Condition Assessment of Water Pipes

Newfoundland Department of Environment and Conservation 2007

Osama Hunaidi and Marc Bracken

Overview

- Background on Condition Assessment and Asset Management
- Background on the NRC/Echologics Condition Assessment
- Review of our R&D Efforts: City of Hamilton, City of Winnipeg Studies
- Recent City of Chicago Study
- R&D on PCCP

What is Condition Assessment?

A process or processes that establish a record of the state of the critical aspects of an object at a given time. For cast and and ductile iron pipes, a critical aspect is pipe wall thickness and degree pitting corrosion.

Why do Condition Assessment?

It’s necessary for identifying options for future action to prevent failure and, to establish a record against which future change can be judged to predict remaining service life.

Inspection Methods

o Direct

- Visual inspection (e.g., using CCTV probes)
- Sampling programs
- Non-destructive testing (e.g., acoustic emission, acoustic leak detection,RFEC, RFEC-TC, magnetic flux leakage, ultrasonic pulse velocity, ultrasonic guided lamb waves, seismic methods)

o Indirect

- Failure history
- Leakage level
- Flow testing
- Soil resistivity

Current Situation

- Cast and ductile iron pipes comprise 70 to 80% of most water distribution networks in Canada and the U.S.
- Large proportions of pipes are fast approaching the end of their “expected life”.
- Replacement cost will be huge (~$6,500 per household)
- Costs are expected to peak in about 20 years when pipes installed in the 1920s and 30s and in the post WW II construction boom begin to fail en masse.

- Traditionally, decisions to replace or rehab buried pipes have been based on general indicators (e.g., break frequency, age, type and size of pipes). These may lead to sub-optimal decisions.
- Optimal decisions require reliable info about the actual condition of pipes.
- Gaining access to inspect buried pipes is difficult, disruptive and costly.
- Hence, condition assessment should ideally be done in a non-destructive and non-disruptive way.

- Non-destructive testing methods are rarely used. Most utilities continue to rely on failure history, flow testing and perhaps visual inspection.
- The result is that many utilities don’t have a definite picture about the condition of their pipes.
- Limited use of most non-destructive testing methods is due to high cost, intrusiveness, and lack of track record.
- Development of NDT technologies for water pipes has been slow. Breakthroughs are few and far in between. Only few players on the scene!

Impediments to Progress of NDT Methods

- The market is not lucrative enough (few $$, minor consequences of failure in most cases, no legislation)
- Difficult testing conditions
  - Underground pipes
  - Complex geometry (frequent bends, small-diameters, etc.)
  - Tubercles and debris
  - Restrictive operating conditions
- Lack of consensus regarding requirements!

New Acoustic Technology for Measurement of Remaining Pipe Wall Thickness

Remaining Pipe Wall Thickness

- A direct indicator of the structural condition of pipes.
- Metallic pipes lose thickness as a result of internal and external corrosion.
- Asbestos cement pipes lose “effective” thickness by the weakening of the wall as a result of the leaching out of the cement by aggressive waters.
- PCCP pipes lose strength as a result of the weakening of the concrete and corrosion-failure of pre-stressing steel.
- Plastic pipes may lose strength as a result of chemical attack.

Current Methods to Measure Remaining Wall Thickness

- Pipe sampling programs
  - Commonly used in the U.K.
  - A 300 mm long sample is taken every 1 km of pipe
  - Sample is cut in half and sand-blasted to measure wall thickness
  - Remaining life of pipe is determined based on statistical analysis
- Remote-field Eddy Current (RFEC) method
  - Required instrumentation is sent inside pipes using remotely controlled pigs
  - Provides a continuous profile of pipe-wall thickness.

Disadvantages of Current Methods

- Pipe sampling programs
  - Thickness values based on exhumed samples may not be representative unless a large number of samples is exhumed
  - Costly and disruptive
- Remote-field Eddy Current (RFEC) method
  - Launching of pigs inside pipes is complex and requires scraping and sweeping of pipes to remove tubercles and debris
  - Data acquisition and analysis are intensive
  - Cost and level of disruption are too high to be justified for most pipes

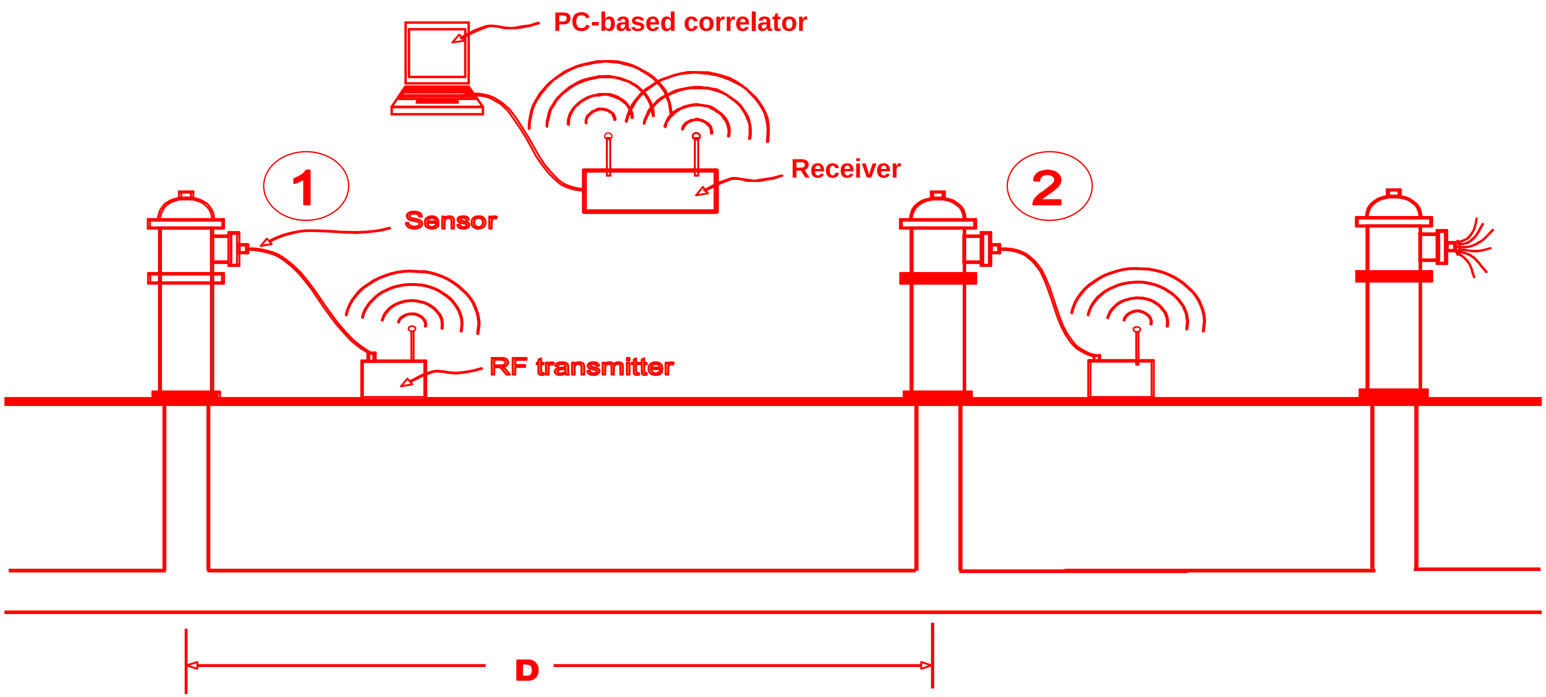
How Does the New Method Work?

- By measuring how quickly low-frequency acoustical signals are transmitted along a section of pipe, and
- By utilizing a theoretical relationship between the propagation velocity of acoustical signals and pipe wall thickness to back-calculate thickness
- Wall thickness around the circumference of the pipe can be specified (e.g., uniform or linearly varying)
- Calculated wall thickness is an average value for pipe section along which velocity is measured (typically 100 metres long)

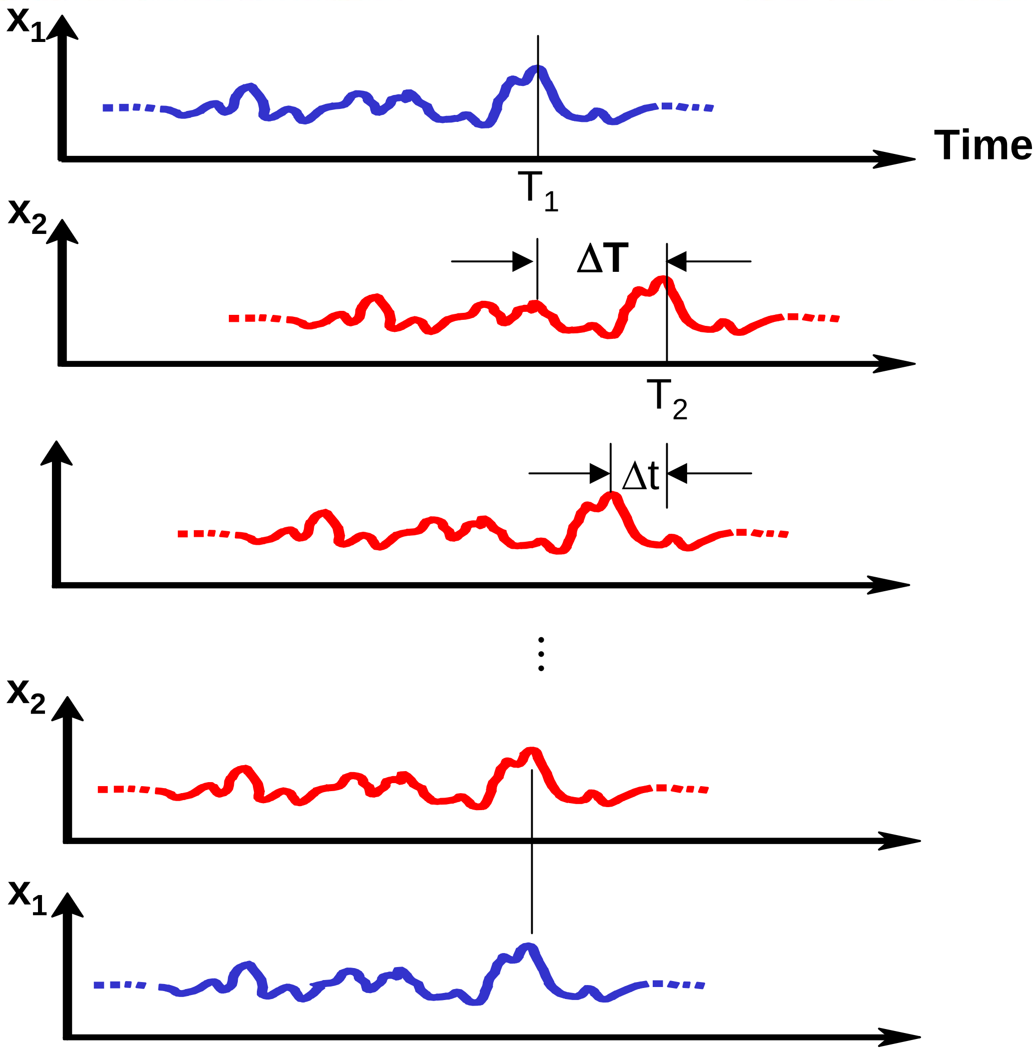
What Makes it Possible?

