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Failure analysis of high strength pipeline with single and multiple corrosions

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ABSTRACT

Corrosion will compromise safety operation of oil and gas pipelines, accurate determination of failure pressure finds importance in residual strength assessment and corrosion allowance design of onshore and offshore pipelines. This paper investigates failure pressure of high strength pipeline with single and multiple corrosions using nonlinear finite element analysis. On the basis of developed regression equations for failure pressure prediction of high strength pipeline with single corrosion, the paper proposes an assessment procedure for predicting failure pressure of high strength pipeline with multiple corrosions. Furthermore, failure pressures predicted by proposed solutions are compared with experimental results and various assessment methods available in literature, where accuracy and versatility are demonstrated.

1. Introduction

Onshore and offshore pipelines, which serve as arteries in oil and gas industry, have been widely accepted as one of the most economical ways of transporting oil and gas over long distance. These pipelines typically connect an inlet, such as an offshore platform or an onshore compressor station, to an outlet, which can be another offshore platform or an onshore receiver station. Various grades of high strength pipe steel such as X80 and X90 are widely used in onshore and offshore pipeline project during recent years. Nevertheless, due to the harsh environment that most of these pipelines are located and corrosive medium transported, deterioration such as corrosion is inevitable. Appropriate residual strength assessment and timely repair or replacement of corroded pipeline can avoid over deterioration and failure, which would result in not only large economical loss but also severe environmental pollution.

Intensive research work has been conducted during last 30 years on failure analysis and corresponding assessment method for corroded pipelines. Several standards have been established for failure assessment of corroded pipelines. Among existing standards, the ASME B31G [1] is still the most widely used. On basis of ASME B31G method, Kiefner and Vieth [2] modified ASME B31G [3] by introducing new bulging factor and flow stress. The modified B31G method improves the accuracy of predicted failure pressure to a certain extent. Based on full-scale experimental test and finite element analysis, DNV and BG technology jointly developed a uniform guideline DNV RP F101 [4] for assessing residual strength of corroded pipelines. Other methods including PCORR method developed by Stephens and Leis [5] and RPA method developed by Benjamin and De Andrade [6] respectively. A significant amount of experimental and numerical works have been performed recently. Focusing on the failure mechanism of intact pipeline, Azevedo and Sinatora [7], Azevedo [8] examined a stress-oriented hydrogen-induced failure of X46 gas pipeline as well as crude oil pipeline, Liu et al. [9] performed the failure analysis of natural gas buried X65 steel pipeline under deflection load using nonlinear finite element method, Alamilla et al. [10] presented a work scheme for failure analysis of buried oil pipelines based on five stages and results are related to each other. In terms of corroded pipeline, Majid et al. [11,12] presented experimental and computational fluid dynamics failure analysis of eroded X42 pipeline, Cronin [13] investigated the failure pressure of X52, X46, X52 and X55 corroded pipeline numerically and experimentally, where a new model for predicting failure pressure was presented, Choi et al. [14] developed limit load solution for corroded gas pipelines made of X65 steel, Netto et al. [15] studied effect of external corrosion defects on failure pressure of pipeline via small-scale experiments test and finite element method, where a simple procedure for estimating failure pressure was developed,

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Cosham et al. [16] presented best practices for assessing corrosion defects in pipelines, Chiodo and Ruggieri [17] examined the applicability of a stress-based criterion based on plastic instability analysis to determine failure pressure of corroded pipelines, Zhou and Huang [18] characterized model errors associated with eight well-known failure pressure models for corroded pipelines based on a full-scale failure pressure test database, Zhu and Leis [19] re-evaluated a large group of failure pressure prediction models for end-capped, defect-free pipes, Ma et al. [20] examined failure pressure of high strength pipeline with single corrosion, Fekete and Varga [21] investigated the effect of width to length ratios of corrosion defects on failure pressure of pipeline numerically, Abdalla Filho et al. [22] presented an semi-empirical method to determine failure pressure of pipelines with external corrosion defects. Although the contributions of above literature made are significant, most of researchers focused on low to medium strength grade intact pipeline or pipeline with single corrosion.

