International Journal of Offshore and Polar Engineering
Vol. 13, No. 1, March 2003 (ISSN 1053-5381)

Computation of Nonlinear Wave Reflections and Transmissions from Submerged Horizontal Cylinder

T. Schønberg
Atkins Process, London, United Kingdom

J. R. Chaplin*
Department of Civil & Environmental Engineering, University of Southampton
Southampton, United Kingdom

ABSTRACT

Nonlinear irrotational 2-D wave-body interactions are investigated using an indirect Desingularised Boundary Integral Equation Method with fully nonlinear free-surface boundary conditions. A fully implicit multi-point method is used for the time-integration, and the model is applied to the interactions of regular waves with a horizontal circular cylinder. There has been no sign of saw-tooth instabilities. The incident waves are modelled explicitly, and efficient sponge layers are used to damp out the computed scattered waves at each end of the domain. Numerical convergence and mass and energy conservation are demonstrated. Excellent agreement is observed between the present results and those from experiments, analytical solutions and other numerical models. Particular attention is given to wave reflections in deep and finite water depths, and to some unexpected wave conditions on the lee side of the cylinder.

INTRODUCTION

The problem of waves diffracted by a submerged horizontal cylinder whose axis is parallel with the wave crests is of both industrial and intrinsic interest. The existence of linear and second-order analytical solutions, numerical solutions to various orders, and a range of good-quality data also makes it an attractive subject on which to test new codes and those that use novel techniques.

Dean (1948) gave the first solution to the linear diffraction problem of a horizontal restrained circular cylinder beneath monochromatic waves in deep water. This work was done in the framework of linear potential theory and deep-water waves using a conformal mapping. Dean showed the remarkable facts that to this approximation the reflection from the cylinder is zero, and that the only effect of the cylinder on the waves is a change in their phase. Expressions for the first-order forces on the cylinder were obtained by Ursell (1950), using a series of multi-pole potentials, and Ogilvie (1963) expanded Dean's solution and derived the second-order time-independent force. The linear problem was solved also by Mehlum (1980), using a conformal mapping, and Grue and Palm (1984), using a boundary integral equation method (also for an elliptic contour and a flat plate).

A second-order solution for deep water waves was obtained by Vada (1987), using a Green's theorem method for a cylinder of arbitrary shape. McIver and McIver (1990) also derived a second-order solution to the problem and showed that there are no reflections to second-order, either. Palm (1991) subsequently proved that there are no reflections to leading order at any harmonic frequency—but not that reflections are entirely absent.

All cases mentioned above refer to waves in deep water. A linear potential flow solution that also includes the effects of the seabed was described by Subbiah et al. (1993), using a Green's theorem method. Second-order solutions for the same problem were obtained by Wu and Eatock Taylor (1990) and Yan et al. (1998).

A fully nonlinear solution to the problem of a horizontal circular cylinder has been made, among others, by Skourup and Jonsson (1992), who—like Longuet-Higgins and Cokelet (1976)—used the Mixed Eulerian-Lagrangian (MEL) time marching scheme, and periodic boundary conditions. This meant that what was actually modelled was an infinite array of cylinders. Skotner et al. (1994) used the model developed by Skourup et al. to study the influence of wave steepness, cylinder submergence and water depth on the forces on the cylinder. Other fully nonlinear computations are described by Brevig et al. (1981) and Stansby and Slaouti (1984), the former for cases where the waves were breaking on the cylinder. Yeung and Vaidhyanathan (1992) used the MEL with a finite-difference scheme for the Laplace equation.

Liu et al. (1992) compared predictions of a high-order spectral method with measurements by Grue (1991). They obtained results for wave reflections from the cylinder and found a mean negative drift force of fourth order in the incident wave steepness. With a boundary integral equation method, Liu et al. (1999) carried out investigations of a cylinder in circular motion, and a cylinder free to respond to an incident wave.

Another series of papers deals with the viscous flow, but this paper is concerned mainly with potential flow nonlinearities. The next section deals with the numerical model, in which we followed the method of desingularised sources. This provided what are argued to be very accurate, fully nonlinear solutions to the problem, and particular attention is directed at identifying reflections from the cylinder, and an unexpected pattern of waves on the lee side.

*ISOPE Member.
Received May 13, 2002; revised manuscript received by the editors December 2, 2002. The original version (prior to the final revised manuscript) was presented at the Eleventh International Offshore and Polar Engineering Conference (ISOPE-2001), Stavanger, Norway, June 17–22, 2001.
KEY WORDS: Nonlinear wave diffraction, horizontal cylinder, wave reflection, desingularised boundary integral equation method.