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A Review on Strength Related of Malaysian Coastal Corroded Subsea Pipelines

Mohd Fakri Muda[1*], Mohd Hairil Mohd[2] Mohd Hisbany Mohd Hashim[3], Mohd Khairul Kamarudin[3], Zainul Faizien Haza[4], Marzuki Abdul Rahman[1]

[1]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA Pahang, Pahang, Malaysia.

[2]Department of Marine Technology, Universiti Malaysia Terengganu, Terengganu, Malaysia.

[3]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

[4]Faculty of Engineering Universitas Sarjanawiyata Tamansiswa, JI. Miliran No.16, Yogyakarta, Indonesia.

* Corresponding author E-mail address: fakri@uitm.edu.my

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Abstract

This study aimed to present a numerical analysis to assess the corrosion factor influencing the residual burst pressure and stress behaviour of Malaysian coastal subsea pipelines. Statistical analyses were carried out to investigate the correlation of point damage location and position of defect area to the burst pressure which was determined using DNV RP F101 codes. Eight critical models were analysed by using finite element method to access the stress behaviour. Based on the results, it was observed that critical frequency of corrosion happened at three locations (i.e. 50 m, 900 m and 1500 m) and most of it occurs at the upper region of the pipeline's wall. Furthermore, the stress behaviour indicates larger defect influence more compared to small defect with a ratio of width cause greater stress than the length of defect. In short, this study provides a focus area in the Malaysian oil industry specifically in subsea pipelines chainage for future research development and rehabilitation assessment.

Keywords: Strength analysis, subsea pipelines, corrosion, finite element method

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1. Introduction

Subsea pipelines are one of the methods to transport fluid or gas from one point to another different point in this oil and gas industry. It is a reliable and the safest method to transport the fluid or gas because each substance contains various kinds of chemical substances and is harmful if exposed to the environment and humans (Leong et al. 2020; Senouci et al. 2014). Casually, long-distance pipelines mainly suffer from mechanical, operational, hazard and corrosion damage. The pipelines which are made of carbon steel normally face the matter of corrosion attacks over the years. The metal on the pipeline's surface area is going to be reduced and if this continuously happens without further treatments, it will cause the pipe to crack and leak (Karuppanan et al. 2014).

Malaysian coastal region as the oil-producing country is well known to use various types of subsea pipelines for raw materials transportation. Each of the types has its own advantages to adjust with the failure parameters that exist on that location. Each of these pipes needs detailed analysis to understand its full behaviour so that engineers can extend its potential to the fullest (Lim et al. 2019). There are several published articles (Terán et al. 2017; Oh et al. 2007; Ahankari and Patil 2020; Wang et al. 2020; Lim et al. 2019; Shou and Huang 2020) that presented the analysis of corroded subsea pipelines which shows the unique behaviour of strength related depending on the location of the pipelines. Each coastal oil area influenced the corrosion rate by several factors like the chemical composition, seabed condition, types of product transportation and many more. The behaviour of corroded pipelines for each specific area should be studied thoroughly for better understanding especially considering the strength-related factor.

For these reasons, this paper has discussed the behaviour of corroded pipelines which contains data from the historical inspection of X42 types of subsea pipelines in Malaysian coastal areas. The approach analysis is statistical and Finite Element Method (FEM) to investigate the behaviour of defected pipelines caused by corrosions. FEM is one of the most often used nonlinear approaches because of its excellent response in terms of pipeline failure prediction when the corrosion mechanism is taken into consideration (Terán et al. 2017). The primary aims of this work were to (1) identify the effect of corrosion factors related to pipeline burst pressure and (2) access stress behaviour of different corrosion levels and sizes by FEM. The outputs of this research can contribute much to the engineers for future rehabilitation steps.

2. Strength Analysis of Subsea Pipelines

Regarding the methods to assess the strength of the corroded subsea pipelines, there are numerous research that has been carried out in recent years. Leong (2020) and Chen et al. (2020) had carried out an analysis on a variety of pipe steel grades and corrosion defect geometries, with the results taking into account the effects of corrosion depth, length, and width on burst capacity (Figure 1). While these researchers (Karuppanan et al. 2014; Liu, Khan, and Thodi 2017; Sun and Cheng 2018; Bin Mohd et al. 2014) studied the performance of aging gas pipelines in terms of burst strength capacity using a combination of empirical models and numerical analysis.

