Structural Engineering and Mechanics, *Vol. 59, No. 5 (2016) 795-802*
DOI: http://dx.doi.org/10.12989/sem.2016.59.5.795

Impact of geometric pattern corrosion on limit failure pressure of buried gas pipelines

Nemat Hassani*, S. Mohammad S. Kolbadi[a], Mahmud Reza Shiravand[b] and Jafar H. Golafshani[c]

Department of Civil Engineering, Shahid Beheshti University, Tehran, Iran

(Received March 22, 2015, Revised March 22, 2016, Accepted March 30, 2016)

Abstract. Gas pipelines are types of structures that are highly susceptible to corrosion. Sometimes, the pipes are subjected to a thinning of the wall thickness at the inside or outside wall due to erosion/corrosion. Therefore, it is important to evaluate the strength of the pipes undergoing corrosion to maintain the integrity of the piping systems. The main purpose of this study is to understand failure aspects caused by degradation of metal due to corrosion through. The ASME standard offers a relationship for the yielding pressure of the corroded pipes which was compared with the finite element results. The results demonstrate to obtain accurate results, the ASME relationship is unreliable. Moreover, pitting corrosion must be considered critical more than of other types.

Keywords: gas pipeline; limit failure pressure; geometric pattern corrosion; ASME code

1. Introduction

Today, underground conduits serve in diverse applications. The damage of buried pipelines due to corrosion may severely affect civil lifeline structures since it may cause fires, economic losses, and disable of lifeline networks. As a matter of fact the damages will be propagated.

Corrosion is one of the most critical degrading mechanisms of structural strength. Moreover, corrosion of most metals is often an inevitable process. When localized, pit or uniform corrosion occurs, strength reduction can be difficult to establish because of the complicated effects of uneven surfaces and uneven material properties on the stress fields and failure modes of the structure. In order to accurately estimate gas pipeline structure life, it is important to understand and evaluate corrosion effects on overall yielding stress caused by internal pressure and the corresponding local strength. The external pressure due to soil is much bit comparing to gas pressure, so it can be negligible.

The American Society of Mechanical Engineering (ASME) B31G, modified ASME B31G and Det Norske Veritas (DNV) RP-F 101 provide coded methods to evaluate the structural integrity of

*Corresponding author, Professor, E-mail: hassaniamoozeshi@gmail.com
[a]M.Sc., E-mail: MohammadKolbadi@ace.sbu.ac.ir
[b]Ph.D., E-mail: M_Shiravand@gmail.com
[c]M.Sc., E-mail: jgolafshan@gmail.com

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http://www.techno-press.org/?journal=sem&subpage=8 ISSN: 1225-4568 (Print), 1598-6217 (Online)

