RESEARCH REPORT

Effectiveness of An Electromagnetic Wave Propagation Technique for the Condition Assessment of Unbonded Post-Tensioned Tendons - An Evaluation Report

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EFFECTIVENESS OF AN ELECTROMAGNETIC WAVE PROPAGATION TECHNIQUE FOR THE CONDITION ASSESSMENT OF UNBONDED POST-TENSIONED TENDONS - AN EVALUATION REPORT

Effectiveness of an Electromagnetic Wave Propagation Technique for the Condition Assessment of Unbonded Post-Tensioned Tendons

An Evaluation Report

Prepared for

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Effectiveness of an Electromagnetic Wave Propagation Technique for the Condition Assessment of Unbonded Post-Tensioned Tendons - An Evaluation Report

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Executive Summary

The effectiveness of an Electromagnetic Wave Propagation Technique (EWPT) in detecting and locating defects in unbonded post-tensioned tendons and measuring the loss of cross-sectional area (LCA) at such defects has been evaluated.

The technique works on the principle that an electromagnetic pulse transmitted through a tendon from one of its ends is reflected from defects in the tendon such as corrosion pits and wire breaks. The distance of a defect from the transmitting end of the tendon is calculated from the arrival time of the reflection and its severity (depth and length) from the reflection's duration, amplitude and shape.

A protocol was prepared by the Institute for Research in Construction (IRC) of the National Research Council Canada (NRC) for the purpose of this evaluation. In accordance with the protocol, tests were conducted in three buildings in Calgary on a total of 86 tendons of various lengths and two sizes. The most important objectives of these tests were to determine the accuracy of defect detection and measurement of LCA, the influence of environmental factors such as water in the tendon sheath, nearby electrical fields and electrical contact with other tendons and metals, and the reproducibility of the technique's findings.

Tests showed that the technique is ineffective in detecting defects and measuring loss of cross-sectional area in unbonded post-tensioned tendons. The technique could not detect a majority of the defects, some as severe as completely broken cables. On the other hand, it reported a very large number of defects that did not exist. The technique appears to be influenced by the presence of electrical conduits near tendons and by electrical contact of tendons with metals although more testing is required to confirm this observation.

The technique in its current state is therefore not recommended for assessing the condition of unbonded post-tensioned tendons.

Résumé

On a évalué l'efficacité d'une technique fondée sur la propagation des ondes électromagnétiques pour détecter et localiser les défauts dans les câbles de post-contrainte non adhérents et pour mesurer la perte de section à la hauteur de ces défauts.

La technique fonctionne selon le principe qu'une impulsion électromagnétique transmise dans un câble à partir de l'une de ses extrémités est réfléchie par les défauts du câble, tels que les piqûres de corrosion et les ruptures de fil. La distance entre un défaut et la source de l'impulsion est calculée en fonction du moment où la réflexion arrive et de son intensité (profondeur et longueur) par rapport à la durée de la réflexion, à son amplitude et à sa forme.

L'Institut de recherche en construction du Conseil national de recherches du Canada a élaboré un protocole d'évaluation. Conformément à ce protocole, des essais ont été menés dans trois bâtiments situés à Calgary, sur 86 câbles de longueurs diverses et de deux dimensions. Ces essais visaient principalement à déterminer la précision de la technique pour détecter les défauts et mesurer la perte de section, à évaluer l'effet de facteurs environnementaux comme la présence d'eau dans la gaine des câbles, les champs électriques situés à proximité et le contact électrique avec d'autres câbles et pièces métalliques ainsi qu'à établir la reproductibilité des résultats obtenus au moyen de cette technique.

Les essais ont montré que la technique est inefficace pour détecter les défauts et mesurer la perte de section dans les câbles de post-contrainte non adhérents. La technique n'a pas réussi à détecter une majorité de défauts, parmi lesquels on comptait même des câbles complètement sectionnés. Elle a toutefois signalé un grand nombre de défauts inexistants. Cette technique semble être influencée par la présence de canalisations électriques à proximité des câbles et par le contact électrique avec d'autres pièces métalliques, quoique de plus amples essais devront être effectués pour pouvoir confirmer cette observation.

Dans sa forme actuelle, la technique n'est donc pas recommandée pour évaluer l'état des câbles de post-contrainte non adhérents.

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1. Introduction

Evaluation of post-tensioned (PT) buildings poses a challenge to the professional engineer. Tendons are hidden from view and external evidence of their corrosion is seldom apparent until it is too late. Therefore, non-destructive techniques that can determine the condition of the tendons in situ are highly desirable.

A technique that can locate damages in PT tendons caused by corrosion or other environmental factors and directly measure the loss of cross-sectional area of the tendons can be an invaluable tool in evaluating the structural capacity of a deteriorated PT member. A newly-developed electromagnetic wave propagation technique (EWPT) has been presented as such a technique by its proponent.

The effectiveness of the EWPT was recently evaluated by the Institute for Research in Construction (IRC) of the National Research Council (NRC) under a contract with the Canada Mortgage and Housing Corporation (CMHC) and a letter of agreement with the proponent. The present report contains the method and findings of this evaluation.

