Inspecting the Uninspectable: a 40-year-old force main beneath a drinking water reservoir. Failure is not an option.

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ABSTRACT

Failure of the City of San Diego's Pump Station No. 77 force main beneath Lake Hodges is not an option – yet the condition of this portion of the 40-year-old pipeline was unknown. The City did not believe it could be inspected. This paper describes the deployment of a cutting edge in-line pipeline inspection technology and the methodology used to determine if maintenance, repair, or replacement of the force main is required.

KEYWORDS: Force main, inspection, non-destructive testing (NDT), remote field technologies (RFT), condition assessment, pipeline cleaning, progressive pigging.

INTRODUCTION

The City of San Diego, CA owns and operates the Pump Station No. 77 (PS77) force main which conveys untreated sewage more than 5 miles through a protected environmentally sensitive habitat and beneath Lake Hodges, a regional drinking water supply reservoir. Installation of the force main, constructed of ductile iron pipe, was completed in 1976.

The force main crosses underneath the lake in twin 2,000-foot long, 16-inch diameter pipelines, designated Lines A and B. In their 40-plus-year operating history, there is no record of the pipelines having been cleaned or inspected.

While the City has performed condition assessment on the land-based portions of the force main at select locations, the subaqueous portion had never been inspected – the condition of Lines A and B was unknown. And the City's understanding was they could not be inspected.

Objective

Failure of the force main, specifically the sub-aqueous portion, is not an option. The negative social and environmental consequences of a failure contaminating a regional water supply that serves 3.3M people and is a protected habitat for federally endangered species are immeasurable. Conversely, the City could face significant negative economic and social consequences due to a costly capital project replacing portions of the force main that was later found to be unnecessary because the pipelines were in good condition.

The City was faced with a challenge that many utility owners are: a gap in the known condition of a high-risk asset. Applying sound asset management principles, the City authorized the Cleaning and Inspection of the Sub-Aqueous Portion of the PS77 Force Main project. The objective was to inspect Lines A and B, assess their condition and identify near-term potential critical failures as well as other repair, rehabilitation, replacement, or operations and maintenance needs of the pipelines.

Background

The PS77 conveyance system includes two pump stations, PS Nos. 77A and 77B. PS No. 77A, the primary duty pump station, is located southeast of Lake Hodges in the community of Rancho Bernardo. It pumps an estimated average of 5.3 million gallons per day dry-weather flow. The PS77 force main is constructed of 20-inch-diameter pipe for the land-based portions of the force main and 16-inch-diameter pipe for Lines A and B.

PS No. 77B, a booster pump station which operates intermittently, is located alongside the northwest shore of Lake Hodges along the force main alignment. The force main alignment climbs 370 vertical feet from its beginning at PS No. 77A to the force main terminus where it discharges to gravity flow. The pipeline operating pressure exceeds 185 pounds per square inch (psi) at the low point, located beneath Lake Hodges.

Figure 1 provides an aerial depiction of the locations of pump stations, Lake Hodges, the southern portion of the force main alignment, the subaqueous portion of the force main, and the project site.

South of the lake crossing, the 20-inch diameter pipeline bifurcates at a concrete vault into Lines A and B. The parallel pipelines cross underneath the lake bed and combine at a concrete vault back into a single 20-inch diameter pipeline. The vaults, known as the South and North Vaults, have valves that allow Lines A and B to be flow isolated. Figure 2 depicts a close-up view of Lines A and B, the South Vault, the North Vault, and the project site.

