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Three-Dimensional Effects on Hydrodynamic Forces Acting on an Oscillating Finite-Length Circular Cylinder

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ABSTRACT

We experimentally investigated the hydrodynamic forces acting on finite-length circular cylinders in an oscillating flow. Forced surging tests were carried out on cylinders whose ratio of length to diameter varied from 1 to 10. The drag coefficients, the added mass coefficients and the lift coefficients obtained were compared with those of a 2-D circular cylinder and a finite-length circular cylinder with end plates. Flow fields around the circular cylinders were also studied using the hydrogen bubble technique.

NOMENCLATURE

A	: projected area of cylinder
A_n, B_n	: nth-terms of Fourier expansions
C_A	: added mass coefficient
C_D	: drag coefficient
C_L	: lift coefficient
D	: diameter of cylinder
F_{exp}	: measured in-line force acting on cylinder
F_L	: lift force
F_{Lm}	: maximum value of lift force
K_C	: Keulegan-Carpenter number
L	: length of cylinder
M	: mass of cylinder
R_e	: Reynolds number
T_y	: period of forced surging test
Y_a	: amplitude of forced surging test
ν	: kinetic viscosity
ρ	: water density
ω	: circular frequency
∇	: volume of cylinder

INTRODUCTION

Ocean structures are usually made of circular cylinders because they have been proven able to withstand high pressure and have nondirectional hydrodynamic coefficients. Research on the hydrodynamic forces acting on a circular cylinder is therefore critical in the design of an ocean structure, and how these forces act on 2-D circular cylinders in a steady or oscillating flow has been the subject of many investigations (Sarpkaya, 1977; Koterayama, 1984; Bird et al., 1986; Koterayama et al., 1988; and Low et al., 1989). Columns and braces are finite-length circular cylinders, however, and data are also required on the hydrodynamic forces acting on these types of cylinders.

Okamoto et al. (1973) measured the longitudinal distribution of hydrodynamic forces acting on a finite-length circular cylinder in a steady flow, and discussed the 3-D effect on hydrodynamic coefficients. Ayoub et al. (1982) measured the spectra of surface-pressure fluctuations at points longitudinally distributed on this type of circular cylinder in a steady flow, and Zdravkovich et al. (1989) measured drag forces acting on a cylinder which had two free ends. These studies were all carried out in a steady flow, but there have been few reports of work in an oscillating flow. This knowledge is very important for a basic understanding of how wave forces act on an ocean structure. Although Kato et al. (1989) recently researched 3-D effects on hydrodynamic forces acting on a 2-D circular cylinder in an oscillating flow using forced oscillating tests, to the authors' knowledge, how these forces affect finite-length circular cylinders in this type of flow has not been reported.

In forced surging tests, we obtained the hydrodynamic coefficients of finite-length circular cylinders in an oscillating flow with various ratios of length to diameter and visualized the flow fields around the cylinders using the hydrogen bubble technique.

MODEL AND EXPERIMENTAL METHOD

The experimental setup is shown in Fig. 1, and five circular cylinder models are shown in Fig. 2; they are made of stainless steel and the surface is very smooth. Models (A), (B) and (C) are finite-length circular cylinders whose length-diameter ratios L/D are 1, 3, and 10, respectively. Model (D) has a dummy model at the upper end in order to diminish the end effects and to remove the effect of wave-making forces on the model; the L/D is 20. The test model and the dynamometer are connected by a pipe installed inside the dummy model; the dummy model is not connected with the dynamometer, which allows the hydrodynamic forces acting on the test model to be measured directly by the dynamometer. Model (D) may be assumed to be a 2-D circular

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KEY WORDS: 3-D effect, finite-length circular cylinder, drag coefficient, added mass coefficient, lift coefficient, flow visualization.