Fatigue of Top Chain of Mooring Lines due to Bending

(following Bureau Veritas Guidance note NI 604 DT R00 E)

1 Introduction

Mooring lines are generally considered to experience only tensile loading and so their fatigue damage is typically computed considering only tension load cycles. However, in some situations, the region of a mooring chain immediately adjacent to the fairlead can experience significant bending moments, which can lead to additional fatigue damage.

BV guidance note NI 604 DT R00 E (Fatigue of Top Chain of Mooring Lines due to In-plane and Out-of-plane Bendings) describes how the total fatigue damage in the top chain due to tension and bending contributions can be determined. This technical note considers how OrcaFlex can be used in this process.

Section 2 gives a brief overview of the calculation methodologies presented in the BV guidance note, while Sections 3 and 4 consider in more detail how OrcaFlex can potentially be used in the analysis work.

2 Summary of Calculation Methods

The basic methodology presented in BV guidance note NI 604 DT R00 E relies on post-processing of line tension, vessel motion and chain angle results from a time domain mooring analysis. OrcaFlex can be used to carry out this mooring analysis. Full details of the mooring analysis methodology are presented in Section 2 of the BV guidance note.

If the system includes a Fairlead Chain Stopper (FCS), the angle between the chain and the fairlead needs to be determined taking account of any rotation in the FCS. Frictional effects from the FCS bearing also need to be considered. The guidance note presents a methodology allowing the angle between the chain and fairlead to be determined through post-processing calculations only. However, it may also be possible to model the FCS behaviour directly in OrcaFlex as part of the time domain mooring analysis.

Once the angle between the chain and fairlead is known, the bending moments in the first few links of the chain can be determined. This is done through consideration of the chain "interlink stiffness". Again, the BV guidance note allows these bend moments to be found through post-processing calculations and presents the methodology to be used. However, it may also be possible to model the interlink stiffness directly in OrcaFlex as part of the time domain mooring analysis.

Finally, the stress ranges (and consequently the fatigue damage), in each of the first few links, can then be determined from the chain tension and bending moments. The BV guidance note again outlines these calculations in some detail. Determination of these stress ranges is something that cannot be carried out within OrcaFlex itself (other than perhaps using the "Externally calculated stress" damage calculation method offered by OrcaFlex fatigue post-processing) and likely requires post-processing by the user.

The remainder of this document summarises how OrcaFlex can be used to provide the inputs necessary for carrying out the fatigue analysis entirely through post-processing calculations - this is the main methodology presented by the BV guidance note. Some brief consideration is also given to alternative modelling methods that may be applied, but please note that these would be considered as “alternative methodologies”, which need to be approved on a case-by-case basis (see Section 2, sub-section 1.1.4 of the BV guidance note).

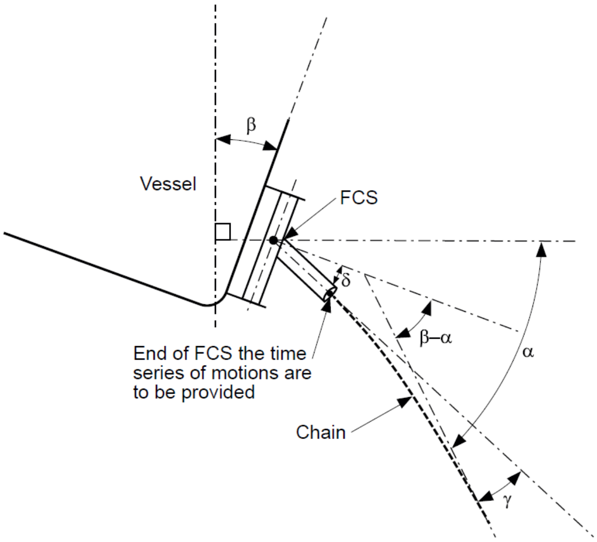
3 Fatigue Through Post-Processing Calculation Only

In this case, the mooring analysis should be carried out assuming a pin-ended connection between the mooring line and the vessel (see Section 2, sub-section 1.1.3 of the BV guidance note). The mooring analysis is to be carried out in the time domain (again sub-section 1.1.3).

Guidance on the sea-states to be considered for the time domain mooring analyses is given in Section 2, sub-sections 2.2.1 and 2.2.2 of the BV guidance note. Note that a number of sensitivities are also to be carried out (see Section 2, sub-section 2.3).

The outputs required from the mooring analysis are time histories of tension at the fairlead location, top chain angle relative to global (α in the BV guidance note) in both in-plane and out-of-plane directions and vessel rotation angle relative to global (β in the guidance note) in both in-plane and out-of-plane directions. These angles are illustrated in the following figure (Figure 1 from Section 2 of the BV guidance note).

Figure 1 : Chain relative angles at FCS



Time histories of both effective tension and angle for both line and vessel can be easily extracted from OrcaFlex either through the GUI or any of the standard automation methods (OrcaFlex spreadsheet or API). However, as a number of angle results are available for OrcaFlex lines, it is worth clarifying which results may be useful.

