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# Numerical study on deployment of subsea template using coupled and uncoupled model

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**Abstract.** This study compares deployment of a subsea template simulated as a coupled model and as an uncoupled model in the time domain simulation software Orcaflex. Defining vessel motion as prescribed simplifies the model and will therefore also decrease the simulation time. Models with predefined vessel motions are called uncoupled models. Vessel motion in a coupled model is a continuously calculated reaction to the forces acting on the vessel. Some software might struggle to run coupled models. The deployment simulations are narrowed down to focus on the incident where the template crosses the splash zone when lifted with an offshore construction vessel. Noticeable differences between the allowable sea state results are observed from the two different simulation methods. Running the time domain simulation as an uncoupled model gives lower allowable sea states than the results from the coupled time domain simulation model.

## 1. Introduction

Installation of subsea production systems involves hazards and high risks because of the harsh nature and uncertainty around the marine environment [1]. This study focuses on the installation of the subsea template. Handling the uncertainties and risk related to the installation phase of offshore equipment such as templates requires engineering analytical work [2]. Numerical models are often implemented in the analysis of various phases of the offshore operation to determine operational limitations which maintain a desired level of confidence that an accident is avoided. Allowable sea state limits for the offshore operations are determined through detailed numerical analysis of the different phases before comparing the critical responses and the respective allowable limits [2]. Normally a combination of significant wave heights and spectral peak periods where the probability of success for the operation is estimated to be above a certain limit are defined [2].

Operational limits for lifting operations have been addressed in multiple papers. A general method for assessment of the operational limitations demonstrated in a case study for installation of an offshore wind turbine monopile is presented in a journal paper by Guachamin-Acero et al [3]. Li et al. [4] performed a case study on lifting operation to study the uncertainties in allowable sea states associated with the sea state description used in the numerical analysis. Guachamin-Acero and Li [5] have presented a general methodology to assess the uncertainty in significant wave height limits due to variability in wave spectral energy distribution. The case that the study used to assess the uncertainties is installation of an offshore wind turbine transition piece.

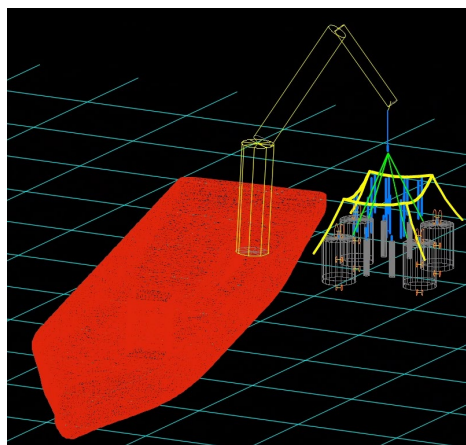
Amer presents a study on an Integrated Template Structure (ITS) deployment covering both overboarding and lowering through the splash zone [1]. The lowering through the splash zone with and



without including the shielding effect is compared and the conclusion is that including the shielding effect will result in higher allowable sea states. This study addresses a similar type of object to be lowered and a similar vessel which lowers the object, but different parameters are investigated. Few studies on the difference between modeling the numerical model as uncoupled and coupled are available. Numerical models of lifting operations can contain vessels with their motion described as a predefined motion or as a motion calculated from the forces acting on the vessel and the vessel's inertia properties. Different software have different options and capabilities when it comes to coupled and uncoupled models. Some software even struggle to run models where the vessel motion is continuously calculated. The simulation time will also decrease if the vessel motion is predefined. Predefined motion can therefore be beneficial to use if the external forces influence on the vessel is not of interest. Predefined vessel motion is called "Displacement RAO" in Orcaflex, this is also referred to as an uncoupled model. The movement of the vessel in the uncoupled model is unaffected by the movement of the lifted object. Continuously calculated vessel motion is called "Load RAO" in Orcaflex and is sometimes referred to as coupled models.

## 2. Numerical model

The deployment model is a model including the construction vessel, winch, lifting wire, slings and the ITS. The model is set up to start with the ITS ready in lowering position before the ITS is lowered down below the sea surface. Two cases are described in this chapter, where the only difference between the two models is the vessel Response Amplitude Operator (RAO) data.



