DEFECT LEVEL CONDITION MODELLING OF SEWER PIPES

Z. Tizmaghz, Ph.D. Candidate, Department of Civil and Environmental Engineering, Faculty of Engineering, University of Auckland, Auckland, New Zealand, E-mail: ztiz284@aucklanduni.ac.nz
J. E. van Zyl, Professor, Department of Civil and Environmental Engineering, Faculty of Engineering, University of Auckland, Auckland, New Zealand, E-mail: k.vanzyl@auckland.ac.nz
T. F. P. Henning, Senior Lecturer, Department of Civil and Environmental Engineering, University of Auckland, Auckland, New Zealand, Email: t.henning@auckland.ac.nz
N. Donald, Principal planner, Nathan Donald, Watercare Services Limited, Auckland, New Zealand, Email:Nathan.Donald@water.co.nz
P. Pancholy, Research Data Engineer, University of Canterbury, Christchurch, New Zealand, Email: purvi.pancholy@canterbury.ac.nz

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ABSTRACT

Sewer pipes are affected by various internal and external factors and therefore need to be maintained and monitored to keep their performance at a desirable level. CCTV plays an essential role in monitoring, assessing, and condition scoring sewers. A condition score is assigned to each sewer pipe based on the type, quantity, and extent of defects observed through CCTV inspections. While the impact of different factors on the condition score has been considered in several studies, the impact of these factors on the underlying defects has not been investigated in detail. The aim of this study was to investigate the effect of various factors, including age, diameter, and slope on the prevenance of eight defect categories in the transmission sewer network of Auckland, New Zealand. A cleaned dataset with the defects identified through recent CCTV inspections of 2817sewers was gathered and linked to a range of physical and environmental factors. Defects were grouped into the following eight categories: gas attack, material damage, infiltration, roots, debris, total joint, structural, and dipped pipe. Results identified statistically significant relationships between defect categories and factors that provide new insights into the drivers of deterioration processes in sewer pipes.

KEYWORDS

Sewers; CCTV inspection; Defects; Deterioration modelling; Asset management.

PRESENTER PROFILE

Zahra had done her bachelor's degree in civil engineering in 2012 before she did her master's degree in water and wastewater engineering. During her master's study, she started working as a water and infrastructure engineer and continued working for six years. Through designing different water and wastewater drainage collection systems and environmental investigations, she got fascinated with the water and wastewater field. So, in 2019, she decided to expand her knowledge in this area by studying for a Ph.D. in wastewater engineering, specifically researching Auckland's sewers.

INTRODUCTION

CCTV plays an essential role in monitoring, assessing, and condition scoring of sewers. A condition score is assigned to each sewer pipe based on the type, quantity, and extent of defects observed through CCTV inspections.

In New Zealand, a condition score is assigned to a sewer pipe based the Gravity Pipe Inspection Manual Standard of New Zealand (Apeldoorn et al. 2019). For the last two decades, many studies have identified and described various factors that affect the condition score of sewers by accepting it as a comprehensive index for the overall condition of sewers. While the condition score is based on type, quality, and quantity of the underlying sewer pipe defects, it does not provide any detail of the underlying defects.

The goal of this study was to investigate the relationship between specific defects included in CCTV inspection reports and various factors to provide insights into the sewer deterioration process. A better understanding of physical and environmental factors affecting pipe defects will allow municipalities to better manage their assets and make efficient CCTV inspection decisions in terms of planning and future installations (Laakso et al. 2018).

After describing the methodology of the study, the paper describes the relationship between defects and pipe age as an example of how each factor was investigated. A summary of the statistically significant correlations between pipe age, diameter, length, and slope and the different defect categories is then presented.