- Long sound waves in pipes, i.e. low frequency signals, are dominated by the contribution of a non-dispersive axi-symmetric wave propagation mode (S_1,n=0).
- The propagation velocity of the (S_1,n=0) mode is nearly constant for frequencies well below the ring frequency of the pipe.
- The (S_1,n=0) mode is water-borne and hence can propagate over long distances (i.e., not significantly affected by mechanical pipe joints).
- The propagation velocity can be derived theoretically.

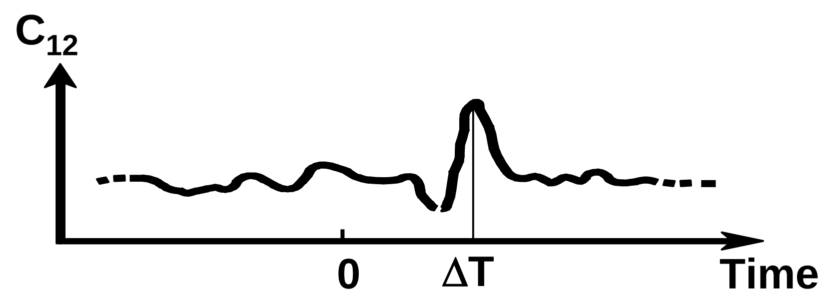
Velocity Measurement



Wave propagation velocity (v) = D / ΔT , where ΔT is time delay between signals 1 and 2



$$C_{12}(\tau) = \lim_{T\to\infty} \frac{1}{T}\int_0^T x_1(t)x_2(t+\tau)dt$$



Components of ThicknessFinderRT

Attachment of vibration sensors (1)

Attachment of vibration sensors (2)

Attach the sensors’s connector to the socket in the wireless transmitter and press the transmitter’s power ON button. A green LED light indicates that power is ON and a red light indicates weak battery. There are no adjustments to be made on the transmitter – signal level is adjusted automatically by the transmitter.

Attachment of vibration sensors (3)

Attachment of vibration sensors (4)

If the pipe cannot be accessed directly, sensors can also be attached to underground valves. Preferably, they should be lowered into valve access chambers and attached directly to valves. However, chambers may be filled with debris and many users prefer to attach accelerometers to valve keys.

Attachment of vibration sensors (5)

Attachment of vibration sensors (7)

Attachment of vibration sensors (8)

Attachment of hydrophones (1)

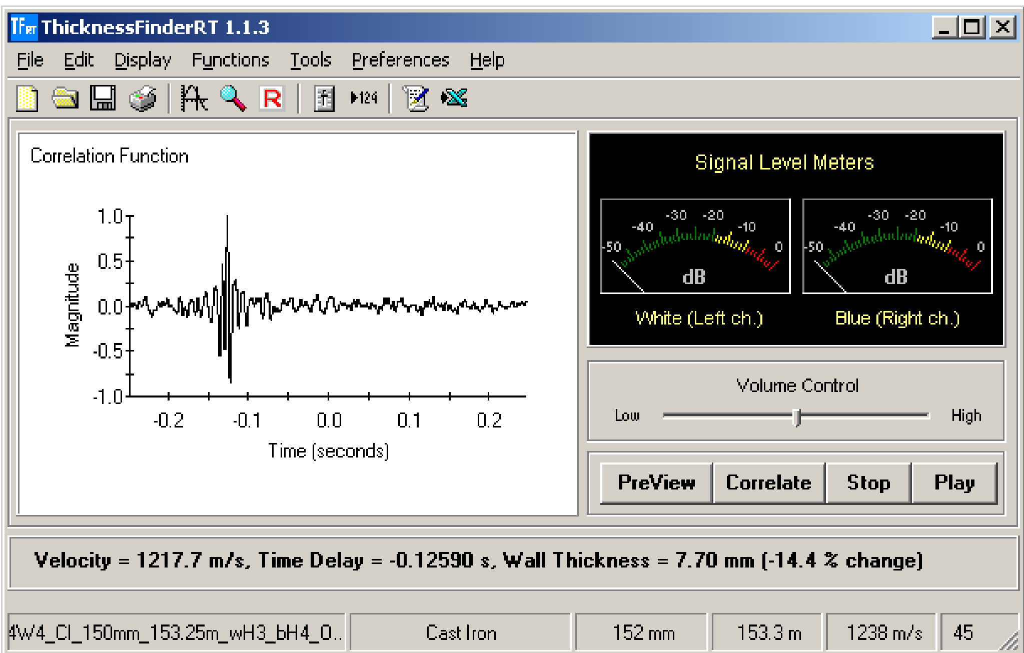
Under certain circumstances, e.g., for plastic and large diameter pipes, hydrophones must be used. The hydrophones must be in direct contact with the pipe's water core. Attach them to fire hydrants using a suitably modified cap. Fire hydrants should be fully charged and de-aired before hydrophones are attached.

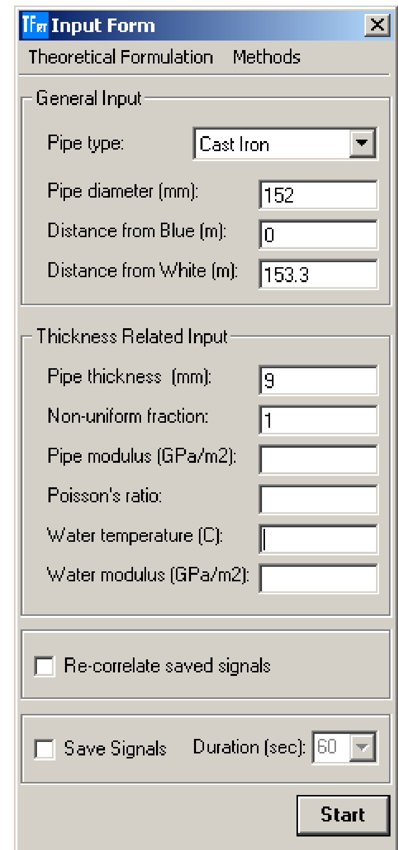
Creating an simulated leak to measure propagation velocity