Figure 1. Aerial view of the southern portion of the PS77 conveyance system (Source: Google Earth)

Figure 2. A close-up aerial view of the South and North Vaults and the dual 16-inch pipelines underneath Lake Hodges (Source: Google Earth)

METHODOLOGY

The methodology to employed in this project included:

- Inspection planning and engineering
- Fieldwork
- Reporting and recommendations

Inspection Planning and Engineering

In the inspection planning and engineering phase, Brown and Caldwell (BC) developed an innovative approach centered around the use of a cutting-edge pipeline inspection technology. BC selected a fully-articulating in-line inspection (ILI) tool equipped with electromagnetics because of its capability to measure pipe wall thickness for the entire length of the pipelines' 360-degree circumference. The tool, named the See Snake, uses remote field technology (RFT), a unique type of electromagnetics, to inspect ferrous pipes for corrosion pits, graphitization, eroded areas, and holes. The RFT technology additionally allows for the tool to be sized at a lesser diameter than the interior diameter of the pipe. This is an important feature of RFT and was critical for this inspection to help minimize risk and ensure that the tool would not become temporarily lodged within the pipe as it traveled within the pipe beneath Lake Hodges. Its novel mechanical design allows it to accommodate interior diameter variations and traverse multiple, 90-degree bends.

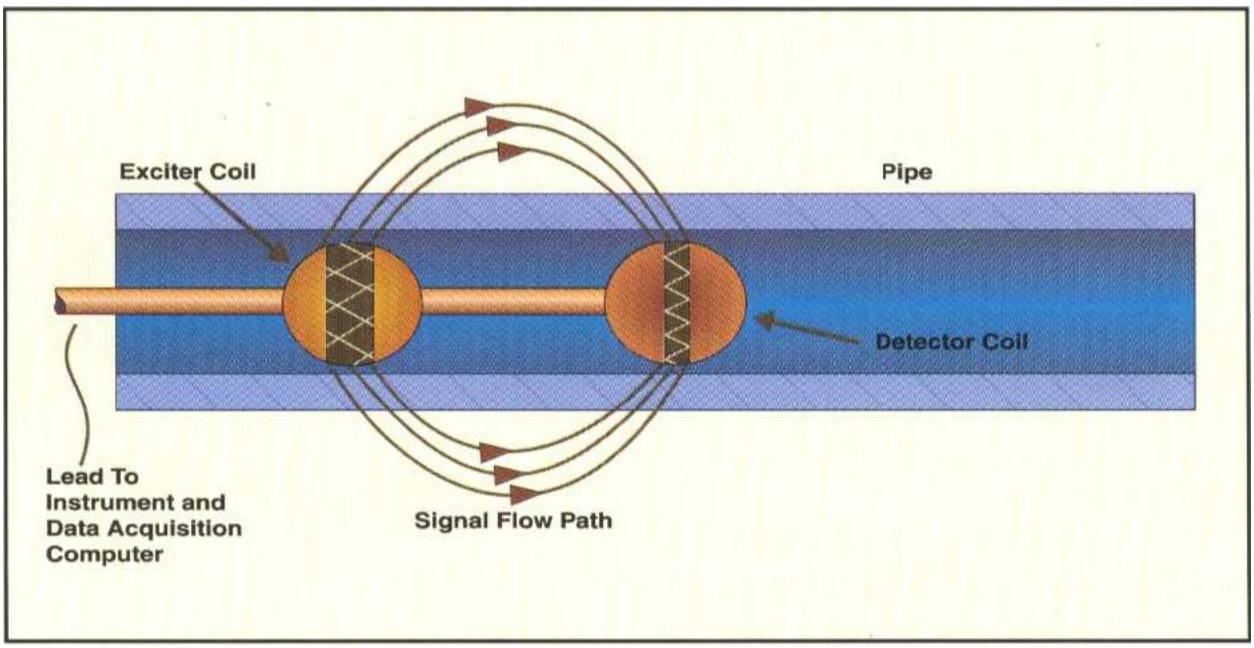


Figure 3. PICA's in-line inspection tool, the See Snake, utilizes Remote Field Technology (RFT) to collect high resolution data and measure pipe wall thickness. (Source: PICA)

BC collaborated with the City's Engineering, Operations, and Corrosion personnel as well as the Pipeline Inspection and Condition Analysis Corporation (PICA), the See Snake technology developer and operator, to craft a carefully orchestrated and detailed field work plan to deploy the See Snake in a 100% free-swimming, non-tethered mode.

