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Model error assessments of burst capacity models for corroded pipelines

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ABSTRACT

The model errors associated with eight well-known burst capacity models for corroded pipelines, namely B31G, B31G Modified, CPS, the CSA model, the DNV model, PCORRC, RSTRENG and SHELL92, are characterized based on a full-scale burst test database that consists of 150 data points collected from the literature for pipe specimens containing single isolated real corrosion defects. The probabilistic characteristics of the model errors, including the mean values, coefficients of variation and probability distributions, for the burst models are obtained by analyzing the ratios between the test and predicted burst pressures corresponding to the test data applicable to the model. For each of the burst models, separate model errors for short and long defects are also evaluated, whereby the short and long defects are separated by the transition normalized defect length that is identified using the weighted average COV approach.

1. Introduction

In the reliability-based design and assessment of oil and gas pipelines, the failure probabilities of the pipeline with respect to various limit states, such as bursts of pristine pipes, corroded pipes and pipes containing stress corrosion cracking due to internal pressure, need to be evaluated to ensure that the maximum allowable failure probability or the target reliability is met for a reference length of the pipeline (e.g. 1 km) over a reference period of time (e.g. one year). In this context, it is critically important to accurately evaluate the model errors associated with the deterministic pipe capacity models corresponding to various limit states and incorporate these model errors in the reliability analysis.

Metal-loss corrosion is a common integrity threat to oil and gas pipelines. The prediction of the burst capacities of corroded pipelines is of significant relevance to the pipeline industry. Many burst capacity prediction models have been developed in the past, e.g. the well-known ASME B31G [1], B31G Modified [2], RSTRENG [2], SHELL92 [3], the DNV model [4] and PCORRC [5,6]. It has been reported [7] that the calculated probability of burst of a corroded pipeline is highly sensitive to the model error associated with the burst capacity model. This highlights the importance of evaluating the model errors for the various burst capacity models for corroded pipelines. The model error for a given burst capacity model can be evaluated by comparing the burst pressures obtained from a set of full-scale burst tests on corroded pipe specimens with the corresponding burst pressures predicted by the model. To this end, a relatively large number of test data is desirable because this minimizes the statistical error associated with the sample size and allows the dependency of the model error on key variables such as the depth and length of the corrosion defect to be investigated.

Inkabi and Bea [8] assembled the University of California, Berkeley (UCB) burst database using the burst test data compiled by the Pipeline Research Council International (PRCI) [9,10] and Det Norske Veritas (DNV) [11]. Both machined and real corrosion defects are included in the database. The UCB database was then used to evaluate the model errors associated with seven burst capacity models for corroded pipelines. The means, standard deviations and coefficients of skewness of the test-to-predicted burst pressure ratios were reported for the seven burst models. The nominal pipe properties such as the specified minimum yield and tensile strengths (SMYS and SMTS) and nominal wall thickness as opposed to the actual values of these properties were used to calculate the predicted burst capacities. This makes it difficult to incorporate the developed model errors in the reliability analysis, which typically involves the actual (and uncertain) values of input parameters. Chauhan et al. [12] recently carried out a study to review the prediction accuracies of six commonly used burst capacity models (i.e. B31G, B31G Modified, RSTRENG, PCORRC, the DNV model and SHELL92) for corroded pipelines. They collected a total of 313 data

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points of full-scale burst tests of corroded pipe specimens, which include 180 data points involving machined defects and 133 data points involving real corrosion defects. The test data were used to evaluate the model errors associated with the six burst capacity models. The actual pipe properties were used to calculate the predicted burst capacities. The means and standard deviations of the test-to-predicted ratios for the six models were reported.

Machined defects and real corrosion defects were combined together in the model error assessments reported in [8] and [12]. However, there is a significant difference between these two types of defects in that the defect depth profile (i.e. the defect profile projected on the through-wall thickness plane in the longitudinal direction of the pipeline) for a machined defect generally has a more or less uniform depth whereas the depth profile for a real corrosion defect is irregular and cannot be characterized by a simple shape (e.g. rectangle or parabola). Because a majority of the burst capacity models approximates the defect profile by a simple shape that depends only on the defect length and maximum defect depth, the difference in the defect profile between machined and real corrosion defects implies that such an approximation has a larger impact on the prediction accuracy for real corrosion defects than that for machined defects. Using the test data reported by Chauhan et al., we observed that the means and coefficients of variation (COVs) of the test-to-predicted ratios calculated for the data involving real defects are significantly different from those calculated for the data involving machined defects. For example, the mean and COV of the test-to-predicted ratios for B31G Modified based on 118 burst test data involving real defects equal 1.342 and 25.5% respectively, whereas the mean and COV of the test-to-predicted ratios for the same model based on 167 burst test data involving machined defects equal 1.071 and 14.9%. The above suggests that the model errors evaluated by combining the machined and real corrosion defects are not appropriate for practical applications, i.e. the reliability evaluation of pipelines containing real corrosion defects.

