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ASSESSING THE RELIABILITY OF EXISTING ANCHOR INSTALLATIONS AT LOCH ALVA AND LOG FALLS DAMS

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ABSTRACT:

Hatch Energy has been working on the rehabilitation of dams on the Musquash River watershed in Southern New Brunswick since 1998. The work started with a condition assessment and dam safety review after a near overtopping event during the freshet in 1998 which required the evacuation of residents downstream of one of the main dams. The condition assessment found that the dams required additional freeboard and additional spillway capacity to pass their inflow design floods, and that stability of the concrete dams did not meet current CDA Guidelines. At the Loch Alva and Log Falls concrete dams it was concluded that post tensioned anchors were needed to meet current dam safety requirements for stability. Although no documentation could be found, subsequent investigations at these two dams showed that anchors had been installed previously, likely in the mid-1970s.

In many older anchoring projects, corrosion protection was not in accordance with current standards and the actual condition of the anchors cannot be reliably established. This paper presents the results of a program of investigations which was undertaken to confirm the integrity of the anchors at the Loch Alva and Log Falls concrete structures and determine how they affected the need for additional stability. This program resulted in reduction in the number of anchors installed from the initial plan of 60 anchors to a total of 15, which resulted in a significant cost reduction.

RÉSUMÉ:

Depuis 1998, Hatch Energy s'emploie à la réhabiliter les barrages du bassin hydrologique de la rivière Musquash dans le Sud du Nouveau-Brunswick. Le tout a commencé par une évaluation de l'état et de la sécurité des barrages lorsqu'un déversement intempestif a failli se produire pendant la crue de 1998, qui a nécessité l'évacuation des résidents en aval d'un des principaux barrages. L'évaluation de l'état des barrages a indiqué que leur revanche devaient être plus élevée et leur capacité d'évacuation des crues nominales, plus grande. Elle a aussi révélé que la stabilité des barrages en béton ne satisfaisait pas aux lignes directrices de l'ACB. On a conclu que les barrages du Loch Alva et des chutes Log avaient besoin d'ancrages de post-tension pour satisfaire aux exigences de sécurité des barrages en matière de stabilité. Bien qu'aucune documentation n'ait été trouvée, des enquêtes subséquentes menées sur le terrain de ces deux barrages ont révélé l'installation antérieure d'ancrages, probablement au milieu des années 1970.

Dans beaucoup d'anciens travaux d'ancrage, la protection contre la corrosion n'était pas conforme aux normes actuelles et il est impossible de déterminer avec certitude l'état réel des ancrages. La communication qui fait l'objet du présent résumé présente les résultats d'un programme d'enquêtes qui a été instauré pour confirmer l'intégrité des ancrages aux structures en béton du Loch Alva et des chutes Log et pour déterminer en quoi ils ont eu une incidence sur la nécessité d'en augmenter la stabilité. Ce programme a permis d'établir que, sur les 60 ancrages initialement prévus, seuls 15 étaient nécessaires, d'où une importante réduction des coûts.

1 INTRODUCTION

The 7.5 MW Musquash Watershed Development in Southern New Brunswick was commissioned in 1921. The development included five concrete dams and approximately 20 earth embankment dams. The system was owned and operated by NB Power until 1972 at which time it was sold to the Province of New Brunswick to become part of the City of Saint John water supply. It continues to generate electricity, but this is secondary to the water supply requirements. Significant rehabilitation and repair was undertaken immediately following the transfer to the Province, but then little attention was paid to the dams until a near overtopping in 1998 which required the evacuation of downstream residents.

Hatch Energy has been working on rehabilitation of dams since then, commencing with a condition assessment and dam safety review. The condition assessment found that the dams required additional freeboard and additional spillway capacity to pass their inflow design floods and that the stability of the concrete dams did not meet current CDA Dam Safety Guidelines. At the Loch Alva and Log Falls concrete dams it was concluded that post tensioned anchors were needed to meet current dam safety requirements for stability. Although no documentation could be found, subsequent investigations at these two dams showed that anchors had been installed previously, likely in the mid-1970s.

In many older anchoring projects, corrosion protection was not in accordance with current standards and the actual condition of the anchors cannot be reliably established. Therefore, the question of reliability of the existing anchors is often an important matter than can have a significant impact on the costs of remedial work to address dam safety issues.

