Large Diameter Watermain Condition Assessment and Evaluation

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Abstract

The City of Salem, Oregon became concerned about the condition and reliability of their 75-year old, 36-inch diameter water supply main following high water losses and the reoccurring need to repair leaking pipe joints. The pipeline of concern is over seven miles long, consists of both steel and reinforced concrete "pressure" pipe sections, and is one of two large parallel water mains which supply drinking water to the City of Salem (City). This paper discusses methods used and challenges encountered during the inspection and evaluation of this large diameter pipeline and rationale developed for recommendations to extend the service life of this infrastructure.

A comprehensive external and internal inspection of the buried pipeline was conducted by Murray, Smith & Associates (MSA) in the fall of 2009. Several test pits were excavated to expose portions of the pipe for external inspection and assessment. From these excavations, test leads and test stations were connected to the steel pipe to conduct pipeline continuity testing, soil resistivity testing and an over-the-line pipe-to-soil electrical potential survey as part of a corrosion evaluation. Internal pipeline inspection included the use of video equipment to observe pipe joint condition, access port locations, areas of corrosion and other anomalies. The pipeline was inspected for leakage using flow data and sonic leak detection methods. These assessment techniques have efficiently provided the City with a thorough understanding of their supply main's condition, materials, and "as-built" components.

Criteria were developed to prioritize the pipe rehabilitation work, focusing City resources on the highest priority issues. These criteria included the risk to human life and infrastructure due to pipe failure, the cost of water loss, the type of retrofit required, and the accessibility to the pipeline. Several trenchless pipe rehabilitation options were determined to be feasible, as was pipe replacement. By applying these criteria to the evaluation findings, a cost-effective pipe rehabilitation and replacement program may be implemented to lessen the risk of pipeline failure and extend the service life of this valuable City infrastructure. The techniques employed for the City of Salem's pipeline assessment were also used recently on a similar project for the City of Everett, Washington and builds upon prior work completed for the Joint Water Commission, Hillsboro, Oregon; the City of Beaverton, Oregon; and others.

Introduction

Drinking water for the City of Salem is conveyed from the water treatment plant at Geren Island in Stayton, Oregon, to the City of Salem service area by way of Franzen Reservoir in Turner, Oregon. Water is conveyed approximately 11 miles between the plant and the reservoir in a combination of 69-inch, 54-inch and 36-inch supply transmission mains. The City contracted with MSA to evaluate the current condition of the 36-inch diameter pipeline and is currently considering various options to rehabilitate 7.5 miles of the pipeline to extend its service life.

General Description of Existing Facilities

The City's water treatment facility is located east of Salem on Geren Island. Surface water is withdrawn from the North Santiam River and passed through a slow sand filtration system before being discharged into two parallel supply mains. Chemical treatment at the Geren Island plant includes the addition of sodium hypochlorite for disinfection.

Prior to 2003, parallel 36-inch and 54-inch diameter supply mains left the Geren Island treatment plant, having a combined capacity of 75 million gallons per day (MGD). The 36-inch diameter pipeline, also referred to as Line 1, was installed in 1936 with portions of both steel pipe and reinforced concrete "pressure" pipe. The 54-inch diameter pipeline, referred to as Line 2, parallels Line 1 to the south and was constructed in 1957. Construction of a 69-inch diameter pipe, known as Line 3, was completed on Geren Island in 2003 to replace a portion of the aging Line 1. In 2006 and 2007, additional Line 3 69-inch diameter pipe was installed to replace Line 1 from SE 70th Avenue to Franzen Reservoir. The remaining portion of Line 1 between Geren Island and SE 70th Avenue is 7.5 miles long, as shown in Figure 1. Approximately 1.4 miles of Line 1 runs beneath buildings and streets in the City of Stayton; the remainder of the Line 1 alignment runs in a northwesterly direction beneath agricultural land. Significant portions of the buried Line 1 alignment can be identified on aerial photos by the difference in groundcover coloration.