**Figure 1.** ITS deployment numerical model.

### 2.1. Vessel setup

Use of load RAO requires some strategically positioned links to keep the vessel from drifting out of position. It is difficult for the numerical tool to remove all the second-order wave load and the vessel will therefore in many cases tend to drift away. In this model, three links are used to keep the vessel in position by restraining surge, sway and yaw motions. The links are connected to the vessel at the same height as the free surface with the other ends fixed to earth. They are modeled as linear springs with a stiffness of 50 kN/m and a length of 1000 meters. The two links restraining sway and yaw motion are connected at the longitudinal center line at stern and the bow of the vessel. The link restraining surge motion is connected at the horizontal position of the RAO origin and points along the longitudinal axis of the vessel.

The link setup is verified by running a set of simulations with different zero up-crossing wave periods. The simulations have a build-up time of 100 seconds, and a normal simulation time of 1 hour. Both beam and head sea have been scanned. The purpose of the simulations is to compare the displacement RAO responses with the load RAO responses when the links are attached to the vessel defined by load RAO. Too soft springs will not sufficiently restrain the vessel in horizontal direction

and may allow it to become unstable. Too stiff links will reduce the energy in the three motions of interest: heave, roll and pitch. A link stiffness of 50 kN/m is found to be acceptable, and the links are 1000 meters long to minimize their contribution in the vertical direction.

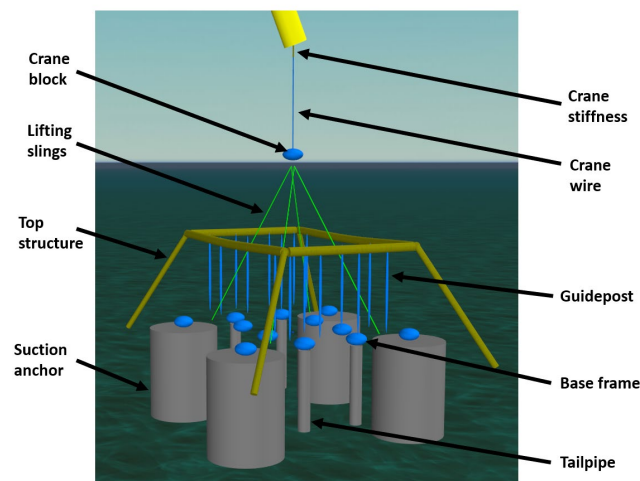
## 2.2. Lifting setup

The crane is modeled using constraints and shapes in Orcaflex (shapes are only used to visualize and has no impact on the numerical model). The constraints make it possible to manipulate the crane in terms of slewing angle, crane boom angle, etc. This is not necessary for this study, but it can be useful if the over-boarding phase of the operation is studied. The constraint positions and orientations are given in Table 1. They correspond to a crane radius of 24,5 m and a crane tip position of (-23,5 m, 35,0 m, 34,2 m) relative to the RAO origin.

**Table 1.** Crane constraint specifications.

	Connected to	X, [m]	Y, [m]	Z, [m]	Azimuth, [°]	Declination, [°]	Gamma, [°]
Crane pedestal	Vessel	-23,45	10,5	1,02	90,0	0,0	0,0
Crane boom	Crane pedestal	0,75	0,0	20,50	0,0	30,0	0,0
Crane jib	Crane boom	0,0	0,0	26,0	0,0	111,0	0,0
Crane tip <sup>1</sup>	Crane jib	0,0	0,0	16,0	-	-	-

The azimuth, declination and gamma angle are defined as rotation around the z-, y- and x-axis. The coordinates are relative to the axis of the object/constraint that the constraint is connected to.



**Figure 2.** ITS model.

The crane stiffness is modeled using a line element with constant length to account for the constant stiffness of the crane. The ITS is lifted using a 4-part lifting set. The lifting slings are connected to the four corners of the ITS (at the location of the designated lifting points) and joined at the crane block, which is modeled as a 3d buoy. The crane block has a mass of 12,8 Te and no hydrodynamic properties are included. The 4-part lifting arrangement is modeled with 4 individual links. Links can either be acting as springs or tethers, which decides how they act when passing the point of 0 tension. The lifting slings are modeled as tethers, meaning that they will become slack if no tension is present. The winch

<sup>1</sup> The crane Tip is not a constraint, but a connection point for the crane stiffness line.

wire is set to pay out wires with predefined stage according to Table 2. The winch wire has an initial length of 8 m. The lifting slings in the 4-part lifting arrangement have linear stiffness properties.