Measurement of sensor-to-sensor distance

Connection of wireless receiver to computer

ThicknessFinderRT





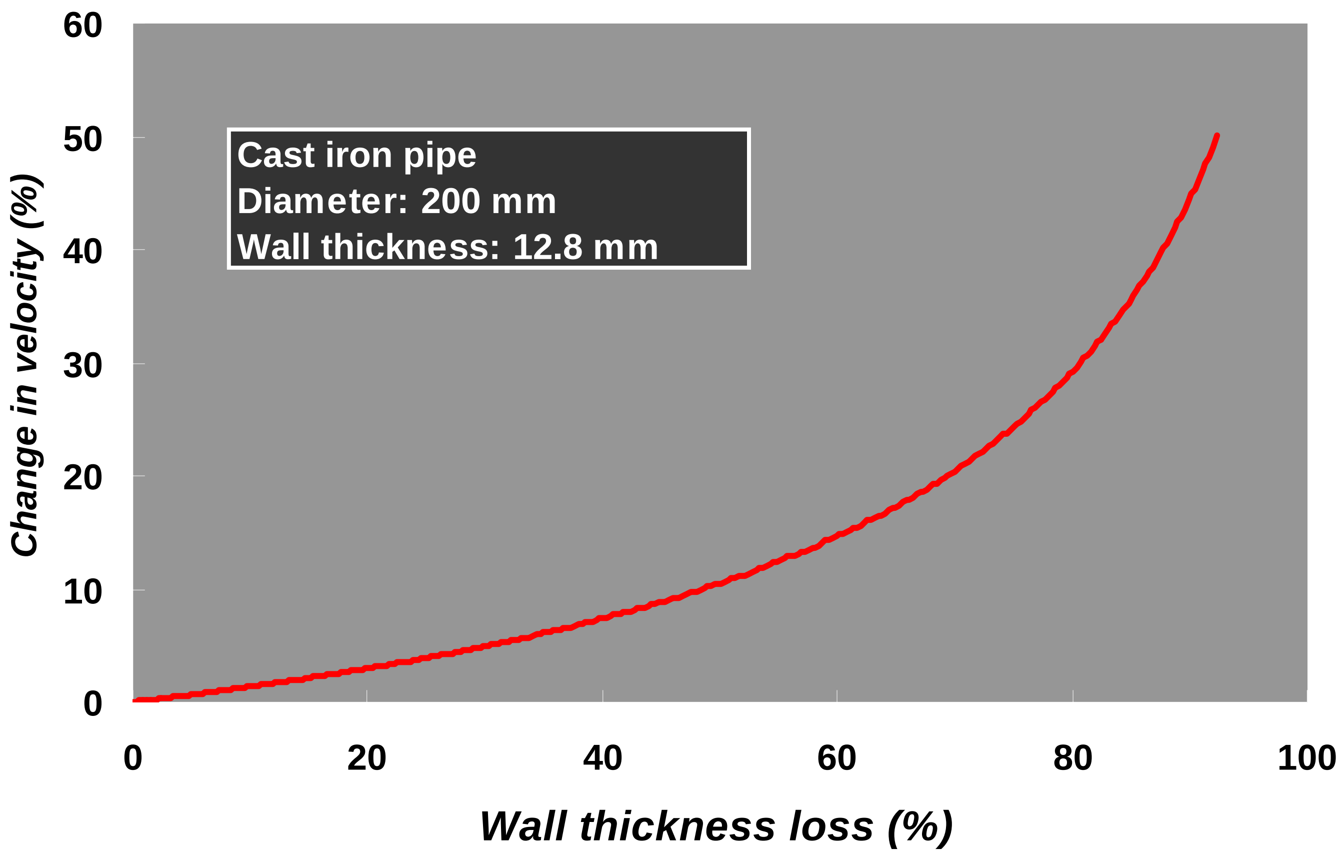
Velocity Equation

$$v = v_o \sqrt{\frac{1}{[1 + (D/e)(K_{water} / E_{pipe})]}}$$

where

v: Propagation velocity of leak noise in pipe
v_o: Propagation velocity of sound in an infinite body of water
D: Internal diameter of pipe
e: Thickness of pipe wall
K_{water}: Bulk modulus of elasticity of water
E_{pipe}: Young’s modulus of elasticity of pipe material

Change in Velocity Vs. Thickness Loss



echo logics

Pilot Tests

- Tests were performed at the water distribution system of the City of Hamilton in Ontario.
- Ten test sites were selected.
- Selected sites included large and small diameter pipes at different levels of deterioration. All pipes were cast iron.
- The level of deterioration was judged on the basis of break history, pipe age and soil corrosiveness.
- Selected pipes pipes were installed between 1860 and 1960.
- Evaluation of the accuracy of the remaining thickness predicted by the new method was based on visual appearance and average wall thickness of exhumed samples as reported by Correng consulting services under contract with the City.

Results of Pilot Tests

	City-supplied info				Prediction by NRC's new acoustic technology		Independent corrosion analysis of exhumed samples by Correng					
Site No.	Pipe rating	Year of construction	Diameter (mm)	Nominal thickness (mm)	Remaining[1] thickness (mm)	Thickness change (%)	Soil type	Soil corrosivity	Condition Rating[2]	Metal loss (mm)	Metal loss (%)	Thickness[3] (mm)
1	Poor	1956	152	9	9.3	3.3	Brown clay	Corrosive	Good / good	0.228	-2.5	9±0.3
2	Good	1922	152	12	11.5	-4.2	Silty clay	Very corrosive	v. good / v. good	1.731	-14.4 (?)[4]	11.4±2.7
3 (1)	Poor	1860	152	11	5.8	-47.3	Brown clay	Very corrosive	v. poor / moderate	1.778	-16.2	11.6±3.3
(2)	-	-	152	11	7.5	-32.7	-	-	-	-	-	-
(3)	Poor	1860	152	11	7.6	-30.9	Brown sand	Moderately corrosive	v. poor / good	2.02	-18.4	11±3.3
(4)	-	-	152	11	9.7	-11.8	Brown sand	-	-	-	-	-
4 (1)	Good	1910-15	152	12	15.9	32.5	-	-	-	-	-	-
(2)	Good	1910-15	152	12	11.6	-3.3	Brown sand	Corrosive	Excellent / v. good	0.711	-5.9	11.7±1.5
5 (1)	Good	1926	152	12	21.7	80.8	-	-	-	-	-	-
(2)	Good	1926	152	12	12.6	5	Brown clay	Corrosive	Good / v. good	0.267	-2.2	11.9±2.4
6	Poor	1949	152	9	8.2	-8.9	Brown clay	Corrosive	v. good / moderate	0.101	-1.1	8.8±0.8
7	-	1860	457	20	20.1	0.5	Brown clay	Moderately corrosive	v. good / good	1.257	-6.3	20.1±2.2
8	-	Pre 1900	457	20	14.9	-25.5	-	-	-	-	-	-
9	-	Pre 1900	152	-	12.3	2.5	-	-	-	-	-	-
	-	Pre 1900	152	-	10.9	-10.0	-	-	-	-	-	-
10	-	-	152	-	8.1	-19.0	-	-	-	-	-	-

1 Remaining pipe wall thickness predicted by NRC's acoustic technology represents an "effective" value from a mechanics of materials point of view, and subsequently it reflects general structural deterioration of pipes. Therefore, for pipes in poor or very poor corrosion condition, predicted remaining thickness will generally be significantly less than actual average thickness.

2 Rating based on corrosion of external / internal surfaces of exhumed samples.

3 Average thickness is based on values at the 3, 6, 9, 12 o'clock positions around the circumference on both ends of exhumed samples except for site No. 1. For site No. 1, the thicknesses of the pipe sample at one end is significantly more than that at the other end, indicating that the sample came from a location near a pipe's bell. For this sample, the thickness was based on measurements at the thinner end.

4 Value is high and appears to be a inconsistent with condition of pipe sample seen in photos in Appendix E and with Correng's corrosion rating of "very good".

Observations & Comments

- Pipe wall thicknesses that were determined by using the new acoustic method were in excellent agreement with average thicknesses and / or corrosion condition rating for exhumed pipe samples reported by Correng.
- The most dramatic and interesting agreement was for the pipe at Site 3. Predicted thickness loss for 3 sections of this pipe was between 30 and 50%, which is significantly higher than losses predicted for pipes at other sites. Corrosion analysis by Correng indicated that pipe samples from this site were in extremely poor condition in comparison to samples from other sites. However, predicted thickness loss was only 12% for a section of the same pipe that was laid in sand.

Observations & Comments (cont'd)

- The predicted thickness loss for pipe at Site 2 was a small 4.2%, which is in agreement with the actual thickness measured by Correng. Interestingly, soil at this site was rated as "very corrosive".
- Section 1 of pipe at Site 4 is cement-lined and this was reflected in an over-predicted thickness of 15.9 mm. Section 2 is not lined and predicted thickness was in close agreement with that of the exhumed sample.
- Predicted thickness for Section 2 at Site 5 was in close agreement with that of the exhumed sample. However, predicted thickness was almost double the nominal value for Section 1; this could be due to the pipe having been replaced by a ductile iron one.
- The 18-inch pipe at Site 7 was found to be in "very good" condition although it's been in service since 1860!

Observations & Comments (cont'd)

- Predicted and measured thickness loss for pipes at Sites 1 & 6 were in agreement and small. However, these pipes were rated by the City as "poor". This is in line with the poor experience of other Cities with pipes of the same1950s and 1960s vintage (spun cast, thin wall, copper services, poor workmanship).

Sample Extraction at Site 3, Section 1 (6-inch, 1860, very corrosive soil)

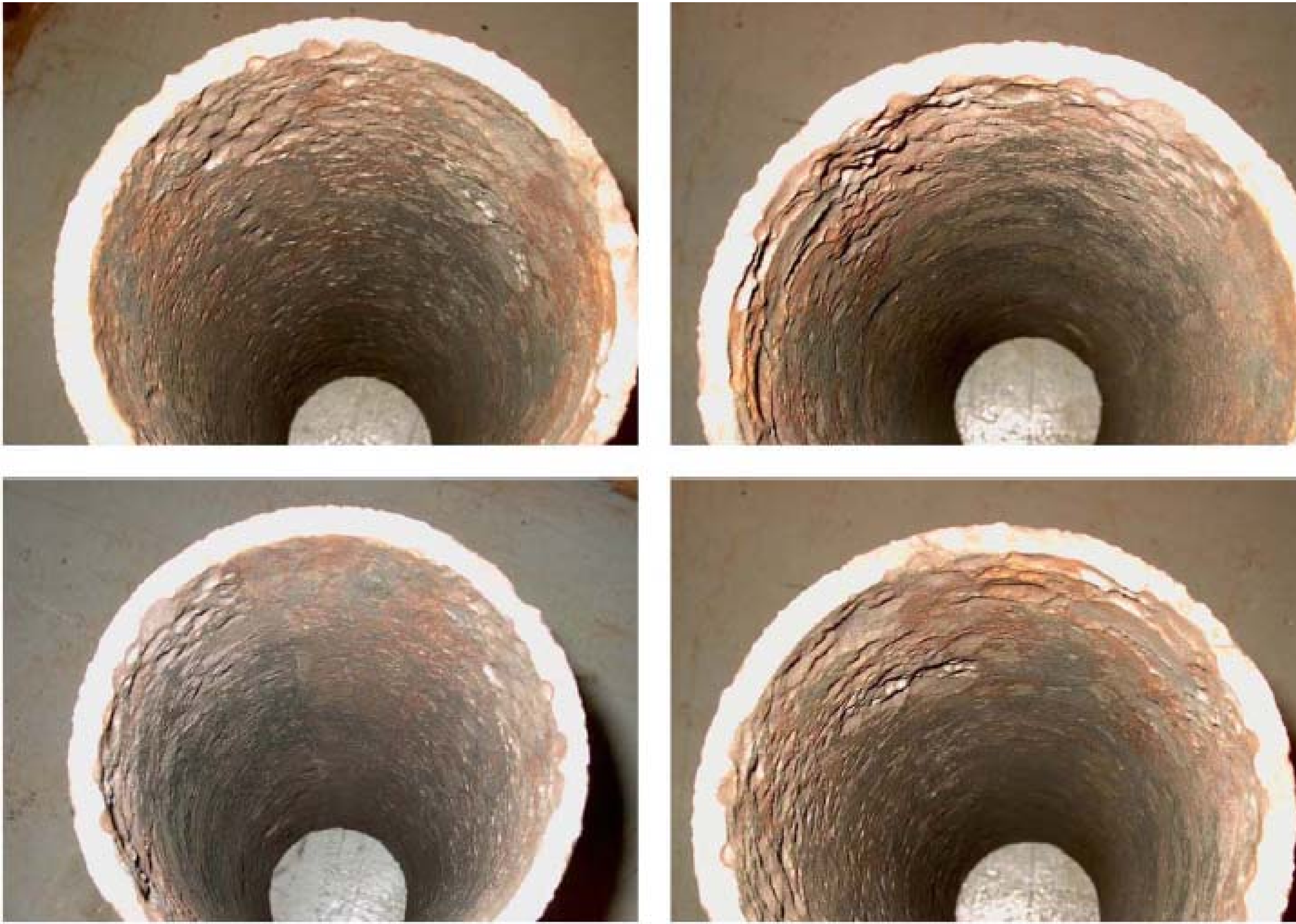
Exhumed as-found samples at Site 3 (Section 1)

