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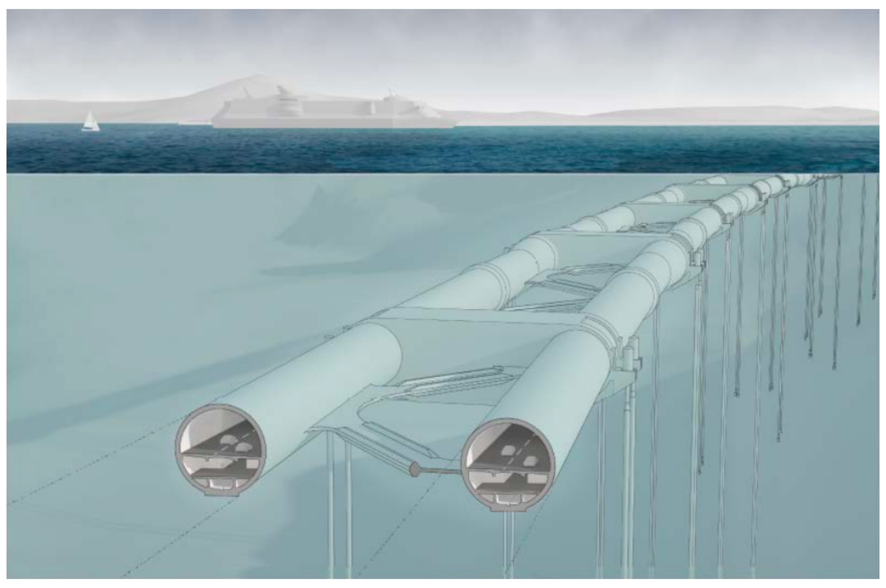
Dynamic Load Effects on Submerged Floating Tube Bridges

Master thesis by Maria Hapnes von Schack - 2017
Supervisor: Bernt J. Leira
Co-supervisors: Tore H. Søreide (dr.techn. Olav Olsen) and Svein Sævik

Introduction

A ferry free coastal highway is under planning by the Norwegian government at the southwest coast of Norway. Some of the fjords to be crossed are very deep and wide, and challenges arise regarding technology that need to be used. An alternative to conventional bridges or tunnels are Submerged Floating Tube Bridges (SFTBs).
One of the fjords to be crossed is the 5 km long Bjørnafjorden, in Hordaland. An assessment study for an SFTB has been performed by the design group Reinertsen, dr.techn.Olav Olsen and Norconsult. During the assessment study, little consideration has been put on the effect of Vortex-Induced Vibrations on the bridge. [1] This is of interest for the design group and is the basis for this thesis. The task is proposed by Tore H. Søreide from dr. techn. Olav Olsen.



Objective and Scope

The objective is to survey the dynamic load effects such as wind-sea, swell and VIV on the bridge. Especially effects from VIV are to be considered and is presented in this poster. A model is to be established in the program Riflex and VIV-analysis performed by the software Vivana. Results will be compared with the general rules for VIV provided by DNV.

Environment

A 100y return period for the current is used and taken from [2]. Current conditions at the different depths are listed below.

Depth[m]	0-3	10	30	50	>100
Current[m/s]	0.7	0.45	0.29	0.25	0.15

VIV and DNV Guidelines

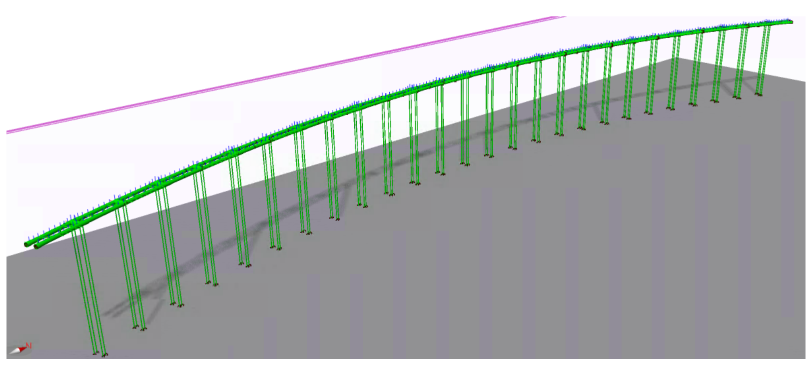
Vortex-induced vibrations (VIV) are oscillations of slender structures due to pressure differences in the fluid along the structure cross-section due to it being exposed to a current. In-line(IL) and cross-flow(CF) oscillations may occur for given values of the reduced velocity, V_R. V_R is a function of the cross-section diameter, the natural frequency and the current velocity.

