Engineering Failure Analysis 55 (2015) 131–138

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Prediction of stress concentration factor of corrosion pits on buried pipes by least squares support vector machine

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ARTICLE INFO

Article history:
Received 24 February 2015
Received in revised form 27 April 2015
Accepted 13 May 2015
Available online 25 May 2015

Keywords:
Buried pipe
Corrosion pit
SCF
LS-SVM
3-D FEA

ABSTRACT

Concentrated working stress of a corrosion pit is known to be an important factor inducing the deterioration and consequently the breakage of a buried pipe. In this paper, we investigate the stress concentration factors (SCFs) of isolated elliptical corrosion pits using 3-D finite element analyses. The elliptical pits are fully characterized by their 3-D geometries, i.e., major and minor diameters and pit depth via a series of parametric studies of finite element pipe models. This is to quantify the effect of geometric variations of the pits on SCF. Realizing the fact that the 3-D finite element analysis is computationally intensive, efficient statistically predictive models have been developed based on least squares support vector machine (LS-SVM) realized in a ubiquitous spreadsheet platform. This approach shows very close predictions of SCF to the numerical findings for elliptical corrosion patterns on buried pipes. Particularly, two typical kernel functions have been adopted to cross validate the excellent performance of the LS-SVM method in SCF prediction of corroded pipes.

1. Introduction

Buried pipes have long been used for urban water distributions. Particularly, during early-mid of last century, buried pipes were vastly made of brittle cast iron (CI), and many of them are still used as trunk mains. As a result of complicated burial conditions, these pipes are being deteriorated by various corrosion behaviours, causing more and more failure events [1]. Among various damage forms in buried CI pipes, pitting corrosion is a common type. The corrosion pits can reduce pipe resistance and give rise to pipe breakage by intensifying the local stress field, of which the stress magnification is best known as stress concentration factor, K_t (SCF) [2]. Note that in the conventional study of fracture related failure such as crack propagation and burst of brittle CI pipes, the fracture roughness rather than K_t is a more suitable physical property. However, the importance of K_t is that it helps understand the maximum stress development, which can properly identify the onset of localized failure of corrosion pit, thereby the water leakage. Hence, the prediction of K_t still plays a significant role in studying the failure of corroded CI pipes. In the classical mechanics of materials, theoretical solutions of SCF can only be obtained for some regularly sharped holes (e.g., circular and elliptical) on plate of uniform thickness [3,4]. Nevertheless, most corrosion pits appear to be non-through wall type and cannot be expressed by a hole-based SCF solution. In view of these circumstances, various numerical solutions for SCF of corrosion pits by finite element analyses have been reported in the literature [5–9]. Idealized patterns of pitting corrosion were created in those finite element models, using for example, the circular and/or elliptical pits. The numerical findings indicated that for an isolated corrosion pit model, the ratio of radius to depth of

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http://dx.doi.org/10.1016/j.engfailanal.2015.05.010
1350-6307/

corrosion pit is an important parameter in the computation of SCF [7]. More recently, interaction between two corrosion pits was also investigated by considering the separation distance in an FE modelling work [6]. It is noted that, simple regression models for SCF prediction are attainable in some of these works. However, most of them are limited to corrosion on plate which could be very different from that on buried pipes with regards to the boundary conditions and stress status. In fact, the numerical simulation of pitting corrosion on buried pipes can be more complicated because of more geometric parameters required for the definition of a corrosion pit. Moreover, it could be a cumbersome work to develop regression models for such cases due to increased number of parameters. Perhaps as a result of this, such investigations are less commonly carried out in the literature.

In this paper, we present 3-D finite element analyses of SCF of corrosion pits for buried pipes. An isolated corrosion pit for each pipe is reasonably represented by an elliptical bowl shape. Based on a numbers of 3-D finite element analyses, least squares support vector machine (LS-SVM) models are developed to predict the SCF of similar corrosion patterns on buried pipes. It is noted that this study focuses on corrosion pits formed on the external surface of pipes, because protective linings are commonly used internally in the water mains and severely corroded pits are usually observed on the external surface.

