The Pipeline

News from DIPRA

Charleston Water System

Flow Test of 97-Year-Old Cement-Mortar Lined Pipe

Charleston Water System in Charleston, SC, has presented four opportunities for DIPRA to evaluate the first cement-mortar lined iron pipe to have been installed in North America. The latest test occurred on November 19, 2019. With the outstanding cooperation of Charleston Water System, DIPRA contracted with M.E. Simpson Co. to conduct flow tests for some 300 feet of pipe on Grove Street in Charleston. This pipeline, installed in 1922, was the first iron pipeline to be provided with cement-mortar lining. Unlike the linings applied today as part of the pipe manufacturing process, this first application of cement-mortar was applied as the pipe was being installed, using a projectile drawn through the pipe prior to being put into service[1].

This pipeline had been tested three times prior to 2019: in 1973, 1981, and 1999. Those tests were conducted using individual pressure gauges to obtain the pressure differential and a level survey to determine the change in elevation at both ends of the pipe section. The pipe was tapped so a caliper could be inserted to measure the pipe inside diameter and a pitot rod to measure the flow velocity. The resultant C for those tests varied between 130 and 131 and became part of a growing documented data set.

Conducting these tests provides real value. DIPRA obtains definitive field data to confirm its recommendation, and participating utilities such as Charleston Water System make a significant contribution to a knowledge base that is made available to all utilities. Because this is, truly, an iconic pipeline – the first iron pipeline with cement-mortar lining that has been serving for nearly one century – DIPRA captured the historic test in a video, available here or visit www.dipra.org/ductile-iron-pipe/pipeline/flow-test-of-97-year-old-cement-mortar-lined-pipe.

Perspective

Measuring Pressure in a Pipeline

In 1729, Daniel Bernoulli achieved a significant breakthrough in his study of the flow of fluids through pipes by inserting a small glass straw into the wall of a pressurized water pipe. As he watched the straw fill with water, he was the first to measure the pressure of a fluid flowing in a pipe. This led to two important developments: physicians had a way to measure blood pressure[i] and the development of Bernoulli's principle that, at any point within a pipeline, the total energy is constant.[ii]

Of course, when measurements are taken between two points in a pipeline, there is always a difference; energy is lost – and this is referred to as head loss.

Predicting Head Loss – the Hazen-Williams Equation

Research into the subject of head loss has given us several models that predict how much head loss must be overcome in designing a pipeline. In water systems, the most popular method of predicting head loss is by using an equation developed in 1905 by Allen Hazen and Gardner Stewart Williams[iii]. The Hazen-Williams equation relies on a dimensionless empirical constant, C, that describes the relative smoothness of the inside surface of a pipe. The smoother the inside surface, the greater the value for C and the lower the predicted head loss.

That is why DIPRA, with the assistance and cooperation of many water utilities, has conducted dozens of flow tests on in-service cement-mortar lined iron pipelines. Those tests provide a basis for our recommended C value of 140 for cement-mortar lined Ductile iron pipe. We reinforced that recommendation by conducting flow tests on pipelines that had been operating in different water systems for years. We have also taken advantage of opportunities to test the same pipelines more than once over a span of years, providing confirmation that the lining has reliable longevity.

i This was the way blood pressure was measured until 1896, when the sphygmomanometer was developed by an Italian doctor, Scipione Riva-Rocci.

ii Guillen, M., "Five Equations That Changed the World," Hyperion, New York, NY 1995.

iii Hazen, A. and Williams, G.S., "The Elements of Gagings and the Friction of Water Flowing in Pipes, Aqueducts, Sewers, Etc...", *John Wiley and Sons,* London, First Edition, 1905.

The Layout

The 1922 pipeline is an 8-inch pipe in a residential area (see Figure 1). The section being tested has minimal minor losses, with only residential service connections along the length being tested. The testing involved connecting to the pipeline at 152 and 174 Grove Street, some 300 feet apart. These were the same locations that were used in prior flow tests, which gives an excellent opportunity to evaluate the long-term condition of the lining.

The crews of Charleston Water System and M.E. Simpson Co. worked together to ensure the direction of flow was limited to the pipeline by closing nearby isolation valves. They then opened a hydrant outside of the section being tested in order to establish a constant flow within the pipeline. Charleston Water System also exposed the pipe about halfway between the two connections and installed a corporation stop so that the inside diameter and the velocity of flow could be established by inserting a caliper (to measure the inside diameter) and pitot rod (for velocity measurements).