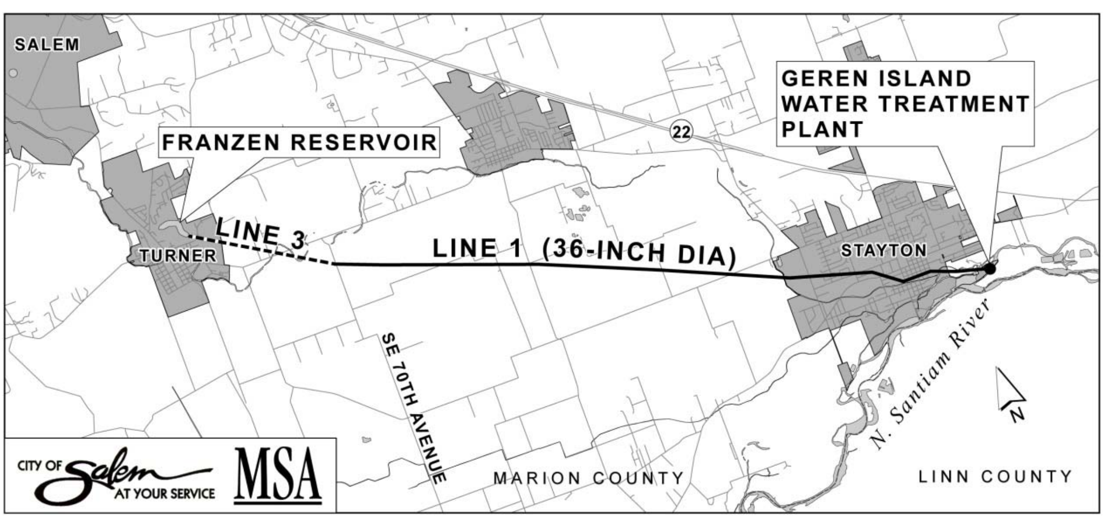

Figure 1: Overview Map

Franzen Reservoir is a 100 million gallon storage facility located southeast of Salem in the City of Turner. It was constructed in the 1950's as an open reservoir and was tied into the existing Line 1 supply main. Franzen Reservoir was lined and covered in 2006; at the same time, the Line 1 connection at Franzen Reservoir was replaced with a 69-inch diameter pipe (Line 3).

External Concrete Pipeline Assessment

A sample of concrete pipe from an abandoned portion of Line 1 was cut and removed for inspection. What was initially presumed to be a pipe material similar to concrete cylinder pipe, was in fact found to be reinforced concrete "pressure" pipe. The reinforced pipe wall is approximately 5 inches thick with ¼-inch diameter steel hoop reinforcement. The pipe joints, located approximately 8-feet on center as shown in Figure 2, were filled with grout and encased with 4-inch thick steel reinforced concrete collars. Figure 3 shows a section view of the concrete pipe joint, which appears to have factory installed collars (top piece) on one end of each pipe, such that a "bell end" (bottom left piece) was fashioned which would then fit over the "spigot end" (bottom right piece) of the adjoining pipe. What is assumed to be factory applied grout is the darker colored grout on the left side of the joint. The concrete reinforcing was colored black on the sample for contrast. Over the past several decades, leaks have been detected and repaired using stainless steel bands at several locations along the concrete portions of the 36-inch pipe. From the exterior, the pipe collars were observed to be in overall good condition. Leaks in the concrete pipe appear to be caused by failing grout seals at the pipe joints. Grout failure is believed to be exacerbated by road and railroad vibrations and settlement.

Figure 2 – Concrete Pipe Segment

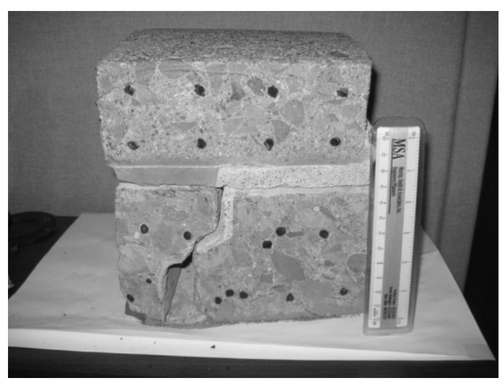

Figure 3 – Concrete Pipe Joint Section

The exterior surface of the in service concrete pipe was exposed in a few locations and inspected, appearing sound with no signs of exposed steel reinforcement, concrete spalling or cracking.

External Steel Pipeline Assessment

The City removed a sample of steel pipe from an abandoned portion of Line 1 to inspect the wall thickness and the coating and lining characteristics. The pipe is generally 1/4-inches thick, coated with a wrapped coal tar coating system, and lined with what appears to be coal tar.