Corrosions are usually located on the internal or external pipeline surfaces and distributed randomly by nature as shown in Fig. 1, where corrosions could interact with neighboring ones and in turn affect the failure pressure of pipeline. As far as pipeline with multiple corrosions is concerned, Chouchaoui and Pick [23,24] initially investigated the failure pressure of pipeline with two corrosions. Chauhan [25], Silva et al. [26], Chen et al. [27] predicted the failure pressure for pipeline with two corrosions using nonlinear finite element analysis and subsequently validated using full-scale experimental tests. Benjamin et al. [28,29], De Andrade and Benjamin [30] conducted full-scale experimental test with the purpose of investigating the failure pressure of pipeline with multiple corrosions. Nevertheless, less attention is paid on failure assessment method for high strength pipeline especially for those with multiple corrosions, which may be important in engineering practice. To fill this gap and provide a more reliable assessment method for corroded high strength pipeline, failure pressure of high strength pipeline with single and multiple corrosions is investigated in this paper. Consequently, regression equations and assessment procedure for predicting failure pressure of high strength pipeline with single and multiple corrosions are developed.

2. High strength pipeline with single corrosion

2.1. Failure analysis of high strength pipeline with single corrosion

General-purpose finite element analysis program is employed in this paper, where the incremental plasticity theory considering large strain and displacement, stress-stiffening and material nonlinearity are used in order to study the highly nonlinear characteristics of failure behavior of corroded pipeline. Finite element model for pipeline with single corrosion is illustrated in Fig. 2. Two grades of high strength pipe steel most commonly used in industry i.e. X80 and X90 are considered herein, and pertinent parameters are listed in Table 1. True stress and strain relationships for X80 and X90 pipe steel are illustrated in Fig. 3.

Since stress failure criteria is supposed to be reasonably accurate in determining the failure pressure of corroded pipeline as elaborated by Chiodo and Ruggieri [17], variations of von Mises equivalent stress denoted as σ_e at locations of outer area, mid area and inner area through the ligament of corrosion with respect to internal pressure for X80 and X90 pipeline are illustrated in Fig. 4. Note that the von Mises equivalent stress variations with respect to internal pressure for X80 and X90 steel pipeline are similar. They all undergo three stages before final numerical instability, namely, elastic deformation stage, the plasticity spreading stage and the post-yield hardening stage, where P is applied internal pressure, which can be written as:

$$P_0 = \frac{2t}{D-t}\sigma_u \quad (1)$$

where D is the diameter of pipeline, t is the wall thickness of pipeline.

The first stage is a linear response stage till to a point when the yield strength is reached in the corroded area. As the pressure continues increasing, second stage reaches where plasticity spreads through the ligament of the corrosion from the outer surface to the inner surface one after the other. After yielding, a third stage attains when the equivalent stresses in the ligament reach ultimate tensile stress. Whereas, failure does not occur in this stage due to pipe steel strain hardening effect. A stress failure criterion assumes that failure occurs when the minimum von Mises equivalent stress in the ligament of corroded area is equal to the ultimate tensile strength of pipe steel. The corresponding applied internal pressure is determined to be the failure pressure of corroded pipelines.

2.2. Regression equations for failure pressure prediction

To give a reliable regression equations for failure pressure prediction of high strength pipeline with single corrosion, X80 and X90 pipeline with a wide range of nondimensional corrosion depth d/t = 0.2, 0.4, 0.6 0.8, corrosion length $L/\sqrt{Dt}$ = 0.5, 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, corrosion width $W/\pi D$ = 0.2, 0.4, 0.6, 0.8

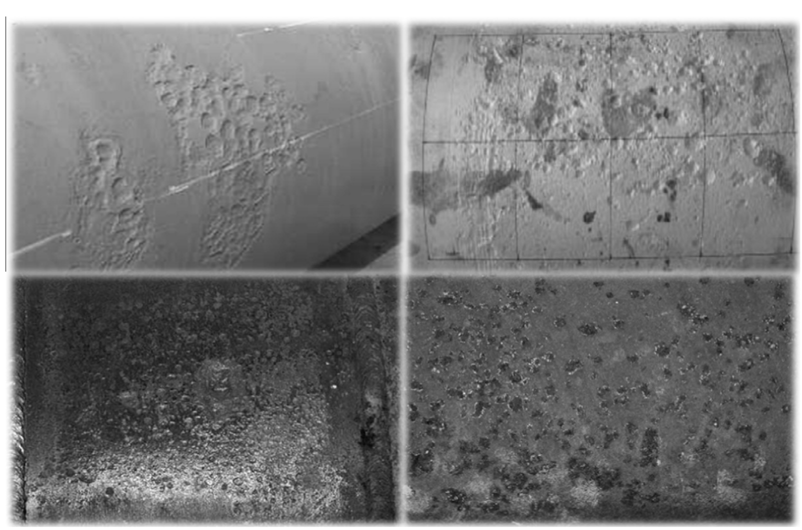

Fig. 1. Schematic of pipeline with multiple corrosions.

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