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Wave Forces on Horizontal Cylinders at Low Keulegan-Carpenter and Reynolds Numbers

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ABSTRACT

Hydrodynamic forces on a horizontal cylinder with a circular and elongated rectangular cross-section in regular waves are studied experimentally and numerically. In the laboratory experiment, the cylinder is fixed beneath the waves with its axis parallel to the wave crests. The kinematics of the wave flow are determined from the linear wave theory using the measured wave height and period. The experiment is conducted for low Keulegan-Carpenter numbers and relatively low Reynolds numbers (KC<6 and 10,000<Re<30,000). In addition, we present a numerical simulation method for a two-dimensional flow around a cylinder undergoing orbital motion in still water. Experimental results on the horizontal cylinder in regular waves show that the trend of both drag and inertia coefficients is quite different from that obtained from a planar oscillatory flow test or results for a vertical cylinder. From the numerical simulation it is found that separation of the boundary layer begins at about KC = 1.5 for a circular cylinder in orbital motion, much smaller than that in planar oscillation. For the elongated rectangular cylinder, the force coefficients are much more complicated than for the circular cylinder because the flow always separates. It is found that the forces on an elongated rectangular cylinder fixed in waves are generally much larger than that when harmonically oscillating in still water at the same KC and Re numbers.

INTRODUCTION

Water particles of deep water waves are almost circular, and the velocity vector rotates one cycle in each wave period. The orbital motion about a vertical cylinder can be simulated in a planar oscillatory flow by the combination of the normal flow to the cylinder axis and tangential to it, and the resulting wave forces are roughly the same as those by a planar oscillatory flow. However, for a horizontal cylinder beneath regular waves with its axis parallel to the wave crests, as the flow rotates around the cylinder, the wave force is different from that in a planar oscillatory flow.

A few experimental studies are available about wave forces acting on horizontal cylinders; these forces may be important in some applications. For example, a semisubmersible usually consists of several very large, elongated, rectangular, lower hull structures and a few small vertical cylinders. A better understanding of these forces is often needed in various marine engineering applications.

The viscous force acting on a fixed cylinder in sinusoidal oscillatory flow can be predicted using the Morison equation (Morison et al., 1950) with two empirical coefficients:

$$F=\frac{1}{2}\rho DC_D U|U|+\frac{1}{4}\rho\pi D^2 C_M\frac{dU}{dt} \quad (1)$$

where F is the force per unit length; U, the incident flow velocity taken at the section center; D, the diameter of the cylinder; ρ, the density of the fluid; C_D, the drag coefficient; and C_M, the inertia coefficient; and dU/dt the fluid acceleration.

Extensive laboratory experiments have been made with oscillatory plane flows around a fixed cylinder or a cylinder oscillating in still water (Sarpkaya and Isaacson, 1981) to study the coefficients C_D and C_M. It is shown that the two empirical coefficients depend on the Keulegan-Carpenter number K_C and the Reynolds number R_e. For a fixed vertical cylinder or a horizontal cylinder in shallow waves, the Morison equation has been modified so as to predict viscous wave forces with a certain engineering accuracy (Demirbilek et al., 1987). This equation can also be used to predict wave forces on a horizontal cylinder submerged in deep waves, provided the two empirical coefficients are specified.

Koterayama et al. (1978) measured the wave forces acting on a horizontal circular cylinder in regular waves at large K_C number range. Chaplin (1984a, 1984b) studied the same problem for small K_C numbers and found that a reduction of the wave force is caused by the nonlinear effect of the oscillatory boundary layer due to viscosity. Ikeda et al. (1988) experimentally studied wave forces acting on a horizontal cylinder and showed that another contribution to the reduction of the wave force probably comes from the rotating vortex. This paper reports the results of a laboratory experiment and a numerical simulation on horizontal cylinders in regular waves.

The laboratory experiment was conducted in a wave tank, and the wave forces acting on a fixed horizontal cylinder submerged in regular waves were measured. For comparison, forced oscillation tests were also made on a horizontal cylinder in still water. Two cross-sections, a circular and an elongated rectangular, were considered. The horizontal cylinder tested was large, and the K_C number small. This experiment represents low K_C and relatively low R_e values (K_C<6 and 10,000<R_e<30,000).

The numerical simulation uses a finite difference method to describe 2-D viscous flow about a fixed horizontal cylinder in waves. The simulated flow patterns are used to find the relation between the vortex-shedding phenomenon and the wave forces and force transfer coefficients.

LABORATORY EXPERIMENT

Laboratory experiments were made with a long horizontal circular and an elongated rectangular cylinder. The experiments

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