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Effect of axial length parameters of ovality on the collapse pressure of offshore pipelines

Zhiyuan Fan[a,b], Jianxing Yu[a,b], Zhenzhou Sun[a,b,*], Huakun Wang[a,b]

[a] State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China
[b] Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai Jiaotong University, Shanghai 200240, China

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ABSTRACT

Axial length parameters of ovality are observed to have effects on the buckling capacity of a pipeline through a parameter analysis. The collapse pressure measured was considerably higher than that calculated by offshore standard DNV-OS-F101 (DNV) when the axial length of ovality was shorter. Effects of composite defects in the form of corrosion ovality on collapse pressure were examined through combined experimental and numerical efforts. We find that the final collapsed configuration and buckling capacity of a pipe are not only affected by the amplitude of maximum ovality and geometric parameters of corrosion but also by their positions. Finally, an improved formula and procedure for estimating the collapse pressure of a pipe with composite defects is established.

1. Introduction

The local buckling of deep-sea pipelines subjected to external pressure is a key issue of pipeline design that is well understood. The collapse pressure is affected by various factors such as the following: the diameter-to-thickness ratio, material properties, initial geometry imperfections [1–3], the anisotropy of the yield stress, and the residual stress of the manufacturing process [4]. Other installation and operational factors that can affect the collapse pressure include dents caused by impaction [5], local buckling caused by excessive bending [6] and excessive axial force [7,8]. Corradi [9] and Yu [10] et al. verified that ovality is the most significant initial defect that causes buckling in a subsea pipeline early on.

The standard DNV-OS-F101 [11] makes reference to the following formula for calculating the characteristic collapse pressure P_c under external pressure:

$$\left.\begin{aligned} &(P_c - P_{el})\cdot(P_c^2 - P_p^2) = P_c\cdot P_{el}\cdot P_p\cdot f_0\cdot \frac{D}{t},\\ &P_{el} = \frac{2E\left(\frac{t}{D}\right)^3}{1-\nu^2},\ P_p = 2\cdot f_y\cdot \alpha_{fab}\cdot \frac{t}{D},\ f_0 = \frac{D_{\max}-D_{\min}}{D} \end{aligned}\right\} \quad (1)$$

where E is Young's modulus, ν is Poisson's ratio, f_y is the characterized yield strength, D is the outer diameter of a pipe, t is the wall thickness of a pipe and α_{fab} is the production factor.

Although Formula (1) is widely used, alternative methods can be applied [12] for thick-walled pipes in deep-water areas [13]. Fraldi et al. [14–17] illustrated the method's shortcomings in detail and determined that it neglects the effects of the actual shape of the stress-strain curve and of real cross-sectional imperfection shapes. Formula (1) also neglects axial length parameters of cross-section imperfections, which have never been examined in previous studies.

Throughout its operation, a pipe suffers metal loss due to corrosion, which in turn causes a decline in its buckling capacity. Netto [18–21] put forward a formula for evaluating the collapse pressure of a pipe with corrosion defects through experimental and numerical efforts. Yan et al. [22] derived analytical formulas of instability failure for corrosion rings subjected to external pressure and studied the effects of coupling corrosion. Previous studies on the behaviors of pipelines experiencing wall thickness reduction have primarily focused on the singular effects of corrosion without considering real cross-sectional imperfection shapes and axial distribution parameters.

In this paper, the effects of ovality axial length parameters on the buckling behaviors of pipes were studied through combined experimental and numerical efforts. The buckling performance of a corroded pipe was studied from a new focus on corrosion-ovality defects. The effects of the relative positions of initial ovality and corrosion were studied through experimental efforts. Finally, a simple formula was developed for estimating the collapse pressure of a pipe, and we thus contribute a beneficial formula for use in design and optimization strategies.

2. Experiments

Twenty additional small-scale and seamless steel specimens were

* Corresponding author at: State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China.

