Appendix to report:

SBJ-33-C5-OON-22-RE-021

K12 - DESIGN OF MOORING AND ANCHORING

Appendix title:

APPENDIX C – HIGH CYCLE FATIGUE

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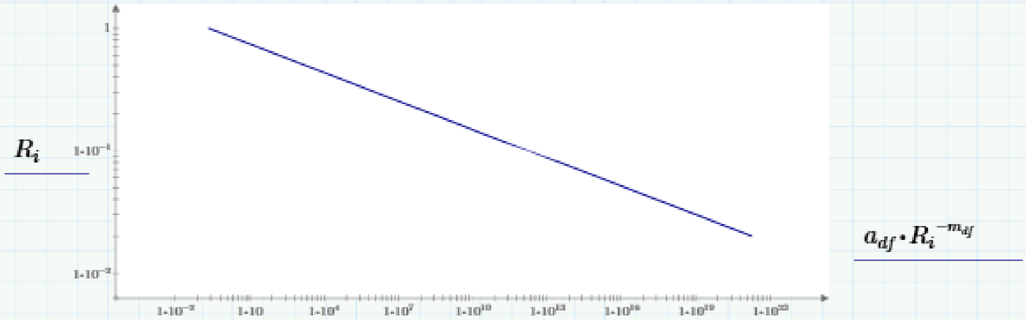
1 INPUT

1.1 Fatigue properties

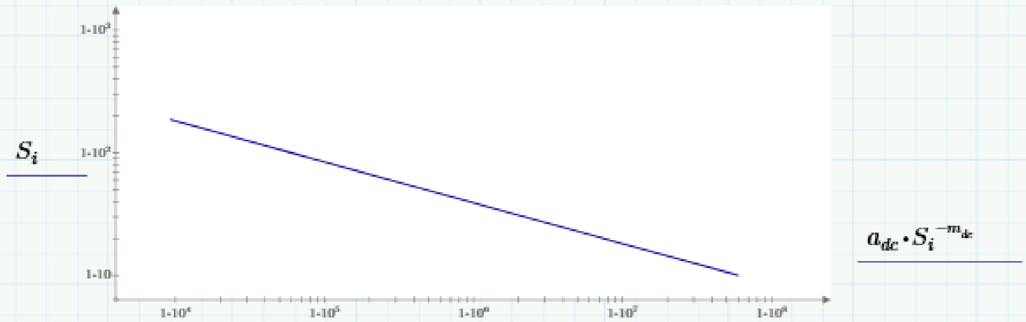
according to DNVGL-OS-E301, 6.6, for fibre rope

Intercept parameter of the R-N curve	$a_{df} := 0.259$
Slope of the R-N curve	$m_{df} := 13.46$
Number of stress ranges (number of cycles)	$n_c(R_i) := a_{df} \cdot R_i^{-m_{df}}$
Design fatigue factor	$DFF_f := 60$



according to DNVGL-OS-E301, 6.2, for chain

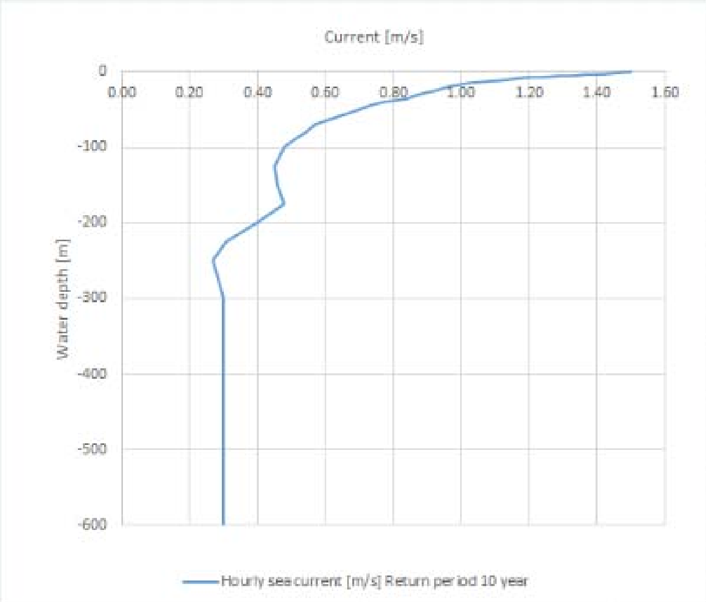
Intercept parameter of the S-N curve	$a_{dc} := 6 \cdot 10^{10}$	
Slope of the S-N curve	$m_{dc} := 3$	
Number of stress ranges (number of cycles)	$n_c(S_i) := a_{dc} \cdot S_i^{-m_{dc}}$	$S_i := 0, 10 .. 200$
Design fatigue factor	$DFF_c := 10$	



