CLASS 150 ASBESTOS CEMENT (AC) WATERMAIN PIPE CONDITION EVALUATION DEEP BAY WATER DISTRICT

Prepared for:

The Deep Bay Waterworks District
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1 INTRODUCTION

The Deep Bay Waterworks District on Vancouver Island is concerned about the condition of their asbestos cement (AC) water distribution system, and would like to evaluate its remaining service life. The Materials and Corrosion Engineering Group of Levelton Consultants Ltd. was engaged by Ms. Leslie Carter of the Deep Bay Waterworks District to assist them in evaluating the condition of their asbestos cement (AC) water distribution mains.

This report addresses a single AC pipe sample originating from Lot 10, Shoreline Drive in Bowser, British Columbia (4-inch diameter; Sample X-87).

Levelton's evaluation of the AC pipe sample considered in this report included: visual examination aided by low power stereomacroscopy; crush strength testing; hydrostatic strength testing; hardness and scratch testing; phenolphthalein indicator "staining"; chemical analysis of pipe cross-sections using scanning electron microscopy/x-ray energy dispersive spectography (SEM/EDS) techniques; and an estimation of the remaining service life prior to failure due to cement mortar leaching, based on our test results.

2 CONCLUSIONS AND COMMENTS

Calculations of the remaining service life before failure due to cement mortar leaching for the AC watermain pipe sample considered in this report (Sample X-87) indicate that the section of pipe originating from Lot 10, Shoreline Drive has an approximate additional service life of 20 years.

The single crush sample taken from AC pipe Sample X-87 (Lot 10, Shoreline Drive) met the as-manufactured crush strength requirement for 4-inch diameter, Class 150 AC pipe; in fact it met the crush strength requirements for Class 200 AC pipe. AC pipe Sample X-87 also met the as-manufactured hydrostatic strength requirements for Class 150 AC pipe.

Sub-samples X-87 R1 (from end ring) and X-87 HR1 (from hydrostatic fracture ring) demonstrated cement mortar leaching primarily on their internal diameter surfaces.

The nominal calcium content observed in the pipe sample considered in this report was lower than the typical levels previously observed in other studies. We would attribute this to a variation in the manufacturing process rather than a decrease in the calcium content due to cement mortar leaching.

3 RECOMMENDATIONS

1. That if any further AC water distribution pipe is replaced in the Deep Bay Waterworks District, consideration be given to carrying out evaluation of additional pipe lengths to further develop the information database of long-term AC pipe behaviour in the Deep Bay Waterworks District.

4 SUMMARY

4.1 VISUAL EXAMINATION

The AC pipe sample considered in this report was: visually examined upon receipt; marked as to assumed orientation; documented photographically; and marked for further sub-sampling to complete hydrostatic and crush strength testing and laboratory analyses.

Figures 1 to 4 show the AC pipe sample upon receipt and after cleaning the external diameter surface. See also Summary Table A for visual observations.

4.2 SOIL TEST

No soil samples were submitted for analysis with AC pipe Sample X-87 (Lot 10, Shoreline Drive).

4.3 HYDROSTATIC STRENGTH

A hydrostatic pressure test was carried out on AC pipe Sample X-87 (Lot 10, Shoreline Drive, Bowser, B.C.) as per ASTM C 296 "*Standard Specification for Asbestos-Cement Pressure Pipe*" Section 7.2 and ASTM C 500 "*Standard Specification for Asbestos-Cement Pipe*" Section 4. ASTM C 296 requires as-manufactured asbestos cement pipe to sustain a hydrostatic pressure of four times the rated working pressure for the class of pipe for not less than 5 seconds.

AC pipe Sample X-87 (Lot 10, Shoreline Drive) failed at an internal gauge pressure of 735 psig, which met the as-manufactured hydrostatic strength requirement for Class 150 AC pipe (600 psig). The failure exhibited a longitudinal fracture with one forked end. The non-forked fracture end terminated in the coupling used to seal the pipe end (Figures 5 and 6).