2. Evaluation Protocol

A protocol was developed by NRC/IRC to evaluate the EWPT which was agreed to and signed by the proponent. The complete protocol is given in Appendix I while the most relevant portions are restated below.

2.1 Objective of Evaluation

The objective was to determine if the EWPT is effective in detecting and locating defects in unbonded PT tendons such as corrosion pits, cracks and breaks that amount to a loss of cross-sectional area (LCA) and in measuring the LCA. If found technically effective, its cost-effectiveness would also be studied.

2.2 Evaluation Criteria

To assess the technique's effectiveness requires determining whether the technique is influenced by the following: moisture in the tendon or in the surrounding concrete; electromagnetic fields created by electrical conduits in the slab; contact of the tendon with non-prestressed reinforcing bars and steel chairs supporting the tendon.

It is also important to determine if the technique has any "blind spots", i.e. parts of the tendon where defects can go undetected. The accuracy and resolution of the loss of cross-sectional area and distance of a defect from a reported reference point, limits of tendon length, reproducibility of measurements, ruggedness of the equipment, and subjectivity of the reported findings are also important issues for the technique's success.

The following criteria were thus considered applicable in the protocol for judging the effectiveness of the technique:

1. *Simplicity*
   a. Type, number, weight and size of field equipment
   b. Field power requirements

c. Ease of installation

d. Ease in interpreting field data

e. Destructiveness to building under investigation

f. Disruptiveness to building functions and occupants

2. *Accuracy and Reliability*
   a. Closeness of measured defect parameters (location and loss of cross-sectional area) to actual conditions
   b. Reproducibility of measurements
   c. Ability to ignore or filter spurious signals including those produced by contact with or closeness to other metallic elements and electrical conduits
   d. Sensitivity of technique to environmental conditions such as temperature, humidity, wetness of slab, and electrical or electromagnetic fields
   e. Dependence on operator or interpreter
   f. Ruggedness of equipment
   g. Frequency of calibration

3. *Range and Sensitivity*
   a. Types of detectable and measurable defects in tendons
   b. Threshold sensitivity and resolution of the loss of cross-sectional area
   c. Resolution of distance to locate defects along tendon length
   d. Maximum length of tendon that can be tested by the technique

2.3 Method of Evaluation

The following tasks were carried out to evaluate the technique:

1. Interview of the proponent to acquire information on the working principle, equipment, field procedure, analysis and interpretation of field data, manner of reporting results, limitations of the technique known to the proponent, and range of costs for using the technique on actual structures

2. Observation of operation at two building sites

3. Blind tests on tendons with mechanically-inflicted defects inserted into existing ducts in a post-tensioned building

4. Blind tests on tendons in their natural states in three post-tensioned buildings

3. Description of Technique

The following information was collected by NRC/IRC from interviews with proponent personnel before and during field testing of the technique. More detailed information on the working principle and operation of the technique was considered proprietary and hence not divulged by the proponent.

3.1 Working Principle

An electromagnetic pulse is transmitted into a tendon at one of its ends. The pulse propagates down the tendon and is reflected back towards the transmitter from tendon anomalies such as corrosion pits and wire breaks or from material interfaces such as the steel-air interface at the other end of the tendon. The reflected waves are captured by the transmitter, now acting as a receiver, recorded and displayed on a video screen. Up to 128 pulses are automatically transmitted for each tendon test with each new reflection being added to those previously collected. The average waveform is calculated and displayed by the device and, if considered acceptable by the operator, transmitted to a computer where it is stored for later analysis. Stored signals are analyzed in the time domain by the operator by examining the properties of reflections (peaks and valleys within waveform).

The distance of the anomaly from the transmitting end of the tendon is calculated from the arrival time of the reflection and its severity (depth and length) from the reflection's duration, amplitude and shape. The analysis is performed on each of the reflections selected by the operator. Anomalies are classified into grade categories based on the estimated LCA.

3.2 Equipment

A *main device* with pulse generator capabilities outputs an electromagnetic pulse with a half sine-wave shape and 2-10 ns duration. The device is powered by battery to reduce noise from ground loops. The pulse is transmitted by a special *co-axial cable* having an electrical impedance comparable to that of the tendon. An *alligator clip* connects the co-axial cable to the tendon. Pulse reflections from anomalies and interfaces follow the same path in reverse and are recorded and displayed by the device now acting as a *digital storage oscilloscope*. A proprietary *computer program* controls the operation of the device from transmitting the pulses to downloading averaged reflected waveforms to a *computer* for storage.

3.3 Field Procedure

Information about the layout, location and length of tendons is obtained from building drawings, if available, and/or from a survey of the PT member using a covermeter, if required. No attempt is made to note and map intermediate anchors in the tendons, electrical conduits attached to the surface or buried in the member, or any other feature.

The tendon is exposed by removing any waterproofing membrane and the grout plug at one of the end anchors. If access to both ends is severely restricted, concrete is chipped at the nearest possible location to the end and the tendon sheath removed to expose a small length of tendon. The co-axial cable is connected to the tendon after the exposed end or section is nominally wiped and cleaned.

