Fatigue Analysis and Design of Mooring Systems. Assessment and Comparison of Different Analysis Methods.

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Scope of work

The purpose of the mooring system is to keep a floating vessel safely at a required position. It normally consists of 8-16 mooring lines of heavy chain, steel wire ropes and/or synthetic polyester ropes connected to a seabed anchor. Fatigue damage is an important issue for these mooring lines The content of this master thesis is related to the fatigue design of mooring components according to the Fatigue Limit State (FLS) criteria.

Scope of work for the thesis is given below.

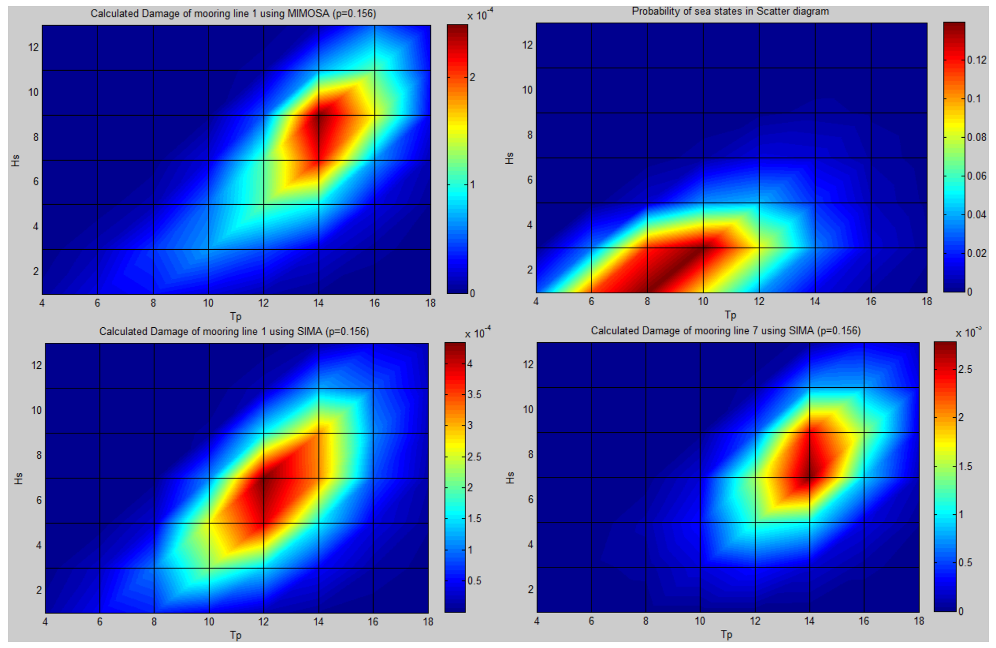
1. Review relevant literature and describe the different aspects and differences of using Frequency domain (FD) and Time domain (TD) analysis methods.
2. Establish numerical simulation models for TD and FD analysis.
3. Estimate the fatigue damage by performing a long term simulation in both the FD and TD.
4. The seastates contributing most to the fatigue damage shall be reported as well as the most critical mooring line components.

Contributions

The work in this thesis is focused on the improvement of the design of FPSO mooring system especially against the fatigue damage. It is built on the work performed during the project work carried out autumn 2014, but the focus and content of this MSc is related to the fatigue design of mooring components. Authors main contributions are:

1. finding out the sea states contributing most to the fatigue damage based on Heidrun metocean design basis (Statoil, 2004) as well as the most critical mooring line components
2. Comparative study of different fatigue analysis method e.g. simple summation (SS), combined spectrum (CS), Dual narrow-band (DN) and rain-flow counting method.
3. performing analysis for the chosen sea state which gives highest fatigue damage to check in detail which parameters are important and responsible for the differences in results.

