A CASE STUDY ON THE SEISMIC PERFORMANCE OF WASTEWATER PIPELINES FOLLOWING THE VALENTINE'S DAY EARTHQUAKE

Miao (Melanie) Liu (Beca Ltd), Marcus Gibson (Beca Ltd), Kelly Tang (Beca Ltd), Greg Preston (UC Quake Centre)

ABSTRACT

A study is undertaken to compare the performance of wastewater pipelines in Christchurch in the aftermath of the 14 February 2016 earthquake (Valentine's Day Earthquake). The strong ground motion of this earthquake is similar to the Ministry of Business, Innovation and Employment earthquake serviceability limit state loading ground acceleration for the Canterbury region. As a result, this earthquake presented an opportunity to assess the seismic performance of wastewater networks during a SLS equivalent event.

In this study, a small sample of 26 gravity pipelines were selected from the wastewater network in North New Brighton and Parklands suburbs in eastern Christchurch. The study compared CCTV records collected pre- and post-Valentine's Day Earthquake for the selected assets. Among the selected wastewater pipelines, 36% were in areas where liquefication was observed. Earthquake induced structural defects have been the focus of the study. All structural defects were categorised into three groups: lateral pipe related, pipe related and pipe joint related structural defects. The pre- and post-earthquake CCTV footage of the 26 pipelines were compared to identify the changes to the defects.

This study is funded by the EQC/Quake Centre Industry Fellowship Scheme. The size of the sample was limited by the availability of baseline pre-Valentine's Day earthquake CCTV records that was not influenced by any of the significant previous earthquakes. This paper summarises the method adopted, key findings and presents some recommendations for further analysis.

KEYWORDS

CCTV records, earthquake, seismic performance, wastewater, pipe

PRESENTER PROFILE

Melanie is a Civil Engineer, working at Beca and specialising in assessing and improving the resilience of three waters networks. She has assisted local authorities across New Zealand assessing resilience of their 3 waters networks and authored the Quake Centre simplified method for assessing technical resilience of 3 waters pipelines.

1. INTRODUCTION

A 5.7 moment magnitude earthquake, which has become known as the Valentine's Day Earthquake, struck Christchurch at 1:13 p.m. on 14 February 2016. This earthquake triggered peak ground accelerations (PGA) of approximately 0.19-0.21 g and peak ground velocities of 0.28-0.50 m/s in the suburbs of North New Brighton and Parklands in Christchurch, located closest to the epicentre. Surface ejecta, as evidence of liquefaction, was observed in the affected and wider areas in the aftermath of the earthquake. Given that the strong ground motions of this earthquake were very close to the design parameters for serviceability limit state (SLS) (i.e. M_w 6.0 and PGA of 0.19 g) recommended by the Ministry of Business, Innovation and Employment (MBIE). This earthquake presents an opportunity to assess seismic performance of wastewater networks during a SLS equivalent event.

Beca undertook a study to evaluate the performance of the wastewater pipes in Christchurch during the Valentine's Day Earthquake for the University of Canterbury Quake Centre. This was conducted by comparing closed-circuit television (CCTV) records collected pre and post the Valentine's Day Earthquake for the selected pipe assets in North New Brighton and Parklands in Christchurch.

This paper summarises the method adopted, key findings from this study and presents recommendations for further analysis.

2. SCOPE AND OBJECTIVES

This study is intended to investigate the potential change to existing physical defects and/or development of new defects within the selected wastewater pipelines after a SLS equivalent earthquake event, with consideration given to pipe material, asset age, location, and earthquake-induced ground deformation. The outcomes of the study are to improve the knowledge of seismic performance of such assets, refine design standards, and improve rehabilitation solutions for both business-as-usual operation and post-disaster restoration.