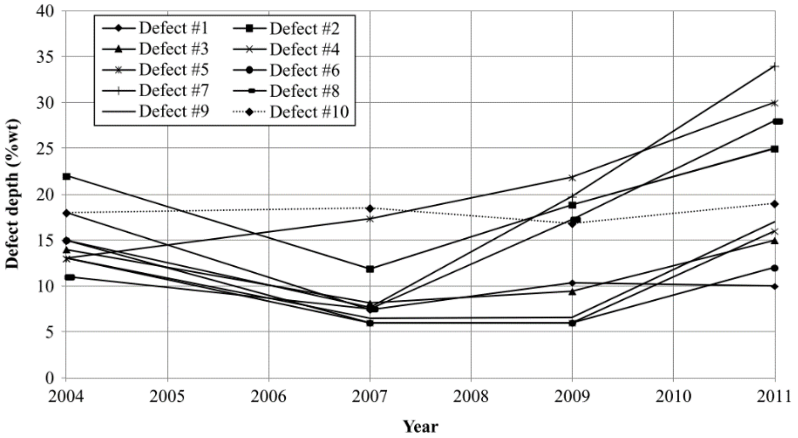


Figure 1. Effects of defects to the pipeline's wall against service time (Al-Amin and Zhou 2014).

All the mentioned research above highlights the critical factors that contributed to the failure of the pipelines. The main parameters of their studies are the physical factor of the pipeline's wall in terms of defects in the metal's wall. This suggested that metal corrosion is one of the main highest considerations in pipelines failure. Therefore, further detailed analysis is needed for pipelines inline systems for better understanding its strength behaviour.

3. Methods

As for this research, there are three stages used in the methodology. The first stages consist of statistical analysis which used a design code to get the estimation of the burst pressure from the pipelines data. Following that, the second stages detail the 3D analysis FEM of the corroded pipelines. During this stage, the modelling was made by using ABAQUS software and the behaviour of the corroded pipelines was accessed like stress and residual burst pressure. Results from the two stages were compared to identify the correlation behaviour of the pipelines in the last stage. Due to the faultlessness of the historical inspection data, this study focuses on X42 types of pipelines only.

3.1. Details of pipelines data and design codes

The data for this research is historical inspection data, also known as pigging data. Pigging data offers critical data about the corrosion defect geometry, such as depth and length, orientation, defect location, and the sorts of corrosion zones that have formed in the defected area (Din et al. 2015). Part of historical data for X42 type pipes is shown in Table 1 for pitting types of corrosion obtained from one of the local oil companies in Malaysia. The type of pipe is API 5L with a diameter, D_o of 168.3 mm and the service life is 19 years. The S-log (distance) described the location in metre of the defected point measured from the starting point of the pipelines, while S-o`clock (position) explains the location of the defected area as shown in Figure 2. The corrosion severity was measured by loss of metal (depth) in the wall thickness of the pipelines.

Table 1. Historical data of X42 subsea pipelines

S-log	S-o'clock	nominal thicknes s	depth	Length, L	Width, D
distance	position				
[m]	[h:m]	[mm]	[%]	[mm]	[mm]
1420.38	9.54	9.5	50	15	51
1717.77	12.36	9.5	49	12	59
32.51	12.4	9.5	41	23	51
1492.45	3.14	9.5	41	13	15
1768.16	2.42	9.50	17	20	59
2543.53	12.20	9.50	12	47	59

*h:m = Hour:minute

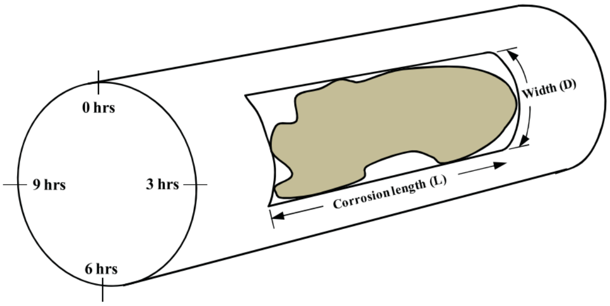


Figure 2. S-o`clock (position) of the corroded area at pipelines surface (Mohd et al. 2014)

