Replacement Strategy for Cast Iron Pipes in Western Australia

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Abstract

The Water Corporation spent approximately 1 million AUD on cast iron pipes bursts. At present the replacement for cast iron pipes is based on pipe age and burst rate. The objective of this project is to identify underlying factors that affect pipes burst rate in order to plan a large-scale cast iron pipe replacement program for WC. Statistical analysis indicate that pipe burst rate is dependent on the pipe age and manufacturing batch, other factors such as soil aggressiveness, depth to ground water and operating pressure were also investigated to identify their effects on pipe burst rate. Experimental investigation established the pipe external graphitization mechanism through hardness testing and microstructure analysis and it was also found that hardness of pipes installed during 1950s is much lower than pipes installed in other decades, and this is in consistent with the statistical data analysis.

1. Introduction

Water Corporation has 2200 km of cast iron (CI) pipes in Western Australia (WA), installed between 1920s and 1980s, and the pipes were responsible for about 300 pipe bursts last financial year. This cost the Water Corporation approximately 1 million AUD for repairs and service disruptions. At present the replacement strategy for CI pipes is based pipe age and burst rate.

Pipe age is not the only factor responsible for the pipe bursts, and the burst rate statistics in the past may not predict the future failure pattern if the key underlying factors responsible for pipe failures are not identified. (Rajani and Kleiner, 2001) reported that operational, environmental and physical factors are three groups of factors that affect pipe burst rate. This study was designed to identify the key factors that are responsible for the deterioration of CI pipes in the WA environment through statistical data analysis of burst records, and an experimental study on graphitization of CI pipes. The outcome of this study provides a solid scientific basis for recommendation of pipe replacement programs and budged forecasting.

2. Methodology

This study consists of two main parts, historical data analysis and an experimental study. The historical data analysis examined the 10-year historical burst rate statistics of CI pipes with the aim of establishing correlations between the observed burst rates and physical factor (pipe age), environmental factors (such as soil aggressiveness and groundwater level) and operational factor (operating pressure).

The experimental investigation focused on achieving mechanistic understanding of CI pipe deterioration mechanisms and manufacturing batch that has potential to affect pipe burst rate. (Pratt, 2011) found that deterioration in CI pipes is mainly caused by external graphitization, where iron is selectively leached out of cast iron microstructure due to environmental attack, this leaves behind a graphitized zone with little strength. (Schweitzer, 2010) In this study, the graphitized zone of a collection of CI pipes samples of different installation dates was studied. Coupled with microstructure analysis, hardness of the samples was measured across the ferrous (healthy) and graphitized zones of CI pipe cross-section. This provides a quantitative measure of the mechanical deterioration caused by the external graphitization of CI pipes. Hardness is a measure of material's resistance to localized plastic deformation and it is proportional to tensile strength. (Callister, 2007) Hardness testing requires lower cost compared with other methods of mechanical testing. The combined results of data analysis and experimental investigation were used to support the recommendations regards replacement strategy for remaining CI pipes in WA.

3. Results and Discussion

Analysis of burst rate reveals the key factors that are responsible for the deterioration of CI pipes, including the pipe age, soil aggressiveness, depth to ground water, and operating pressure. The key findings are summarized below.