Hatch Energy has project experience with older anchored structures including inspection of anchors exposed in dams that were being demolished and has also undertaken research on steel corrosion to develop an approach for assessing anchor reliability. The results of the program of investigations (both non-destructive and destructive) undertaken to confirm the integrity of the anchors at the Loch Alva and Log Falls concrete structures is presented in this paper. The result of the assessment allowed reduction of the number of anchors installed from the initial plan of 60 anchors to a total of 15, which resulted in significant cost reductions.

2 REHABILITATION OF MUSQUASH

In the fall of 1998, Hatch Energy was commissioned to review the structural integrity and flood handling capacity of the dams on the Musquash System to develop operational procedures and identify and prioritize repair and other construction requirements. In March 1999, Hatch Energy submitted its report, *Musquash Watershed Dam Study* which presented a total of 228 prioritized recommendations to address the deteriorated conditions: the integrity of the dams, the limited discharge capacity, and the concerns about the stability of the structures. A rehabilitation program commenced in the summer of 2000 to address these recommendations and has been on-going since then.

To date, nearly $11 million has been spent on studies and dam rehabilitation and there is still an estimated $4 million of capital works required to complete the work that was identified. Some of the work done was carried out by the Department of Natural Resources, including clearing vegetation from the earth dams, fencing and signage, installation of water level recording at all reservoirs.

The majority of the work, however, has been undertaken by contractors working under the direction of Hatch Energy. Work done to date includes:

- raising and stabilization of earth dams and abutments at Loch Alva, Halls Lake and East Musquash Reservoir
- construction of new saddle dykes at East Musquash Reservoir
- gate hoist repairs at the Log Falls tunnel
- new gates and hoisting equipment at East Musquash Concrete Dam
- stabilization of East Musquash Concrete Dam

- stabilization of Loch Alva and Log Falls Concrete Dams
- replacement of low level gates and hoists at Loch Alva Concrete Dam

3 THE DAMS AND THE EXISTING ANCHORS

The configurations of Log Falls and Loch Alva dams are shown in Figures 1 and 2. Both dams consist of concrete gravity sections and earth abutments. Much of the concrete portions of the dams are overflow spillways. Each dam has low-level gates that are used to discharge water downstream: at Log Falls, the discharge is spill from the system, but at Loch Alva discharge is to the East Musquash reservoir for use in power generation and water supply.

