Impact of Seasonal Swell/Shrink Behavior of Soil on Buried Water Pipe Failures

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ABSTRACT: Unpredictable failures of buried water pipes have been identified as a common problem for utilities in Melbourne, Australia as well as in many other parts of the world. Statistically, about 4000 failures are being reported yearly in Melbourne. Though the exact timing of these failures is unpredictable, a clear relationship indicating peaks in dry summers is seen between the seasonal climate changes and pipe failure records, for Melbourne. Since more than 60% of the soils around the pipe network in Melbourne has been identified as expansive, the effect of swell/shrink behavior of soil with the seasonal climate changes on pipes has been accepted as a major reason for failures of small diameter (<300 mm) pipes in the region. This paper summarizes some of the factors affecting these failures as part of a detailed investigation to study the interaction between soil-pipe and climate changes.

1 INTRODUCTION

Water is an essential requirement for any urban entity. Since clear water sources are not available everywhere, water should be cleaned, treated, stored at one place and then be distributed to individual house units and other service centers. In this sense, a transportation mode is required to carry water safely from storage locations to these locations. Pipe networks have been used commonly for this since long time ago. In cities like Melbourne and Sydney, pipe networks are being in service for the last 150 years. Therefore a proper maintenance is required to ensure the functionality of these pipe networks to sustain a quality service. This is one of the major tasks costing millions of dollars in every year to be carried out by all water utilities.

1.1 *Melbourne pipe network*

Melbourne water pipe network is one of the oldest pipe systems in Australia, which fulfils water requirements of about 4.25 million people who live in Melbourne metropolitan areas. *Melbourne Water* is the major water supplier to the above population and the distribution is accompanied by three retail water authorities. They are *City West Water Ltd*., *South East Water Ltd*. and *Yarra Valley Water*. These authorities owns approximately 12000 km of pipe assets with different diameters from 25mm to 400mm. The oldest construction date of the pipe network is recorded as 1/1/1840 by Gould (2011). Most of these old pipes are made of brittle materials such as cast iron, galvanised wrought iron and asbestos cement.

1.2 *Pipe failures*

Failure of a water pipe means the pipe is no longer able to transport water to its destination under the required pressure. This can be due to a pipe breakage or a leak. A buried pipe can be treated as a structure which is with certain strength and bearing some internal and external loads. Both applied load and the strength are functions of time. With material defects such as corrosion, the overall strength can reduce with the time. Deterministically, whenever the load on the pipe exceeds its strength, a failure is expected.

Loads on the pipe can be divided into two main categories. They are internal (loads on the inner surface) and external (loads on the outer surface) loads. The major internal load on the pipe is due to the water pressure. External loads come from the soil overburden pressure, traffic loads, loads due to swell/shrink behavior of reactive soils, etc.

Since the pipe network in Melbourne is considerably older, pipes may have deteriorated and high frequency of failures is experienced. Statistical analyses of these reported pipe failures have been used to identify certain failure patterns and likely causes (Chan (2013), Gould (2011)). This paper focuses on one of the major hypotheses, which is the effect of shrink/swell effect of reactive soil surrounding the buried small diameter (<300mm) water pipes in Melbourne on their failure rates and patterns.

2 STATISTICAL ANALYSIS OF MELBOURNE PIPE FAILURE DATA

Chan (2013) and Gould (2011) have presented following statistical analyses for reported pipe failures in Melbourne metropolitan area. The data for the analyses were taken from the maintenance records of City West Water Ltd. (CWW) and South East Water Ltd. (SEWL). A data set was selected for the analyses by removing unclear records from the raw data. Table 1 and 2 show a summary of selected pipe asset data and failure data used by Gould respectively.

Table 1. Selected pipe asset data by Gould (2011)

Authority	No. of Assets	Length of assets (km)	Earliest construction date	Most recent construction date
CWW	77,790	4,089.5	6/4/1856	31/8/2006
SEWL	135,101	7,917.0	1/1/1860	31/8/2006
Total	212,891	12,006.5	6/4/1856	31/8/2006

Table 2. Selected pipe failure data by Gould (2011)

Authority	Number of Failures	Earliest Failure Date	Most Recent Failure Date
CWW	26,041	01/09/1996	31/08/2006
SEWL	13,646	01/09/1996	31/08/2006
Total	39,687	01/09/1996	31/08/2006

In order to identify possible reasons and certain patterns of these failures, above data have been analysed with a number of factors affecting the pipe failures. Kleiner and Rajani (2002) have presented some factors that directly affect pipe failures (see Table 3).

From these factors, pipe material, diameter, pipe age, soil type/moisture and water pressure have been considered in Gould (2011), because of the availability of information.

