Analysis of ROV Lift Operation

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Introduction

As a subsea service company, DeepOcean wish to operate in the widest range of sea conditions. The majority of all offshore operations are performed using remotely operated vehicles (ROVs). During launching of the ROV-system, lifting through the splash zone is considered as the most critical phase of the operation. The Recommended Practice from DNV, [1] proposes a systematic approach for estimating the hydrodynamic loads occurring in the splash zone. A maximum operational significant wave height, H_s, is determined using a proposed acceptance criteria. Experience from the industry have on the other hand shown that the method is unreasonable conservative, consequently leading to a restrictive operational H_s window. The Recommended Practice from DNV allow for other approaches for determining the operational H_s, such as time domain analyses in computational programs.

Objective

The main objective of this Master's Thesis is to perform analytical calculations conforming to the Recommended Practice proposed by DNV and simulate the lift operation in two different simulation programs, Simulation of Marine Operations (SIMO) and OrcaFlex. The challenge of interest is to compare the results obtained by the computaional models with reference to the analytical reults.

Lifting In the Splash Zone

A structure that is being lowered through the splash zone is exposed to a number of different forces and the problem is highly non-linear. According to the Recommended Practice a slack lifting wire should to all extent be avoided. The total lift line force due to an object's penetration through the splash zone may by expressed by the following equation:

$$\underbrace{F_L(t)}_{\text{Line force}} = \underbrace{(M_s + A_{33})\ddot{x}}_{\text{Inertia force}} - \underbrace{B_1\dot{x_r}}_{\text{Linear damping}} - \underbrace{B_2\dot{x_r}\mid\dot{x_r}\mid}_{\text{Quadratic damping}} - \underbrace{(\rho V + A_{33})a_w}_{\text{Wave forces}} - \underbrace{\frac{dA_{33}^{\infty}}{dt}\dot{x}_r}_{\text{Slamming}} + \underbrace{W}_{\text{Weight}} \tag{1}$$

When estimating forces occurring in the splash zone it is convenient to model the drag and damping as a sum of a linear and quadratic term, instead of the quadratic drag of Morison's equation [2]. These two terms, as well as the slamming term are dependent on the vertical relative velocity between the object and the water particles.

The Simplified Method

The Simplified Method described in [1] is based on three main assumptions in order to be valid. It assumes that the horizontal extent of the object that is being deployed is small compared to the wave-length. This assumption allows the hydrodynamic loads to be calculated at characteristic points of the structure, and then added together. It is also assumed that the vertical motion of the object follows the motion of the crane tip and that the vertical forces dominate the load case. The Simplified Method propose an accept criteria to ensure that the lifting wire is always in tension. The lifting wire may become slack if the upward hydrodynamic loads are larger than the static weight of the lifted object. A conservative estimate is made by ensuring that the acceptable limit of hydrodynamic loads should not exceed 90% of the static weight of the object.

$$F_H \leq 0.9F_{stat} \tag{2}$$

The total hydrodynamic force as it is defined in the Simplified Method is a function of the slamming force F_S, varying buoyancy force F_ρ, mass force F_M and the drag force F_D.

$$F_H = \sqrt{(F_D + F_S)^2 + (F_M - F_\rho)^2} \tag{3}$$

Hydrodynamic Coefficients

Proper evaluation of the hydrodynamic properties of the structure penetrating the splash zone is an important aspect of determining the wave loading and motion response of the lifted object. The hydrodynamic coefficients depend on the geometry of the structure, Reynolds number and the Keulegan-Carpenter number. In addition, the motion direction, frequency of oscillation and the proximity to the free surface are important parameters. An objects hydrodynamic properties may be estimated theoretically, empirically or by model tests.

Method and Modelling

Load Cases in the Simplified Method

As the ROV and TMS are being lowered through the wave zone, there will be different hydrodynamic loads acting on the system at different stages of the operation.. Four different load cases have therefore been defined for the analytical calculations according to the Simplified Method.

