Data analysis and laboratory investigation of the behaviour of pipes buried in reactive clay

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ABSTRACT

Buried pipe failures due to ground movement is a common problem which leads to the loss of water or gas supply in urban areas. Statistical analysis of pipe asset data indicates that pipe failure is correlated to ground movement caused by the shrinking and swelling of reactive soils due to seasonal climatic variations. This problem was studied in a large scale laboratory experiment, where a two meter long polyethylene pipe is buried in a box filled with reactive clay soil. The clay soil was subjected to capillary wetting conditions by supplying water to the bottom of the box, simulating seasonal climatic change by increasing the soil moisture content. Deformation of the pipe during soil movement was measured by a series of strain gauges attached to the pipe. Soil temperature, moisture content and suction were measured using the thermocouples, theta probes and thermal matric sensors respectively. This paper reports the statistical analysis of field data and the experimental setup for studying buried pipe failures.

1 INTRODUCTION

The buried reticulation pipe system in Australia extends over hundreds of thousands of kilometres. Failures of these pipes can lead to the loss of water and gas services, having a negative social and economic impact. Pipe failures can be caused by one or a combination of factors, including ageing, corrosion, improper installation, earthquakes, third party damage and ground movement. There is clear evidence that the ground movement which results in pipe failure is a result of shrinkage and swelling of soil. The shrinkage and swelling of soil is caused by moisture content changes due to seasonal variations in climate.

The detrimental affect of reactive soil has been reported on in various part of the world where the shrinking and swelling of soil have introduced cracks in pavement and buildings. When soil moisture content fluctuates, matric suction will change within the soil causing it to shrink or swell with decreasing or increasing moisture content respectively. Usually, ground movement in reactive soils is not uniform due to factors including variations in soil profile, change in ground cover, the presence of trees, and point sources of water such as small pipe leaks. Differential ground movement imposes stresses on pipes and can potentially lead to failure. In order to study this problem, an analysis of field pipe failure data and a large scale laboratory experiment were conducted. Results of the analysis and details of the experimental setup are presented in this paper.

2 CLASSIFICATION OF REACTIVE SOIL

The shrinking and swelling characteristic of reactive soils is related to change in moisture content. Soils are primarily wetted by rainfall but are also affected by pipe leakage and human activity (e.g.

garden watering). The drying of soils occurs primarily by evaporation; however moisture extraction by large trees also reduces the soil moisture content. As the wetting and drying of soils occurs mainly due to rainfall and evaporation, movement of reactive soils will only occur for the first few metres below the ground surface where the soil suction is influenced by the prevailing climate, e.g. the depth of soil suction change. The depth of the soil suction change for design purposes can be obtained from the climatic map of Victoria (Figure 1) published by Australian Standards (AS2870, 1996). The map designates five climatic zones; the depths of suction change for each zone are given in the brackets.

The potential ground movement of a site can be classified using the Australia Standards (AS2870, 1996). Sites are classified with reference to their reactivity from no movement to extreme. The classification is dependant on the site soil profile and climatic zone. Table 1 gives the site reactivity classifications for Victoria. According to this classification system, the extremely reactive soils in Victoria mainly comprise of basaltic clays and limestone clays. Basaltic clay consists of Newer and Older Volcanics, and limestone clays belong to the Shepparton Formation (Birch, 2003). The Newer Volcanic and Shepparton Formation are primarily situated in the western region of Victoria while the Older Volcanics are situated in the Melbourne city area. These extremely reactive soils are predominantly located within climatic zones 3 and 4.