The results of the hydrostatic testing are shown in Summary Table A.

4.4 CRUSHING STRENGTH

A single crush strength test was carried out on a 12-inch length removed from AC pipe Sample X-87 (Lot 10, Shoreline Drive). The crush sample was tested as per ASTM C 296 "*Standard Specification for Asbestos Cement Pressure Pipe*" Section 9 and ASTM C 500 "*Standard Test Method for Asbestos Cement Pipe*" Section 6, except that, instead of air drying the sample prior to crush testing (as per ASTM Standard C 296 Section 11), it was soaked in water for at least 24 hours to better simulate buried service conditions.

The crush sample taken from AC pipe Sample X-87 met the as-manufactured crush strength requirement for 4-inch, Class 150 AC pipe specified in ASTM C 296; in fact it met the crush strength requirement for Class 200 AC pipe. Crush strength test results are shown in Table 1 following (see also Summary Table A).

Table 1 – Crush Strength Test Results

Sample No.	Site	Crush Strength lb_f/ft	Pass/Fail
X-87	Lot 10, Shoreline Drive	8,800	Pass (Class 150)[(1)(2)]

(1) Class 150 (ASTM C 296) minimum crush strength: 5,400 lb_f/ft.

(2) Class 200 (ASTM C 296) minimum crush strength: 8,700 lb_f/ft.

4.5 RING SAMPLES

An end and a hydrostatic fracture ring section were removed from AC pipe Sample X-87; and labelled X-87 R1 and X-87 HR1, respectively. These ring sections were removed from the sample to facilitate visual examination, phenolphthalein indicator “staining” and scratch hardness testing (Figures 7 to 12). A summary of our visual observations aided by low power stereomacroscopy is as follows:

- The end (X-87 R1) and hydrostatic (X-87 HR1) ring sections taken from the AC pipe Sample X-87 (Lot 10, Shoreline Drive) showed apparent cement mortar leaching on both inside and outside diameter surfaces. Leached pipe wall appeared separated from sound pipe wall material by a distinct leaching front (Figures 11 and 12).

4.6 PHENOLPHTHALEIN INDICATOR “STAINING”

A sub-sample for phenolphthalein indicator “staining” was selected and removed from the end ring by examining the ring for the area of maximum cement mortar leaching attack. A sub-sample from the hydrostatic ring section was removed from adjacent to the fracture. The sub-samples were cut from the ring sections and polished prior to phenolphthalein indicator “staining” (Figures 13 and 14). A summary of our visual observations aided by low power stereomacroscopy is as follows:

- The sub-samples taken from both the end and hydrostatic ring sections of AC pipe Sample X-87 (Lot 10, Shoreline Drive) appeared to demonstrate cement mortar leaching on both internal and external diameter surfaces.

4.7 HARDNESS TESTING

The outside diameter surface of the AC pipe sample considered in this report was randomly probed with a sharp pick upon receipt to evaluate for localized soft spots. The pipe section demonstrated uniform hardness over its full length with slight softening observed.

Comparative scratch hardness tests were carried out on the polished sub-samples used for phenolphthalein indicator “staining” to evaluate the degree of attack and softening. Softening was detected on both the inside and outside diameter surfaces of the two sub-samples evaluated (X-87 R1 and X-87 HR1).

4.8 CHEMICAL ANALYSES

Chemical analyses were carried out on the two AC pipe sub-samples used for phenolphthalein indicator “staining” shown in Figures 15 and 16 (X-87 R1 and X-87 HR1). Chemical analyses were carried out using scanning electron microscopy/x-ray energy dispersive spectrography (SEM/EDS) techniques. Multiple area scans, approximately 2.6 mm wide by 2.0 mm in the pipe wall thickness direction, were carried out for each sample to provide approximate complete coverage from inner to outer diameter surfaces.

The results of the chemical analyses are displayed graphically in Figures 17 and 18 and the data is tabulated in Appendix I.

