Factors Influencing Pipe Failures in the WA Environment

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Abstract

This document summarises an investigation conducted into the deterioration and failure of the Water Corporation's pipeline assets in the Perth metropolitan region, focusing on Reinforced Concrete and Cast Iron pipes. Pipeline failure is a common occurrence, generally resulting in damage to surrounding land and infrastructure, and loss of water and water supply to housing. The main objective of this project is to improve the knowledge base of the Asset Management Group by implementing a sample collection and analysis procedure, and analysing relationships between pipe failure rates and the Western Australian environment. Cast Iron pipes were observed to regularly fail as a result of external corrosion and failure rates show a strong correlation to the Ferrous Corrosivity Scale. Reinforced Concrete pipes were most commonly observed to fail as a result of joint failures. Failure rates of both pipe materials were found to peak in mid winter, which is attributed to an increase in soil moisture content causing soil expansion.

1. Introduction

The Asset Management Group at the Water Corporation (WC) continuously attempts to improve reliability of the WC's assets. Research and development is crucial to WC's commitment to providing reliable water and sewage services to the residents of Western Australia. The objectives of this project are designed to improve the knowledge base of the WC by implementing a sample collection and analysis procedure, and analysing relationships between pipe failure rates and the Western Australian environment. This project is the first of its kind in WA and as such it acts as a template for future projects. The materials investigated have been limited to Reinforced Concrete (RC) and Cast Iron (CI). The goal is to generate a comprehensive understanding of RC and CI pipeline deterioration and failures through analysis of failed pipe samples delivered to the Kwinana Sample Facility and historical analysis of work orders.

2. Background

The failure of a buried pipe occurs when the applied stresses exceeds the structural capacity of the pipe to resist them (Gould *et al*. 2011). The structural capacity reduces over time due to material deterioration, the mechanisms of which are dependent on the pipe material as described by Rajani & Zhan (1996). Pipe barrel and joint failures result from a combination of causes, namely: operational, environmental and material characteristics. Once installed, common failure modes, longitudinal and circumferential cracks result from stresses acting on the pipe in conjunction with internal and external deterioration.

Buried pipe deterioration can result from internal or external corrosion and reduces the structural capacity of the material. The most common from of corrosion for CI and RC pipes is graphitisation and cement leaching respectively (Rajani & Kleiner 2001).

Relationships between climatic conditions and intra-yearly variations in pipe failure rates have been investigated by several authors including Hu & Hubble (2007) and Rajani & Zhan (1996). A major cause of stresses acting on buried pipes is attributed to soil expansion and contraction under particular climatic conditions (Gould *et al*. 2011). Temperature and soil moisture content have been identified in the literature as having the most significant correlation to failure rates (Gould *et al*. 2011; Hudak *et al*. 1998; Hu & Hubble 2007).

3. Methodology

The key to the success of this project is the relationship between the literature, sample analysis and historical work order analysis. Through this process a strong theoretical and practical understanding of pipe failures was obtained. Figure 3.1 outlines the structure which items have been completed and the connections between the outcomes.

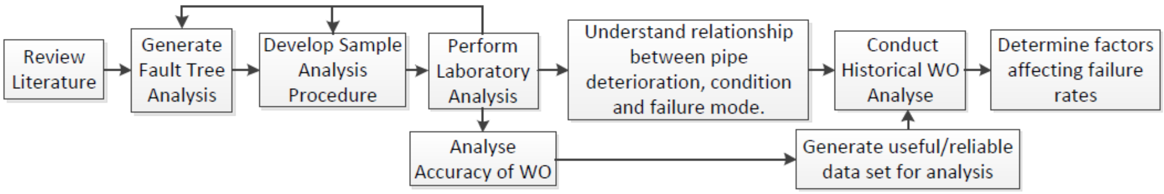

Figure 3.1 Process diagram representing the structure of the project

The first major outcome of this project was the development of the Sample Analysis procedure. The procedure was generated with reference to literature, discussions with experienced Water Corporation employees and from personal experience at the Kwinana Sample Facility. The procedure was constantly updated to ensure relevant information was being extracted safely and efficiently.

A number of analytical methods were used to investigate the factors influencing failure rates; a histogram method introduced by Gould (2011), graphical analysis used by Hu & Hubble (2007) and numerical correlation analysis. All methods were used to develop a comprehensive understanding of the factors influencing pipe failure rates.