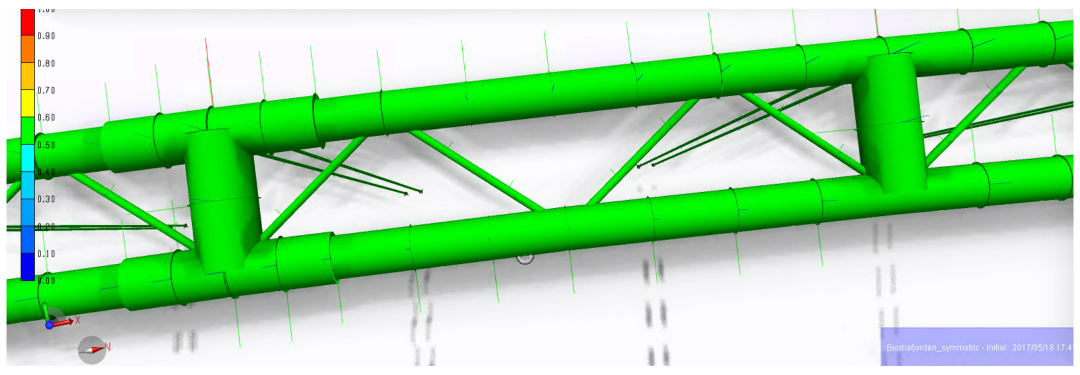
$$V_R = \frac{U_C}{f_n D} \tag{1}$$

DNV provides empirical models [3] giving ranges for V_R where VIV may occur.
IL VIV is of interest for the bridge, while both IL and CF VIV is of interest for the tethers.

Modelling and Method

The SFTB is modelled in SIMA/Riflex as close to the original drawings as possible. The bridge of two tubes is curved with a radius of 6400 m and submerged to a depth of -37.5 m at the center-point of the tubes. The length in centerline is set to 5304 m. Six different cross-sections are used in the model. The main tube has a diameter of 12.6 m. 26 groups of 4 tethers are stabilizing the bridge.
Coordinates for all intersections between beams of inner and outer tube are found by geometrical considerations by use of MATLAB. The bridge is modelled with ends fixed to model the transition to the rock tunnel. The sea depth is assumed constant at -550 m. The bottom of the tethers are assumed fixed to the seabed.
The materials used for all parts except tethers are concrete with an E-modulus of 30 GPa. Tethers are in steel with an E-modulus of 207 GPa. The reinforcement and pre-stressing in the concrete is not included in the analysis. Hence, the E-modulus given to the program will give a larger deformation of the structure than in reality.