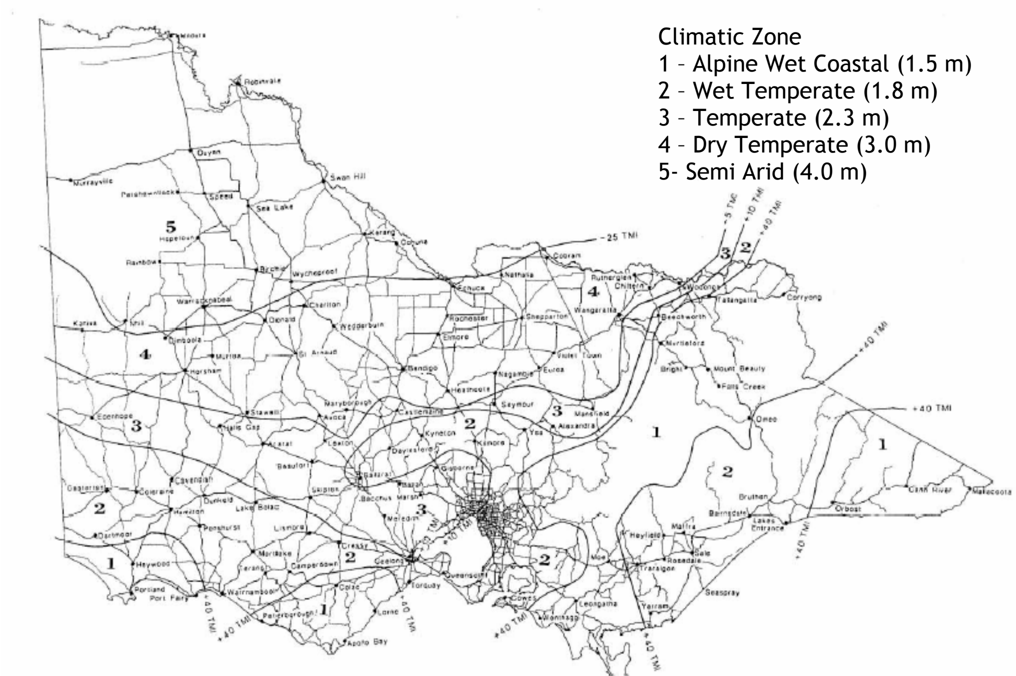

Figure 1: Climatic zones of Victoria (AS2870 1996)

Soil Profile	Zone 1	Zone 2	Zone 3	Zone 4 & 5
Basaltic Clays	Moderate	High	High to Extreme	Extreme
Non – Basaltic Residual Clays	Moderate	Moderate	Moderate to High	Moderate to High
Limestone Clays	High	High	High to Extreme	Extreme
Quaternary Alluvials and Tertiary Sediments (silts or sands overlying clays)	No movement	Not reactive to Slightly	Slightly	Slightly to Moderate
Quaternary Alluvials and Tertiary Sediments (clay depth greater than Hs)	Slightly	Moderate	Moderate to High	Moderate to Extreme

Table 1: Classification of Victorian soil reactivity dependent on climatic zone (AS2870 1996)

3 DATA ANALYSIS

The statistical analysis was undertaken using pipe failure data from City West Water (CWW) Ltd. CWW supplies water to Melbourne's central business district and the inner and western suburbs (Figure 2) through a 3,615 km pipe network. CWW's western distribution area is located in a region of reactive soils from the Newer Volcanics formation, while part of the city distribution area is located in a region of reactive soils from the Older Volcanic formation. For the statistical analysis these areas were considered as reactive soil zones, whereas other areas containing less reactive soils were considered as non-reactive soil zones, even though they will also exhibit shrink and swell behaviour to some extent.

CWW's pipe management system is recorded as two data sets, asset data and failure data. The asset data contains details of the entire pipe asset including pipe ID, installation date, location, material types, sizes etc. The failure data contains information on which asset had failed, the time the failure was detected and failure type. There were seventeen different pipe material types in total, (Figure 3), with cast iron constituting approximately 32% of the pipe assets in service. Cast iron was also the oldest pipe material in the network, the data indicates that cast iron pipes installed in the 1800's are still in use today. The flexible plastic pipes such as polyethylene, PVC and UPVC constitute approximately 33% of current pipe assets.

Analysis of asset and failure data in relation to soil reactivity and pipe length shows that 67% of CWW's pipe assets are installed in a reactive soil zone, and these assets account for 75% of pipe failures. There are clear evident that failure rate (Table 2) in reactive soil is higher than non-reactive soil for the eight years of failure pipe records. It is evident that soil reactivity has some influence on pipe failure however other factors including physical properties of pipe are also important.