METHODOLOGY

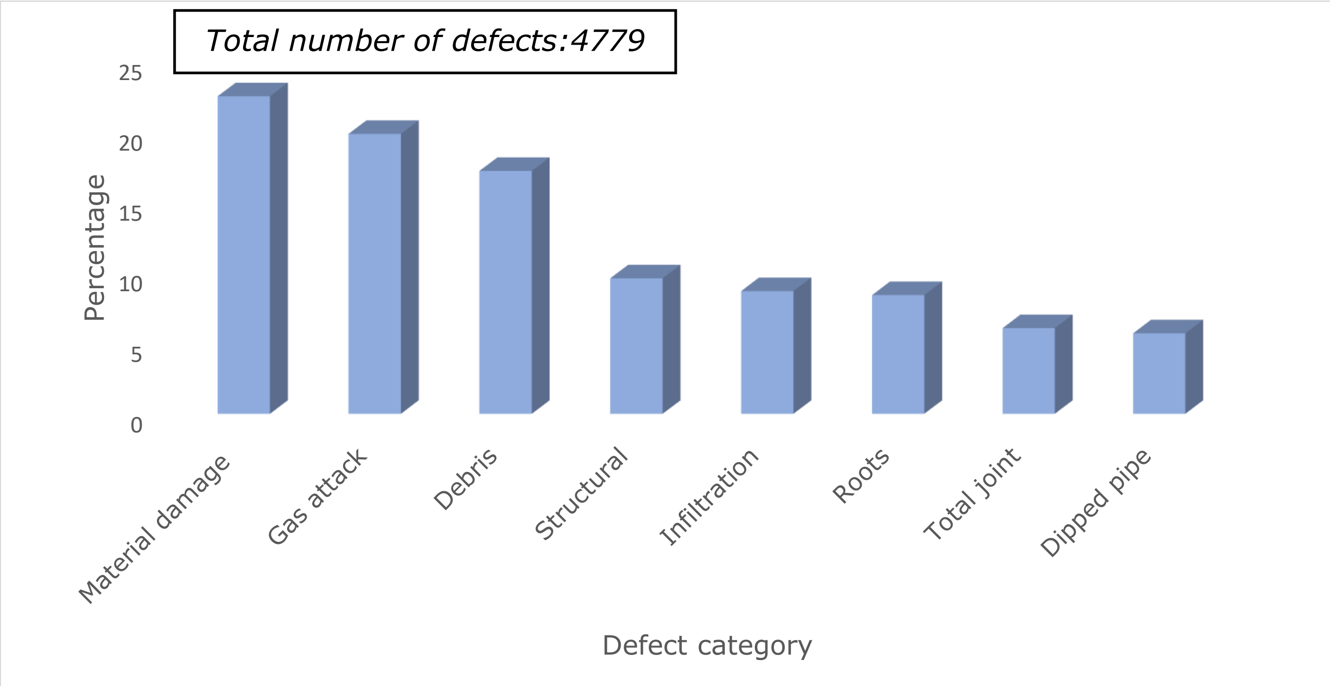
The CCTV-based defect dataset was obtained from Watercare Service limited; a Council-owned entity responsible for managing Auckland's 9800 kilometers of sewer pipes. Only the transmission sewer pipes were included in this study as they are regularly subjected to CCTV inspections. The transmission sewer dataset consisted of 4779 pipes with a total length of 246 km, representing about 3% of the whole network.

CCTV inspection reports on 16 different defects and the estimated condition score. Overall, in the Auckland sewer network, the condition score of most pipes was three or less, and very few pipes had a score of four or five.

While detailed datasets such as the distance and quantity of each defect are provided in CCTV inspection reports, only the prevalence of different defect categories was considered in this study.

Figure 1 provides the prevalence of 8 simplified defect categories in Auckland's transmission sewer system.

Figure 1. The prevalence of defects categories in the Auckland transmission sewer system



Several factors, including pipe age, diameter, length, and slope were investigated. After linking the factor and defect data, records with missing or unrealistic data and lined pipes were removed from the database. The box plot technique was then used to remove outliers. These steps reduced the number of datasets from 4779 to 2817 records.

RESULT AND DISCUSSION

INTRODUCTION

The relationship between different factors and each of the defect categories were investigated respectively. Each factor was split into a convenient number of groups, and fractions of pipes with each defect were calculated for each group and plotted. Categories with less than 1% of the total number of pipes which is 30 are excluded from significance estimations.

Data outliers were identified using Tukey's fences method (Thompson 2000), i.e. any point that lies more than 1.5 times of the interquartile range outside the interquartile range (Dümbgen and Riedwyl 2012) and excluded from the analysis.