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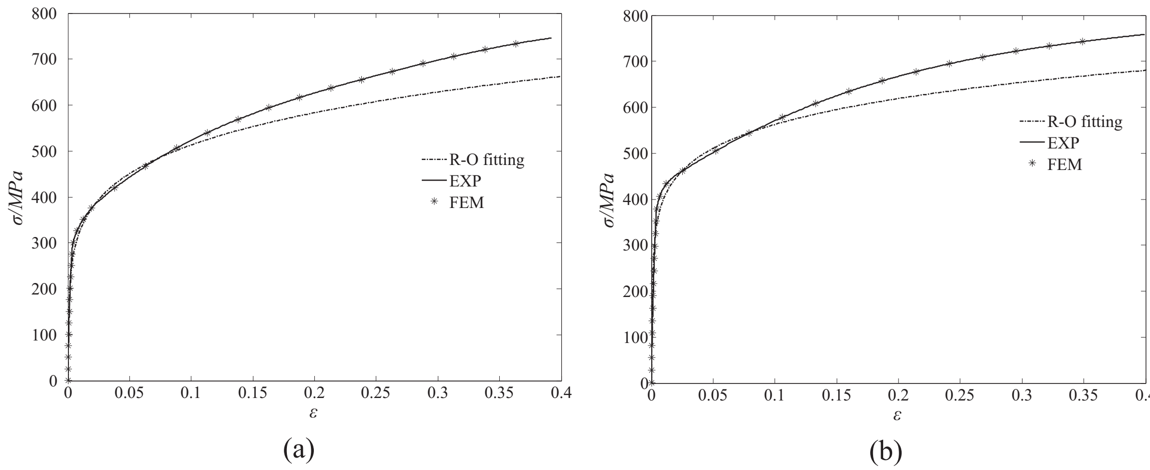

Fig. 1. Engineering stress-strain curves of the specimens: (a) Material A, (b) Material B.

manufactured and divided into three categories: ovality, corrosion and ovality-corrosion pipes. The specimens are formed from four long pipes (E1 to E4) composed of mild steel SS304. The nominal material and geometric parameters are as follows:

Material: SS304
Diameter (D): 51 mm
Thickness (t): 3 mm
Diameter-thickness ratio (D/t): 17
Total length (L): 1150 mm

2.1. Material characterization

The measured engineering stress-strain curves of the pipes used to manufacture the specimens are shown in Fig. 1(a) and (b). The curves represent the average test results of two test coupons cut in the axial direction of each long pipe. Two different mechanical behaviors were found for the same material, as shown in Table 2 and Fig. 1.

Using the Ramberg and Osgood model (RO Model) to describe the relationship between stress σ and strain ε, the resulting formula is written as follows:

Table 1
Nomenclature definitions.

Nomenclature	Definition
D	Outer diameter of the pipe
t	Wall thickness of the pipe
E	Young's modulus
ν	Poisson's ratio
zl	Straight length of ovality in the axial direction of the pipe
lt	Transition length of ovality in the axial direction of the pipe
Δ_O	Average ovality along the axial direction
Δ_{max}	Maximum ovality along the axial direction
σ_y	Nominal yield strength
f_y	Characterized yield strength
n	Hardening parameter
l	Corrosion length in the axial direction
δ	Corrosion depth
c	Corrosion arc length
P_{co}	Collapse pressure of the pipe
Θ	Angle between the long axis of maximum ovality and the diameter of the defect center
Φ	Angle between the long axis of the crushed section and the long axis of maximum ovality
w	Radial displacement
v	Hoop displacement

Table 2
Material parameters of the tested pipes.

Material	E GPa	n	σ_y MPa
SS304 (A)	193	7.6	237
SS304 (B)	193	7.4	300

$$\varepsilon = \frac{\sigma}{E}\left[1 + \frac{3}{7}\left(\frac{\sigma}{\sigma_y}\right)^{n-1}\right] \tag{2}$$

where n is the hardening parameter, σ_y is the nominal yield stress, and E is the elastic modulus.

2.2. Geometric parameters

The dimensions of the test and initial geometric imperfection parameters were measured using conventional calipers. The measured data were used to calculate the out-of-roundness of the measured cross-sections, which is defined as follows:

$$\Delta = \frac{D_{\max} - D_{\min}}{D_{\max} + D_{\min}} \tag{3}$$

Fig. 2 shows the different sectional ovalities measured along the pipe, which indicates that ovality does not remain constant. To best illustrate the experimental and numerical models, a cross-sectional schematic of the pipe deformation pattern is shown in Fig. 3 based on the following assumptions:

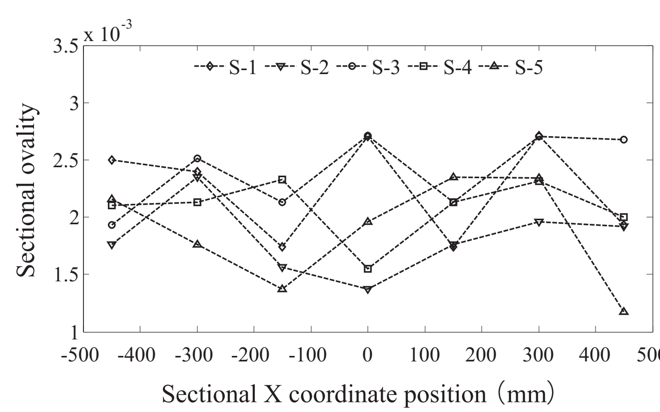

Fig. 2. Sectional ovalities measured along the pipe.