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Nonlinear Wave Diffraction by Submerged Horizontal Circular Cylinder

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This paper presents an experimental and numerical study of 2-D wave diffraction by a fixed horizontal-axis submerged circular cylinder. The objective of the paper is to report and validate results from the fully nonlinear 2-D boundary-element method code CANAL; to assess the capability of the physical wave flume and the measurement methodology to study this type of problem; and to contribute to the understanding of the wave diffraction by a circular cylinder. Two test cases are presented, both in deep-water conditions. The cylinder axis submergence is $1.5r$ (r is the cylinder radius) for the first case, and $3r$ for the second, the latter corresponding to the experimental study presented in the paper. A discretization convergence evaluation is also presented for the second case. The good agreement between the numerical and the experimental results proves that this numerical model is able to accurately simulate this type of problems. No reflection was noticed on the incident wave side of the cylinder. It was found that nonlinear resonant interactions occur between the fundamental frequency and the harmonics on the transmitted wave side of the cylinder. Free waves were observed on this part of the wave flume.

INTRODUCTION

The interaction between a horizontal submerged cylinder and regular surface waves has been studied analytically, experimentally and numerically by many authors. The great variety of available good- quality studies makes it a good choice for testing numerical codes and experimental techniques.

The study of the interaction between fully submerged bodies and surface waves is of long-standing interest to many offshore engineering applications, namely submerged breakwaters and some wave energy devices. Unlike surface-piercing bodies, which are exposed to extreme forces originated by severe free-surface wave motions, completely submerged bodies may produce the desirable reflective and dissipative properties with less demanding structural designs.

The presence of a submerged obstacle near the free surface may originate a reflected wave and a modified transmitted wave. The properties of the transmitted and the reflected waves are dependent on the relation between the incident wave characteristics (amplitude and frequency) and the obstacle properties (shape, characteristic dimension and submergence depth).

The interaction between gravity monochromatic waves and a fixed submerged horizontal circular cylinder, with its axis parallel to the crests of the incident wave, was first studied by Dean (1948), using a conformal mapping technique and the linear potential wave equation. Dean proved that, to the 1st order, the circular cylinder reflects no wave energy independently of its radius, depth of submergence or frequency. The transmitted waves merely experience a change in phase but not in amplitude. Using a multipole expansion, Ursell (1950) found the complete linear solution and reproduced Dean's conclusions, proving their uniqueness. Ogilvie (1963) (as also Arena, 1999) extended Ursell's method and applied it to fixed and oscillating cylinders, calculating the 1st- and 2nd-order forces on the cylinder.

Chaplin (1984) studied experimentally the nonlinear forces and the nonlinear features of the reflected and transmitted waves originated by a fixed submerged horizontal cylinder. His study revealed nonlinear components of these forces with frequencies up to 3 times the fundamental wave frequency. Chaplin also showed that the reflection is negligible either to the 2nd or 3rd order.

Vada (1987) used an integral-equation method based on Green's theorem to solve the 2nd-order wave-diffraction problem for a submerged cylinder of arbitrary shape. Vada computed the 1st- and 2nd-order force components, transmission and reflection coefficients, directly from 2nd-order potential, for circular and pontoon-like cylinders, and found good agreement with Chaplin's experimental results (1984) and with Ogilvie's results (1963). Vada observed that the magnitude of the 2nd-order reflection coefficient was of the same order as the accuracy in his numerical scheme.

Following Vada's 1987 work, McIver and McIver (1990) proved analytically that the 2nd-order reflection coefficient for a submerged circular cylinder is zero in water of infinite depth, for all incoming wave frequencies. In a concurrent numerical work, Wu (1991) concluded the same.

For monochromatic incident waves and infinite water depth, Palm (1991) showed analytically there is no reflection of order m, and frequency mf (m integer), from a fixed submerged circular

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