Collapse Failure of Submarine Pipelines with Corrosion Defect

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Abstract. Corrosion is a common type of defects which results serious impact on the safe operation of submarine pipelines. Considering the influence of corrosion defects, the collapse failure mode and collapse pressure of submarine pipelines are investigated. It is concluded that corrosion has a significant effect on the collapse failure of submarine pipelines. Under various corrosion depth and width, different collapse modes are obtained. In terms of collapse pressure, the influence of corrosion depth is more pronounced than corrosion width. The deeper the corrosion defect is, the less impact the corrosion width could cause.

1. Introduction
Corrosion is one of the common failure modes of submarine pipelines, it is imperative to evaluate the residual strength of pipeline with corrosion defects. At present, intense investigation has been conducted on failure of submarine pipelines under internal pressure [1-12]. But when it relates to external pressure the study seems to be not mature enough. Sakakibara [13] investigated the ultimate collapse pressure of submarine pipelines with constant depth internal corrosion defects experimentally and numerically, where the finite element models were established to calculate the collapse pressure and the FEM results agree well with experimental results. Netto [14-15] studied the collapse pressure of submarine pipelines with constant depth corrosion defects using finite element method, and proposed a set of fitting formula for predicting the collapse pressure of submarine pipelines with axial long corrosion defects. Fan [16] analyzed submarine pipelines with the constant depth corrosion defects with initial ovality and developed the equation for calculating the collapse pressure. Considering parameters of material anisotropy, frictional force, initial defect, Cai [17-18] studied the residual strength of submarine pipeline with dent defects and corrosion-dent-groove coupled defects under bending moment. The research results show that the dent plays a leading role in the coupling defect. This paper focus on the collapse failure mode and failure pressure of submarine pipelines with corrosion defects.

2. Finite element model
Commercial software Abaqus is used to study the failure of pipelines with corrosion defects. The finite element model is shown in figure 1.
3. Buckling and collapse mode of pipelines with corrosion defects

Numerical model for submarine pipelines with corrosion defect is established. The eigenvalue buckling analysis is firstly carried out considering various corrosion width and corrosion depth. Figure 3 shows the first four modes of the eigenvalue buckling mode of submarine pipes. It is noted that the corrosion defect has a significant influence on the buckling mode of the eigenvalue of the pipe. When the eigenvalue buckling analysis is performed, the effect of corrosion defects should be considered.

3.1 Corrosion width

In order to investigate the effect of corrosion parameters on collapse modes of the pipeline, various corrosion depth and corrosion width are considered. It is shown that collapse modes of the pipeline are varied for different corrosion width. As shown in figure 4, with the corrosion width increases, the corrosion collapse mode changes from elliptical collapse to pear-shaped collapse mode, and then gradually changes to U-shaped collapse mode, where $d_i/t_0$ is non-dimensional corrosion depth.
3.2 Corrosion depth
With the same corrosion width, the difference of corrosion depth also has a great influence on the collapse mode of submarine pipelines. Figure 5 shows the variation of collapse modes of the pipeline with different corrosion depth of defect. It is illustrated the collapse mode presents elliptical collapse for shallow corrosion depth cases. With the increasing of corrosion depth, it changes to heart-shaped collapse, and then changes to U-shaped collapse, where $\beta$ is the non-dimensional corrosion width.

(4) Effect of corrosion defects on collapse pressure
Based on the investigation of collapse mode of submarine pipelines with corrosion defects, effect of corrosion defects on collapse pressure of submarine pipelines is investigated furthermore.

4.1 Corrosion width
Figure 6 shows the variation of collapse pressure of submarine pipelines under various corrosion width. For all cases of corrosion depth, as the corrosion width increases, the collapse pressure of the pipeline gradually decreases. It can be seen from the figure that turning points are different for different corrosion depth cases. For $d_c/t_0 = 0.2$, the curve turns at $\beta = 0.1$ and $\beta = 0.6$. For $d_c/t_0 = 0.4$, the curve turns at $\beta = 0.05$ and $\beta = 0.5$. For the case of $d_c/t_0 = 0.6$, the curve presents as a horizontal line first and turn down at $\beta = 0.1$, then become horizontal line again at $\beta = 0.4$. For $d_c/t_0 = 0.8$ there just one turning point at $\beta = 0.3$. For all situations the corrosion width hardly affects the collapse pressure when $\beta \geq 0.6$. Meanwhile, with the increase of corrosion depth, the turning point of corrosion width curve will move left, that is to say, the deeper the defect is, the less impact the corrosion width could cause.
4.2 Corrosion depth

Figure 7 shows the collapse pressure of the pipeline with constant depth corrosion defects. With the increasing of the corrosion depth, the collapse pressure shows a linear downward trend. For the case of $d_e/t_e = 0.2$, no matter how the corrosion width changes, the non-dimensional collapse pressure won’t drop below 0.55. On the contrary, when $\beta = 0.2$, it is noted that the curve of collapse pressure has a rapidly declining trend with the increase of corrosion depth. Therefore, it is concluded that the effect of corrosion depth on collapse pressure is more pronounced than corrosion width. In terms of residual strength evaluation of submarine pipelines with corrosion defects, large corrosion depth cases should be focused.

![Figure 7. Collapse pressure of submarine pipelines under different corrosion depth.](image)

5. Conclusion

Corrosion defect has significant effect on the collapse pressure of submarine pipelines. When conducting integrity assessment, it is necessary to consider the influence of corrosion defects on collapse failure of submarine pipelines. Under the increasing corrosion width, the collapse mode changes from elliptical collapse mode to pear-shaped collapse mode, and finally transforms to U-shaped collapse mode. With the increasing corrosion width, the collapse mode changes from elliptical collapse mode to heart-shaped collapse mode, and finally transforms to U-shaped collapse mode. As far as collapse pressure is concerned, the effect of corrosion depth is more pronounced than corrosion width.

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