There are many industry design codes that can be referred to determine the burst pressure, P_f of corroded pipelines. Most published codes are ASME B31G, DNV RP F101, PCORRC and others. According to Mohd et al. (2014), burst pressure determination for DNV RP F101 codes gives the closes value to the validated FEM analysis. Referring to that, this study highlighted similar codes to determine the residual burst pressure of the corroded pipelines using equation 1 (Mohd et al. 2014; Practice 1999). SMTS refer to specified minimum tensile strength and Q stands for length correction factor. A total of 330 points of pigging data were considered in this study.

$$P_f = 0.9F\ SMTS \frac{2t}{D-t}\left(\frac{1-\left(\frac{d}{t}\right)}{1-\frac{1}{Q}\left(\frac{d}{t}\right)}\right) \tag{1}$$

3.2. *Finite element modelling*

The three-dimensional elastic-plastic finite element modelling was carried out using ABAQUS Version 6.4. A base pipe model with an artificial defect according to the corroded pipes data was modelled with both ends set to fixed (encastre) condition. A Uniform load of 60 MPa for 600 seconds was applied to the inner surface of the pipelines to mimic the burst pressure of 0.1 MPa/s acting in the pipelines. Sensitivity analyses (Figure 3) were carried out to find the mesh refinement in the defect zone to improve the accuracy of stress and strain calculations in the region of the defect. To verify the modelling, the first base model is validated to the published studies from Oh et al. (2007) before applying to the rest of the corroded data. The modelling of the FEM is shown in Figure 4.

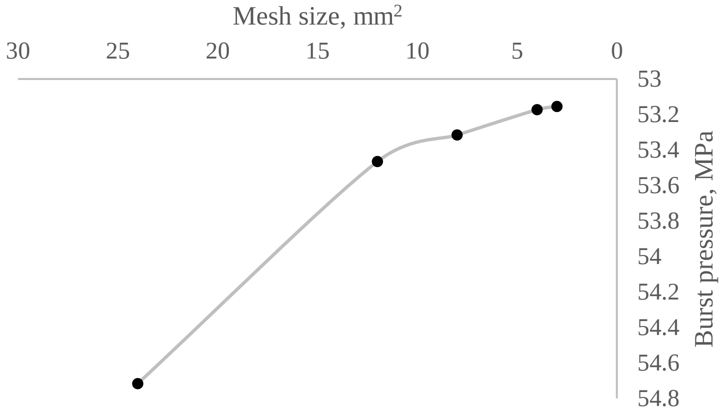


Figure 3. Sensitivity analysis of meshing sizes for the FEM

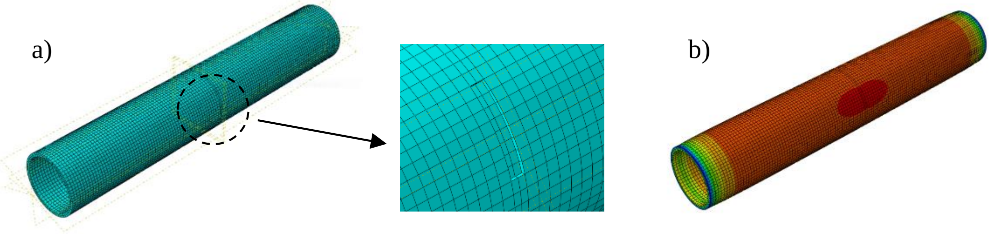


Figure 4. FEM of the corroded pipelines a) Model before analyse, b) Model after analyse

