International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 19, No. 1, March 2009, pp. 46–51

Roll Response of Various Hull Sectional Shapes Using a Navier-Stokes Solver

Yi-Hsiang Yu and Spyros A. Kinnas
Department of Civil, Architectural, and Environmental Engineering,
The University of Texas at Austin, Austin, Texas, USA

A finite volume method-based Navier-Stokes solver is developed for the prediction of the flow around hull sections in roll motion. The corresponding hydrodynamic loads on the hull are determined, and the results are compared with published experimental data. The present method is applied to several hull shapes subject to prescribed roll motions or in transient roll-decay motions. It is found that, due to the effects of viscosity, the results are nonlinear with roll angle, even for small angles. From the analyzed hull geometries, the one with 4% bilge keels was found to be the most effective in reducing roll motions.

INTRODUCTION

Ship-shaped hulls have often been found to be subject to excessive roll motions, which inhibit their use as a stable and uninterrupted production platform. Bilge keels have been used widely as an effective and economic way of mitigating roll motions over a large range of frequencies. The performance of a hull subject to roll motions is measured, conventionally, in terms of hydrodynamic added-mass and damping coefficients. Vugts (1968) was the first to measure and calculate the hydrodynamic coefficients on hull sections (without bilge keels) in roll motion, and to point out the importance of the effects of viscosity. The estimation of these coefficients through various numerical methods and validation through experiments has been the focus of research over the years (Na et al., 2002; Wilson et al., 2006; Yeung et al., 1998; Yeung et al., 2000). Yuck et al. (2003) investigated experimentally the prediction of the damping coefficient on a nonconventional hull section, where they found that the roll damping could change significantly due to hull geometry.

A 2-dimensional Navier-Stokes solver (NS2D) was developed by the Ocean Engineering Group (OEG) of the University of Texas at Austin based on Choi (2000), Choi and Kinnas (2001, 2003), and Kinnas et al. (2003). NS2D was then extended to predict the flow around ship-shaped hull sections and the corresponding hydrodynamic loads, with an emphasis on roll. A step-by-step approach was followed towards this goal by initially performing NS2D simulations for moderate roll angles and for hulls with or without bilge keels (Kinnas et al., 2006, 2007; Yu et al., 2005), where the results from NS2D were correlated with published experimental data and the results from other numerical methods (Vugts, 1968; Yeung et al., 1998, 2000). Vinayan et al. (2005) applied a Mixed Euler-Lagrange approach-based Boundary Element Method (BEM) solver, also developed by OEG, to model the ship motion problem in potential flow, and they studied the nonlinear free-surface effect on the corresponding hydrodynamic loads under large roll angle amplitude. The BEM solver was used as a verification tool of the results from the *inviscid version* of the NS2D solver, and for the free-surface calculation, in the context of nonlinear theory, in Kinnas et al. (2006, 2007) and Yu and Kinnas (2008). The effect of turbulence was found to be small when predicting the hydrodynamic loads in problems involving roll motions of ship-shaped hulls (Yu, 2008; Yu and Kinnas, 2008), as also mentioned in Wilson et al. (2006).

This paper focuses on the prediction of the effects of the hull section geometry and of the roll angle amplitude on the hull response in prescribed roll or in transient roll-decay motion, by using the present Navier-Stokes solver. The predicted moment histories and corresponding hydrodynamic loads from NS2D are presented. In the study, 4 different hull model geometries are analyzed, and the maximum amplitude of the roll motion is set to 20°.

METHODOLOGY

This section presents the governing equations and the numerical scheme. The Finite Volume Method (FVM) is applied on collocated grids and combined with a pressure-correction scheme (SIMPLEC). The hull motions, the geometries of the analyzed hull sections, and the grid resolutions are also provided in this section. The detailed formulations along with several verification and validation studies are given in Yu (2008).

Governing Equations and Numerical Formulations

The discrete representation of the continuity equation and the conservative form of the Navier-Stokes equations are given as:

$$\begin{gathered}\sum_{\partial\forall}\rho(\vec{U}_f\cdot\vec{n})A_f=0,\\ \frac{\partial\vec{U}_P}{\partial t}\forall+\sum_{\partial\forall}\left[v_n\vec{U}_f-\nu\left(\frac{\partial\vec{U}}{\partial n}\right)_f\right]A_f=-\frac{1}{\rho}\sum_{\partial\forall}p_f\vec{n}A_f,\end{gathered}\tag{1}$$

where $\forall$ represents the cell area; $\partial\forall$ denotes the boundary of the cell, and v_n is the normal velocity on the cell face; $\partial/\partial n$ indicates the derivative with respect to the normal direction of the cell face; and $\vec{n}$ is the unit normal vector to the cell side. Subscripts "P" and "f" represent the values located at the cell center and at the midpoint of the cell face, and A_f is the length of the cell side. $\vec{U}=(u,v)$ represents the total flow velocity vector with respect to the inertial coordinate system with (u,v) being the 2 velocity components, respectively; ρ represents density, p denotes the hydrodynamic pressure, t indicates time, and ν represents the kinematic viscosity.

Received April 4, 2008; revised manuscript received by the editors November 18, 2008. The original version (prior to the final revised manuscript) was presented at the Eighteenth International Offshore and Polar Engineering Conference (ISOPE-2008), Vancouver, July 6–11, 2008.
KEY WORDS: Bilge keels, ship-shaped hulls, FPSO, roll, Navier-Stokes equations, finite volume method (FVM).