1.2 Mooring line characteristics

Diameter fibre rope	$D_{fr} := 0.177\ m$
Diameter chain	$D_c := 0.092\ m$
Corrosion allowance chain/year	$c := 0.2\ mm$
Total length mooring line	$L_{tot} := 1048\ m$
Total mooring line stiffness	$K := 0.13\ \frac{MN}{m}$
Vertical angle of mooringl line	$\alpha := 32\ deg$
Minimum breaking Strength fibre rope	$S_{mbs} := 10\ MN$
Designlife fibre rope	$DL_f := 100$
Designlife chain	$DL_c := 100$
Stress concentration factor fibre rope	$SCF_{fr} := 1.2$

1.3 Current



Return period 10 year	Horizontal	Decomposed
Current middel between 10m and 100m depth	$u_{max} := 0.76\ \frac{m}{s}$	$u_{maxD} := u_{max} \cdot \cos(\alpha) = 0.64\ \frac{m}{s}$
Minimum current along fjord	$u_{min} := 0.01\ \frac{m}{s}$	$u_{minD} := u_{min} \cdot \cos(\alpha) = \left(8.48 \cdot 10^{-3}\right)\ \frac{m}{s}$

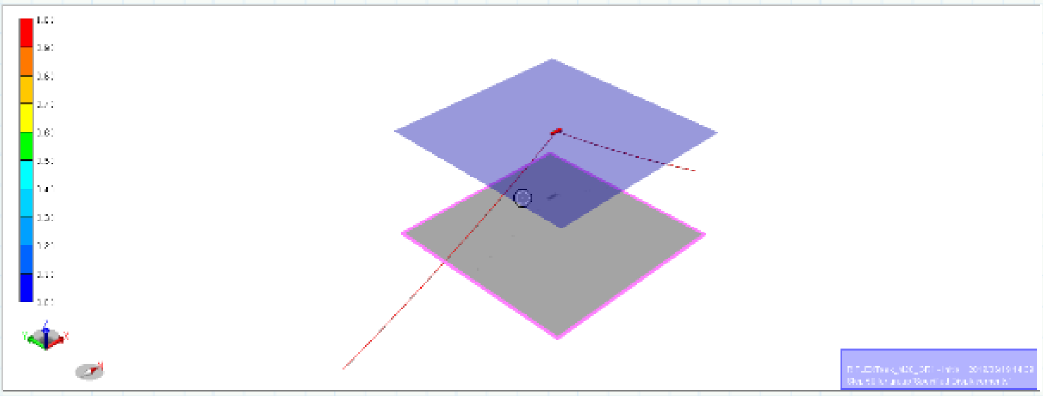
2 CROSS FLOW SCREENING

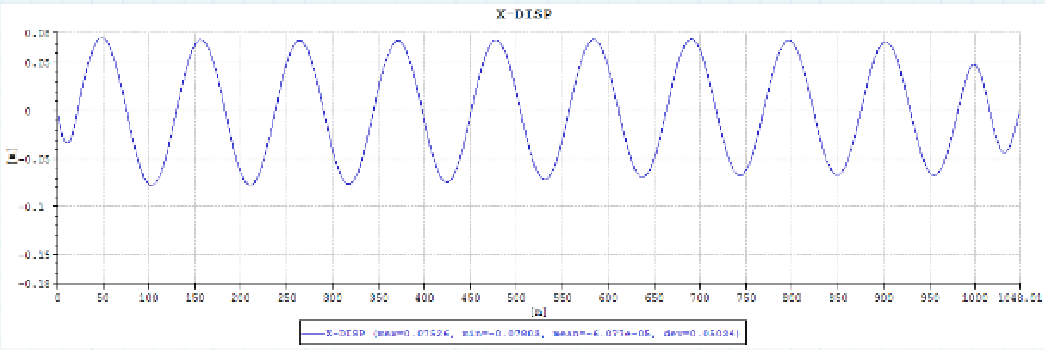
Crossflow criterion according to DNVGL-RP-C205 (current induced vortex shedding)	$3 \le V_R \le 16$	
Reduced velocity (DNVGL-RP-C205)	$V_R(u, f_i) := \dfrac{u}{f_i \cdot D_{fr}}$	
The upper bound natural frequency where vortex shedding may occur is defined by lower boundary of the cross flow criterion (3) and high current.	$f_{imax}(u) := \dfrac{u}{3 \cdot D_{fr}}$	$f_{imax}(u_{max}) = 1.431\ \dfrac{1}{s}$
