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Burst strength behaviour of an aging subsea gas pipeline elbow in different external and internal corrosion-damaged positions

Geon Ho Lee, Hassan Pouraria, Jung Kwan Seo and Jeom Kee Paik

The Korea Ship and Offshore Research Institute (The Lloyd's Register Foundation Research Centre of Excellence), Pusan National University, Busan Korea

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ABSTRACT: *Evaluation of the performance of aging structures is essential in the oil and gas industry, where the inaccurate prediction of structural performance can have significantly hazardous consequences. The effects of structure failure due to the significant reduction in wall thickness, which determines the burst strength, make it very complicated for pipeline operators to maintain pipeline serviceability. In other words, the serviceability of gas pipelines and elbows needs to be predicted and assessed to ensure that the burst or collapse strength capacities of the structures remain less than the maximum allowable operation pressure. In this study, several positions of the corrosion in a subsea elbow made of API X42 steel were evaluated using both design formulas and numerical analysis. The most hazardous corrosion position of the aging elbow was then determined to assess its serviceability. The results of this study are applicable to the operational and elbow serviceability needs of subsea pipelines and can help predict more accurate replacement or repair times.*

KEY WORDS: Elbow; Corrosion; Burst pressure; API X42 steel; Elbow damage; Corrosion failure mode.

NOMENCLATURE

C	Curve fit coefficient
D	Specified outside diameter of the pipe
d	Depth of corroded region
f_d	Defect factor (Goodall formula)
G	Defect coefficient
L	Length of corroded region
LF	Lorenz factor
M	Bulging stress magnification factor
P_f	Failure pressure of the corroded pipe
P_O	Plastic limit pressure of elbow without defect
P_L	Plastic limit pressure of elbow with defect
Q	Length correction factor
R_b	Elbow bend radius
R_m	Elbow mean radius
$SMTS$	Specified minimum tensile strength
$SMYS$	Specified minimum yield strength
t	Elbow wall thickness
α	Circumferential angle from the crown of the elbow
γ	Axial half-angle of local thinned area
γ_d	Partial safety factor for corrosion depth
γ_m	Partial safety factor for longitudinal corrosion

Corresponding author: *Jung Kwan Seo*, e-mail: *seojk@pusan.ac.kr*

θ	Circumferential half-angle of local thinned area	σ_u	Material ultimate tensile stress
σ_f	Flow stress (Goodall formula)	σ_y	Material yield stress

INTRODUCTION

Corrosion is a critical problem in the gas pipeline industry and elbows are one of the most corrosion prone structures in gas pipelines. It is especially important to maintain gradually corroding metal pipelines in the subsea industry. As corrosion grows, it causes material degradation in the corroded area, which finally ends in structural failure or a burst pipe. Some studies have attempted to predict pipeline failure in terms of the remaining strength capacity using deterministic or probabilistic approaches.

Previous studies have assessed the importance of corrosion damage evaluation for numerous structures, including gas pipelines and offshore structures, and assessed their mathematical models (Bai and Bai, 2005; Bai and Bai, 2014; Kim et al., 2013; Kyriakides and Corona, 2007; Mohd et al., 2014). These techniques have been widely used in the last few decades. Sharma (2007) discusses the pipeline integrity regulation requirements (ASME B31.8S, 2014; API RP 580, 2013; API RP 1160, 2013; ASME B31G, 2009, and API 1156, 1999) and how it can be best implemented to achieve reliability, sustainable profitability and regulatory compliance of pipeline systems. Those regulations are not specifically designed for subsea pipeline. Several evaluation codes have been developed for these approaches, such as ASME B31G (2009), Modified B31G (Szary et al., 2006) PCORRC (Cosham and Hopkins, 2004), DNV-RP-F101 (2010), and Shell 92 (Klever et al., 1995). Because these conventional design codes are based on various assumptions and simplifications, they are not fully able to predict the failure probability of pipelines, especially when the shape of the structure is more complicated than a simple straight pipe. As a result, the safety factors used in these methods are too high.

The calculations of the pipeline life time and the out of service time are shorter than in reality due to the very conservative nature of the codes. In fact, code-based corrosion assessments are mostly probabilistic. Accordingly, the measurements calculated based on the codes are somewhat uncertain and inaccurate and the deterministic methods frequently fail to predict the exact burst pressure. The conservative nature of the codes has motivated researchers to select statistical probabilistic methods to obtain more precise and accurate output results. A great deal of attention has focused on developing probabilistic models that predict the failure criteria of straight pipelines and their remaining life time by producing failure equations. However, very few studies have examined complicated shape structures such as elbows, U shapes and T shapes. Besides the conventional design codes, numerical analysis methods have been used to evaluate the burst pressure and calculate the remaining strength of elbows with defects.

Although the existing research has mainly focused on the defect size, few studies have considered the location of the defect. Defects located on extrados exhibit different behavior than those located on intrados or the crown area of the elbow. This motivated the authors of this study to develop a new method to achieve more accurate failure modes for all defect locations on the elbow.

Another motivation of this study is to take advantage of the corroded straight pipe formulas, which were developed using several industrial design codes, to find an easier and more accurate method for assessing elbows with defects. A quick calculation of the structure life time and maximum allowable pressure without using Finite Element Analysis (FEA) or computational analyses are the main goals of this study. In addition, the findings of this study are compared with the existing research and methods.

Duan and Shen (2006) examined the plastic limit pressure of elbows without defects and with local thinned areas located in the extrados using FEA and experiments. They proposed an empirical formula for the limit load of elbows with local thinned areas located in the extrados by fitting the FEA results and experimentally validated the developed formula. Li et al. (2001) studied local thin areas and material degradation caused by erosion/corrosion in piping systems and proposed a method to assess the acceptability of the local thin area in an elbow. They then compared the developed method with FEA results. Mohd et al. (2014) examined a straight pipe with a single defect and developed an assessment method by comparing the code-based design data and FEA results.

In the present study, the burst pressure of a corrosion damaged elbow was predicted by numerical analysis using ANSYS nonlinear FEA software (ANSYS, 2012). The FEA was performed to prevent uncertainties and inaccuracies in the