Pipeline Fatigue Assessment

The purpose of this MathCAD sheet is to calculate cumulative pipeline fatigue damage using the well defined 'rainflow counting' process. The algorithms herein use pipeline variable stresses (as consequence of internal pressure and temperature variations) and uses the Rainflow counting method to determine the stress cycle ranges and the number of cycles per stress range. This will then allow the prediction of pipeline fatigue life.

The rainflow counting routine used herein is that which is taken from Downing, S. D. and Socie, D. F., 'Simple Rainflow Counting Algortihms', International Journal of Fatigue, Vol 4, No. 1, January 1982.

Algorithm one (of Downing et al) was made use of in this sheet. The calculation is performed in three discrete steps as follows:

1. Sorting of the data in order to start and end with a maximum peak, and filter for peaks and valleys. The sorting is a necessary pre-conditioning step.
2. Rainflow cycle counting; the data are then rearranged and filtered to provide an array of cyclic and mean values for each cycle. In addition, the array is also set to contain the maximum cyclic and corresponding mean for the entire data array.

The data can also be factored for wall losses on account of corrosion.

Summary Details

Name of Asset	UKCS Pipeline
Operator	UKCS Operator
Designation	36-Inch Main Oil Export Pipeline
Assessment Case	Rainflow Counting Method: Operating Hoop Stresses
Description	This sheet calculates the pipeline fatigue life based on operational pressures (hoop stresses)

Units Definitions

$^\circ \equiv deg$ $^\circ C \equiv K$ $BBL := 42 \cdot gal$ $BBLD := BBL \cdot day^{-1}$ $SCF := ft^3$ $SCFD := SCF \cdot day^{-1}$

$MMSCFD := 10^6 \cdot SCFD$ $SCM := m^3$ $SCMD := SCM \cdot day^{-1}$

Pipeline Operating Pressure Data

Input Pipeline Operating Pressure History — DATA := Pressures.xlsx

Assign Time Record — $t_r := DATA^{\langle 0 \rangle} \cdot s$

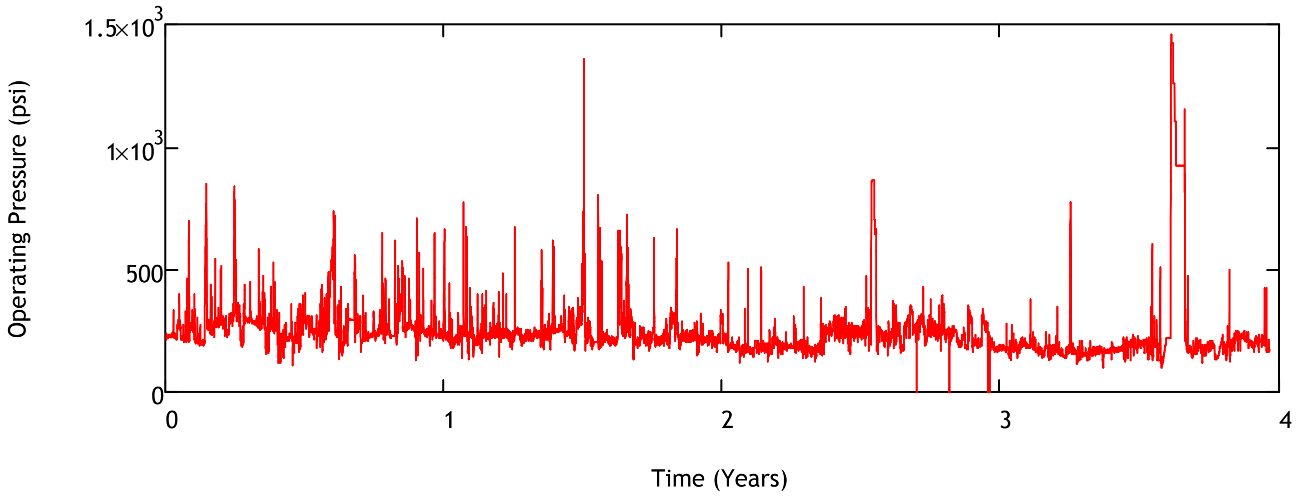
Assign Pressure Record — $P_r := DATA^{\langle 1 \rangle} \cdot psi$

