WAVE DRIFT FORCES AND RESPONSES IN DEEP WATER AND EXTREME ENVIRONMENTAL CONDITIONS

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The results of an experiment carried out on a semi-submersible model to measure the steady drift force and low frequency surge motions are presented. The influence of mooring systems was also investigated in different combinations of current and sea state in the experiments. The measurements were carried out with a 1/50 scale model that was moored, in separate experiments, using horizontal springs and catenary mooring lines. The mean values of steady drift motions and the standard deviation of the low frequency motion amplitudes are presented for each system. It was found that for both horizontal and catenary moorings, the presence of a current increased the damping ratio of the system. In the case of the catenary mooring system, as expected, the presence of mooring lines and their interaction with waves and current increased the damping compared to the damping of the horizontal mooring system. The measured mean values of the surge motions in a wave–current field have been compared to the superposed values of those obtained from waves and current separately. It was found that there is good agreement in moderate sea states, while in higher sea states the measured motion responses are larger. In the wave-current field, the standard deviation of the surge motion amplitudes was found to be less than that obtained in waves alone when the model was moored with catenary mooring lines.

1. INTRODUCTION

Slow-drift motion is an important aspect of the analysis of offshore production systems that can often become a critical parameter in the design of mooring lines and riser systems. In the slowly varying motions can be defined as resonance oscillations excited by non-linear interaction effects between the waves and the body motion and to be calculated using the potential theory (Faltinsen 1990). It has been shown that the resonance is one of several interaction phenomena causing the large amplitude oscillations of moored vessels (Bernitsas et al. 2006). The interaction between slowly varying wave drift forces and the dynamic bifurcation could result in 2-3 times larger oscillations than the resonance phenomenon. In moderate sea states the predictions based on potential theory correlate well with measurements. However in severe wave conditions model tests have shown that there is an increase in wave drift forces as the sea states increases. This effect can be explained by viscous drift forces acting in the waterline zone of a structure (Stansberg 1994; Dev 1997). The slowly varying oscillation amplitudes are mainly controlled by the amount of slow drift damping present in the system. The main physical contributions to the slow drift damping are: wave drift damping; viscous hull damping; wave radiation damping; mooring and riser line damping and aerodynamic damping. The investigation of wave-current interaction is also of interest in order to determine the effect of current on the drift force damping components in severe environmental conditions.

The objective of the study presented in this paper was to investigate the wave drift forces and responses of a moored semisubmersible production platform in a current only, and in regular and irregular waves with and without currents, when subjected to severe environmental conditions. The tests were carried out in two configurations: one with a catenary mooring system and the other with horizontal lines above the free surface. In particular, the objective was to explore the following phenomena:

- The second-order low frequency wave drift force components,
- The slow drift damping components, and
• The effect of sea state on drift damping and drift force excitation forces.

It was intended that the data gathered would be used to extend the knowledge of the phenomena involved and for validating theoretical/numerical models.

2. THE EXPERIMENTS

The experiments were carried out in the ocean basin of MARINTEK. The description of the laboratory and details of current generation are given in (Stansberg 2008). The model used for the experiments was a 1/50th scale semi-submersible with four square columns and four interconnected rectangular pontoons, both with rounded edges. The model was moored with four mooring lines. The full scale geometrical characteristics are given in Table 1.

<table>
<thead>
<tr>
<th>Table 1: Geometrical Characteristics of the semisubmersible (full scale values)</th>
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<tbody>
<tr>
<td>Length /breadth outside pontoons(m)</td>
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<tr>
<td>Height to upper deck(m)</td>
</tr>
<tr>
<td>Breadth of pontoons(m)</td>
</tr>
<tr>
<td>Height of pontoons(m)</td>
</tr>
<tr>
<td>Column length (m)</td>
</tr>
<tr>
<td>Column breadth(m)</td>
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<td>Column corner radius (m)</td>
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<tr>
<td>Draft (m)</td>
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<td>Displacement ( tonne)</td>
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<td>Water depth (m)</td>
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The tests were conducted using two different mooring systems; horizontal and catenary mooring. In both systems, the model was held in position using four mooring lines which were attached to the corner of each column. The tests with horizontal and catenary mooring lines aimed at identifying the effect of damping due to the mooring lines on the motions of the semisubmersible in waves and in waves and current. The horizontal mooring stiffness, $k$, was 144.8 kN leading to natural surge period of 146 s. The characteristics of each of the two mooring systems were determined by the static pull-out tests.

Two sets of tests were carried out, a preliminary set including wave and current calibration, decay and static pull-out tests, and the main experimental programme involving, regular wave, and irregular wave tests (with and without current). Most of the tests were carried out in head seas and few tests were carried out in oblique (45 degrees) seas. In all tests, waves and current approached the model from the same heading angle.

3. RESULTS

A selection of the results is shown in Figures 1 to 6. Figures 1 and 2 are presented for illustrative purposes to show the form of the time series for the surge response (Figure 1) to irregular seas with and without current whose spectra are shown in Figure 2. The mean values of the low frequency surge motion, and their standard deviations, are shown in Figures 4 to 6. The measured mean values of the surge motions in a wave-current field have been compared to the superposed values of those obtained from waves and current separately. Figs 3 and 4 show that there is good agreement in moderate sea states, while in higher sea states the measured motion responses are larger. In the wave-current, Fig 6 show that the standard deviation of the surge motion amplitudes was found to be less than that obtained in waves alone when the model was moored with catenary mooring lines.
Figure 1: Irregular wave time series

Figure 2: Wave spectra

Figure 3 Mean values of low-frequency surge motion, horizontal mooring

Figure 4 Mean values of low-frequency surge motion, catenary motion

Figure 5 Standard deviation of low-frequency surge motion, horizontal mooring

Figure 6 Standard deviation of low-frequency motion, catenary mooring
4. CONCLUSIONS

4.1. The second-order low frequency wave drift force components:
   The wave drift forces calculated from the measured displacements in regular waves and multiplied by the appropriate mooring stiffness show that the mooring lines increase the second order forces.

4.2. The slow drift damping components:
   The damping ratios are calculated in still water for both horizontal and catenary mooring systems in order to identify the mooring line damping. It was found out that the mooring lines caused an increase in damping from 0.23 to 0.3. The work to predict this increase using analytical methods (Huse, 1989a and 1989b) is ongoing.

4.3. The effect of sea state on drift damping and drift force excitation forces:
   Neither the drift forces nor drift damping were determined directly from the irregular wave experiments, however the effect of seastates on mean surge drift motions were measured (Fig 3-6) and these will be used in conjunction with ongoing numerical analysis to identify the effect of seastates on drift damping and drift excitation forces.

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REFERENCES


Stansberg, C.T., 1994, Low-Frequency Excitation and Damping Characteristics of a Moored Semisubmersible in Irregular Waves Estimation from Model Test Data. 7th International Conference on the Behaviour of Offshore Structures, Massachusetts Institute of Technology, Elsevier Science Ltd.