Advanced Condition Assessment of Hunter Water's Cast Iron Watermains

Introduction

Buried assets that form trunk and reticulation water mains form the largest asset group of all major water utilities. As such, considerable resources go into the maintenance, assessment and subsequent predictions on the performance of these resources. Hunter Water Australia (HWA) has been conducting condition assessment work for Hunter Water Corporation (Hunter Water) for over a decade on the trunk water main network in the Hunter region of NSW. At selected sites, pipes are exhumed to determine condition using abrasive blasting. This work is typically carried out by HWA as part of broader assessments of the Hunter Water network, and serves as an independent arbitrator of the current condition assessment process, using the Linear Polarisation Resistance (LPR) technique. A doctoral research project currently being undertaken by the lead author is also using these sites to further interrogate the use of electrochemical testing in soils (LPR is one of many electrochemical measurement techniques), and the application of such a test to the long-term prediction of corrosion in the buried environment.

As part of Hunter Water's commitment to the Advanced Condition Assessment and Pipe Failure Prediction Project, and taking advantage of this scheduled condition assessment program, the University of Newcastle was invited to a number of recent exhumation sites to collect data for Activity 3 (Corrosion Modelling) of the Advanced Condition Assessment and Pipe Failure Prediction Project. At the current time, 11 sites have been assessed by The University of Newcastle in conjunction with HWA's condition assessment program. The project requires the accurate collection of data regarding corrosion losses of pipes that have been in service for some time, and the collection of the associated soil and environmental parameters at each site. The aim of the corrosion modelling section of the Advanced Condition Assessment and Pipe Failure Prediction Project is to use this data to develop and calibrate a model, which will enable more accurate modelling of corrosion losses in a buried environment.

This article will detail the procedures used for the collection of accurate corrosion data, in order to quantify in-situ corrosion losses of in-service ferrous pipes. Case studies are presented from three recent exhumation sites, and the preliminary results of initial data collection are briefly discussed. This data will contribute to both the electrochemical testing research and the corrosion modelling being developed as part of the Advanced Condition Assessment and Pipe Failure Prediction Project.

Risk Analysis on Abrasive Blasting

In-situ corrosion measurement using an invasive procedure, such as abrasive blasting of a live main, carries an inherent safety risk. Following discussions with Hunter Water, HWA conducted an extensive analysis of the risks associated with these works and developed a set of guidelines to be followed at each site prior to (and during) any works being carried out. These guidelines minimise safety risks, whilst also ensuring that accurate data is recorded. Principally this involved the following:

- Manual inspection of each pipe prior to any blasting, to ensure that a rough indication of corrosion losses is known prior to blasting.
- The pipe sections where works are to be carried out are isolated from the broader network to limit both pressure and to reduce risk. This approach is similar to that applied to other invasive repair work carried out on the network.
- During abrasive blasting, the depth of any observed corrosion is periodically measured before continuing, and serious corrosion loss is very carefully blasted.
- A repair clamp is kept on site in the unlikely event of a rupture.

Scope of Works

Where possible, the scope of work at each sample site was to exhume a whole pipe length and abrasive blast the length in-situ to measure and thereby quantify corrosion losses. Following abrasive blasting a selected portion of each pipe was scanned using a handheld Creaform Laser Scanner to accurately map (in 3D) the corrosion losses observed on each pipe. This 3D scan subsequently allows measurement of the pit depth and other corrosion parameters digitally. The software program supplied with the laser scanner has the facility to determine and map corrosion depths over the surface of the pipe. Corrosion depth versus axial and circumferential position can be exported into tables of nominated grid spacing (in this case 2 mm x 2 mm grid) suitable for analysis in programs such as Excel. From this tabulated data a number of parameters can be determined, such as maximum penetration (and its statistical variation), average corrosion loss, and volume of corrosion loss.

In addition to the digital assessments each pipe was inspected visually and the deepest pits were measured using a pit depth gauge. Due to the constraints of the laser scanner and workplace health and safety (WHS) issues at certain sites (for example, the water table preventing exhumation of the entire pipe) it was not always possible to obtain a laser scan of each pipe or indeed the whole pipe. In these cases, manual techniques, including use of a pit depth gauge, were used to supplement or replace the laser scanning results.