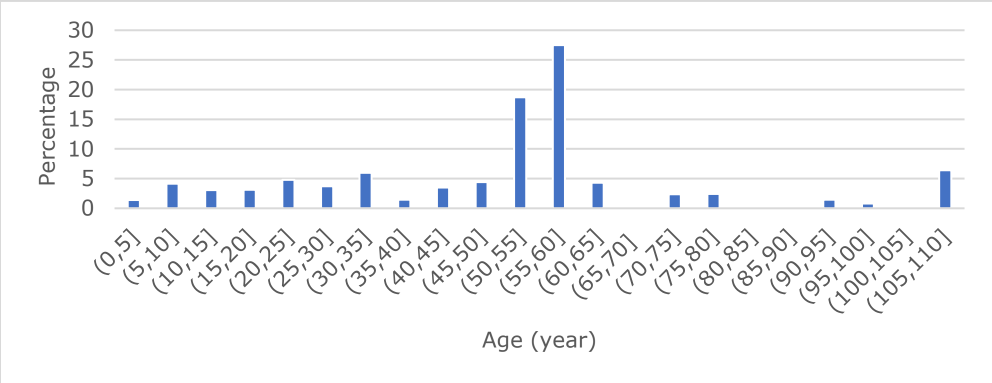
The significance of the regression slopes was determined through the P-value, which checks the null hypothesis (Dahiru 2008). A significance level of 0.05 was considered in most cases.

PIPE AGE

Pipe age of transmission sewer pipes is considered as the difference between the year that the CCTV inspection was conducted and the installation year. The oldest and youngest pipes in the network were installed in 1910 and 2018, respectively.

The distribution of pipe age, based on 5-year intervals, is shown in Figure 2.

Figure 2. The distribution of sewers age, total number of pipes: 2780



The prevalence of pipes with each defect was plotted against pipe age, as shown in Figure 3. Despite the limitations of the CCTV inspection data, clear relationships between age and four of defect categories debris, structural, infiltration and roots are observable. Four defect categories including debris, infiltration, structural, and roots were found to be significantly affected by age. Apart from debris, all slopes are positive showing an increase of defect prevalence with sewers age. Statistically significant linear regression slopes for the relationship between pipe age and the different defect categories are listed in Table 1.

Figure 3. The fraction of pipes with different defects as a function of age: a) material damage b) gas attack c) debris d) structural e) infiltration f) roots