A summary of our comments regarding the chemical analyses completed on the AC pipe sub-samples considered in this report are as follows:

- Nominal calcium concentrations in the two sub-samples considered in this report (X-87 R1 and X-87 HR1) were lower than typically observed (observation: approximately 18-22%; typical: approximately 25%).

- End ring AC pipe Sub-sample X-87 R1 and hydrostatic ring Sub-sample X-87 HR1 showed cement mortar leaching primarily on their internal diameter surfaces.

- The two sub-samples considered in this report showed nominal silicon contents of approximately 20%, which is typical of AC pipe samples observed in past studies completed by Levelton.

- No iron pickup was observed on either of the sub-samples examined in this report. External diameter surface iron pickup did not appear to be a factor in the degradation of the pipe sample considered in this report.

4.9 REMAINING SERVICE LIFE – ESTIMATE

The major problem experienced with asbestos cement pipes, other than mechanical fractures, results from leaching of the cement mortar binder from both the inside and outside diameter surfaces. This attack can severely lower the pipe's overall strength. The leaching rate depends on a number of factors, the most significant of which are the aggressiveness of the groundwater and potable water in contact with the pipe surfaces and the nominal calcium content of the binder material. Cement mortar leaching can vary dramatically from pipe section to pipe section and external attack can be highly localized due to variations in the pipe bedding, local soil conditions, groundwater paths, dissolved iron content in the groundwater, etc.

The cement mortar leaching of AC pipe appears to occur due to an inward movement of a distinct front separating the leached material from the sound pipe body. The leached material remaining on and near the surface tends to act as a barrier through which moisture must diffuse in order to continue the leaching process. As the thickness of this barrier increases (i.e. as more of the pipe wall is leached), the rate of leaching slows. Previous studies by Levelton and others have shown that the depth of leaching of asbestos cement pipe is approximately proportional to a function of time. Thus, the future depth of attack can be estimated if the age and current depth of attack are known.

To estimate the remaining service life of a section of AC pipe, samples of the pipe are ranked from 1 (best) to 5 (worst/replace immediately) based on such factors as crush strength, hydrostatic strength, degree of cement mortar leaching attack, calcium content, etc. The pipe sample considered in this report was ranked 1 based on the results from our analysis and testing.

Estimates of additional service life to failure due to cement mortar leaching were calculated based on: the above ranking; the unaffected wall thickness; the assumption that cement mortar leaching attack rate is proportional to a function of time; and that failures are unlikely to occur with some percentage additional cement mortar leaching attack (life factor). These calculations indicate the AC pipe Sample X-87 (Lot 10, Shoreline Drive) has an additional service life of approximately 20 years (see Summary Table B).

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SUMMARY TABLE A – TEST RESULTS AND OBSERVATIONS ON AC PIPE SECTION – THE DEEP BAY WATERWORKS DISTRICT

SUMMARY TABLE A

Sample No.	Location	Date Received	Size, in.	Manufacturer Marking	Visual Observations	Crushing Strength		Hydrostatic Strength			Wall Thickness, in.	Phenolphthalein Staining, Figure No.
						Test Results, lb_f/ft	Pass/Fail Class 150[(1)]	Test Results, psig	Pass/Fail Class 150[(2)]	Remarks		
X-87	Lot 10, Shoreline Drive	12 September 2008	4	4" Class 150 TESTED AT 525 LBS AWWA TRANS	• 72 inches in length. • Heavy waffle pattern. • Brown colouration on areas of the external diameter surface.	8,800	Pass	735	Pass	• Longitudinal fracture with one end forked, the other terminated in the coupling.	0.556 – 0.639	13 and 14

(1) ASTM C 296 Crushing Strength

Nominal Size in.	Minimum Crushing Strength, lb_f/ft		
	Class 100	Class 150	Class 200
4	4100	5400	8700
6	4000	5400	9000
8	4000	5500	9300

(2) Hydrostatic Strength

Class (Nominal psi)	Pressure, psi	
	Proof (3 ½ X)	Hydrostatic (4 X)
100	350	400
150	525	600
200	700	800