Results and discussions



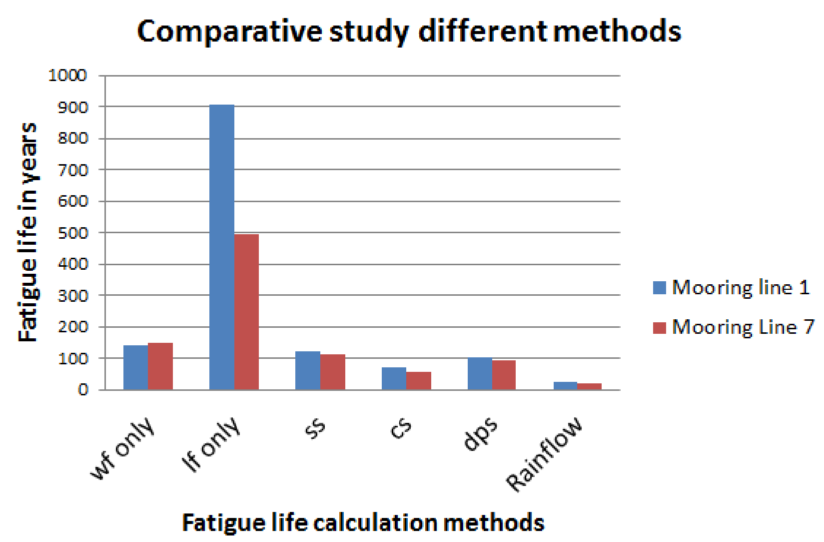


Figure 4: Probability of seastates and the respective calculated fatigue damage for line 1 and line 7

From the scatter diagram of heidrun metocean design basis another scatter diagram is created with 41 seastates (figure upper right corner). Using this scatter diagram long term simulation has been carried out both in MIMOSA (FD) and SIMA (TD) and the fatigue damage for different seastates

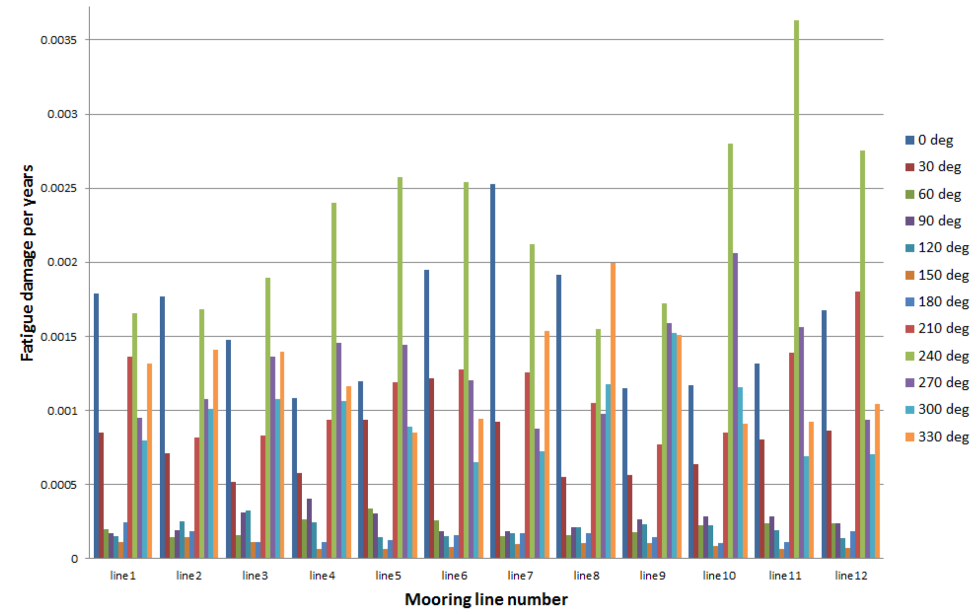


Figure 5: Comparative study of different methods

are shown in the above figures for mooring line 1 and 7. Total Fatigue damage of the mooring lines are calculated using all the methods as stated in DNV-OS-E301. Figure 5 illustrates the fatigue life of mooring line 1 and 7 calculated by these methods.

Fatigue damage of all mooring lines due to the directional probability of environmental loadings are shown in the figure 6 in lower left corner.

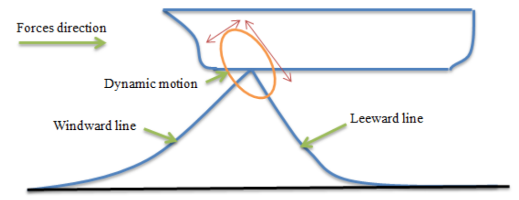


Figure 8: Wave frequency motion loop for leeward and windward lines.

