Maximum Permissible Pipe Loadings Part 2

Akimasa Mochizuki

Mohamed Elchalakani
Department of Civil, Environmental and Mining Engineering
University of Western Australia

Perry Beor
CEED Client: Water Corporation

Abstract

Adequate pipe cover prevents pipe assets failing from excessive traffic loading from the surface. Over time, water pipes and other utility pipelines have been installed and become intricate networks. Replacement of pipes due to other earthworks is complex, and sustainable asset management is essential. One of the measures used to overcome the need for replacement during new works is reducing pipe cover. If approved, this considerably lowers the cost of new works over these pipes. Ho investigated Cast Iron and Mild Steel last year, leaving PVC and Asbestos pipes to be researched by FEM and validation tests to establish sufficient pipe cover. Through these tests, this project found that 200mm pipe cover is too shallow to be permitted with appropriate safety factors, and 400mm cover is sufficient for both PVC and AC pipes.

1. Introduction

The Water Corporation (WC) operates its water and wastewater services with over 35,000 km of the water pipe and 17,000 km of sewers (Water Corporation, 2020). As part of its responsibility for those assets, it seeks to protect them from excessive internal and external loads. These pipes are mostly installed with a defined specific cover, being the clearance between the surface of the ground and the top of pipes, in order to avoid exposing them to excessive live load.

Over time the original cover may be reduced or undergo unanticipated excess loadings due to earthworks or construction. The Water Corporation approves or rejects proposals provided to cater for such scenarios by means of engineering solutions, cover requirement relaxations or alternative construction methods. In order to do this effectively, they require knowledge about the safety factors and specific requirements for these situations.

1.1 Current Water Corporation Practices and Previous Research

Cover requirements are found in Water Corporation's Design Standards and incorporate the purpose of the pipe, the size of the pipe and the location of the pipe relative to traffic infrastructures.

To deal with the issue, the first step is to measure the properties of in-situ pipes based on their different sizes and materials such as cast iron, mild steel, asbestos and PVC pipes. In 2020, Ho conducted the laboratory experiments for DN100 and 150 Cast Iron and Mild Steel Cement Lined (MSCL) pipes and derived the safety factors (Ho, 2020). In this year, Asbestos (AC) and Polyvinyl Chloride (PVC) pipes are tested as well as comparing analysis using a Finite Element (FE).

The concept of cover relaxation is to be expected since the current guidelines in WC are more strict than other water supplier's regulations. If WC eases the cover requirement, both WC and construction companies are allowed to complete the project without spending any extra cost and time. In addition, customers also share the benefit of not stopping water supply during construction. The reduced amount of construction leads to a better environment, and, especially for AC pipe, much-decreased risks since WC need not cut them when it comes time to replace. In addition, WC can ensure the safety of pipes that are accidentally in service in a shallower cover environment than the current criteria.

1.2 Pipe Testing Scope

All the samples for the loading test were sourced from recent removals from sites. In WC, three types of AC pipes, namely Sutton, Magnani and Mazza, have been in service and have different material properties (Scott & Marlow, 2016). Installed years were used to identify the latter two pipes since those pipes are difficult to distinguish by their appearance.

Regarding PVC, WC is currently installing Modified PVC(PVC-M), yet formerly they used unplasticised PVC (PVC – U). 100mm and 150mm diameter pipes are commonly used for water pressure systems, so both PVC-U and M with DN100/150 pipes are tested.

2. Process

To develop the minimum cover, firstly FE analysis was used to find its theoretical value by a computational method. This was then validated by recreating the ground embedded situation using a rectangular container. In addition, previous studies suggested formulae to calculate the strength of pipes, and the results were compared with those values.

2.1 Traffic Load

First and foremost, the sorts of traffic load were used for this research was compared. Austroad states 91mm of radius footprint (0.0260m^2) with 20kN (Ho, 2020), while the American Association of State Highway and Transportation Officials (AASHTO) uses 10in x 20in of tire footprint (0.129m^2) with 20 kips (88.96kN) (Stuart, 2011). Concerning stress, Austroad sets 750 kPa as normal stress. According to (Moser & Folkman, 2008), the tyre footprint of dual wheels is nearly rectangular. In this project, a rectangular plate was used to apply stress onto the soil surface, while a more conservative 750 kPa of stress was used for the safety factor development.