At each site, soil samples were collected and sent to an external laboratory for testing to characterise the soil environment surrounding the pipe. Samples were tested for both physical and chemical attributes such as moisture content, soil type, pH, nutrient content, permeability and chemical components such as chloride and sulphate. These soil properties have been previously identified as having an impact on the long-term corrosion rate of buried cast iron (Cole 2012).

To date, 11 sites have been sampled, using both manual corrosion measurement techniques and/or the 3D laser scanner in conjunction with The University of Newcastle. This complements roughly 23 samples already collected for the electrochemical testing research.

Preliminary Results

The results obtained to date for the three case studies are presented as both a 2D and 3D representation of the sampled pipe section. For two sites (WS4 and WS5) the laser scan could be carried out through a full 360 degrees around the pipe, whilst one site (MC4) was limited to all but the base of the pipe due to constraints caused by the local water table. The results of the laser scanning and preliminary analysis have been presented in terms of a maximum observed corrosion loss (as a pit depth), a map of all scanned corrosion losses, a brief discussion of the observed corrosion and a brief description of the local soil and environmental conditions.

Site 1 – WS4 – WS4 is a DN 375 cast iron (CI) pipe located adjacent to a stormwater channel in Broadmeadow, NSW (Figure 1). The soil at this site was classified as sandy clay with moisture content of 16.2%. While the water table was not noticeable on site, exhumation revealed that the pipe was propped up on stone and hardwood, indicating that the ground conditions at installation may have been significantly wetter than those observed in 2013. Also of note was the presence of coal and other assorted contaminants within the soil profile at this site. Sample WS4 was actually first identified as a DN 375 cement lined cast iron (CICL) pipe installed in 1972, however upon exhumation, the pipe was actually revealed to have been installed in 1884. The error was likely due to an error in the digitisation of the paper records. The results of the 3D laser scanning on WS4 (see Figures 2 and 3) highlight that for a pipe nearing 130 years of service, this asset is in excellent condition with a maximum pit depth of 7.5 mm (measured manually). The corrosion on this pipe was mostly observed at the 3 and 9 o'clock positions and was present as large areas of general corrosion, as opposed to highly localised attack.

It should be noted that a vertically cast iron pipe from 1884 is likely to have a highly varied wall thickness, partly due to the tolerances and type of casting. It is also worth noting that any pipe manufactured prior to 1929 would not have a factory cement lining. Early cast iron pipes operated by Hunter Water were likely to have been in-situ lined during the 1950's. The design thickness of these pipes was actually cast into the pipe (¾ cast onto socket) and in this case, each pipe is likely to be around 18 mm thick (although other sections of this pipe are known to be up to 23mm thick). Assuming a regular wall thickness, this represents a maximum corrosion penetration of around 42% of the original wall, and a linear corrosion loss of around 0.06 mm/yr. It would not be unreasonable to suggest a probable life in excess of 250 years based on this simple analysis for a pipe such as this in these soil conditions. This of course assumes that no internal corrosion has occurred, which is unlikely on a pipe that was not internally lined for around 65 years.

Site 2 - WS5 - WS5 is located in Waratah, NSW near the sites of the now disused Waratah reservoirs. The soil type at this site was classified as silty clay and the soil moisture content was measured as 16.4%. Also of note was the relatively homogenous nature of the soil at this site. The pipe at this site was listed as a DN 600 CI main installed around 1930. Upon exhumation, the manufacturer, date and thickness were found cast into the socket, which was a common practise at the time. In this case the details 'G & C H', 1926 and $^7/_8$(22 mm) were recorded, indicating