- ROV system hanging in the air
- ROV system directly above the sea surface
- ROV submerged, TMS above the sea surface
- ROV system fully submerged

Time Domain Analyses

The large non-linarites that occur during lowering through the splash zone are best taken into account by simulating the operation in a time domain computer program. This is more accurate than the analytical calculations outlined by the Simplified Method. The time domain analysis numerically integrates the equation of motion described above.

The time-domain simulations may either be simulated a large number of times to obtain a statistical confidence in an irregular sea state. An alternative to approach is to investigate the maximum relative velocity between the crane tip and the vertical component of the wave elevation. To ensure that this represents a worst-case scenario, this is investigated for the maximum relative velocity and maximum relative acceleration.

OrcaFlex

The motions of the vessel are described by first order motion transfer functions (RAOs). As a simplification the ROV-system has been modeled as one item, which is represented by a buoy that may move in 6 degrees of freedom.

SIMO

Similar to OrcaFlex, the vessel motions are described by RAOs. In addition, the vessel requires a hydrostatic stiffness matrix and a simplified dynamic positioning (DP) system. The ROV-system is modeled as a body with six degrees of freedom. The ROV-system is modeled be 24 slender elements, and the ROV consists of 20 slender elements. Hydrodynamic forces are calculated for each slender element using Morison's equation. The slender elements may be denoted with depth dependent coefficients, as the proximity to the free surface is an important aspect of lowering through the splash zone.

Results

Results from the Simplified Method clearly show a conservative estimate as a slack launching wire is likely to occur in all load cases, except when the ROV is hanging in the air. The largest hydrodynamic forces occur in load case 2, where the hydrodynamic force is in the region of 300 - 350 kN for H_s = 4.5 m, and the static force is 69.2 kN.

A study of the maximum relative velocity and acceleration has been performed to form the basis for the analyses of determining an operational H_s on the forthcoming analyses. A three hour sea state with H_s = 4.5 m, T_z = 11 s and head sea is investigated in this study. A number of 15 different seeds are investigated to ensure that the largest relative velocity and relative acceleration is obtained. The ROV is lowered such that the time instant of maximum relative velocity or maximum relative acceleration corresponds to when the ROV hits the water. The winch tensions for the two cases are plotted in the figure below.

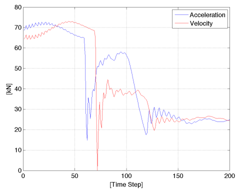

Figure 1: Lift line tension in the study of maximum relative velocity and maximum relative acceleration

As described above the drag may be modeled as sum of a linear and quadratic contribution or as a quadratic drag from Morison's equation. A study of the linear contribution has been made by comparing the lift line tension for two lowering operations in the same sea state with different drag modeling.

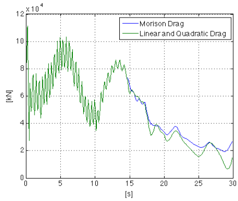

Figure 2: Comparison of modeling of drag

Conclusions

Based on the analytical calculations performed according to the Simplified Method, it may be concluded that the approach does indeed hold conservatism.

From Figure 1 it is seen that the largest relative velocity between the vertical water particle velocity and the vertical velocity of the crane tip may represent a worst-case scenario for the lift line tension. This may be used for analyses when determining an operational H_s for the lifting operation.

Figure 2 shows that the linear damping contributes significantly to the hydrodynamic forces in the splash zone. The lift line tension is likely to be underestimated when the drag and damping is modeled by a quadratic term only.

References

[1] DNV. *DNV-RP-H103 "Modelling and Analysis of Marine Operations"*. Det Norske Veritas AS, April 2011.

[2] O. Øritsland and E. Lehn. Hydrodynamic Forces and Resulting Motion of Subsea Modules During Lifting in the Splash Zone. In *Eight International Conference on Offshore Mechanics and Arctic Engineeringh International Conference on Offshore Mechanics and Arctic Engineering*, volume 2, March 1989.