Table 3. Factors affecting pipe failures by Kleiner and Rajani (2002)

Static factors	Dynamic factors	Operational factors
Material	Age	Replacement rates
Diameter	Temperatures (soil, water)	Cathodic protection
Wall thickness	Soil moisture	Water pressure
Soil (backfill) characteristics	Bedding condition	
Installation	Dynamic loadings	

2.1 *Pipe diameter and material*

The statistical data analysed by Gould (2011) shows 93% of the considered pipe assets are small diameter (<300mm) pipes and only 7% is large diameter (>300mm). This is due to the use of large diameter pipes (also known as distribution mains or critical mains) is limited only for carrying water from storages to local distribution points. In material wise, 33% of the pipe network is made of cast iron, 24% is PVC and 16% is Asbestos Concrete. Following the majority of the pipe assets, the failure data also show the highest failure rate (no. of failures per 100km per year) for small diameter cast iron pipes (60 failures/100km/year). Also it shows that for most of the materials, the failure rate increases as the pipe diameter decreases.

2.2 *Pipe age*

The pipe age significantly affects the pipe failure rates, especially for the cast iron and asbestos cement pipes (Gould, 2011). This may be due to few reasons. Most of the old (aged) pipes are made of these two materials. Also the possibility potential to material deterioration such as by corrosion is relatively high for these materials. Therefore the pipe age is directly affecting the strength of the pipe, which leads to high failure possibilities for these aged pipes.

2.3 *Soil type*

The soil type is affecting the pipe failures as a dynamic factor. This factor is critical when a pipe has been buried in reactive soils. The reactive soils are clayey soils that show significant changes in its volume due to moisture content variations. They tend to swell on wetting and shrink on drying. When a pipeline is buried in such a soil, it tends to impose some movements on the pipe as the soil moves with its volume change. This can create some additional stresses on the pipe.

As shown in Fig. 1, more than 60% of Victorian soils are rated as very or moderately expansive. This means the majority of the pipe network is laid in those reactive soil zones. Fig. 2 confirms this as the length of assets in stable soils (ST) is very low compared to assets in expansive soils (VE, ME, EX, SE).

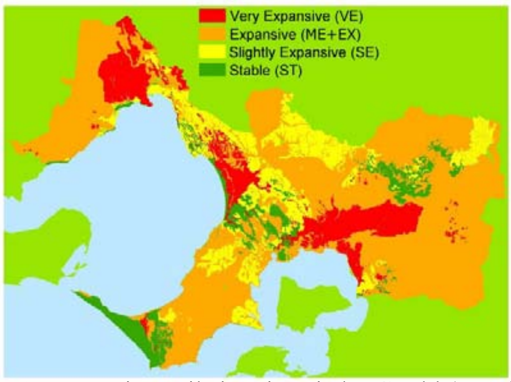

Fig 1. Expansive soils in Victoria by Gould (2011)

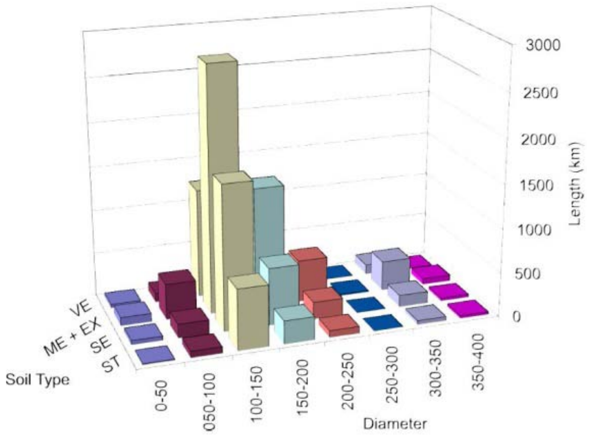

Fig 2. Pipe assets in expansive soils by Gould (2011)

Fig. 3, shows that the highest failure rate is also for very to moderately expansive soils. It can be clearly seen that the failure rate is increasing in expansive soils as the diameter decreases. As shown in Fig. 3, the highest failure rate corresponds to very expansive soils (VE) and 50-100mm, 100-150mm diameter groups show the significance of the effect of soil reactivity for small diameter pipe failures. Even though the lengths of assets are very small for that parameter combination, it represents the highest the failure rate.

It is a clear indication of the influence of soil reactivity on the pipe failures in Melbourne (especially for small diameter pipes).

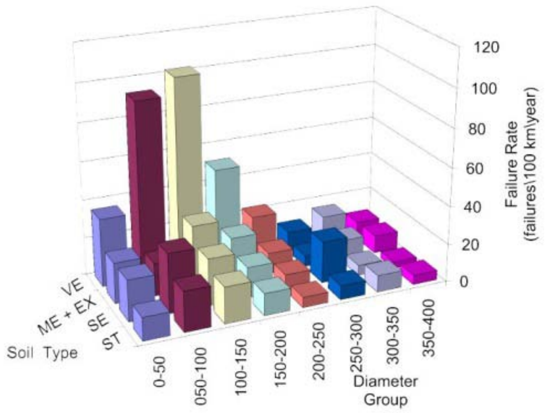

Fig. 3 Pipe failure rates in expansive soils by Gould (2011)

2.4 *Soil moisture/climate effect*

The soil reactivity or the swell/shrink behavior is a function of the soil moisture variations. Since the soil moisture variation is related with climate changes such as droughts, rainfalls and seasonal changes, the variation of pipe failure rates with climate changes is expected to follow a certain pattern. Intra year pipe failure rates presented by Gould (2011) (see fig 4) indicates a common variation for failure rates in all 10 years. This shows the failure rate is peaking in the period of January-March, which is the driest part of the year (i.e., having the lowest soil moisture).