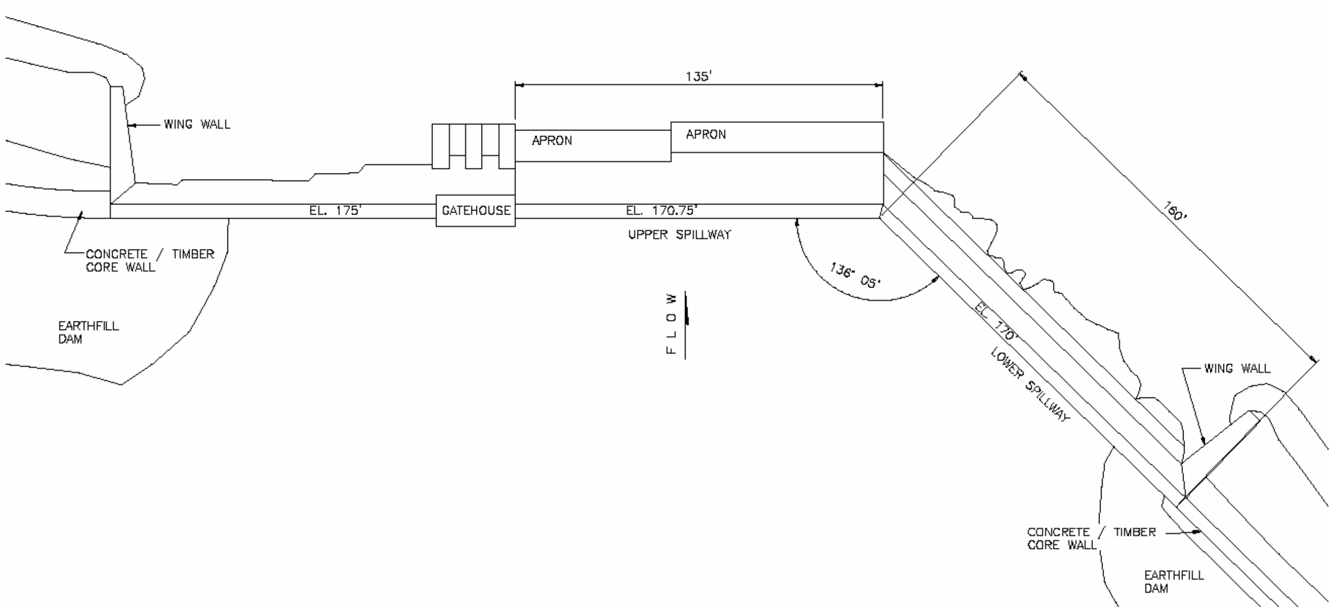

Figure 1: Log Falls Dam Layout

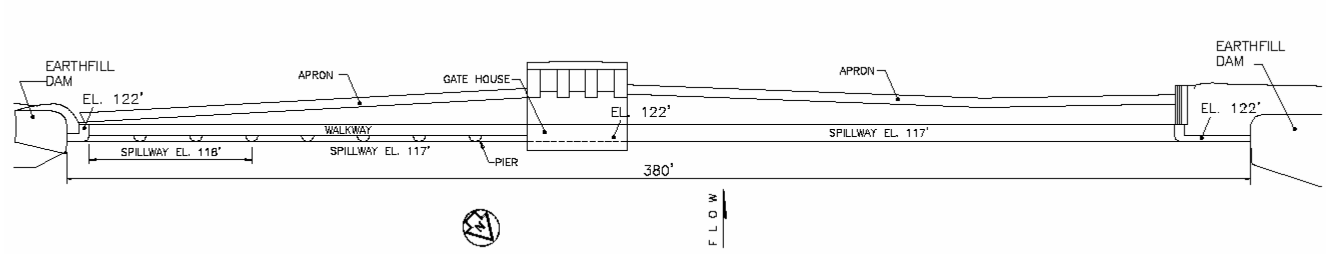

Figure 2: Loch Alva Dam Layout

The condition assessment of the Loch Alva and Log Falls structures found that there was physical evidence of existing rock anchors: concrete patches were visible at both dams. A background search of existing drawings found details of bar anchors installed in the gravity section and gate house section of Log Falls Dam in 1964 but no details of anchors in the spillway sections of the Log Falls Dam nor any details of the anchors at Loch Alva Dam were found. Figure 3 shows the concrete patches at Log Falls Dam.

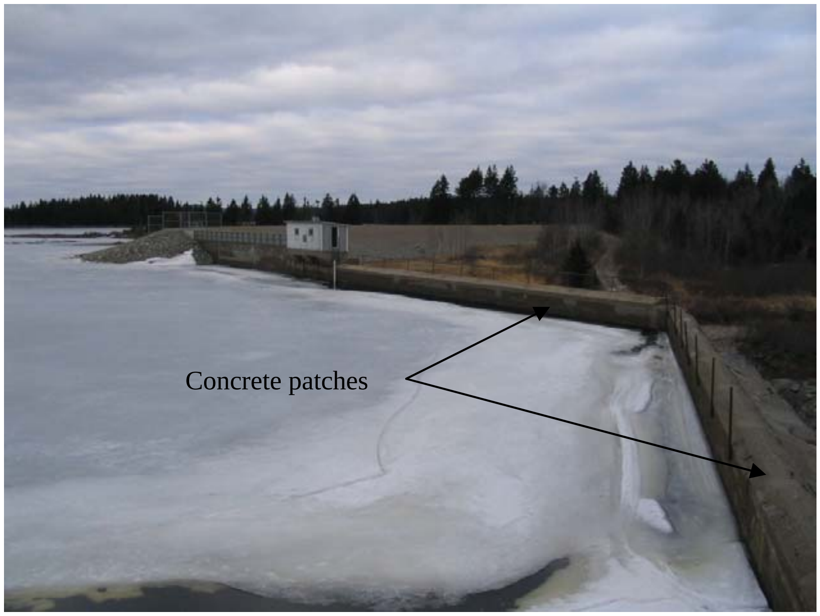

Figure 3: Concrete Patches Visible At Log Falls Dam Prior To Investigations

A drawing showing details of anchors installed in a third dam on the same watershed, at the outlet of Seven Mile Lake, was also found. This drawing proved to be of great value because it provided an indication of the type of anchors that may have been installed in Loch Alva Dam and the remainder of Log Falls Dam in the 1970s. Information on the drawings provided the name of the anchor supplier, and we were able to contact them and their records confirmed that the anchors installed in the spillway sections at Log Falls Dam and at Loch Alva Dam were multi-strand anchors similar to those at Seven Mile.