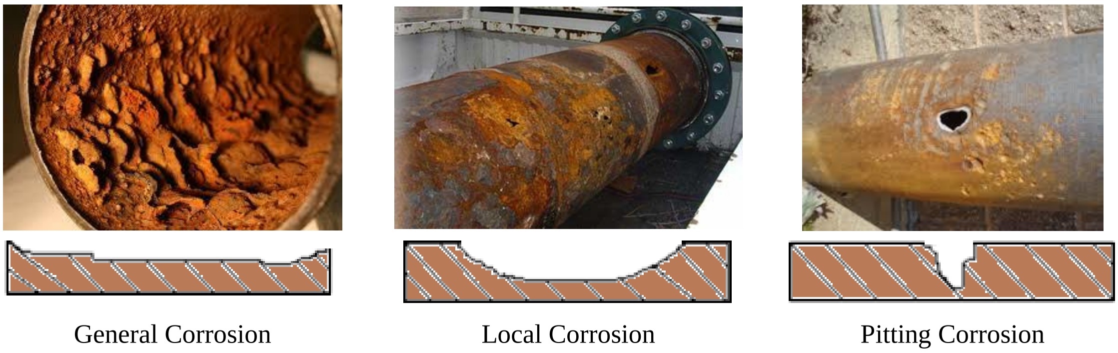


Fig. 1 Corrosion defect shapes

corroded pipelines. Besides these guidelines, Zheng *et al*. (2004), Kim *et al*. (2004, 2005) also proposed an analytical formula for the burst capacity of corroded pipelines. Under similar loading conditions, Roy *et al*. (1997), Katsumasa *et al*. (2002), Shinji *et al*. (2007) conducted experimental tests of various size pipes. They analyzed corroded pipelines failure modes and conducted parametric studies regarding the failure of corroded pipes. These analyses provide a valuable database to compare to and verify the numerical results. Nakai *et al* (2004, 2005). Conducted experimental testing on tensile strength and ultimate collapse strength of pit-corroded plates. He compared test results to those from finite element analyses with good agreement. He found that "tensile strength decreases gradually while the elongation decreases dramatically in pitted plates" (2004).

Corrosion defect shapes can be divided into general/uniform corrosion, local corrosion and pitting corrosion according to corrosion failure characters shown as Fig. 1. Because of the protection of coatings, the big area general corrosion situation of pipelines is few, while two kinds of corrosion shape as local corrosion and pitting corrosion shape in the damaged defects between substrate and coating of pipelines exit usually (Peng *et al*. 2009).

In this study, according to corrosion failure characters of buried gas pipelines, electrochemical corrosion ratio and length of the local corrosion and pitting corrosion flaws were compared by Faraday's Law based upon ASME-B31G criteria (ASME-B31G 1991).

The ASME B31G method is a single mathematical expression that produces a conservative result using an assumed parabolic or cone profile for short corrosion and a rectangular profile for long corrosion.

2. Limit failure pressure of corrode pipeline based on ASME criteria

Limit failure pressure (P) is the limit pressure in the pipeline as failed. The formula of limit failure pressure of pipeline with corrodes defects based upon ASME-B31G criteria can be obtained as Eq. (1) (ASME-B31G 1991)

$$P = \sigma_f \frac{2t}{D}\left[\frac{1-{}^{h}\!/_{t}}{1-{}^{h}\!/_{tM^{-1}}}\right] \tag{1}$$

Where P is failure pressure of corroded pipeline, D, t, h and l are external diameter, wall thickness, length and depth of corrosion respectively; σ_f is flow stress.

But the maximum allowable working pressure predicted based on ASME-B31G criteria is more conservative so in order to removing or eliminating the shortage, Folias factor M and yield limit of pipe material σ_s were improved as Eqs. (2)-(3)-(4) (Nakai *et al*. 2005, Paik *et al*. 2003)

$$M = \sqrt{1 + 0.6275(\frac{l}{\sqrt{Dt}})^2 - 0.003375(\frac{l}{\sqrt{Dt}})^4} \qquad (\frac{l}{\sqrt{Dt}})^2 \leq 50 \tag{2}$$

$$M = 0.032(\frac{l}{\sqrt{Dt}})^2 = 3.3 \qquad (\frac{l}{\sqrt{Dt}})^2 \rangle 50 \tag{3}$$

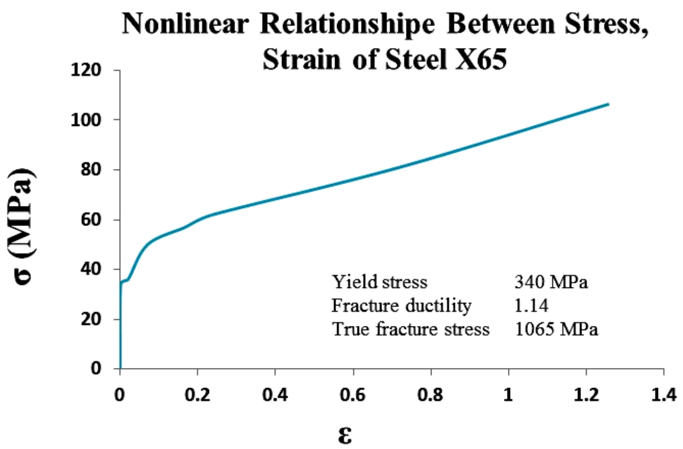
$$\sigma_f = (\sigma_s + 68.95) \tag{4}$$

3. Pipe specimens

The material of pipe specimens are carbon steel pipes for high pressure service, called 'STS370', which are commonly used in piping systems. The carbon steel of STS370 is similar to that of ASME A333 Gr.6. The elasto-plastic behavior of the steel material is defined as follows (see in Fig. 2).

