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Risk assessment based on analytical evaluation of structural integrity and life of drilling rig pipe

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Abstract

Risk assessment procedure based on structural integrity evaluation has been applied to oil drilling rig pipe. The new concept based on application of structural integrity evaluation to assess risk level according to probability and consequence of failure was used. Analytical expressions for surface cracks are used to calculate stress intensity factors for different crack geometries. Oil drilling rig welded pipe integrity has been evaluated analytically by simple application of the Failure Assessment Diagramme (FAD), i.e. by using the ratio of linear elastic fracture mechanics parameter, K_I, and its critical value, K_{Ic}, in relation with the ratio of applied stress and its critical value, to define the point in FAD. Probability of failure is then taken according to the position of the point in the FAD, corresponding to oil drilling rig welded pipe data. The same logic is employed in the case of cyclic loading, i.e. fatigue crack growth. In that case, structural life is estimated by using Paris law to calculate crack length vs. number of cycles, to be used in risk assessment procedure and by managers to make decision about further use of damaged pipes, based on data provided by engineers.

Keywords: Risk assessment ; Drilling rig pipe ; Structural integrity and life assessment

1. Introduction

Oil drilling rig pipes are prone to cracking due to presence of corrosion agents, both under static and dynamic (cyclic) loading, [1-4]. The new concept based on application of structural integrity evaluation to assess risk level according to probability and consequence of failure was used. Analytical expressions for surface cracks are used to

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calculate stress intensity factors for different crack geometries. Oil drilling rig welded pipe integrity has been evaluated analytically by simple application of the Failure Assessment Diagramme (FAD), Fig. 1, i.e. by using the ratio of linear elastic fracture mechanics parameter, K_I, and its critical value, K_{Ic}, in relation with the ratio of applied stress and its critical value, to define the point in FAD. Probability of failure is then taken according to the position of the point in the FAD, corresponding to oil drilling rig welded pipe data. The same logic is employed in the case of cyclic loading, i.e. fatigue crack growth. In that case, structural life is estimated by using Paris law to calculate crack length vs. number of cycles, to be used in risk assessment procedure and by managers to make decision about further use of damaged pipes, based on data provided by engineers. Also to be noticed, the procedure introduced here for risk assessment is not limited to oil drilling rig pipes, but it is rather a general one, applicable to any component with known geometry, material properties and loading data.

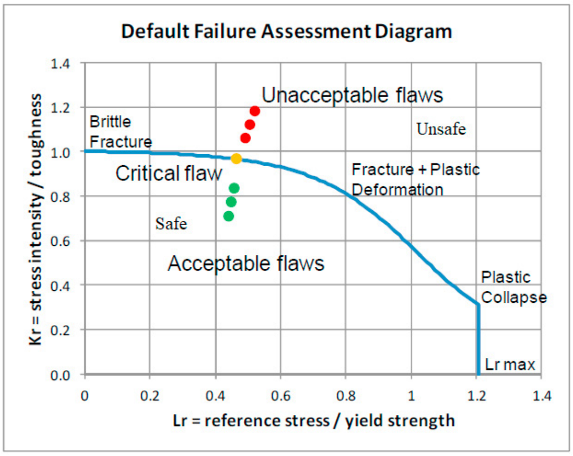

Figure 1: Failure Assessment Diagram

Structural integrity assessment of oil drilling rig pipe is of utmost importance due to their proneness to cracking under corrosive environment. This can be achieved by means of experimental, numerical and analytical methods, as shown in number of papers [1-4], where new concept was introduced, based on application of structural integrity evaluation to assess risk level according to probability and consequence of failure, [5-8]. It was shown that experimental methods, based on strain measurement, are the least conservative, while numerical methods, based on FEM, are in good agreement, but more conservative in predicting the failure pressure, [1-4]. Analytical expressions for surface cracks are used to calculate stress intensity factors for different crack geometries, [1]. This applies both to static and cyclic loading.

2. Structural integrity and life of drilling rig welded pipe

The High Frequency (HF) welded pipe with an axial crack, Fig. 1, made of API J55 steel, used as oil drilling rig device, is analysed here as the case study. Basic operating data is:

- maximum pressure 10.01 MPa,
- minimum pressure 7.89 MPa,
- testing pressure 22 MPa,
- number of strokes of pump rod, n_{PR}=9.6 min^{-1}.

The axial surface crack (depth a=3.5 mm, length 2c=200 mm) was made by electro erosion, positioned in the base metal (BM) of an exploited pipe (8 years), since it was the weakest link regarding fracture toughness, K_{Ic}=91.4 MPa√m=2890 MPa√mm. Other data needed here are: thickness B=6.98 mm, Yield Strength R_{eH}=380 MPa, Tensile Strength R_m=560 MPa, whereas more details about the pipe and material can be found in [1-4].