4. Results and Discussion

4.1. Statistical analysis

Figure 5 shows the distribution of defected points by distance versus the burst pressure for API 5L X42 inline pipelines systems. The maximum allowable operating pressure (MAOP) for these pipes is 13.1 MPa (Bin Mohd et al. 2014) where residual burst pressure below these value is considered unfit for service. As can be seen, all defected points are still in minor condition and the highest frequency of lowest burst pressure points is located at 50 m, 900 m and 1500 m regions. One point shows the worst corrosion severity at 1492.45 m with a residual burst pressure of 46.5 MPa. From the perspective of defected point position on the pipeline surface position as shown in Figure 6, most corrosion occurs at the first and fourth quadrant of the pipeline's surface. The trend most typically occurs at the upper region of 0^0 to 45^0 positions on the pipeline's wall. The rate of these defected points is much influenced by the depth of subsea and the condition of the seabed (El-Abbasy et al. 2015). Dissolved oxygen which functions as an oxidant to discharge electrons at the cathode, surrounds and protects the pipework in seawater. On a metal surface, the higher the concentration of dissolved oxygen, the greater the rate of corrosion. These factors for external corrosion will be considerably exacerbated, like a fall in seawater temperature, an increase in current velocity, and coating degradation (Yang et al. 2017). Therefore, points distance of 50 m, 900 m and 1500 m should be the focus for corrosion parameters investigation.

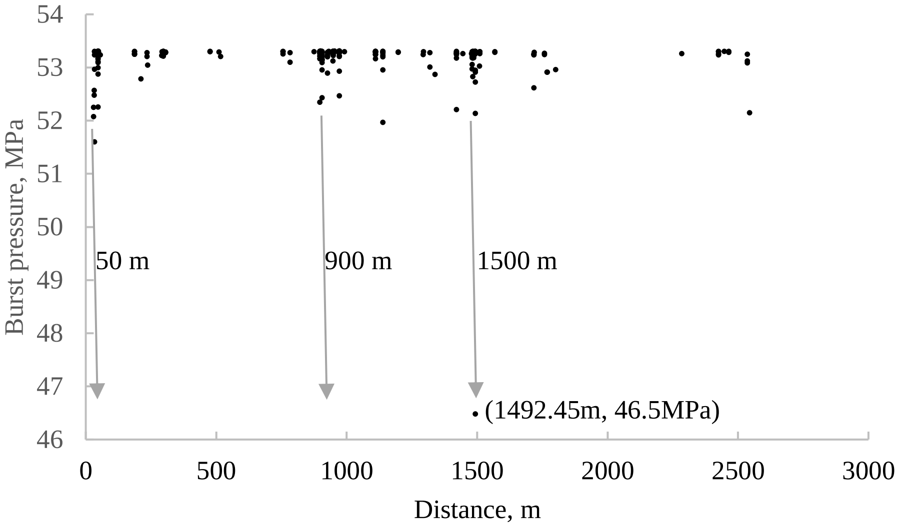


Figure 5. Distribution of point location versus burst pressure[2]

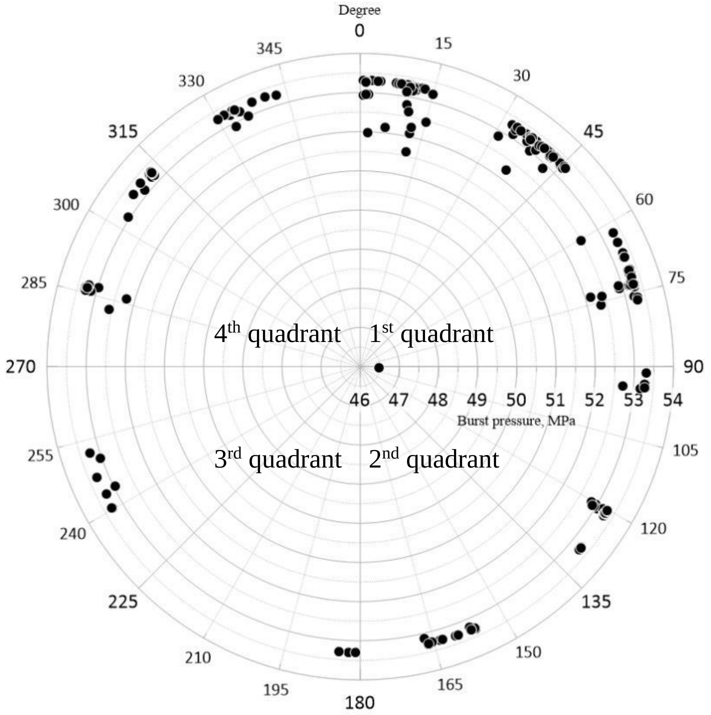


Figure 6. Distribution position of defected area on pipe surface versus burst pressure