Portions of steel pipe are currently exposed along the alignment. At two such locations, the pipe is submerged in an irrigation ditch along SE 70th Avenue and in a river channel at the City of Stayton's Pioneer Park. A portion of steel pipe is also exposed as it goes above grade and crosses over the Salem Ditch, referred to as the "Goose Neck" crossing, just west of Stayton. Ultrasonic thickness measurements were taken of the pipe coating at the exposed locations. The coating thickness varies due to original application technique, wear and weathering.

Six test pits were excavated to expose the steel pipe along active portions of Line 1 near where the pipeline transitions from steel to concrete pipe. The steel pipe was inspected at each test pit location, which included taking coating thickness measurements, ultrasonic pipe wall thickness measurements, and visually inspecting the buried pipe condition. The external surface of the buried steel pipe appeared to be in good condition, with the exception of some isolated areas of coating damage due to tree roots and previous excavations.

Corrosion Assessment

MSA contracted with Cascade Corrosion Consulting Services (CCCS) to analyze the steel portions of the pipeline for existing corrosion damage and future potential for corrosion. The City recently experienced a failure of Line 2 due to corrosion, and suspected the 36-inch transmission main may have similar corrosion issues.

At the six test pits, test stations were installed. City crews welded brackets onto the steel pipe and ran wire test station leads from the brackets into a valve box installed at grade. Once backfilled, CCCS used the test stations to carry out various corrosion tests on the pipeline, as well as assessing the surrounding soils for corrosive properties. From the corrosion and soil testing, CCCS developed a corrosion assessment report for the steel pipe sections which is summarized below.

Pipe Continuity

The electrical continuity of the pipeline was assessed by inducing a substantial current in the pipeline at a test station and verifying influence at the adjacent test stations along the steel pipe. Electrical continuity was confirmed along most of the steel pipeline, with the exception of a section near Geren Island where it is suspected mechanical couplings along this stretch of pipe cause the discontinuity.

Pipe-to-Soil Potential

The pipe-to-soil potential was measured by CCCS at each of the six test stations, and an over-the-line potential survey was conducted where the steel pipe was found to be discontinuous. The pipe-to-soil potential analysis identified areas along the pipeline which have a high probability for corrosion to occur. One particular portion of the steel pipeline, which runs through a dairy farm, is categorized as having a "90% probability of corrosion activity" in the CCCS report, and is therefore a high risk location.

Soil Resistivity, pH and Redox

The soil resistivity is a measure of the electrical resistance provided by the soil. The lower the resistivity is, the more conductive the soil is. A soil with a resistivity less than 5,000 ohms-cm provides a highly corrosive environment for the pipeline. A soil resistivity greater than 10,000 ohms-cm is considered to be only slightly corrosive, buffering the pipeline from the flow of electrical current onto, and off of, the pipe. Soil resistivity measurements along the 36-inch steel pipeline ranged from 3,543 ohms-cm (highly corrosive) to 210,650 ohms-cm (slightly corrosive). Soil resistivity alone does not indicate corrosion potential, but must be looked at in association with soil gradation, groundwater conditions, soil oxygen content, and similar factors. Soil samples at the test pit excavations were analyzed to determine pH and reduction/oxidation (redox) characteristics to evaluate such conditions. CCCS identified a 1.2 mile segment of the steel pipe as being susceptible to failure due to seasonal soil corrosion or oxidation reduction corrosion.

Internal Pipeline Video Inspection

MSA contracted with Bravo Environmental to provide video inspection services of the Line 1 interior via a remotely operated, vehicle mounted video camera unit, referred to as a Storm Drain Tractor, while the pipe was drained. A 1,900 foot long spool of cable was attached to the camera vehicle, allowing a maximum of 3,800 feet of pipe inspection from each access port utilized. Representative segments of the pipe were video inspected providing a characterization of the pipe interior. Six access ports were used to insert the video equipment into the pipe, four existing access ports and two new core drilled access ports with manholes as installed by the City. The video inspection access port locations were chosen to not only utilize existing access ports, but also to ensure areas of concern for leakage and corrosion could be accessed by the video inspection equipment. Areas of concern identified included pipe material transition joints, locations of suspected leakage, waterway crossings, road crossings, and the railroad crossing.

