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Sway and Roll Hydrodynamics of Cylindrical Sections

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ABSTRACT

The Free-Surface Random-Vortex Method (FSRVM, Yeung, 2002) is applied to investigate two types of forced motion problems with the effects of viscosity considered. A submerged body undergoing periodic swaying oscillation is considered and compared with the results of the vorticity-diffusion theory of Yeung and Wu (1991), which had the convective terms of the Navier-Stokes equations neglected. A practical shape consisting of a rectangular cylinder with horizontal and vertical keels or baffle-plates is used to study the roll inertia and damping characteristics. Comparison is made with some recent experimental results to illustrate the efficacy and accuracy of the theory.

INTRODUCTION

With an increase in the variety of design solutions for offshore drilling and operation systems, such as FPSO, truss-spar systems and multi-hull support, among other unconventional shapes, it is helpful to have available a scientifically rational and fast method with which to estimate and evaluate the hydrodynamic characteristics of these systems. Hydrodynamic properties affect exciting wave loads, stability and amplitude of motion response, structural integrity, and safety and hazards of operations. In this paper, we have undertaken a special study of the application of a recently developed viscous-flow computational method to two specific problems related to cylindrical sections. The method of analysis called the Free-Surface Random-Vortex Method (FSRVM) was outlined in Yeung et al. (1998) with an overview of its wide-ranging capabilities given in Yeung's review article (2002). This integral equation-based method can merge inviscid-fluid modeling with the solution of the Navier-Stokes equation. This is a considerable improvement over the solution of the linearized Navier-Stokes flow developed in the '90s by Yeung and Wu (1991). This work provided the necessary Green-function expressions for viscous flow by neglecting the convective terms in the Navier-Stokes equations, yet allowing the inclusion of free-surface effects. This was essentially a free-surface vorticity-diffusion theory, which marked the beginning of the many recent efforts to model viscous effects on free-surface flows. In this paper, after providing a short exposition of the key FSRVM elements, we discuss first a comparison of the fully nonlinear results from this more powerful formulation with those from Yeung and Wu for a submerged, swaying circular cylinder. The second investigation concerns a surface-piercing rectangular cylinder with bilge keels that has been studied extensively by Yeung et al. (2000). However, Na et al. (2002) recently presented some experimental data of the same section with several different bilge-keel configurations for Hyundai's FPSO designs. Our computations for the prescribed roll motion of this cylinder are shown for two keel geometries and compared with these published data. Na et al. omitted measuring the change of the added mass moment of the inertia of roll, which is essential in determining the roll resonance period. Na et al. were apparently unaware of the effects of viscosity on the added moment of inertia, as reported in Yeung et al. (1998). Our computations were found to be in good agreement with Na's measurements of damping coefficients. Recently, Yuck et al. (2003) computed roll damping using a separate viscous code and added onto it the the inviscid wave damping. This ad-hoc procedure cannot be justified since siginificant separation changes the "effective shape" of the body (Yeung et al., 1998).

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KEY WORDS: Roll damping, roll RAO, FPSO, wave-induced motion, bilge keels, motion attenuation, hydrodynamic coefficients.

METHODOLOGY

The method used to simulate the two-dimensional prescribed body motion is the FSRVM, developed originally by Yeung and Vaidhyanathan (1994). The FSRVM has been successfully validated against the experimental results of a "rolling-plate" geometry (Yeung and Cermelli, 1998) as well as of rolling rectangular cylinders (Yeung et al., 1998). The FSRVM is essentially a boundary element method (BEM) using a vorticity and stream-function formulation. It also models nonlinear wave-body interactions with the inclusion of viscous effects. The solution is obtained by decomposing the flow field into an irrotational component and a vortical component. The irrotational component of the flow is solved using a complex-variable boundary integral method, based upon the instantaneous geometry of the computational domain and the associated vorticity field. The latter is subsequently solved using a random vortex method (RVM) first proposed by Chorin (1973). In this method, the vorticity field is represented by a large number of vortex blobs that are initially generated to satisfy the no-slip condition on the body. The blobs are subsequently convected away from the body by the solution of the irrotational field and an additional random diffusion component, from which the method derives its name. At each time step, hydrodynamic forces on the body are calculated from the total solution.

Governing Equations and Boundary Conditions

The governing equations for a 2-D, incompressible and viscous fluid are:

$$\frac{D\xi}{Dt} = \nu \nabla^2 \xi \tag{1}$$

$$\nabla^2 \psi = -\xi \tag{2}$$