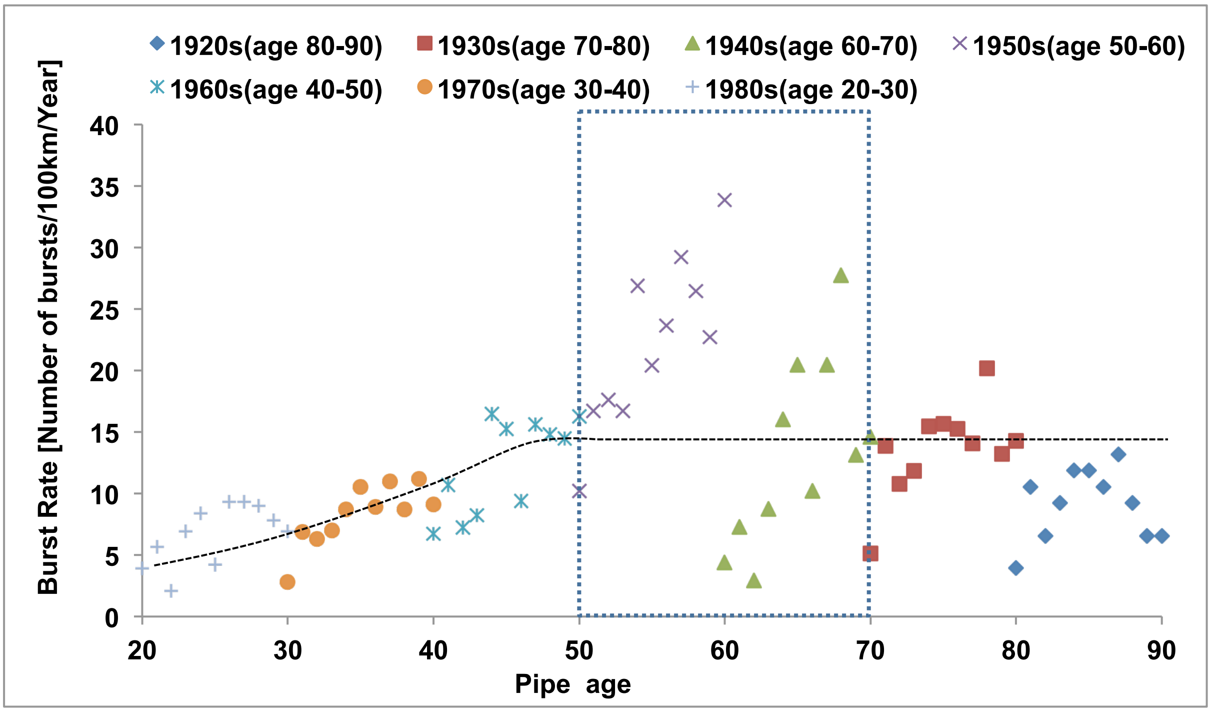


Figure 1 Summary of average pipe burst rate versus pipe age (data collected 2000-2010)

Figure 1 summarizes the average burst rate (expressed at number of bursts per 100 km of pipeline per year) vs. the installation time. If we exclude the CI pipe data installed in 1940s and 1950s as this group is an anomaly, which will be explained later, it is clear that the average burst rate increases for pipes during initial 50 years of installation, and settles at a relatively stable rate of around 15 bursts per 100 km per year afterwards. If this level of average burst rate is acceptable, then a large-scale replacement of CI pipes installed between 1920-1930s and 1960-1980s is not warranted. Instead we should only replace particular pipe sections with repetitive bursts, most likely resulting from either operational or environmental specifics. From the data contained in the dashed box, it can be seen that pipes installed in 1940s and 1950s display unusually high burst rates, even when compared with much older pipes. Our experimental investigation revealed that the CI pipes installed in the 1950s have an average hardness of around 30% lower than the CI pipes in all other installation years (see Figure 5). This suggests that the unusually high historical burst rates of CI pipes installed in 1940s and 1950s are mainly due to the intrinsic lower strength of the pipes. This finding suggests that we should focus future large-scale replacement programs on the CI pipes installed in 1940s and 1950s.