BC and PICA have teamed and executed numerous projects inspecting thousands of linear feet of pipelines for public utilities and private companies across the United States. PICA has executed numerous pipeline inspections worldwide. The inspection of Lines A and B would be a first for this type of free-swimming deployment for the inspection of a sewer force main beneath a body of water.

Following selection of the pipeline inspection technology, BC performed the engineering design of needed modifications to the South and North Vaults and developed and submitted the "*Field Work Inspection Plan for Force Main Inspection and Condition Assessment*". The Field Work Inspection Plan was a comprehensive plan detailing the piping and vault modifications to be constructed and the pipeline cleaning and inspection activities, methods, and procedures to be implemented.

Fieldwork

After City approval of the Field Work Inspection Plan, BC solicited proposals and cost quotations from several subcontractors. BC then contracted, coordinated, and directed all the work activities of several specialty service providers.

The following companies were selected to assist BC in conducting the proposed scope of work:

- Arrieta Construction Inc. (El Cajon, CA) – General Contractor selected to perform site preparation, thrust restraint installation, piping modifications, construction of pig launching and receiving facilities, and inspection support services.
- Doyle Precision Services (Gardena, CA) – Selected as the specialty contractor to perform pipeline progressive pigging cleaning.
- PICA (Edmonton, Alberta, Canada) – Selected as the pipeline inspection technology services contractor and provider of the See Snake in-line inspection tool.

Prior to mobilizing onsite, the BC team held numerous meetings with the City to discuss each step of the fieldwork plan, identify safety concerns, develop risk mitigation strategies, delineate roles and responsibilities, and establish communication protocols.

Field work activities included:

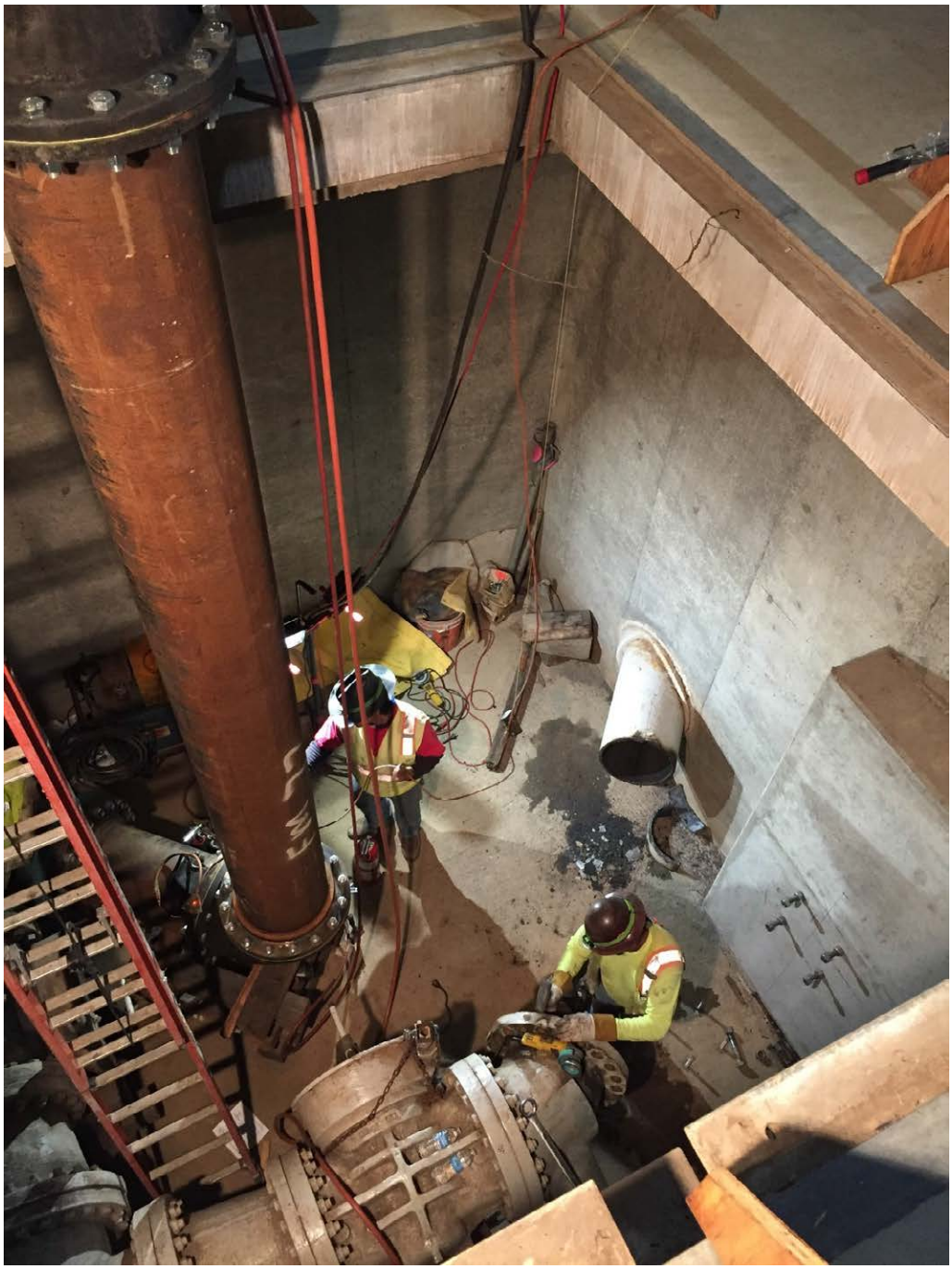
1. Site reconnaissance, field measurements, materials procurement, and delineation of environmentally allowable work areas and dates
2. Mobilization, site preparation, and pre-cleaning and inspection construction
3. Piping modifications within the North and South Vaults (Line A)
4. Pipeline cleaning by the progressive pigging method (Line A)
5. Dimensional line proving using a caliper gauge tool (Line A)
6. Pipeline inspection (Line A)
7. Repeat steps 3-6 for Line B
8. Removal of temporary piping used to launch and receive the cleaning pigs and ILI tools; site cleanup and demobilization.

The team worked together to overcome a multitude of challenges. The fieldwork window was limited due to the environmentally sensitive habitat housing the federally protected California Gnatcatcher. City biologists designated restricted areas for construction work, material staging and vehicle parking. The unpaved access roads to the South and North Vaults were significant challenges. Vehicular travel time between the vaults was more than one hour. The roads, part of the San Dieguito River Park, are popular hiking and biking trails regularly used by the public. To minimize public and social impact, the project team coordinated with park rangers and communicated the project's overall positive benefit to the public.

Six weeks of construction activities were required to modify the piping inside the vaults, install new, permanent epoxy coated steel wyes to create interior pipeline access points on Lines A and B at the South and North Vaults for this project and future cleaning and inspection projects, construct the pig launching and receiving facilities, and prepare the sites for the pipeline cleaning and inspection operations. Due to the high pipeline operating pressures, the launching and receiving facilities were designed to withstand forces in excess of 30,000 pounds.

Photographs 1 through 4 depict key steps in this phase of the field activities.

Photograph 1. Project team including Arrieta Construction and City of San Diego mobilized at the South Vault.



Photograph 2. Portions of the existing PS77 Force Main piping inside the vaults were removed and replaced with wye fittings to create permanent interior pipeline access locations.

Photograph 3. Permanent concrete thrust blocks and pipe anchorages and supports were installed in addition to temporary piping, fittings, valves, and hoses in preparation for cleaning and inspection activities.

Photograph 4. View of the launching facilities, jockey pump, and spill containment measures located at the South Vault facing north with Lake Hodges and the North Vault in the distant background.