The flow of water in the pipe is considered "turbulent flow*," so the velocity must be measured at several points traversing the inside diameter of the pipe. The spacing of the readings is established by the measured inside diameter. From these readings, an average velocity is determined using the "Equal Areas Method" for turbulent flow.

* In turbulent flow the speed of the water at a given point is continuously undergoing changes in both magnitude and direction, while its overall bulk moves along a specific direction (Encyclopedia Britannical).

Figure 1: Grove Street Test Site Layout

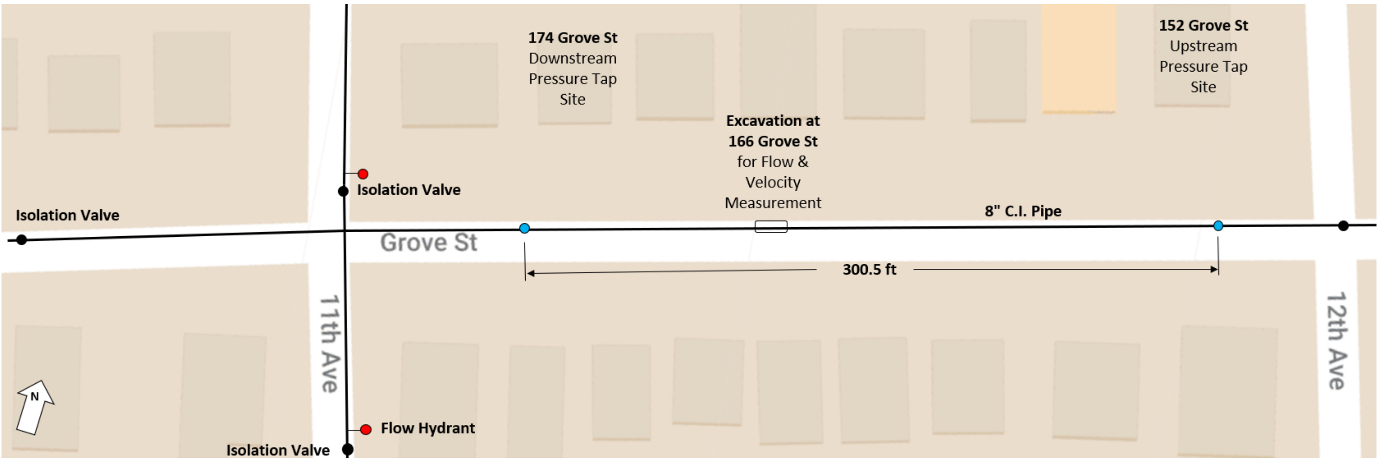

Figure 1: Grove Street Test Site Layout: Schematic layout of flow test. Head loss and velocity are measured using a Polcon Sentry Differential Pressure Recorder connected to pre-selected upstream and downstream sites. Flow is stabilized by closing appropriate isolation valves and opening a hydrant outside of the section of pipeline being tested.

Figure 2: Sentry flow meters

Typical Turbulent Flow Velocity Profile

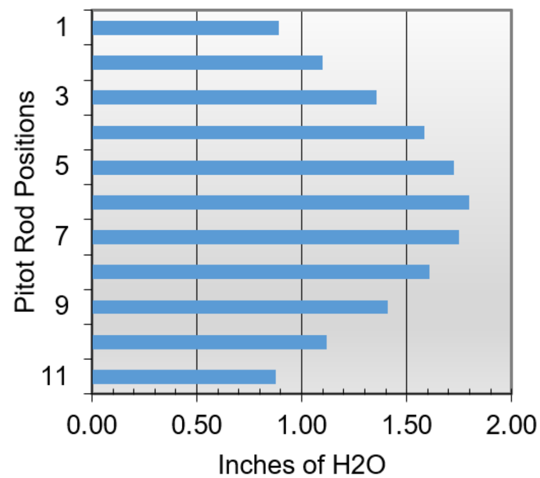

Figure 2: Sentry flow meters used to measure velocity and headloss. On the right is the representative profile of turbulent flow in a pipeline.

After determining the velocity regime, flow tests were conducted using a Polcon Sentry Differential Pressure Recorder connected to both ends of the pipeline being tested. The differential pressure recorder accounts for both pressure and elevation differentials with a precision to 1/10,000th of an inch of water.