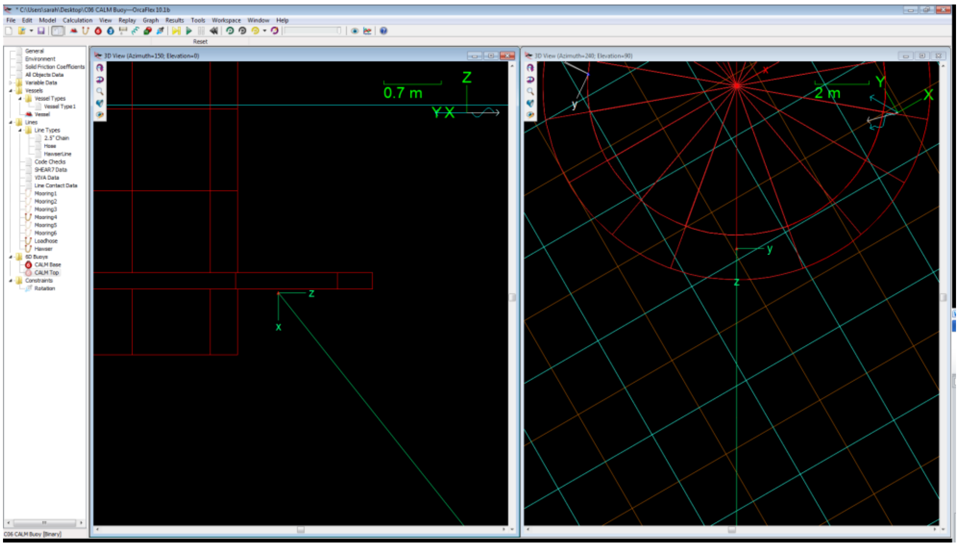
The BV guidance note directly requests line and vessel angles relative to global. However, these results are then used to calculate the relative angle (β – α). As shown in the Figure above, (β – α) corresponds to the chain angle measured relative to the vessel’s local horizontal axis.

Line angles relative to global can be directly extracted from OrcaFlex using Declination results, but these are not presented in terms of the in-plane and out-of-plane directions. To obtain in-plane and out-of-plane angles separately, the relative angle (β – α) must be directly extracted.

Fatigue of Top Chain of Mooring Lines due to Bending

This can be done by taking the OrcaFlex Ez-angle components at End A of the pin-connected mooring line.

The Ez-angle presents the "conical" angle between the line and the line end local z-axis direction. By setting the line local z-axis direction to be horizontal relative to the vessel and aligned with the plane of the mooring line, (β – α) can be directly extracted in both the in-plane and out-of-plane directions. The required configuration for the line end axes is shown in the following OrcaFlex screen-shots:



In this case, the line Ezx-angle will represent (β – α) in the plane of the mooring line. The line Ezy-angle represents (β – α) out of the plane of the mooring line.

4 Mooring Analysis Using "Alternative Methodologies"

There are two possible alternative methodologies that can be applied, which could potentially reduce the amount of post-processing calculation required. These are outlined below.

4.1 FCS Rotation

The FCS rotational behaviour can potentially be directly included in the OrcaFlex mooring analysis simulations. In this case the mechanical rotation of the FCS is physically represented in the OrcaFlex model.

One option is to model this using a Constraint object. This constraint would connect the mooring line to the vessel and would have the appropriate rotational degree of freedom set Free. At present, OrcaFlex Constraints cannot directly include friction effects, however, it is possible to define a non-linear rotational stiffness, which can be optionally treated as hysteretic. Using a non-linear, or hysteretic, stiffness may be adequate to capture frictional effects in some cases.

To fully capture the detailed frictional stick-slip behaviour of the FCS in OrcaFlex, an applied moment controlled by an external function can be applied to the line top end. Although this approach is perfectly feasible, our experience is that small time steps are generally required to allow this particular external function to run successfully.

Fatigue of Top Chain of Mooring Lines due to Bending

4.2 Chain Interlink Stiffness

It is also possible to directly include the chain interlink stiffness in the OrcaFlex mooring analysis simulations. This is done by applying non-zero bending stiffness to a short line representing the first few chain links of interest. This allows direct calculation of the bending moments within these first few links.

In this case, it is worth noting that OrcaFlex calculates bending moment as:

$M = EI.c$ where M = bending moment, EI = bending stiffness, c = curvature.

Thus care must be taken to define a value of bending stiffness (EI) in OrcaFlex that gives the correct bending moment for a given chain interlink angle (α_{int} from the BV guidance note).

To do this, curvature must be related to chain interlink angle. Assuming that each link remains straight (as shown in Figure 2 of Section 3 in the BV guidance note), these terms can be related as follows:

$c = \alpha_{int} / L$ where L = chain link length and α_{int} is in radians.

For systems without an FCS, the behaviour of the chain is then fully characterised in the OrcaFlex model. However, if an FCS is present, then the bending moments in the chain will not be correct unless the rotational behaviour of the FCS is also physically represented in the OrcaFlex model.

We hope that the information in this article is useful, but do contact us if you have any comments or questions.

The Orcina Team
orcina@orcina.com