International Journal of Offshore and Polar Engineering
Vol. 10, No. 4, December 2000 (ISSN 1053-5381)

Wave-Induced Motion of Floating Cylinders Fitted with Bilge Keels

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ABSTRACT

The effects of small bilge keels fitted at the corners of a rectangular cylinder are investigated experimentally and computationally. The freely floating cylinder is subjected to incident beam waves. As fluid viscosity affects the motion of the cylinder, a prediction of the motion response requires the solution of the Navier-Stokes equations with additional complexities coming from free-surface effects and free-body motion. The fully nonlinear problem is solved by using the Free-Surface Random-Vortex Method (Yeung and Vaidhyanathan, 1994), with recent extensions to include the effects of free-body motion (Yeung and Liao, 1999). Frequency-domain response in waves is obtained by simulating this 3DOF system in the time domain over a range of frequency. Comparison with experiments is seen to be rather satisfactory. Both experiments and time-domain solutions indicate a strong drift velocity, which is relatively insensitive to the presence or size of the keels, but dependent on the wave frequency. As expected, the keels are found to be effective in reducing the resonant modes of motion, heave and roll, near their respective resonant response peaks.

INTRODUCTION

Time-domain solutions are desirable when large-amplitude motion of bodies is of concern. For motions such as roll and sway, influenced substantially by viscous effects, time-domain formulation is the only logical approach. Within the context of potential-flow theory, Maskell and Ursell (1970) were one of the first workers to examine the time-dependent problem. Since then, various inviscid models have been developed and presented in Chapman (1979), Yeung (1982), Newman (1985), and more recently Celebi and Beck (1997) and Bingham et al. (1994) for freely floating bodies, either in the transient state or subjected to some excitation.

Inviscid models tend to overpredict body response in waves, especially for certain ranges of frequency (see e.g., Downie et al., 1990; Yeung and Ananthakrishnan, 1992). This can be improved by introducing artificial or empirical damping terms. Such effects were studied by Himeno (1981), and applications can be found in Cointe et al. (1990), Tanizawa (1990) and Sen (1993). This approach is, however, not entirely based on rational mechanics.

An efficient grid-free method, the FSRVM (Free-Surface Random-Vortex Method), was developed to model viscous free-surface flow (Yeung and Vaidhyanathan, 1994). Its successful applications have been made to forced oscillation of cylinders (Yeung and Vaidhyanathan, 1994; Yeung et al. 1998), substantiated by flow visualizations (Yeung et al. 1996) and experiments (Yeung et al. 1996; Yeung and Cermelli, 1998). The FSRVM, referred to as "code," has been recently extended by Yeung and Liao (1999) to simulate response of cylinders in waves. The fluid and body-motion coupling algorithm can be treated in a manner similar to Vinje and Brevig (1980). However, the code contains realistic physical effects arising from flow separation, which is a part of the solution process.

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Received May 25, 2000; revised manuscript received by the editors October 9, 2000. The original version (prior to the final revised manuscript) was presented at the Tenth International Offshore and Polar Engineering Conference (ISOPE-2000), Seattle, USA, May 28-June 2, 2000.
KEY WORDS: Navier-Stokes solver, FSRVM, vortex methods, ship motion, roll damping, bilge keels, separated flow, drift velocity.

This paper takes such motion-response studies one step further by considering the possible presence of bilge keels. It is well known that bilge keels reduce roll motion, a highly viscous and nonlinear behavior, which we endeavor to model and study here both experimentally and numerically. To validate the theoretical calculations, a set of experiments is designed and conducted at the Ship-Model Testing Facility of the University of California at Berkeley. A cylinder restricted in lateral motions is placed across a wave tank with incident waves. The cylinder responds in sway, heave and roll. Inviscid theoretical results are obtained by shutting off the fluid viscosity in the code, thus allowing the effects of viscosity to be assessed.

EXPERIMENTAL SETUP

A schematic for the experimental setup is shown in Fig. 1. A 2.4 x 0.3 x 0.3-m rectangular acrylic cylinder shown in Fig. 3 is constrained in lateral motions by steel horizontal guides. It is free to respond in sway, heave and roll. The model is geometrically similar to the one used in the numerical computations and the bilge radius $r = 6.35 \times 10^{-3}$ m. was determined accordingly. Heave rods are mounted at both ends of the cylinder. Roll bearings at the base of the heave rods allow roll motions up to 35° from the vertical position. At no point in any runs did that limitation become problematic. Both heave rods slide vertically into an aluminum bracket that we will refer to as a slider, allowing an unrestricted heave motion. These two sliders (one on each side of the tank) are mounted on a pair of horizontal rods that run along the length of the tank. Low-friction precision roller bearings allow the sliders to move horizontally in sway (or drift), restraining lateral motions towards the tank walls. The length of the heave rods and the water level were determined such that the cylinder would not touch the horizontal rods on a wave crest, nor will the heave rods fall off the slider on a trough. The wave tank is equipped with a flap-type wavemaker powered by a hydraulic cylinder that can accept an arbitrary function of voltage as input. A ramped sinusoidal input was used, with the ramp function being a full hyperbolic tangent function that starts from zero and approaches unity within the first 2 periods of oscillations.

Accelerations in sway, heave and roll of the cylinder were measured by 2 linear and 1 angular accelerometers placed on the axis of the cylinder at the calm-water level (Fig. 1). These readings are