Exhumed sand-blasted samples at Site 3 (Section 1)

Exhumed as-found samples at Site 3 (Section 1)




Exhumed as-found samples at Site 3 (Section 1)



Sample extraction at Site 7 (18-inch CI constructed in 1860)

Exhumed as-found sample at Site 7

Exhumed sand-blasted sample at Site 7

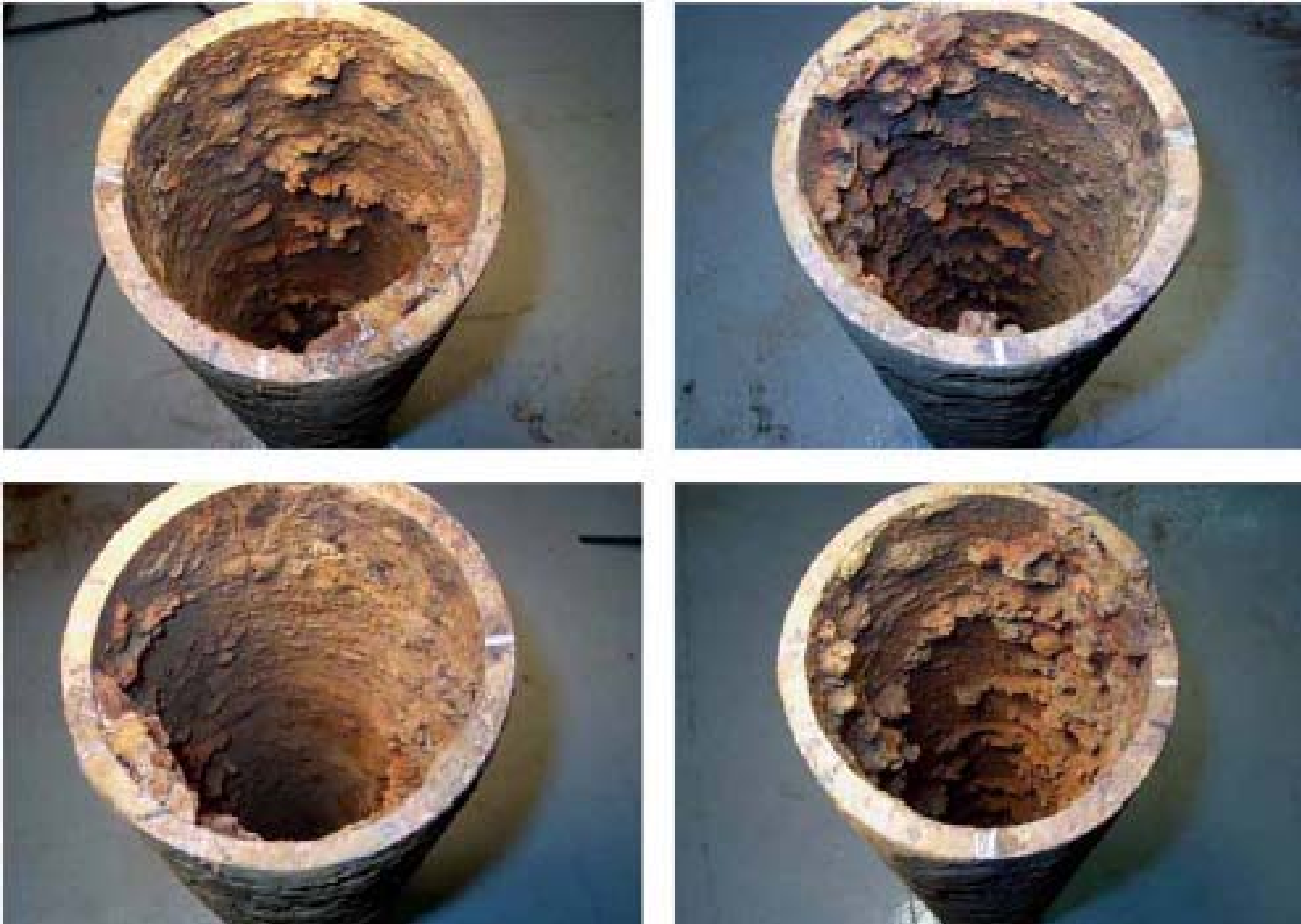
Exhumed as-found sample at Site 7

Exhumed sand-blasted sample at Site 7

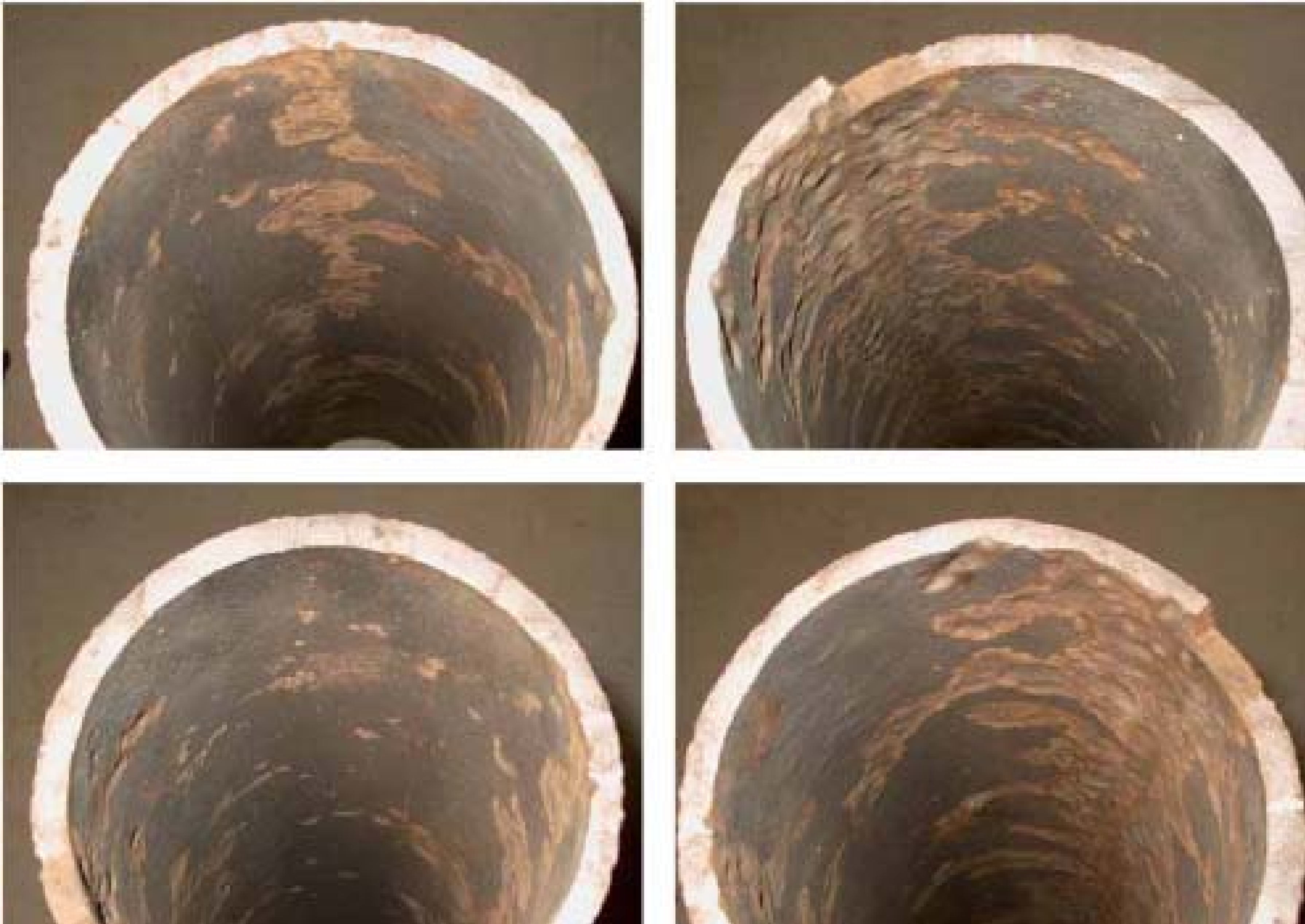
Exhumed as-found sample at Site 2 (6-inch, 1922, very corrosive soil)