**Table 2.** Construction vessel - Winch simulation settings.

	Stage duration, [s]	Simulation time at stage end, [s]	Mode	Value, $\left[\frac{m}{s}\right]$
Stage 0	8	0	Payout rate change	0,2
Stage 1	120	120	Payout rate change	0

### 2.3. ITS model

The ITS is a typical subsea template, which is to be installed on the seabed. It consists of 4 suction anchors, 4 tailpipes, 16 guideposts, a base frame and a top structure. The suction anchors are hollow with a roof plate on top. These roof plates have two ventilation holes each, which are too small to evacuate the trapped water while lowering the template. The tailpipes are open ended and will therefore have negligible added mass in vertical direction. The main properties for the template are given in Table 3. The vertical center of gravity for the entire structure is located approximately at the same height as the top of the suction anchors.

The ITS is modelled as a combination of lines, 3d buoys and 6d buoys and they are connected to a common 6d buoy. This common buoy has only negligible properties and serves its only purpose by connecting different components together. The suction anchors and the tailpipes are modeled as 6d spar buoys. The guideposts are represented with 3d buoys. The base frame, which connects the tailpipes, suction anchors and guideposts together, are modeled as 12 individual lumped 3d buoys. The top structure, which serves as a protection for the template, is modeled using line elements.

Normally, several tugger winches are connected in such heavy lifts. Their main purpose is to control the horizontal pendulum motion of the ITS during the over-boarding phase of the lift, but they are left connected until the object is lowered to approximately 50 m water depth. At this stage the ROV disconnects the tugger wires from the object. The tugger winches have been excluded from this study since the pendulum motions during lowering through the splash zone are secondary.

**Table 3.** ITS main properties.

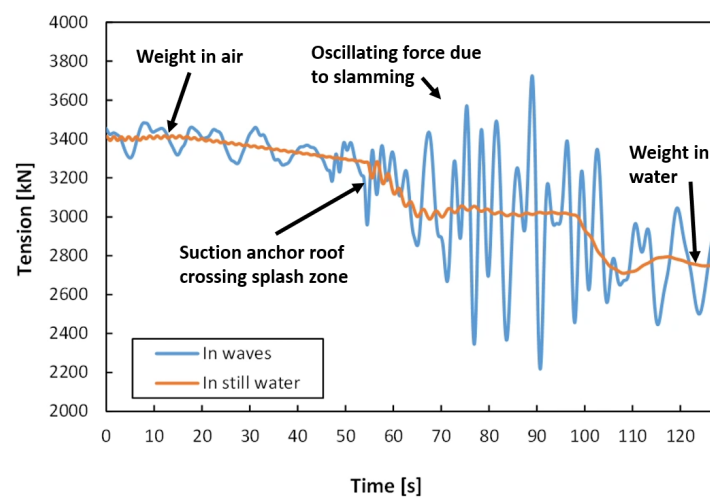
Parameters	Value
Overall length, [m]	29,0
Overall width, [m]	20,8
Overall height, [m]	16,5
Mass, [Te]	335,0
Weight in water, [kN]	2546,2
Suction anchor OD, [m]	6,0
Suction anchor height, [m]	7,9

The hydrodynamic properties for the ITS are calculated according to DNV's recommended practice for modeling and analysis of marine operations [7]. Detailed modeling of the hydrodynamic properties of the ITS is not covered in this paper, but it is worth mentioning that the added mass and rate of change for added mass for the suction anchors has been modeled as depth dependent coefficients.

