Hydrodynamic Investigation of Two-Dimensional Ship Section with Bilge-Boxes

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Introduction

Roll motion is considered as one of the most difficult responses to be mathematically treated, this is due to the importance of the viscous effects. Several parameters may affect the roll motion hydrodynamically, as shown by Ommani et al. (2015) among others. Hence, tedious parameter study needs to be involved when predicting the roll motion.

Model the problem with "full" Navier-Stokes methods are still considered less effective when doing the design-loop, the approaches carry large computational cost even for two-dimensional case. For the conventional ship hull shape, potential-flow solver with the semi-empirical formula correction that based on the extensive investigations mainly by Ikeda et al. (1976, 1977a,b) has been widely adopted by the industry. The unconventional hull shape, on the other hand, one needs to rely with the model test and/or numerical modeling.

Another candidate is to combine Potential and Navier-Stokes methods, Potential Viscous Code (PVC) (see Kristiansen and Faltinsen (2012)), which simplified the computation and reduce the simulation time greatly. Tailor made of PVC for roll motion, PVC2D-Roll, has been under the series of validation study of ship roll motion (see Ommani et al. (2015, 2016b,a)) , and will be continued in the present study by comparing with the model tests.

Limitations and Objectives

The study is limited to the two-dimensional body in still water, without forward speed, wind and current. The motivation of using two-dimensional case is for having detailed and controlled observation of physics and the possibility to extend the study into three-dimensional case in the future.

The objectives of present study are:
1. Literature study for an overview of previous numerical and experimental studies related to the ship roll motion, and the relevant mathematical model
2. Construct and perform forced roll motion model test
3. Perform the numerical study using PVC2D-Roll
4. Numerical and experimental parameter study with the emphasize on the effect of varying forcing amplitudes and periods, and also bilge boxes length
5. Analyze the obtained forces experienced by the bilge boxes

Model Particulars

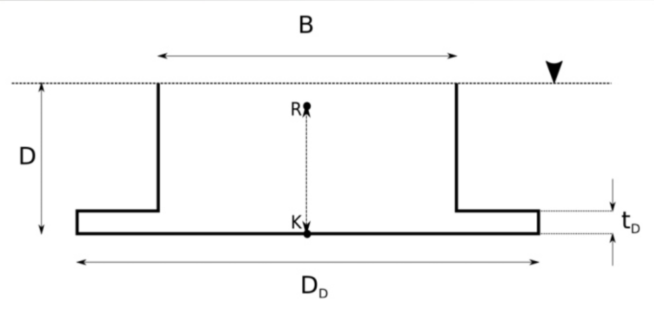

Fig. 1: Description of the model main particulars

Table 1: Non-dimensionalized particulars of the model that used in the present study

Parameters (Non-dimensionalized)	BB1	BB2	BB3
Breadth (B/B)		1.00	
Draught (D/B)		0.32	
Keel-to-centre of rotation (KR/B)		0.2912	
Disk thickness (t_D/B)		0.056	
Disk diameter (D_D/B)	1.20	1.30	1.40
Section area (A/(BD))	1.035	1.0525	1.07

Mathematical Model

The pure forced-roll motion in calm water can be represented by :

$$I_4 + A_{44}\ddot{\eta}_4 + B_{44}(\dot{\eta}_4) + C_{44}\eta_4 = F_4 \quad \text{with} \quad B_{44}(\dot{\eta}_4) = B_1\dot{\eta}_4 + B_2\dot{\eta}_4|\dot{\eta}_4| + B_3\dot{\eta}_4{}^2 + \dots$$

The nonlinear damping term can be equivalently stated as:

$$B_e = B_1 + \frac{8}{3\pi}\omega\eta_{4a}B_2 + \frac{3}{4}\omega^2\eta_{4a}^2 B_3$$

which is a function of roll amplitude and period.

