Assessment of the Remaining Safety of Pipelines with Corrosion Defects

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Abstract. Corrosion is one of the common defects of offshore pipelines and risers. By the time, corrosion defect will reduce the strength of pipelines to limited value, then, a reinforcement solution need to be proposed. The most effective and popular method is installing the Clock Spring. The safety of pile before and after repair, is evaluated by experimental formula accordance to ASME B31G or DNV RP101 standard. However, there are still some disadvantages with using experimental formula, typically as incorrect description of the defect shape on the surface of pile may lead to the deviations of analysis result. This paper presents the results of studying the safety of corrode pile subjected to internal pressure by a numerical simulation in two cases: before and after repair.

Keywords: Internal pressure · Corrosion defects · Numerical simulation · Clock spring · Von Mises stress · FE method

1 Introduction

After a long period of operation under many effects of the marine environment, the steel pipes are corroded and losen metal on the surfaces. This corrosion causes many incidents which affect the entire pipelines and also cause a lot of damages for operators. Therefore, to minimize the risks, corrosion defects survey and inspection are carried out annually as a mandatory regulation. The investigation and inspection of corrosion defects include field work (such as measurement, pig release to determine the position, size, extent of wall corrosion) and work in the room (such as stress analysis, evaluate the remaining working ability of the pipe at the corrosive locations). However, the companies who own the pipelines, still need a more reliable evaluation method to ensure operational safety as well as optimize operating costs before choosing the solution for repair or replacement. One of the most effective repair solutions in order to extend the lives of the corroded pipelines is using Clock spring, a composite wrap repair sleeve and reinforcement system uniquely designed for high-pressure transmission pipelines. The Clock Spring, has been tested and proven up to 8,000 psi and is expected to last 50 years or longer, deeming it a permanent repair by regulators (Fig. 1).

In recent years, many other evaluation methods have been developed mainly based on finite element (FE) studies and burst test results. In this paper, FE method was chosen

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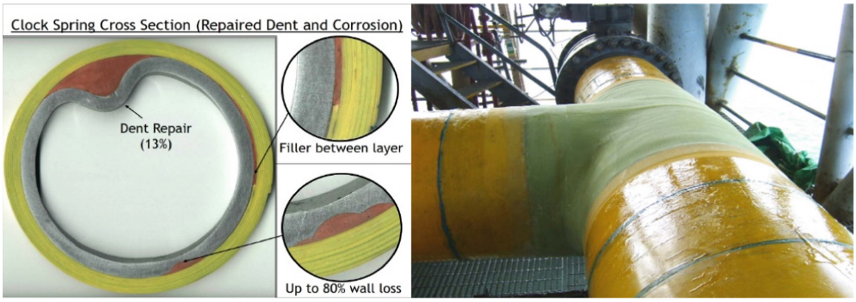

(a) (b)

Fig. 1. (a). The typical Clock Spring cross section, and, (b). A steel pipe with Clock Spring

to model the corrosion defects on the surface of a steel pipe and evaluate allowable limited pressure in two cases: before and after wrapping by Clockspring. Beside, the results from FE model were compared to the failure pressures which were predicted by some conventional methods.

2 Accessment Methods

Semi-empirical Methods: There are two standards, namely ASME B31G and DNV-RP-101, regularly were used to evaluate the remaining strengthen of the corroded pipe. In which, the DNV method can be applied to corrosion subject to axial and bending loads.

ASME B31G is a manual for evaluating the remaining strengthen of corrode pipe. The steps for calculation are shown briefly below:

Step 1: The depth of a corrosion pit is expressed as a percent of the nominal wall thickness of the pipe by:

$$\%P = 100d/t \tag{1}$$

Where:

d: measured maximum depth of the corroded area
t: nominal wall thickness of the pipe

Step 2: Determining the maximum allowable longitudinal extent of the corroded area, LM

$$L_M = 1.12B\sqrt{Dt} \tag{2}$$

D: nominal outside diameter of the pipe

$$B = \sqrt{\left(\frac{d/t}{1.1d/t - 0.15}\right)^2 - 1} \tag{3}$$

Step 3: Determining the factor z:

$$z = L^2/Dt \tag{4}$$

Step 4: Determining the failure pressure S_F:

$z \leq 20$,

$$S_F = S_{flow}\left[\frac{1 - 2/3(d/t)}{1 - 2/3(d/t)/M}\right] \tag{5}$$

$z > 20$,

$$S_F = S_{flow}[1 - d/t] \tag{6}$$

Step 5: Compare S_F to the stress S_o: $S_F \sim S_o$*SF

$$S_o = P_o D/2t \tag{7}$$

P_o: Operating pressure.
SF: Safety factor = 1.25.

DNV-RP-F101 gives recommendations to assess corroded pipelines subject to internal pressure, and internal pressure combined with longitudinal compressive stresses. The allowable corroded pipe pressure is determined from the equations below:

Longitudinal corrosion defect, internal pressure loading only:

Step 1: Calculate the failure pressure of the corroded pipe Pf

$$P_f = \frac{2tf_u(1 - d/t)}{(D - t)(1 - \frac{d}{tQ})} \tag{8}$$

Where:

$$Q = \sqrt{1 + 0.31\left(\frac{l}{\sqrt{Dt}}\right)^2} \tag{9}$$

Step 2: Calculate the safe working pressure of the corroded pipe

$$P_{SW} = F.P_f \tag{10}$$

F: Safety factor

Internal pressure and combined compressive loading:

Step 1: Determine the longitudinal stress, at the location of the corrosion defect, from external loads, as axial, bending and temperature loads on the pipe. Calculate the nominal longitudinal elastic stresses in the pipe at the location of the corrosion defect, based on the nominal pipe wall thickness.

$$\sigma_A = \frac{F_X}{\pi(D - t)t} \tag{11}$$

$$\sigma_B = \frac{4M_Y}{\pi(D - t)^2 t} \tag{12}$$

Combined nominal longitudinal stresses:

$$\sigma_L = \sigma_A + \sigma_B \tag{13}$$

Step 2: Determine whether or not it is necessary to consider the effect of the external compressive longitudinal loads on the failure pressure of the single defect:

$$\sigma_L > \sigma_1 \tag{14}$$

Where:

$$\sigma_1 = -0.5 f_u \frac{(1 - d/t)}{\left(1 - \frac{d}{tQ}\right)} \tag{15}$$

Step 3: Calculate the failure pressure of the single corrosion defect under internal pressure only, using the following equation, Ppress

$$P_{press} = \frac{2tf_u(1 - d/t)}{(D - t)(1 - \frac{d}{tQ})} \tag{16}$$

Step 4: Calculate the failure pressure for a longitudinal break, including the correction for the influence of compressive longitudinal stress

$$P_{comp} = \frac{2tf_u}{(D - t)} \frac{(1 - d/t)}{\left(1 - \frac{d}{tQ}\right)} H_1 \tag{17}$$

$$H_1 = \frac{1 + \frac{\sigma_L}{f_u}\frac{1}{A_r}}{1 - \frac{1}{2\mathrm{A}_r}\frac{(1-d/t)}{\left(1-\frac{d}{tQ}\right)}} \tag{18}$$

$$A_r = 1 - \frac{d}{t}\theta \tag{19}$$

Step 5: Determine the failure pressure of a single corrosion defect subjected to internal pressure loading combined with compressive longitudinal stresses: Pf = min (Ppress; Pcomp).
Step 6: Calculate the safe working pressure of the corroded pipe, PSW

$$\mathrm{P_{SW}} = \mathrm{F.P_f} \tag{20}$$

F: Safety factor

FE Methods: The development of computer technology has created conditions for the engineers to solve many complex structural problems on finite element analysis software. This is a numerical method which used to simulate load conditions on a physical system and determine its behavior. Thanks to this method, the number of test samples is reduced because computer simulation allows many models to be simulated quickly and conveniently. Therefore, it saves costs, time and creates more reliable quality designs. In this paper, ANSYS software was used to make a model of defected pipe and analysis stress of pipe subjected to internal high pressure.