Exhumed sand-blasted sample at Site 2

Exhumed as-found sample at Site 2

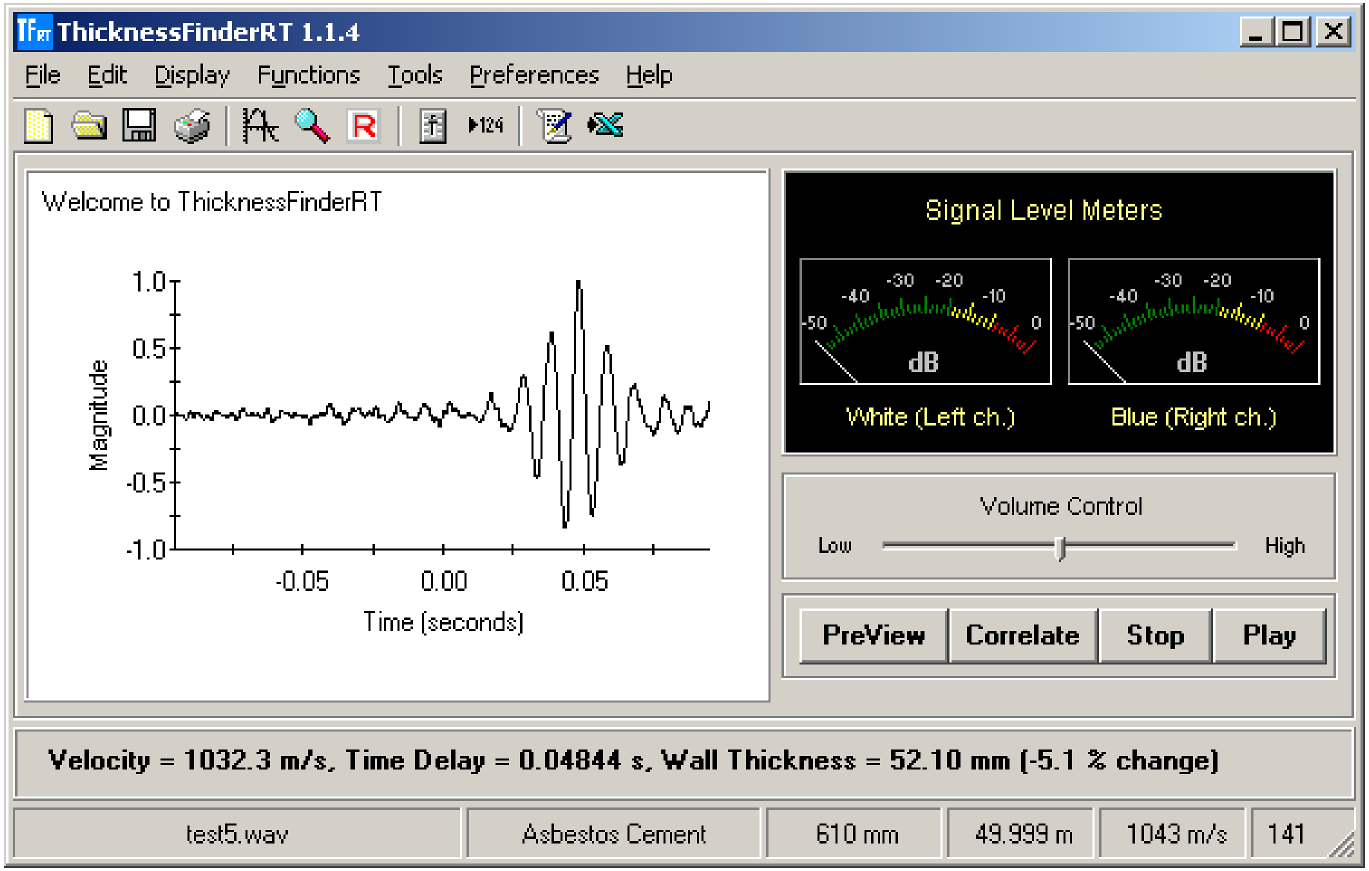


Exhumed sand-blasted sample at Site 2



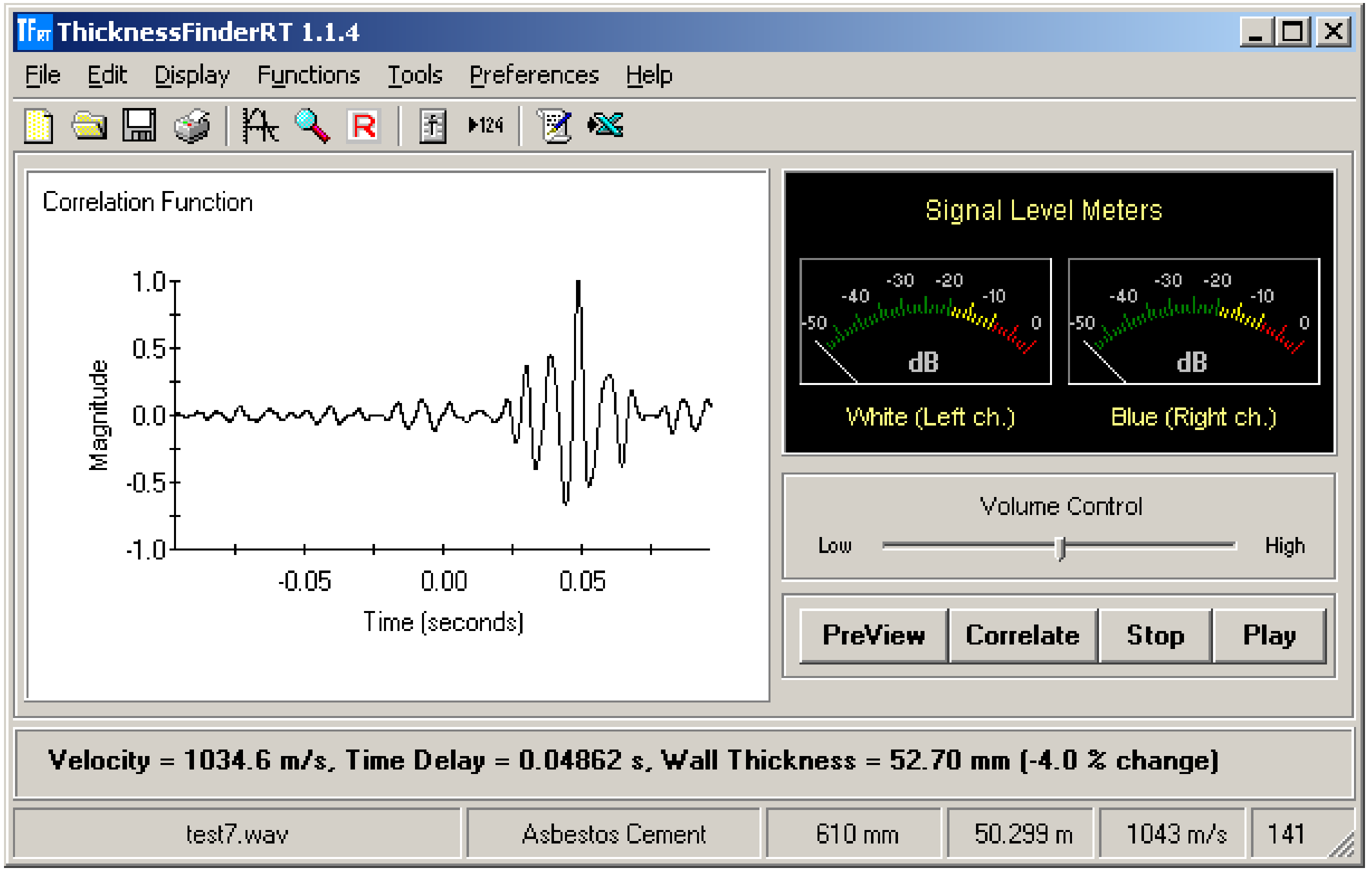
24-inch Asbestos Cement Pipe, Western Canada

24-inch AC Pipe (section 1)



echo logics

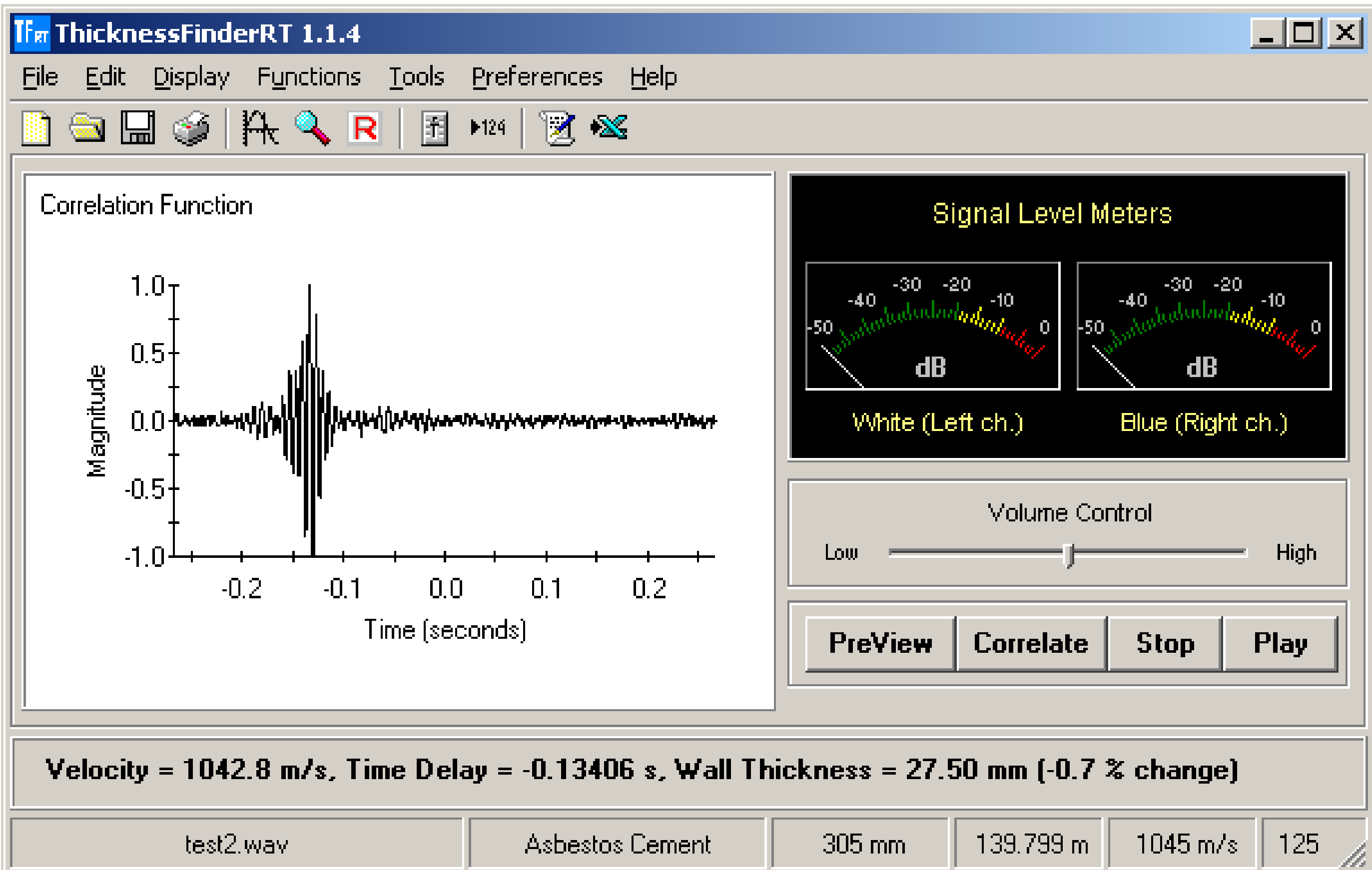
24-inch AC Pipe (section 2)