2.2 Finite Element Analysis

FE analysis is a computerised method for simulating how an object would react to real world forces such as heat, vibrations or other physical forces. Even though Abaqus has been commonly used for this type of research, due to the commercial availability of the software, Ansys was chosen for FE analysis instead. The concept of the system is the same, and expected data is not affected.

Since AC pipe is classified as rigid pipe, large deflections are not expected. Thus, the aim of FE analysis is to estimate the breaking strength. Due to the fact that AC pipes are deteriorated by soil and lose their strength, degraded existing tensile strength was computed by a formula developed by (Scott & Marlow, 2016):

$$\sigma_{ts} = -10.666x + 15.682\ (MPa)$$

where x is deteriorated rate

Moreover, PVC also exhibits varying material properties by time, so those of PVC samples were determined by a tensile test conducted following the method (Lee, (2016)) following AS1145 (Standard Australia, 2001).

2.3 Loading Test

A loading test was conducted in a structural laboratory replicating the actual trench to validate FE results. Fibre Reinforced Plastic (FRP) was used to place pipes and sand considering its cost-effectiveness and durable strength. For sand, dry superfine granular sand and brickies sand were used for the lower layer and upper layer for the stability of the test, respectively. Previously serviced pipes were used as described above. The box was 1500mm long, 850mm wide and 1000mm deep based on the previous research (Howard, 1973 and Kraus et al., 2014) and the FEM results.

Figure 1. FRP Container and Metal Plate before Loading

While 200mm was set as soil cover in the previous research, it was not reasonable in this case considering the thickness of the asphalt and the damage from the cutter. Additional 400mm cover case, median value between the current minimum and previous study, was also chosen. Almost the same 10inch x 20inch metal plate, which the American Association of State Highway and Transportation Officials (AASHTO) suggested as a tyre surface, was placed on the top surface and started loading until its failure at a speed of 2mm/min. A Linear Variable Differential Transformer (LVDT) recorded the displacement between the load cell and the metal plate. Since a certain amount of compaction was predicted, the actual deformation of the pipe was computed by subtracting redundant pipe cover.

2.4 Factor of Safety

For AC pipes, the factor of safety was calculated simply using failure stress divided by existing strength. Because Ho revealed in his research that PVC pipes only deformed into a heart-shape and did not exhibit fracture, the factor is the result of the strength when it reaches 5% of deflection divided by existing strength.

3. Result and Discussion

3.1 Tensile Test

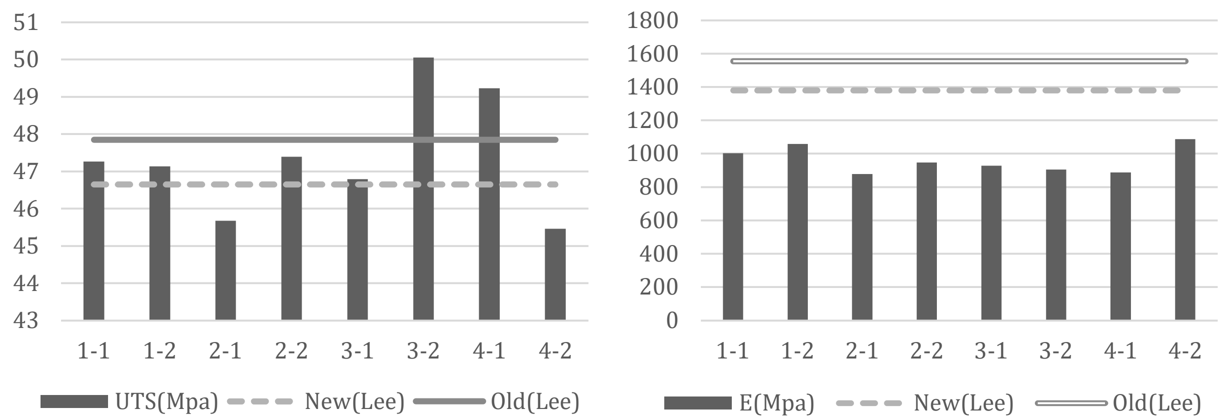

Figure 2. Result of Tensile Strength and Young's Modulus of DN 100 samples: Two coupons were extracted from each pipe