The inventory of existing anchors at the Log Falls and Loch Alva Dams are presented in Table 1.

Table 1: Inventory of Existing Anchors

Log Falls Dam

No. of Anchors	Type	Manufacturer	Location
18	Bar	Stressteel	gravity section
4	Bar	Stressteel	gate house section
19	Multi-wire	BBR	spillway sections

Loch Alva Dam

Anchor No.	Type	Manufacturer	Number of Wires
24	Multi-wire	BBR	spillway sections
2	Multi-wire	BBR	gate house section

4 THE DECISION TO ASSESS THE EXISTING ANCHORS

The decision to test the existing anchors was driven by the potential for eliminating 40 to 50 new anchors from a proposed stabilization program and saving as much as $500,000 in construction cost. This potential saving had to be weighed against the cost of an assessment program and the level of confidence that might, or might not, be developed with respect to the remaining service life of the anchors.

Lift-off tests have long been recognized as a means of proving that the anchors are still stressed; however, lift-off tests were never viewed as a means of evaluating remaining service life. Only in the last few years have methods been developed for estimating the continuous length and the extent of corrosion of an in-situ anchor. These are the characteristics that must be quantified before remaining service life can be estimated. Consequently, until recently, designers of stabilization works have simply assumed that rock anchors have an expected service life in the order of approximately 30 years, and that any anchors that reach that age should be replaced by new anchors.

The assessment of the existing anchors at Log Falls and Loch Alva dams included the background research into the type and details of the anchors installed, as previously discussed, and a physical testing program of a selected sample of existing anchors. The physical testing program was performed in phases allowing for preliminary results to be assessed from each phase in order to confirm that continuing the testing program was worthwhile. The total costs for the assessment was approximately $85,000.

5 THE TEST PROGRAM

The test program was performed in three phases and was conducted during the first three months of 2006. A sample of anchors was selected from each dam. At Log Falls Dam, two of the bar anchors in the gravity section and four of the multi-wire anchors were selected: two in the upper spillway section and two in the lower spillway section. At Loch Alva Dam, six of the multi-wire anchors were selected for testing: two in the upper spillway section, one in the gate house section and three in the lower spillway section.

Phase 1 was initiated by chipping concrete at the twelve anchor heads. Lift-off tests were then performed to determine the amount of residual prestress in the anchors. This was followed by integrity testing of the anchors, Phase 2, which included electrical and acoustical nondestructive test (NDT) techniques to determine the continuous length and extent of corrosion of the same in-situ anchors. The final phase was to cut off the head of two multi-strand anchors at each dam to directly observe the extent of any corrosion within the head of the anchors.

5.1 Phase 1 – Chipping and Lift-off Testing

The twelve anchor heads were exposed and the physical characteristics of the anchor heads were determined. These characteristics were compared with the available drawings and information from the manufacturer. A summary of the anchor heads which were chipped is presented in Table 2.

Table 2: Anchor Characteristics

Log Falls Dam

Anchor No.	Type	Manufacturer	Number of Wires	Rod or Wire Diameter	Area of Steel	Ultimate Stress
				(in)	(in^2)	(ksi)
1 & 2	Bar	Stressteel	na	1.375	1.48	160
3 to 6	Multi-wire	BBR	15	0.276	0.90	250

Loch Alva Dam

Anchor No.	Type	Manufacturer	Number of Wires	Rod or Wire Diameter	Area of Steel	Ultimate Stress
				(in)	(in^2)	(ksi)
1,2,3,5,6	Multi-wire	BBR	14	0.276	0.84	250
4	Multi-wire	BBR	13	0.276	0.78	250

Lift-off testing was then performed on all twelve anchors to determine the residual loading on the anchors. The results of the lift-off tests are summarized in Table 3. A photograph of the equipment used to perform the tests is shown in Figure 4. The preparation for the lift-off testing had to consider the possibility that the anchors could be fully grouted with the grout adhering to the anchor. If that were the case, then the stretching of the anchor during the test would only occur at the very top of the anchor. With the condition of the anchors unknown, the possibility of anchor failure during the testing had to be prepared for.