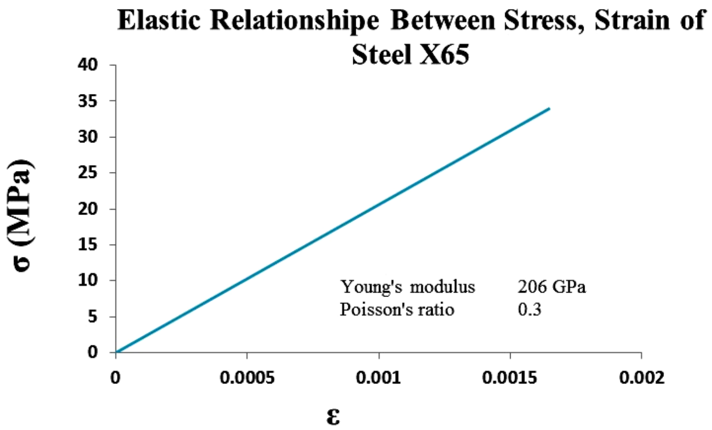
Since the chemical process of corrosion caused a huge reduction of the stiffness in corrosion location, thus, corrosion effect is expressed by local wall thinning roundly.

The fracture behaviors of pipes with wall thinning on the outside of the pipes are almost identical to those of pipes with wall thinning on the inside surface. So, it is no important to assessing the internal and external corrosion separately. The geometric characteristics of corroded pipe can be seen in the Fig. 3.



(a)

Fig. 2 Stress-True strain curve of Steel X65: (a) Nonlinear and (b) linear (Paik *et al*. 2003)



(b)

Fig. 2 Continued

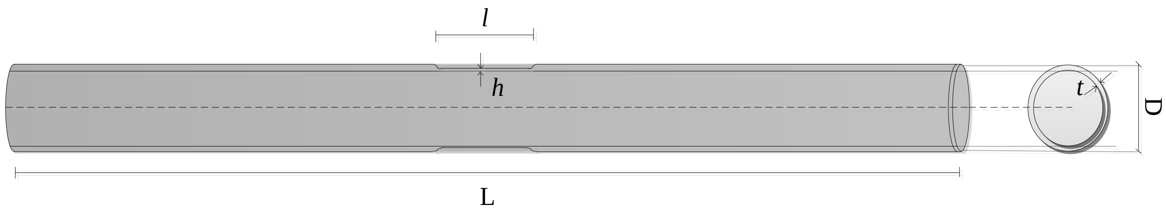


Fig. 3 Shape and dimensions of a pipe specimen with circumferentially local wall thinning (Kolbadi 2014)

Table 1 Geometric dimension of the pipe

L	*D*	*t*	*h*	*l*	*α=h/t*
Pipe's length	External diameter	Thickness of sound pipe	Thickness of corroded pipe	Corrosion length	Corrosion ratio
30 m	1 m	14.3 mm	Variable	2 m	0~1

The magnitude of α varied from 0 to 1. If α be closed to 1, it means the pipe is sound and if α tended to 0, there is so corrosion on the pipe's wall (Table 1).

4. FEM Analysis

4.1 Uniform corrosion

The effect of uniform corrosion on the pipes whether internal or external is same, so pipe's wall thickness was reduced to demonstrate degradation of metal due to corrosion. The pipe thickness is less than of diameter and length, so quadratic shell element was used to modeling. The axial strain was neglected, because the pipe is very long and satisfies the plane-strain assumption. Therefore, the near and far boundary conditions were considered as a symmetric that is shown in Fig. 4.