### 3. Operational Criteria

The splash zone crossing of the ITS is governed by two criteria. The maximum dynamic hook load (DHL) shall not exceed the capacity of the crane, and both the crane wire and the four lifting slings

between the hook and the ITS shall never become slack. There is no defined maximum sling load limit for the lifting slings. These will normally be designed based on information from the time domain simulations. Each sea state is simulated 50 times with different wave seeds to achieve statistical confidence for the maximum and minimum sling forces. Maximum values are based on a 95% probability of non-exceedance. The minimum values are estimated using the same probability of non-exceedance as the maximum values. A comparison between the dynamic hook load in waves and the dynamic hook load in still water for the lowering phase can be seen in Figure 3. The figure shows that oscillating forces can cause high dynamic tension in the wire. These oscillating forces are induced by the slamming loads which occurs when the suction anchors cross the splash zone. The slamming loads increase with the relative velocity between the lifted object and the sea surface. The dynamic loads are also influenced by the inertia forces and the drag/damping forces.



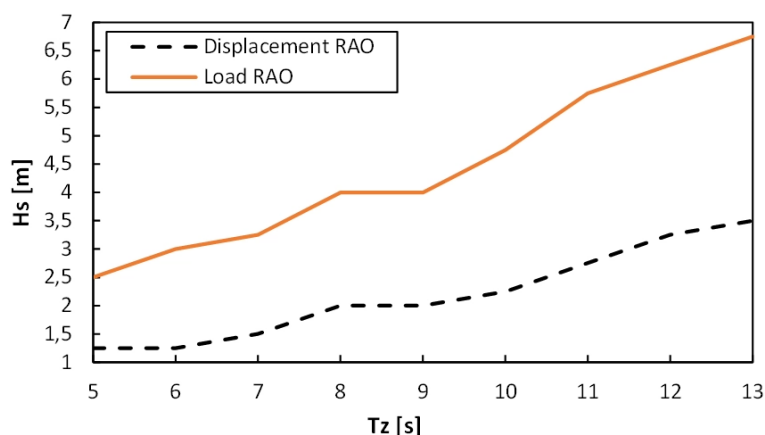
**Figure 3.** Time history of DHL.

According to DNV's recommended practice for modeling and analysis of marine operations [2], slack slings shall as far as possible be avoided. Equation (1) shall be fulfilled to have a sufficient margin against snap forces due to slack sling. The submerged weight of the template corresponds to a mass of 270 Te. Combining this with the 10 % margin against slack sling gives that the minimum dynamic hook load from the time domain simulations shall not be below 27 Te