4. Results and Discussion

4.1 Sample Analysis Procedure

The developed procedure aims of allow users of the Kwinana Sample Facility to safely and efficiently move, analyse, and dispose of pipe samples. The steps of the sample analysis procedure are shown in Figure 4.1 as a process diagram. The process diagram outlines some of the decision making required to ensure the results of the analysis are of a high standard.

<u>Sample Selection Process:</u> After delivery the samples are sorted into those with and those without appropriate identification. Appropriate identification is crucial to the analysis of the sample. If a sample does not have sufficient identification information then the corresponding work order and pipe ID cannot be identified.

<u>Pipe Material Identified:</u> Pipes identified as RC or CI are separated for further analysis. Other materials are stored for future analysis.

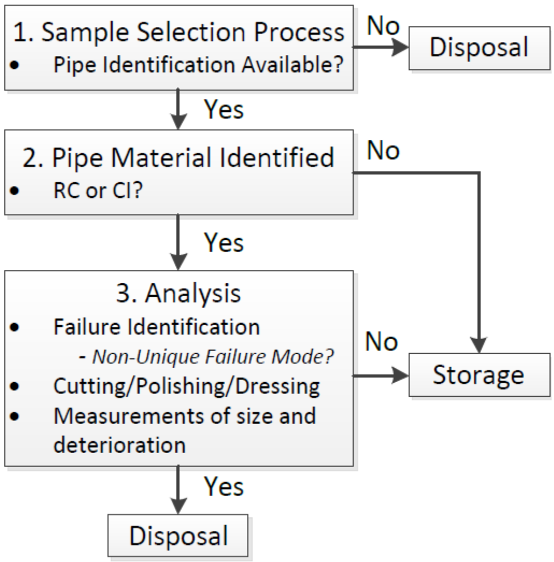

Figure 4.1 Process diagram representing the analysis procedure

Analysis: Firstly, the failure mode is identified and documented. If a pipe is identified as having corroded locally, the operator is to cut a sample that does not go through the locally corroded region. The deterioration analysis must represent the condition of the whole sample not just a localised failure. Further polishing and surface dressing for CI and RC samples is required before measurements can be taken.

The deterioration of RC and the cement lining of CI pipes are determined with use of the chemical Phenolphthalein. A steel ruler is used to measure the deterioration. Measurements are taken at 45 degree increments starting at the top of the pipe as marked with spray paint by the contractors. Table 4.1 outlines the parameters measured for the respective material.

CI	RC
- CI Wall Thickness - Internal & External Graphitisation of CI - Cement Lining Thickness Total - Leached Cement Lining Thickness	- RC Wall Thickness - Internal & External Leaching

Table 4.1 Summary of measured parameters

All observations and measurements are entered into a specifically designed Access Database.

4.2 Environmental Effects Analysis

This analysis investigates the relationship between RC and CI failure rates and their respective climatic and soil parameters, with use of historical work order data.

4.2.1 Work Order Data

Water pipe failure work order data provided by the Water Corporation was used in this analysis. Data from the observation period of July 1999 to June 2010 was extracted. The quality of the data was poor, therefore extensive filtering was required to ensure the accuracy of the analysis. The filtered data set included 2,800 km of CI pipe with over 4100 failures and 2,750 km of RC pipe with 4000 failures.

4.2.2 Climate Parameters

Similarly to Gould (2011), failure correlations to eight monthly climatic parameters have been investigated: minimum temperature, maximum temperature, rainfall, average antecedent precipitation index (API), minimum API, maximum API, mean evaporation, and net evaporation. This data was extracted from the Bureau of Meteorology website, for ten weather stations across the metropolitan area. Using GPS coordinates of the pipes and the weather stations one can determine the closest weather station and thus the most accurate climate data relating to the pipe failure.

API is a measure of soil moisture content that is calculated as a daily time series and relates to rainfall on the day and the days prior. In Victoria this parameter was determined by Gould (2011) to correlate positively to increased failure rates.

4.2.3 Soil Parameters

All water pipes within WA have been assigned a soil type. This analysis investigates four soil parameters: salinity, pH at 50 – 80 cm, water logging, and corrosivity scale rating. The four parameters are scaled from one to five, where one is low and five is high. The relationship between all of these parameters and failure rates are investigated.

