter high-speed cutting tool. A 2-kg hammer and a 5-kg instrumented hammer were used to test the system's ability to distinguish acoustic signals produced by objects striking the slab from those produced by wire ruptures. The proponent of the system was not at the site and was not informed of the time of these tests prior to their being undertaken.

A long-term monitoring program was also undertaken in another building in Calgary, as the ultimate proof of the technique's effectiveness lies in verifying its ability to report spontaneous (naturally occurring) ruptures in tendons.

## Results

The system-reported wire snaps were examined to determine if they matched the time and location of the wire cuts made. Of the twelve tendons cut, seven appear to have been detected as at least one wire snap was reported by the acoustic continuous monitoring system. The five other tendon cuts were not detected by the acoustic continuous monitoring system. For three of these cuts, it was determined that the noisy grinder triggered the system into recording mode, forcing it to miss the wire snaps that followed moments later. For the other two of

these five tests, unknown to NRC/IRC who were conducting the test, the system had been turned off for data downloading. Within a few days of the start of the monitoring, field work on another evaluation technique commenced at the same building.

While this overlap of research activities helped reduce overall evaluation costs, this additional technique involved chipping concrete from the slab, which frequently triggered the data acquisition system. As a result, the system had to be turned off several times to download large amounts of data generated primarily by the chipping activities.

The first two of the four impacts of Impact Test 2 were reported as wire snaps. However, Impact Tests 1, 3, 4, and 6 were not reported as wire snaps. The system was off for data downloading during Tests 5 and 7. The identified location of the cut tendon varied between 0.55 m and 2.59 m along the length of the tendon and between 0.03 m and 0.87 m in the perpendicular direction.

The long-term monitoring part of this research project has been ongoing since September 1995. Five spontaneous wire breaks were reported as of March 1997. Independent physical reviews of the tendons confirmed the results; broken tendon wires were found within 750 mm of the reported locations.

Several other buildings in Canada and the United States are currently being monitored by the acoustic continuous monitoring system on a commercial basis. In one building, 12 wire ruptures were reported. Ten were confirmed by visual inspection. The eleventh was found on the designated tendon but 5 m from the reported location. The twelfth was a spurious event. Similar results have been reported by the proponent on another building.

## Implications for the Housing Industry

The acoustic continuous monitoring system is based on sound scientific principles. The equipment is reliable, sophisticated and rugged. The tests show that the system is capable of detecting wire ruptures in unbonded post-tensioned tendons and reporting when and where a rupture occurred. While the system is unlikely to miss capturing wire ruptures, it may sometimes report spurious events as wire ruptures. However, the likelihood of such false reporting appears to be small. The cost of monitoring post-tensioned buildings by the acoustic monitoring system depends principally on the area of the slab to be monitored, its accessibility, and the required frequency of monitoring reports.

It is estimated that the cost of installation, in 1998 dollars could vary from \$5 to \$10 per m<sup>2</sup> and for monitoring, from \$0.60 to \$0.90 per m<sup>2</sup> per year.

Installed in a new building soon after construction, the acoustic continuous monitoring system could provide the information required for evaluating the residual capacity of post-tensioned members. This information could then be used to assess the structural impact of tendon rupture and for determining repair needs at any time during the life of the building. In existing buildings containing previously broken tendons, system monitoring for several months could help identify problem zones, where inspection of tendons should be concentrated. The monitoring may even help identify the underlying cause of the problem, thus allowing timely intervention.

At the present time, the acoustic continuous monitoring system does not attempt to determine the number of wires ruptured during an event. The lost capacity of a tendon is directly proportional to the number of wires ruptured and multiple-wire breaks occurring simultaneously in a tendon are not uncommon. Therefore, it is recommended that the capability to determine the number of wires ruptured be developed, if possible, to help engineers more accurately assess lost structural capacity. This capability could also minimize the need for destructive field investigations. A further improvement in the reliability in locating tendon ruptures is also recommended.

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**Research Reports:** *Effectiveness of an Acoustic Continuous Monitoring System for Post-Tensioned Buildings—An Evaluation Report*

**Research Consultant:** Institute for Research in Construction, National Research Council Canada

A full report on this project is available from the Canadian Housing Information Centre at the address below.

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