Figure 2 depicts the result of the tensile test. As Lee found previously, there was no significant difference between new and old pipes even though some pipes were not properly preserved and exposed to sunlight. Looking at the Young's Modulus, the current result contradicted data from previous research. Lee claimed that legacy pipes became stiff, yet this data showed becoming more elastic. This is because of the creep effect by soil loading for the long term. In terms of input value for FEM, one GPa was used for Young's Modulus.

3.2 Loading Test (PVC only)

It can be seen from Figure 3 that during the test, the loading data showed a particular drop, then it increased again. The observed initial cover was 200mm, but reduced to 160mm after the test. The pipe cover reduced 40mm after the test; this was simply because the compaction by the jackhammer did not achieve the target compaction rate. Loading data turned upward at the displacement of 50mm. The 10mm gap was thought due to deformation of the pipe during this stage. Based on this hypothesis, and computing the pipe deformation, it was deformed by (30+10=40)mm. Theoretically, PVC pipes can deform into their original inside diameter in open space. The fact that deformation stopped around 40mm was due to soil hindrance around pipes, which was much stiffer than PVC.

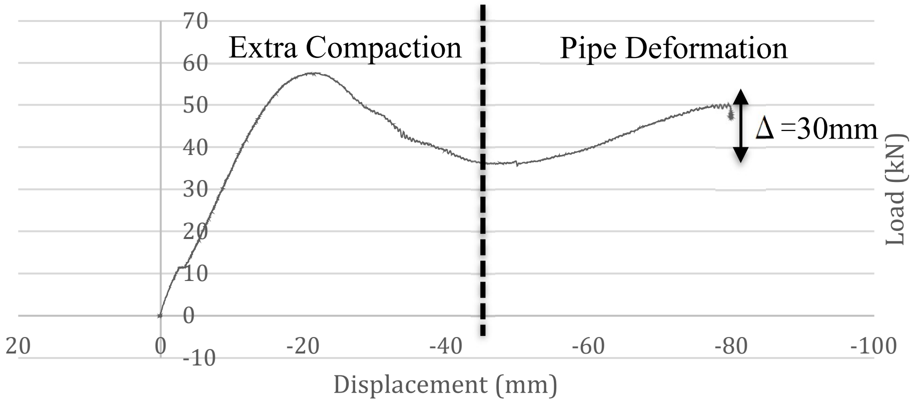

Figure 2. Loading Test Result of PVC 100-2

3.3 Finite Element Model and Safety Factor

3.3.1 PVC

Although the pipe deformed a certain amount during the compaction stage, the allowable deformation point was taken at 6.1mm (5% deflection) from the first point of the pipe deflection stage. Calculated at this point, FEM showed a relatively higher safety factor than the experiment (Table 1) because of different soil property and compaction process.

