International Journal of Offshore and Polar Engineering
Vol. 13, No. 3, September 2003 (ISSN 1053-5381)

A Study on Roll Damping of 2-D Cylinders

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ABSTRACT

In this paper, the roll damping for a nonconventional cross-section, referred to as the step model, is investigated numerically and experimentally. The step model may be adopted as cross-sections along the parallel middle body of offshore floating structures such as a ship-based Floating Production and Storage Offloading vessel (FPSO). In order to validate the present approach, a typical cross-section with bilge is considered, and our results are compared with published data. In the case of the step model, it was found that not only the viscous damping component, but also the wave damping component increases considerably compared to the section with bilge.

INTRODUCTION

Operability has become an important issue for floating offshore structures such as a ship-based Floating Production and Storage Offloading vessel (FPSO), drillships and shuttle tankers as they are increasingly being deployed to a sea depth of more than 1,000 m and/or in severe seas. In order to improve these vessels' operability, an accurate motion analysis is necessary, especially in connection to roll motion, as this directly affects stability and operability. In fact, the roll angle of an FPSO is restricted to 5° in order to stay operational. Roll motion has to be controlled in order to reduce down time. An exact estimation of roll damping is of central interest in this analysis, because roll damping is critical to roll motion at resonance. As is well known, a rolling ship exhibits large list near resonance, which may lead to cargo shift, loss of deck cargo, and eventually to final undesirable consequences such as capsizing.

Experimental research on roll damping of 2-D cylinders has been carried out extensively by Vugts (1970) and Ikeda (1977), to name only a few among many others. Vugts measured heave, sway and roll motions of forward, aft and midship sections of a vessel with the free surface, and then analyzed the interaction effects. Ikeda (1976) proposed several useful formulas for roll damping of ships with bilge and also for pressure distributions on ship hulls. Ikeda (1977) and Himeno (1981) divided roll damping into wave-making, frictional and eddy-making components. Taz Ul Mulk and Falzarano (1994) used a frequency-dependent hydrodynamic model and derived linear and nonlinear roll damping empirically. Schmitke (1978) presented a theoretical model in order to predict vessel motions in oblique seas and compared the relative magnitude among roll components. Yeung (1998, 1999) solved the flow generated by roll motion by using the FSRVM (Free Surface Random Vortex Method). He was able to prove that the added roll moment could be reduced significantly by the viscous effect. Ikeda and Chaplin (1999) provide a comprehensive overview of this topic.

In this work, the viscous damping is determined on the one hand by using the available viscous code, in which the fluid domain is taken as unbounded—i.e., as a state without free-surface effect—and on the other hand, by separately using a well-established potential code. The numerical results were compared with experiments. Three types of models—bilge model, box model and step model—were considered. In this work, the main focus is on the examination of roll damping for the step model, adapted only recently for the midship section of offshore vessels.

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Received August 5, 2002. Revised manuscript received by the editors July 3, 2003. The original version was submitted directly to the Journal.
KEY WORDS: Roll damping coefficient, 2-D cylinder, step section, forced oscillation test, potential and viscous computations.

EXPERIMENT

Roll Equation

For small roll angles, the uncoupled roll motion of a 2-D cylinder can be described by:

$$(I+a_{44})\ddot{\phi}+b_{44}\dot{\phi}+c_{44}\phi = Me^{i(\omega t-\varepsilon)}, \tag{1}$$

where a_{44} is the added moment of inertia, and b_{44} is the roll damping coefficient, M the amplitude of the forced moment, and ε the phase difference between the roll angle and the forced moment.

Substituting $\phi=\phi_a e^{i\omega t}$ into Eq. 1 and taking the imaginary part, we have:

$$b_{44} = -\frac{M\sin\varepsilon}{\omega\phi_a}, \tag{2}$$

where ϕ_a is the roll angle.

Only the damping force remains at resonance ($\varepsilon = 90°$) as shown in Eq. 2, because the inertia moment cancels out the restoring moment. The roll damping coefficient can then be determined by measuring the forced moment (M) at resonance, which in turn is dependent on the floater's GM. This is the length between the