Ferrous and Cement Corrosivity Scales developed by the WC relate the effects of different soil types to either ferrous or cement based pipes respectively. These parameters were developed with reference to literature. Corrosivity ratings are assigned based on an equation that relates all available soil parameters.

4.3 Cast Iron Pipe Analysis

As of the 5th of September 2011, 22 CI samples have been analysed at the Kwinana Sample Facility. Table 4.2 outlines the failure modes of the analysed pipes.

Failure Mode	No. of Samples
External Corrosion	14
Other	4
No Observed Failure	4

Table 4.2 Observed CI failure modes

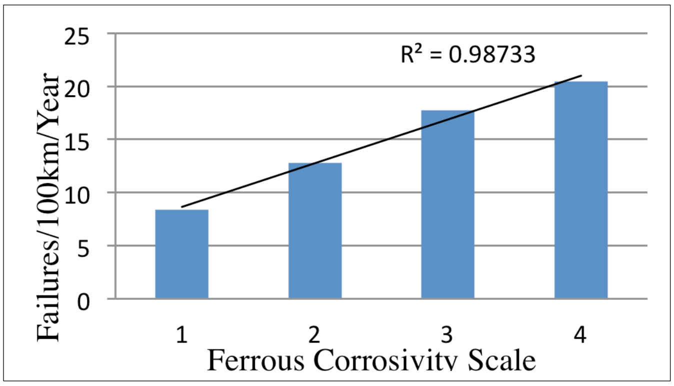

Figure 4.2 Ferrous Corrosivity Scale Correlation

The most common failure mode observed was external corrosion (graphitisation). The graphitisation was often observed on the base of the CI pipes. Severe graphitisation weakens the base of the pipe making it susceptible to cracking.

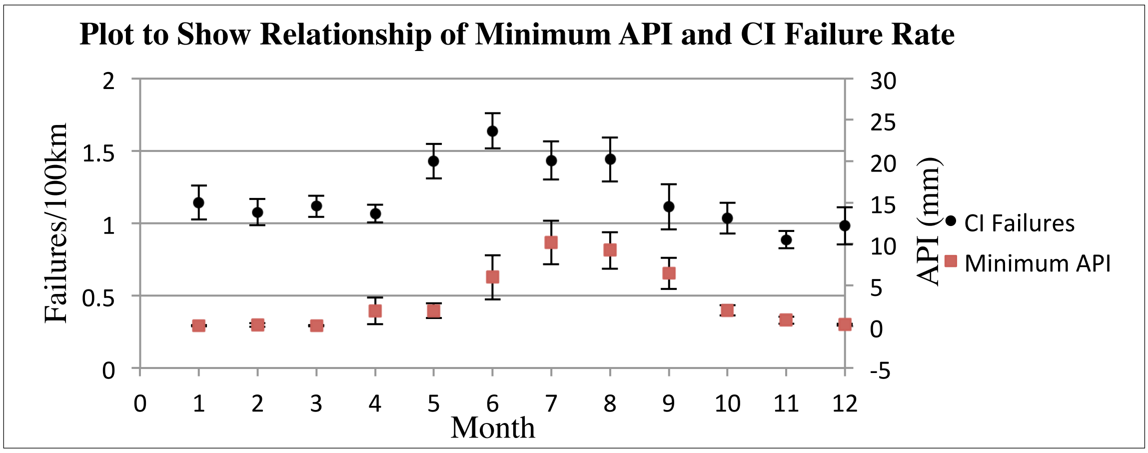

Figure 4.3 Minimum API and CI failure rate analysis

Correlations to a number of climatic conditions were determined. The parameters Monthly Rainfall and Minimum API were found to correlate positively to CI failure rates and Mean Evaporation was found to correlate negatively. The strongest correlating parameter was Minimum API which is shown in Figure 4.3. The respective correlations to these parameters suggest that failures of CI pipes are more common when soils are expanding due to increased soil moisture content. The expanding soils induce flexural stresses on the pipe causing cracks in areas of severe graphitisation.

A very strong correlation was found between CI failure rate and the Ferrous Corrosivity Scale. Point 5 is excluded due to a lack of pipes buried in this soil. This correlation confirms the observed trend of external corrosion induced failures.

