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Diffraction Theory as a Tool for Predicting Airgap Beneath a Multicolumn Gravity-based Structure

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This work investigates the feasibility of using diffraction solutions to predict extreme green-water levels beneath multicolumn gravity based structures. The ultimate aim is to provide improved design tools for predicting the height the deck structure must be raised above mean sea level (airgap) for the lower deck to avoid green-water impact. Such tools, when fully validated, will replace the need to carry out model tests during preliminary design. Results for a real platform configuration are examined in this paper to highlight the key issues complicating the validation of diffraction-based design tools for real structures. Incident regular waves are considered.

INTRODUCTION

The interaction of large ocean waves with oil and gas production platforms remains a major design consideration. There is particular interest in the offshore industry in the prediction of the maximum height above mean sea level to which significant volumes of water are projected. While not always threatening the overall integrity of the structure, water projection can damage equipment and lead to expensive production downtime. At present most platform designs incorporating large-diam columns (e.g., gravity-based structures) are model-tested in wave tanks with little idea beforehand as to the effect the wave-structure interaction will have on extreme water levels. Linear diffraction solutions, which are based on small-amplitude wave theory, are commonly used by the offshore industry prior to model testing to obtain an estimate of the extreme free-surface magnifications. There is a considerable need for a validated design methodology that enables the accurate prediction of extreme free-surface magnifications in the vicinity of multicolumn structures.

The proposed problem has been approached using linear and 2nd-order diffraction solutions. The important features of a nonlinear diffraction solution have been investigated by extending linear diffraction theory to a 2nd-order approximation using a Stokes expansion procedure. A quadratic boundary element method has been used to solve the 3-dimensional water wave diffraction problem.

In order to assess the validity of using diffraction solutions in the design of offshore structures, a programme of wave tank experiments has been undertaken for a specific 4-column gravity-based structure. The structure tested consists of a multilevel deck supported above the ocean surface by a concrete gravity substructure resting on the seabed. The concrete substructure is composed of a caisson with 4 large-diam columns mounted on top. The principal objective of the tests was to determine the airgap required for the lower deck to avoid green-water impact under extreme storm conditions.

Comparisons have been made between the measured surface magnifications in the vicinity of the structure and those predicted by linear and 2nd-order diffraction theories for incident regular waves. Through comparing experimental data with diffraction solutions, the ultimate aim is to address the following key question: If you do not carry out model tests, then can you rely upon linear and 2nd-order diffraction solutions to accurately guide airgap design? Progress towards a definitive answer to this question is pursued in this paper.

The current use of linear diffraction theory to guide airgap design is commonly acknowledged to be inadequate. Thus, from the offshore industry's standpoint, the emphasis of current research should address the utility of 2nd-order diffraction theory at predicting green-water levels. In addition, studying 2nd-order diffraction theory will enable the examination of nonlinear wave phenomena, such as 2nd-order near-trapping of waves between columns. Robust fully nonlinear codes are not currently available to perform these tasks.

The magnitude of the 2nd-order contributions (sum and difference) to the overall diffracted wave field has been found to be considerable and should then not be neglected in design.

DIFFRACTION THEORY

The analysis of wave-body interaction is a 3-D, fully nonlinear problem, which has not been exactly solved, even in regular 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 diam) 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 regular 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).

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