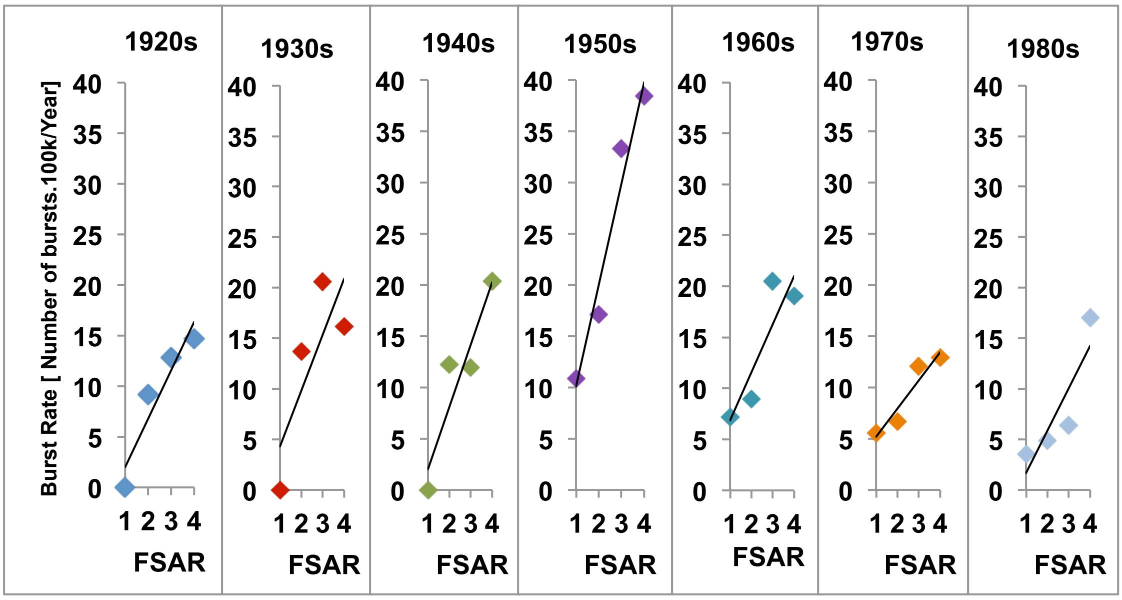
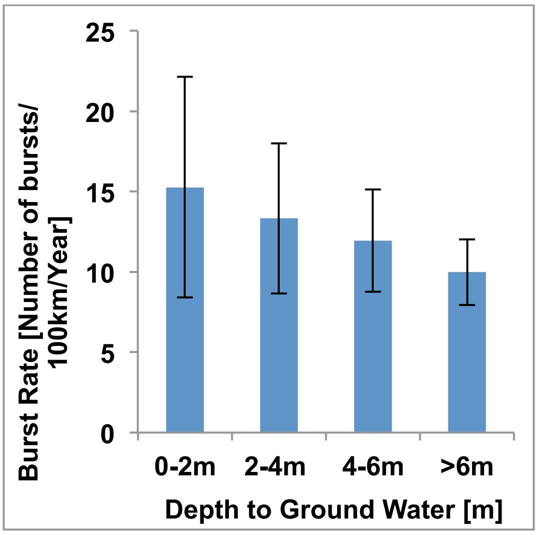


Figure 2 Average pipe burst rate versus ferrous soil aggressiveness rating (FSAR)

The effects of environmental factors such as the soil aggressiveness and depth to ground water were also studied. Correlations between CI pipes external corrosion rate and specific soil properties were investigated previously. (Seica et al., 2002;Doyle, 2000) Since different locations have different specific soil properties, and previous results have limited applicability, as a result of that, WC developed a ferrous soil aggressiveness rating (FSAR) based on WA soil environment and it is defined as a measure that takes into account salinity, pH, and waterlogging. The soil aggressiveness is increasing with FSAR. Figure 2 shows the effect of soil aggressiveness on the burst rate of CI pipes. As expected, a higher burst rate was observed for all pipes in more aggressive soils. In particular, the performance of pipes installed in the 1940s and 1950s are very poor in aggressive soils. This observation re-iterates the need to make the replacement of CI pipes installed in 1940s and 1950s as a priority for large-scale replacement programs, especially when they are buried in aggressive soil. Ground water will affect the soil wetness and salinity, thus it has potential to affect the pipe burst rate. This study examined the effect of depth to ground water. Figure 3 shows the effect of distance between the CI pipes and depth to ground water. It can be seen that the closer the pipe is to the ground water, the higher the burst rate is, within the distance of 0-6 m. In general, the effect of depth to ground water is less significant than manufacturing batch, pipe age and soil aggressiveness. This study has also revealed the significant effect of operation pressure on the burst rate as shown in the Figure 4. This figure shows that pipes which are operated at higher water pressure on average for a long time will have higher risk of bursts.