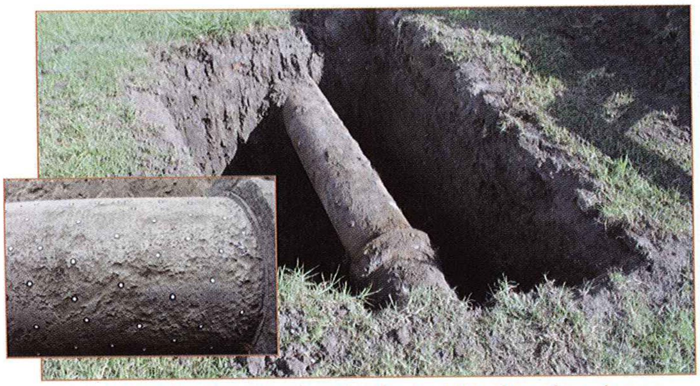


Figure 1: WS4 before abrasive blasting and the sites of maximum corrosion loss after abrasive blasting (inset).

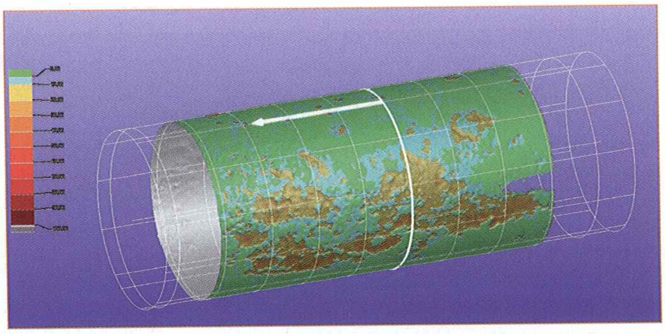


Figure 2: 3D scan results for pipe WS4; most corrosion at this site was located roughly at the springline (horizontal).

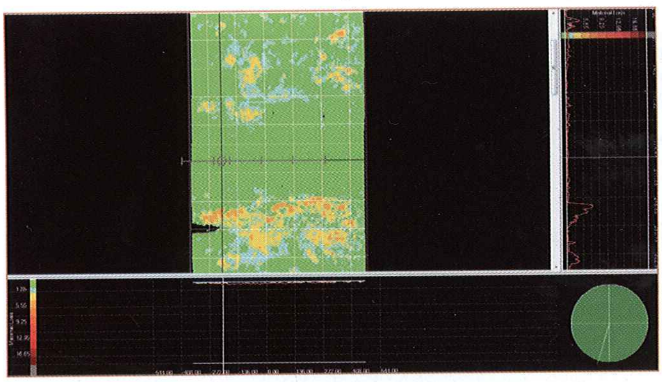


Figure 3 – 2D representation of the data presented in figure 2.

Figure 4: WS5 prior to abrasive blasting (inset – corrosion on bottom of pipe after abrasive blasting).

Figure 5: WS5 during the scanning process, this took approximately 1.5 hours on this 600mm pipe.

that the recorded install date is consistent with the pipe details. Figures 4 and 5 show this pipe before and after the abrasive blasting. The inset in Figure 4 shows a close-up photograph of the deepest region of corrosion, which was located on the underside of the pipe. This pipe was also found to be to be in good condition for its age. Corrosion losses at this site were largely non-existent. A single significant corrosion site, located directly on the underside of the pipe (see Figures 6 and 7 and the inset in Figure 4), was measured to have a pit depth of around 10mm (9.2mm manually and 10.5mm using the laser scanner software). This represents a corrosion loss of around 47% of the original wall thickness, although again it should be stressed that the wall thickness of a vertically cast iron pipe such as this can vary by a significant amount, both in the circumferential and axial directions.

Site 3 MC4 – sample MC4 is located in Mayfield, NSW (see Figure 8) and the site conditions were entirely different from those seen at sites 1 and 2. Located adjacent to a small natural creek the water table at this site was touching the bottom of this pipe. Natural variation in the water table would suggest that for at least small portions of the year, this pipe is partially submerged. The soil at this site was notable for its high moisture content (23.4%) and relatively high levels of organic carbon. The pipe at this site was a DN 300 CICL pipe installed in 1967. Of note at this site was the lack of a selected backfill; the use of selected backfill was adopted in the Hunter region in the early 1960's, and was used sporadically until the early 1980's, when its use became common practise with the introduction of Ductile Iron pipes. Large aggregate was present within the soil matrix and may be a remnant of the installation process.