The electromagnetic pulse is transmitted into the tendon and its reflections collected by the main device. In some field tests observed by NRC/IRC, line power was used instead of battery power as the operator considered the battery life somewhat unpredictable. Five separate tests are conducted on each tendon and thus five average waveforms are recorded for each. If reflections are observed in the averaged waveforms that are considered as 'noise' by the operator, the alligator clip is removed and reattached to the tendon and the test redone. About two to three minutes are typically required to test a tendon.

3.4 Data Analysis

Waveforms stored on the computer are processed back in the laboratory by the operator. The waveforms are displayed on a monitor in the time domain and reflections considered significant (by the operator) selected for analysis. The analysis is not software-automated but is performed manually, step by step, by the operator. Time-domain properties examined in the analysis for each of the selected reflections are arrival time, duration, shape, rise and fall times, and amplitude. The analysis is rather tedious and time-consuming. About four days are required to properly analyze one day's field data.

3.5 Report

The key part of the technique's report is a table containing for each tendon tested, tendon identification and length, the grade of each defect detected in the tendon, and the location of the defect on the tendon. The grades used to denote the defects have the following relationship with LCA expressed as a percentage of the area of the undamaged tendon:

Grade	LCA, %	
0	< 6	(below the technique's detection threshold)
1	6 - 8	
2	8 - 12	
3	12 - 20	
4	> 20	

As Grade-0 defects cannot be detected by the technique, only Grades 1 through 4 are relevant to an evaluation.

The location of a defect (called anomaly in the proponent's report) is reported with a resolution of ±(0.5+0.05L) m, where L is the 'estimated' distance of the defect from the probing end. This means that if the distance of a defect is estimated by the operator as, say 20 m, it is reported as lying within a 3 m long segment of tendon beginning at 18.5 m. The 'minimum resolvable separation distance' between anomalies is stated to be 0.5 m in the reports, indicating that defects closer than 0.5 m cannot be distinguished.

4. Field Evaluation of Technique

Field tests on the technique were carried out in three post-tensioned buildings, all located in Calgary. Two of these buildings were previously investigated by the technique from which structural assessments of the buildings were made. The tendons in all three buildings, constructed during the seventies, are of the stuffed type.

All tests in Building A were carried out on a parking garage floor located below grade. The tendons are about 20 m long between end anchors and of 12.5 mm nominal diameter. In Buildings B and C, the tests were carried out on the ground floor directly above the parking garage. Tendons in these buildings are of 15 mm nominal diameter and about 54 m long in Building B and from 6.4 m to 19.5 m in Building C.

Thus the population of test tendons covered a good range of length, size, location and environment. A total of 86 tendons were investigated by the technique.

4.1 Test for Accuracy

Seven new tendons were stripped of their sheaths and prepared with artificial defects for testing in Building A. Six of these tendons were abraded and cut with a high-speed mechanical tool creating defects of various amounts of LCA at different locations along the tendons. These tendons were then inserted into empty sheaths in Building A and stressed in the usual manner. The remaining tendon was cut into two pieces and inserted into a single empty sheath. A gap of about 100 mm was left between the two pieces which simulated a completely broken tendon.

Ten tendons were cut in situ in Buildings A and C, three completely and seven partially with one to three wires cut. The remaining 69 tendons, distributed amongst the three buildings, were investigated in their natural states, i.e. without alterations of any kind.

4.2 Test for Reproducibility

The technique was tested for reproducibility of its findings by repeating its investigation of the 31 tendons in Building A one day after the first investigation. Ten of these tendons were deliberately altered before the second investigation as described in the following section. No artificial changes were made to the other 21 tendons between the two investigations. As none of the alterations amounted to any loss of cross-sectional area, no change in the technique's findings was expected in the second investigation.

4.3 Test for Environmental Influence

The following conditions were introduced to 10 tendons in Building A to determine the influence of the following factors on the performance of the technique: water in the sheath, tendon contact with wet slab and metals and presence of insulated electrical wiring in the slab. To ascertain the influences of these factors, the tendons were investigated by the technique before and after the following changes were made.

1. About a litre of water was poured into an empty sheath before introducing a new tendon into the sheath. Some of the water was pushed out by the tendon during its insertion.
2. Two tendons were stripped at a recess in the slab soffit and a moist rag was put in contact with both tendons and the concrete slab.
3. Two tendons were electrically connected by a piece of steel placed below stripped tendon sections and pressed to remain in contact with the tendons.
4. An insulated electrical extension cord was attached to the slab soffit and placed across five tendons. The cord supplied power to a 1500 W heat gun which was left ON during testing.

5. Results and Observations

All 86 tendons tested by the technique were extracted from the slabs and 61 of these visually inspected to log the actual defects. The latter included all the tendons with artificially created defects. Visual observations were compared with the findings to determine the technique's effectiveness.

The technique's proponent submitted two reports, one dealing with the tendons from Buildings A and B and the other with those from Building C. In both reports, the defects were graded according to the scale given in Section 3.5. The same scale was used to grade actual defects found from the visual inspection for a direct comparison with those reported by the technique. Visually inspected defects having less than 6% LCA were ignored as such defects fall below the technique's detection level.

