Master Thesis in Marine Technology, Hydrodynamics - 2013

Vortex Induced Vibrations of Slender Marine Structures

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Scope

Gain new and valuable information of the phenomenon of Vortex Induced Vibrations on slender marine structures, such as risers and free-spanning pipelines, by studying experimental results. Use interesting findings to improve VIV-prediction programs like MARINTEK's VIVANA. Some of the areas to be studied from test-results: Dominating frequencies and their interaction in time and space, mode competition, actual change of added mass.

Introduction

The phenomenon of vortex induced vibrations and the response it may give a slender marine structure is still not fully understood. Especially, there are uncertainty of how and if different active response frequencies interact and it is not found a clear pattern that can describe this correctly, only some approaches.

As risers and other types of slender structures are commonly used in various subsea operations, which is an industry in growth, it is important to gain more detailed knowledge of their response. A consequence of obtaining new knowledge is of course to also improve existing tools for prediction of VIV. By investigating results from a VIV - model test, one may be able to find patterns and conclusions that can be implemented in, and hence improve, a VIV-prediction program.

VIVANA is a commonly used computer program that predicts responses related to VIV, also here improvements are wanted. Related to the mentioned problems by prediction of VIV, it is especially how the active and dominating response frequencies are chosen and how they are modelled to interact that is the core of the desired improvement in VIVANA. So a study of how VIVANA execute these parts of the analysis today is an important part of this master thesis in order to understand how the program may be improved and what should be explored from the model test results.

Brief theory

A detailed literature study of VIV is performed in the Project thesis, Brunborg [2012], but a small capture is made here.

As understood from the name, vortex induced vibrations are responses on a structure due to vortices. The vortices are shaped along and shed behind a slender structure (often with circular cross-section) that is exposed to a current. The shape and size of both the structure and the current are some of the factors influencing the vortex shedding. The forces induced on the structure from the vortices may appear in cross-flow and/or in-line directions, creating an oscillating movement that may cause fatigue and drag amplification. It is known that this oscillating movement may appear at several frequencies. The big question is how they interact, as one position at the structure can only experience one frequency at a time. Two approaches for organizing this interaction, that for instance is used by the prediction program VIVANA, is called space- and time sharing. Space sharing, or concurrent frequencies, means that several response frequencies act at the same time, but are each only excited at a specific zone along the structure. Time sharing, or consecutive frequencies, means that one frequency controls the motion along the entire length of the structure, but only for a limited time period. After a while, a different frequency will take over and control the process.

References

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In addition I want to thank Jie Wu at MARINTEK for providing most of the MATLAB-codes that has been the basis of this thesis. He has also been helpful and always available for questions regarding the codes.

Methods

Measurements from the High Mode VIV model test done on a riser of length 38m for the Norwegian Deepwater Programme, are processed in different ways in MATLAB. The model-riser was set up horizontally and towed in ways simulating both uniform and sheared current, and with different velocities. More information about the NDP-test can be found in Braaten & Lie [2012].

The following shows some of the figures generated through MATLAB:

- **Plot of dominating frequencies**
  The measured time series of strain-signals are transformed into time-frequency domain by using a Wavelet-analysis, which is described in Grossmann & Morlet [1984]. The signals are also filtered to avoid transients and "noise". This is described in more detail in my Project Thesis, Brunborg [2012]. Note that only cross-flow are investigated in this thesis.
  Below is an example of such a frequency-plot, for the NDP-riser in uniform current with velocity 0.5m/s.

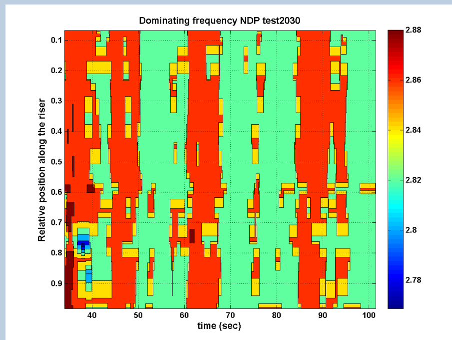

Figure 1: Dominating frequencies for case 2030, velocity of current is 0.5m/s. Color scale on right hand side indicate the size of the frequency in [Hz]

From this plot one can study how the dominating frequencies vary along the riser and in time. It is especially for investigating the two approaches space- and time sharing, this is a good figure. Space- and time sharing are two methods for characterizing interaction between active frequencies, used for instance in computer program VIVANA, as mentioned in the small theory part.

- **Plot of amplitudes**
  With the same filtering as for the previous plot, the raw signals can be plotted in space and time to show the time development of the motion's amplitude. An example of this type of plot is shown below, for the same case as the other plot.

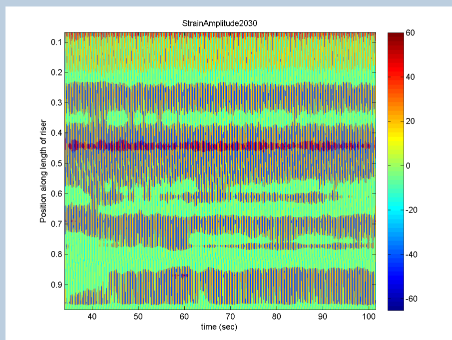

Figure 2: Strain amplitudes for case 2030, velocity of current is 0.5m/s. Color scale on right hand side indicate the size of the strain-amplitude in [μm/m]

From such a plot one can study the competition between modes, which modes that are actually present and sort of see a direct picture of the riser-motion. (The plots are, as mentioned, based on strain signals, but it still gives a good picture of the behaviour. However, it would be preferable to also look at such a plot based on displacement values.)
I also "played" some more with the results from the NDP-test, but the two plots described above ended up being the most important ones.