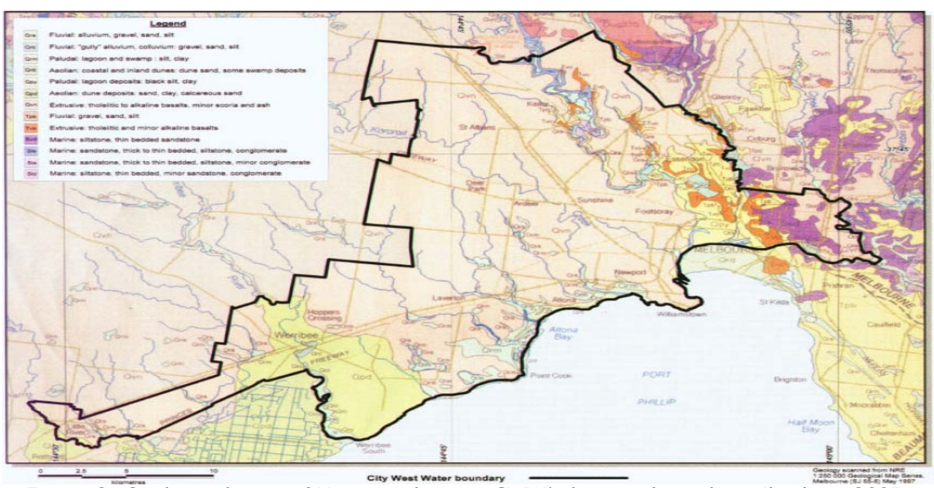

Figure 2: Geological map of Victoria showing CWW's licence boundary (Ibrahimi 2005)

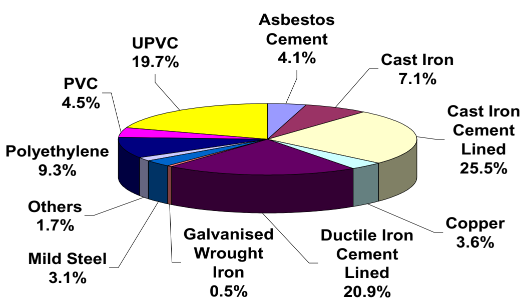

Figure 3: Pipe asset material

	Failure rate (Fail/100km)	
Year	Reactive	Non-Reactive
1996	26.8	19.5
1997	182.5	100.3
1998	119.8	69.6
1999	68.9	50.6
2000	71.6	65.0
2001	88.5	58.4
2002	63.3	49.6
2003	113.8	69.8
2004	60.7	43.0

Table 2: Failure rate of CWW's pipe network

Change in ground moisture content has a more extreme effect in reactive soils than in non-reactive soils, therefore seasonal change in climate conditions may lead to variation in failure rates between summer and winter (Ibrahimi, 2005). Figure 4 shows the monthly failure rate in reactive soil from August 1996 to July 2004. The graph indicates that there is a discernable seasonal variation in pipe failures. The monthly average failure shows more failures occurring during the summer in January, February and March than in winter during August, September and October. On average, there were around two times more failures in summer than winter, confirming that pipe failures are affected by climate. It is worth noting that in the summer of 1996/97, 1997/98 and 2002/03 there was large difference in pipe failures rates between summer and winter, while seasonal variation was minimal in 1998/99 and 2001/02. The average monthly failure rate for non-reactive soil was also plotted to verify the effect of seasonal variation in reactive and non-reactive soil. The net evaporation plotted in Figure 5 shows a relatively wetter summer during 1998/99 and 2001/02, providing evidence that the difference in failure rate between years was caused by the change in soil moisture content due to seasonal changes of local rainfall and evaporation. The data suggest that more failures will occur in a dry summer than a wet one.