The defects detected by the technique were reported to lie within ranges that varied from 0.6 m to 6.4 m. For some tendons the ranges amounted to as much as 30% of the tendon length. Several ranges were also found to be much higher than that obtained using the resolution formula (Section 3.5) given by the proponent.

Comparison of the technique and visual inspection findings for six tendons from Building A is shown in Table 1 and for all tendons in Appendix II. It was called a match in this comparison if a defect of the same grade reported by the technique was found by the visual inspection anywhere in the tendon segment reported by the technique as the defect location. If more than one defect were found by visual inspection within the segment, it was still called a match provided the grade of the largest actual defect was the same as that of the technique-reported defect.

The results of the Reproducibility and Environmental Influence Tests conducted in Building A are illustrated in the tables of Appendix III in which visual inspection and two sets of technique findings are compared. Only those tendons are listed for which technique findings from the two investigations differed whereas tendon conditions (mechanical defects) remained unchanged.

Observations made from the comparisons are summarized below (Tables 2 and 3).

5.1 Detection Accuracy

1. Visual inspection revealed a total of 68 defects with LCA's greater than 6% (Table 2), and therefore within the technique's stated detection capability.
   a) Forty-nine of these defects went undetected by the technique. Nine of 13 actual Grade-4 defects, including two completely broken (cut) tendons, were among those undetected.
   b) Four defects were detected by the technique which matched both grade and location.
   c) The remaining 15 defects were matched by the technique only in location; their grades were mostly underestimated by the technique.
2. The technique reported 158 defects not found by the visual inspection (Table 3).

a) One defect was reported as Grade 4, 13 as Grade 3, 100 as Grade 2, and 43 as Grade 1.

b) Eighty-three of these defects were reported on 29 tendons that were completely devoid of defects – seven as Grade 3, 43 as Grade 2, and 33 as Grade 1.

5.2 Reproducibility

3. From the reproducibility study on 21 tendons which were not artificially altered in any manner between the two sets of EWPT tests, eight tendons were reported with 10 more defects by the second investigation than by the first. One of these 10 defects is of Grade 3, five are of Grade 2, and four of Grade 1. One tendon defect reported in the first investigation was not reported in the second. The remaining 13 tendons were reported with the same number and distribution of defects from both investigations.

5.3 Environmental Influence

4. Of five tendons crossed by a live electrical wire only during the second investigation, four were reported with new defects by the second investigation – one with a defect of Grade 4, two with Grade 3, and one with Grade 2.

5. Of two tendons electrically connected by a piece of metal before the second investigation, both were reported with new defects by the second investigation — one with two defects of Grade 2, and the other with two defects of Grade 1.

6. Water in the sheath and moist patches do not appear to have influenced the technique's findings.

6. Discussion

The stated observations clearly indicate that the technique, as tested, is not effective in detecting defects and measuring loss of cross-sectional area in unbonded post-tensioned tendons. It could not detect a majority of the defects, some as severe as completely broken cables. On the other hand, it reported a very large number of defects that did not exist.

No consistency is observed in the discrepancy between actual and reported defects, rendering it difficult to find causes for the unsatisfactory performance of the technique. Its reporting of a large number of non-existent defects is possibly explained by the observation that the technique is influenced by live electrical wires running along the slab surface and by electrical contact of the tendons with each other or with other metal objects. These conditions are quite common in unbonded post-tensioned construction. However, these apparent influences should be confirmed by further testing of the technique in the laboratory.

As the technique was not found effective in performing the most significant function, i.e. detecting defects, no attempt was made to evaluate its other features listed in the Evaluation Criteria, such as dependence on operator, frequency of calibration, and threshold sensitivity and resolution.

7. Conclusion

The technique, as tested, cannot be recommended as a reliable procedure for detecting defects and estimating their severity (LCA) in unbonded post-tensioned tendons.

8. Recommendation

The proponent has proposed to improve the technique and requested that it be re-evaluated for its capability to estimate only the severity but not the location of the largest LCA in a tendon. Since such capability would still be useful for evaluating PT buildings, a re-evaluation of the technique would be worthwhile after these improvements are made.

However, the evaluation should begin with systematic laboratory testing to identify the parameters that govern the technique's performance and to ascertain the limitations of the technique before conducting field tests where the environmental conditions are largely unknown and uncontrollable.

Table 1 Comparison of visual inspection and technique findings

Tendon Number	Actual Defect		Technique Finding		Comment
	Location, m	Grade	Location, m	Grade	
1	3	1	0 - 1	2	Over
			3 - 4	1	
	6.1	3	6 - 8	2	Under
	12.0	2	12 - 13	2	Match
	15.1	4			
			16 - 17	1	
2			0 - 2	3	
	3.7	1			
			6 - 7	2	
	8.7	3			
			12 - 13	2	
	17.3	4			
3			0 - 1	2	
	3.0	2	2 - 3	1	Under
			4 - 6	1	
	6.2	3			
			8 - 9	2	
	15.8	4			
4	1.2	1			
			2 - 3	2	
			4 - 5	2	
	11.9	3			
	13.8	1			
			14 - 16	1	
	18.4	1			
5			2 - 3	2	
	5.7	2			
			7 - 9	3	
	14.8	2	14 - 15	1	Under
6			2 - 4	2	
	5.7	3			
			6 - 7	2	
			10 - 11	2	
	19.1	3			