	Surface Stress (kPa)	Safety Factor
Experiment	306	0.408
FE Analysis	1060	1.41

Table 1. Comparison of Safety Factor of PVC

3.3.2 AC

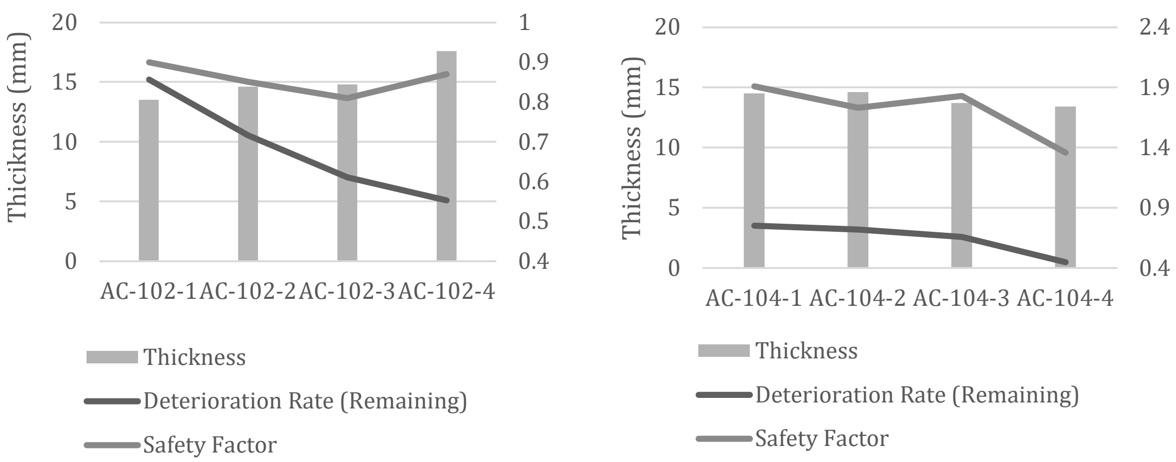

Figure 4. FE Model of AC Pipe for 200mm (Left) and 400mm (Right) Cover

Figure 4 depicts the safety factor of AC100 in both 200mm and 400mm cases. In the 200mm cover case, all the samples did not meet the criteria. Even though the AC102-4 only retained 55% of original strength, the factor of safety was almost the same as one that had the highest strength. Unlike the 200m cover condition, in the 400mm cover, all the samples exceeded the safety factor of one. Since the deterioration rate of each sample was similar to that of the 200mm cover, extra soil cover significantly prevented propagating loading. AC104-3 had a higher safety factor than AC104-2; this is because of the diameter difference, as the former had a larger diameter.

4. Conclusions and Future Work

The tensile test conducted to provide input data for FE analysis showed contradicted previous CEED research. During the embedded stage in the ground, the pipes received effective soil stress, rendering them elastic. Moreover, the soil around PVC pipe in the ground hinders excessive pipe deformation. More samples with different cover will be tested in this project.

For AC pipes, the pipes in the 400mm cover pass the safety criteria, whilst those in the 200mm showed a low safety factor. In addition, the thicker pipes gave a higher safety factor. These findings will be validated using the same container as for PVC pipe testing.

In conclusion at this point, the 400mm cover can be determined as the allowable cover for both PVC and AC pipes due to the low safety factor in the 200mm case.

5. Acknowledgements

I would like to express massive appreciation for many people who have supported this project. These include Glen Williams for providing an insight into operating pipe statistics, Martin Marerwa for preparing the existing data of AC pipe, Tim Ryan for organising pipe samples and delivery, Prof. Barry Lehane for providing advice on laboratory equipment and property of sand, Stephen Naulls, Richard Bowles and Mark Henderson from the UWA for adapting and making the procedure to the equipment, Sandra Henville, John Walter for all safety procedure in the laboratory, and those at Water Corporation and UWA not mentioned who have given assistance and knowledge.

6. Reference

Ho, K. (2020). Maximum Permissible Pipe Loadings. 2020 CEED Final Paper
Howard, A. K. (1973). Laboratory Load Test on Buried Flexible Pipe - Progress Report NO.6 - Steel and Fiberglass Reinforced Resin Pipe in Sand Backfill. Engineering and Research Center Bureau of Reclamation.
Kraus, E., Oh, J., & Fernando, G. E. (2014). Impact of Repeat Overweight Truck Traffic on Buried Utility Facilities. Journal of Performance of Constructed Facilities, 28(4), 4014004.
Lee, I. (2016). PVC Pipes – Performance and Condition Assessment. 2016 CEED Final Paper
Moser, P. A., Folkman L. S. (2008). Buried Pipe Design, Third Edition. The McGraw-Hill Companies, Inc.
Scott, G., & Marlow, D. (2016). Asbestos Cement Renewal Modelling.
Standard Australia. (2001). AS 1145.2-2001 Determination of tensile properties of plastics materials - Test conditions for moulding and extrusion plastics.
Stuart, J. S. (2011). Evaluation of HEPE and PVC Pipes Used for Cross-drains in Highway Construction.
Water Corporation. (2020). Annual Report 2020.