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Investigation of hydroelastic effect in analysis of high-speed craft

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Hydroelastic effect in bottom slamming problem of high-speed craft is one of the most challenging issues in structural design. In this paper, numerical method is used to investigate the hydroelastic effect in bottom-water impact analysis of high-speed monohull craft. Slamming with two viewpoints of rigid and elastic structures (hydroelastic effect) is modelled by coupled computational fluid dynamic (CFD) and finite element method (FEM) techniques. The results showed that considering hydroelastic effect, especially in high-impact speed, reduces the structural deformations and stresses compared with quasi-statistic analysis. The effect of different parameters, such as boundary condition, plate properties, wedge deadrise angle, and impact velocity in slamming problem, was investigated. The results for aluminium and steel plate with the same bending strength showed that dynamic characteristic of plate material is a major parameter in hydroelastic analysis result. Finally, a simplified method is used to apply the effect of hydroelasticity in bottom plate design. This work is hoped to advance the hydroelastic analysis art in bottom structural design of high-speed monohull craft.

Keywords: slamming; hydroelasticity; fluid-structure interaction; ship structure

1. Introduction

Bottom slamming occurs when emerged bottom of a vessel re-enters the water surface (Bertram 2000). Bottom structure in local analysis due to this load is mainly investigated by two methods. In the first method, hydrodynamic loads are calculated by modelling the impact of rigid structure with water surface and within the next step, bottom structure is analysed using calculated pressures. In the second method, hydroelasticity effect is considered in the slamming model. The term of hydroelasticity refers to considering the mutual effects of water and structure on each other in all fluid-structure interaction problems. The hydrodynamic and structural damping, the effect of plate deformation on hydrodynamic pressure, and dynamic analysis of plate are the main considerations of hydroelastic model. The optimum structure of high-speed craft must not only have sufficient strength to resist rough operational condition in sea, but be enough light weighted to reach the desired vessel's maximum speed. The bottom slamming prominently occurs in high-speed crafts, hence the structural analysis of this load plays an important role in design of these vessels. Local bottom slamming in high-speed monohall crafts is a challenging sample of hydroelasticity. Modelling water surface, turbulence effect, water jet around the body, pressure change, and besides these items structural deformation by the minute increases the analysis complexity.

The study of slamming-induced local stresses in the steel and aluminium wetdeck of a multihull vessel by Faltinsen et al. (1997) showed that these stresses are strongly influenced by dynamic hydroelastic effects. Furthermore, Faltinsen (1999, 2000) developed experimental, analytical, and numerical methods to study the effect of hydroelasticity in slamming and concluded that maximum pressure cannot be used to estimate the maximum slamming-induced stresses as the dynamic hydroelastic effects pledge to play a significant role when the maximum pressure is large. The significance of hydroelasticity increases with the (1) reduction of deadrise angle, (2) increase of impact velocity, and (3) value of the highest local natural period of the structure. The latter was also mentioned by Maki et al. (2011). The ratio between the impact duration and the period of the first vibration mode of dry structure can be used as a key factor in making decision, when the hydroelasticity effects should be considered in slamming analysis (Bereznitski 2001). But in case of low deadrise angle and high-impact speed, more than one mode shape is subject to structural deformation (Panciroli et al. 2012).

The solution stability in explicit finite element (FE)-modelling of rigid body–water interaction is highly dependent on the mesh-density/contact-stiffness relation. As a too low contact stiffness may cause incorrect physically fluid leakage, and a too high contact stiffness may result in

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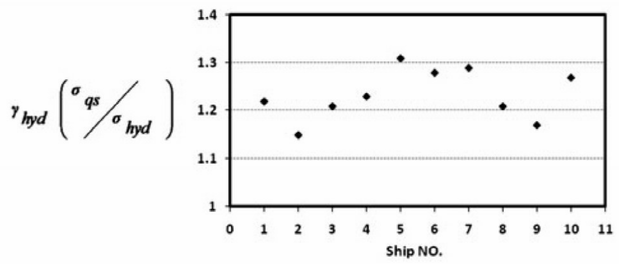

Figure 12. Hydroelasticity factor for 10 various high-speed crafts which were designed by DNV and KR equations.

changing vessel characteristics like impact pressure, plate thickness, spacing between longitudinal stiffeners and girders cause the differences, but the coefficients are in a same range. The average value of hydroelasticity factor, according to the results is 1.23. By applying the calculated factor in DNV and KR equations, the bottom thickness shows reduction by 10%.

5. Conclusions

In this study, the bottom slamming of high-speed crafts regarding the hydroelasticity effect was studied by numerical method. Comprehensive analysis on the results of quasi-static and hydroelastic analysis such as deformations, pressures, and stresses were carried out. The two models had slight differences in pressures, but the dissimilarities in deformations and stresses were more significant. During slamming, the maximum difference between quasi-static and hydroelastic happened at the moments of observing the maximum pressure (complete wetting moment). Also, it was clear that the effect of hydroelasticity increases at higher impact speeds, small impact angles, and reduction of plate's fixity. In case of quasi-static analysis with same bending stiffness and loading conditions of proposed model, the results were the same for the steel and aluminium plates, while the effect of dynamic material characteristics was quite evident in hydroelastic analysis. The dynamic material characteristic plays an important role in slamming problem and can be only experienced in the hydroelastic model.

The hydroelastic effect was evaluated through a typical high-speed craft design. This effect was applied in design using the hydroelasticity factor, which is the ratio of maximum quasi-static stress to hydroelastic stress. The hydroelastic effect was investigated for 10 high-speed crafts and the average value of hydroelasticity factor was calculated in these vessels to apply the hydroelastic effect in the bottom plate thickness equation. This ratio reduces the bottom plate thickness by 10% in DNV and KR equations for monohull high-speed crafts. Additional researches following this study are required. First, experimental tests should be conducted to evaluate plate behaviour during the impact, especially for investigating the effect of dynamic material characteristic. Second, the proposed approach for applying hydroelasticity in bottom plate thickness design should be studied in full-scale model and trial measurements.

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