Installation of subsea structures: Hydrodynamic challenges

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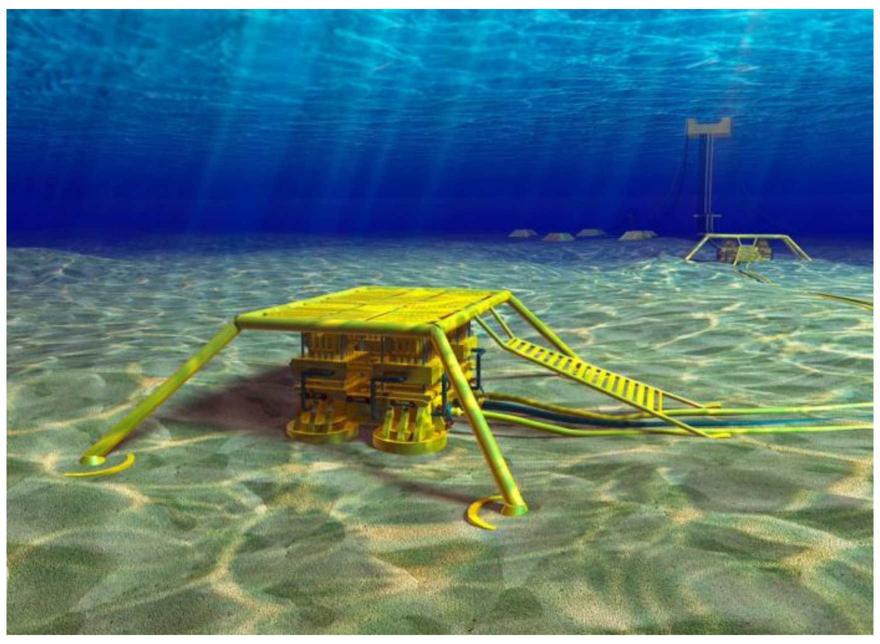
Scope

- Ensure safe lifting operations during installation of subsea structures.
- Expand theoretical model from project work 2013.
- Compare theoretical model versus full-scale pressure measurements inside single suction anchor.
- Investigate critical natural periods of dynamic systems.
- Perform statistical calculations and compare with measurements from installation in North Sea.
- Provide suggestion for design improvements.

Introduction

For installation of large subsea structures in harsh conditions in the North Sea large and complex installation-vessels with large crane capacity are required. Larger and more complex vessels results in increased installation-costs. Therefore oil companies want to use as small installation vessels as possible, which increase the dynamic interaction between vessel and structure during installation. To meet this demand, contractors and class societies performs thorough hydrodynamic analyses like simulation of operations, model testing and numerical calculations.

This thesis investigates hydrodynamic challenges with subsea protection structures with suction anchors as foundation. A subsea protection structures protecting an underlying well-head is shown in the figure below.



Subsea protection structure on the Fram field, taken from http://www.offshore-technology.com

Summary of project work

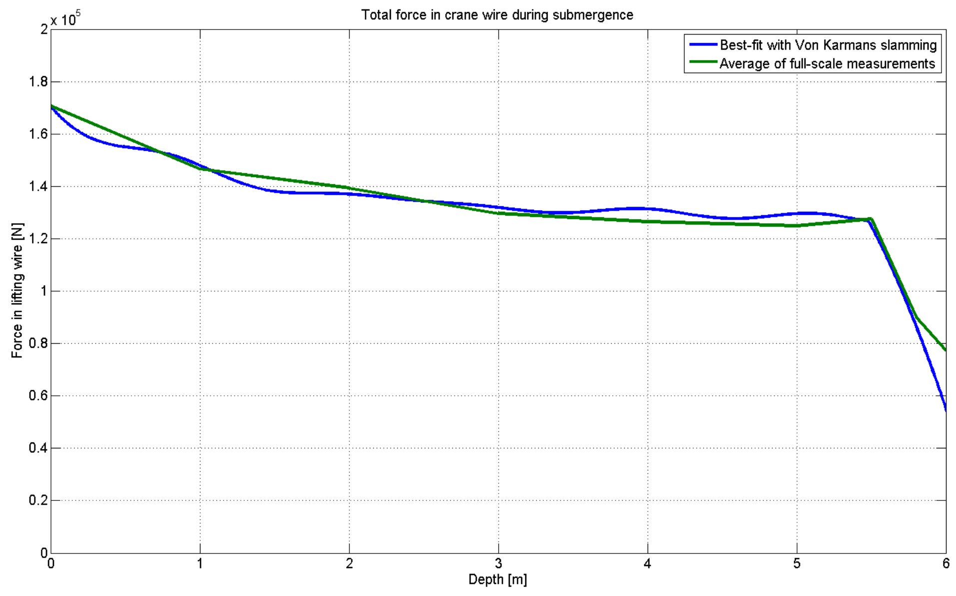
1. Created simplified model for calculating hydrodynamic loads on suction anchor.
2. Based on air cushion theory for Surface effect ships.
3. Non-linear problem for the dynamic air cushion pressure was solved numerically.
4. Including slamming calculation when water impacts against suction anchor-top.
5. Concluded with impact being most critical with respect to slack in lifting wire.
6. Comparison with full scale force-measurements performed by Subsea 7 of a single suction anchor.