Biofilm encountered on the concrete pipe interior walls caused the camera vehicle to lose traction in some locations. Bravo Environmental retrofitted the vehicle to compensate for this loss of traction by adding additional weight to the vehicle and installing screws to the vehicle tires to act as studded traction tires. These additional traction measures were generally effective. The biofilm eventually built up on the tire studs, causing a loss of traction.

Figures 4 and 5 below are photos taken inside the 36-inch pipe. Figure 4 shows a portion of the concrete pipe. Damp areas can be seen at each pipe joint from groundwater infiltration. Figure 5 is a typical photo of the steel pipe interior surface. Spots of corrosion and blistered lining are evenly distributed throughout the pipe wall, with a few larger patches evident.

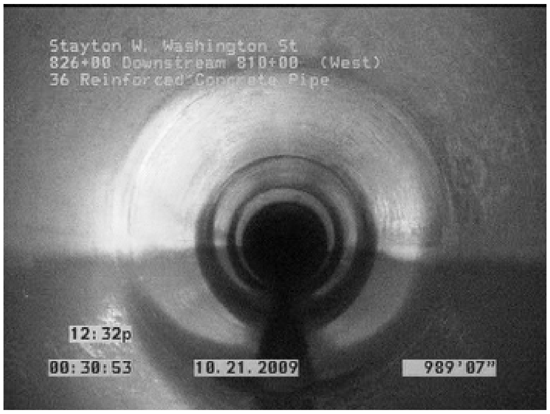

Figure 4 - Concrete Joint Seepage

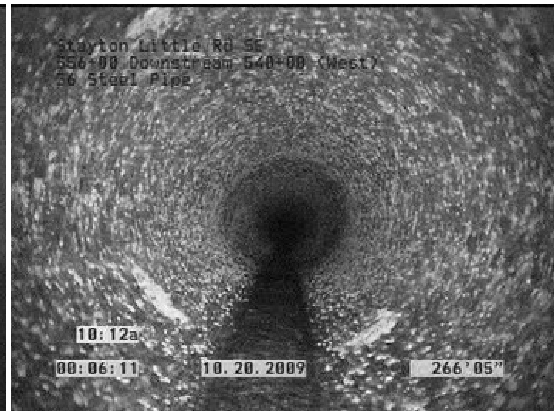

Figure 5 – Typical Steel Pipe Interior

Pipeline Leakage Testing

The City initially suspected a leak of approximately 1 MGD in Line 1, based on previous observations. Daily water loss in Line 1 was measured by forcing all supply through Line 1 between November 10 and November 29, 2009. The City took daily meter readings using the Supervisory Control and Data Acquisition (SCADA) system to determine the volume of water leaving Geren Island, the City of Turner's water demand served by Line 1, and the volume of water entering Franzen Reservoir. The following assumptions were applied to the leakage assessment: the new 69-inch diameter pipe sections do not leak, no groundwater is entering the pressurized pipe along the alignment, and the transmission main remains full during the leakage test.

The SCADA readings report the total volume of water passing the meter, so daily readings were taken at approximately the same time each day in order to convert the volume reading into a flow rate. The volumes diverted to the City of Turner and entering Franzen Reservoir were subtracted from the volume leaving the Geren Island treatment plant to calculate the total daily water loss. Review of the data determined for the test period, the 7.5 miles of the Line 1 supply main lost approximately 0.94 MGD.

Leak Detection

MSA contracted with American Leak Detection to locate leaks along the Line 1 alignment, focusing primarily on the sections of concrete pipe. The leak detection method used on Line 1 is referred to as ground microphoning, and consists of a trained technician placing a microphone directly on the ground, or onto the pipe when possible, to listen for leak noise. A very sensitive ground microphone was used to pick up audible vibrations created as water passes through fissures in the pipe wall. The sound emitted from a leak is dependent upon the size of the leak, the pressure in the pipeline, the pipe material and the depth of the backfill material. When possible, the microphone was either placed directly onto the pipe at air release valves and access ports, or connected to a metal rod which was inserted into the ground until contact with the pipe was made. This allowed the technician to listen to the pipe without the sound being dampened by backfill or interfered with by other ground noise. Knowing the pipe characteristics and listening to the pipeline at known leak locations enabled the technician to differentiate pipe leak noise from background noise.