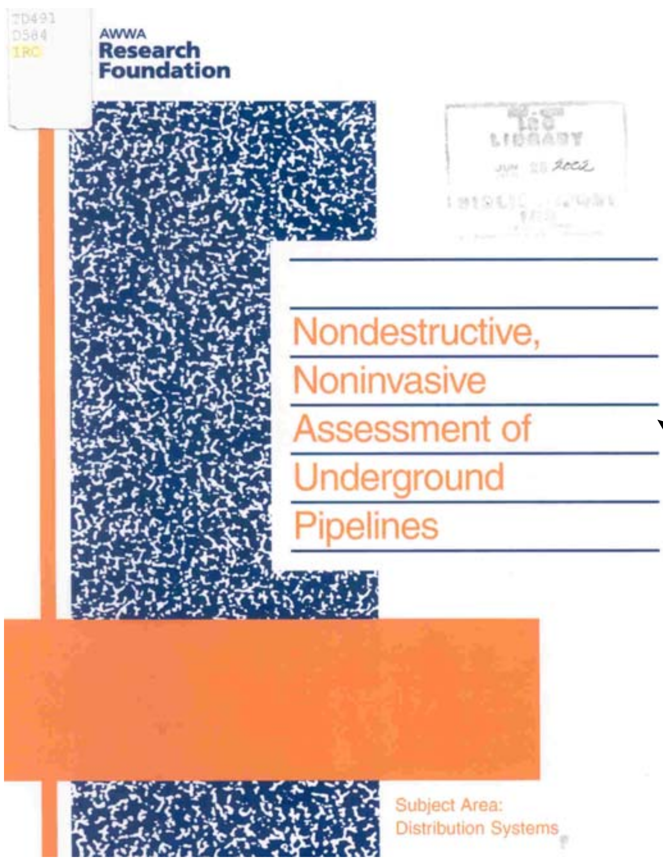
Nominal wall thickness for AC pipes

Pressure Class 150					
Inches			Millimeters		
I.D.	O.D.	Wall Thickness	I.D.	O.D.	Wall Thickness
3.95	5.07	0.56	100.3	128.8	14.2
5.85	7.17	0.66	148.6	182.1	16.8
7.85	9.37	0.76	199.4	238.0	19.3
10.00	11.92	0.96	254.0	302.8	24.4
12.00	14.18	1.09	304.8	360.2	27.7
14.00	16.48	1.24	355.6	418.6	31.5
16.00	18.72	1.36	406.4	475.5	34.5
18.00	21.30	1.65	457.2	541.0	41.9
20.00	23.64	1.82	508.0	600.5	46.2
24.00	28.32	2.16	609.6	719.3	54.9
30.00	35.42	2.71	762.0	899.7	68.8
36.00	42.46	3.23	914.4	1078.5	82.0

12-inch AC Pipe



Is the new method suitable for PCCP?



The compressional and shear wave arrival times are known for good pipe (~70 micro seconds compression and 130 micro seconds shear), but broken strands reduce the compression modulus in concrete, which decreases propagation velocities. Pipe containing broken strands may have arrival times as large as 130 micro seconds compression and 230 micro seconds shear. The decreased compression modulus also reduces the amplitude of propagating acoustic signals.

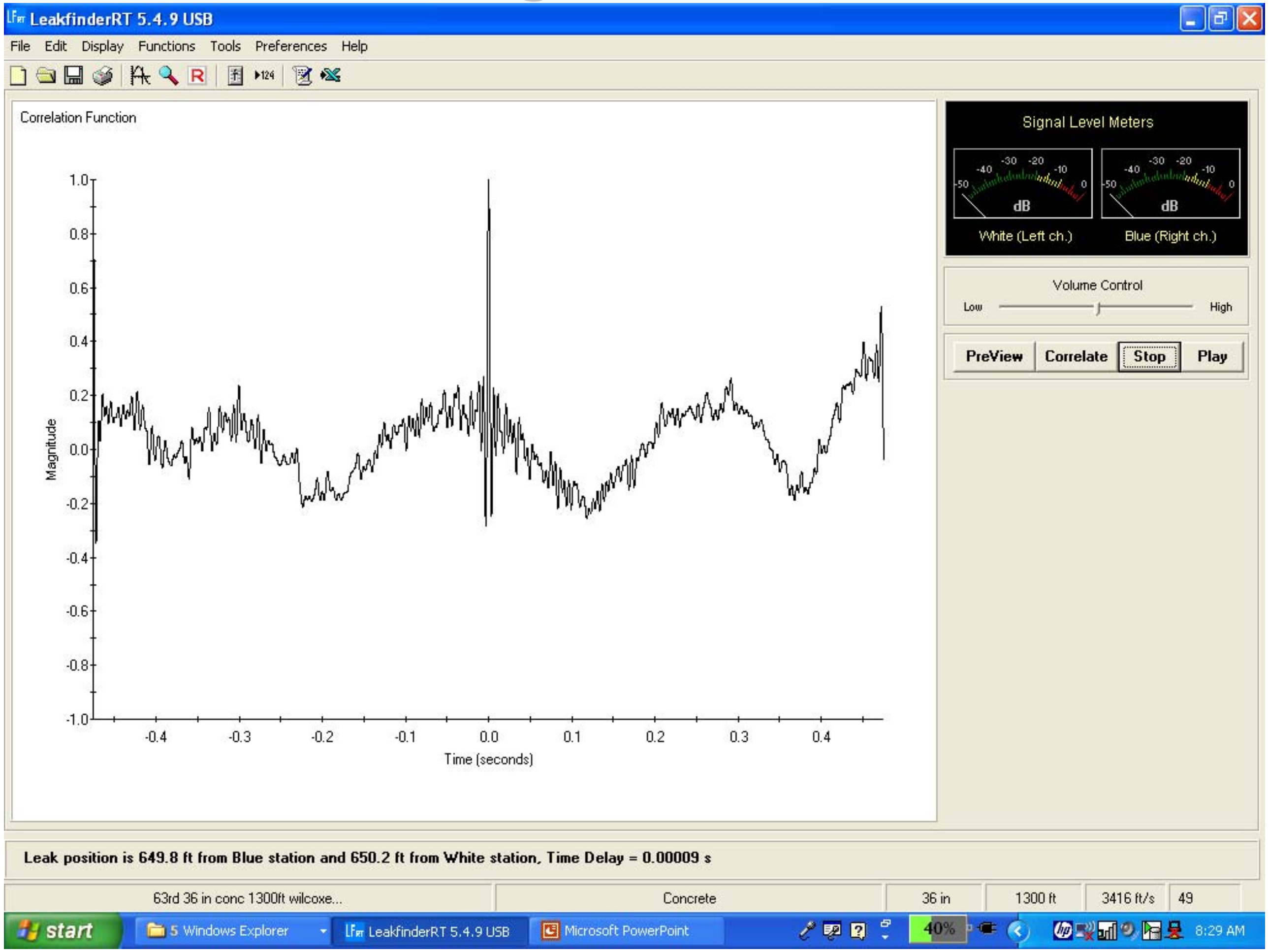
City of Chicago: 36 and 60" PCCP

- Chicago has lots of large concrete pipe
- Have found problems with some pipe
- Broken and corroded tendons
- Cannot shut pipes down for in-pipe technologies

City of Chicago cont.