The theoretical model use the continuity equation for the air inside the suction anchor to describe the dynamic air cushion pressure as shown in the equation below.

$$-\rho_c Q_{out} = \frac{d\rho_c}{dt}\Omega_c(t) + \rho_c \frac{d\Omega_c}{dt}$$

Parameter-study for force calculations

Different parameters has been varied in the numerical calculations including irregular waves created with the Jonswap-spectrum. The best-fit comparison with the full-scale measurements is shown in the figure below with a maximum deviation of 9 %.



Thus it can be concluded that the theoretical model developed during project work 2013 gives satisfying results when comparing with full-scale measurements. All calculations are performed with Matlab.

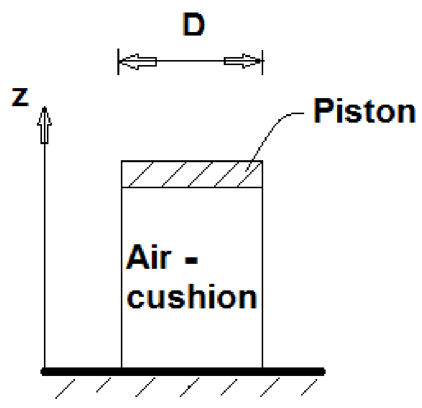
Full scale pressure measurements

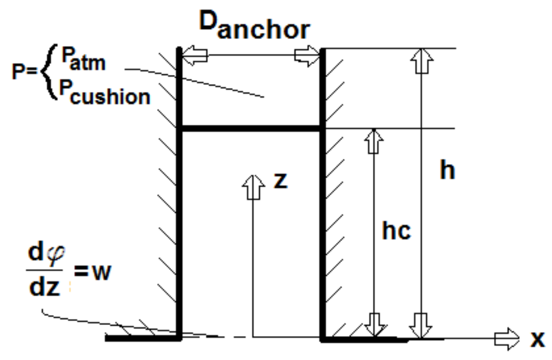
The initial pressure measurements performed by the Norwegian Geological Institute showed that the pressure was oscillating after impact of the water against the top of the suction anchor. By studying videos of the full-scale test, oscillations of the suction anchor was also obtained. This implied that the natural period of one of the following systems had been excited:

- Oscillating air cushion inside suction anchor
- Oscillating water with air cushion as upper boundary inside the suction anchor
- Oscillating water with atmospheric pressure as upper boundary inside the suction anchor

Modelling of air cushion

Two simplified 1-D piston-mode models was used for modelling either the oscillating air cushion or the oscillating water as shown below in the left and right figure respectively.





In the right figure the water is bounded above by either air cushion pressure or atmospheric pressure. More recent pressure measurements inside the suction anchor showed that it was the pressure measured outside the suction anchor that was oscillating most significantly. Therefore a resonance analysis of the following systems were also performed:

- Entrapped waves between suction anchor top and free surface generated after impact.
- Using the measured inner-pressure directly in the theoretical models described in the right figure above.

Also, the natural period of the lifting system consisting of crane, lifting wire and suction anchor was found.

Results from resonance-study

The natural periods for the different systems described in the previous section versus the observed oscillation period of the suction anchor from videos are shown in the table below.

Case	Natural period [s]
Air cushion with added mass from WAMIT	1.1
Coupled air cushion and water	1.2
Atmospheric pressure (No coupling)	5.2
Coupled air cushion and water with added mass	2.0
Lifting system	0.9
Entrapped waves generated after impact	1.1
Measured pressure	0.6
Suction anchor from videos	5.0

Analysis of installation in the North Sea

In february 2013, a subsea protection structure were installed by Subsea 7 on behalf of Det norske oljeselskap ASA. The installation is shown in the figure below where impact on the top of the suction anchor is indicated by the spray of water and air through the ventilation hatch.

For reproducing the force measured in the lifting wire at installation Subsea 7 provided measurements of:

- Vessel motions and crane tip velocity
- Significant wave height (Hs) and peak period (Tp) measured with a wave buoy at the site

These data were post-processed and used in the theoretical model for calculating the dynamic air cushion pressure and thus the force in the lifting wire. For calculating wave realizations to be used in the calculations, the measured Hs and Tp were used as input to the Torsethaugen-spectrum which accounts for both wind-and swell sea. To account for the relative heading between wind and swell sea 3-D waves has been calculated to see the effect on the results. This was done by applying a spreading function to the Torsethaugen-spectrum. However, satisfying results from the numerical calculations has not been obtained at the current time and are therefore not presented.

Conclusions

For the resonance-study it can be concluded that there is not any air cushion present which influences the oscillation of the pressure inside the suction anchor. Therefore it is most likely the piston motion of the water inside the suction which forces the suction anchor to oscillate. However, the lowering of the suction anchor is stopped right after submergence where an impulse due to the inertia of the suction anchor when the lowering suddenly stops might be able to excite the natural period of the lifting system. In addition there are some uncertainty with the pressure sensors which show that the pressure oscillates with 5 [s] before and after the impact of the water which might indicate that the sensors are at resonance.

For comparison with the measurements from the operation, the results have not been reproduced by the theoretical calculations due to lack of knowledge of the vertical motion of the suction anchors. A more thorough study of the videos from the lowering will be performed when these are available and the observations from this study will then be implemented in the calculations.

Acknowledgements

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