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Whipping response analysis by one way fluid structure interaction—A case study

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ABSTRACT

Accurate prediction of whipping induced hull girder response is important for evaluation of hull girder stresses and fatigue life assessment of ships structure. Traditionally, strip theories and panel methods have been popularly used for seakeeping analyses of ships for evaluating the slamming loads. These loads are used for whipping response prediction by idealizing the ship's hull as a free–free beam. In the present work, numerical seakeeping computations have been performed assuming ship's hull as a rigid beam. Wave loads thus computed are applied on to the real flexible structure of the ship to obtain the bending moment response amidships. For this purpose, modal superposition technique is utilized. Interaction of fluid (water) with structure (ship) is accounted only once, i.e. while computing fluid forces the structure is considered as rigid. Whipping response is hence obtained considering one way Fluid Structure Interaction (FSI). The obtained peak values are quite close to the experimental values. It is concluded that added mass effect and damping due to the degree of coupling between fluid and structure plays a vital role in whipping response prediction. The present method being computationally efficient and reasonably accurate can be practically used for whipping response predictions at initial design stage.

1. Introduction

The structural analysis of ship hull girder is popularly performed considering it to be a beam. For dynamic analysis, the mass of the hull and additional mass due to the presence of surrounding fluid, also known as added mass is taken into account (Mukhopadhyay, 1989). Gu et al. (1989) presented a time domain formulation of hydrodynamic loading considering the nonlinear effect for a slender ship. Hydro-elasticity phenomenon was considered and the ship was represented by a Timoshenko beam. Destuynder and Fabre (2009) discussed detailed mathematical modeling of springing, whipping and slamming for ships. Complexity of the problem with respect to interaction of structure with fluid was outlined. Whipping response analysis studies of ships are reported in Lin et al. (1997), and Park et al. (2003, 2005). The slamming response can be analyzed considering vibration of an elastic beam subjected to pure impulse loading. The calculated sectional forces (static part) at a given beam cross section can be superimposed on to the sectional forces due to regular wave at various frequencies. In general, whipping response can be calculated using numerical integration in time domain or mode superposition (ABS, 2010; LR, 2015). For large deformation the geometric and material nonlinearities need to be considered necessitating use of non-linear solution methods. The mode superposition is applied, assuming small deformation response so that the modal responses are independent of each other. The elastic degrees of freedom in terms of the added-mass of water over the ship's hull should be accounted, which corresponds to results from "Wet modes" (Paik, 2010). Fluid structure interaction by accounting for added mass effects in transient dynamic slamming response is described briefly by Thomas et al. (2003).

Paik et al. (2009) described three approaches for whipping analysis. The simplest approach assumed rigid-body motion, in which stress and bending moments were computed by the integration of hull surface pressure forces. An enhanced approach (second method) was to compute forces based on rigid-body motion with computational fluid dynamics (CFD), and then use these forces on the beam model considering added mass to predict flexural responses. Based upon the deformations of the hull, the computed pressures were not updated iteratively, thus making it a one-way interaction. In one-way coupling the modal analysis for the structure needs to account for the effects of the added-mass force due to the elastic degrees of freedom. Specific to a surface vessel, it is necessary to account for the added mass of the water

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due to the elastic vibrations, and this is especially important when slamming occurs. The most advanced approach (the third method) was to compute the flow field and elastic deformations in a two-way coupled manner, where the surface pressures and the structural deformations were obtained iteratively after convergence at each time step.

Hirdaris et al. (2014) reviewed hydroelasticity methods in detail. Current research works on slamming loads, experimental hydroelasticity and full scale measurements were covered in this review. Understanding hydroelastic response of ships is very important for structural design verification. The 3D hydroelastic theories are presently under development. CFD based approaches are being followed by various researchers. Limitations of CFD are computational efficiency and capturing free surface flows. With the increase in computational efficiency and advancements in various free surface capturing techniques CFD based methods appeared promising and encouraging for further investigation. Also the need for availability of quality benchmark data is emphasized in this paper. Such data typically for global loads from model tests is very much required. Full scale measurements provide most robust form of validation in terms of reality but such data is very limited.

Hirdaris et al. (2010) outlined the overview of the various studies of hydroelasticity. Hydroelastic predictions with model tests as well as full scale measurements and software development for the same are detailed. Authors have described hydroelasticity theory in two- and three-dimensional form. The two-dimensional analysis consists of beam structural idealization and strip theory for the fluid forces and fluid structure interactions whereas in three dimensional FE analysis structural idealization combined with source distribution over the mean wetted surface is used for the detailed design. In case of Full scale measurement contribution of the hull flexibility to cumulative fatigue damage index has been studied on board ship by actual measurement of data and good agreement between hydroelastic prediction and measurement was found.

