



eddy, wave, lift and bilge keel. Most modern potential flow ship motions simulation tools use this method to predict the roll motion. However, Ikeda's method is typically only valid for smaller roll motions which were only performed for roll amplitudes up to 10 degrees, and later extended to 15 degrees, where linearization is applicable. Although these limitations were acknowledged in the development of the models, the method has a few weaknesses and overestimates the results at larger roll amplitudes. The developments in CFD and experimental flow measurements have been beneficial to study these weaknesses and limitations.

Since the roll damping is dominated by vorticity, CFD based Unsteady RANS solvers have the potential to produce superior roll damping predictions compared to existing methods since the effects due to viscosity, creation of vorticity in the boundary layer, vortex shedding, and turbulence are naturally included in the calculations. The advantages, such as low cost and fast computational time compared to experiments, lead researchers to use CFD for the estimation of roll damping.

Yeung & Ananthkrishnan [5] were perhaps the first to attempt to capture the flow attributes through the application of URANS techniques, and their efforts have set the direction for further studies in this area. URANS-equation methods have been used to study the flow around two-dimensional oscillating cylinders (Korpus & Falzarano, [6]; Yeung, et al., [7]; Sarkar & Vassalos, [8]). Bassler [9] investigated the hydrodynamics of large amplitude ship roll motion as components of the added inertia and damping based on the results of forced roll test and CFD. It was shown that the effects of the hull geometry, bilge keel geometry, deck edge and the free surface all affect the hydrodynamic components during large amplitude roll motions. Avalos, et al. [10] developed a 2D,

incompressible Navier-Stokes solver to simulate free roll decay of FPSO with and without bilge keels. The simulations were compared with the experiments carried out by Oliviera and Fernandes [11]. It was observed that the vortex size and hence roll damping depends on the amplitude on roll motion and the width of bilge keel. Van Kampen [12] showed a practical method to evaluate the roll damping and motions of an FPSO with aberrant bilge keels and/or riser balconies in waves by using a commercial CFD code and the numerical results were used to modify traditional Ikeda's method. Irkal, et al., [13] carried out numerical simulations using the RANSE solver FLOW-3D to obtain the best configuration of the bilge keel for use in reducing the roll motion. The velocity and vorticity patterns around the bilge keel obtained from numerical simulations and validated with PIV measurements. Yıldız, et al., [14] showed the shallow draft effect on roll damping by using URANS method and validated the results with experiments. They also showed why Ikeda's estimation method overestimates the roll damping values at shallow draft.

Although there have been many studies on roll damping estimation by using experiments or CFD methods, there is still a critical need for development of methods for predicting large amplitude roll damping of ships with appendages. In this study, the effect of large amplitude roll motion on roll damping is investigated by using a commercial CFD code. Also the roll damping coefficients are calculated by using Ikeda's estimation method. The vorticity generation around the hull is visualized by using numerical solver. The effect of vortex shedding and free surface interaction is investigated at different roll amplitudes. It is observed that the roll damping is decreased when the bilge keel interacts with the free surface. Ikeda's method does not consider the















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