Laser scanning of this site was conducted, however scanning was limited to the top 85% or so of the pipe because of the local water table (see Figures 8 and 9). At the base of the pipe, manual corrosion measurements were taken. The corrosion observed at this site is entirely different from that observed at sites 1 and 2. In this case, many small, well-formed circular pits were identified. The depth of these pits increased almost linearly, from around 3-4 mm near the top of the pipe to 6.5mm towards the bottom.

Electrochemical Testing Research

The electrochemical testing research aims to measure the corrosion rates of ferrous materials such as mild steel and cast and ductile irons over an extended period (up to 2 weeks) in soils collected at sites such as those presented in this paper. It is hoped that this longer-term electrochemical test may help to more accurately describe the observed corrosion rates and long-term corrosion mechanisms in underground environments. Each test is being conducted at the moisture content measured at the sample site. Whilst not presented here, early results (Dafter in Prep) indicate that corrosion rates observed in the cell closely mirror that observed over the longer term. It should be stressed that measurement of these field samples is but a small component of further interrogation of electrochemical testings of soils.

Corrosion Modelling Research

The long-term corrosion data collected at these sites will be related to shorter-term data from historical records (National Bureau of Standards Tests) under similar environmental conditions. This will be done to construct corrosion (maximum penetration and average corrosion) versus time plots under environmental conditions common for pipes assessed in this project. This information will then be used to calibrate a corrosion model, which is based on the processes that control the long-term development of corrosion of cast iron in a soil environment. More information on this work will be presented at the 2013 ACA conference (Petersen in Prep).

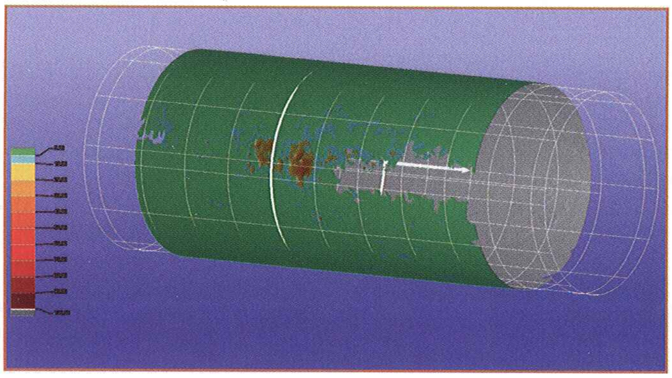


Figure 6: 3D scan of sample WS5, virtually no corrosion was observed except for the 2-3 localised sites of general attack.

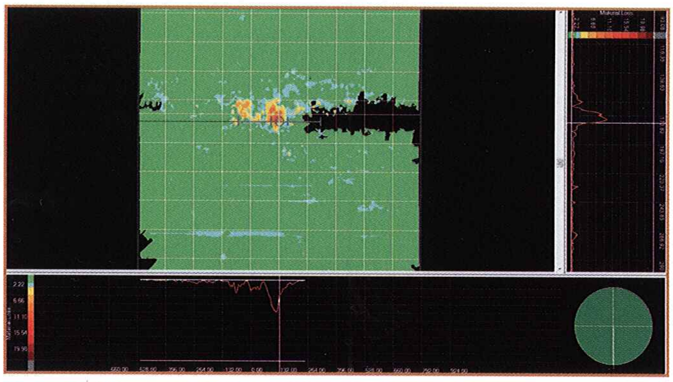


Figure 7: 2D representation of the pipe displayed in figure 6.

Figure 8: MC4 after abrasive blasting (inset – close up of deepest pit on underside of pipe).