As the leeward line is slacked it experienced more wave frequency motion than the windward line which is more tightened and this phenomenon is illustrated in figure 8.

Simulation model

Asgard A FPSO is choosen for analysis. Vessel file is directly taken as a MIMOSA input file from the output file of WADAM and provided by the supervisor. Same MIMOSA mooring file is used as in the master project.

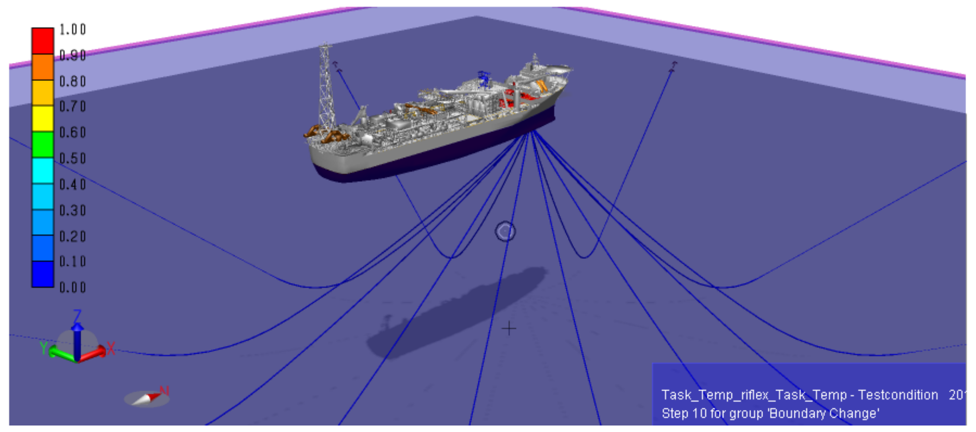


Figure 1: Simulation model in SIMA for fatigue analysis in TD

The MIMOSA program will be used for frequency domain analysis and the SIMA program will be used for fully coupled approach in time domain (TD). As two different software packages is used the models in both softwareâĂŹs needs to be equivalent. So, some checks and verification have been carried out to ensure that.

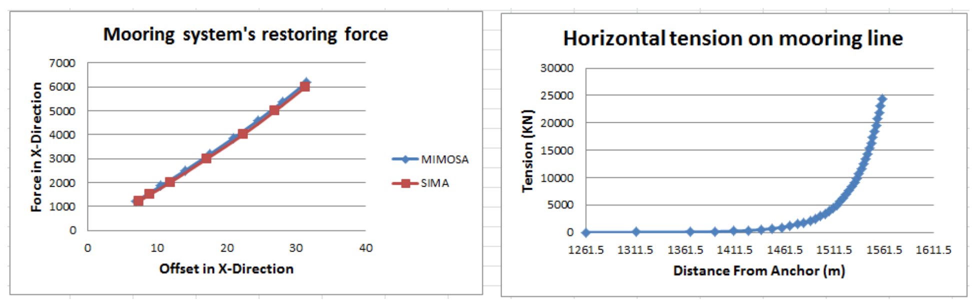


Figure 2: Mooring system verification

The properties of the mooring lines are given in following table.

Segment	Diameter (m)	Segment Length (m)	Nb. of elements	Modulus of elasticity	Unit weight In water (N/m)	Drag coeff. in normal dir.	Breaking strength (kN)
1 Chain	0.137	930.0	30	5.105e+07	3.197	2.4	16992
2 Chain	0.142	285.0	30	5.095e+07	3.427	2.4	18033
3 Wire	0.147	300.0	20	1.130e+08	0.787	1.8	18000
4 Chain	0.147	52.0	10	5.085e+07	3.680	2.4	19089

*segment number starts from anchor.

Analysis methods and regulations

In this thesis *only Tension-tension (T-T) fatigue* is considered for fatigue damage calculation. Bending-tension (B-T) and free bending fatigue has not been taken into account. Different methods for calculation fatigue on mooring line is described in DNV-OS-E301 chapter 6 and ISO 19901-7 chapter 9. The methods for calculating fatigue damage are given below.