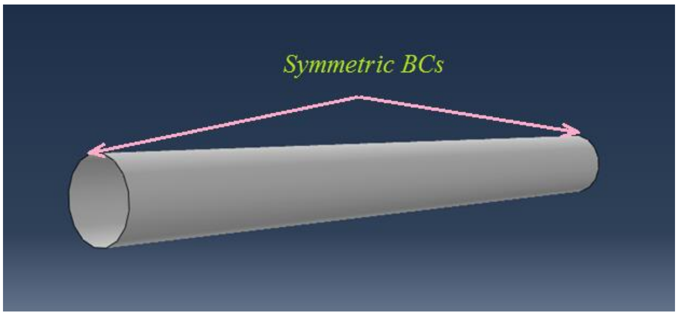


Fig. 4 Boundary condition of the pipe

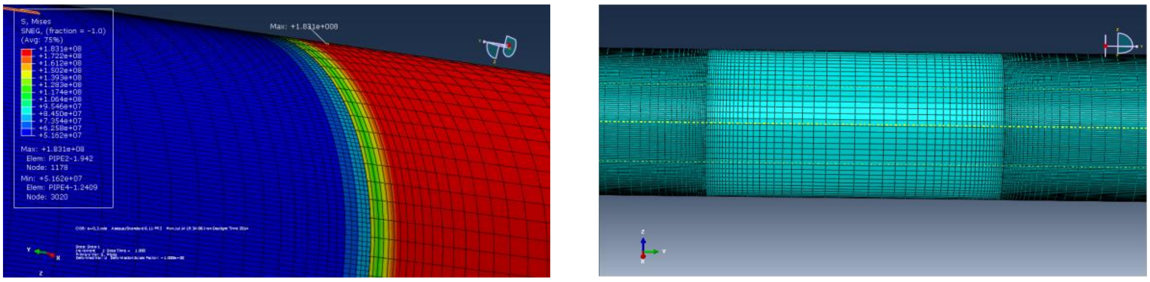


Fig. 5 Mesh and stress contour of the local corrosion (Corrosion length=2 m)

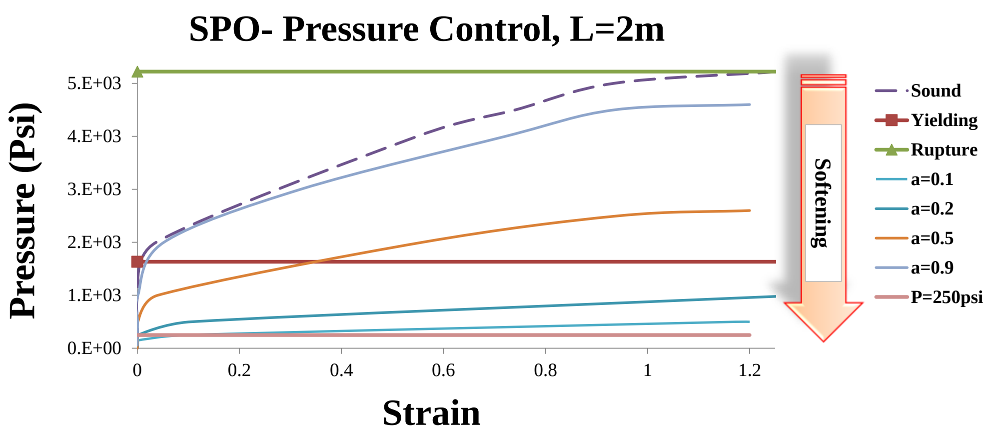


Fig. 6 Pressure- True strain curve for local corrosion (l=2 m, α=various)

Using finite element method and static pushover analysis (SPO), the elasto-plastic behaviors of the corroded pipes for α= 0.1, 0.2, 0.5, 0.9 and 1 was obtained. (Figs. 5-6).