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Experimental Setup

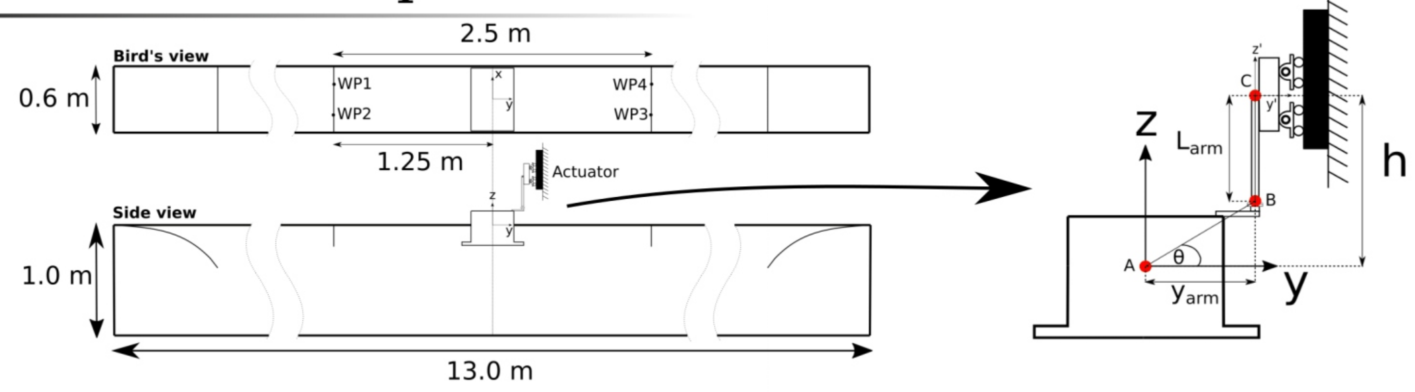

Fig. 2: Illustration of the forced-oscillation model test setup in Ladertanken

Model tests took place in Ladertanken laboratory, Norwegian University of Science and Technology. Forced-roll oscillation model tests are useful for quantification the hydrodynamic features of roll motion based on linear equation of motion. Two accelerometers were used to measure the motion, and one strain gauges for acquiring the total force applied to make the model rotates. In addition, eight strain gauges were installed in the bilge-boxes. Four wave gauges were placed 1.25 m from the model to obtain the radiated waves from the oscillation.

Numerical Implementation

PVC2D-Roll

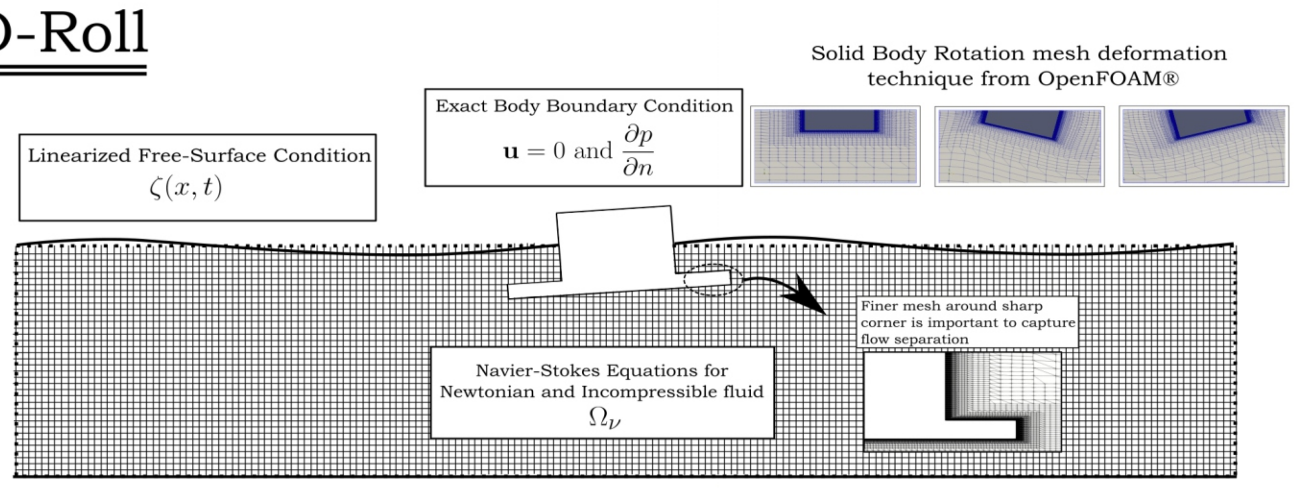

Fig. 3: Overview of the physical assumptions that implemented in the numerical model