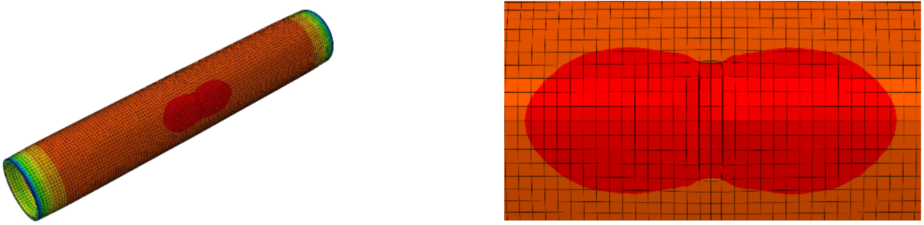
4.2. *Finite element analysis (FEA)*

Due to finite element modelling for each model consuming a lot of time, only eight models were considered for FEA in this study. The models range between 30% to 50% for metal loss and various defect shapes. The mechanical properties of the X42 pipes were retrieved from a previously published study by Mohd et al. (2014) and the base finite element model was validated first with studies from Oh et al. (2007) before the models ran for the rest of the sample data. The stress behaviour of the FEA is shown in Figure 7. The red area denoted the highest stress occurs on the wall of the pipelines. It is apparent that a small defect area will lead the stress to disperse to the whole structure of the pipelines as shown in Figure 7a, 7b and 7d. The width of the defect most contributed to the stress value compared to the length of the defect. This is in agreement with the results reported by Leong et al. (2020), where the author state that the area of stress concentration in the defect region diminishes as the defect width lowers as compared to other models with larger defect areas.

When the defect area becomes larger, the stress becomes more concentrated to the defect region and less scattered to the other section, as present in Figure 7c, 7e and 7f. This centered stress is much more risked as it can trigger a small crack or rupture at the bottom edge of the defect area that will lead to structure failure (Oh et al. 2007). In terms of the orientation of defects, the width in circumferentially aligned with the body of the pipelines gives much more effects to the stress compared to the defect's length, as shown in Figure 7d, 7e and 7f. In summary, the circumferentially aligned and larger defects bring higher risk to the stress of corroded pipelines. The developed FE model can be used by engineers to predict the strength of corroded subsea pipelines.

