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# Viscous Effects in Wave-Body Interaction

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## ABSTRACT

**The laminar flow about a circular cylinder beneath a Stokes waves train is numerically investigated. An efficient grid-free algorithm is developed by coupling an accurate boundary integral equation method for computing the velocity field with a viscous vortex method for solving the Navier-Stokes equations near the body. The problem of generating the incident wave system is effectively circumvented by means of a perturbation formulation which assumes the Stokes wave solution as the base flow. For $\beta \approx 500$ and $Kc$ = O(1) the systematic comparison with the available experimental values for the Fourier components of the loading is presented. An overall good agreement is observed, even for the added inertia coefficient which is known to be largely affected by viscous effects.**

## INTRODUCTION

The flow of an incompressible viscous fluid about a circular cylinder beneath a regular Stokes wave train is a typical problem of marine structures' hydrodynamics. When the relevant wavelengths are comparable with the characteristic dimension of the body, the hydrodynamic loads are quantitatively dominated by the momentum exchange between the wave and the body. Consistently, it is widely accepted that the nonlinear potential flow theory effectively describes the force on the structure. In fact, experimental analysis confirms that the vertical mean value of the hydrodynamic force and of both the second and third harmonics of the fluctuating components are well explained in terms of the inviscid wave diffraction in agreement with the predictions of weakly or fully nonlinear models (Ogilvie, 1963; Vada, 1987; and Liu et al., 1992).

However, the potential theory fails to exhaustively capture the entire phenomenon. Actually, a significant reduction in the amplitude of the fundamental harmonic of the loading is emphasized by Chaplin (1984), with respect to purely inviscid models. This correction exhibits a marked dependance on the Keulegan-Carpenter number $K_c$. When no significant separation occurs, the observed $K_c^3$ behaviour has been ascribed to a Kutta-Joukowsky-like force originating from the streaming flow within the wave-induced boundary layer. If both the wavelength and the submergence are much larger than the radius, the free surface effects can be neglected and the driving field is well approximated through an orbital flow. Concerning this problem, a considerable insight has been gained by Stansby and Smith (1991) and by Chaplin (1993) through the numerical solution of the full Navier-Stokes equations. For a high Reynolds number and small wave amplitude, the major features of the steady state solution of the complete problem have been fully addressed in Yan and Riley (1996) through an elegant perturbation approach.

In order to analyze the phenomenon under more general conditions, i.e., when significant separation occurs, we have to consider the full Navier-Stokes equations for a free surface flow. More specifically, we discuss in detail different solutions for $K_c$ ranging from 0.3 to 1.2 and for a fixed value of the frequency parameter $\beta$ = Re/$K_c$, where Re is the Reynolds number. The value of $\beta$, 9120 in Chaplin's experiments is presently 483 due to limits in the computational resources while our range of the Keulegan-Carpenter number is restricted by the occurrence of wave breaking at $K_c \simeq 1.2$, a value close to the experimental observations. The other relevant parameters, radius-to-wavelength ratio and submergences of the cylinder, are selected to match those considered in Chaplin (1984).

In these conditions, the wave dynamics are essentially nonlinear, owing to the small submergence of the cylinder, and are tightly coupled to the vorticity field. On the other hand, the Reynolds number is large enough to confine the vorticity close to the body and away from the free surface. We have then to consider the fully nonlinear behaviour of the free surface and flow separation near the body, but we may neglect the viscous effects at the interface.

The present approach couples, through a fractional step algorithm, a boundary integral equation method for the free surface (Casciola and Landrini, 1996) with a viscous vortex method for the vorticity (Graziani et al., 1995). A similar numerical procedure has been recently adopted also by Yeung et al. (1996). In

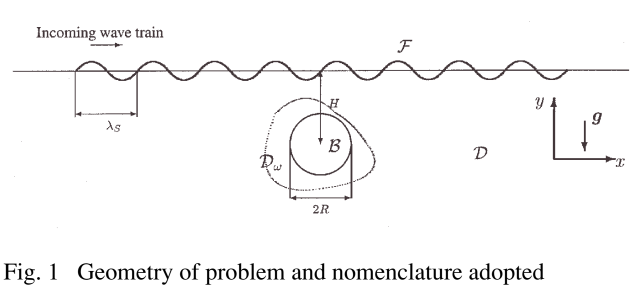

Fig. 1 Geometry of problem and nomenclature adopted

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KEY WORDS: Nonlinear free-surface flows, wave loading, wave-induced vortex shedding, wave diffraction.