The objectives of the study are to:

- Observe and record the performance of the selected wastewater pipelines during the Valentine's Day Earthquake, approximately equivalent to a SLS seismic event

- Review the impact of observed ground displacements on the physical defects of pipelines, considering pipes with different materials and ages

- Review the performance of the wastewater pipelines in defect categories: lateral-related, pipe-related, and pipe joint-related defects

- Compare observed performance to expected theoretical performance, with the potential to use this knowledge to provide design recommendations

3. THE VALENTINE'S DAY EARTHQUAKE

On 14 February 2016 at 1:13 p.m., a magnitude 5.7 earthquake hit the eastern side of Christchurch at a focal depth of 8 km. This earthquake is known as the Valentine's Day Earthquake. Localised liquefaction manifestations occurred in parts of the eastern suburbs of Christchurch. The characteristics of the Valentine's Day Earthquake are summarised in Table 1.

Table 1. Characteristics of the Valentine's Day Earthquake

Date	Magnitude	Estimated Peak Ground Velocity [PGV][1]	Estimated Horizontal Peak Ground Acceleration [PGA][1]	Epicentre depth (km)
14 Feb 2016	M_w 5.7	0.28 - 0.50 m/s	0.19 - 0.21 g	8

[1] The range reported is for the study area only and was sourced from www.geonet.org.nz strong ground motion database at the NBLC (New Brighton Library) and HPSC (Hulverstone Drive Pumping Station) seismograph sites located 2 km and 4 km from the epicentre of the Earthquake, respectively.

Given that the PGAs of this earthquake were very close to the design values for SLS (i.e. M_w 6.0 and PGA of 0.19 g), recommended by MBIE, this earthquake presents an opportunity to assess the seismic performance of wastewater networks during a SLS equivalent event.

4. DATA CAPTURE

4.1 SELECTION OF PIPELINES

The selection of the wastewater pipelines for this study relied heavily on the availability of good quality and easily interpreted CCTV inspection data sourced from the Christchurch City Council (CCC)/Stronger Christchurch Infrastructure Rebuild Team (SCIRT) database. Critical data for the study includes asset characteristics, construction details, CCTV recordings and records of surface evidence of liquefaction triggering. Criteria used to select wastewater pipelines for this study are as below:

- Pipes are located within North New Brighton and Parklands as liquefaction was observed in these suburbs and the recorded PGA and PGV values are approximate equivalent to SLS events

- Pipes were damaged during the 2010-2011 Canterbury Earthquake Sequence (CES), but the severity of the damage did not reach the threshold of decisions on pipe renewal/repair, based on the Infrastructure Recovery Technical Standards and Guidelines (IRTSG 3.1, 2012) and Guideline 043 (SCIRT, 2013)
- CCTV footage is available prior to the Valentine's Day Earthquake (but after the 23 December 2011 earthquake) and substantial repairs/replacement have not been completed on the pipeline following this CCTV inspection. The CCTV footage and reporting were completed by contractors in accordance with New

Zealand Gravity Pipe Inspection Manual (New Zealand Water and Wastes Association (NZWWA), 2006)

- A range of different pipe materials to be covered
- DN150 mm gravity wastewater pipes selected for consistency

A small sample of 26 gravity pipelines was selected from the Christchurch wastewater network, refer Figure 1 for study areas and pipeline locations. The observations of liquefaction after the earthquake were obtained from the New Zealand Geotechnical Database (Liquefaction and lateral spread observations for 14 February 2016 Earthquake). CCTV footage of the 26 pipelines were provided by CCC, together with log sheets where professional assessors have interpreted the CCTV footage and coded defects to the New Zealand Gravity Pipe Inspection Manual (NZWWA, 2006). The CCTV footage of the selected pipelines was validated against the log sheets provided and reasonable agreement was found between the footage and log sheets.