The lower bound natural frequency where vortex shedding may occur is defined by upper boundary of the cross flow criterion (16) and low current.	$f_{imin}(u) := \dfrac{u}{16 \cdot D_{fr}}$	$f_{imin}(u_{min}) = 0.004\ \dfrac{1}{s}$

3 LOCAL MODEL

A local model is established in the finite elemnt software SIMA. Eigenmodes are calculated to find number of sine waves to corresponding upper bound frequnecy ($f_{imax}(u_{maxD})$).

The plot below shows the model, and the mode shape at natural frequency $f_{imax}(u_{maxD})$.





Number of peaks from Egienvalue calcualtion at $f_{imax}(u_{maxD})$ $\quad i := 21$

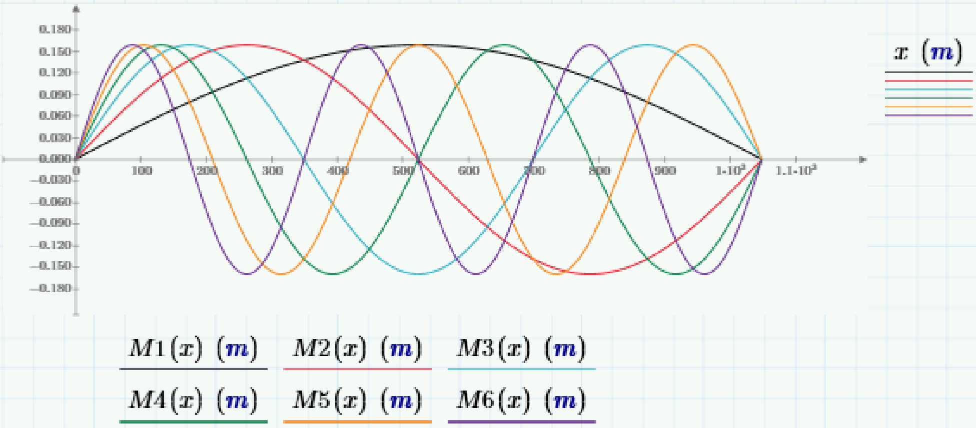
4 MODE SHAPE EVALUATION

Mode shapes are asessed to determine the change in mooring line length when eigenmodes are excited. Change in length will be used to calculate tension range (see under damage calculation)

$$x := 0, \frac{L_{tot}}{1000} .. L_{tot}$$

$$M1(x) := \sin\left(\frac{\pi \cdot x}{L_{tot}}\right) \cdot 0.9\ D_{fr} \quad M4(x) := \sin\left(\frac{4\ \pi \cdot x}{L_{tot}}\right) \cdot 0.9\ D_{fr} \quad M5(x) := \sin\left(\frac{5\ \pi \cdot x}{L_{tot}}\right) \cdot 0.9\ D_{fr}$$

$$M2(x) := \sin\left(\frac{2\ \pi \cdot x}{L_{tot}}\right) \cdot 0.9\ D_{fr} \quad M3(x) := \sin\left(\frac{3\ \pi \cdot x}{L_{tot}}\right) \cdot 0.9\ D_{fr} \quad M6(x) := \sin\left(\frac{6\ \pi \cdot x}{L_{tot}}\right) \cdot 0.9\ D_{fr}$$