4.2 Pitting corrosion

In the long structures such as pipes, the plane-strain assumption can be considered. Therefore, a part of the pipe is intended and a quarter of the pipe has been modeled. The symmetric conditions in longitudinal direction and constrain conditions in radial direction (two orthogonal axes as seen in Fig. 7) was applied. Solid hexahedra element shape with eight nodes was used which is a kind

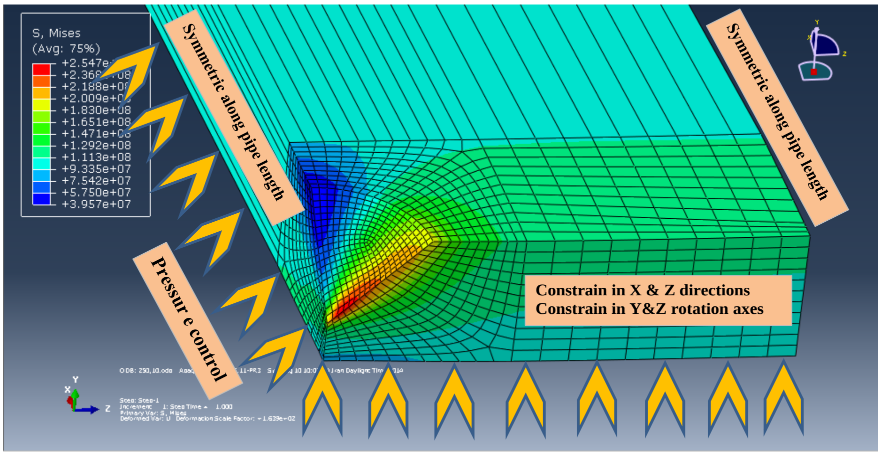


Fig. 7 Boundary conditions in corroded pipe for pitting

Table 2 Geometric shape of conical pitting corrosion

θ (Rotation angel of cone)	Corrosion ratio $\beta = (h-t)/t$		
45°	Huge=0.3	Medium=0.65	Bit=0.85

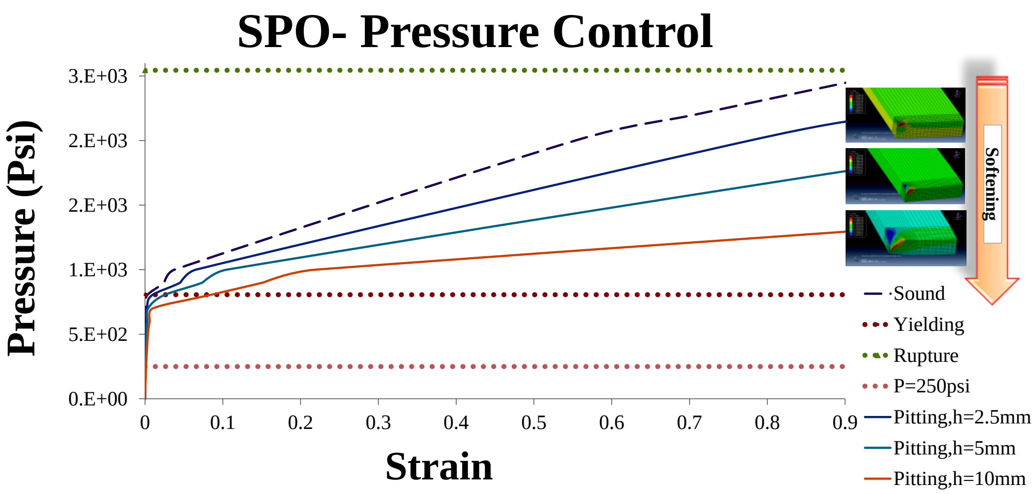


Fig. 8 Softening in nonlinear behavior with increasing corrosion depth in pitting corrosion

of 3D Stress elements.