Because the ILI tool would be launched in non-tethered, free-swimming mode, cleaning by the progressive pigging method was performed to clean the pipes and remove potential obstacles such as settled or attached debris. The progressive pigging started by launching low-density, sacrificial cleaning swabs at the South Vault, propelling the pigs forward using the PS77 pumps at flow ranging from 1,700 to 2,000 gallons per minute (gpm), and receiving them at the North Vault. In subsequent, progressive runs, higher density pigs were deployed. Photographs 5 and 6 depict the various types of cleaning pigs procured for this project and preparations for a pig launch operation. After each run, which ranged in duration from 8 and 25 minutes, the pigs were visually examined. This procedure was repeated until a pig sized near the pipe internal diameter was run through the pipe without issue.

Photograph 5. Various types of cleaning pigs procured for the progressive pigging operations

Photograph 6. Preparing for the launch of a cleaning pig at the South Vault

Once pigging was completed, a line proving device (i.e. a caliper gauge tool) was deployed for a final check of interior pipe geometry and cleanliness. The caliper gauge tool is depicted in Photograph 7. Deployment of the caliper gauge tool in advance of the See Snake deployment was one of many risk mitigation strategies utilized by the team.

Photograph 7. The caliper gauge tool was deployed in advance of the See Snake

Following successful deployment and retrieval, inspection, the caliper gauge tool was inspected. Once the condition of the tool was determined to be in satisfactory condition, the pipeline was deemed ready for inspection. The See Snake, staged at the project site and prepared for deployment, is shown in Photograph 8.

Photograph 8. The See Snake's fully-articulating design allows it to traverse multiple, 90-degree bends in a free-swimming, non-tethered mode.

The See Snake collects high resolution data. Therefore, it must travel at a maximum inspection speed of 15 feet-per-minute (corresponding to approximately 156 gpm in a 16-inch-diameter pipe). Because the PS No. 77A pumps were incapable of turning down this low without potential damage, a "jockey pump" was procured and installed at the South Vault.

The inspections were performed at night during the hours between 10 p.m. and 6 a.m. because the City has a limited window available for the shutdown of PS No. 77A. Photographs 8 and 9 depict the insertion of the 14-foot-long, 800-pound ILI tool into the launching facilities. Once inserted into the line, the See Snake was propelled forward by the jockey pumped flows in the closed loop system between Lines A and B. The See Snake runs were each approximately 4 hours in duration.

Photograph 9. The 14-foot long, 800-pound See Snake and tow-pig assembly were inserted into the launch facilities at the South Vault with the assistance of a truck-mounted crane.

Photograph 10. Once inserted into the pipeline, the See Snake traveled at a maximum speed of 15 feet-per-minute

Following each run of the See Snake, PICA downloaded the inspection data and performed quality-assurance checks to confirm the data collected was complete and useable. Once the data passed PICA's on-site quality assurance check, the inspection was deemed complete. PICA then begun the lengthy analysis of the data and condition reporting.

RESULTS

Pipeline Inspection Data

PICA reported the results including the pipe wall thickness measurements based on the RFT data analysis and a description of the pipe features identified. Table 1 summarizes the field data collected.

Table 1. Summary of Collected Field Data						
Site	Pipe Diameter (in)	Pipe Material	Line	As-Built Length (ft)	Actual Collected Inspection Footage (ft)	Individual Pipe Sticks
PS No. 77 Force Main	16	DIP	A	1,987	1,974	115
	16	DIP	B	2,042	2,019	117

The remaining wall (RW) thickness was determined for each individual pipe stick of Lines A and B. The inspection data yielded no indications of through-holes (zero RW thickness) in either pipeline.

However, the analysis indicated a total of 25 pipe sticks on Line A (22 percent of the total sticks in Line A) and 16 pipe sticks on Line B (14 percent of the total sticks in Line B) with signs of wall loss areas.

2 sticks on Line A and 2 sticks on Line B have locations where less than 50 percent of the original pipe wall thickness is remaining. All four of these pipe sticks are located on the portions of Lines A and B that are buried beneath the Lake Hodges lakebed.