$$F_{hyd} \leq 0,9 \cdot F_{static-min} \quad (1)$$

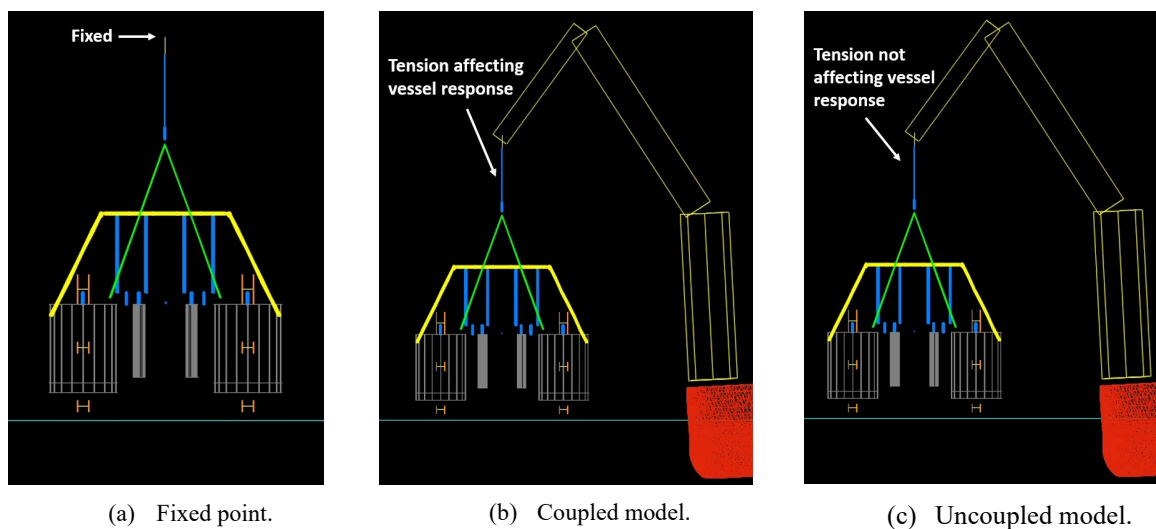
#### 4. Results and discussion

The results of obtained allowable sea states for the coupled and uncoupled models are presented in Figure 4. Both graphs have the same trend. The magnitude of the allowable sea state at each wave period is, however, significantly lower when using the uncoupled model. This is because the lifting wire between the load and the crane tip will act as a spring in the coupled model, which will try to compensate the relative motion between the load and the vessel. Increasing the crane radius will further increase this effect, as the moment around the longitudinal axis caused by the ITS will increase when the radius increases. Larger difference between the two graphs is expected for a bigger crane radius because the movement of the vessel in the uncoupled model is unaffected by the movement of the ITS.



**Figure 4.** Allowable sea state for lowering ITS through splash zone using displacement RAO.

Three different cases with the same wave condition and the same wave seeds have been simulated in order to take a closer look at the differences between the responses by using coupled and uncoupled models. The first model is a model where the crane tip is connected to a fixed point, so there is no crane tip motion. Only the winch payout speed influences the vertical motion to the ITS prior to start of submergence. The second model is the coupled model (Load RAO), where the ITS motion will influence the vessel responses in waves. The third model is the uncoupled model (Displacement RAO), where the vessel motions are pre-generated in waves and unaffected by the ITS.



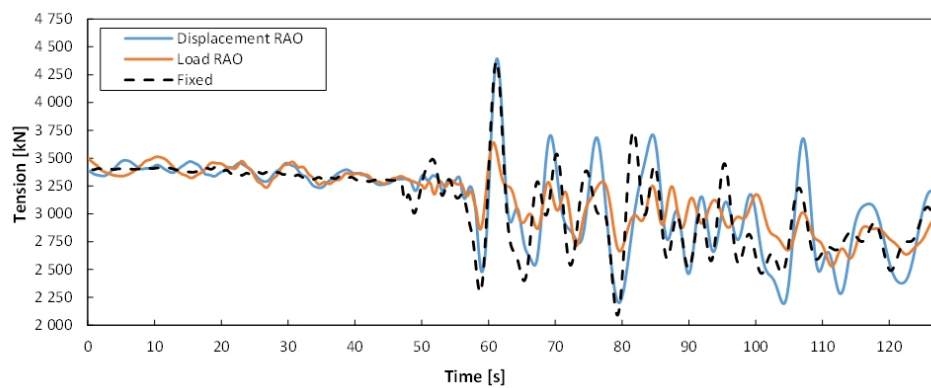
**Figure 5.** ITS Deployment - Illustration of three different modelling cases.

Figure 6 compares the lift wire tensions generated from the three different cases for a given sea state. According to this figure, the maximum peak loads for the fixed crane tip and the vessel described with Displacement RAOs are clearly higher than the peak loads for the vessel described with Load RAO. The tension in the lifting wire is directly related to the relative displacement between the crane tip and the lifted object. The force in the lifting wire is according to Hooke’s law, a product of displacement and the spring constant. Comparing the time history of lifting wire tension, sea surface clearance and crane