Explanation of comments:

Match: Technique finding matches visual inspection in both location and Grade
Over: Technique finding overestimated the defect's Grade
Under: Technique finding underestimated the defect's grade
A blank line under comment indicates no match

Table 2 Reported Outcome for Actual Defects

Actual defects		No. of defects reported by the technique				No. of defects not reported by the technique
Grade	Number	Grade 4	Grade 3	Grade 2	Grade 1	
4 (WTC)[1]	4	0	1	1	0	2
4 (PTC)[2]	9	0	0	0	2	7
3	26	0	1	2	3	20
2	7	0	0	1	3	3
1	22	0	0	3	2	17

[1]Whole tendon cut, [2]Partial tendon cut

Table 3 Correspondence Between Technique - Reported And Actual Defects

Technique-reported defects		No. of actual defects at reported locations				No. of non-existent defects
Grade	Number	Grade 4	Grade 3	Grade 2	Grade 1	
4	1	0	0	0	0	1
3	15	1	1	0	0	13
2	111	2	2	2	5	100
1	56	2	5	3	2	44

Appendix I

NRC/IRC PROTOCOL FOR THE EVALUATION OF THE TECHNIQUE

1. Introduction

NRC/IRC has been recently mandated by the Canada Mortgage and Housing Corporation (CMHC) to evaluate some of the promising techniques of evaluating and repairing post-tensioned building components. An electromagnetic wave propagation technique is one of the evaluation techniques to be validated.

This document, prepared by NRC/IRC, is intended to form the basis of an agreement between NRC/IRC and the proponent for the former to carry out the evaluation. The document defines the criteria and method for the evaluation of the technique as well as the responsibilities of the proponent and of NRC/IRC in carrying out the evaluation.

2. Objective and Scope

The objective of the present evaluation of the electromagnetic technique is to determine its cost-effectiveness as a tool for the non-destructive in-situ evaluation of the state and condition of unbonded post-tensioned tendons in building components. Defects or flaws in the tendons that are relevant are only those having structural implications.

3. Technique Features under Evaluation

The technique will be evaluated for its capability to detect and locate the following defects in post-tensioned tendons in a real-life building:

1. Corrosion pits in tendon wires
2. Cracks and other mechanical defects in tendon wires
3. Broken wires or whole tendons

If field conditions permit, the technique will also be evaluated for its capability to detect tendons that are destressed due to reasons other than breakage of its wires.

4. Evaluation Criteria

In general, the following criteria will be applied to evaluate the capabilities and limitations of the technique:

A. *Simplicity*
   - a. Type, number, weight and size of field equipment
   - b. Field power requirements
   - c. Ease of installation
   - d. Ease in interpreting field data
   - e. Destructiveness to building under investigation
   - f. Disruptiveness to building functions and occupants

B. *Accuracy and Reliability*
   - a. Closeness of measured parameters to actual conditions
   - b. Repeatability and reproducibility of measurements

c. Ability to ignore or filter spurious signals from tendons including those produced by contact with or closeness to other metallic elements and electrical conduits
d. Sensitivity of technique to environmental conditions such as temperature, humidity, wetness of slab, and electrical or electromagnetic fields
e. Dependence on operator or interpreter
f. Ruggedness of equipment
g. Frequency of calibration

C. Range and Sensitivity

a. Types of detectable and measurable defects in tendons
b. Threshold sensitivity and resolution of the loss of cross-sectional area
c. Resolution of distance to locate defects along tendon length
d. Maximum length of tendon that can be evaluated by the technique

5. Method of Evaluation

NRC/IRC will carry out the evaluation of the technique by

a. conducting interviews of proponent personnel and/or studying written materials obtained from the proponent,
b. verifying the technique findings of artificially generated tendon defects, and
c. verifying the technique findings from a real-life field investigation.

A panel of consulting engineers conversant with repair of post-tensioned buildings will be invited to provide comments on the NRC/IRC evaluation programme and on the results of the evaluation as well as to witness the field verification of the technique findings. The names of the consulting engineers in this panel are given in Section 9.

5.1 Interviews and written submissions

NRC/IRC will interview proponent personnel and/or study written materials by the proponent to obtain information on the following:

a. Working principle of the technique
b. Method and manner in which the field data are acquired, interpreted and translated to reported findings
c. Limitations of the technique
d. Range of costs for real-life use of the technique

5.2 Field evaluation

Field evaluation of the technique will be carried out on either one or both of Buildings A and C in Calgary. The technique was previously used in both buildings to evaluate the condition of tendons in selected floor slabs.

Up to 100 tendons in one or both buildings will be re-assessed by the technique. All tendons will be located in the main and/or garage floors of the buildings. To ascertain reproducibility of the findings, the earlier findings will be compared with those obtained from this field evaluation. Alternatively, the proponent may repeat some measurements under the present evaluation if preferred.

Some of the tendons will be intentionally damaged to test the technique's capabilities in detecting and locating specific defects.

