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

Vol. 31, No. 2, June 2021, pp. 199–209; https://doi.org/10.17736/ijope.2021.ak41
http://www.isope.org/publications

Comparative Study on Eddy Roll Damping with Experimental Results Using a High-order Fractional Step Finite Volume Solver

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This paper studies eddy roll damping numerically by using our developed high-order fractional step finite volume solver, where a fourth-order compact scheme and a fractional step method along with an explicit fourth-order Runge–Kutta scheme are employed to discretize the spatial and instantaneous terms of Navier–Stokes equations. Harmonic excited rolls are simulated for the seven ship sections of a classical experiment conducted by Ikeda, Himeno, and Tanaka in 1977. The roles of roll amplitude and circular frequency are investigated. For comparison, the simulations are accorded with the experiment. It is found that the calculated roll damping tallies well with the experimental results. For eddy roll moment, the phase is insensitive to circular frequency, but for total roll moment, the phase presents a visible shift against roll amplitude. The eddy damping moment is proportional to the square of the product of roll amplitude and circular frequency, consistent with that drawn in the experiment. Besides, features of dynamic pressure and vorticity contours are explored, corroborating that flow separation is indeed the effect of an adverse pressure gradient over the ship hull.

INTRODUCTION

Flow separation from a rolling hull as a result of a great adverse pressure gradient and fluid viscosity will cause vortices to detach from the ship hull, which raises a lot of difficulties in the calculation of roll damping. Eddy roll damping component, for example, accounts for a crucial role because of the intricate behaviors of the detached vortices; therefore, further studies should be pursued.

In Ikeda et al. (1978), roll damping of a naked hull with zero forward speed was separated into friction, wave, and eddy components. Among them, friction component is a result of viscous shear stress on the ship hull, and it can be successfully predicted by laminar boundary layer theory. Wave component stems from the distribution of dynamic pressure on the ship hull owing to the evolution of a free surface, and it is capable of being simulated by potential flow theory. As for eddy component, it is hinged on the distribution of dynamic pressure on the ship's hull, and it is normally regarded as a nonlinear effect because of flow separation and vortices detached from the hull. Thereby, eddy roll damping is difficult to predict, and it is worthwhile to research it.

Ikeda et al. (1977) realized early the importance of eddy roll damping, but because at that time computational fluid dynamics (CFD) was immature, experimental investigations into flow visualization, pressure, and force measurements were feasible choices to investigate it. On the basis of eddy roll damping from experiments, they reckoned that the eddy damping moment is proportional to the square of the product of roll amplitude and circular frequency. They introduced a dimensionless quantity, the eddy damping coefficient C_R, which is irrelevant to roll amplitude and circular frequency any more, and is determined only by the shape of the ship's hull. After careful observation of flow fields, they found that the location of vortex detachment from the ship's hull is dominantly related to two geometric features—that is, a half beam-draft ratio and an area coefficient of the ship's section—and pressure attenuates linearly from the detachment point around the ship's bilge. In this way, pressure distribution over the ship's hull is determined by the location of detachment and the endpoint where pressure is prescribed; thereby, the empirical formula for eddy roll damping was derived.

Himeno (1981) systematically reviewed the derivation of empirical formula for each damping component. He pointed out that separation of roll damping into different components is not strictly based on a hydrodynamic point of view but on the convenience of practice in the prediction of roll damping and implementation of experiments.

After the establishment of the empirical method, a numerical approach—namely, the embedded vortex approach—emerges. Braathen and Faltinsen (1988) applied a vortex tracking method to study the characteristics of vortices shed from a two-dimensional rectangular cylinder undergoing harmonic rolls. The effect of free surface waves was incorporated, and viscous roll damping was accounted for by an empirical formula. They found that roll damping as a result of eddy and wave making cannot be separated in a simple way.

Ikeda (2018) pointed out that a deep understanding on vortex characteristics around a rolling hull can be reached by using the CFD method. Entering the 21st century, along with the rapid development of computing technology, the CFD approach has become mainstream in roll simulation. Sarkar and Vassalos (2000) applied COMET to model the velocity vectors and hydrostatic pressures in the vicinity of a rectangular cylinder undergoing harmonic roll motions. Later, Chen et al. (2002) applied a chimera Reynolds-averaged Navier–Stokes (RANS) method to simulate the velocity vectors and dynamic pressure contours around a harmonic rolling ship with fine resolution. Then, Kinnas et al. (2007) presented the dynamic pressure distribution over a floating production storage and offloading (FPSO) hull attached with bilge keel in harmonic roll by means of a Navier–Stokes two-dimensional (NS2D) solver. Yu and Kinnas (2009) employed this NS2D solver further to model the separated flows around various ship sections subject to harmonic roll and free roll decay motions. Later, Jaouen et al. (2011) analyzed the dynamic pressure and vorticity contours around a harmonic rolling body with

Received September 9, 2020; revised manuscript received by the editors November 16, 2020. The original version was submitted directly to the Journal.
KEY WORDS: Eddy roll damping, harmonic roll, dynamic pressure, vorticity contours, high-order fractional step finite volume solver.