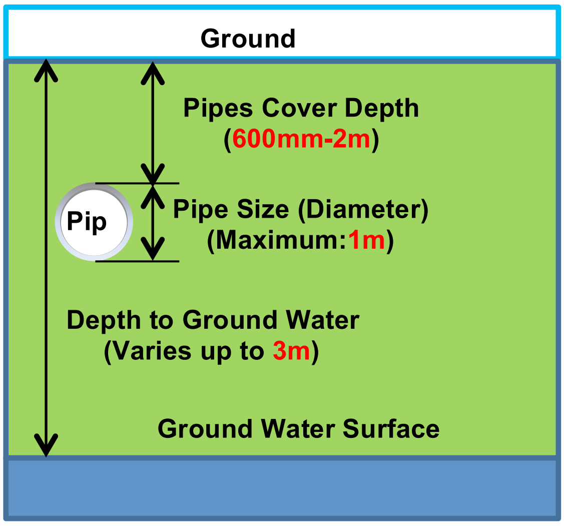


Figure 3 Average pipe burst rate versus depth to ground water

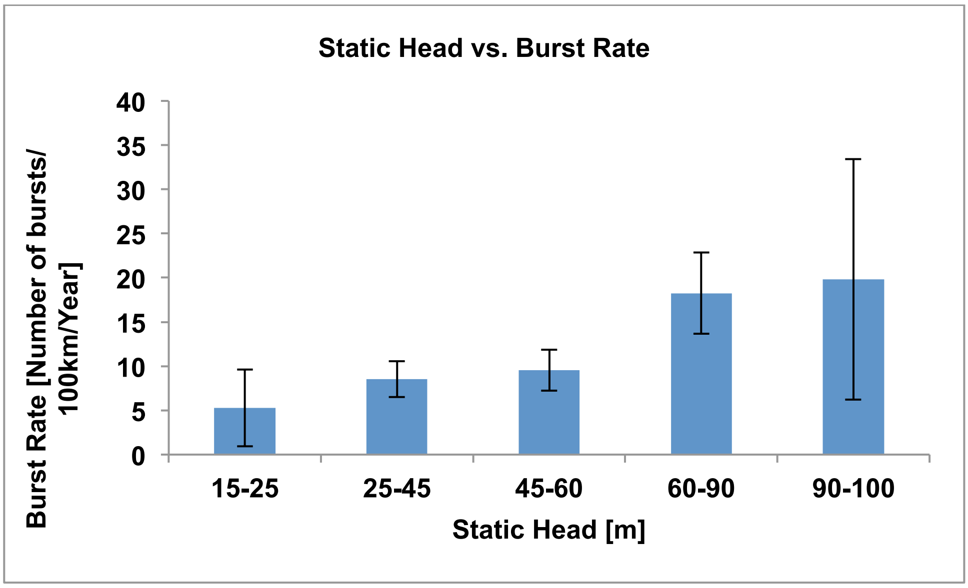


Figure 4 Average pipe burst rate versus operating pressure

Figure 5 shows that the pipes manufactured in the 1950s (example 1956) has an initial hardness well below the other years and has had the largest reduction in hardness of 83% compared to others. This result is in consistent with statistical analysis result as discussed above.