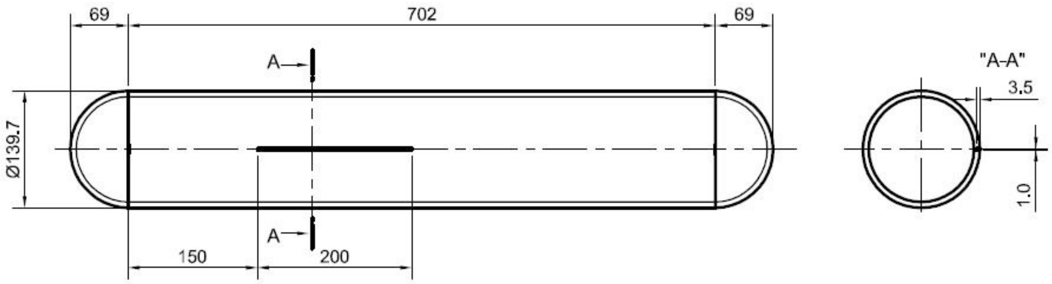

Figure 2. Oil rig pipe, as tested under pressure, [1]

Analytical procedure

API 579

The Mode I Stress Intensity Factor for cylinder – surface crack, longitudinal direction – semi-elliptical shape, internal pressure

$$K_1 = G_O \sigma \sqrt{\frac{\pi a}{\emptyset}} \qquad , K_1 = G_1 \sigma \sqrt{\frac{\pi a}{\emptyset}}$$

The values of G_o and G_1 at the crack deepest and surface point are:

Deepest point $G_o = a_0 + a_1 \left(\frac{a}{t}\right)^{0.5} + a_2 \left(\frac{a}{t}\right) + a_3 \left(\frac{a}{t}\right)^3$

Surface point $G_1 = c_0 + c_1 \left(\frac{a}{t}\right) + c_2 \left(\frac{a}{t}\right)^2 + c_3 \left(\frac{a}{t}\right)^4$

where values of $a_{0\,,} a_1, a_2, a_3$ and $c_{0\,,} c_1, c_2, c_3$ are given in [9], as well as other needed quatities:

$$\emptyset = 1.0 + 1.464 \left(\frac{a}{c}\right)^{1.65} \qquad \sigma_{ref} = \sqrt{9(M_s * \sigma)^2}/3 \qquad M_s = 1 \Big/ 1 - \frac{a}{t} + \left({}^{a}/_{t} \Big/ {M_t} \right)$$

Newman solution

Adjust form by Newman solution for a thin walled shell is given by

$$K_1 = \left[M_F + \left(E_K \sqrt{\frac{C}{a}} - M_F \right) \left(\frac{a}{t}\right)^s \right] \frac{\sigma \sqrt{\pi a}}{E_K} M_{TM}$$

where M_F is the function depending on the geometry (ratio $\frac{a}{c}$)

$$M_F = 1.13 - 0.1 \left(\frac{a}{c}\right), \; E_K = 1.0 + 1.464 \left(\frac{a}{c}\right)^{1.65} \qquad S = 2 + 8 \left(\frac{a}{c}\right)^3 \qquad 0.02 \leq \left(\frac{a}{c}\right) \leq 1$$

$$M_{TM} = \frac{1 - C \frac{({}^{a}/_{t})}{M_T}}{1 - C({}^{a}/_{t})} \qquad C = 0.85$$

BS-7910 Solution

The SIF can be simply expressed as a function of crack size and loading conditions using a closed form solution given by:

$$K_1 = \sigma_o Y \sqrt{\pi a}$$

Since parameter Y depends upon the geometry of the component and the crack, it is a complex function of the crack size [11] **.**The geometric function for the calculation of SIF is given in Annex M of BS-7910 and is stated as: $Y = M f_w M_m$where M is the bulging factor . The detailed calculation for evaluating Y is given in [11]. Once the value of Y has been calculated next step involves the calculation of K_1.

Static loading

Table 1 shows the comparison of the values of K1 between the three methods and results obtained from FEM. We note through the comparison that the Newman method is the closest. After calculating K_I, one can calculate K_r and also L_r, to get the corresponding point in FAD for service pressure p=10 MPa, as shown in [12].

Table 1: Comparison of the values of K1 between the three methods and results obtained from FEM

a, mm	K_I (BS7910	K_I (API579)	K_I (Newman)	K_I FEM
3.5	930	824	1257	1896
4.19	1546	1075	1531	2198
4.88	2139	1381	1861	2432
5.57	2913	1747	2316	2745
6.26	4035	2179	3099	2984
6.9	10655	2645	4762	3647

Table 2: show the comparison (Lr,Kr) between three approaches

	BS 7910			API 579			Newman solution		
a/2c=200	Lr	Kr old	Kr new	Lr	Kr old	Kr new	Lr	Kr old	Kr new
3.5	0.260	0.321	0.242	0.420	0.285	0.214	0.431	0.434	0.327
4.19	0.263	0.535	0.402	0.519	0.372	0.280	0.438	0.529	0.398
4.88	0.267	0.740	0.557	0.678	0.477	0.359	0.450	0.643	0.484
5.57	0.276	1.007	0.758	0.975	0.604	0.455	0.471	0.801	0.603
6.26	0.302	1.396	1.051	1.730	0.754	0.567	0.512	1.072	0.807
6.9	0.729	3.686	2.775	6.072	0.915	0.688	0.596	1.647	1.240