The pipe alignment was located using as-built maps, field locates, ground reference points, and a GPS unit. Nearly all road crossings were previously marked with blue locate paint and stakes. Reference points were identified near these locates, such as tall trees or buildings, which could be seen from a long distance and used for a bearing. In a few areas, the buried pipe alignment was visible due to a change in topography over the pipe or a change in the groundcover condition over the pipe. Bends in the pipeline posed a challenge and were located using a GPS unit which was preprogrammed with the latitude and longitude of the bend locations. The alignment was periodically “dowsed” by the technician to verify the location of the pipeline. Using these techniques, a reasonably accurate alignment was marked with flags to guide the technician.

At several locations along the pipeline alignment, water was observed flowing out of the ground. This water was determined to be chlorinated, and therefore likely originating from a leak in Line 1, by using an insitu DPD (n,n-diethyl-p-phenylene diamine) colorimetric method (DPD test), which tests for free chlorine present in a water sample. Free chlorine reagent powder was added to approximately 10mL of sampled water, causing the water to turn pink when free chlorine was present. This test was used to determine the presence of chlorine but not the concentration.

The leak detection work confirmed the majority of leaks are concentrated at roadway and railroad crossings, as initially suspected. Some leaks were found in the middle of agricultural fields, which are assumed to be caused by the perennial use of heavy farming machinery over time.

Pipeline Condition Assessment Summary

The Line 1 data gathered using the methods described above was compiled and overlaid on a map in order to produce a summary and look for patterns in the pipe condition.

Concrete Pipe Condition

Though the concrete pipe appeared overall to be structurally in good condition, the pipe joints, in most cases, were observed from the pipe interior to be in poor condition. Joints had cracked and failing grout, and in some cases, water was observed infiltrating into the drained pipe during video inspection. A review of all pipeline information collected to date showed a strong correlation between leaking concrete pipe joints and roadway and railroad crossings. Grout failure in the concrete pipe joints at these locations is likely caused by minor ground settlement over time and larger live and impact loads.

Steel Pipe Condition

The steel pipe exterior appeared to be in good condition. The pipeline exterior coal tar coating system overall appeared to be intact, with a few exceptions of minor damage caused by tree roots, irrigation piping, or previous excavation damage. The video inspection showed the steel pipe interior surface to have moderate to extensive corrosion occurring due to partial or, in some cases, complete lining failure.

The pipeline corrosion assessment carried out by CCCS concluded soil and environmental conditions exist which are detrimental to the service life of the steel portions of the Line 1 supply transmission main. In particular, there is concern the steel pipe adjacent to Geren Island is highly susceptible to further corrosion damage considering it has tree root intrusion into the pipe coating and crosses two water ways; the pipeline is exposed on the channel bottom at one crossing and tunnels beneath a creek at the second crossing. The westerly section of steel pipe is susceptible to corrosion due to exposure to modestly corrosive soil conditions.

Recommendations

Nearing 75 years of age, portions of the City of Salem's 36-inch diameter Line 1 appear to have reached their service life. Repairs and rehabilitation are needed in the near term to prevent further deterioration which could result in pipeline failure, increased loss of treated water, high pipeline replacement costs, and increased liability due to the risk of damage to property and life. Several options for pipe rehabilitation are presented below, and will be further assessed in the next phase of this project. Pipeline rehabilitation recommendations include the installation of an external corrosion protection system to preserve the steel pipe, and a combination of trenchless pipe rehabilitation systems and pipe replacement.

Cathodic Protection System

Protecting longer sections of the existing steel pipe from corrosion can best be achieved using an impressed current cathodic protection system, which involves installing a centralized rectifier and anode bed at each site. For such a system to work, the steel pipe section must be electrically continuous and isolated from the remainder of the pipeline. Short sections of steel pipe can be effectively protected by a passive anode cathodic protection system with buried anodes connected to the pipe via a test station. Sections of the steel pipeline determined to be discontinuous will require further assessment, such as longitudinal resistance testing, to locate electrical discontinuities in the pipe where joint bonding will be required to create continuity.