With these measurements, the Hazen-Williams equation was solved for C:

$$C = \frac{V}{1.318(R)^{0.63}(H_L/L)^{0.54}}$$

Where:

C = Hazen-Williams Flow Coefficient (C factor)

V = Average Velocity of Flow (fps)

R = Hydraulic Radius (ft) = Pipe Inside Diameter/4

H_L = Head Loss (ft)

L = Length of Pipeline (ft)

1.318 = conversion factor for English units (1/sec)

Test Results in Charleston

Five flow tests were conducted on the pipeline. Data and results for the five test average, and each of the individual flow tests are shown in Table 1 below[i]:

Table 1: Pipeline Data and Test Results	
Pipeline Data	
Length of Pipeline tested	300.5 ft
Measured Inside Diameter	7.625 in
Hydraulic Radius of Pipe	0.1589 ft

Test Results						
Test Number	Time of Day	Flow Rate (gpm)	Velocity (fps)	Head Loss (in. of water)	Head Loss per Foot	C
Test 1	1:15 PM	330.4	2.3216	9.1444	0.0025	141.6
Test 2	1:30 PM	331.9	2.3321	9.8240	0.0027	136.8
Test 3	1:50 PM	329.8	2.3173	9.2161	0.0026	140.7
Test 4	2:05 PM	329.6	2.3159	9.1841	0.0025	140.9
Test 5	2:15 PM	329.7	2.3166	9.2395	0.0026	140.5
Average Results		330.3	2.3207	9.3216	0.00258	**140.1**

Table 1: The results of five flow tests on the 97-year old cement-mortar lined iron pipe. The average of the five tests revealed a C factor of 140, which validates the recommendation made for cement-mortar lined Ductile iron pipe. The length of time that the pipeline has been in service provides excellent confirmation of the longevity of cement-mortar linings.

Figure 3: Velocity Measurements

Figure 3: Tapped pipe with pitot rod inserted. Velocity measurements taken at points traversing the inside diameter of the pipe.

The average of the five tests was C = 140.1, a very encouraging result indicating the lining is still doing its job, protecting the inside of the pipe while continuing to present an outstanding "smooth" surface after an impressive 97-years of service.

It is interesting to note that the results of the testing done in 2019 seem to be better than previous results for this pipeline. The precision of the instruments used by M.E. Simpson can be expected to account for much of this improvement. Another factor would be the ongoing flushing program that is part of the routine maintenance protocols of Charleston Water Supply.

i For details of the test procedure and calculations, DIPRA's "Report of Flow Test – 8-inch Cast Iron Pipe – Charleston, SC, November 19, 2019" is available upon request.

Consistent Results Over the Years

DIPRA has conducted dozens of flow tests over the years to develop the C value recommended for cement-mortar lined pipe. Table 2 summarizes these results, the average value of which is the basis for DIPRA's recommendation of C = 140 for cement-mortar lined pipe. A plot of those individual results in Figure 4 provides a visual representation of how well the results straddle the recommended C = 140.

Table 2: Flow Tests of Cement-Mortar Lined Gray Pipe and Ductile Iron Pipe After Extended Periods of Time

Location	Size (Inches)	Length (Feet)	Age (Years)	Hazen-Williams C
Baltimore, MD	12	909	18	136
Birmingham, AL	6	473	6	141
	6	473	14	138
	6	473	17	133
Blackwood, NJ	12	1546	11	131
Catskill, NY	16	30,825	25	136
Champaign, IL	16	3,920	12	137
	16	3,920	22	139
	16	3,920	28	145
	16	3,920	36	130
Charleston, SC	6	300	12	146
	6	300	16	143
	8	300	51	131
	8	300	59	130
	8	300	77	130
	8	300	97	140
	12	500	15	145
	12	500	25	136
Chicago, IL	36	7,200	12	151
Concord, NH	12	500	13	143
	12	500	29	140
	12	500	36	140
Danvers, MA	20	500	31	135
	20	500	38	133