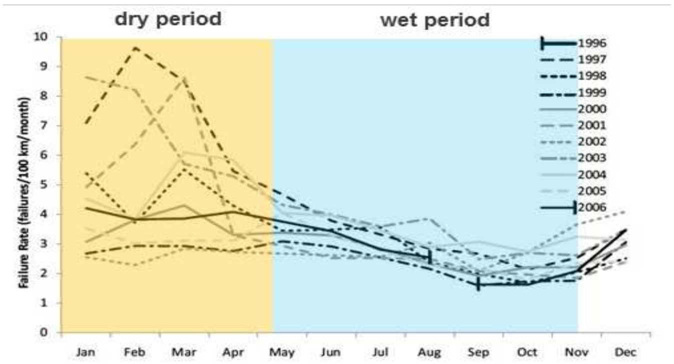

Fig 4. Intra year pipe failure variation by Gould (2011)

Since the soil moisture and hence the soil reactivity is the only fact that can vary with the seasonal climate changes (no freezing is present in Melbourne), this intra year variation of failure rates confirms the significance of the swell/shrink behavior of reactive soils for the pipe failures in Melbourne.

However the reason for the peak failures in dry summers is not clear in current literature and this is identified as one of the major research gaps to be filled.

3 FIELD OBSERVATIONS

The effect of soil reactivity on a buried pipe has been investigated in laboratory by Chan (2008). A pipe has been placed in a box filled with expansive soils and pipe movements and strains have been monitored with increasing soil moisture and an upward deflection of the pipe up to 15mm (100mm diameter, 2m long pipe). This observation confirms that the pressure coming from swelling soil can deform a pipe and can cause for the failure due to additional stresses creates by the deformation. A similar scenario has been observed by Chan (2013) for two in service buried pipes in selected field sites. Both pipes were instrumented with strain and displacement gauges and pipe movements were monitored continuously for two years with the seasonal climate changes. Fig. 5 shows the observed pipe movements in the dry periods and wet periods.

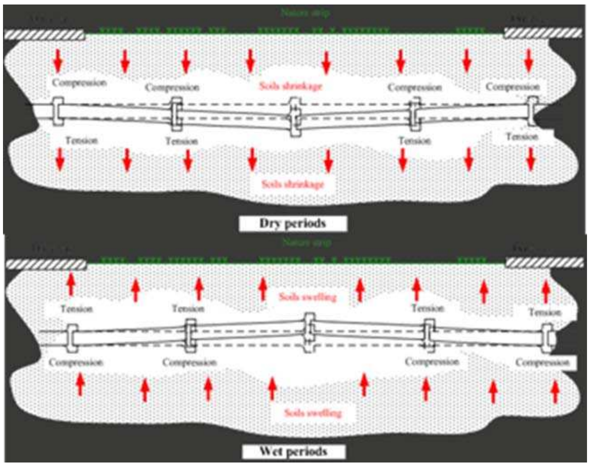

Fig 5. Field pipe movements observed by Chan (2013)

4 FURTHER INVESTIGATIONS

Both statistical analysis and field observations suggest that the swell/shrink behavior of reactive soil is a key factor for pipe failures in Melbourne. However the current investigations are not capable of explaining the reason for higher failure rates in the dry summers in Melbourne and also them unable to forecast the future failures adequately. Therefore, the requirement of further developing understanding and predictive capability of pipe failures linked with climate and soil type has been highlighted by all water authorities in Melbourne.

A research project has been initiated to investigate the relationship between soil moisture variations in reactive fields and resultant pipe failures. The primary goal of this research is to develop capability to quantify the stresses coming on the buried pipes due to soil reactivity subject to climate influence. A finite element model is being developed to simulate the swell/shrink behavior of reactive soil interaction with the pipe. The model is expected to be capable of determining stresses in a pipe for a given moisture change. Since the soil at pipe depth is believed to be unsaturated, the numerical model is being developed to capture the hydro-mechanical behavior of unsaturated soils.

Later, the stress estimations from the model are planned to be used in generalized data platform such as in a Geographical Information System (GIS). This will help identify possible failure locations for known soil moisture variations for strategic pipe asset management.

5 CONCLUSIONS

The following conclusions are made from the data analyses and field observations presented in this paper.

- The swell/shrink behavior of reactive soil is a major factor for pipe failures in Melbourne
- This soil effect is more significant on small diameter pipe failures, because of the low inertia to bend.
- The effect from soil drying is higher than the effect from wetting, theoretical basis for which needs further explanation.

Further investigation is proposed to study the soil-pipe interaction in detail and to develop capabilities to forecast failures from known soil moisture/climate changes.

ACKNOWLEDGMENTS

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