Length of line in modeshape i

$$l(i) := \int_0^{L_{tot}} \sqrt{1 + \left(0.9\ D_{fr} \cdot \frac{i\ \pi}{L_{tot}}\right)^2 \cdot \cos\left(\frac{i\ \pi \cdot x}{L_{tot}}\right)^2}\ dx$$

Delta in length for modeshape i

$$\Delta L(i) := l(i) - L_{tot}$$

Delta in length for modeshapeat frequency $f_i(u_{max})$

$$\Delta L(i) = 0.026\ m$$

5 DAMAGE CALCULATION

5.1 Fibre Rope

Tension due to change in length	$T(i) := K \cdot \Delta L(i)$	$T(i) = 0.003\ MN$
Tension ratio according to DNVGL-OS-E301:	$R(i) := 2 \cdot SCF_{fr} \dfrac{T(i)}{0.95 \cdot S_{mbs}}$	$R(i) = 8.653 \cdot 10^{-4}$
Cycles to failure	$N_{if}(i) := a_{df} \cdot R(i)^{-m_{df}}$	$N_{if}(i) = 4.355 \cdot 10^{40}$
Natural frequency	$f_i := f_{imax}(u_{maxD})$	
No of cycles at 100 lifetime	$n_{if} := f_i \cdot 60\ s \cdot 60 \cdot 24 \cdot 365 \cdot DL_f = 3.8 \cdot 10^9$	
Total damage at 100 years lifetime	$D_{tf} := \dfrac{n_{if}}{N_{if}(i)} \cdot DFF_f$	$D_{tf} = 5.274 \cdot 10^{-30}$

5.2 Bottom chain

Tension due to change in length	$T(i) := K \cdot \Delta L(i)$	$T(i) = 0.003\ MN$
Cross section area chain	$A_c := 2 \cdot \pi \cdot \left(\dfrac{(D_c - c \cdot 0.5\ DL_c)}{2}\right)^2 = 0.011\ m^2$	
Stress in chain	$S(i) := \dfrac{T(i)}{A_c}$	$S(i) = 0.324\ MPa$
Cycles to failure	$N_{ic}(i) := a_{dc} \cdot \left(S(i)\ \dfrac{1}{MPa}\right)^{-m_{dc}}$	$N_{ic}(i) = 1.759 \cdot 10^{12}$
No of cycles at 100 lifetime	$n_i := f_i \cdot 60\ s \cdot 60 \cdot 24 \cdot 365\ DL_c = 3.8 \cdot 10^9$	
Total damage at 100 years lifetime	$D_{tc} := \dfrac{n_i}{N_{ic}(i)}\ DFF_c$	$D_{tc} = 0.022$

5.3 Combination of fatigue damages

Combination of fatigue damage from two dynamic processes is checked according to DNVGL-RP-C203.

Fatigue damage for VIV

$$D_1 := \frac{D_{tc}}{DFF_c \cdot DL_c} = 2.176 \cdot 10^{-5}$$

Fatigue damage for Tension-Tension fatigue

$$D_2 := \frac{0.6}{DFF_c \cdot 100} = 6 \cdot 10^{-4}$$

Mean zero up-crossing frequency for VIV

$$v_1 := f_{imax}\left(u_{maxD}\right) = 1.214 \ \frac{1}{s}$$

Mean zero up-crossing frequency for T-T

$$v_2 := \frac{1}{30\ s} = 0.033 \ \frac{1}{s}$$

Combined fatigue damage

$$D_{comb} := D_1 \cdot \left(1 - \frac{v_2}{v_1}\right) + v_2 \cdot \left(\left(\frac{D_1}{v_1}\right)^{\frac{1}{m_{tc}}} + \left(\frac{D_2}{v_2}\right)^{\frac{1}{m_{tc}}}\right)^{m_{tc}}$$

Calculated designlife from combined fatigue in bottom chain:

$$Designlife := \begin{cases} \text{if } \frac{1}{D_{comb} \cdot DFF_c} > 100 & \text{"> 100 years"} \\ \text{else} & \frac{1}{D_{comb} \cdot DFF_c} \end{cases}$$

$$Designlife = \text{"> 100 years"}$$