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Water Wave Diffraction and the Spectral Response Surface Method

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For the purposes of guiding air-gap design, wave-structure interaction is modelled using linear and 2nd-order diffraction theory. A 4-column gravity-based structure is considered, consisting of a subsurface caisson with 4 large-diameter columns mounted on top. The diffraction analyses are combined with the spectral response surface (SRS) method of Tromans and Vanderschuren to compute extreme surface elevation statistics. Water is predicted to reach very high elevations both close to the columns and at the geometric center of the structure. Comparisons with real wave data are made and conclusions on the ability of this approach to reproduce real wave measurements beneath a gravity-based structure are discussed.

INTRODUCTION

With energy companies developing more offshore oil and gas infrastructure in what is perhaps becoming a more hostile ocean environment, there is an urgent need to improve current understanding of extreme ocean waves and their interaction with structures. Air-gap design, which requires the accurate prediction of the maximum height above mean sea level to which green water is projected, is of particular interest to the offshore industry.

At present the offshore industry is not able to accurately predict the large free-surface magnifications resulting from wave-structure interaction. Although large ocean waves and wave-structure interaction effects may not always threaten the overall integrity of an offshore structure, vertical water projection can damage equipment and lead to long periods of expensive production downtime.

Wave-structure interaction is modelled using linear and 2nd-order diffraction theory. In this study, the 3-dimensional water wave diffraction problem is solved using a quadratic boundary element method. It is noted that a robust, fully nonlinear diffraction code is not currently available to reliably study nonlinear diffraction effects.

A gravity-based structure, consisting of a subsurface caisson with 4 large-diameter columns mounted on top, is considered in this paper.

This study is an extension of the work presented by Walker et al. (2006), which compared measured surface elevations beneath a 4-column gravity-based structure with linear and 2nd-order diffraction solutions for incident regular waves. The diffraction analyses are now incorporated into the surface response surface (SRS) method of Tromans and Vanderschuren (1995). The SRS method is used to compute extreme surface elevation statistics (e.g. crest elevations corresponding to given probabilities of exceedance) around the platform, and comparisons with experimental data are made. Conclusions on the ability of this approach to reproduce real wave measurements beneath a platform structure are discussed. Combining the use of diffraction theory with the SRS method could provide an invaluable tool for offshore structure design.

DIFFRACTION THEORY

The analysis of wave-body interaction is a 3-D, fully nonlinear problem, which has not been exactly solved, even for monochromatic waves. However, if certain assumptions and simplifications are accepted, low-order analytical models can be developed. If the typical dimension associated with a body (e.g. column diameter) is sufficiently large compared with the wavelength and surface wave amplitude, then separation effects due to viscosity can be neglected and diffraction effects dominate. In any case, the effects of viscosity are expected to have much less influence on surface elevations than on wave forces. In addition, diffraction theory assumes that the flow is incompressible and irrotational, and that surface tension effects can be neglected. Together, these assumptions imply that a scalar velocity potential can describe the flow, satisfying Laplace's equation within the fluid domain.

Solutions to the linear diffraction problem have been successfully implemented and are generally accepted in the offshore industry. It was Havelock (1940) who began work in this area by developing an analytical solution for the diffraction of incident monochromatic waves from a single cylinder in water of infinite depth. McCamy and Fuchs (1954) extended this result to finite water depth. An overview of this early work is given by Mei (1989).

For the case of waves incident upon an array of bodies (e.g. 4 columns), the effect of a given body on the incident wave will be to produce a scattered wave which will in turn be scattered

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