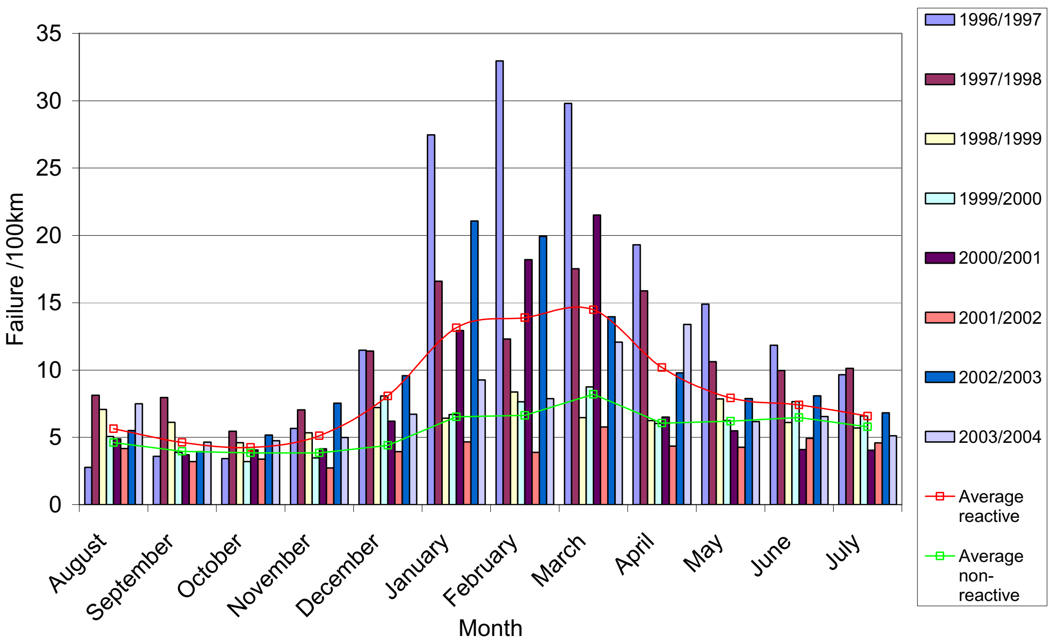

Figure 4: CWW monthly pipe failure rate in reactive soil

The climatic variation of pipe failures may be better understood by comparing the pipe failures to net evaporation. Net evaporation is the loss of moisture from the soil by evaporation, the values were calculated in millimeters. Net evaporation can be calculated by subtracting observed rainfall from gross evaporation where positive and negative values indicate dry and wet ground conditions respectively. Monthly rainfall and evaporation data provided by the Victoria Climate and Consultancy Section of the Bureau of Meteorology were used in the calculation. The monthly net evaporation from August 1996 through to August 2004 has been plotted in Figure 5 with the corresponding failure rate in reactive and non-reactive soil. Trewin and Jones (2004) stated that rainfall totals from October 1996 have been at or near the lowest on record since 1900 for a period of eight years in Southern Victoria. Large scale pipe failure events can be identified in Figure 5 as Peak1, 2 and 3, where up to 3 times more failures had occurred in the summers of 1996/97, 2000/01 and 2002/03 than other summers. The net evaporation shows that extremely dry climate during these summers were correlated to increase in pipe failures.