The present paper is based on the one way FSI approach for obtaining whipping response of a vessel. The objective is to evaluate the vertical bending moment (BM) response due to whipping amidships. The governing vibration mode on vessel is the vertical two node hull girder vibration mode, which is associated with the lowest natural frequency in most cases. The two node vibration mode is most easily excited and usually gives the largest vibration bending moment amidships (Det Norske Veritas (DNV), 2013). Hence two-node vertical vibration wet mode is considered for calibrating added mass in the initial stage, i.e. fine tuning natural frequency of the FE model with the experimental data in the present study.

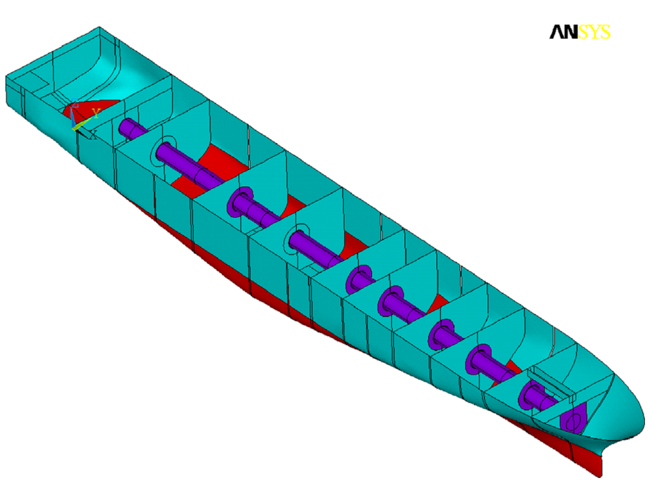

Fig. 1. 3D view of segmented backbone model.

2. Case study

Benchmark study on slamming and whipping was performed by ISSC 2012 Dynamic Response committee II.2, detailed results were published by Drummen and Holtmann (2014). From the comparison of results of the analyses by various participants of this benchmark study it was concluded that more sophisticated methods are required for evaluating response induced due to whipping phenomenon. More complex methods require detailed modeling to be performed. This may introduce additional uncertainties which may finally yield inappropriate results. The benchmark studies concluded upon the need to validate and gain experience using dedicated tools to minimize the uncertainties related with hydroelastic modeling assumptions during ship design. In the present paper benchmark data (Drummen and Holtmann, 2014) has been used for FSI, i.e. hydroelastic simulations.

Segmented model of 173 m long ferry vessel with a scale ratio of 1:36 is considered for the work presented in this paper (Fig. 1). Model particulars of vessel are given in Table 1. Various inputs used in the case study are given in Table 2.Numerical simulations for wave load computations are performed using CFD solver StarCCM+ based on Reynold's Averaged Navier Stoke's Equation (RANSE). Structural solution is obtained using finite element (FE) solver ANSYS. Intermediate computations and the final results are compared with the published experimental results (Drummen and Holtmann, 2014).

3. Methodology

Flowchart of the methodology followed in the present work is shown in Fig. 2.

3.1. Fluid domain computations

3.1.1. Computational domain

The computational domain was modeled using StarCCM+ 7.04 consisting of a rectangular domain with domain extents of 1 ship length forward (Inlet), 2 ship length aft (Outlet), 1 ship length in Port side (Port Wall) and Starboard side (Stbd Wall), 0.75 ship length in top (Top) and 1 ship length in Bottom (Bottom) direction from ship as shown in Fig. 3. 3.7 million trimmed hexahedral grid is generated to model the continuum as shown in Fig. 4. Mesh refinement was carried out near the free surface where in volumetric block is modeled to capture free surface (Fig. 5).

3.1.2. Wave generation and boundary conditions

A first-order head sea wave with wave frequency and wave amplitude as given in Table 2 was used for numerical simulation. A total of 40 grid points per wavelength and 20 grid points per wave amplitude were provided near the free surface in order to capture wave in accordance with ITTC (2011). An inlet boundary condition is defined at inlet, bottom and sides of the tank where the first order wave is defined, an opening boundary condition with entrainment pressure set to zero relative pressure is defined at the top, and an opening boundary condition with entrainment pressure set to static pressure of water is defined at the outlet region as shown in Fig. 6. A standard $k-\omega$ based SST turbulence

Table 1
Model particulars.

Length between perpendiculars	4.81 m
Breadth	0.72 m
Depth	0.486 m
Draft	0.175 m
Total mass	320.73 kg