Second Order Motion Responses of Semi-submersibles: Numerical and Experimental Study

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ABSTRACT

In this study, numerical and experimental assessment of the 2nd order responses of a twin hulled semi-submersible subjected to monochromatic, bi-chromatic and random seas has been attempted. For numerical analysis, the 2nd order wave forces resulting from the 2nd order temporal acceleration and the structural 1st order motions have been obtained. The latter has been estimated by an iterative frequency domain analysis. Experimentally, the semi-submersible was modeled to a scale of 1:100 using Froude’s scaling law principles. The measured drift force has been compared with available formulae in the literature and reported. The numerical results have shown good agreement with the experimental results.

KEYWORDS: Second order drift forces; Low frequency motion responses; Nonlinear dynamic analysis; Frequency domain analysis; Semi-submersible model; Time domain analysis; Wave basin testing.

INTRODUCTION

Sea-keeping characteristics of a floating structure kept in a position by its own power or moored to either sea floor or to another structure by some mechanical means, determine its ability to survive the environment. Stationary floating vessels in irregular waves are subjected to large, so-called 1st order wave forces, which are linearly proportional to the wave height and which have the same frequencies as the waves. They are also subjected to small, so-called 2nd order, mean and low frequency wave forces. The frequencies of the 2nd order low frequency components are associated with the frequencies of the wave groups occurring in irregular waves. In case of mooring systems, the 2nd order wave forces are of great importance. When the incident waves include slowly varying components, the frequency of these components may be close to the natural frequency of the mooring system, thus possibly causing breakage of anchor lines and the mooring system (Prins 1995).

The components of mean and low frequency 2nd order wave forces can affect different structures in different ways and though of the same origin, they have been called by different names. The horizontal components of the mean and low frequency 2nd order wave forces are also known as wave drift forces because, under the influence of these forces, an unrestrained floating vessel undergoes a steady slow drift motion in the general direction of the wave propagation. The vertical components of the 2nd order wave forces are sometimes known as suction forces. These components of the 2nd order forces have been identified as causing the phenomena of the steady tilt of semi-submersibles with low initial static stability as indicated by Atlar (1986), Rainey (1986) and Wu (1993). Depending upon the frequency of the waves, it has been found that the difference in the suction forces can result in a tilting moment, which can lead the platform to tilt away from the oncoming waves. This effect is of importance in specifying the static stability requirements for semi-submersibles.

Semi-submersibles are usually designed such that their natural frequencies, in various modes of platform motion, lie outside the frequency range of maximum wave energy. The typical natural periods of semi-submersible platforms given by Patel and Witz (1991) and Chitrapu (1992) are presented in Table 1. It can be seen from this table that the risk of existence of springing forces is high in the horizontal (surge, sway and yaw) degrees of freedom and should be considered in the design of the mooring system.

Table 1: Typical natural periods of moored semi-submersibles

<table>
<thead>
<tr>
<th>Mode of Motion</th>
<th>Natural Period (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surge, Sway</td>
<td>&gt; 60</td>
</tr>
<tr>
<td>Heave</td>
<td>20-25</td>
</tr>
<tr>
<td>Pitch, Roll</td>
<td>20-30</td>
</tr>
<tr>
<td>Yaw</td>
<td>&gt;100</td>
</tr>
</tbody>
</table>

In this numerical and experimental study, a deep insight into the effect of mean and low frequency wave exciting forces on the motion responses of semi-submersibles have been attempted. In the experimental study, a linear mass spring system was arranged to model an existing semi-submersible using Froude’s similitude principles. The model and restraining system were calibrated in order to provide the desired mass spring system characteristics. The mean drift forces corresponding to the regular wave trains in the dominant frequency range of the ocean were evaluated from the system restraining forces and the structure reactive inertia forces.

Numerically, the steady drift forces on the semi-submersible were calculated using Weggel’s (1997) formulae assuming that the steady drift force originates at the splash zone. For the evaluation of the wave forces up to 2nd order, Rainey’s (1986) modified version of the force (Morison) equation was used. The general equilibrium of the mass spring system was maintained by the nonlinear dynamic algorithm using Newmark-β technique, which resulted in the structure motion and restraining system tension responses.

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