The minimum measured wall remaining on Line A was 31 percent RW (0.16 inch) and Line B was 27 percent RW (0.14 inch).

Comparatively, per the As-Built drawings provided by the City, Lines A and B pipes were constructed of Class 6 thickness, 16-inch-diameter ductile iron pipe. Based on standards at the time of installation, the pipe had a wall thickness of 0.52 inch. This assumed original wall thickness was confirmed by thickness measurements obtained from cut sections of existing pipe in the field.

In addition to wall thickness measurements, the inspection data confirmed the presence of various expected and unexpected pipeline features such as taps, blow-off assemblies, and deflections.

Figure 4 is a sampling of one graphical depiction of the results of PICA's analysis of the pipeline inspection data for Line A. Each data point represents a location where a pipe wall measurement of less than 100% RW was obtained. Multiple wall-loss areas on a single pipe stick are depicted in Figure 4 as Tmin1, Tmin2, Tmin3.

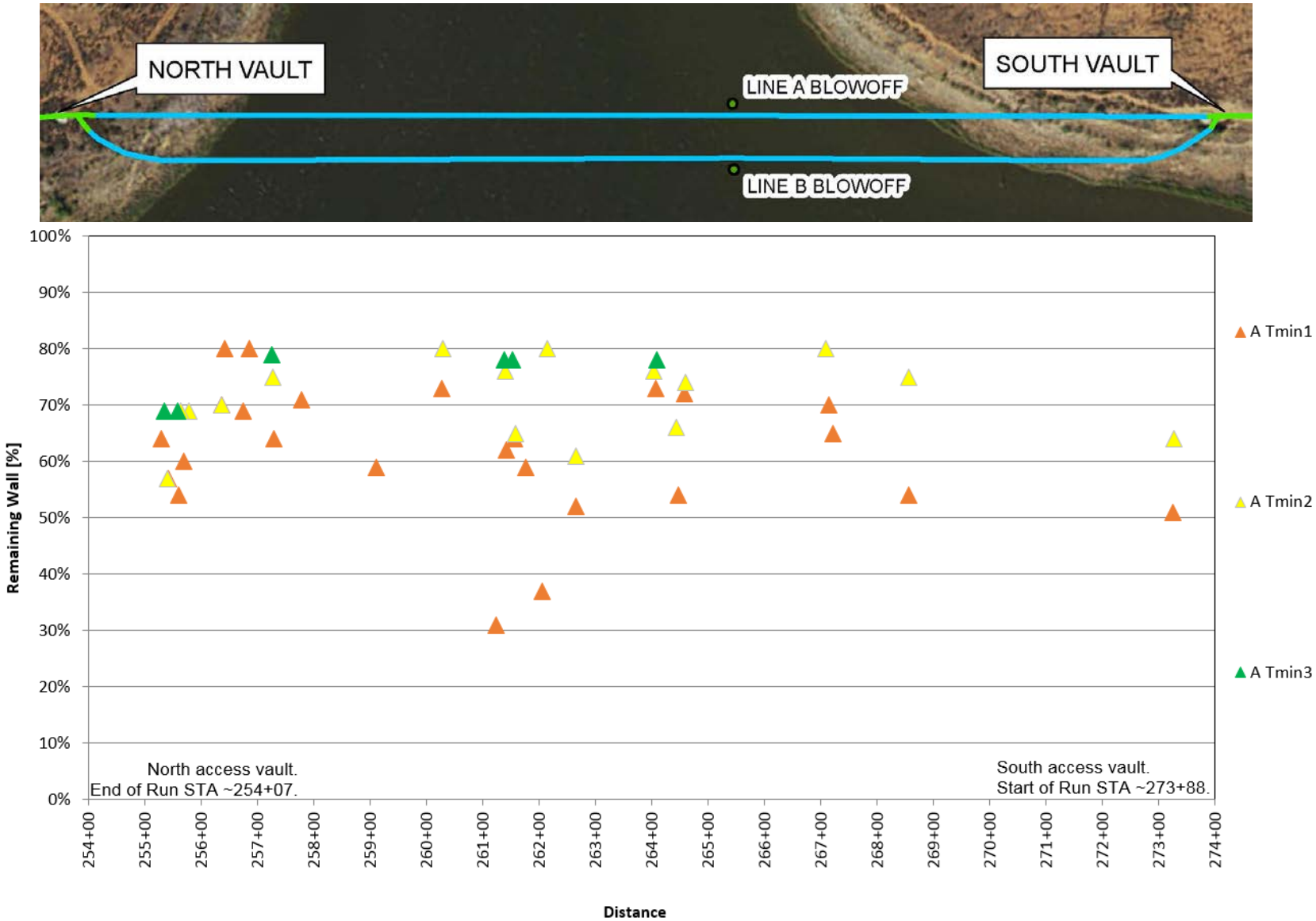


Figure 4. Distribution of wall loss indications along Line A. Two locations were measured with of less than 50% of the original pipe wall thickness remaining.

Condition Assessment

To assess the current condition of the pipelines, BC performed Factor of Safety calculations using the wall thickness measurements obtained by the See Snake inspection. The Factors of Safety are calculated for the minimum remaining pipe wall thickness in each pipe stick and are based on the pipe wall's capacity to resist forces due to internal pressure and external loading. Recommendations actions such as spot-repair, rehabilitate, replace, or re-inspect in 5-10 years are made for each pipe stick based on the calculated Factor of Safety values.

The majority of the pipe sticks on both Lines A and B have a minimum Factor of Safety of greater than 2.0. However, two pipe sticks, one on Line A and one on Line B, have calculated Factors of Safety between 1.5 and 2.0 for the external loading condition. In each case, even with less than a third of the original pipe wall remaining, the calculated Factor of Safety for the internal pressure condition was greater than 2.0.

Additional Observations