Technique findings on the condition of tendons will be verified by conducting visual and/or other examination deemed appropriate by NRC/IRC on a sample of tendons.

6. Proponent Responsibilities

The proponent will carry out the following tasks at no cost to NRC/IRC, assuming all risks and liabilities for injury to their personnel and damage to their equipment and the building:

1. Perform all work in the field and in the office required to evaluate up to 100 tendons in the above-mentioned buildings using the technique.
2. Explain the data acquisition process to and facilitate its observation by NRC/IRC personnel during the field investigation.
3. Submit a report to NRC/IRC that will include, for each tendon investigated,
   i) a list of defects found that indicate a loss of cross-sectional area,
   ii) the estimated loss of cross-sectional area at each such defect,
   iii) the location of each such defect on the tendon measured from a clearly established reference point, and
4. Provide NRC/IRC personnel, through interviews, the reasoning behind the interpretation of the field data and their translation into the reported findings.

The proponent is not obligated to divulge any information to NRC/IRC that they consider proprietary or that has the potential to compromise their competitiveness. However, lack of certain information may limit the ability of NRC/IRC personnel to properly evaluate certain capabilities of the technique. NRC/IRC will identify such instances, if any, in its report.

7. NRC/IRC Responsibilities

NRC/IRC will perform the following tasks at no cost to the proponent:

1. Identify the area of the slab or the individual tendons to be investigated by the technique, as conditions dictate.
2. Provide access to the ends of the tendons required by the proponent to conduct the investigation.
3. Verify technique findings by performing visual inspection and/or other examination on a selected number of tendons deemed appropriate by NRC/IRC.
4. Provide the proponent a copy of the excerpts of the NRC/IRC report to CMHC that pertains to the evaluation of the technique.

8. NRC/IRC Rights

NRC/IRC has the right to disclose its evaluation of the technique to CMHC and to the members of the panel of consultants given in Section 9.

NRC/IRC will also have the right to publish its evaluation in scientific research journals and magazines. The technique will not be identified specifically but only by its generic name in such publications.

9. Panel of Consultants

The following consulting engineers will be invited to provide their comments on the present NRC/IRC protocol for the evaluation of the technique and on the findings of the evaluation:

Mr. Norm Webster	Read Jones Christofferson Ltd., Calgary, Alberta
Mr. David Woodall	Campbell Woodall and Associates, Calgary, Alberta
Mr. Anast Demitt	Adem Engineering, Calgary, Alberta

More members from the consultant community may be added to the panel in the future.

10. Time Schedule

The anticipated time slots during which the interviews and the field investigation will be carried out are given below:

1. Pre-field-investigation interview(s)	June 8 to 14, 1995
2. Field investigation	June 14 to 17, and August 1995
3. Post-field-investigation interview(s)	September 1995

NRC/IRC will notify the proponent of more specific dates as soon as details of the field conditions are known.

Appendix II

COMPARISON TABLES FOR VISUAL INSPECTION AND TECHNIQUE FINDINGS

Note:

Words in the comment column of these tables have the following meaning:

Match: Technique finding matches visual inspection in both location and Grade
Over: Technique finding overestimated the defect's Grade
Under: Technique finding underestimated the defect's Grade
A blank line under comment indicates no match.

Building A

Tendon Number	Actual Defect		Set 1 Finding		Comment
	Loc [m]	Grade	Loc [m]	Grade	
1	0.3	1	0 - 1	2	Over
			3 - 4	1	
	6.1	3	6 - 8	2	Under
	12.0	2	12 - 13	2	Match
	15.1	4			
			16 - 17	1	
2			0 - 2	3	
	3.7	1			
			6 - 7	2	
	8.7	3			
			12 - 13	2	
	17.3	4			
3			0 - 1	2	
	3.0	2	2 - 3	1	Under
			4 - 6	1	
	6.2	3			
			8 - 9	2	
	15.8	4			
4	1.2	1			
			2 - 3	2	
			4 - 5	2	
	11.9	3			
	13.8	1			
			14 - 16	1	
	18.4	1			
5			2 - 3	2	
	5.7	2			
			7 - 9	3	
	14.8	2	14 - 15	1	Under
6			2 - 4	2	
	5.7	3			
			6 - 7	2	
			10 - 11	2	
	19.1	3			

Building A (continued)

Tendon Number	Actual Defect		Set 1 Finding		Comment
	Loc [m]	Grade	Loc [m]	Grade	
7			0 - 1	2	
			2 - 3	3	
			6 - 8	2	
			12 - 13	2	
			14 - 16	2	
	16.8	4 (WTC)			Whole Tendon Cut
8	0.9	1			
			1 - 2	1	
			7 - 8	2	
	9.8	3			
			11 - 13	2	
			15 - 16	3	
9			1 - 3	1	
			7 - 8	1	
			9 - 11	2	
			12 - 13	2	
			15 - 16	3	
10			0 - 2	1	
			5 - 6	2	
			10 - 11	2	
11			0 - 2	1	
			3 - 4	2	
			8 - 9	2	
			12 - 16	1	
12			6 - 8	2	
13			1 - 2	2	
			10 - 11	2	
			12 - 15	1	
	16.4	3	16 - 17	1	Under
14			0 - 1	2	
			4 - 5	2	
15					
16					
17			1 - 2	3	
			4 - 6	1	
			15 - 16	1	
	16.6	1			

