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Effects of Wave Directionality on the In-Line Loading of a Vertical Cylinder

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ABSTRACT

This paper presents results from an experimental investigation into the loading on a rigid vertical circular cylinder in irregular unidirectional and multidirectional waves in water of uniform depth. The ambient flow at the location of the cylinder was measured directly using perforated-ball velocity meters (PVMs), in order to avoid uncertainties associated with the use of wave theories. Reynolds numbers were in the range of 10^4 to 7×10^4, and Keulegan-Carpenter numbers ranged from 0 to 16. In-line Morison coefficients and root-mean-square force coefficients are estimated from the loading measured on force sleeves at three elevations along the length of the cylinder. Results are presented for the probability distributions of forces and peak forces, and for Morison and rms force coefficients. Effects of wave directionality are compared with Dean's analytical predictions.

INTRODUCTION

Wave force predictions on slender rigid cylinders are traditionally based on data from tests in unidirectional waves. It seems likely that this procedure is conservative for real offshore conditions where waves are multidirectional or short-crested. However, there is little evidence on which to assess the margins of error; previous measurements in multidirectional waves have concentrated on extreme waves or on the inertia regime. Very little information is available on the effect of directionality on the loading when both drag and inertia forces are important. Some results are given by Aage (1990) for the total loading on a vertical cylinder, showing a reduction in the in-line loading of about 15%, for a spreading function derived from North Sea measurements.

This paper describes laboratory measurements of both sectional and total forces on a vertical circular cylinder in multidirectional waves. The experiments were conducted at the Hydraulics Laboratory of the National Research Council of Canada (NRC) and are described in full by Irani et al. (1992). Initial results from these tests were given by Chaplin et al. (1992), considering only measurements made in unidirectional regular and irregular waves.

Throughout the test program particular emphasis was placed on obtaining good-quality measurements of particle kinematics at the cylinder's location, with the purpose of avoiding uncertainties associated with the estimation of particle kinematics from wave theories. Measurements were made in unidirectional waves, and in multidirectional waves having a $\cos^{2s}$ spreading function with indices $s = 8$ and 2. Keulegan-Carpenter and Reynolds numbers are in the range of 0 to16, and 10^4 to 7×10^4 respectively.

EXPERIMENTAL SETUP

The experiments were carried out in the multidirectional wave basin of NRC's Hydraulics Laboratory in Ottawa. The basin is 50 m long and 30 m wide and is equipped with a segmented wave machine (Miles et al., 1986) comprising 60 independent units each 0.5 m wide and 2.1 m high. The present experiments were conducted in a mean water depth of 2 m.

Test Cylinder

The general arrangement of the 100-mm-diameter cylinder is shown in Fig. 1. The cylinder is made of stainless steel and incorporates 10 instrumented force sleeves along its length. The force sleeves are 50 mm long, and flush with the external surface. The entire cylinder was covered by a very thin latex tubing, tightly stretched along its length, to prevent water flowing through the 0.5 mm gaps at the ends of the force sleeves. The cylinder was filled with water, to minimize pressure differences across the latex tubing.

The cylinder was mounted near the center of the wave basin, at a distance of 11.2 m from the wave board. It was supported on a system of load cells to provide measurements of the total in-line and transverse forces on the entire cylinder.

The natural frequency of an individual force sleeve vibrating in water on its internal support was above 50 Hz, and the fundamental frequency of the whole cylinder oscillating in water was about 12.4 Hz. The agreement between the total in-line and transverse forces measured directly from the load cells and the total forces obtained by integrating the loads on the force sleeves was very good (Chaplin et al., 1992).

Particle Velocity and Surface Elevation Measurements

Force coefficients presented in this paper were obtained from velocity measurements made with perforated-ball velocity meters (PVMs). Each PVM comprises two perforated, hollow, plastic balls mounted on strain gauged cantilevers. The 0.038-m-diameter balls were mounted in orthogonal pairs with the supporting arms at 45° to the vertical. From measurements of four components of force on a pair of perforated balls, all three components of velocity can be deduced. The PVMs were calibrated on a two-dimensional carriage system, and in a wave flume with reference to a Laser Doppler Anemometer. The instrument and its development are described in detail by Chaplin and Subbiah (1994).

Water surface elevations were measured using capacitive-wire

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