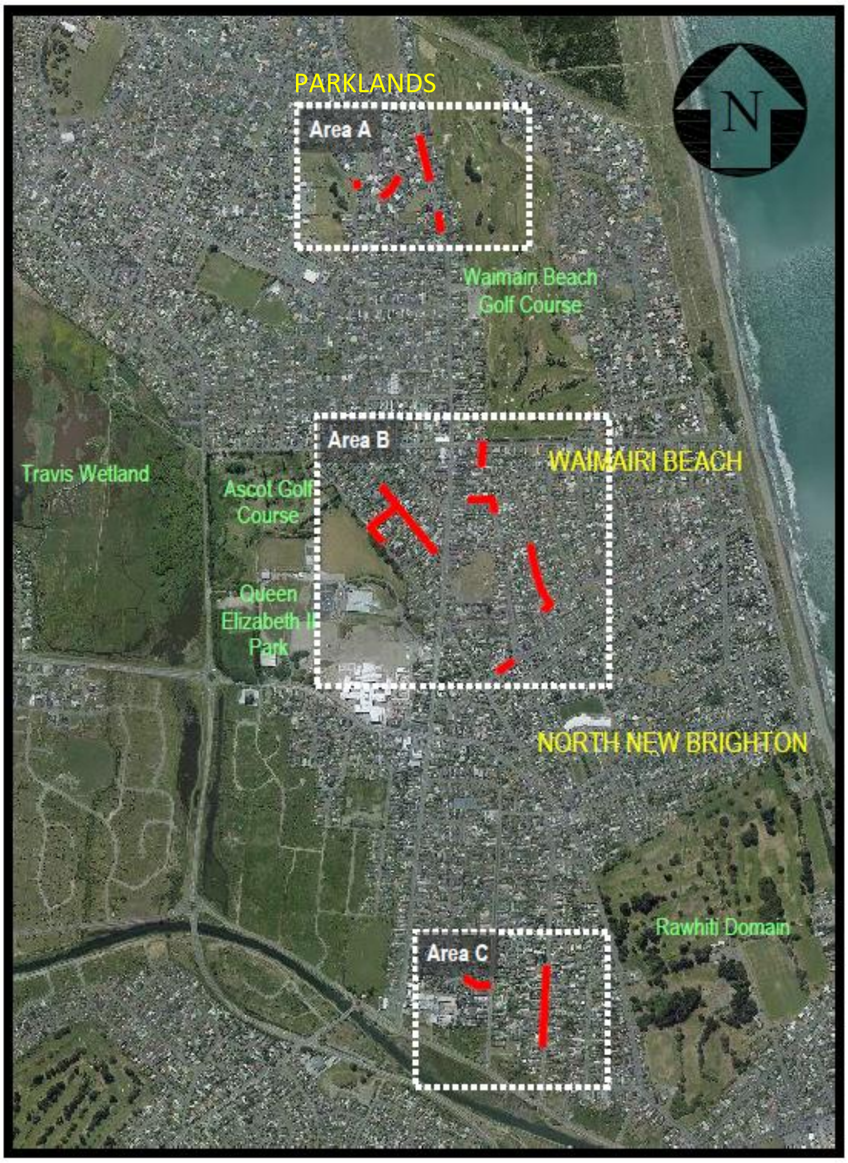

Figure 1. Location of project study areas and wastewater pipelines

4.2 PROPERTIES OF SELECTED PIPELINES

The selected 26 pipelines with a total pipe length of 1646.6m was assessed for the study. 78% of the pipelines selected were constructed from spun concrete (CS), which were constructed between 1954 and 1975 (i.e. 41 to 62 years old). Polyvinyl Chloride (PVC) pipes comprised 17% of the assessed pipe and were constructed between 2002 and 2004 (i.e. 12 to 14 years old). Asbestos cement (AC) pipes made up the remaining 5% of the studied length of pipe and were constructed in 1974 (i.e. 42 years old). All selected pipelines have a nominal diameter of 150mm. Figure 2 below summarises the properties of the selected pipe in this study.