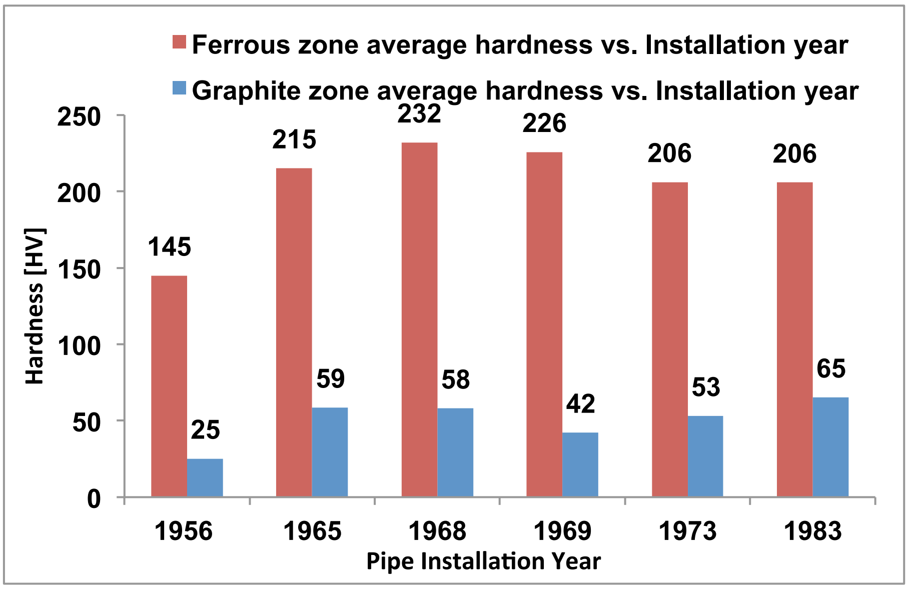


Figure 5 Average pipe hardness versus pipe installation year

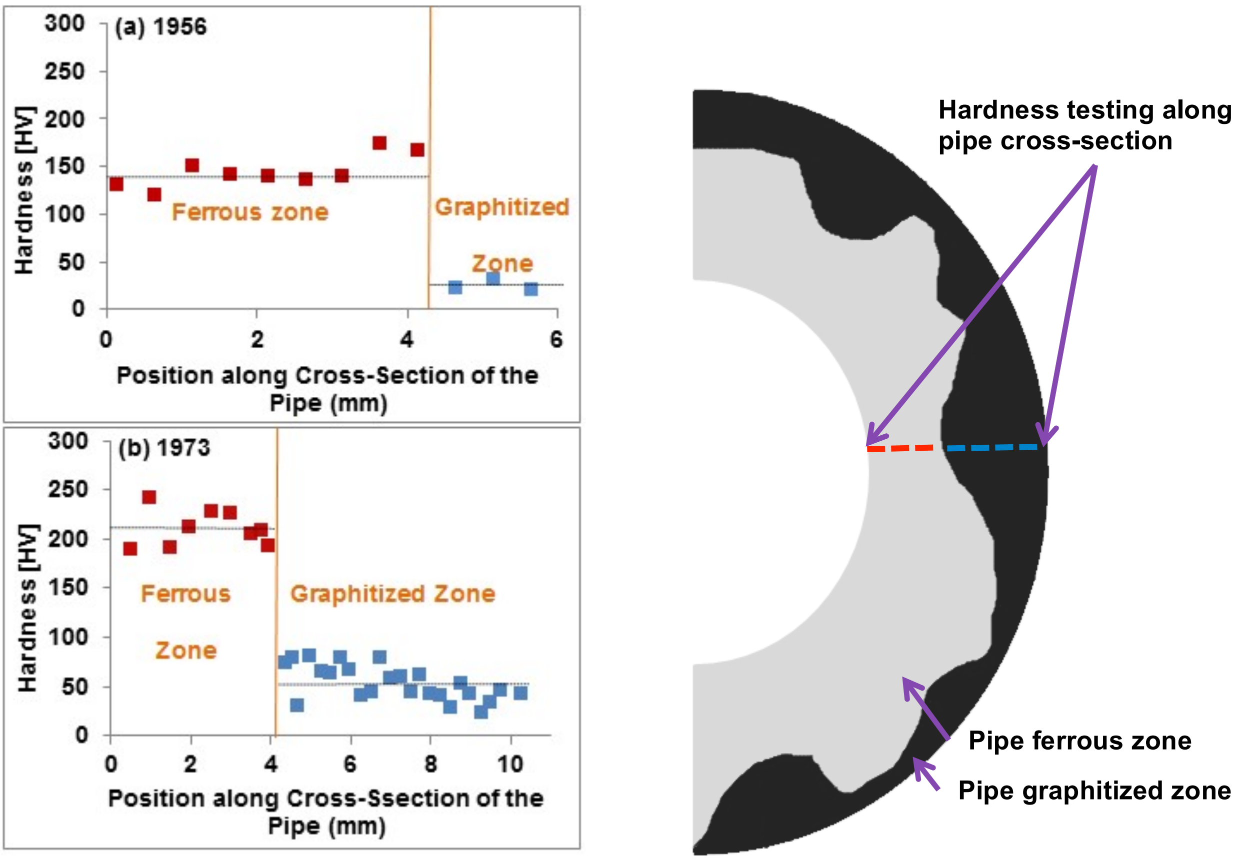


Figure 6 Comparison of hardness step change for pipes installed in different years

From Figure 6, it can be seen that instead of a transition zone, a definite step change exists between the ferrous and graphitized zones. On average, the hardness drops by 75% and occurs as a “step change”.

4. Conclusions and Future Work

The key outcome of this study indicates that for long term replacement planning, the following factors in order of importance are: pipe manufacturing batch, pipe age, soil aggressiveness, operating pressure and depth to depth to ground water level. As the long-term replacement program is based on the average statistics in this study, we should continue to monitor burst rate to identify local specific problem areas having abnormally high repetitive bursts. This can be due to other factors such as maintenance practices, ground movement and traffic.

5. Acknowledgements

In addition to the project supervisors named on the front page of this report, I would like to thank Gerry McCourt, Shane Oldham and Esther Loh from Water Corporation for their contribution and assistance on the project.

6. References

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