

# A Study on Random Wave Force Coefficients Using Numerical Simulation of Flow Fields

Changhong Hu and Wataru Koterayama\*  
Kyushu University, Kasuga, Japan

## ABSTRACT

A new approach to investigate the hydrodynamic forces acting on a vertical cylinder in random waves is presented. The time series of random wave force is obtained from numerical simulation of a two-dimensional irregular oscillating flow around a circular cylinder by numerical solution of the incompressible Navier-Stokes equation expressed in a generalized coordinate system through the use of the MAC method. The random waves are chosen from laboratory experimental data. To obtain the Morison force coefficients, two methods are used: least squares fit of total force time series and least squares fit on a wave-by-wave basis. The phenomena found in calculated results are similar to those in the experiments, and the study revealed that the so-called history effect of random wave forces is mainly due to the vortex shedding, which is confirmed by computed flow patterns.

## INTRODUCTION

In order to predict hydrodynamic forces acting on a cylinder in an ocean environment more realistically, the random nature of the waves should be considered, but many researchers consider the Morison equation is still valid for random waves; this equation can be expressed as:

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

where  $F$  is the force per unit length;  $U$ , the instantaneous flow velocity taken at the section center;  $D$ , the diameter of the cylinder;  $\rho$ , the density of the fluid;  $C_D$ , the drag coefficient; and  $C_M$ , the inertia coefficient.

One of the main difficulties in the prediction of random wave forces lies in the estimation of  $C_D$  and  $C_M$  for the Morison equation. It is well-known that for regular waves or sinusoidal flows,  $C_D$  and  $C_M$  generally depend on the characteristics of the flow, such as  $K_C$ , the Keulegan-Carpenter number, and  $R_e$ , the Reynolds number. But for irregular waves the values of  $C_D$  and  $C_M$  that should be used remain quite questionable although the matter has received much attention. Generally methods of analyzing the measured random data can be classified into different groups, depending on whether the basis of analysis is time domain or frequency domain, or whether or not the force coefficients  $C_D$  and  $C_M$  are assumed constant for a particular force record. Isaacson et al. (1991) compared five different methods using a numerically generated random wave and a force record simulated by the Morison equation with constant  $C_D$  and  $C_M$ ; they concluded that the method of least squares fit of the force time series and the so-called wave-by-wave method tend to give an accurate prediction of the Morison force coefficients. Koterayama et al. (1992) investigated the nature of the hydrodynamic forces in a field test using an ocean research platform and in a laboratory

experiment. The force coefficients  $C_D$  and  $C_M$  obtained from least squares fit of the complete force time series are well ordered as a function of significant value of  $K_C$  numbers, while the values determined from least squares fit on a wave-by-wave basis are widely scattered with no apparent meaningful tendency. The authors considered the main reason for the scattered behavior to be a purely hydrodynamic problem rather than the accuracy of force measurement.

The two most common ways to obtain the force of a random wave to study Morison-type wave force prediction models are: laboratory experiments or field tests in an actual sea environment; and numerical simulation of random wave forces using the Morison equation. The field test is close to a real situation but factors of currents, wave breaking, wave directionality, and measurement errors make it difficult to isolate a single wave to study its influence. Even for the laboratory experiment it is difficult to be perfectly free from measurement errors. The second method can avoid these effects, and the force record can be generated under artificial conditions. But as an idealized force record is far different from a real random wave force, the usage of this method is restricted. A new method is described here to obtain a more realistic random wave force record, free from the above-mentioned complex factors.

In this paper, a two-dimensional irregular oscillating flow around a circular cylinder is solved by directly integrating the Navier-Stokes equations in a form using primitive variables, to simulate the hydrodynamic force on a vertical cylinder in random waves. One idea behind this study is that it seems impossible in a laboratory experiment to make a flow-visualization of random waves for in-depth investigation. But this is not difficult by using the technique of numerical simulation of a flow field. The random waves are chosen from experimental work (Koterayama et al., 1992), and the Morison force coefficients are obtained by the least squares fit of the total time series and by wave-by-wave method. Phenomena of the force coefficients similar to those of the experiment are obtained from the calculation, and are discussed using the computed flow patterns.

## NUMERICAL METHOD

The basic equations of a two-dimensional incompressible viscous flow are the equation of continuity and the Navier-Stokes equa-

\*ISOPE Member.

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