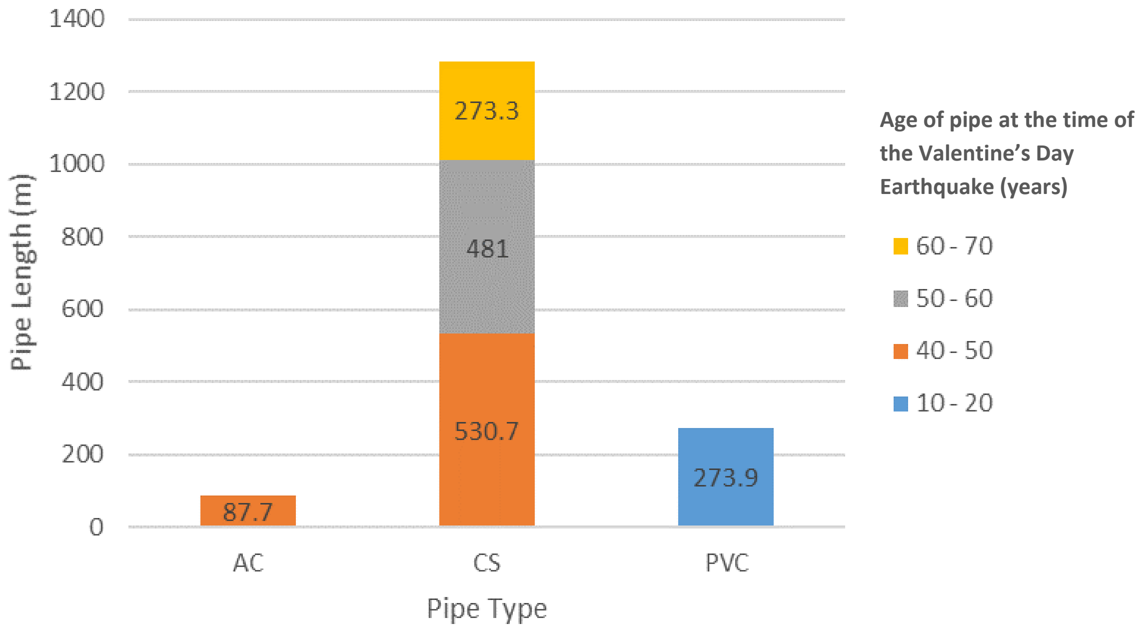

Figure 2. Pipe type and age of the selected wastewater pipelines

Among the selected wastewater pipelines, 36% are in the areas where liquefaction ejecta was identified. It is of note that the absence of liquefaction ejecta does not necessarily mean that liquefaction did not occurred. Table 2 below summarises the pipelines in areas where evidence of liquefaction was observed at the surface and where it was not observed.

Table 2. Distribution of pipelines across areas where surface evidence of liquefaction was and was not observed

Pipe material	Pipe length in areas where liquefaction ejecta was not observed (m)	Pipe length in areas where liquefaction ejecta was observed (m)
Asbestos Cement (AC)	0	87.7
Concrete (CS)	957.4	327.6
Polyvinyl Chloride (PVC)	93.6	180.3
Total	1051.0	595.6

4.3 CATEGORISATION OF PIPE PERFORMANCE

The log sheets and CCTV footage for the 26 pipelines studied were reviewed to identify condition change for the existing defects and development of new defects. The comparison review grouped observations into the following categories: No Change, Worse, New, Better, Cannot Identify. In the cases where existing defects could not be inspected either pre- or post-earthquake, due to concealment by water flow within the pipes or low video resolution, the defects were categorised as Cannot Identify.

Structural pipe defects are the focus of the study. Other pipeline features, such as debris, encrustation deposits and obstructions have effects on the functionality of the pipeline, however they are not directly caused by seismic events. Hence, they were excluded from the analysis. Some structural defects, such as dips along the pipeline and surface damage on the pipes, were also excluded. Pipe dip defects have been excluded from the study due to the lack of profilometer data. Surface damage defects are generally associated with pipe surface degradation over time due to abrasive erosion or chemical corrosion and are less likely to be influenced by an earthquake. As a result, this defect type was also excluded from the analysis.

For analysis purpose, all structural defects in this study were categorised into three groups as shown in Table 3. The causes of these defects are likely to be induced by the Valentine's Day Earthquake, with the potential causes examined on a case by case basis.