Building A (continued)

Tendon Number	Actual Defect		Set 1 Finding		Comment
	Loc [m]	Grade	Loc [m]	Grade	
18			5 - 6	2	
			8 - 11	2	
			15 - 16	1	
	18.2 - 18.9	3			
	19.0 - 19.2	3			
19			1 - 3	2	
			6 - 8	2	
20			2 - 3	2	
21			0 - 1	2	
			4 - 6	2	
	10.0	4	9 - 11	1	Under
	11.9	3			
22			1 - 2	2	
			5 - 6	2	
			15 - 16	2	
23			0 - 1	2	
			11 - 13	2	
			15 - 16	2	
24			1 - 2	2	
			4 - 5	2	
			10 - 11	2	
	13.4 - 13.5	3			
	17.6 - 18.1	3			
25			0 - 1	2	
			5 - 8	2	
			15 - 18	1	
26			3 - 4	2	
	7.3 - 19.7	1	6 - 8	2	Over
	9.0	4 (DWC)			Double Wire Cut
	12.5	4 (SWC)			Single Wire Cut
27			1 - 2	3	
			4 - 6	2	
			12 - 13	2	
28					
29					
30			2 - 3	2	
			5 - 7	1	
31			2 - 3	2	
	19.6	3			

Building B

Tendon Number	Actual Defect		Technique Finding		Comment
	Loc [m]	Grade	Loc [m]	Grade	
2	3.3	1			
			6 - 9	2	
			20 - 21	2	
			23 - 24	1	
			28 - 30	2	
			32 - 35	1	
			40 - 42	2	
	56.2	1			
3			9 - 10	1	
			13 - 14	1	
			15 - 16	1	
			19 - 21	2	
	37.6	1			
			42 - 46	2	
	53.8	3			
5			0 - 2	2	
			4 - 6	2	
			9 - 12	2	
			16 - 19	2	
	33.3	2			
			44 - 45	2	
	53.1	3			
6			0 - 1	2	
			3 - 6	2	
			12 - 13	1	
			15 - 16	2	
	24.4 - 24.7	1			
	25.3 - 25.7	1	25 - 26	2	Over
	55.5 - 58.0	1			
7			8 - 9	2	
			14 - 15	2	
			20 - 21	2	
	24.5 - 25.2	3			
	26.0 - 26.2	3			
8			0 - 1	2	
	2.9 - 3.0	1	3 - 4	2	Over
			10 - 13	2	
			22 - 13 (?)	2	Disregard
	25.4 - 25.9	3			
	26.4 - 27.2	3			
	27.6	4			
			44 - 45	2	
27			0 - 1	2	
			10 - 12	1	
			30 - 31	2	

Building C

Tendon Number	Actual Defect		Technique Finding		Comment
	Loc [m]	Grade	Loc [m]	Grade	
2 E			5.0 - 7.5	2	
	17.5	1 Wire	14.8 - 20.4	1	Under
2 W			3.0 - 4.0	1	
			5.8 - 10.8	3	
	17.7	Cut			
			19.4 - 20.4	2	
9 E			1.0 - 1.8	1	No Tendon Inspection Data
			3.0 - 4.0	1	
			5.8 - 12.0	1	
			17.8 - 20.4	1	
9 W			1.0 - 1.6	1	No Tendon Inspection Data
			3.0 - 4.0	1	
			5.8 - 12.0	2	
			17.8 - 20.4	2	
21 E			1.0 - 2.4	2	
			6.2 - 7.6	1	
			10.2 - 11.2	1	
			14.2 - 18.8	3	
21 W			1.0 - 2.2	2	
			3.0 - 4.2	1	
			6.2 - 7.2	2	
			9.8 - 12.2	2	
			14.5 - 17.8	2	
			18.5 - 20.4	1	
27 W			0.0 - 1.4	4	
	2.3	1 Wire			
	2.9	2 Wires			
			3.5 - 6.6	2	
	17.1	Cut	16.5 - 17.4	3	Under
31 E			2.6 - 4.4	2	
			5.8 - 6.8	1	
			8.8 - 11.2	3	
			15.4 - 17.2	1	
			18.2 - 20.4	2	
31 W			1.2 - 5.6	1	
	10.9	2+ Wires	9.8 - 11.0	1	Under. Third wire was nicked
			13.4 - 14.0	2	
			19.4 - 20.4	3	

Building C (continued)