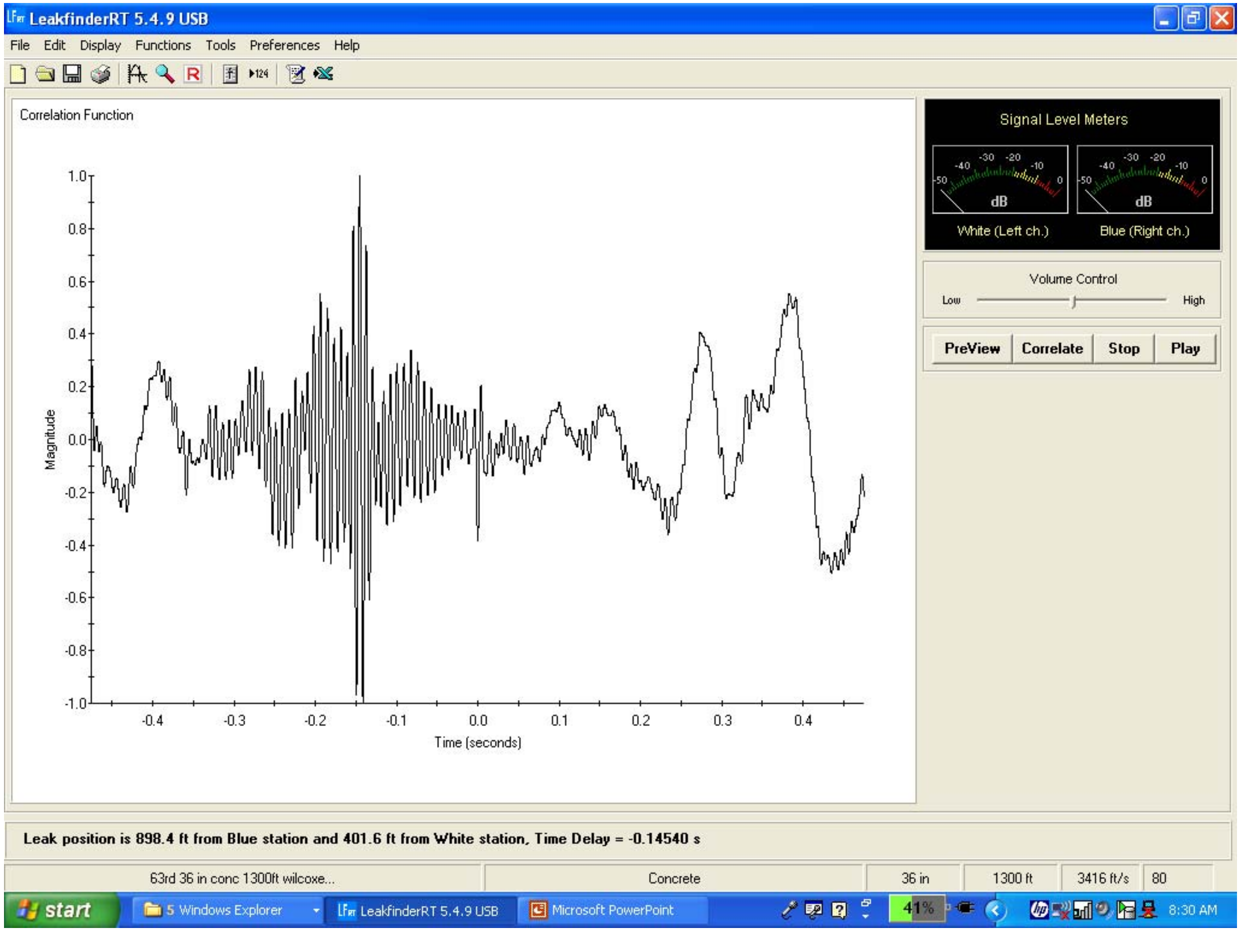
- Existing Leak on 36” main, 400m between hydrophone sensors
- Used new signal processing based on tests from Halton and Las Vegas
- Measured Velocity
- Pinpointed leak to within 3’
- Measured Velocity for condition assessment data base

