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Second Order Roll Motions for FPSO's Operating in Severe Environmental Conditions

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Abstract

The paper describes the numerical calculation of the second order roll moment and the comparison with the results obtained with model tests performed for a concept design of FPSO to operate in severe environmental conditions. The importance to take into account the second order roll motion for FPSOs with reduced metacentre height is then demonstrated. The roll motions for ship shaped units have been an issue of major concern for the deep waters operations. For the new units, the hull may be designed in order to achieve good motion characteristics avoiding delays and production down time. One technique used to limit the roll response in the new FPSOs designs is to obtain the roll natural period outside of the period range of linear wave energy (roughly from 3s to 20s). However recent experiments have demonstrated the occurrence of roll motions even for FPSOs with large resonance period, which is explained by the second-order excitations.

Introduction

It is observed that several FPSOs operating in different areas around the world experience large roll motions, resulting in delays and production down time. For the new constructions, the optimization of the hull geometry in order to achieve good motions characteristics has been an issue of major concern. One technique used to limit the roll response is to design the unit such that the roll natural period is outside of the range of linear wave energy (roughly from 3s to 20s). However, recent tests for FPSOs with roll resonant periods larger than the maximal linear wave period have demonstrated the presence of roll response at their natural periods, what is attributed to non-linear mechanisms.

We consider the theory of second-order wave diffraction and radiation within which the wave loads occurring at the difference of wave frequencies can be evaluated. These low-frequency wave loads are considered to be the main source of large period roll motion. Much work has been done for the prediction of the horizontal components of second-order loads and two classes of theories have been developed: far-field formulation based on the momentum principle and the near-field based on the direct second-order pressure integration on the hull surface. The fruitful results have been obtained in the application to the design of mooring system. However, few works as in Pinkster et Dijk (1985) and in Chen et Molin (1989) have been pursued on the computation of the vertical components of second-order loads due to two critical issues associated with their numerical evaluation.

One concerns the accurate prediction of second-order wave moments and another, the coupling of linear and second-order motions. Concerning the vertical components (force in the vertical direction and moments around the horizontal axis), the far-field formulation cannot be applied. Furthermore, since diffraction and radiation velocities are singular in the zone of hull close to sharp corners, the near-field formulation, in most cases, cannot give convergent results. Recently, a new formulation to evaluate the second order loads was proposed by Chen (2004), which is obtained by applying the variants of Stokes theorem and Green theorem to a domain limited by a control surface. As this formulation is written on a control surface at a certain distance of the body it is so called middle-field formulation and applicable to the evaluation of both horizontal and vertical low frequency loads.

This paper describes the numerical calculation of the second-order roll moment performed for a concept design of FPSO with large roll natural period. The convergence of the results obtained using the near field formulation and the middle field formulation is evaluated. The roll response calculated is compared with measurements of model tests.

Second Order Theory for Low-Frequency Loads

The low-frequency loads are the second order loads oscillating at a frequency equal to the difference of the first-order wave frequencies. The horizontal low-frequency loads are already known as the main source of excitation for the low-frequency motions of moored vessels, and many works have