Utilization of results

The desirable goal is to do observations that can be compared to and, if possible, improve the computer program VIVANA. There are of course several parts of the analyses in VIVANA that can be investigated for improvement, but in this thesis it is focused on the part where active frequencies are chosen. Within this part of the analysis it is especially one section that is time-demanding and a good candidate for improvement. That is the iteration which is needed due to the lack of correct added mass used in the initial eigenvalue analysis. The added mass used to find the initial eigenvalues is the still-water-value, and therefore the frequencies found from this needs to be iterated to adjust the added mass. This is done based on added-mass curves from Gopalkrishnan [1993]. The whole process with this iteration and choice of frequencies are described in more detail in [Larsen, 2010, p. 41-43]. A good explanation is also found in Larsen [2012].
To calculate the added mass from the obtained results, I had to register the values of the active frequencies and the mode number from the above described plots, for each case. The active frequency for each case are taken as the average of the minimum and the maximum seen frequency on each frequency-plot. The mode that seems to be dominating in each case, is approximately found by "counting" the *tops* of the amplitude-plot, as it is cross-flow which is considered. For case 2030 the mode number is taken to be 7, from counting the dark "rows" on figure 2. The values for each case are inserted in the following expression for added mass:

$$m_A = \frac{T + \frac{n^2\pi^2 EI}{l^2}}{(\frac{\omega_{BS} l}{n\pi})^2} - m \quad (1)$$

where T is the tension [N], n is the mode number, EI is the stiffness [Nm^2], ω_{BS} is the value for which the found active frequencies are inserted, and m the mass [kg/m] of the waterfilled riser-model.
Equation 1 is a transformation of the expression for eigenfrequency for a beam with tension (like slender marine structures):

$$\omega_{BS} = \frac{n\pi}{l}\sqrt{\frac{T}{m+m_A} + (\frac{n^2\pi^2}{l^2} * \frac{EI}{m+m_A})} \quad (2)$$

Which again is based on the fact that the stiffness of a beam with tension is the sum of the stiffness for a string with tension and a beam without tension.
When all values for added mass are calculated for both uniform and sheared current cases they are plotted in a graph to see the development of added mass for increasing current velocity and mode.

Results and conclusion

In general the frequency and amplitude plots show quite messy pictures, which means it is not very easy to draw any conclusions directly from the plots related to for example space- and time sharing. Maybe, the same plots based on displacement-values would provide better information. However, when using the information from the plots in calculation of added mass it is obtained far more interesting results.
The plots showing the development of added mass for increasing current velocity are shown separately for uniform and sheared currents below:

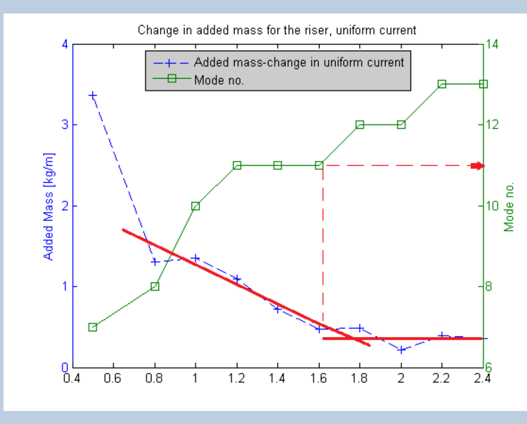

Figure 3: Plot of actual added mass for the NDP-riser in uniform current, with increasing current velocity. Calculations are based on observations of dominating mode and active frequencies (based on strain). Trend lines and the dominating mode for each case is also shown.

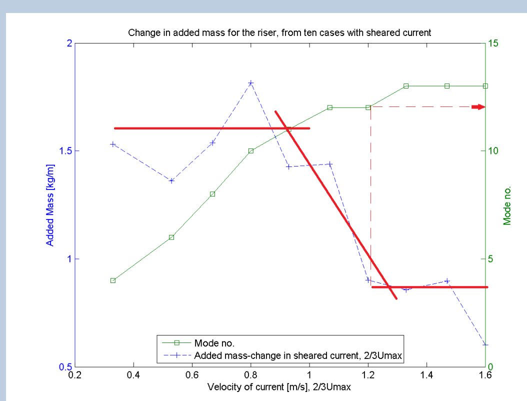

Figure 4: Plot of actual added mass for the NDP-riser in sheared current, with increasing current velocity. Plotted each case against velocity=2/3Umax. Calculations are based on observations of dominating mode and active frequencies (based on strain). Trend lines and the dominating mode for each case is also shown.

Although the information in the figures above are based on quite few cases and has some uncertainties related to the values in the calculation taken from previous plots, it can be concluded that a trend is seen. The trend is most clearly seen for the uniform current cases, where the added mass seems to stabilize for cases with a current velocity higher than approximately 1.6m/s and modes above 11. The values for the sheared current cases are a bit more fluctuating, but the trend can somehow be seen here as well, for cases with velocity higher than approximately 1.2m/s and modes above 12-13. Which values of velocity and mode making the division to constant added mass is very rough and in general a lot more detailed analyses needs to be done in order to make this a usable fact, but it should be a good indication of the behaviour of added mass in reality. If this indication can be proved it will give a basis for an important improvement in VIVANA. The iteration for adjusting added mass will not be necessary for cases with current velocities/modes higher than the values corresponding to constant added mass. Then this constant value can be inserted in the initial eigenvalue-analysis instead of the still-water-value.