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Drag and Inertia Force Coefficients Derived from Field Tests

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ABSTRACT

Field tests were carried out over a two-year period to obtain the drag and inertia coefficients of a surface-piercing vertical cylinder fixed in irregular waves using an ocean research platform. The platform was set 2 km offshore for collection of ocean environmental data on wind, waves and current. The wave forces were measured with two 2-component dynamometers set at either end of the test cylinder: Data on waves were recorded using a wave height meter array, and orbital velocity was also measured with a 3-component electromagnetic current meter to confirm the accuracy of estimated values of orbital velocity calculated from wave data and linear wave theory. The following was found.

(a) the values of C_D and C_M obtained from least squares fit of the complete force time series of a random wave record were well ordered as a function of Keulegan-Carpenter number K_C defined by significant orbital displacement and the diameter of the cylinder, but those determined by the least squares fit on a wave-by-wave basis were widely scattered.

(b) ocean wave force exerted on the cylinder was well represented by Morison's formula; the ratio of predicted wave force by this formula to the directly measured force was 90%, and the ratio was very stable throughout the experiments.

INTRODUCTION

The hydrodynamic forces acting on a cylinder in a harmonically oscillating flow (Keulegan and Carpenter, 1958) or in regular waves (Koterayama, 1979) have been investigated in detail and accurately in various laboratories. But for the design of an ocean structure it is difficult to use these results directly because of the many unknown factors, such as the effects of scale, roughness (Sarpkaya, 1976), current (Moe and Verley, 1980; Koterayama, 1984), random waves (Bostrom and Overvik, 1986), wave spreading (Sarpkaya and Isaacson, 1981) and three-dimensional effects (Nakamura et al., 1991) on the wave force coefficients. A designer needs a robust combination of wave force coefficients and wave force prediction method. The effects of irregularity and spreading of waves should be included in the main frame of the wave force prediction method, and the other factors mentioned above should be taken into consideration when necessary. Wave irregularity and spreading are ever-present, and therefore any wave force prediction method which does not consider them is useless to the designer of an ocean structure. Recent investigations on a means of applying experimental data in a wave force prediction method have indicated that the scattered values of wave force coefficients obtained from field experiments have posed the major problem in the past (Dummer et al., 1986; Wegel and Beebe, 1957).

In the field experiments (Thrasher and Aagaard, 1970; Heideman et al., 1979; Bishop, 1978; Mizuno et al., 1990), the difficulties in measuring accurately time series of forces, waves and the phase difference between them further complicate the problem, so that applicability of the Morison formula is still uncertain.

Field experiments in this study were intended to apply the Morison formula to random and spreading waves and establish coefficients and the prediction method.

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KEY WORDS: Wave forces, drag and inertia coefficients, vertical circular cylinder, field experiments.

FIELD OBSERVATION SYSTEM

The test cylinder is fixed to an ocean research platform set 2 km off the coast, where the water depth is about 15 m. A schematic view of the platform is shown in Fig. 1. The diameter D and the length L of the test cylinder are 0.5 m and 9 m, respectively, and the mean length of the submerged portion is 5.5 m, which varies slightly with the tide. The forces acting on the cylinder are measured by two 2-component dynamometers set at either end of the cylinder. The waves are measured by the wave height meter array, suspended from three legs of the platform. The orbital velocity near the test cylinder is measured by the 3-component electromagnetic current meter to confirm the accuracy of velocity values estimated from a wave height meter data and linear wave theory. These analog data are transformed into digital data with sampling frequencies of 10 Hz and transmitted to the laboratory by a telemeter system. Collection of data is automatic when the significant wave height is greater than 0.5 m.

EQUATIONS

The time series of surface elevation is represented as:

$$\zeta(t)=\sum_{i=1}^{M} a_i \sin(\omega_i t+\varepsilon_i) \tag{1}$$

where ζ is surface elevation, a_i the amplitude of ith component of wave, ω_i the circular frequency of waves, and ε_i the phase.

The orbital velocity $u(z,t)$ and acceleration $\dot{u}(z,t)$ are obtained as follows:

$$u(z,t)=\sum_{i=1}^{M}\left\{-\frac{gk_i}{\omega_i}a_i\frac{\cosh k_i(h-z)}{\cosh k_i h}\sin(\omega_i t+\varepsilon_i)\right\} \tag{2}$$

$$\dot{u}(z,t)=\sum_{i=1}^{M}\left\{-gk_i a_i\frac{\cosh k_i(h-z)}{\cosh k_i h}\cos(\omega_i t+\varepsilon_i)\right\} \tag{3}$$