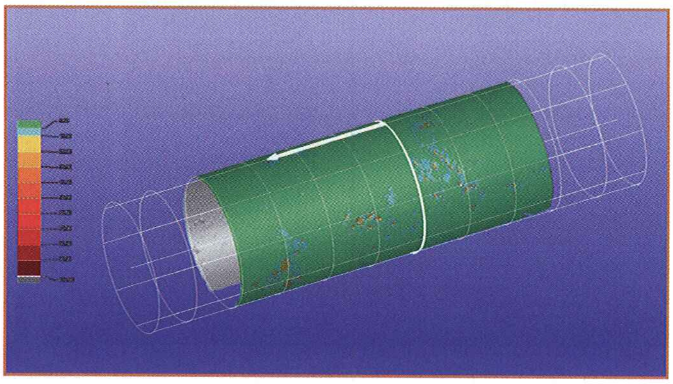


Figure 9:3D scan of pipe sample MC4.

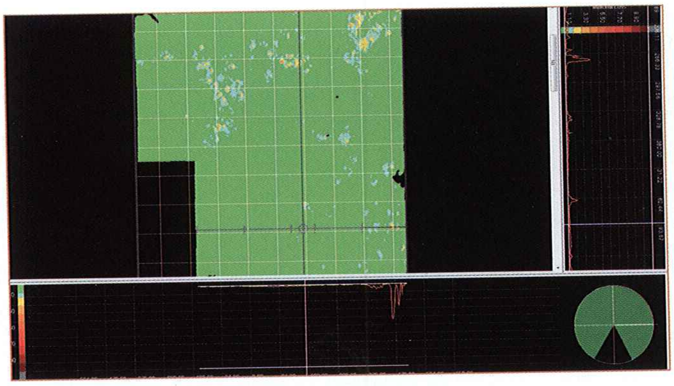
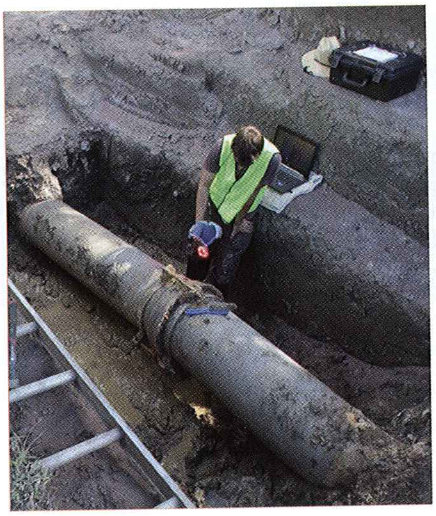


Figure 10: MC4 2D scan.

Prediction of failures on underground assets such as this failed DN 500 cast iron pipe are the significant driver of this research.

Mild steel and cast iron samples following exposure to the electrochemical test cell for corrosion rate measurements.



Laser Scanning in Progress.

Mechanical removal of graphitised zone in a corroded cast iron pipe.

Project Outcomes

The laser scanning results presented within this article have shown the technique to be a reliable way of obtaining accurate quantitative measurements of corrosion losses. Indeed, the technique has produced a considerable amount of data for use by the critical pipes team on the modelling component of this work. The results are considerably more comprehensive than those obtained using manual techniques alone. These preliminary results illustrate the complex and highly varied nature of underground corrosion processes, and highlight the challenges ahead for both research projects noted in this article.

For further information on the Advanced Condition Assessment and Pipe Failure Prediction Project please see www.criticalpipes.com

Acknowledgements

The authors would like to thank the staff of both Hunter Water and HWA for their assistance during the planning and subsequent fieldwork components of this project. In addition, the patience of both the civil contractor (Offaly Constructions) and abrasive blasters (KGB) was appreciated during some of the more delicate and time consuming phases of this work. The authors would offer a special thanks to Sydney Water for the loan of the laser scanner used during the collection of this data.

This publication is an outcome from the Advanced Condition Assessment and Pipe Failure Prediction Project funded by Sydney Water Corporation, Water Research Foundation of the USA, Melbourne Water, Water Corporation (WA), UK Water Industry Research Ltd, South Australia Water Corporation, South East Water, Hunter Water Corporation, City West Water, Monash University, University of Technology Sydney and University of Newcastle. The research partners are Monash University (lead), University of Technology Sydney and University of Newcastle.

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