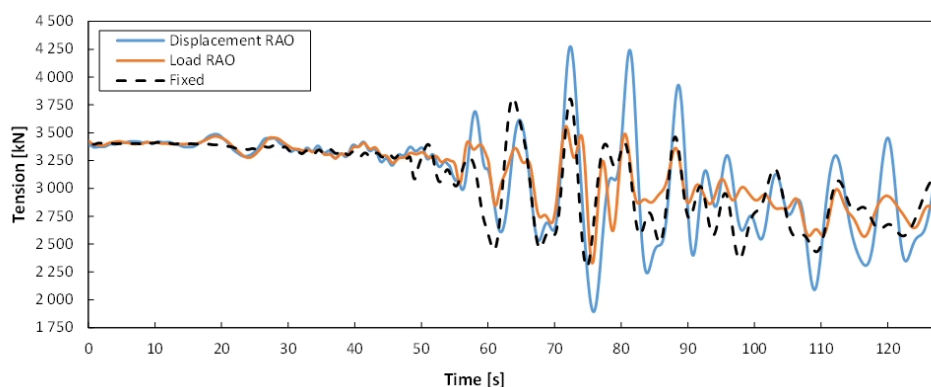


tip heave motion suggests that the lifting wire tension is related to the vessel's ability to adjust its motion to the lifted object. When the crane tip is fixed or the vessel is modelled using Displacement RAO, the vessel cannot adjust its motion because the motions are predefined and independent of the lifted object. However, when using Load RAO, the vessel motions are solved in the time domain by considering the tensions in the lift wire that are caused by instantaneous motions from the ITS. In this case, the vessel is able to adjust to the ITS' motion and thus the relative displacement between the crane tip and the ITS decreases. Hence, the maximum wire tension is also reduced.

The time histories by using different wave seeds under the same sea states are also compared in Figure 6. By comparing the results using two different seeds, it can be seen that the maximum dynamic load does not necessarily happen directly after the roof of the suction anchors hits the free surface. The magnitude and location of the maximum peak load for the uncoupled model depends on the timing of the crane tip motion relative to the occurrence of the slamming force. The variations in the tensions are more violent for the fixed and uncoupled models than those for the coupled model. The standard deviations for a sample of 50 simulations, presented in Table 4, reflect the variation of maximum values per sample. The standard deviation for the sample of coupled model simulations is clearly the lowest.



(a) Seed 32



(b) Seed 44

**Figure 6.** Dynamic hook load for the three cases in ( $H_s = 2,5$  m and  $T_z = 8$  s).

**Table 4.** Standard deviation of DHL for  $H_s = 2,5$  m,  $T_z = 8$  s (50 Seeds).

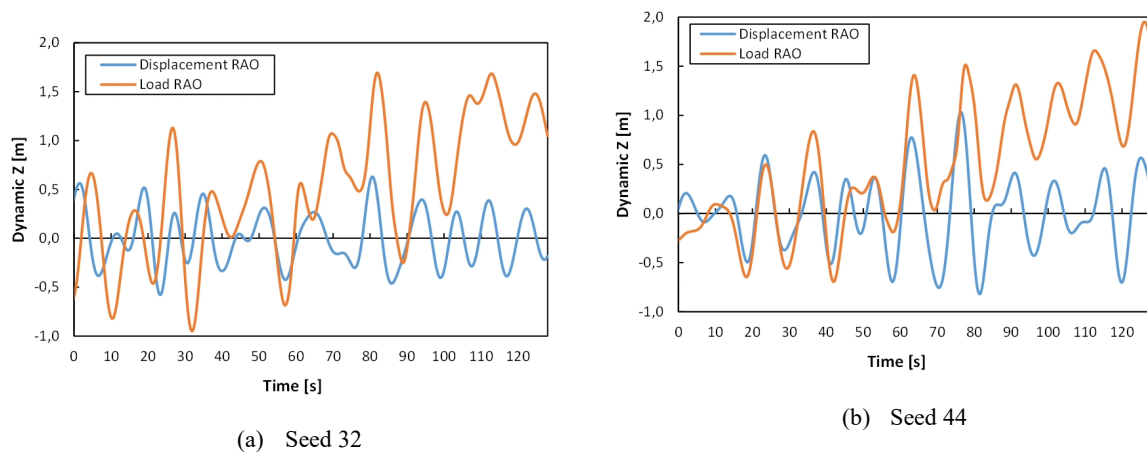
	Displacement RAO	Load RAO	Fixed crane tip
Standard deviation, [kN]	283,5	66	263,7