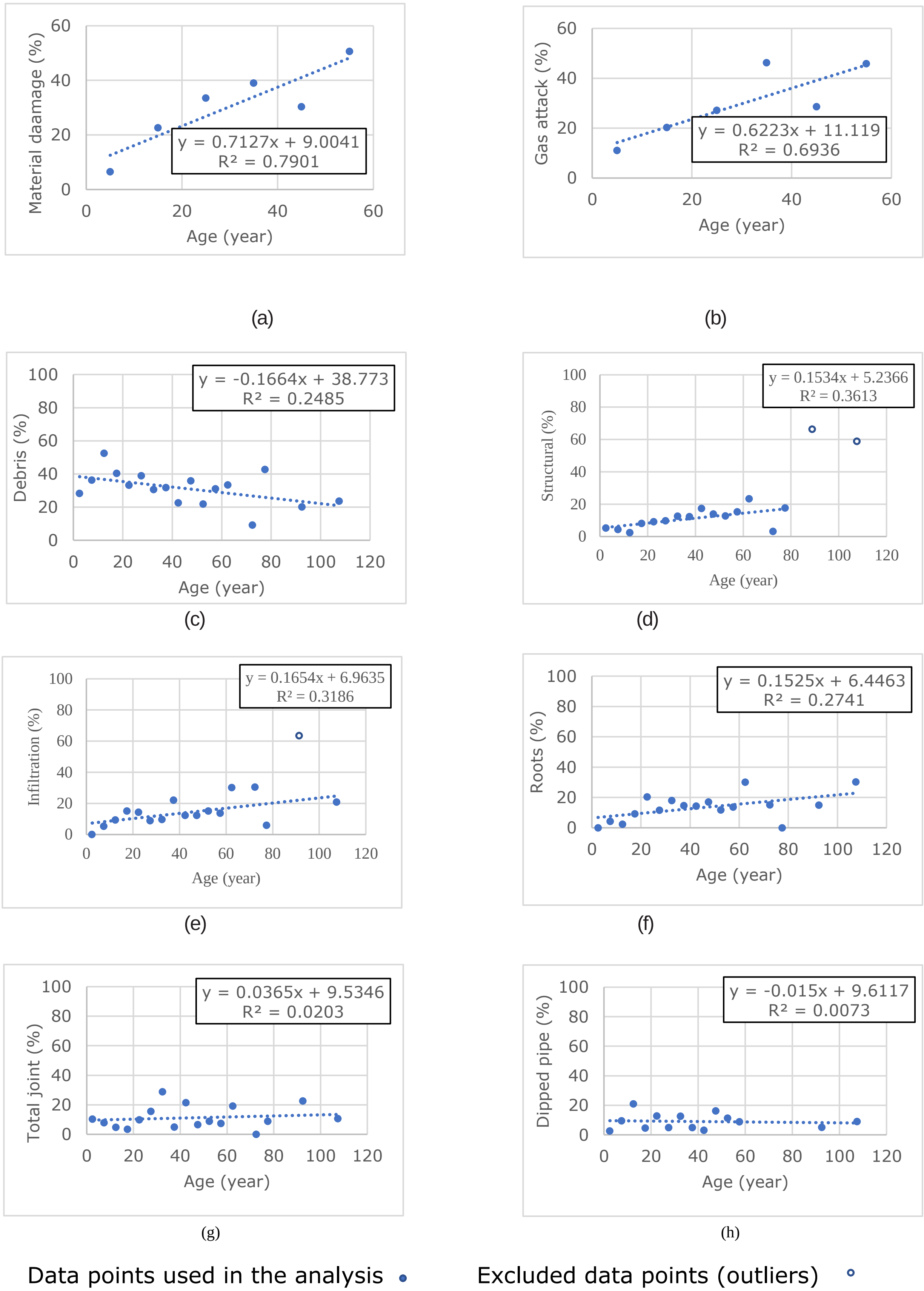


Table 1. Significant linear regression slopes for the relationships between pipe age and the different defect categories

Defect category rank	Age (year)
1. Material damage	0.622
2. Gas attack	0.712
3. Debris	-0.166
4. Structural	0.153
5. Infiltration	0.165
6. Roots	0.152

The results show that material damage and gas attack (limited to pipes younger than 60 years) have the greatest prevalence growth with aging of 0.71 % and 0.62 % per year, respectively. This is followed by infiltration, structural defects, and roots with growth rates of 0.16%, 0.16%, and 0.15 % per year, respectively. Interestingly, the trend for debris, which is significant, is negative, reducing at 0.16 % per year. This may be due to the increasing flow rate over the years as suburbs densify. Finally, no significant correlation was found between pipe age and total joint and dipped pipe defects.

The above results align with the trend that can be expected through known physical deterioration mechanisms in sewer pipes, as well as the findings of previous studies showing that pipe age has an adverse effect on sewers condition (Ahmadi et al., 2014; Ana et al., 2009; Cigada et al., 2011,). These studies all considered pipe condition scores in their deterioration models and did not consider any specific defects. This study provides significant new insights, showing that material damage and gas attack are probably the main causes of the observed reduction in pipe condition over time, with infiltration, structural damage, and roots also playing significant roles.

It is noteworthy to add that while both infiltration and roots are one of main defects in sewer pipes worsening by age, they are unlikely to occur without pipe structural damage, and thus their growth is also an indication of other structural defects through other mechanisms with age (Lubini and Fuamba (2011)).

While an overall positive trend between age and defects were determined in this and other studies, Davies et al (2001) did not find a significant correlation between pipe age and deterioration rate. However, they did not have access to sewer pipe age data and used property age as a surrogate, which may be the reason for their result.

RESULTS SUMMARY

The linear regression slopes of the various relationships investigated were normalized to allow them to be compared on the same scale. Figure 4 provides a summary of all statistically significant normalized slopes between variables and defects.