Location	Size (Inches)	Length (Feet)	Age (Years)	Hazen-Williams C
Dothan, AL	12	1000	5	137
Greenville, SC	30	87,400	13	148
	30	87,400	20	146
	30	50,700	19	148
	30	50,700	25	146
Greeneville, TN	12	500	13	134
	12	500	29	137
	12	500	36	146
Knoxville, TN	10	500	16	134
	10	500	32	135
	10	500	39	138
Manchester, NH	12	550	5	142
	12	550	21	135
	12	1,955	45	133
Memphis, TN	10	1,070	31	135
Orange, CA	6	1,004	26	140
Safford, AZ	10	23,200	16	144
S. Burlington, VT	24	1,373	8	138
Seattle, WA	8	2,686	29	139
Tempe, AZ	6	1,235	24	144
Tacoma, WA	8	2,257	16	136
Wister, OK	18	3,344	30	139

The value of cement-mortar linings has been confirmed in a number of technical articles and studies[2,3,4,5,6,7] over many years, perhaps the most comprehensive study being conducted by the Water Research Foundation (WRF) in their 2011 report "Life Expectancy of Cement Mortar Linings in Cast and Ductile Iron Pipes"[8]. A primary conclusion of this report is "(t)he assessment of 121 samples supplied from the service, together with a review of reports from a range of sources on CML performance, leads to the conclusion that…CML lined iron pipes typically have a predicted life exceeding 100 years." Similarly, the Product and Material Information and Guidance regarding the Water Supply Code of Australia reports "…confidence of a service life in excess of 100 years" for cement-mortar linings.[9]

The results of the testing of the 97-year old cement-mortar lined iron pipe in Charleston certainly support these conclusions.

Figure 4: Plot of C-Factor Results

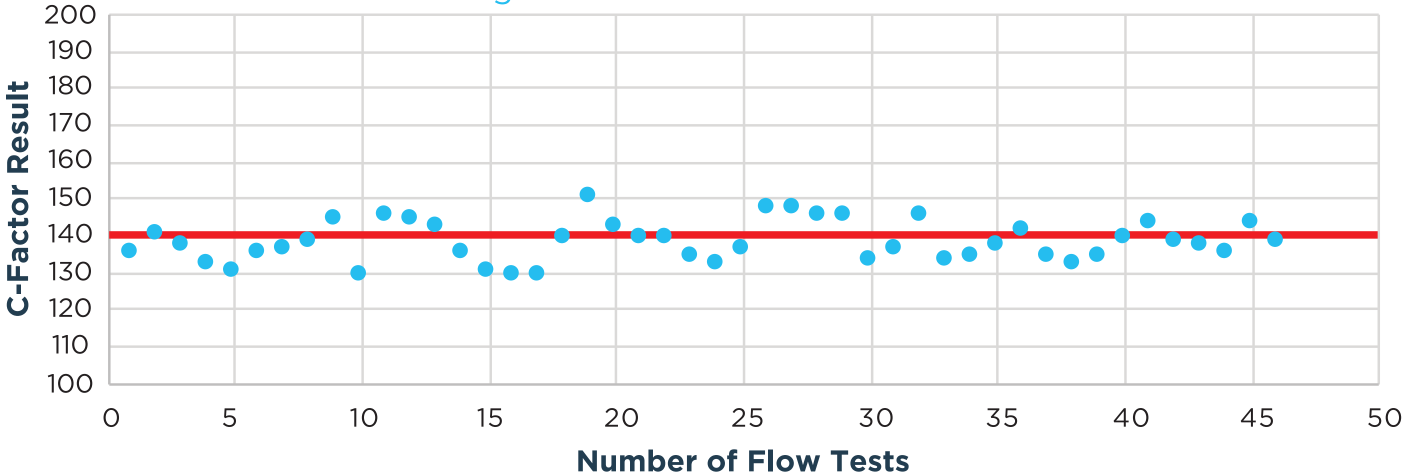

Figure 4: Flow test results from Table 2 – the basis for C of 140 for Cement-Mortar Lined Ductile Iron Pipe.

Turbulent Flow in Water Pipelines

Hydraulic models have long agreed that all pipes with inside surfaces that are classified as "smooth" will have similar values for C. This is because, in turbulent flow, there is a laminar layer of water that hugs the inside circumference of the pipe. In smooth pipes, head loss results from the shear force between that laminar layer and the turbulent regime that occupies the remainder of the inside diameter. If the inside surface of the pipe is "smoother" than the thickness of the laminar layer, all smooth pipes will have virtually the same C factor[10].

Since plastic pipes used in North American water infrastructures have the same outside diameter as Ductile iron pipe, the inside diameters will differ – with the advantage going to Ductile iron. The plastic pipes will have thicker walls because they are much weaker pipe materials. This is the primary reason for the energy and greenhouse gas saving advantages to Ductile iron pipe.