Fatigue

The crack growth to its critical size primarily depends on external loads and crack growth rate. Paris equation for metals and alloys, establishes the relationship between fatigue crack growth da/dN and stress intensity factor range ΔK, using the coefficient C and the exponent m:

$$\frac{da}{dN} = C(\Delta K)^m = C\left(Y(\frac{a}{W})\Delta\sigma\sqrt{\pi \cdot a}\right)^m \quad (1)$$

In the case considered here, i.e. edge crack growing into depth, one gets:

$$\frac{da}{dN} = C(\Delta K)^m = C\left(Y(\frac{a}{W})\Delta\sigma\sqrt{\pi \cdot a}\right)^m \quad (2)$$

where Y(a/W) is the geometry factor depending on crack length. Paris law is then integrated and transformed to calculate the number of cycles from initial to final crack length:

$$N = \frac{2}{(m_p-2)\cdot C_p\cdot(Y(a/W)\cdot\Delta\sigma)^{m_p}\cdot\pi^{\frac{m_p}{2}}}\left(\frac{1}{a_0^{\frac{m_p-2}{2}}} - \frac{1}{a_{cr}^{\frac{m_p-2}{2}}}\right) \tag{3}$$

where C_p and m_p denotes real data used here: C_p=1.23E-13, m_p=3.931 for new material, C_p=2.11E-15, m_p=6.166 for old material [12]. For the initial external damage, length 2c = 200 mm and depth a = 3.5 mm, calculation was done for new and material from exploitation, as well as for two values of stress ratio R = 0.8 and R = 0.7. The results of crack growth as a function of the number of cycles N for new material and for stress coefficients R = 0.8 and R = 0.7 shown in Figure 3 indicate a much shorter life (almost 5 times) for the stress ratio R = 0.7 in relation to R = 0.8. When it comes to material from exploitation, this influence is even more pronounced ,where the number of cycles to crack penetration is cca 12 times smaller, Figure 4.

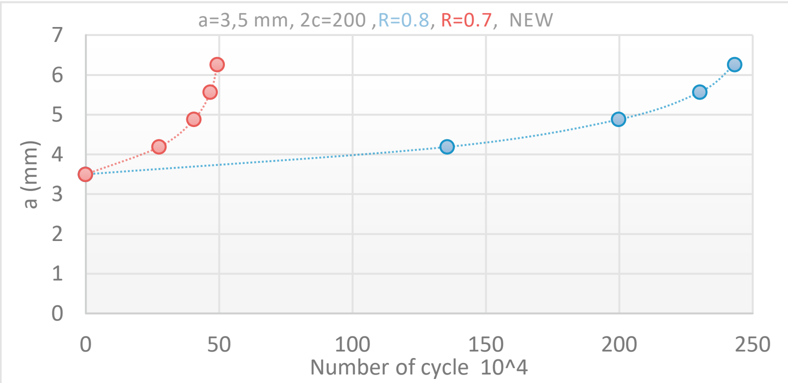

Figure 3: Influence of stress ratio on service life; (depth crack) new material

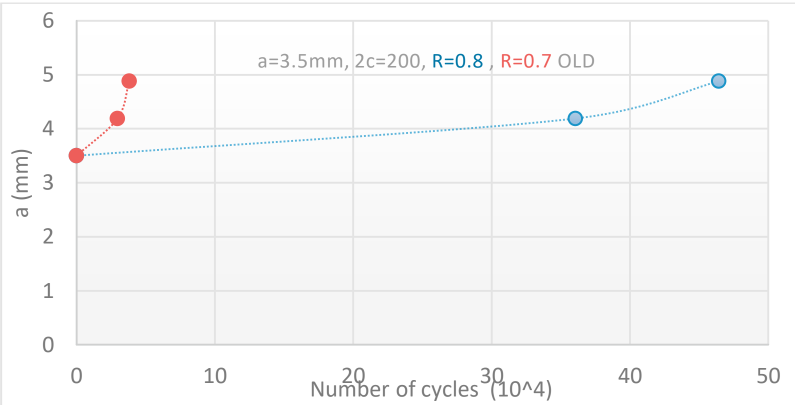

Figure 4: Influence of stress ratio on service life; (depth crack and surface crack) old material

		Consequence category					
		1 – very low	2 - low	3 - medium	4 - high	5 - very high	**Risk**
Probability category	≤0.2 very low						**Very low**
	0.2-0.4 low						**Low**
	0.4-0.6 medium						**Medium**

0.6-0.8 high						**High**
0.8-1.0 very high			a=3.5 mm, 2c=200 mm, R=0.8, R=0.7			**Very High**

3. Conclusions

Based on presented concept and results, one can conclude the following:

• The simple engineering analysis, based on analytical calculation of fracture mechanics parameters, is useful for risk assessment of components with relatively simple geometry, such as rig oil pipe.

• Even if the absolute values are overconservative, one can use analytical method to evaluate the effect of some parameters like stress ratio and material properties, on structural integrity and life.

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