Table 3. Categorisation of physical defects

Category	Defect type
Lateral pipe related structural defects	Lateral sealing fault and other lateral problem, such as infiltration
Pipe related structural defects	Circumferential crack, longitudinal crack, multiple cracks, deformed flexible pipe
Pipe joint related structural defects	Displaced joint, faulty joint, open joint

5. ANALYSIS AND DISCUSSION

5.1 OVERVIEW OF PIPE PERFORMANCE BASED ON DEFECT CATEGORISATION

A total of 99 wastewater lateral structural defects were observed within the selected pipelines, of which 88% had No Change to the severity of defect. The percentages of New and Worsening lateral issues were 2% and 6%, respectively. Around 4% of lateral defects could not be coded due to the defects being obscured by water.

A total of 35 pipe related structural defects were observed. The pipe related structural defects included cracks within pipe walls (longitudinal and circumferential) and deformed pipes. 19 defects, accounting for 54% of the total observed, did not record a change in severity of the defect. The percentages of New and Worse defects were 17% and 6%, respectively. Approximately 23% of pipe related defects could not be coded due to either defects being covered by water or poor video quality.

There were 75 pipe joint related structural defects observed within the selected pipelines, of which almost 75% had No Change to severity of the defects and 19% could not be coded due to defects being covered by water or poor video quality. Approximately 6% of the defects had a Worse condition in the post-earthquake CCTV footage. There were no New joint related defects identified.

Figures 3 to 5 below summarise the change in defect severity between the pre- and post-earthquake CCTV datasets.

