Advanced Condition Assessment & Pipe Failure Prediction

Optimal management of water infrastructure

Fact Sheet No. 13, February 2014

Progress on Activity 1

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Pipe Stress Prediction Models for uniform pipes

Overview

The primary objective of Activity 1 of the project is to obtain the methods for estimation of the remaining life of water mains. Usually, these water pipes are subjected to significant stresses due to internal (water pressure) and external (traffic and earth) loads. As many of these pipelines have been laid sometime in the last century or earlier, in most cases their condition has deteriorated primarily by electro-chemical and (or) micro-biological corrosion. Corrosion activity (internal and external) can manifest in various forms , but in many cases will lead to a reduced pipe thickness, which in turn will lead to increase in pipe stresses induced by these external and internal loads. The stress state of the pipeline can be different depending on the type of corrosion pattern in the pipe. Buried water mains can have different types of corrosion varying from uniform corrosion, patch corrosion or pitting corrosion (see Fact Sheet No. 2). The current fact sheet proposes a model that can be used to compute the stresses of the pipeline in uniformly corroded pipes (also applicable to new pipes), which considers most external/internal factors in detail. The stress calculated for a uniform pipe thickness also provides the reference stress required for pipes with other forms of corrosion.

Development of new pipe stress prediction equation

The level of the stress to which the pipelines are subjected from traffic loads depends on soil condition as well as pipe properties (material, sectional and operating properties) in addition to the magnitude of the traffic load (*W*). From the soil condition perspective, soil modulus (E_S), density (γ), lateral earth pressure coefficient (*k*) and soil Poisson's ratio (υ_S) can be dominant. Pipe material modulus (E_p) and Poisson's ratio (υ_p), sectional properties such as thickness (*t*) and diameter (*D*), and operating pressure (*P*) can also have significant control on the level of stress that the pipe is subjected to. Buckingham's pi theorem was used to obtain the regression model that can predict the maximum pipe stress for a given condition (Equation 1).

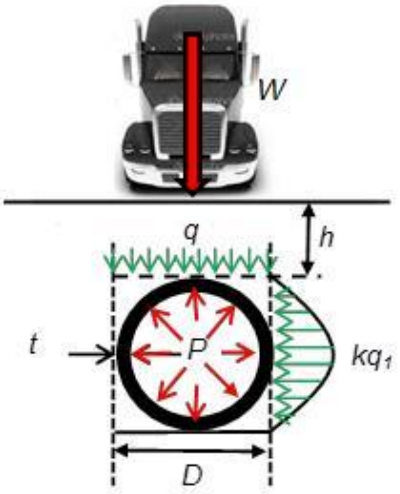

Figure 1. Typical simplified pipe burial condition

$$\left(\frac{\sigma . D^{2}}{(W+\gamma . D^{2} . h)}\right)=\phi\left(\frac{E_p}{E_s}, \frac{h}{D}, \frac{D}{t}, \frac{P}{E_s}, \frac{E}{\gamma \cdot h}, k, \upsilon_s, \upsilon_p, \frac{W}{\gamma . D^{2} . h}\right) \quad \text{Eq. 1}$$

Finite Element Analyses

Three dimensional (3D) finite element analyses were carried out using ABAQUS 6.11/standard to obtain the pipe and soil stress distribution around the pipe, and to predict the non-linear regression to capture pipe maximum circumferential tensile stress. The behaviour of both soil and pipe were assumed as a linear elastic material similar to what is assumed in the derivation of available analytical solutions. Figure 2 shows a typical mesh used.

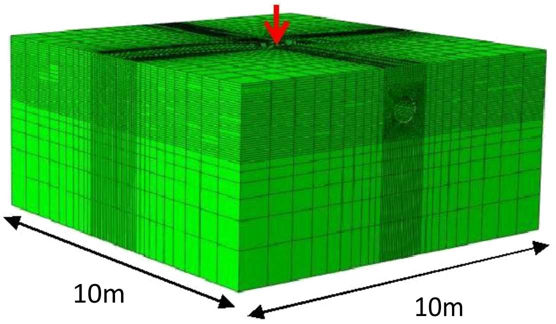

Figure 2: Model dimensions and mesh discretization of the FE model

In the current study, physical variables identified in the problem have been varied within a practical range, as shown in Table 1, to capture the pipeline stress. The range of variables considered was also limited by the overall computational effort needed.