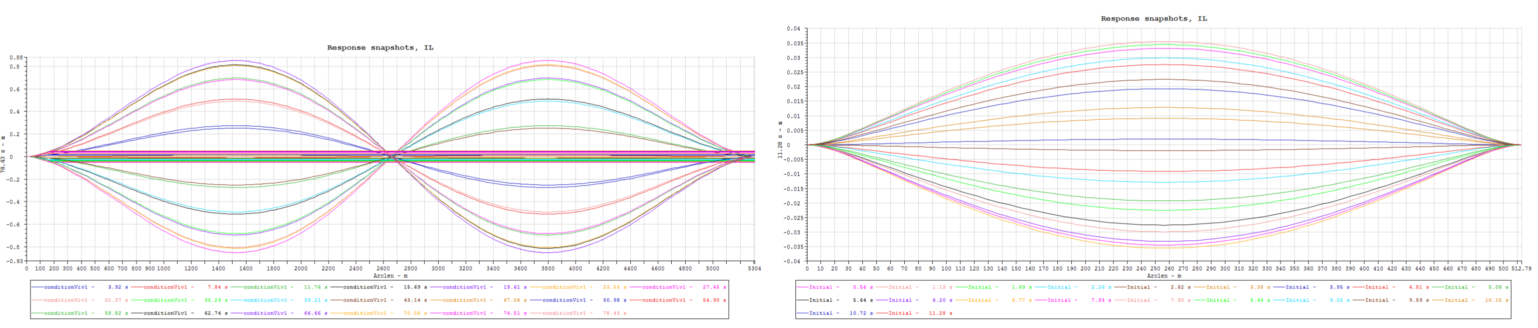




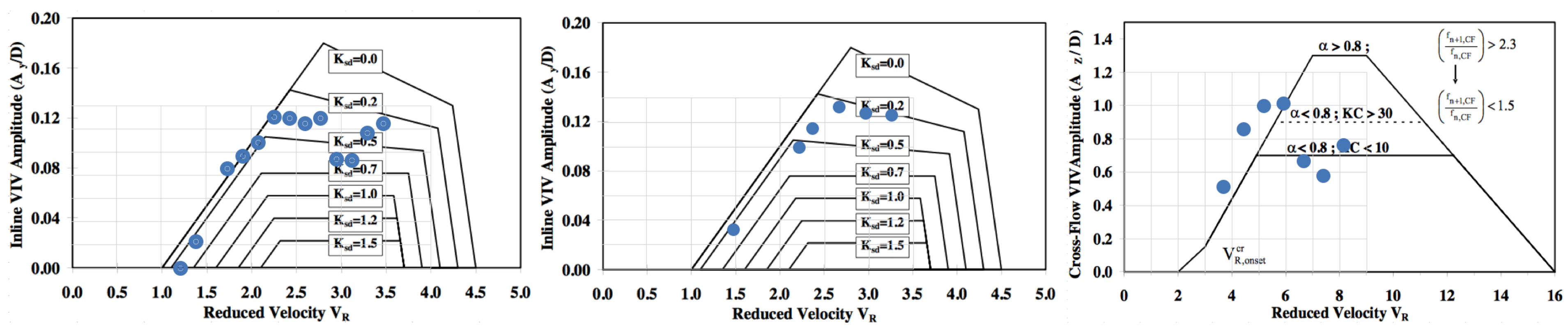
As Vivana does not calculate wake-induced current, the response computed is the same for both tubes and all tethers. Only one tube and one tether is considered.

Results and Discussion

The maximum IL response amplitude of the tube for the 100y current is 0.85m. The response frequency is 0.013Hz(first mode), and the corresponding period 78.43s. The snapshots of the response can be seen below(left). Following requirements from The Norwegian Public Road Administration (NPRA), the horizontal acceleration is calculated and found to be within requirements for driving comfort. The maximum IL response amplitude of the tether is 7.5cm. The response frequency is 0.077Hz(first mode). No cross-flow excited at the 100y current, as expected from estimates of V_R from found natural frequencies and DNV guidelines. The fatigue life is found to be $33 * 10^4$years, which gives no concern w.r.t the given operational design life of 100y.



Results from scaling of the current velocity is compared with the DNV predictions. Amplitudes calculated by Vivana is then shown as a function of the reduced velocity in plots below (marked by blue dots) on top of the DNV model (black lines). Only excitation of the first mode is included. For the bridge (left plot), there is an unexpected decrease in the amplitude around $V_R = 3$. The reason for this is unknown. For the tether IL (middle plot), the response does not follow a specific value for the structural stability parameter, K_{sd}. However, it can be discussed that the results follow the $K_{sd} = 0.2$ line, but that the amplitude response is less than expected. Response from CF (left plot) are unexpected as the amplitudes are outside the predicted DNV range. Also here, a decrease is found, around $V_R = 7$. The response is within the maximum amplitudes, but for lower V_R than expected.



Conclusion

From the analysis it can be concluded that the vibrations due to vortex shedding from a 100y current are not of a high concern to the proposed design. For the current case, the DNV maximum amplitude estimates as a function of reduced velocity for IL seem to fit better than for CF. Due to limitations in Vivana, the effect on tubes in tandem is not investigated.

Acknowledgements

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References

[1] Haugerud, S. A. *Bjørnafjord Submerged Floating Tube Bridge. K3/K4 Technical Report* Dr. Techn. Olav Olsen, Norconsult, Reinertsen. 2016.
[2] Fjeld S., Nestegård, A., Frisch, I., Haugerud, S. A. *Bjørnafjord Submerged Floating Tube Bridge. Design Basis. Revision 03* Dr. Techn. Olav Olsen, Norconsult, Reinertsen. 2015.
[3] Det Norske Veritas *Recommended Practice DNV-RP-F105 Free Spanning Pipelines* February, 2006.