SUMMARY TABLE B – ESTIMATE OF ADDITIONAL SERVICE LIFE FOR AC PIPE SAMPLE – THE DEEP BAY WATERWORKS DISTRICT

SUMMARY TABLE B

Sample No.	Location	Size, in	Date Installed	Wall Thickness, inch[(1)]			Unaffected Zone[(1)]	Unaffected Zone[(2)]	Crush Strength, lb_f/ft	Maximum Hydrostatic Strength, psig	Nominal Calcium Content	Nominal Silicon Content	Nominal Iron Content OD Surface	Service Life Ranking	Life Factor	Current Years of Service	Estimated Additional Service Life, Years	Replace by Year	Sample No.
				Total	Degraded Zone OD	Degraded Zone ID													
X-87 R1 End Ring	Lot 10, Shoreline Drive	4	1979	0608	0.238	0.116	42%	65%	8,800	735	25%	19%	3%	1	0.30	29	20	2029	X-87 R1 End Ring
X-87 HR1 Hydro Ring				0.556	0.114	0.092	63%	71%			24%	20%	2%						X-87 HR1 Hydro Ring

(1) Degraded zone thicknesses based on phenolphthalein "staining".
(2) Degraded zone thicknesses based on SEM/EDS analyses.

Figure 1: View of AC pipe Sample X-87 (Lot 10, Shoreline Drive) in the as-received condition.

Figure 2: Close-up view of AC pipe Sample X-87 (Lot 10, Shoreline Drive) in the as-received condition, showing adhered dirt and sand and the heavy waffle pattern on the sample external diameter surface.

Figure 3: View of AC pipe Sample X-87 (Lot 10, Shoreline Drive) after cleaning showing areas of brown staining on the external diameter surface.

Figure 4: Close-up view of the external diameter surface of AC pipe Sample X-87 after cleaning showing the waffle pattern and an area of brown staining.

Figure 5: View of the hydrostatic strength fracture of Sample X-87 (Lot 10, Shoreline Drive) showing the longitudinal fracture (middle left) and forked end (middle), typical of hydrostatic pressure fractures observed in previous studies completed by Levelton.

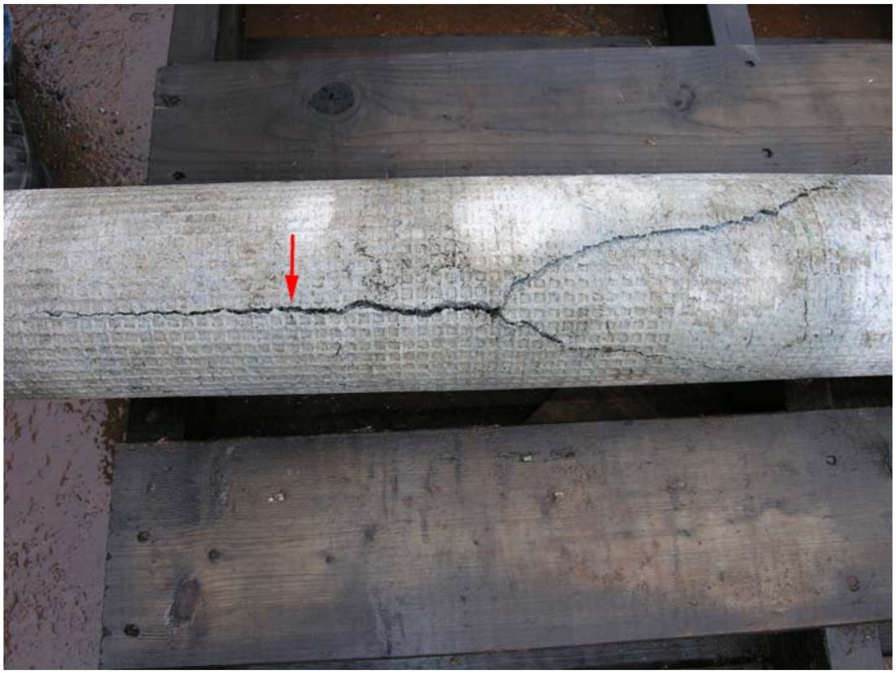

Figure 6: Additional view of the hydrostatic fracture of Sample X-87. The fracture would likely have originated in the longitudinal portion of the fracture shown (indicated by the arrow), which is where the hydrostatic ring section was removed from for further testing.