To demonstrate this advantage, DIPRA has conducted side-by-side flow tests that compare cement-mortar lined Ductile iron and PVC pipes in Blackwood, NJ[11]; Dothan, AL[12]; and Wister, OK[13]. Note how similar the resultant values for C are. These results fit modern hydraulic theory of flow in pipes and showed why the larger inside diameter for Ductile iron presents verifiable energy savings, as shown below.

Figure 5: Flow Test Results

Location	Year Installed	Year Tested	Pipe Size (in)	Flow Rate (gpm)	Pipe Material	Measured Inside Diam. (in)	C Factor	Velocity (f/s)	Headloss (f/1000f)
Blackwood, NJ	1975	1986	12	750	CML DI	12.20	131	2.0	1.2
	1976				PVC	11.53	138	2.3	1.5
Dothan, AL	1981	1986	12	750	CML DI	12.28	137	2.0	1.2
	1980				PVC	11.65	140	2.3	1.5
Wister, OK	1969	1999	18	1500	CML DI	18.53	139	1.8	0.6
	1998				PVC	17.08	141	2.1	0.8

Figure 5: Note how close the calculated values for C turned out to be. Note also that when the flow through these pipes are normalized, it is the actual inside diameter that is the determinant regarding head loss for each pipe. Higher head loss translates into more energy required to deliver a given flow; and more greenhouse gas emissions that result from the consumption of the additional.

Information Utilities Can Use with Confidence

The Ductile Iron Pipe Research Association conducts research to fully understand the performance of iron pipe under the varying conditions it may experience when in service. We work to ensure that the utilities that place their trust in iron pipe do so believing in the value this resilient, reliable pipe offers.

The results of this flow test of a 97-year-old iron pipe on Grove Street in Charleston, SC, provide definitive evidence of the long-lasting efficacy of cement-mortar lined iron pipe.

DIPRA notes the professionalism exhibited by the M.E. Simpson Co. in their conduct of this testing. DIPRA also recognizes the "above and beyond" nature of the cooperation provided to us by Charleston Water System in conducting this work. It is this type of cooperation that is the touchstone of those professionals that provide safe, reliable drinking water to many millions of customers throughout North America. We express our gratitude and recognition to those who help set the bar on "best practices" for the water distribution industry.

References

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3 Scott, G. N., "Corrosion Protection Properties of Portland Cement Concrete," *Journal of the American Water Works Association,* August 1965, pp1038-1052.

4 Hall, S., "Corrosion Protection Provided by Mortar Lining in Large Diameter Water Pipelines After Many Years of Service," *American Society of Civil Engineers,* Proceedings of the 2013 International Pipelines Conference, Ft. Worth, Texas, June, 2013.

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7 Product and Material Information and Guidance – Water Supply Code of Australia, *Water Services Association of Australia,* Version 1.1, WSA 03-2011, p10.

8 Munster, T., Davis, P. et al, "Life Expectancy of Cement Mortar Linings in Cast and Ductile Iron Pipes," Water Research Foundation, Denver, CO, USA and *Commonwealth Scientific and Industrial Research Organisation,* Highett, Victoria, Australia, 2011.

9 Product and Material Information and Guidance – Water Supply Code of Australia, *Water Services Association of Australia,* Version 1.1, WSA 03-2011, p10.

10 Lamont, P.A., "Common Pipe Flow Formulas Compared with the Theory of Roughness," Journal of the American Water Works Association, Denver, CO, May 1981.

11 "Report on Flow Test: 12-inch Ductile Iron Pipe & 12-inch PVC Pipe, Blackwood, NJ," Ductile Iron Pipe Research Association," May 14, 1986.

12 "Report on Flow Test: 12-inch Ductile Iron Pipe & 12-inch PVC Pipe, Dothan, Alabama," Ductile Iron Pipe Research Association, February 25-26, 1986.

13 "Report on Flow Test: 18-inch Ductile Iron Pipe and 18-inch PVC Pipe; Poteau Valley Improvement Authority, Wister, OK," Ductile Iron Pipe Research Association, October 19, 1999.

For more information, contact DIPRA or any of its member companies.

Ductile Iron Pipe Research Association

An association of quality producers dedicated to the highest pipe standards through a program of continuing research and service to water and wastewater professionals.

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