Duration of Time Record — $n_{period} := \max(t_r)$ — $n_{period} = 3.966 \cdot yr$

Average Operating Pressure — $\mu_p := \text{mean}(P_r)$ — $\mu_p = 245.284 \cdot psi$

Standard Deviation Operating Press — $\sigma_p := \text{stdev}(P_r)$ — $\sigma_p = 123.383 \cdot psi$

Maximum Operating Pressure — $P_{max} := \max(P_r)$ — $P_{max} = 1.46 \times 10^3 \cdot psi$

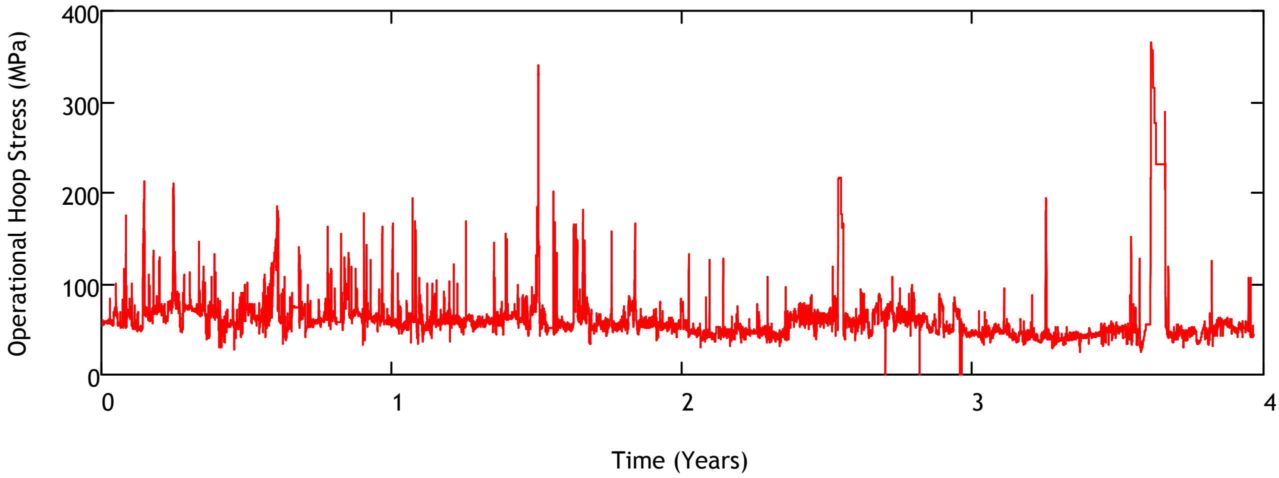


Hoop Stress Data

Pipeline Outside Diameter — $D_s := 36 \cdot in$

Nominal Wall Thickness — $t_{nom} := 18.1 \cdot mm$

Cumulative Corrosion at COP (Estimated)	$C_{loss} := 5.5 \cdot mm$	
Estimated Wall Thickness at COP	$t_{wall} := t_{nom} - C_{loss}$	$t_{wall} = 12.6 \cdot mm$
Number of Data Points	$k := length(P_r)$	
Data Range	$j := 0 .. k-1$	
Operational Hoop Stresses	$\sigma_{h_j} := \frac{P_{r_j} \cdot D_s}{2 \cdot t_{wall}}$	



Material of Construction	API 5L X52	
Youngs Modulus	$E := 207 \cdot GPa$	
Average Hoop Stress (Normal Operating)	$\mu_h := mean(\sigma_h)$	$\mu_h = 61.365 \cdot MPa$
Lambda (Eqn D.8-13 DNV-RP-C203)	$\lambda := \sqrt{\frac{12 \cdot \mu_h}{E \cdot t_{wall}^2}}$	$\lambda = 4.734 \cdot m^{-1}$
Length Parameter (in D.8-12 DNV-RP-C203)	$l_f := \frac{\pi \cdot D_s}{8}$	$l_f = 359.084 \cdot mm$

Rainflow Counting of Time-Record and Fatigue Life Estimate

The analysis below makes use of the above routines to calculate the range and mean stresses of the above time-record of data. These data may then be used with the material S-N data in order to calculate the fatigue life of the pipeline.