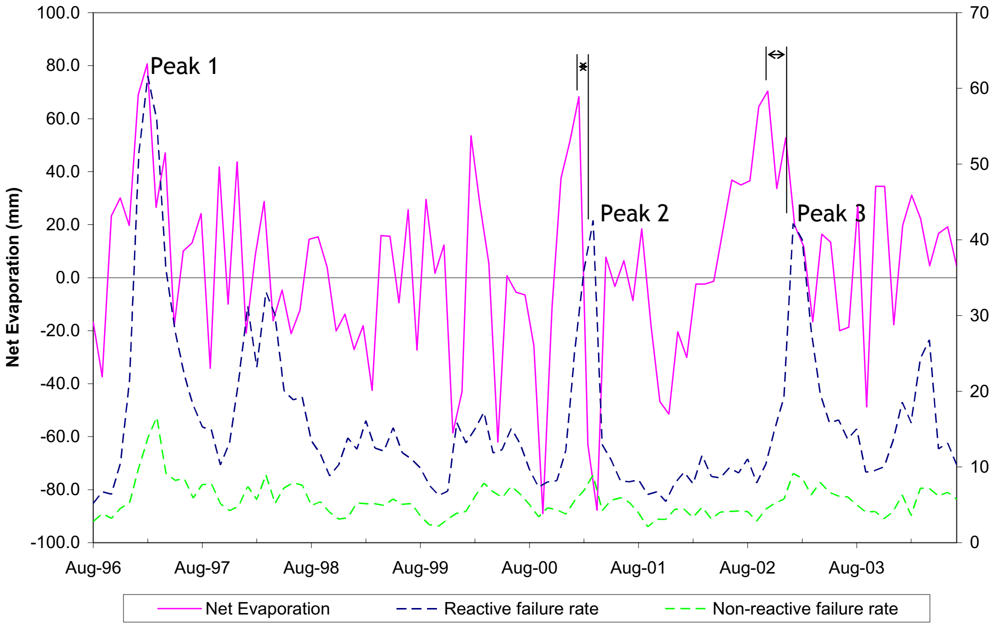

Figure 5: Net evaporation and CWW pipe failure

4 LABORATORY INVESTIGATION

4.1 Soil classification

The aim of the laboratory investigation was to gain understanding of the behaviour of pipes buried in reactive soils. The soil used for the experiment was Merri Creek clay. Merri Creek is located at the northeast side of Melbourne, and is a tributary of the Yarra River (Mitchell and Clark, 1991). The clay soil was mainly developed from basalt flows of the Newer Volcanics, which is same as the soil formation located within the CWW western distribution area. However, weathering and re-distribution by drainage and erosion from nearby sedimentary outcrops may also have contributed to the soil development. Merri Creek clay is an extremely heavy and sticky grey to black clay soil, mainly associated with drainage systems. These soils do not generally develop a pronounced Gilgai surface, but nevertheless crack with a blocky structure on drying (Frood, 1992). The soil properties were classified according to Australian Standards (AS1289, 2000), giving results of liquid limit of 74%, a plasticity index of 41% and a linear shrinkage of 13%. The soil was classified as a very high plasticity soil material with high shrinkage potential. The swelling oedometer test also showed the soil to have a maximum heave of 29% under free swelling. These findings verified the high shrink and swell characteristic of the clay soil, confirming its suitability for this investigation.

4.2 Experimental setup

The large scale experiment setup was designed to simulate the field pipe situation. A 2 metre pipe specimen was installed in a soil box (2 m long x 0.8 m wide x 1 m deep) filled with reactive Merri Creek clay (Figure 6). A polyethylene pipe was used for the experiment because it was more flexible than other pipe types, which allowed greater strains to be realised in order to obtain results of greater magnitude and reduced the effect of noise. A wooden frame, scoria and a layer of geotextile were fitted at the bottom of the box to support the soil and provided room for water flow at the base. A large scale Mariotte bottle was used to maintain the water table at the base of the soil, the soil was wetted by capillary action.

Soils movement was recorded using strain pots connected to steel rods buried below and above the pipe. The pipe deformation was measured using strain gauges attached to the pipe surface, each strain gauge was covered with underwater glue to protect them against the soil moisture. The box was instrumented to measure soil movement, moisture content variations using theta probes, soil suction variations using thermal matric sensors, and temperature variations using thermocouples. All of these apparatus were continuously monitored by data loggers.

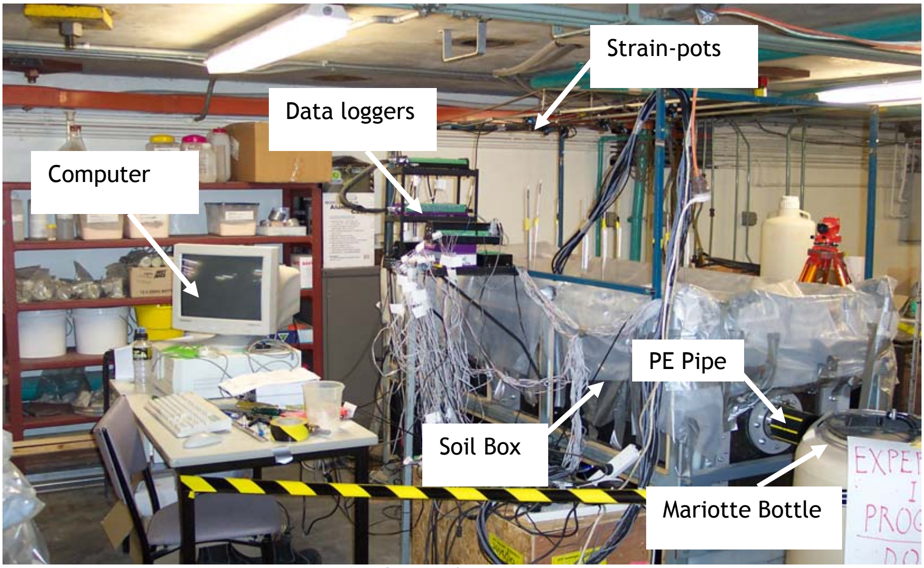

Figure 6: Photo of experiment setup

5 CONCLUSIONS

The analysis of City West Water's pipe data confirms that there is a clear relationship between pipe failure and the seasonal variation of soil moisture content. The most obvious example of this relationship is in reactive soils which are known to cause significant damage to buried pipes, not only in Victoria but around the world. This problem was studied in a large scale laboratory investigation. A large scale pipe testing rig was developed for studying the behaviour of pipes in reactive soils. Pipe and soil movement in a wetting event was simulated by increasing the water content of the soil. The results of the study will be reported in future publication.

6 ACKNOWLEDGEMENT

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