Figure 7: View of end ring section (X-87 R1) from AC pipe Sample X-87 (Lot 10, Shoreline Drive) with markings showing the area to be cut out for further analysis.

Figure 8: Close-up view of Figure 7 (end ring Section X-87 R1) showing the area marked for removal and further laboratory analysis.

Figure 9: View of hydrostatic ring section (X-87 HR1) from AC pipe Sample X-87 (Lot 10, Shoreline Drive) with markings showing the area to be cut out for further analysis.

Figure 10: Close-up view of Figure 9 (hydrostatic ring section X-87 HR1) showing the area marked for removal and further laboratory analysis (hydrostatic fracture shown at the left).

Figure 11: View of Sub-sample X-87 R1 shown in Figure 8 after removal and polishing. On the external diameter surface, leached and sound pipe wall material appeared separated by a distinct leaching front (dark line between arrows).

Figure 12: View of Sub-sample X-87 HR1 shown in Figure 10 after removal and polishing (hydrostatic fracture shown at left). On the external diameter surface, leached and sound pipe wall material appeared separated by a distinct leaching front (dark line between arrows).

Figure 13: View of Sub-sample X-87 R1 shown in Figure 11 after polishing and phenolphthalein indicator "staining". The pink colouration, caused by the phenolphthalein “staining”, indicates a band of unleached (sound) pipe wall.

Figure 14: View of Sub-sample X-87 HR1 shown in Figure 12 after polishing and phenolphthalein indicator "staining" (hydrostatic fracture shown at left). The pink colouration indicates a band of unleached (sound) pipe wall.

Figure 15: View of Sub-sample X-87 R1 shown in Figure 13 after polishing, phenolphthalein indicator “staining”, drying and marking for SED/EDS analysis.

Figure 16: View of Sub-sample X-87 HR1 shown in Figure 14 after polishing, phenolphthalein indicator “staining”, drying and marking for SED/EDS analysis (hydrostatic fracture at left).

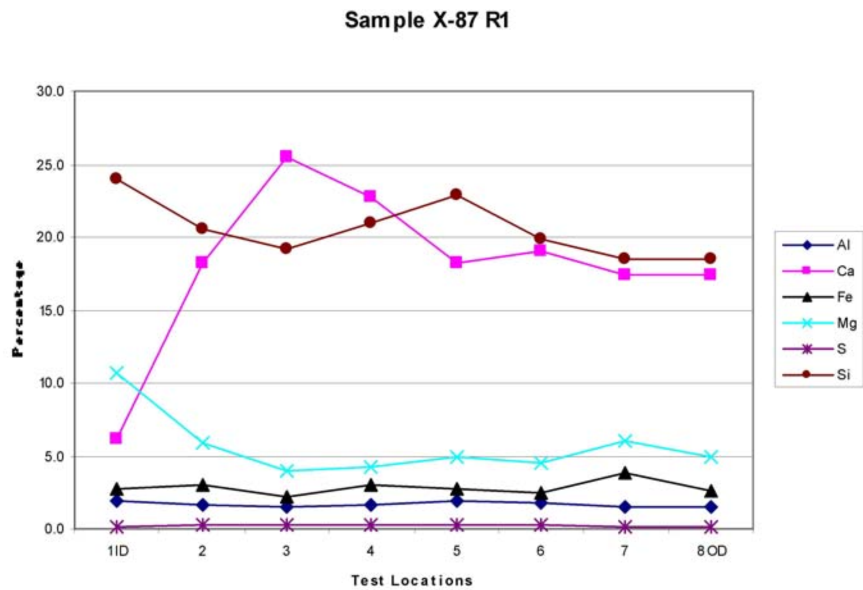

Figure 17: SEM/EDS chemical analysis of end ring Sub-sample X-87 R1 taken from AC pipe Sample X-87 (Lot 10, Shoreline Drive).