Vector of Stresses	$\sigma := \sigma_h \div MPa$
Peak and Valley of Sorted Data	$y := PVF(\sigma)$
Rainflow Counting	$y_{rfc} := RFC(y)$
Define Stress Range (MPa)	$\Delta S := y_{rfc}^{\langle 0 \rangle} \cdot MPa$
Define Mean Stress (MPa)	$S_{mean} := y_{rfc}^{\langle 1 \rangle} \cdot MPa$
Define Maximum Stress (MPa)	$S_{max} := S_{mean} + \frac{\Delta S}{2}$
Length of Column Vector	$b := length(S_{mean})$
Define Range (for Matrix Values)	$n := 0 .. b - 1$
S-N Curve	F1 (with Cathodic Protection)
Intercept with Log N Axis	$loga_1 := 11.299$
Characteristic Fatigue Strength Constant for LHS of Curve	$a_1 := 10^{(loga_1)}$
Inverse Slope of Left-Hand of Bi-linear Curve	$m_1 := 3$
Inverse Slope of Right-Hand of Bi-linear Curve	$m_2 := 5$
No of Cycles Where Slope Change Occurs	$N_s := 10^6$
Stress Value at SN Curve Intersection	$S_{sl} := 10^{\left(\frac{\log\left(\frac{a_1}{N_s}\right)}{m_1}\right)} \cdot MPa$ $S_{sl} = 58.389 \cdot MPa$

Characteristic Fatigue Strength Constant for RHS of Curve	$a_2 := 10^{\left(\log(N_s)+m_2\cdot\log\left(\frac{S_{sl}}{MPa}\right)\right)}$	$a_2 = 6.787\times 10^{14}$
Girth Weld Joint Misalignment (for Calculation of SCF)	$\delta_m := \min(0.15\cdot t_{nom}, 3\cdot mm)$	$\delta_m = 2.715\cdot mm$
Out of Roundness (Maximum per DNV-OS-F101)	$\delta_{OOR\_max} = \frac{D_{max} - D_{min}}{D} \le 0.03$	
Out of Roundness (for Calculation of SCF)	$\delta_{OOR} := D_s\cdot 0.03$	$\delta_{OOR} = 27.432\cdot mm$
Stress Concentration due to Joint Misalignment (See 2.10.1 DNV-RP-C203)	$SCF_{circ} := 1 + \frac{3\cdot\delta_m}{t_{nom}}\cdot\exp\left(-\sqrt{\frac{t_{nom}}{D_s}}\right)$	$SCF_{circ} = 1.391$
Stress Concentration due to Out-of-Roundness (See D.8-12 DNV-RP-C203)	$SCF_{OOR} := 1 + \frac{1.5\cdot\delta_{OOR}}{t_{nom}\cdot\lambda\cdot l_f}\cdot\tanh(\lambda\cdot l_f)$	$SCF_{OOR} = 2.251$
Select Stress Concentration Factor	$SCF_a := SCF_{circ}$	
Damage Due to a Single Stress Reversal for Stress Range 'x' (DNV S-N Curve)	$D(x) := \begin{cases} \frac{\left(\frac{x\cdot SCF_a}{MPa}\right)^{m_1}}{a_1} & \text{if } x > S_{sl} \\ \frac{\left(\frac{x\cdot SCF_a}{MPa}\right)^{m_2}}{a_2} & \text{otherwise} \end{cases}$	
Fatigue Damage Per Stress Range	$D_{fat_n} := D(\Delta S_n)$	
Cumulative Fatigue Damage	$D_{cum} := \sum_n D_{fat_n}$	$D_{cum} = 2.386\times 10^{-3}$

Annual Fatigue Damage $D_{ann} := \frac{D_{cum}}{n_{period}}$ $D_{ann} = 6.02 \times 10^{-4} \cdot yr^{-1}$

Design Fatigue Factor $DFF := 6$

Unfactored Fatigue Life $Life_{unf} := D_{ann}^{-1}$ $Life_{unf} = 1.662 \times 10^{3} \cdot yr$

Factored Fatigue Life $L_f := \frac{Life_{unf}}{DFF}$ $L_f = 277.017 \cdot yr$

DNV-OS-F101 Design Fatigue Factor (Section 5, Table 5-11)

Table 5-11 Allowable Design Fatigue Factor

Safety Class	*Low*	*Medium*	*High*
DFF	3	6	10