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Loading on a Horizontal Cylinder in Irregular Waves at Large Scale

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ABSTRACT

Measurements of forces on a horizontal cylinder submerged with its axis parallel to the crests of irregular waves reveal nonlinearities that cannot be attributed to diffraction or to drag loading. Laboratory experiments were undertaken using a 0.5 m diameter cylinder in waves of significant height, 1.5 m, giving maximum Keulegan Carpenter numbers of about 10. Inertia coefficients derived on a wave-by-wave basis display considerable scatter, but the median value of C_m drops to about unity as K_c approaches 5. There is also a large reduction in the median value of C_m at Keulegan Carpenter numbers below 0.2. These results suggest that the loading on a cylinder in orbital flow at low Keulegan Carpenter numbers is strongly affected by a recirculating current generated by viscosity, and is much influenced by the history of the flow.

INTRODUCTION

There is evidence to suggest that wave loading on a horizontal cylinder is rather more complicated than that on a vertical one. In wave force measurements at large scale, Bearman et al. (1985) showed that Morison's equation, with optimal coefficients, closely followed the measured in-line loading on a vertical cylinder, and that drag and inertia coefficients for regular waves appeared to depend only on the Keulegan Carpenter number. On the other hand, measurements of loading on a horizontal cylinder parallel to the wave crests were found to be in serious disagreement with Morison's equation, and the drag and inertia coefficients were widely scattered, as was found also by Teng and Nath (1985).

One of the important differences between the loading in unidirectional waves on a stationary vertical cylinder and that on a horizontal one is associated with forces induced by vortex shedding. In the first case, vortex shedding forces hardly influence the in-line loading, except in ways which can be represented in terms of drag and inertia components. On the other hand, vortex shedding from a horizontal cylinder in waves (or more generally from one subject to orbital flow in the plane at right angles to its axis) can be expected directly to generate force components collinear with both the incident velocity vector and the incident acceleration vector. These contributions to the loading are not present in any vectorised form of Morison's equation, but represent a substantial part of the total force. In analysing measurements made at small scale with Keulegan Carpenter numbers up to about 2.5, Otsuka et al. (1990) attributed a large reduction in the inertia force to the presence of separated vortices which migrate around the cylinder.

Another distinct feature of the flow around a horizontal cylinder beneath waves is a recirculating current which at low Keulegan Carpenter numbers is generated by nonlinear properties of the boundary layer. This has been studied at small scale (Chaplin, 1984a, 1984b), and also linked with a major reduction in the loading from that predicted on the basis of potential flow. Though the mechanism is not well-understood (and may be closely related in some cases to the presence of separated vortices), it seems likely that the circulating flow creates an asymmetry in the pressure distribution around the cylinder analogous to that produced by the Magnus effect. The direction of the resulting lift is opposite to that of the inertia force; its magnitude, for given orbit ellipticity, is proportional to the cube of the wave height.

This paper analyses measurements of the force generated by long-crested irregular waves on a submerged horizontal circular cylinder whose axis is parallel to the wave crests. The experiments were carried out as part of a series of tests using a 0.5 m diameter cylinder in waves up to 2 m high, at the Delta Flume of the Delft Hydraulics Laboratories. Other parts of the same programme have been reported, among others, by Bearman et al. (1985), Chaplin (1988), and Klopman and Kostense (1990).

The purpose of this paper is to study the irregular wave loading on the horizontal cylinder in the Delta Flume, in the light of earlier work on regular waves. The tests were carried out mostly in conditions usually assumed to be well-represented by ideal fluid flow, and free from effects of diffraction. Nevertheless, both inertia and drag coefficients derived from individual waves show very wide scatter. There is clear evidence that inertia coefficients fall substantially below 2 with increasing Keulegan Carpenter numbers below 5, and that the ideal fluid result $C_m = 2$ leads to a significant overprediction of peak forces.

EXPERIMENTS AND DATA PROCESSING

The experiments were carried out at the Delta Flume of the Delft Hydraulics Laboratories. The experimental arrangements have been described previously in publications concerned with other tests in the same series (Bearman et al., 1985; Chaplin, 1988; Klopman and Kostense, 1989). This section outlines the overall arrangements for measurements on the horizontal cylinder in irregular waves.

The cylinder is sketched in Fig. 1. It had a diameter of 0.5 m, and was provided with two 0.25 m long force sleeves which were mounted internally on strain-gauged flexures. In addition, at one cross-section between the force sleeves, there were 26 flush-mounted surface pressure transducers equally spaced around the cylinder's circumference. In these experiments, the surface of the cylinder was smooth.

The Delta Flume is 230 m long, 5 m wide, and in these tests was operated with a mean water depth of 5 m. It is equipped with a servo-controlled piston type absorbing wavemaker, and at the opposite end, a 1:6 solid concrete beach. The cylinder was mounted

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