Tendon Number	Actual Defect		Technique Finding		Comment
	Loc [m]	Grade	Loc [m]	Grade	
47 E			2.2 - 3.6	2	
			7.4 - 13.8	2	
			19.4 - 20.4	2	
47 W			2.4 - 4.0	2	
			13.6 - 17.2	2	
82 E			1.9 - 3.2	3	
82 W			1.9 - 3.1	3	
96 E			0.6 - 2.1	2	
			2.6 - 3.1	1	
	3.2	1 Wire			
96 W			0.0 - 0.2	1	
			0.6 - 2.0	2	
			2.5 - 3.4	1	
			4.8 - 6.4	2	
103 W	0.1	1 Wire	0.0 - 0.1	1	Under
			0.6 - 2.0	2	
			2.9 - 3.5	1	
108 W			0.0 - 0.2	1	
			1.1 - 2.2	3	
			4.7 - 6.4	1	
109 W			0.0 - 0.2	1	
			0.7 - 2.3	2	
			4.8 - 6.4	1	
112 E			0.0 - 0.2	1	
			0.6 - 1.6	2	
			4.8 - 5.8	2	
112 W			0.0 - 0.2	1	
			0.6 - 1.5	2	
			2.9 - 3.4	1	
			4.7 - 6.4	2	
118 N			0.0 - 0.2	1	
			0.6 - 1.5	2	
			4.8 - 5.6	1	
118 M			0.0 - 0.2	1	
			0.6 - 1.5	2	
			4.7 - 5.6	1	

Building C (continued)

Tendon Number	Actual Defect		Technique Finding		Comment
	Loc [m]	Grade	Loc [m]	Grade	
118 S			0.0 - 0.2	1	No Tendon Inspection Data
			0.6 - 1.5	2	
			4.7 - 5.6	1	
125 N			0.0 - 0.2	1	
			1.0 - 1.5	1	
			2.5 - 3.4	1	
			4.7 - 5.1	2	
125 M			0.0 - 0.2	1	
			0.6 - 1.5	1	
			2.5 - 3.4	1	
			4.5 - 5.2	2	
125 S			0.0 - 0.2	1	
			1.0 - 1.5	1	
	2.7	Cut	2.5 - 3.3	2	Under
			4.8 - 5.1	1	

Appendix III

COMPARISON TABLE FOR REPRODUCIBILITY AND ENVIRONMENTAL INFLUENCE TEST

Note:

The following table contains the results of only those tendons for which technique findings for Set 1 differed from Set 2. No changes in mechanical defects occurred between the two investigations, although environmental changes were induced as described in the main report. Tendons subjected to environmental changes were Nos. 16, 18, 19, 20, 30 and 31.

Building A

Tendon Number	Actual Defect Loc [m]	Actual Defect Grade	Set 1 Finding Loc [m]	Set 1 Finding Grade	Set 2 Finding Loc [m]	Set 2 Finding Grade	Comment
2			0 - 2	3	0 - 2	3	
	3.7	1					
			6 - 7	2	6 - 7	2	
	8.7	3					
					10 - 11	2	
			12 - 13	2	12 - 13	2	
	17.3	4					
3			0 - 1	2			
	3.0	2	2 - 3	1	1 - 3 (2 - 3)	2 (1)	Overlapping
			4 - 6	1	4 - 6	1	
	6.2	3					
			8 - 9	2	8 - 9	2	
					12 - 13	1	
	15.8	4					
8	0.9	1					
			1 - 2	1	1 - 2	2	
					5 - 6	2	
			7 - 8	2	7 - 8	2	
	9.8	3					
			11 - 13	2	11 - 13	2	
			15 - 16	3	15 - 16	3	
9			1 - 3	1	0 - 3	1	
			7 - 8	1	7 - 8	1	
			9 - 11	2	9 - 11	2	
			12 - 13	2	12 - 13	2	
			15 - 16	3	15 - 16	3	
11			0 - 2	1	0 - 2	1	
			3 - 4	2	3 - 4	2	
					5 - 6	2	
			8 - 9	2	8 - 9	2	
			12 - 16	1	12 - 16	1	
12					2 - 3	3	
			6 - 8	2	6 - 8	2	
14			0 - 1	2	0 - 1	2	
			4 - 5	2	4 - 5	2	
					12 - 13	1	
					18 - 19	1	
16					5 - 6	2	

Building A (continued)

Tendon Number	Actual Defect		Set 1 Finding		Set 2 Finding		Comment
	Loc [m]	Grade	Loc [m]	Grade	Loc [m]	Grade	
18					0 - 1	4	
			5 - 6	2	5 - 6	1	
			8 - 11	2	8 - 11	2	
			15 - 16	1	15 - 16	1	
	18.2 - 18.9	3					
	19.0 - 19.2	3					
19			1 - 3	2	1 - 3	2	
			6 - 8	2	6 - 8	2	
					14 - 15	3	
20			2 - 3	2	2 - 3	2	
					5 - 6	3	
26			3 - 4	2	3 - 4	2	
	7.3 - 19.7	1	6 - 8	2	6 - 8	2	
	9.0	4 (DWC)					Double Wire Cut
	12.5	4 (SWC)			12 - 13	2	Single Wire Cut
27			1 - 2	3	1 - 2	3	
			4 - 6	2	4 - 6	2	
			12 - 13	2	12 - 13	2	
					14 - 15	1	
30			2 - 3	2	2 - 3	2	
			5 - 7	1	5 - 7	1	
					8 - 9	1	
					10 - 11	1	
31			2 - 3	2	2 - 3	2	
					6 - 7	2	
					18 - 19 (?)	2	
	19.6	3					