Pipe Rehabilitation/Replacement Methods

Both trenchless rehabilitation and pipeline replacement methods are being considered. Trenchless pipeline rehabilitation encompasses a variety of technologies and methods generally intended to extend the service life of an existing pipeline with less disruption than pipeline replacement construction. Trenchless pipeline rehabilitation technologies can be divided into two categories: structural and nonstructural linings.

Structural Lining

Structural lining rehabilitation methods generally involve inserting a reinforced, watertight liner in close contact with the inner surface of the existing pipe. The watertight liner is designed to withstand internal and external pressure loads independent of the host pipe. The most common structural rehabilitation methods are sliplining, cured in place pipe (CIPP), and fiber reinforced polymer (FRP) liners.

Nonstructural Lining

Nonstructural lining utilizes a coating or liner of corrosion resistant material on the inner surface of an existing pipeline. The liner prevents internal surface corrosion, seals small holes and joint cracks, and extends the pipeline's service life. The new lining material relies on the structural integrity of the existing pipe; therefore, the existing pipe must be in good structural condition for this approach. Cement mortar lining, epoxy lining, and CIPP are commonly used nonstructural lining methods.

Pipe Replacement

Although more disruptive than a trenchless rehabilitation solution, some areas may benefit from traditional pipe replacement. It may be beneficial to reroute Line 1 through the City of Stayton, locating it within the public right-of-way. Pipe replacement through long stretches of agricultural land may potentially be less costly than a trenchless rehabilitation option. Further analysis is intended to answer these questions.

Pipeline Rehabilitation Prioritization

Repairing and rehabilitating all 7.5 miles of the 36-inch Line 1 supply main may be cost prohibitive to the City if done during a single fiscal year, therefore a phased approach is recommended so available funds are invested in the portions of pipe with the highest risk of failure. This analysis did not include a formal risk assessment, but does take into account the following five criteria used to determine high risk areas and prioritize the pipe rehabilitation work.

***Risk to Life* -** Preventing injury and fatalities is the main concern when prioritizing pipe rehabilitation projects. Those sections of pipe which pose the greatest risk to human life should a failure occur are rated as the highest priority for rehabilitation.

Risk to Property – The risk to property, assigned the second highest weight rating, accounts for the threat to structures and infrastructure should the pipeline fail. This criterion considers the high cost, both financial and intrinsic, of infrastructure loss and replacement.

High Leakage Rate – Water loss along the pipeline is not only a financial loss to the City, but an indication of pipe failure, therefore leaking pipe segments are considered a higher priority for rehabilitation.

Impact to the Public – This criterion accounts for all other impacts to the public should the pipeline fail, such as traffic delays, utility disruptions, localized flooding, economic disruption, etc.

Good Accessibility – This criterion focuses on the site accessibility as it relates to the pipeline rehabilitation work. Sites which are easily accessible are considered to be of higher priority for rehabilitation work than sites difficult to access.

Based on these criteria, a preliminary list of prioritized pipeline rehabilitation work is listed in Table 1.

Table 1
Prioritized List of Pipeline Rehabilitation Work

Order of Priority	Proposed Work Components
1	Concrete pipe lining under buildings and homes
2	Concrete pipe lining under roadways and adjacent to railway
3	Remaining concrete pipe lining
4	Steel pipe section under railway – Interior lining and exterior cathodic system
5	Exposed steel pipe under waterways – Interior lining and exterior cathodic protection
6	Steel pipe interior lining
7	Steel pipe with coating damage in Pioneer park- Exterior cathodic protection
8	Steel pipe near dairy farm – Exterior cathodic protection
9	Above ground and remaining steel piping – Exterior corrosion and cathodic protection

Conclusion

The various techniques employed on the City of Salem's 36-inch diameter Line 1 supply main provided a very effective and efficient evaluation of the unique pipeline materials along this challenging alignment. This assessment of Line 1 has provided the City with a thorough understanding of their supply main's condition, materials and "as-built" components, including the access port locations needed for future assessments and repairs. In order for the City to best manage risk, invest limited financial resources, and sustain useful function of Line 1, rehabilitation priorities have been established. Recommended additional assessment work on Line 1 includes further analysis of the steel pipe for cathodic protection and examination of trenchless pipe rehabilitation options applicable to large diameter, pressurized, potable water transmission mains in order to ensure this important infrastructure asset remains in service for decades to come.