THE USE OF BROADBAND ELECTROMAGNETIC TECHNOLOGY FOR INTEGRITY INSPECTION OF A 760 mm (30-inch) CAST IRON AND STEEL LINE

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1. INTRODUCTION
   The ability to inspect Cast Iron mains using internal non-destructive methods has been a weak point in prolonging the use of the pipe when used in key locations and larger diameters. Current methods of inspecting ferrous materials do not produce satisfactory results with cast iron. The potential exists for a method of inspecting existing pipe assets and extending the life of the piping system by confirming the remaining wall thickness and condition.

   Public Service Electric and Gas (PSE&G), contracted with Jason Consultants International, Inc (Jason), for the inspection and assessment of two 760mm (30-inch) cast iron and steel lines, both approximately 146.3 m (480ft) long, under the Passaic River in Harrison, New Jersey, USA. These mains are a critical part of the gas delivery system, and PSE&G wished to have a clear assessment of their condition, pending any waterfront renewal or development adjacent to the location of the mains.

   Jason retained the services of Rock Solid Pty. Ltd, an Australian company who have extensive experience with non destructive assessment of cast iron piping. Rock Solid had developed an approach using Broadband Electromagnetic (BEM) technology to develop an inspection system that can inspect all types of ferrous pipes. It does not need contact with the metal, and can be used where the pipe has been lined. In cast iron inspection it will detect wall loss, graphitization and cracks.

   This paper will present the results of the project and the lessons learned.

2. BROADBAND ELECTROMAGNETIC TECHNOLOGY
   Broadband Electromagnetics (BEM) methodology is related to geophysical equipment which has been used in the Australian exploration industry for many years. It is currently being utilized in the mineral exploration industry in the search for massive sulfide ore deposits. Rock Solid’s background knowledge of this technology and experience in its use in the exploration industry has allowed us to modify it for NDT inspections, suitable for acquiring detailed information about the current condition of surface or sub-surface ferrous infrastructure.

   The technique works by inducing eddy currents to flow in close proximity to the transmitter (Figure 1). In a ferrous pipe these eddy currents migrate with time allowing a complete profile of the ferrous pipe to be obtained.

   BEM data recorded can reveal the location of perturbations in the thickness of the ferrous pipe and with appropriate configurations indications of fracturing can also be detected (Figure 1c).
**Figure 1 (a)** Schematic diagram of a primary field distribution originating from an axial sensor configuration.

(b) Plan view of an induced eddy current from a flat plate with no defects.

(c) The introduction of a fracture into the plate disrupts the regular eddy current pattern displayed in Figure 1b. In contrast, a region of thinning does not create a complex pattern although a significant reduction in signal amplitude is observed.

BEM data is recorded at distinct frequency increments with the duration and number of increments being dependent upon the material conditions as well as the nature of the target. These parameters can easily be set with the aid of a pre-survey calibration of the ferrous material or less accurately with the aid of 'as built' documentation.

In cast iron, BEM can identify and locate metal loss that produces wall thinning or graphitization, and also locate cracks. BEM does not require contact with bare metal, and in water pipes can read pipe condition through a cement lining.

3. **HISTORY OF THE PSE&G CAST IRON MAINS**

The 760mm (30-inch) cast iron mains were installed in a lined tunnel under the river in 1914. Piping wall thickness (taken from contemporary reference sources) is 21.6mm (0.85inches). The horizontal sections are 12 lengths, joined with a flange. A lead gasket was installed to complete the seal. The vertical sections have both flanged and conventional caulked bell and spigot joints. The length of the horizontal sections is approximately 118.87 metres (390 feet), and they are approximately 15.24 metres (50 feet) below ground level. Total length of each line surveyed was approximately 140.2 metres (460 feet).

The lines run in a north-south direction, with an elbow on each of the north ends and a tee on the south ends. (See illustration in Appendix A). On the tees, the stub leg serves as a drip (syphon) to collect liquids that are pumped out on a set schedule.

In the 1970’s the tunnel containing the pipes was breached, and a diver confirmed that water had infiltrated the space around the pipes. The Passaic River is tidal, so water infiltrating the tunnel would have been brackish.
In 1995, work was undertaken to initially line the pipes, and subsequently to seal each of the interior pipe joints using Weko seals. At that time other work was undertaken: First, the annular space around the pipes was grouted using conventional pipe grout. This was performed without pumping out the water present in the tunnel. Secondly, the top 4.6 metres (15 feet) of the vertical sections of cast iron on each vertical section was replaced with 760mm (30-inch) steel piping.

4. APPROACH

4.1. Site Preparation
Prior to the pipe investigation, the lines across the river were isolated and purged using nitrogen. Before any other work proceeded, the de-pressured piping was allowed to stabilize, to determine if there was any on-going infiltration of water. The drips (syphons) were monitored over a period of several days to confirm lack of water. Salt water can affect the equipment readings (non-saline water does not), and this was the concern, to confirm that the tidal river water was not intruding.

Next the external piping was disassembled and fittings removed to gain access. Although it was not necessary for the technology to operate, PSE&G made the decision to clean the inside of the piping using hydro-cleaning. (high pressure water). The water was collected into a tank for analysis and disposal.

Before any other work took place, a visual inspection was performed by contractor personnel, who specialize in interior work.