Results

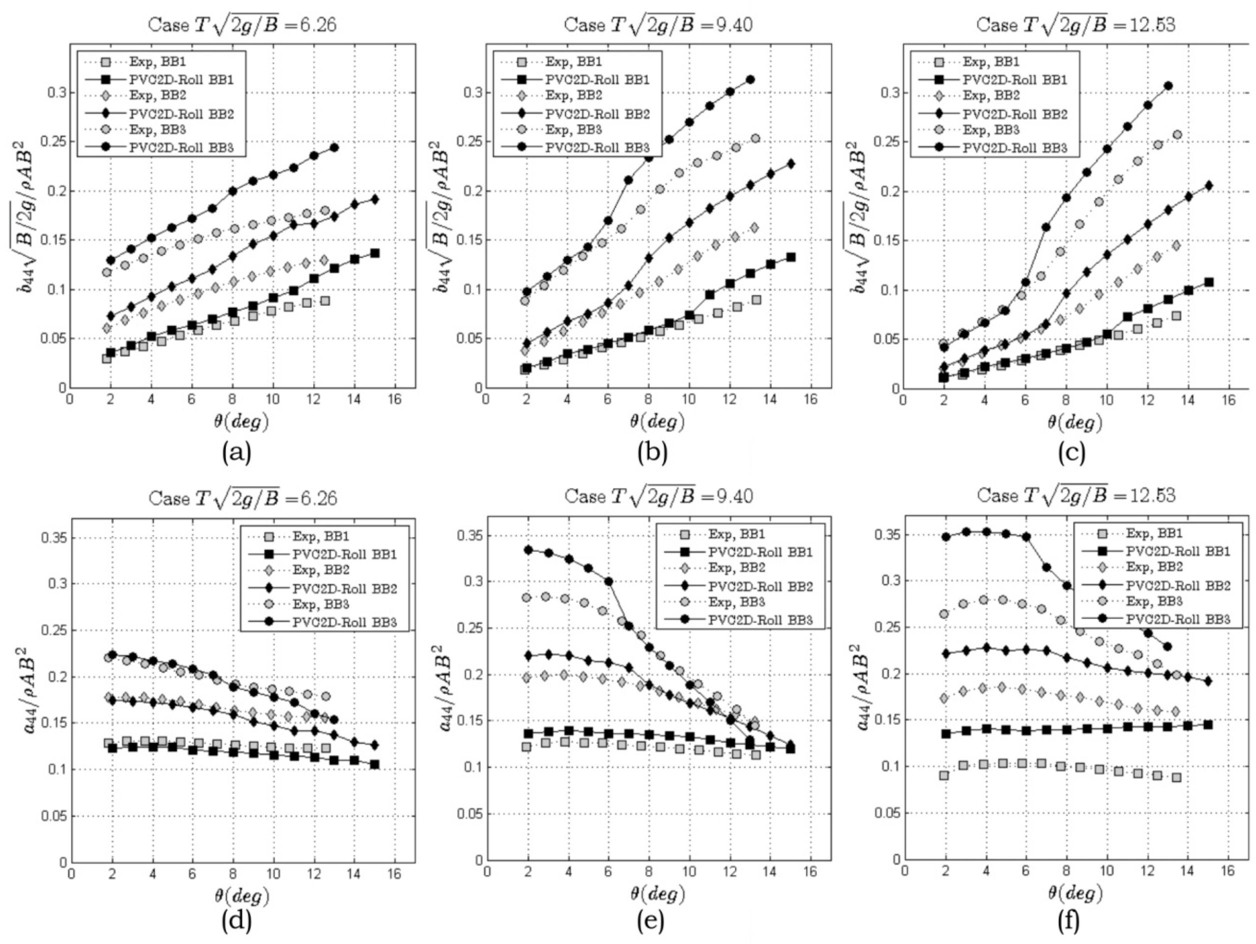

Fig. 4: Comparison of extracted hydrodynamic coefficients from both of model test and CFD. (a),(b) and (c) are the damping coefficients of BB1, BB2 and BB3 with respect to amplitudes and periods. On the other hand, (d), (e) and (f) are for the added-mass coefficients.

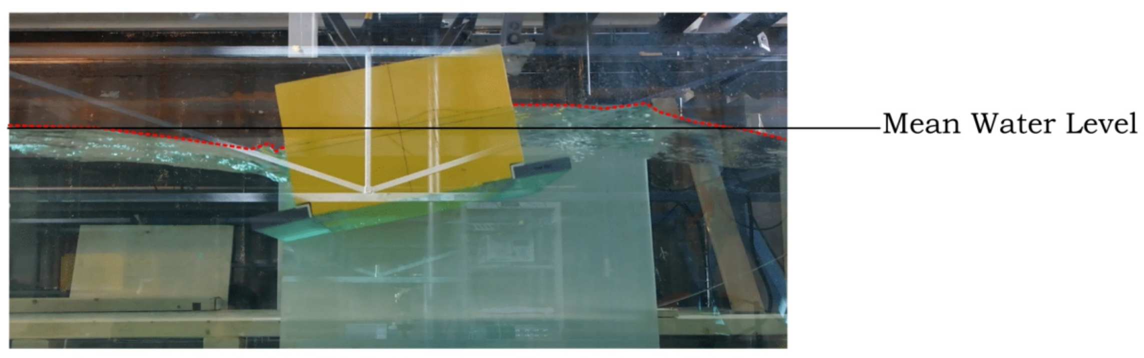

Fig. 5: Example of condition where the potential free-surface condition is not applicable to model the case. Free-surface is attracted and disturbed by the present of sufficiently large bilge-boxes.

Preliminary Conclusions and Recommendations

1. Fig. 4 (a), (b) and (c) show damping coefficient dependency on roll amplitude, period and bilge-boxes length. Damping coefficients with respect to roll amplitude for the smallest bilge-boxes BB1 tend to show quadratic behavior. When the bilge-boxes length increases, the behavior is not quadratic anymore.

2. Fig 4 (d), (e) and (f) show that added-mass coefficients for BB1 are approximately independent of roll amplitude, while this does not hold true especially for the largest bilge-boxes BB3. Some significant changes are visible on (e) but tend to be independent of roll amplitude again on (f). The results suggest to use nonlinear mathematical model of added mass for sufficiently long bilge-boxes.

3. Damping coefficients are in agreement with the PVC2D-Roll only for some extent. It is believed that for larger roll amplitude, velocity and bilge boxes, the free-surface linear condition is not sufficient (see Fig. 5). Modeling the free-surface with Volume of Fluid (VOF) method is preferred for the future study. The discrepancies on added-mass coefficients on fig. 4 (f) are still investigated.