3 FE Modeling Cases

Model Data: Three cases were modelled to estimate the failure pressure values, which use the corrosion defect length (L) and the wall thickness (t) as variables. These data and the parameters of material steel and Clockspring are presented in Table 1 and Table 2 below:

Table 1. Case data

Case	Depth of defect	Width of defect	Length of defect	Position
1^{st}	4.15 mm	58 mm	139 mm	Surface/Longitudinal pipe
2^{nd}	5.01 mm	64 mm	1202 mm	Surface/Longitudinal pipe
3^{rd}	4.15 mm	1276 mm	58 mm	Surface/Circumferentinal pipe

Above data was taken from the report of defect accessment of 16A riser pipeline – Bach Ho oil field – Viet Nam - 2016.

Table 2. Parameters of steel material and clockspring

Parameters	Units	Steel pipe	Clock Spring
Material	–	API 5L X52	Polyethylense
Diameter of pipe	mm	406.4	–
Wall thickness	mm	14.3	17.5
SMYS	MPa	359	–
SMTS	MPa	455	25
Modulus	MPa	207000	6900
Poisson factor	–	0.3	0.42
Weight	kG/m^3	7850	950

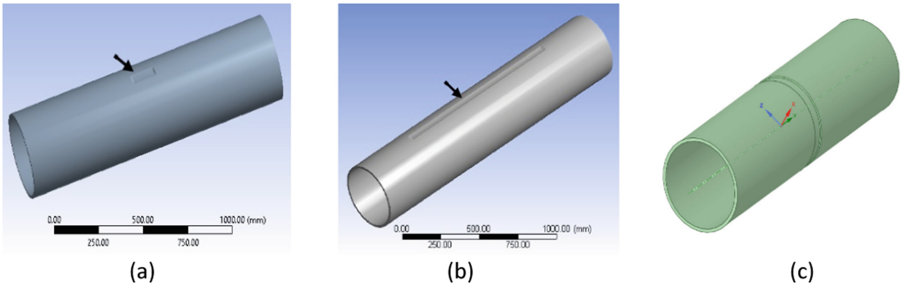

Fig. 2. Pipelines with various defects before wrapped by clockspring (a) Case 1; (b) Case 2; (c) Case 3

In this study, the failure pressure value is considered when Von Mises stress reach maximum stress of the material. Von Mises stress is included of the three principal stress components as below (Fig. 2):

$$\sigma_{VM} = \left(\frac{1}{\sqrt{2}}\right)\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \tag{21}$$

Where:

σ_1 = axial stress acting along the longitudinal direction
σ_2 = hoop stress acting along the circumferential/tangential direction
σ_3 = radial stress acting along the radial direction
σ_{VM} = Von Mises stress.

All boundary conditions such as the constraints and loads are applied to model. The failure pressures were determined by simulating with incremental internal pressure loading, until the von Mises stress is equal to the critical stress of material at failure, σ_{crit} = 600 Mpa (Fig. 3):

$$\sigma_{crit} = K\varepsilon_{crit}^{n} \tag{22}$$

Where:

- K: hardening coefficient, K = 876 Mpa;

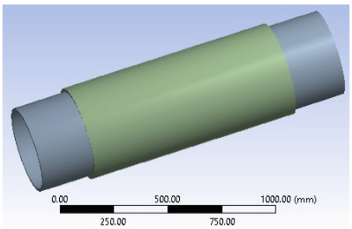

Fig. 3. A model of corroded pipe after wrapped by clockspring

- ε_{crit}: critical strain, $\varepsilon_{crit} = 0.105$;
- n: hardening exponent, n = 0.2;

4 Results and Discussions

4.1 Failure Pressure

The results of failure pressure are shown in Table 3 and Fig. 4.

