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Probabilistic Fatigue and Corrosion Fatigue Analysis of Frame to Hull Joints

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ABSTRACT

Reported are fatigue crack growth (FCG) investigations on a quenched and tempered high-yield steel in air and in sea-water at cathodic protection. Using the FCG curves found, together with an assumed operational profile (o.p.) of loads, reliability computations were performed on three full-penetration fillet welded joints. For a lower loaded joint, exposed to sea-water, very small and ever decreasing failure rates were found, even after as many as 200 traverses of the o.p. For two higher loaded joints, not exposed to sea-water, a failure rate of 0.01 per o.p. was found to occur at approximately 1 to 6 traverses of the o.p., also depending on the weld toe radius.

NOMENCLATURE

a : crack depth, m
a_0 : apparent initial crack depth, m
a_c : critical value of crack depth, m
C : constant in FCG equation, with dimension such that ΔK is in MPa√m and da/dN in m/cycle
CDF : cumulative distribution function
COD : (critical value of) crack (tip) opening displacement, mm
CP : cathodic protection
E : modulus of elasticity, GPa
e : thickness of plate, m
$F_L(t)$: Pr ($L < t$), CDF of fatigue life
F_{max} : maximum load during load cycle, kN
F_{min} : minimum load during load cycle, kN
$F_X(x)$: Pr ($X < x$), CDF of X
$f_X(x)$: dF_X/dx, PDF of X, with dimension of X^{-1}
FCG : fatigue crack growth
ΔK : stress intensity factor range during stress cycle, MPa√m
ΔK_{th} : threshold value of ΔK, MPa√m
L : fatigue life, o.p. traverses
N : number of load or stress cycles
o.p. : operational profile of loads or stresses during design life
PDF : probability density function
p : constant (exponent) in FCG equation
p_3, p_4 : parameters of 3-step discrete distribution: probabilities of occurrence of x_o and x_1, respectively
Pr : probability
q : constant (exponent) in FCG equation
R : F_{min}/F_{max}, load ratio
$r(t)$: failure rate, failures per o.p.
r_{wt} : radius of curvature of weld toe, mm
t : duty time, o.p. traverses
ΔV_{CP} : CP potential versus Ag/AgCl reference electrode, mV
X : stochastic variable
x : dummy parameter in $F_X(x)$ and $f_X(x)$, with dimension of X
x_0, x_2 : parameters in 3-step discrete distribution, MPa in this application
x_1 : $(x_0 + x_2)/2$, MPa in this application
x_{med} : median of X, with dimension of X
θ : weld angle (see Fig. 5), degrees
μ : scale parameter of lognormal and reversed lognormal distributions, with $x_{med} = \exp\mu$
υ : frequency of load or stress cycles, kc/o.p.
υ_i : number of fatigue crack initiations, per m weld length
σ : shape parameter of lognormal and reversed lognormal distributions
$\Delta\sigma$: stress range during stress cycle, MPa
$\Delta\sigma_e$: fatigue limit, MPa
σ_{max} : maximum stress during a definite duty time interval, MPa
σ_r : residual stress due to welding, MPa

INTRODUCTION

In an earlier paper (Tichler and De Jong, 1989), the probabilistic approach of fatigue by means of the program FAILURE RATE has been described. This program essentially consists of numerical integration of a fatigue crack growth (FCG) relationship. Starting from the statistical distributions of the input parameters, the fatigue life distribution is computed by means of Monte Carlo simulation. The results were verified by comparison with fatigue life distributions derived from experimental results. In the present paper, the application of the program to three full-penetration fillet welded joints will be described.

Joint 1 is a frame to hull joint, exposed to sea-water under conditions of cathodic protection (CP). Therefore, FCG curves for the

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KEY WORDS: Corrosion, fatigue, ship hull, weldments, failure rate, probabilistics.