The pre-cleaning and inspection construction activities for this project required several temporary shutdowns and restarts of PS No. 77A to allow for the installation of the fittings at the South and North Vaults. During one shutdown/restart sequence, a surge event was observed by the project team at the South Vault.

Subsequently, while removing the bolts on a ductile iron spool piece on the piping inside of the South Vault, the flange fell apart. Multiple full-penetration cracks were observed, as depicted in Photograph 11. The corrosion of the cracked materials confirmed that the cracks were not recent and occurred prior to the execution of this project.

Photograph 11. Cracked flange discovered with rust observed throughout the thickness of the flange.

In follow on conversations with the City, it was noted that previous repairs to a different cracked and leaking flange in the South Vault had been completed within the past 10 years.

CONCLUSION

Recommendations

Excavations to validate and confirm the findings of ILI tools were recommended, where feasible. Validation excavation locations are selected and performed at specific location/s along the inspected pipeline's alignment. The pipeline is exposed and direct assessment techniques are performed to measure pipe wall thickness and compared to the data obtained by the ILI tool at that same location. Given the alignment of the inspected portion of the PS77 force main in relation to the protected environment and proximity to Lake Hodges, BC selected and recommended a potentially feasible location for the City to perform a validation excavation.

Because multiple locations were found to exist where the calculated Factor of Safety was less than 2.0, it was recommended that Lines A and B be re-inspected within a period of 7 years via the same pipeline inspection methods and utilizing the permanent access locations installed during this project. The pipeline inspection data should be compared to the data obtained during this project to assess changes in the pipe wall thickness. Based on the results of the re-inspection, the inspection interval (duration between inspections) and/or the replacement planning horizon should be assessed.

Because of the observed evidence of transient surge events and the risk they pose to the PS77 conveyance system, it was recommended the suspected cause(s) be located and remedied. And pressure transient surge monitoring be performed and the PS77 conveyance system be tested to confirm the remedy was effective.