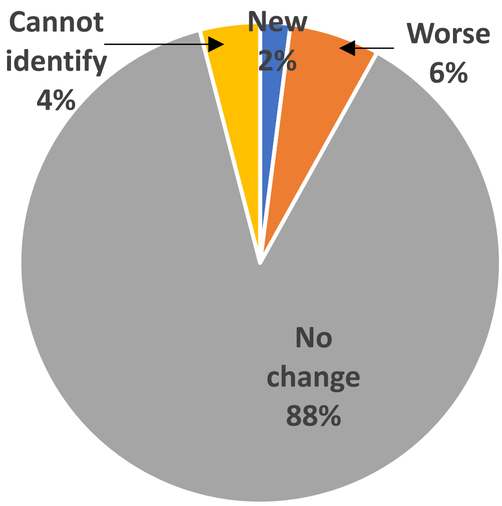

Figure 3. Percentage of lateral related defects

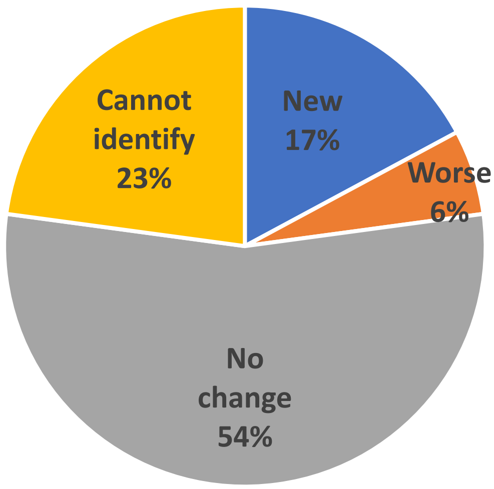

Figure 4. Percentage of pipe related defects

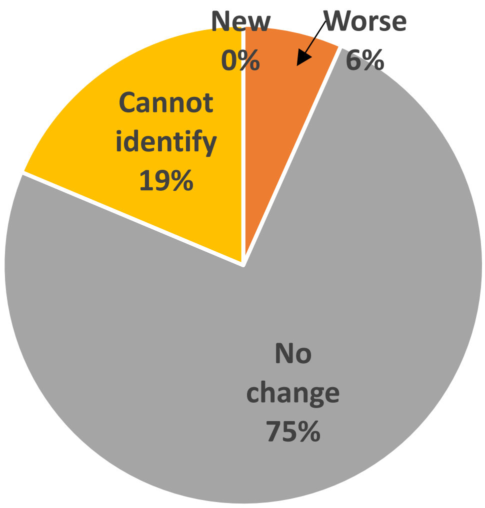

Figure 5. Percentage of pipe joint related defects

5.2 PIPE PERFORMANCE BASED ON MATERIAL TYPE

The overall defect change rate, defined as the number of observed physical defect change over the total length of the selected wastewater pipelines, by material type, is shown in Table 4. Due to limited sample size for AC pipes, a conclusion cannot be drawn and hence AC pipes were excluded from further assessment. As Table 4 shows, concrete pipes have a higher defect change rate compared to PVC pipes. This difference in performance between small diameter concrete and PVC pipes is consistent with the observations from the 2010-2011 CES. This is likely due to the concrete being more brittle in nature and relatively old in pipe age. Concrete pipes were all laid before 1980 and in some cases were around 60 years old, whereas the PVC pipes were all laid after 2000.

Table 4. New defects for selected wastewater pipes during the Valentine’s Day Earthquake

Pipe material	No. of defect change	Defect change rate per km	No. of defect change in areas where liquefaction ejecta was not observed [Defect change rate per km]	No. of defect change in Areas where liquefaction ejecta was observed [Defect change rate per km]
Concrete	20	15.6	16 [16.7]	4 [12.2]
PVC	1	3.7	0 [0]	1 [5.5]

As shown in Table 4, the defect change rate is higher for CS pipes located in areas where liquefaction ejecta was not observed compared to CS pipes located in areas where liquefaction ejecta was observed. To understand the type of defect and how the Valentine’s Day Earthquake has impacted the pipelines, assessment was undertaken based on defect categorisation. Table 5 summarises the type and quantity of defects in CS pipes. As shown in Table 5 below, structural defects identified within pipes in areas where liquefaction ejecta was observed all relate to the main pipe, such as circumferential cracks. For CS pipes located in areas where liquefaction ejecta was not observed, structural defects tend to be related to either lateral pipes (50%) or pipe joint (31%). 80% of the defects identified within pipelines in areas where liquefaction ejecta was not observed are existing but degraded, whereas all defects identified within pipes in areas where liquefaction ejecta was observed are New.

Three out of four of the New defects for CS pipes within areas where surface evidence of liquefaction was observed were located immediately adjacent to each other (within 0.5m length of pipe), so are most likely associated with a single failure mechanism/event. For this reason, these three structural defects can be grouped and assessed as a single defect. This gives a revised New defect rate of 6 per kilometre (km) for CS pipes located within areas where liquefaction ejecta was observed. This revised New defect rate is substantially higher than what would be expected for shaking induced damage alone, indicating that ground deformation (settlement) has dominated the New structural damage.

Table 5. Concrete pipes defect details

Location of pipe	Pipe related structural defects		Pipe joint related structural defects		Lateral pipe related structural defects	
	New	Worse	New	Worse	New	Worse
Areas where no surface evidence of liquefaction was observed	1	2	0	5	2	6
Areas where surface evidence of liquefaction was observed	4	0	0	0	0	0

PVC pipes in areas where no surface evidence of liquefaction was observed performed well during the Valentine's Day Earthquake, with no defect change identified. In areas where surface evidence of liquefaction was observed, only one New defect was identified, which was caused by pipe deformation. Whilst this indicates that young and flexible pipes (i.e. PVC) exhibit better performance compared to old and brittle CS pipes, the sample size for the PVC pipes is small and caution should be used in drawing conclusions for this pipe type.

5.3 PIPE PERFORMANCE BASED ON PIPE AGE

No clear relationship between pipe age and pipe performance was identified in this study. PVC pipes in this study were laid between 2002 and 2004; CS were between 1954 and 1975 (Figure 6).