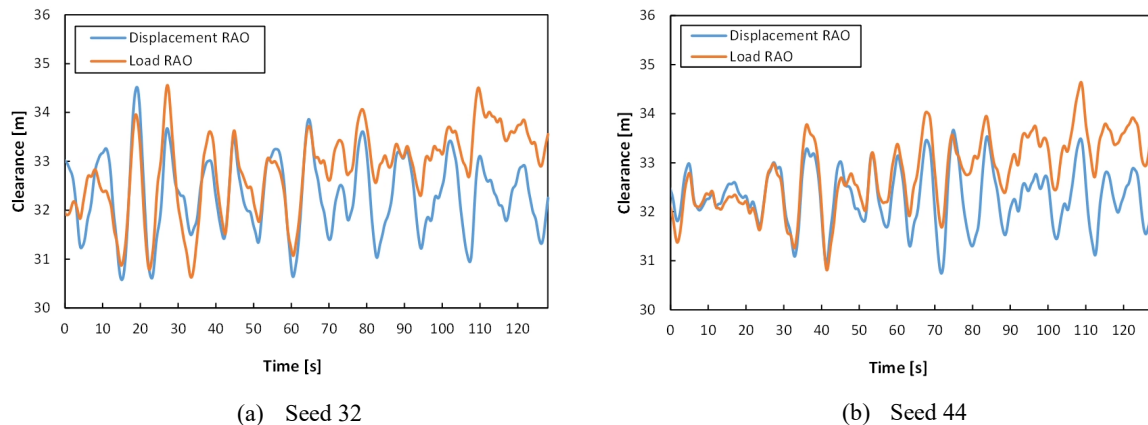
The standard deviation for the Load RAO is lower because the crane tip adjusts to the motion of the ITS and will therefore create incidents with higher level of resemblance to each other. This means that the maximum values obtained from simulations with a coupled model will deviate less from each other as opposed to uncoupled models and fixed crane tip models, where timing is crucial.

Figure 7 and Figure 8 compare the time histories of the heave motion of the crane tip and the clearance between the crane tip and the sea surface using coupled and uncoupled models, respectively. Figure 7 shows that the heave motion of the crane tip for the coupled model has higher amplitudes than the heave motion of the crane tip for the uncoupled model. Figure 8 shows that both models have similar amplitudes prior to the point where the template crosses the splash zone. During splash zone crossing, the amplitude of the sea surface clearance reduces using the coupled model, while the time history using the uncoupled model remains the same level. An amplitude of 0 m would mean that the crane tip follows the sea surface perfectly. It is evident for both seeds that the amplitude of the sea surface clearance in the coupled model simulations reduces at around 60 to 80 seconds. This is the same area where the peak wire tensions in Figure 6 occur. At this stage, the motion of the template is affected by the motions of the waves due to hydrodynamic loads from the waves. This happens regardless if the model is coupled, uncoupled or just a fixed crane tip. However, the vessel described with load RAO (coupled) can adjust its motions to the motions of the template, which reduce the relative sea surface clearance. The results of the sea surface clearance are consistent with the dynamic tensions in Figure 7. In addition, the mean value of the heave motions and the sea surface clearance time histories increase after the ITS crosses the free surface because of the contribution of the buoyance from the ITS components.

A general comment to the results presented in Figure 4 is that the overall operational sea states also depend on other phases of the lift. This study does not cover the over-boarding phase of the lifting operations and sea state limitations given by the manufacturer has not been considered. The experience of the offshore crew executing the operations will also play a major role in whether the operation will commence or not.



**Figure 7.** Heave motion at the crane tip ( $H_s = 2,5$  m and  $T_z = 8$  s).



**Figure 8.** Sea surface clearance at the crane tip ( $H_s = 2,5$  m and  $T_z = 8$  s).

## 5. Conclusion and recommendations

This study compared different methods for simulation of vessel motion during a deployment analysis. The results substantiate DNV's statement that applying uncoupled vessel RAOs will typically give conservative results as the crane tip motion will be reduced by the lifted object in most cases [7]. This is true for the ITS deployment simulated in this study as a significant decrease in allowable sea states can be seen when changing from a coupled model to an uncoupled model. This is because of the coupled model vessel's ability to adjust to the motion of the lifted object when large hydrodynamic forces are applied to the object.

Predefining the vessel motions in an uncoupled model may lead to under-estimation of the allowable sea state for the lifting operation. There is often a high cost related to the vessel conducting the marine operations and the crew onboard such vessels. Setting operational limitations higher than necessary can potentially lead to waiting on weather for the construction vessel which subsequently causes unwanted economical losses.

For future projects it would be interesting to run a sensitivity study by changing the weight of the lifted object to investigate how it affects the gap between the maximum tension results for the coupled model and the uncoupled model. Heavy objects should influence the motion of the vessel more than light objects when simulated as a coupled model.

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