Table 3: Results of Lift-Off Tests

Log Falls Dam

Anchor No.	Type	Manufacturer	Ultimate Stress	0.6 x Ultimate Load	Lift-Off Pressure	Lift-off Load	Percent Ultimate
			(ksi)	(kips)	(psi)	(kips)	(%)
1	Bar	Stressteel	160	143	nt	nt	nt
2	Bar	Stressteel	160	143	nt	nt	nt
3	Multi-wire	BBR	250	135	4900	200	89
4	Multi-wire	BBR	250	135	4900	200	89
5	Multi-wire	BBR	250	135	4400	180	80
6	Multi-wire	BBR	250	135	4700	192	86

Loch Alva Dam

Anchor No.	Type	Manufacturer	Ultimate Stress	0.6 x Ultimate Load	Lift-Off Pressure	Lift-off Load	Percent Ultimate
			(ksi)	(kips)	(psi)	(kips)	(%)
1	Multi-wire	BBR	250	126	2700	110	53
2	Multi-wire	BBR	250	126	3300	135	64
3	Multi-wire	BBR	250	126	3400	139	66
4	Multi-wire	BBR	250	117	4200	172	88
5	Multi-wire	BBR	250	126	3700	151	72
6	Multi-wire	BBR	250	126	3500	143	68

nt - no testing equipment available for bar anchors

Figure 4: Lift-Off Test in Progress at Log Falls Dam

5.2 Phase 2 – Integrity Testing of the Anchors

The integrity testing of the anchors was performed by sub-consultants. Brief descriptions of the electrical and acoustical tests that were used to assess the integrity of the anchors are as follows:

- **Spread Spectrum Reflectometry:** A coded electrical signal is sent down a conductor, where it reflects from any significant change of impedance (such as the end of the conductor) along the travel path. For accuracy and noise reduction, a coded series of pulses is used. Increasing the number of pulses in the series improves the accuracy of the measurements. The reflected signal still retains the code, which can compared to the original signal to determine the travel time and hence the distance to and from the point of different impedance.
- **Half-Cell Potential Measurement:** This is an electrochemical type test. The potential along the surface of each tendon is measured with respect to a reference electrode (copper/copper sulphate half cell in this case). Access holes (approximately 50 mm diameter and 600 mm deep) are drilled to allow for proper placement of the reference electrode. Interpretation of half-cell potential measurements is used to assess whether the presence of corrosion along the surface of the ground anchor is "likely", "uncertain", or "not likely". This test will not indicate the severity of corrosion, nor whether or not there has been any loss of anchor capacity.
- **Polarization Resistance Measurement:** This is another electrochemical type test. Placement of a reference electrode is necessary as described for the half-cell potential measurement. In this case the change in potential along the surface of an element is monitored in response to an impressed current. Results from this test may yield information about the surface area of the element in contact with grout (i.e., an assessment of grout cover/quality), and it may also be possible to measure instantaneous corrosion rate. Since the measurement only renders corrosion rate at an instant in time, it does not reveal loss of section without extrapolation of the results. Another limitation is that the measurement represents an average over the surface area. It does not directly indicate the presence of localized corrosion that may be many times higher than the average. However, it can indicate whether the observed rate of corrosion is "severe", "moderate", "average" or "below average" compared to observations that have been made at other sites.
- **Sonic Echo Test:** This is a mechanical, wave propagation type test in which seismic waves are propagated along the length of the anchor. Results from the test are useful to assess grout quality, loss of cross section greater than 20%, and a qualitative estimate of remaining prestress (i.e., "significant loss of prestress" or "element appears to sustain a relatively high level of prestress").

- **Ultrasonic Test:** This is another mechanical, wave propagation type test that employs high frequency sound waves. Results are useful to assess loss of anchor section within a short distance from the head of the anchors. A good acoustic coupling between the ultrasonic transducer and the bolt head was required and achieved.

The spread spectrum reflectometry test was developed by Dr. Cynthia Furse at the University of Utah under the auspices of the CEA Technologies Incorporated (CEATI) and performed at Musquash by staff from New Brunswick Power. McMahon & Mann Consulting Engineers, P.C. (MMCE) from Buffalo, New York performed the remaining tests under the direction of Dr. Ken Fishman. Dr. Fishman had the opportunity to develop his expertise while involved in research sponsored by the National Cooperative Highway Research Program. This research resulted in a protocol for condition assessment that is described in *NCHRP Report 477 - Recommended Practice for Evaluation of Metal-Tensioned Systems in Geotechnical Applications*, 2002.