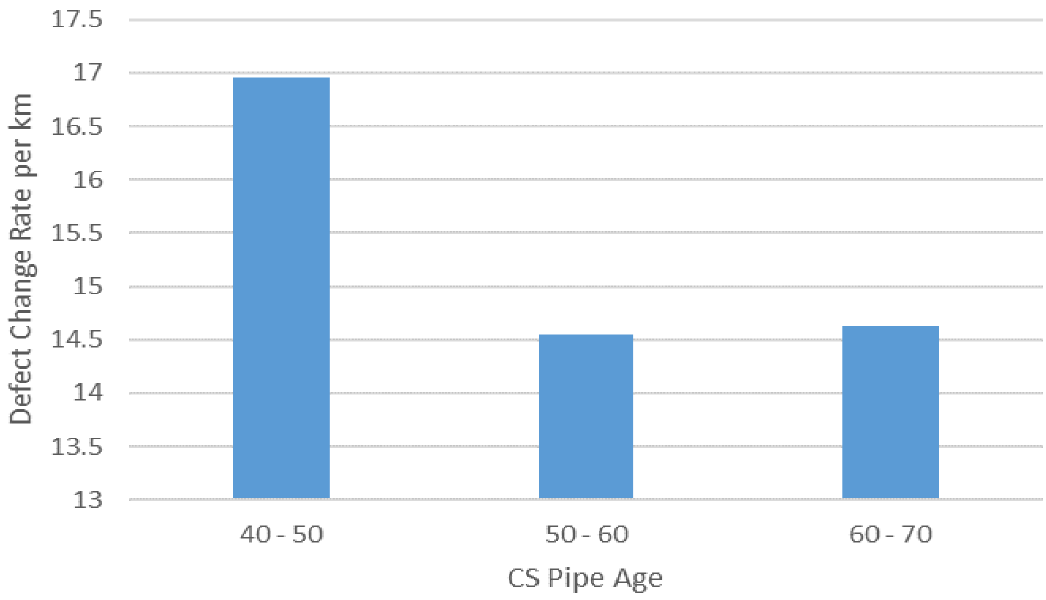

Figure 6. Defect change rate based on pipe age

5. KEY FINDINGS AND LIMITATIONS

The findings of this study are as follows:

- The Valentine's Day Earthquake did cause a change in the CS pipe condition, with increased circumferential cracking noted in areas where surface liquefaction had been observed, and defects to laterals and pipe joints where surface liquefaction had not been observed. A 10% increase in structural defects were identified as being either New or Worsened due to the Valentine's Day Earthquake.
- PVC pipes appeared to perform better during the Valentine's Day Earthquake with only one defect change identified (equivalent to an increase of 3.7 defects per km), noting that this is based on limited data. In comparison, concrete pipes have much higher defect change rate (i.e. 15.6 per km). This is likely due to the ductile behaviour of PVC pipes and relatively younger age compared to the CS pipes.
- Defects identified in the CS pipes within areas where surface evidence of liquefaction was observed tend to be New defects, whereas defects identified within areas where liquefaction was not observed at the surface tend to be existing defects that have worsened due to the Valentine's Day Earthquake.
- There is no clear relationship observed between pipe age and pipe performance for CS pipes.

It is worth noting that the abovementioned findings are generalised based on the observation of the survey records of 26 selected pipelines, considered to be a small statistical sample, and the findings may not be applicable to the entire network.

Review of the CCTV data indicates that this earthquake caused a number of new dips to develop, being observations of local pooling of water within the pipeline. However, it is not possible to quantify change based on visual assessment, and pooled water obscured possible defects. According to the experience from the Christchurch rebuilding, profilometer is a useful tool to investigate dips along pipelines. Nine pipes were examined by profilometer surveys prior to the Valentine's Day Earthquake. However, no further profilometer surveys were undertaken following the earthquake, hence it has not been possible to undertake a comparison and draw any conclusions. Further profilometer surveys would assist in understanding the changes to dips.

Due to the limited number of sampled pipelines, it is possible that profound conclusions cannot be drawn or reliable conclusions may not be able to be satisfactorily determined. In cases where conclusions were drawn, they may not be widely applicable across New Zealand due to the limited size of the sample.

ACKNOWLEDGEMENTS

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