Correlation Using Standard Methods



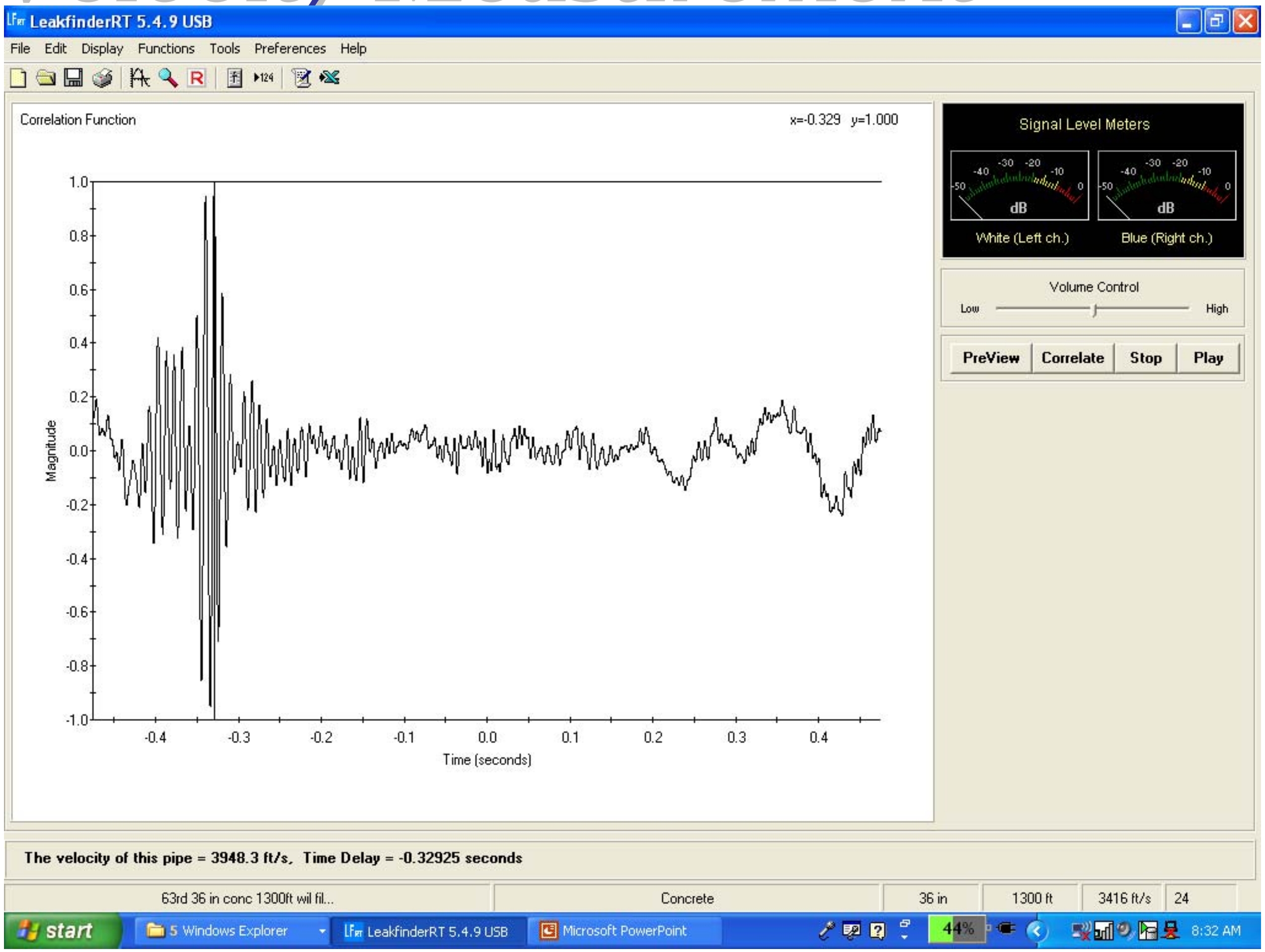
echo logics

Final Correlation



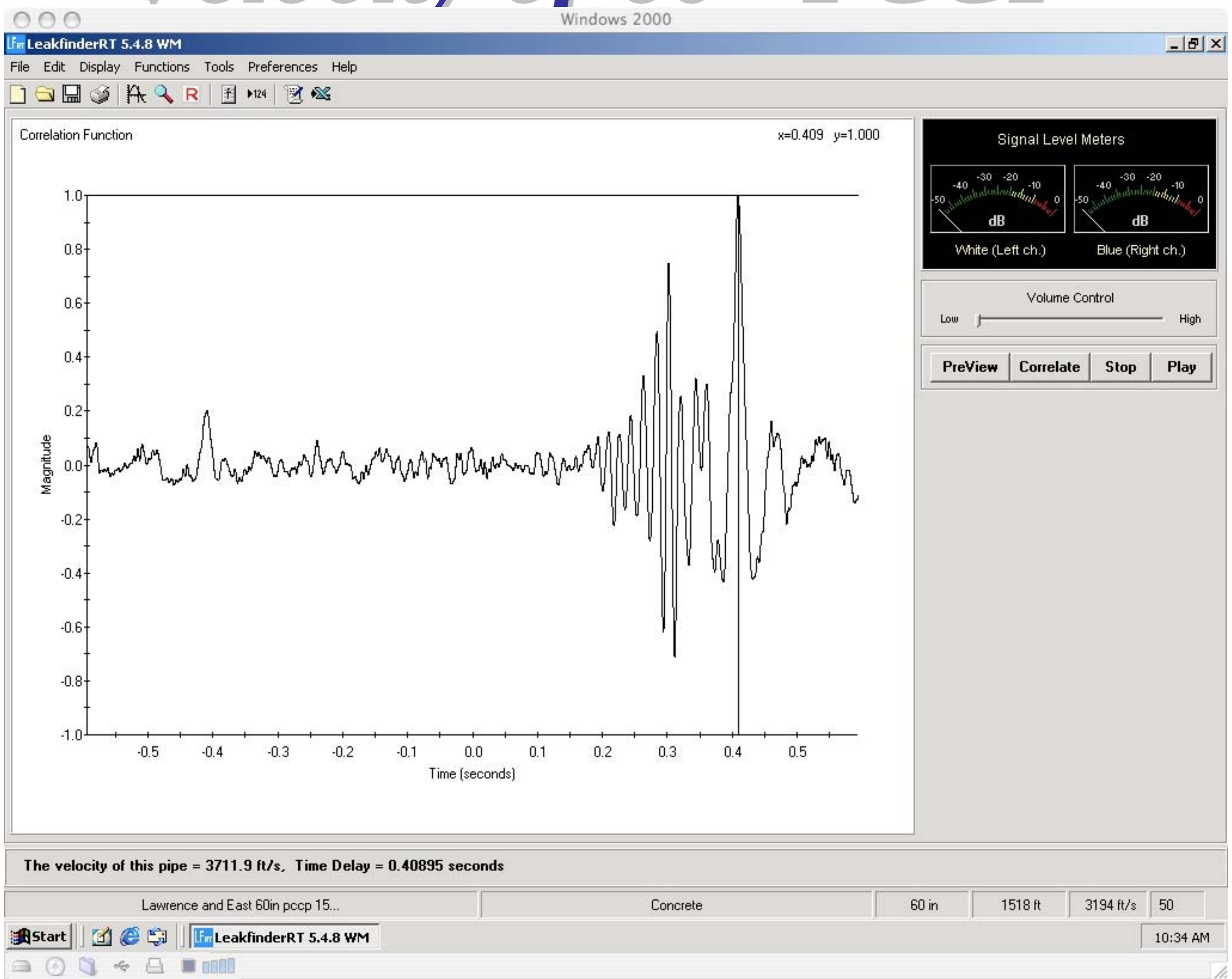
echo logics

Velocity Measurement



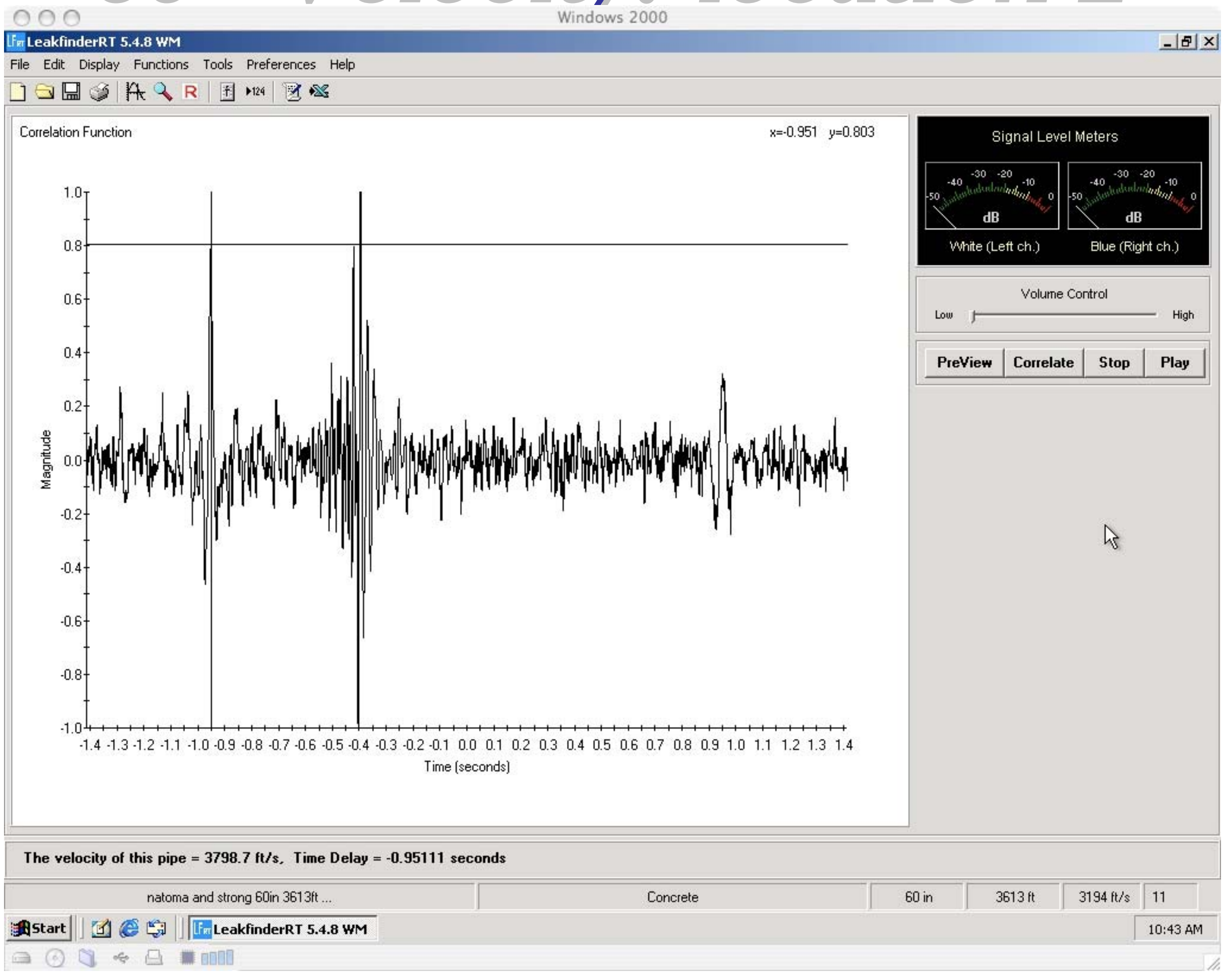
echo logics

Velocity of 60" PCCP



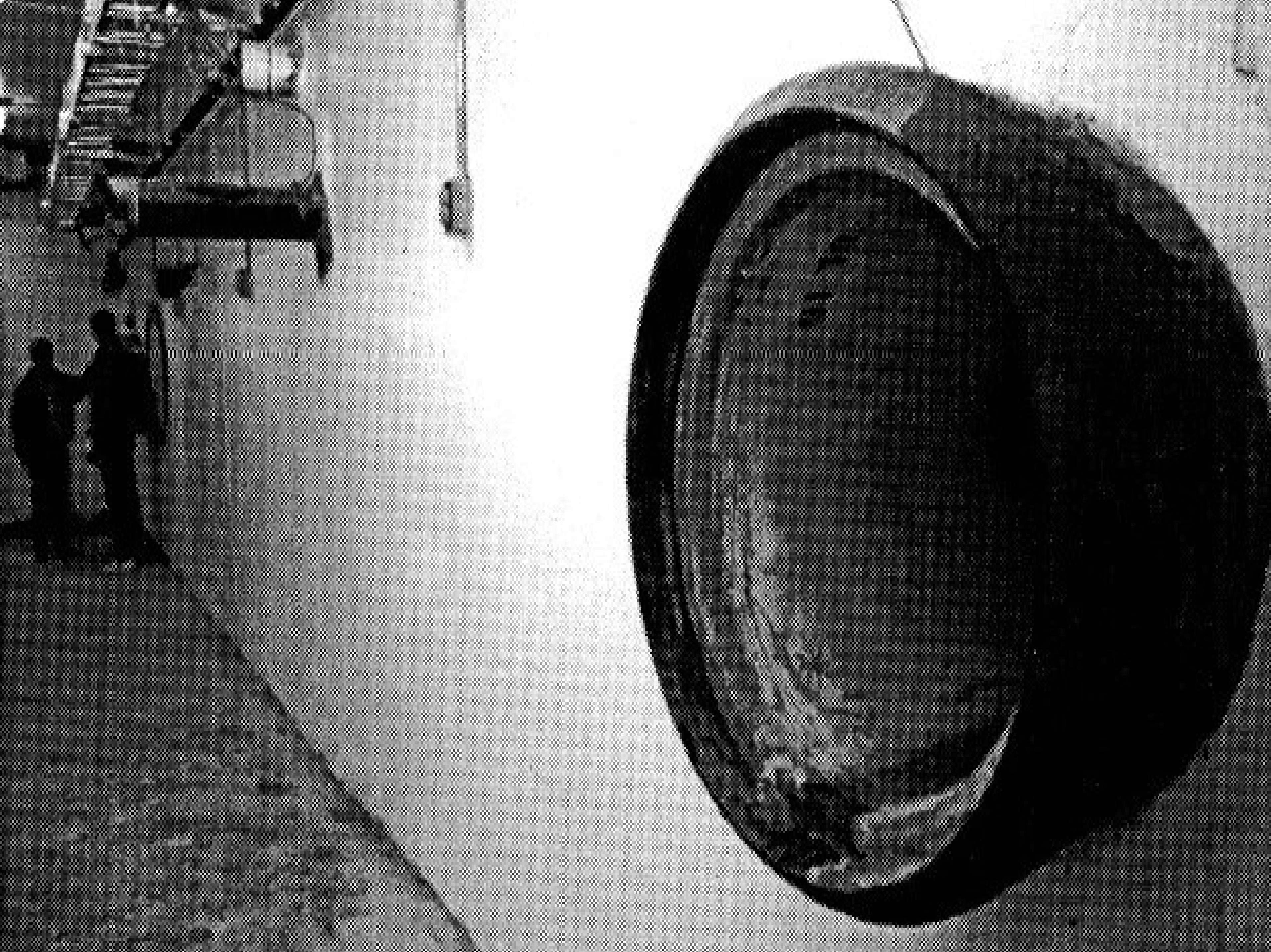
echo logics

60" Velocity: location 2



NRC Experimental Pipeline Facility

- Created to allow high-risk testing under field conditions that are virtually identical to fully functioning pipeline systems.
- A 30 m x 40 m pipe bed
- Ability to bury pipes at up to 4 m
- Accommodates all types and sizes of pipes used in municipal water systems
- Ability to replicate in-service conditions such as pressure, water flow, leaks, defects and deterioration of pipe wall materials, deficiencies in backfill materials, etc.
- Electrical network to evaluate cathodic protection techniques
- A separate pipe section to test residential service lines
- A separate 200 m (600 ft) long PVC pipe section to investigate leak detection problems in plastic pipes
- Presently has 38 m long 600 mm PCCP pipe (2 sections)



Thank you!