4.2. Assessment
In order to assess the condition of the 760 mm (30 inch) pipes, Rock Solid built an array of 32 sensors, 304.8mm (12 inches) long (called a “droid”). This droid is shown below in Figure 2. The droid contained an on-board data transmission system and a cable communication system to allow data logging at a surface laptop computer. A pneumatic system expands the droid out to the inside surface of the pipe, readings are taken, and then the droid is advanced one foot to take the next set of readings.

For the elbows and tees, a single hand sensor, approximately 50mm (2 inches) square, was used to take readings in a 50mm (two-inch) grid marked on the inside of the fittings. (Figure 3). Data was transmitted from the sensor via a cable and signal transmission system to a surface laptop. (Figure 4)

For the cast iron mains, the east and west horizontal legs were investigated using the droid, in a total of 34 sections. Some of the sections were short lengths of pipe. The sections were read up to as close to the Weko seals as practical. Readings were taken from the north towards the south. See Figure 3 for a schematic of the survey of a pipe length.

Figure 2
5. DATA GATHERING

During the data gathering, any visual record of pipe anomalies can be referenced or compared to measured results.

Since there were no actual pipe samples to be used to calibrate the sensor readings, it was assumed that the “best” readings were full pipe thickness, and any subsequent readings were a percentage of that wall thickness. From Rock Solid’s perspective, the wall thickness is referred to as “apparent” wall thickness, since no physical calibration against a sample of pipe took place. It should be understood that we are referencing millimeter accuracy, and readings would only vary by a millimeter. If pipe samples are available, the equipment is calibrated against the sample.

In most circumstances small amounts of water, such as the build up at the Weko seals after the hydro cleaning, are not a problem, and the readings reflect this situation.

Salt water can affect readings, and thus there had been confirmation of lack of salt-water intrusion before starting.

In total, 67 cast iron pipe segments, 16 steel segments, 2 elbows and two tees were assessed.
6. TOPOGRAPHIC MAPS

Data gathered in the field is converted to a topographic map, using proprietary software. The illustration above shows a sample of a pipe section plot. The pipe is horizontal, with the 180° position running through the horizontal centerline, and the 0° at top and 360° position at the bottom. Colors are used to differentiate between differing thicknesses, so that a visual assessment can be made. An individual topographic map was provided for each individual pipe segment and fitting.

7. ANALYSIS OF RESULTS

7.1. Averaged Area of Readings
Each sensor averages over an area of approximately 50mm (2”) square. This means that any anomaly or flaw within or on the pipe wall must be viewed as a percentage of the overall volume of ferrous material scanned. It is therefore important to note that a surface scratch or an isolated small pit will not be seen as significant and may not have enough impact to affect a particular reading.
It is also not possible to assess whether a noted wall thinning is as a result of ferrous loss on the front or the back of the pipe wall or a combination of both. Similarly a cluster of pits will appear as a general wall thinning rather than a pit cluster.

7.2. Apparent Wall Thickness
It is not possible to tell whether the pipe wall is thinner or whether the metallurgy of the wall has been altered. Thinning may be the result of original casting or abrasion: Pipe alteration due to graphitization will also appear as thinning.
Either situation will display a lower reading value and effectively the pipe will have been altered structurally in each case. This is another reason why we refer to apparent wall thickness rather than true wall thickness.

8 FINDINGS

Initial observations of pipe condition documented anomalies at various points, which coincided with readings taken in the pipe.

Close appraisal of the results for the mild steel pipe sections shows that there are no appreciable variations in pipe condition and therefore no reason for concern with respect to the steel pipe condition is necessary.

For the cast iron:
- In general horizontal pipe showed a wall loss of 20%, which is well within limits for pipe of this age.
- Vertical sections had a slightly higher loss, but still within acceptable limits
- The elbows were in good condition, with maximum wall loss at 20%. Tees showed similar results.

9. CONCLUSIONS

The condition assessment survey program of steel and cast iron pipelines running below the Passaic River from Harrison to Newark in New Jersey was successfully implemented and completed for PSE&G between August 8 and 25, 2002.

The NDT investigation was undertaken primarily to evaluate the extent of corrosion of both the mild steel and cast iron section of pipeline using a BEM technique, which is designed to measure intensity variations of ferrous material providing a corresponding correlation with wall degradation.

On the basis of the BEM results obtained, the results indicate that the cast iron pipes tested are generally in reasonable condition, considering their age. However, some pipes have been identified as exhibiting higher levels of corrosion. These appear to be predominantly at about the center of the Passaic River crossing and also at the midsections of the vertical runs.

From the shape of the wall-loss patterns (base, crown and some sides), it is possible that much of the wall loss was initiated when the pipes were inside a leaking tunnel, that affected the top, then rolled to the base, of the pipe. The corrosion could have continued after grouting.

The operational criteria for PSE&G will determine the policy with regard to these pipelines but it is considered that the pipelines will be structurally sound for the near future.

In reviewing data and plots presented, PSE&G decided to use the information as a baseline and perform an additional integrity inspection in three years’ time.

It was concluded that the Broadband Electromagnetic Technology performed well in a situation that other technologies could have performed. The results obtained enabled PSE&G to make an informed assessment on the condition of an important cast iron feeder main, and make operating decisions based upon this.