The conclusion from the first test (Spread Spectrum Time Domain Reflectometry (SSTDR)) is that the anchors are continuous over the lengths presented in Table 4. These lengths seem reasonable when compared to estimates based on
the thickness of the shims under the anchor heads (assumed to correspond to 60% of ultimate stress) and the information presented on anchor drawings. They also seem reasonable after taking into account the probable circumstances under which they were installed. Whereas some of the anchor lengths appear to be much longer than necessary, based on the available profiles of the foundations, it is likely that the designer of the anchors chose to pick common anchor lengths for groups of anchors to ensure that all of the anchors in each portion of the dams were long enough.

Table 4: Estimates of Anchor Lengths

Log Falls Dam

Anchor No.	Type	Manufacturer	Height of Shims	Free-Stressing Length: Based on Shims	Free-Stressing Length: From Dwgs*	Minimum Embedment on Drawings	Overall Length: Based on Shims	Overall Length: From Dwgs	Overall Length per SSTDR
			(in)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
1	Bar	Stressteel	na	nda	30	18	nda	48	43
2	Bar	Stressteel	na	nda	30	18	nda	48	43
3	Multi-wire	BBR	2.5	39	34	13	54	47	45
4	Multi-wire	BBR	2.25	36	36	13	51	49	45
5	Multi-wire	BBR	1.5	24	18	13	39	31	45
6	Multi-wire	BBR	2	32	18	13	47	31	45

Loch Alva Dam

Anchor No.	Type	Manufacturer	Height of Shims	Free-Stressing Length: Based on Shims	Free-Stressing Length: From Dwgs*	Minimum Embedment on Drawings	Overall Length: Based on Shims	Overall Length: From Dwgs	Overall Length per SSTDR
			(in)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
1	Multi-wire	BBR	1.25	20	8	13	33	21	ftr
2	Multi-wire	BBR	1.5	24	8	13	39	21	ftr
3	Multi-wire	BBR	2.5	39	33	13	54	46	ftr
4	Multi-wire	BBR	4.875	77	20	13	92	33	ftr
5	Multi-wire	BBR	1.5625	25	15	13	40	28	ftr
6	Multi-wire	BBR	1.4375	23	13	13	38	26	ftr

* "From Dwgs" indicates that free-stressing length was estimated from bedrock profile on available drawings

The observations made during the remaining tests were as follows:

- **Half-Cell Potential Measurement:** Half-cell potentials (E_{corr}) indicate that the grout is effectively passivating the anchors. For some of the tested anchors, there is an apparent shift in the potentials towards the uncertain range relative to corrosion, but the readings do not appear to be unusually low (i.e. more negative than -350 mV). A photograph taken during a half-cell potential measurement at Loch Alva Dam is shown in Figure 5.
- **Polarization Resistance Measurement:** Polarization measurements indicate that anchor samples are surrounded by grout for lengths that are nearly equal to the installed lengths as estimated from the existing drawings.
- **Sonic Echo Test:** Sonic echo test results indicate that the anchor samples are sustaining significant levels of prestress (no observable loss of prestress). BBR wire elements are most vulnerable within the anchor head assembly wherein the wires do not appear to be surrounded by grout. This accounts for approximately the first 150 mm of length including the stressing head and underlying shims. Reflections observed from the impact tests are attenuated indicating the elements are surrounded by grout and the location of the reflections appear to correspond to the "known" stressing length and total length of the installation. Reflections from the distal end (end of the bonded zone) are not apparent in the data. In several instances a very low amplitude reflection was observed. This also indicates that the elements are surrounded by grout such that energy from the impact is not readily transmitted down the length of the anchor, but is dispersed into the surrounding grout/concrete.
- **Ultrasonic Test:** Ultrasonic tests conducted on the Stressteel rod samples reveal a subtle reflection corresponding to an area near the backside of the anchor plate. This reflection could be due to the start of the grout column or from a small loss of cross section of the element in this area.

Figure 5: Half-Cell Potential Measurement in Progress

5.3 Phase 3 – Destructive Testing

Various recommendations were made by MMCE including ongoing monitoring and the removal of the head assembly from at least one of the wire-type anchors to determine the condition of the wires within the anchor head. It was decided to remove four, two from each dam, and it was found that all of the wires were greased within the heads and that the grease was in tact with no signs of corrosion of the wires. One of the dismantled heads is shown in Figure 6.