Table 3. Results of the failure pressure

Case	ANSYS	ASME B31G	DNV RP 101
1st	20.49 MPa	18.14 MPa	18.65 MPa
2nd	15.60 MPa	9.020 MPa	10.32 MPa
3rd	33.80 MPa	20.08 MPa	21.71 MPa

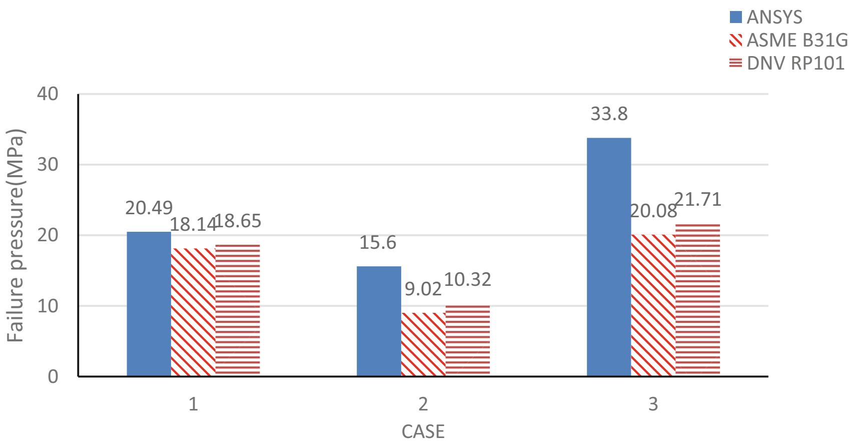

Fig. 4. The chart of failure stress in case 1, 2, 3

4.2 Maximum Von Mises Stress

The results of the Von-mise stress of the pipe before and after wrapping, have change clearly. From the over-the-limit stress value of material (567 Mpa) down to about below 400 Mpa (Table 4).

The case 3 has the corrode defect with circumferential shape. This reason may lead to the result that stress value after wrapping does not decrease significantly but the failure pressure of case 3 is higher than the other cases.

The value of the failure pressure from FE method are higher than the results from ASME B31G and DNV RP101.

Table 4. Results of the maximum Von Mises stress with internal pressure, p = 13.9 MPa

Case	Before repair	After repair
1st	460.48 MPa	384.02 MPa
2nd	567.15 MPa	344.95 MPa
3rd	397.80 MPa	376.20 MPa

5 Conclusions

The FEM method allows to evaluate the stress changes on the corroded pipe before and after wrapping by Clockspring, while the other methods are limited. The analysis results also show the effectiveness of Clockspring coats used for the corroded pipes.

The shape of defects have a important role for the remaining working ability of the corroded pipe.

This study have no the experiments for comparing to the results determined by FE model. This is the scope has to be done in the future for the more reliable assessments and giving the suitable solutions of using Clockspring for corroded pipe.

References

1. Ossai, C.I.: Engineering product development pillar, singapore university of technology and design, "finite element modelling and retained life estimation of corroded pipelines in consideration of burst pressures." Infrastructures **2**, 15 (2017)
2. Terán, G.: Failure pressure estimations for pipes with combined corrosion defects on the external surface: a comparative study. Int. J. Electrochem. Sci. **12**, 10152–10176 (2017)
3. Wang, Y.-L.: State evaluation of a corroded pipeline. J. Marine Eng. Technol. **15**(2), 88–96 (2016)
4. Shang, H.Y.: A methodology for analysis of defective pipeline by introducing stress concentration factor into beam-pipe finite element formulation. Acta Scientiarum Technol. **38**(3), 313–320 (2016)
5. Dick, I., Inegiyemiema, M.: Predicting the structural response of a corroded pipeline using finite element (FE) analysis. Int. J. Sci. Eng. Res. **5**(11) (2014)
6. Karuppanan, S., Aminudin, A.S., Wahab, A.A.: Brust pressure estimation of corroded pipeline with interacting defects using finite element analysis. J. Appl. Sci. **12**(24), 2626–2630 (2012)
7. ASME B31 G -2012, Manual for Determining the Remaining Strength of Corroded Pipelines, the American Society of Mechanical Engineers (2012)
8. DNV RP F101 -2010, Corroded pipelines recommended practice, DNVGL (2010)