Variable Description	Unit	Value
E_s	MPa	2-50
E_p	GPa	100
υ	-	0.3
D	mm	300-1000
t	mm	4-27
H	m	0.3-2.0
k	-	0.1-0.6
P	kPa	0-1500
W	kN	0-75

Table 1: Parameter validity

Proposed Regression Model

The stress prediction equation was developed for the pipes buried in both soft (represented by 5 MPa modulus) and stiff soils (represented by 50 MPa modulus) subjected to traffic load and internal pressure. A number of trials with varying success were undertaken to devise a suitable equation relating the non-dimensional quantities. The proposed equation is given by equation 2. Table 2 gives the regressed model co-efficients. The Comparison of the predictions between the numerical model and the equation is shown in Figure 3.

$$\frac{\sigma . D^2}{W+\gamma . D^2 . b}=\alpha_1\left(\frac{E_p}{E_s}\right)^{\beta_1}\left(\frac{E_s}{\gamma \cdot b}\right)^{\beta_2}\left(\alpha_2\frac{\left(\frac{p}{E_s}\right)^{\beta_3}}{\left(\frac{t}{D}\right)^{\beta_4}\left(\frac{W}{\gamma \cdot D^2 \cdot b}+1\right)^{\beta_5}}+\alpha_3\frac{\left(\frac{t}{D}\right)^{\beta_6}\left(\frac{W}{\gamma \cdot D^2 \cdot b}+1\right)^{\beta_7}}{\alpha_4\left(\frac{E_p}{E_s}\right)+\alpha_5\left(\frac{p}{E_s}\right)+\alpha_6\left(\frac{b}{D}\right)+\alpha_7 k}\right)$$

Eq. 2

Parameter	α_1	α_2	α_3	α_4	α_5	α_6	α_7
Value	0.12	4.08	-1.76E+06	7.65E+04	4.17E+06	-3.23E+07	-3.55E+07
Parameter	β_1	β_2	β_3	β_4	β_5	β_6	β_7
Value	0.086	0.94	0.89	0.88	0.94	-0.51	-0.71

Table 2: Regressed model coefficients

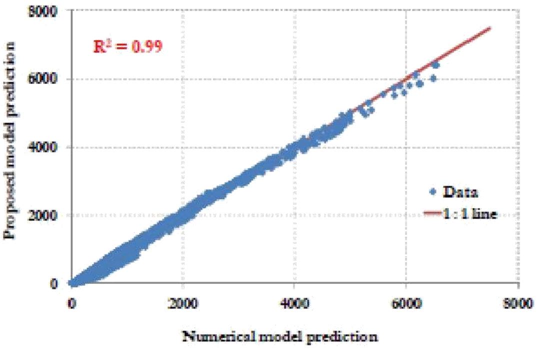

Figure 3: Comparison of the predictions from the numerical model and the equation

Summary and Conclusion

Currently available methods generally over-predict the pipe stresses to varying degrees, depending on the simplifying assumptions used by them to make the problem solvable as a statically determinate problem. To address limitations identified in these equations but yet to develop a simplified solution for practical use by water authorities, a new closed-form solution was developed to compute the maximum pipe stress using a combination of non-dimensional analysis, 3-D FE analysis and non-linear regression. The equation is explicit, meaning that it can be directly used either with a calculator or a spreadsheet to compute stresses once the main external and internal factors are estimated. It should also be noted that the new equation was developed for a range of operating conditions and, therefore, its validity outside this range needs to be checked further prior to its use in pipe settings outside these operating conditions.

Partners

The partners in this research project include Sydney Water Corporation, UK Water Industry Research Ltd, Water Research Foundation of the USA, Water Corporation (WA), City West Water, Melbourne Water, South Australia Water Corporation, South East Water Ltd and Hunter Water Corporation. Monash University leads the research supported by University of Technology Sydney and the University of Newcastle. Other collaborators include Dr Balvant Rajani from Canada.

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