4.4 Reinforced Concrete Pipe Analysis

As of the 5th of September 2011, 37 RC samples have been analysed at the Kwinana Sample Facility. Table 4.3 outlines the failure modes of the analysed pipes.

Failure Mode	No. of Samples
Joint Failure	28
Crack	2
Internal Corrosion	5
No Observed Failure	2

Table 4.3 Observed RC failure modes

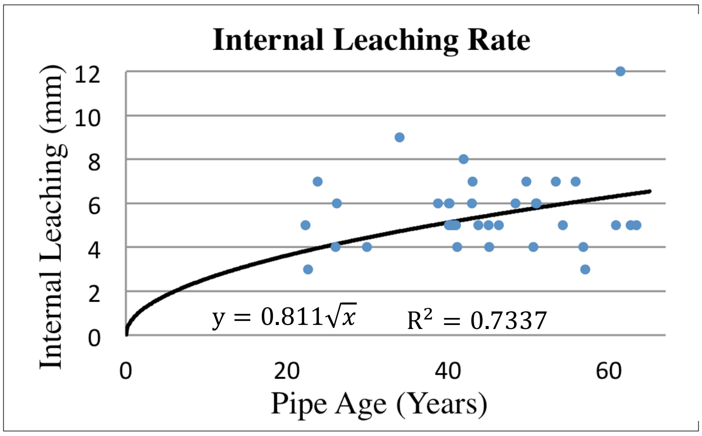

Figure 4.4 Internal leaching of RC over time

It can be seen that a large number of the samples failed as a result of joint failures. These 28 samples had an average condition rating of 1.2 out of 5, which means they are in very good condition. Internal corrosion was more aggressive than external corrosion in all analysed samples. Figure 4.4 is a plot of the internal leaching of the analysed samples against age. Leaching rate is said to be a function of the square root of age (Standards Australia, 2006).

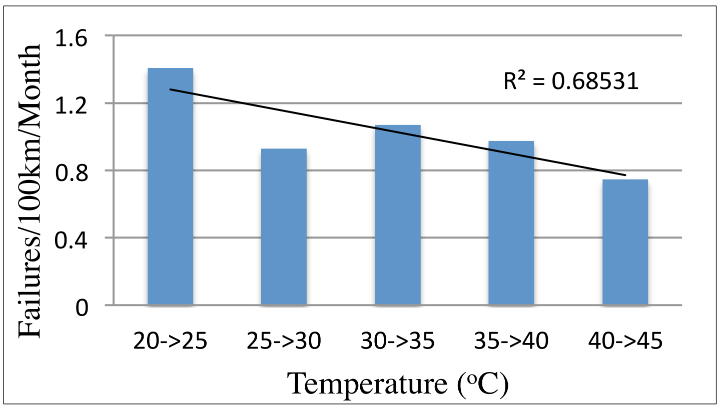

Figure 4.5 Highest Monthly Temperature and RC failure rate analysis

The strongest correlation to RC failure rate was a negative correlation to Highest Monthly Temperature as shown in Figure 4.5. The parameters Monthly Rainfall and Minimum API were found to correlate positively to failure rate. These correlations suggest that soil movement influences failures of RC pipes. This soil movement results from soil expansion that occurs as the soil moisture content increases during the winter months. This movement induces stresses to peak at pipe joints resulting in a higher occurrence of joint failures.

The soil parameter investigation provided no correlation between any of the analysed parameters. This result confirms the laboratory investigation, verifying that RC failures are not related to the corrosivity of their environment.

5. Conclusions

As a result of the implemented sample collection and analysis procedure, 22 CI and 37 RC samples have been effectively analysed, as of the 5th of September 2011. CI pipes were observed to regularly fail as a result of external corrosion on the base whereas RC pipes were commonly observed to fail as a result of joint failures.

The strong correlation of CI failure rate to the Ferrous Corrosivity Scale is a positive result and supports the laboratory analysis result that external corrosion is the most common failure mode. CI pipe failure rates were found to peak in mid-winter, which is attributed to an increase in soil moisture content causing soil expansion.

Joint failures of RC pipes were seen to limit the pipe's operational life. Internal leaching has been determined to fit a function of the square root of pipe age. RC pipe failure rates were also found to peak in mid-winter with correlations to a number of climatic conditions determined. These correlations suggest that soil expansion influences failures rates of RC pipes, which is confirmed by the high number of joint failures observed at the sample facility.

6. References

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