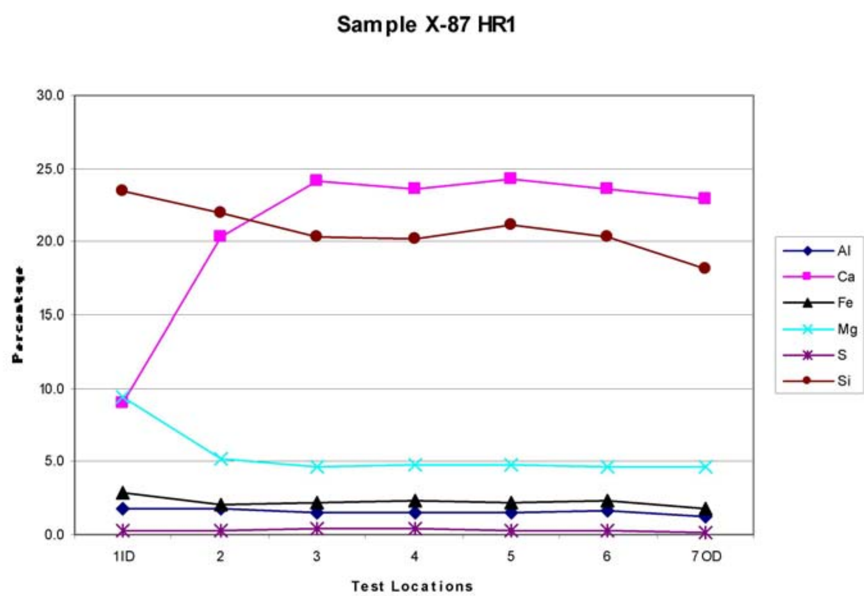

Figure 18: SEM/EDS chemical analysis of hydrostatic Sub-sample X-87 HR1 taken from AC pipe Sample X-87 (Lot 10, Shoreline Drive).

APPENDIX I

Chemical Analysis Tables

Table 1 – SEM/EDS Chemical Analysis – Deep Bay Waterworks District Asbestos Cement (AC) Pipe – Sample No. X-87 R1 (Lot 10, Shoreline Drive)

SAMPLE LOCATION	CHEMICAL COMPOSITION, PERCENT					
	Al	Ca	Fe	Mg	S	Si
1 ID	1.9	6.1	2.7	10.7	0.2	24.0
2	1.6	18.2	3.0	5.8	0.3	20.6
3	1.5	25.5	2.2	4.0	0.2	19.2
4	1.6	22.7	3.1	4.3	0.3	20.9
5	2.0	18.2	2.7	4.9	0.2	22.8
6	1.8	19.0	2.5	4.5	0.2	19.9
7	1.6	17.4	3.8	6.1	0.2	18.5
8 OD	1.6	17.4	2.6	5.0	0.2	18.5

Table 2 – SEM/EDS Chemical Analysis – Deep Bay Waterworks District Asbestos Cement (AC) Pipe – Sample No. X-87 HR1 (Lot 10, Shoreline Drive)

SAMPLE LOCATION	CHEMICAL COMPOSITION, PERCENT					
	Al	Ca	Fe	Mg	S	Si
1 ID	1.8	9.1	2.8	9.4	0.2	23.4
2	1.7	20.3	2.1	5.1	0.2	22.0
3	1.6	24.1	2.2	4.6	0.4	20.4
4	1.5	23.6	2.4	4.8	0.4	20.2
5	1.5	24.3	2.2	4.7	0.2	21.1
6	1.6	23.6	2.3	4.6	0.2	20.3
7 OD	1.2	22.9	1.8	4.7	0.1	18.1