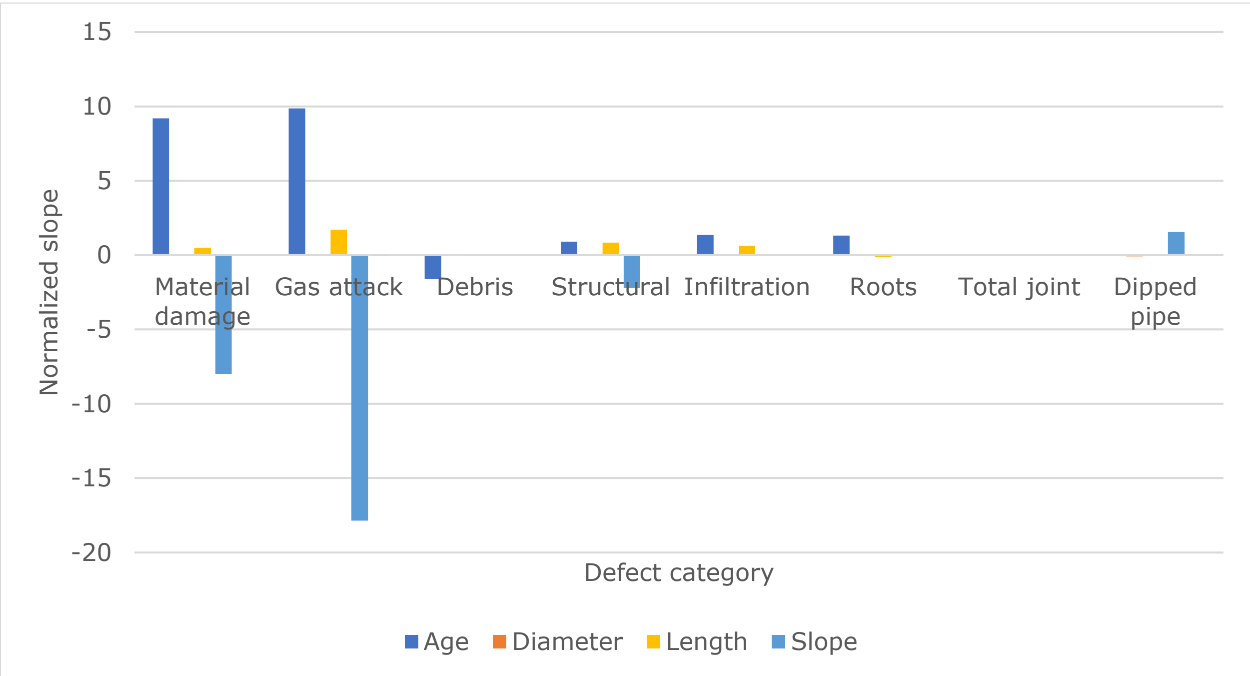
It is clear from the figure that pipe age and slope have the greatest absolute impacts on pipe deterioration. Pipe age has a particularly strong positive impact on material damage and gas attack, and small positive impact on most other defects, except for debris (small negative impact) and joint and dipped pipe (no significant impact).

Pipe slope has a large negative impact on material damage and gas attack, a small negative impact structural damage and a small positive impact on dipped pipe. The reason for the large impacts on material damage and gas attack are not immediately clear, but it may be due to correlations between pipe slope and other factors, such as pipe depth and sewage age. Further work is required to better understand these results.

Pipe length has a small positive impact on material damage, gas attack, structural, and infiltration, and a small negative impact on roots, possibly since longer sewers are also deeper, decreasing the likelyhood of tree roots reaching to the sewer pipes.

Finally, diameter has a small negative impact on dipped pipe, total joint, and roots, but a positive impact on debris.

Figure 4. Statistically significant normalized slopes calculated from linear regression results between continuous numeric variables and studied defects



CONCLUSION

This study investigated how selected factors (pipe age, diameter, length, and slope) affect the prevalence of various defect categories in the transmission sewer network of Auckland. Defects were grouped into eight categories: material damage, gas attack, debris, structural, infiltration, roots, total joint, and dipped pipe.

The study found the most significant impacts to be pipe age, which has a strong positive impact on material damage and gas attack, and pipe slope, which has a strong negative impact on material damage and gas attack. Several smaller, but statistically significant impacts between factors and defect categories were identified.

The results of this study show the potential for CCTV inspection data to better understand the impact of a range of factors on specific aspects of sewer pipe deterioration. While the pipe condition score gives a good overall estimate of the pipe condition, the underlying defect data can provide more detailed insight of specific deterioration processes and the factors influencing them. These insights, in turn, will support better sewer pipe design, maintenance and lifecycle management.

This study is being extended to include several other factors that may affect sewer pipe deterioration, and future work on understanding the distribution of specific defects and their properties is being planned.

ACKNOWLEDGEMENTS

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