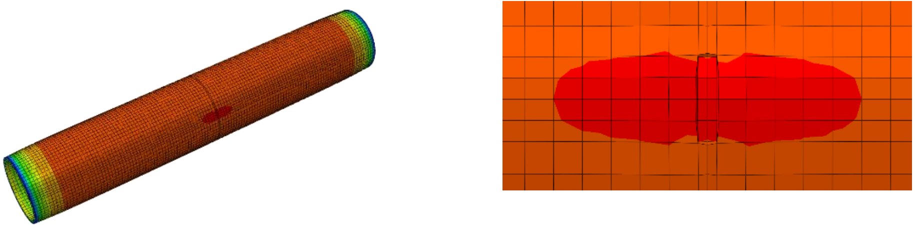
ML : 32% , L x D : 13 mm x 66 mm

a



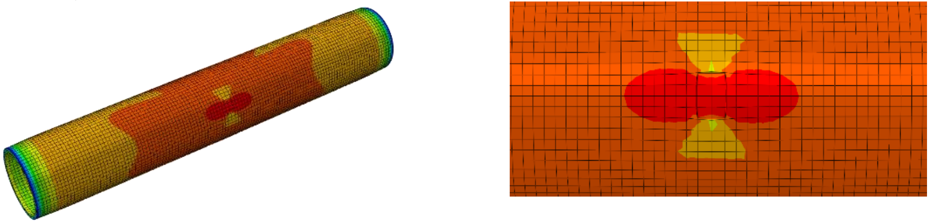
ML : 36% , L x D : 5 mm x 22 mm

b



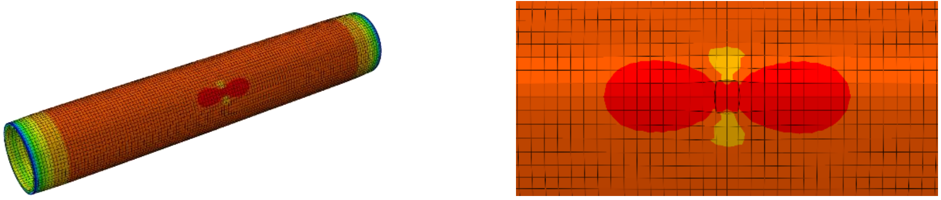
ML : 38% , L x D : 20 mm x 29 mm

c



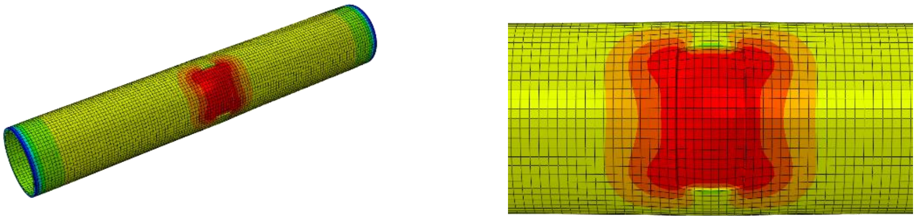
ML : 41% , L x D : 13 mm x 15 mm

d



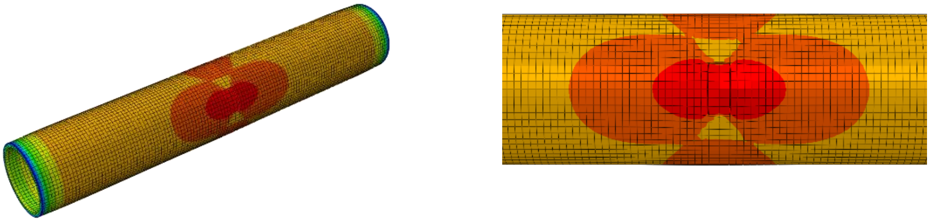
ML : 41% , L x D : 56 mm x 117 mm

e



ML : 41% , L x D : 23 mm x 51 mm

f



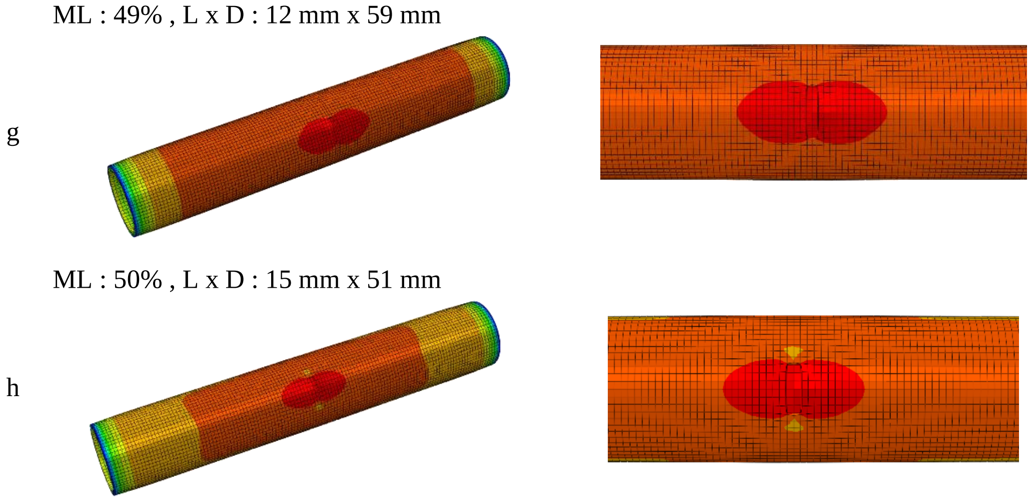


Figure 7. Stress behaviour of FEA. (ML : Metal loss, L x D : length x width)

5. Conclusions

The purpose of the current study was to determine the behaviour of X42 types Malaysian coastal subsea pipelines with numerical analysis. Two methods applied, which are statistical and finite element analysis to access the research objective. This study has suggested a few critical locations need further investigations and behaviour of various corrosions severity had been accessed. FEM models also were published where pipelines assessment and the behaviour can be predicted. The current findings add substantially to our understanding of different pipes behaviour much related to their service locations.

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