Figure 6: Dismantled Head of Multi-Wire Anchor

6 CONCLUSIONS FROM THE TESTING PROGRAM

The lift-off tests proved that all of the tested anchors were still functioning at a high level. The results of the Spread Spectrum Time Domain Reflectometry provided reasonable figures for installed anchor lengths. The results of the tests performed by MMCE indicated that all of the anchors were in good condition. Furthermore, the dismantled heads of four wire-type anchors were in excellent condition. Consequently, it was concluded that the remaining service life of the existing anchors is greater than ten years. It was recommended that half-cell test be done at five year intervals and a more complete set of tests, similar to this program, be carried out in ten years.

7 RECOMMENDATIONS FROM THE TESTING PROGRAM

Following the anchor testing program, the stability of the structures was reassessed based on the conclusion that the existing anchors were still performing as designed. It was determined that a limited amount of additional anchoring was required at both structures in order to conform to the acceptance criteria for stability required in the latest *Dam Safety Guidelines* published by the Canadian Dam Association. Eight additional anchors were installed at Log Falls Dam and three additional anchors were installed at Loch Alva Dam in 2006. Figure 7 was taken during the installation of anchors at Log Falls Dam. The four anchors destroyed as part of the testing program were also replaced. All of the anchors installed in 2006 were double-corrosive protected bar anchors. The testing program allowed the reduction in the total number of anchors installed from an initial estimate of 60 anchors to the 15 which were finally installed. The initial estimate was made assuming that there was no existing anchoring, or that any existing anchors were past their service life and had deteriorated so that they were not contributing to the stability of the structure.

Figure 7: Installation of additional rock anchors at Log Falls Dam, 2006.

8 HATCH ENERGY EXPERIENCE AT OTHER STRUCTURES

In modern practice, anchors installed to enhance resisting forces are double corrosion protected. However this was not the practice a few decades ago. Hatch Energy has been involved in numerous rehabilitation projects, some of which have involved demolition of existing structures prior to reconstruction or repairs. This has present an opportunity to observe the condition of existing anchoring.

At a project in Glens Falls, NY, one inch square bars embedded in limestone with cement grout were installed about 100 years ago to anchor the sluiceways of a dam. Ice forces and high water flows had led to severe deterioration of the concrete structure. As shown in Figure 8, many of the dowels were bent, twisted and even broken off, however, all appeared quite serviceable and none were noted to have either pulled out of the rock or rusted off.

Figure 8: Exposed 100 year old rebar anchors

Similarly, at a project in Ottawa, Ontario, rock anchors that were installed around the turn of the century were exposed in a dam that was being demolished. The anchors were found to be in excellent condition, showing no sign of corrosion or deterioration.

Anchors installed in most rocks are in a mild to non-corrosive environment. Hatch Energy experience suggests that it is entirely reasonable to assume an anchor grouted into rock may still be effective unless it is in a particularly aggressive environment (tailings for example). The bars are often unstressed and therefore not susceptible to stress corrosion. Iron bars are less susceptible to corrosion. The bars are typically permanently submerged. Before such an assumption is made, an investigation and monitoring program should be specified to look for any signs of distress or deterioration that might indicate a loss of anchor effectiveness.

9 CONCLUSIONS

The tests employed during the assessment of the existing anchors at Log Falls and Loch Alva Dams were successfully used in evaluating the existing capabilities and remaining service life of in-situ anchors. The various test methods employed gave consistent results, and all supported the conclusions about the integrity of the anchors. In future investigations it is recommended that all of the methods employed in this program be used; at this point there is not a sufficient data base of test results to allow the recommendation of a single test or any other reduction in the program which was carried out for this project. All of these test methods should be applied at several sites with existing anchors so that a database of results can be developed. The complete program should include the destructive testing to allow analyses of existing anchor heads. This will permit determining the condition of specific zones such as the contacts between the grips and the strands of multi-strand anchors, which are areas likely to first exhibit corrosion and deterioration.

The results of this study should be used as a baseline for future assessment of the anchors. A similar assessment of the anchors should be performed at the Log Falls and Loch Alva dams in ten years to verify the continuing integrity of the anchors.

At Musquash, plans are to undertake a similar testing program at another dam this year. The Seven Mile Lake Dam was constructed in 1926, there are drawings showing that the structure was anchored with Multi-Strand anchors in the early 1970s and this was confirmed by a recent site inspection which found patches on the crest indicating that anchoring had taken place.