Using SPO analysis, the behavior of the corroded pipes was obtained and compared with the sound pipe. It was observed that reduction of the yielding pressure is not noticeable in pitting corrosion (Table 2) and the main difference is nonlinear behavior (Fig. 8). Although, in uniform corrosion, with growth in the depth of corrosion, the yielding pressure and the ultimate pressure are reduce, that it is fully obvious in Fig. 6.

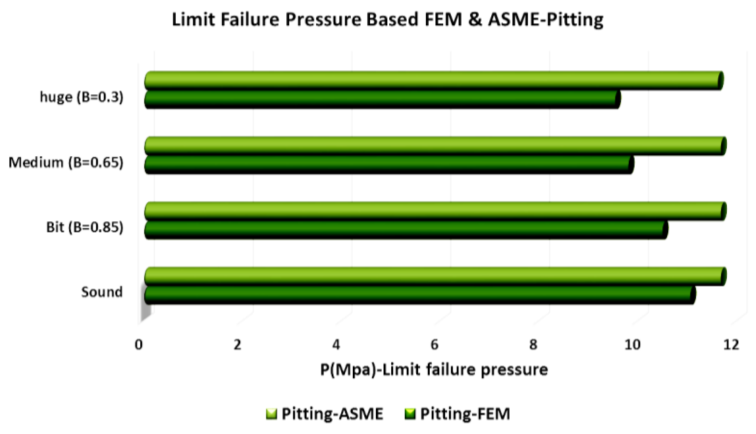


Fig. 9 Comparing the ASME & FEM result for limit failure pressure-Pitting

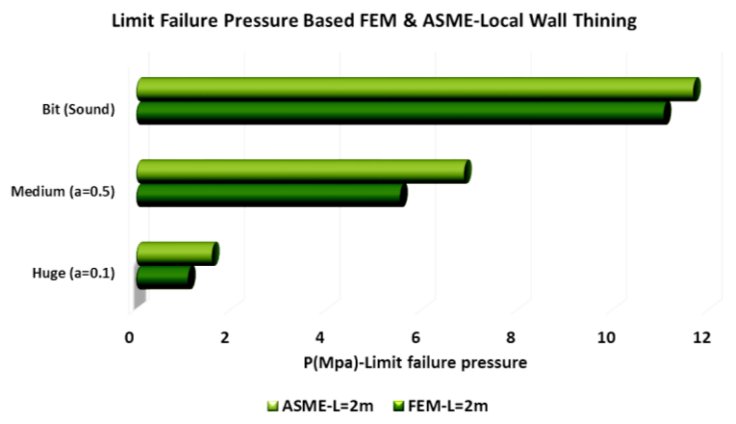


Fig. 10 Comparing the ASME & FEM result for limit failure pressure-Local Corrosion

5. Comparing the ASME code & FEM result for limit failure pressure

According to ASME standard that mentions in part 2, the yielding pressure of corroded pipes has been compared to finite element analysis in two types of corrosion; pitting and local corrosion (Figs. 9 and 10).

5. Conclusions

ASME standard offers a relationship for the yielding pressure of the corroded pipe which was compared with the finite element results. The values of ASME Code in both types of local and pitting corrosions are greater than FEM results. Also the results for pitting corrosion have no appropriate adaptation with ASME, although in local corrosion have good match.

However, for uniform corrosions, the results of ASME relationship can be considered as upper bound results. But it is completely illogical for pitting corrosions. Also, it is not possible to consider it as good criteria for careful analysis for corrosion phenomena in high-pressure gas pipes. So, it is better to this equation be reviewed and revised.

In uniform corrosions, corrosion ratio affects to both yielding pressure and nonlinear behavior of the gas pipes severely, but in pitting corrosions, yielding pressure doesn`t change specifically and the nonlinear behaviors are affected only. So, gas pipeline bust due to pitting corrosions can occur without any significant deformation or warning. Thus, the control of this type corrosion can be considered more important than of other corrosion types and special measures must be adopted.

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