Based on the experiments carried out at University of Waterloo, Cronin [13] established a database of full-scale burst test data involving defect-free and naturally corroded pipe specimens. The database, which contains a relatively small number of data points (8 defect-free pipe specimens and 32 corroded pipe specimens), was used to evaluate the prediction accuracy of five burst capacity models, namely B31G, RSTRENG, PCORRC, SHELL92 and CPS developed at University of Waterloo [13]. Although the actual pipe diameters and wall thicknesses were used in the assessment, the nominal pipe yield strengths (i.e. SMYS) were used to evaluate the accuracy of RSTRENG and B31G whereas the actual pipe tensile strengths were used to evaluate the accuracy of the other models.

The objective of the present study was to evaluate the model errors associated with several well-known burst pressure prediction models for corroded pipelines using a relatively large number of full-scale burst test data collected from the literature. Only test specimens containing single isolated real corrosion defects were considered. The model errors were characterized based on the ratios of the test and predicted burst pressures corresponding to the data points included in the database. The means, standard deviations and COV of the test-to-predicted ratios for the considered burst capacity models were calculated. The probability distributions for the model errors were recommended based on the distribution fitting techniques. For a given burst pressure prediction model, the ranges of the corrosion defect length within which the prediction accuracy of the model is significantly different were identified.

This paper is organized as follows: Section 2 includes a brief summary of the burst capacity models considered in the study; Section 3 describes the burst test data collected from the literature; the analysis results and observations are presented in Section 4 followed by the conclusions in Section 5.

2. Burst capacity models

A total of eight models for predicting the burst capacity of pipes containing isolated axially-oriented corrosion defect was selected from the literature. These models are the B31G, B31G Modified, CPS, the CSA model as suggested in Annex O of the current edition of the Canadian pipeline standard, CSA Z662-07 [14], the DNV model, PCORRC, RSTRENG and SHELL92. All the models except PCORRC and CPS are based on the well-known NG-18 equation [15]; that is, the burst pressure is a function of the material flow stress, the defect area projected on the longitudinal plane in the through pipe wall thickness direction and the Folias factor. The burst pressure prediction equations associated with the above models are given as follows:

B31G

$$P_{b1} = \begin{cases} \dfrac{2t(1.1\sigma_y)}{D} \dfrac{1-\dfrac{2d_{\max}}{3t}}{1-\dfrac{2d_{\max}}{3tM}} & \dfrac{d_{\max}}{t} \le 0.8 \ \text{ and } \ \dfrac{L^2}{Dt} \le 20 \\ \dfrac{2t(1.1\sigma_y)}{D}\left(1-\dfrac{d_{\max}}{t}\right) & \dfrac{d_{\max}}{t} \le 0.8 \ \text{ and } \ \dfrac{L^2}{Dt} > 20 \end{cases} \tag{1}$$

B31G Modified

$$P_{b2} = \frac{2t(\sigma_y + 68.95)}{D} \frac{1-\dfrac{0.85d_{\max}}{t}}{1-\dfrac{0.85d_{\max}}{tM_2}} \quad \frac{d_{\max}}{t} \le 0.8 \tag{2}$$

CPS

$$P_{b3} = P_{LG} + g(P_{PP} - P_{LG}) \tag{3a}$$

$$P_{PP} = 0.9\left(\frac{E\sigma_y^{n_{RO}-1}}{\sqrt{3}\alpha_{RO}n_{RO}}\right)^{1/n_{RO}} \frac{2}{\sqrt{3}} \frac{t}{R_i\left[\exp\left(\dfrac{1}{2n_{RO}}\right)\right]^2} \tag{3b}$$

$$P_{LG} = \frac{2\sigma_{\text{crit}}}{(D-2t)\sqrt{\dfrac{3}{4}}}(t-d_{\max})\exp\left(-\sqrt{\frac{3}{4}}\varepsilon_{\text{crit}}\right) \quad \frac{d_{\max}}{t} \ge 0.2 \tag{3c}$$

$$g = \frac{4\tan^{-1}\left[\exp\left(-\dfrac{L}{2\sqrt{D(t-d_{\max})}}\right)\right]}{\pi} \tag{3d}$$

CSA model

$$P_{b4} = \frac{2t\sigma_f}{D} \frac{1-\dfrac{d_{\text{ave}}}{t}}{1-\dfrac{d_{\text{ave}}}{tM_2}} \tag{4a}$$

$$\sigma_f = \begin{cases} 1.15\sigma_y & \text{SMYS} \le 241 \text{ MPa} \\ 0.9\sigma_u & \text{SMYS} > 241 \text{ MPa} \end{cases} \tag{4b}$$

DNV model

$$P_{b5} = \frac{2t\sigma_u}{D-t} \frac{1-\dfrac{d_{\max}}{t}}{1-\dfrac{d_{\max}}{tM_3}} \quad \frac{d_{\max}}{t} \le 0.85 \tag{5}$$