2. Finite element modelling

A cubic solid model is created to represent the subgrade whose dimensions are presented in Fig. 1. The modelled subgrade is constrained at the four lateral faces, allowing settlement along the boundary and vertically constrained at the base. The subgrade contains up to 188,800 eight-node linear hexahedral elements with particular fine meshes configured in the vicinity of the pipe.

For each subgrade model, a CI pipe with radius $R = 0.5$ m and wall thickness $T = 0.03$ m is embedded 0.8 m underneath the ground surface as shown in Fig. 1. An isolated elliptical corrosion pit is created in the middle of the analysed pipe, and dimensional details are presented in Fig. 2. Such a large diameter CI pipe is selected for analysis because it is commonly used as trunk mains and the failure consequence would cause major loss for community. As for the considered 0.8 m burial depth, it is within the typical range of embedment depth of pipes between 0.5 m and 2 m. Regarding the modelled 8 m long pipe, this may be considered to be a segment of the pipeline; therefore its two surfaces at the two ends are encastred, which is practically correct when considering the effect of joints for each pipe segment. Over 300,000 eight-node linear hexahedral elements are used to mesh each pipe, with extremely fine meshes for corrosion pit at middle section of the pipe.

The gravity is applied through the whole analysis to the whole model including both subgrade and pipes while pipe is also subject to the inner water pressure that monotonically increases up to a typical operating pressure of 600 kPa. The traffic load on the ground surface is, however, not considered, due to its minimum impact to the pipe 0.8 m underground; this can be proved from Boussinesq elastic solution and numerical simulation. Particularly, when comparing the traffic loads (normally less than 20 kN for each wheel) with the operating pressure of 600 kPa, the influence of the traffic loads can be reasonably ignored.

The current analysis assumes CI pipes to behave linearly elastically with 100 GPa Young's modulus and 0.3 Poisson's ratio, when they are subject to water pressure within the normal range less than 1 MPa. This linear idealisation of the pipe's mechanical behaviour yields the maximum tensile stress 1.0 to about 1.3 times larger than that of nonlinearly behaved pipe, as shown in Fig. 3. The stress–strain nonlinearity of CI material has been experimentally observed and studied since 1890s [10,11]. However, the paper aimed to study the SCF within linear elastic stress–strain behaviour so that we simplified the actual nonlinear behaviour by adopting a linear one. The resulted slight overestimate can be considered to provide a factor of safety (FoS) in pipe design and pipe failure assessment analysis. Similarly, only the linear elastic law with 50 MPa Young's modulus and 0.3 Poisson's ratio is used to model the subgrade, and the subgrade-pipe interface is assumed to be frictionless. In doing so, it enables us to focus on the impact of the geometries of the pit corrosions on CI pipe's SCF under operating hydraulic pressure by isolating the extremely complicated, moisture and seasonal changes relevant soil heave and shrinking.

Based on the above configuration of the numerical models, a total of 45 cases have been created to study the sensitivity of the SCF to the dimensions of corrosion by varying a, b and c in Fig. 2. For each numerical model, SCF is obtained by calculating the ratio of maximum principal tensile stress from the corroded region of the pipe to that of the non-corroded pipe.

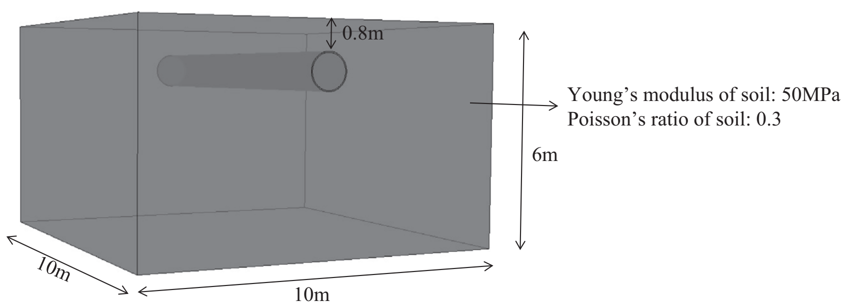

Fig. 1. Finite element model of a buried pipe in subgrade.