1. Simple summation approach (SS)
2. Combined spectrum approach (CS)
3. Dual narrow-band approach (DN)
4. Rain-flow counting method

If the low-frequency content of the stress process is negligible, then a narrow-banded assumption maybe applied and SS approach can be used. If there are both significant wave-frequency and low-frequency components in the tension process, then the expression for a narrow-banded process is no longer appropriate and CS and DN approach are then recommended.The rain-flow counting is expected to provide the most accurate estimate for the probability density of the tension ranges, but this requires relatively time-consuming analysis.

The following S-N curve needs to be used for all methods [2].

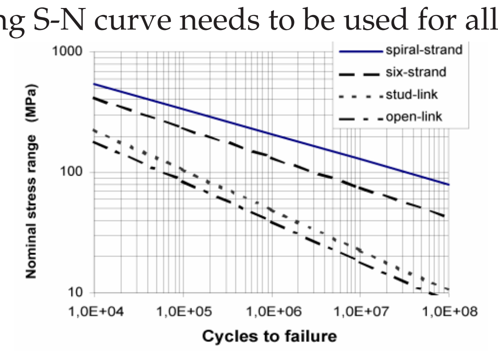


Figure 3: Design S-N curves

According to section 6.3.1 of DNV-OS-E301 the required number of reference sea states should be in the range of 10 to 50 and in general 8 to 12 reference directions provide a good representation of the directional distribution of a long term environment for Fatigue damage prediction.

Conclusion

After analyzing the results from the long term simulations for calculating fatigue damage of mooring lines of a ship-shaped FPSO, the following conclusions are made.

1. Even though the lower seastates have the highest probability of occurrence the fatigue damage in the mooring lines are highest in the higher seastates. This is due to the fact that wave frequency motion are higher in those seastates and creates cyclic loading of higher magnitude and mooring components encounter more fatigue while experiencing high magnitude load cycles.It is found that *seastates having significant wave hight (Hs) between 6m to 10m and peak preiod (Tp) between 10s to 16s gives higher fatigue damage.* Seasates having Hs more than 10m also creates large wave motions but occurrence level of these seastates are very low which eventually leads to lower fatigue damage.
2. Rainflow counting method (TD analysis) gives higher fatigue damage than other methods (FD analysis). The reason behind this is could be that TD analysis gives higher wave frequency than FD analysis but further investigation is needed regarding this issue. Within the FD methods CS approach gives the highest fatigue damage. So, it is more *conservative* than others. In DNV-OS-E301 section 6.3.7, CS is also defined as conservative approach and recommended for calculating characteristic fatigue damage.
3. For all direction of environmental loading it is observed that *leeward lines experience higher fatigue than windward line.* It is a special phenomenon of ship-shaped FPSO which is caused due to elliptically looped wave frequency motion (figure 8).
4. Anchor chain is more vulnerable to fatigue damage than the wire ropes.

References

[1] ISO 19901-7 (2013), Stationkeeping systems for floating offshore structures and mobile offshore units.
[2] DNV 2013,DNV offshore standard, DNV-OS-E301 Position Mooring(Norway).
[3] Larsen, K. (2014). Lecture note on Mooring for master's project. In *(NTNU)*
[4] Statoil. (2004). Heidrun Metocean Design Basis.
[5] Marintek. (2012). MIMOSA and SIMA software's theory and user manual

Recommendations for future work

In SIMA and MIMOSA, the current forces are modelled in different ways, but in this thesis the effect of this issue is not checked in detail. Only constant current profile is included here but for further work *linearly decreasing current profile* can be used. In this thesis modeling is done for 320m water depth. But nowadays mooring systems are designed for deep seas where mooring lines have higher pretensions than shallow water. So, in future it is recommended to *check fatigue life for deep sea mooring system.* As we have seen in this thesis high seastates gives higher damage to fatigue, it will be worth checking whether introducing trusters can reduce the fatigue damage in those seastates.

Special thanks

I am really grateful to my supervisor for proving me necessary input files and helping me throughout the whole thesis work.
I would also like to give special thanks to Aksnes, Vegard and Pal levold from Marintek for giving me guidance related to SIMA.