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Effect of bow flare on the vertical ship responses in abnormal waves and extreme seas

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ABSTRACT

Linear to fully body nonlinear numerical methods based on strip theory are used to analyze the vertical responses of a bulk carrier, containership and a passenger ship. The ships are categorized based on their bow flare angles and the effects of the bow flare variation on the vertical responses are investigated numerically. The numerical ship responses in abnormal waves and extreme sea conditions are also compared with the measurements in a wave tank. The linear method, which does not take account of any body nonlinearity, is able to predict the vertical responses of the conventional ships with large block coefficients, like Bulk carriers and tankers, even in extreme sea conditions. However, pronounced bow flare induces strong nonlinearities in the vertical responses in rough seas and the linear or even partially body nonlinear methods are not enough for accurate calculations in those conditions. The extreme loads acting on the ships are also compared with the rule vertical bending moment.

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1. Introduction

Design wave load bending moment, which is an important parameter in the structural designing of the ships, can be calculated using different methods, viz. empirical formula, long term distribution, critical wave sequence (Adegeest et al., 1998) etc., among which the empirical formula given by the classification society remains the simplest. The nonlinearity in the long term distribution of the loads is better handled through direct methods which rely on the numerical methods that can take account of the nonlinear response associated with large amplitude motion. Guedes Soares and Schellin (1996) proposed a method to take account the nonlinearity in the long term distribution. The long term distribution of the design loads is generally calculated from the short term distribution of the loads by fitting a probabilistic model and extrapolating to the life span of the ship. The short term distributions are calculated from the nonlinear simulation in some of the severe and extreme sea states that are identified from the scatter diagram. However, current methodologies do not include the responses in abnormal waves since the probabilistic model do not represent the abnormal waves, (Fonseca and Guedes Soares, 2010). The reports of ship losses which can be attributed to the occurrence of abnormal waves, (Faulkner and Buckley, 1997), show that the ship responses in abnormal waves are indispensable during the design load calculation. Abnormal waves have been measured at different locations in the ocean (Guedes Soares et al., 2003, 2004) and they are generally identified on the basis of their size in relation to the sea state significant wave height (Clauss, 2002; Kharif et al., 2003).

Numerical prediction of ship responses in abnormal waves and extreme seas is an involved task because of the nonlinearity associated with the free surface and geometry of the ship. Geometrical nonlinearity which mainly results from the rapid change in the underwater volume of the bow sections is relatively easier to consider during the seakeeping calculations than the free surface nonlinearity. Many experimental and numerical studies with important conclusions on the effect of geometrical variations of the bow flares on the ship responses were published. Most of them focused on the occurrences and severity of water on deck and its impact on ship responses. However, at least to the authors' knowledge, not many studies were conducted on the vertical responses of ships with different bow flare angles in real sea with abnormal waves.

O'Dea and Walden (1984) systematically analyzed the effect of different bow shapes on the vertical motions and on the frequency of deck wetness. Four variants of the parent bow shape were tested in regular waves of different wave steepness. It was found that the pitch transfer function decreased as the sea severity increased for all the bow shapes and the second and third harmonics of the pitch motion increased for higher wave steepness. There was no clear indication of the effect of bow shape on the vertical

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motion except for the bow acceleration. The bow acceleration was severely distorted due to the presence of higher order harmonics for the bow section with deep knuckle. Watanabe et al. (1989) investigated the influence of the bow flare shape on the motions and wave loads acting on the S-175 container ship using an original bow flare and a modified one with an overhanging bow with pronounced bow flare. It was reported that the pitching is hardly affected by flare form. However, it was found that the bow flare significantly affects the relative motion at the forward perpendicular (FP). The modified hull with increased above water bow flare angle experienced smaller relative motion at the FP. Since the bow flare did not result in a change in the absolute motion but only in the relative motion, it was evident that the difference in the relative motion came from the wave deformation. It was also found that the bow flare shape is connected to the wave loads through various ways. It affects the hull girder bending moment by means of reserve buoyancy and the nonlinear hydrodynamic disturbances generated in the bow region. The first harmonics of the vertical bending moment (VBM) at amidship was found to be little affected by the bow flare shape. However, the mean and 2nd order harmonic values of the VBM were larger for the modified hull. A significant contribution to the asymmetry in the distribution of the vertical bending moment came from the above water hull form, particularly in the bow flare part. Tests were also conducted in irregular waves and conclusions similar to the tests in regular waves were drawn.

Clauss et al. (2010) presented the influence of the bow shape on the loads in high and steep waves for two different ships, a Roll-on/Roll-off (Ro–Ro) vessel with its V-shaped frame design and the bulk carrier with its full bow. The wave height and steepness was selected to obtain wave profiles with different crest/trough asymmetries according to the various gravity water wave theories. Waves were chosen and classified into three groups: linear, Stokes II and Stokes III waves. The results from this analyses shows that vertical bending moment of the Ro–Ro is strongly affected by the steeper waves, while the responses of the bulk carrier responses were almost linear.

The block coefficient of the ships can serve as tool to determine the nonlinear aspects. In general it is known that nonlinear effects are insignificant for ships with large block coefficient ships like the bulk carrier (C_b=0. 82). However, block coefficients represents the geometry of the hull only up to the mean draft whereas the bow flare angles and the overhanging bows becomes an important source of nonlinearity in the large amplitude motions. In general, the asymmetry between the sagging and hogging moment in high seas can be attributed the bow flare angle.

The objective of the present study is to understand the relationship between the hull geometry and the nonlinear effects in the vertical motions and loads in abnormal waves and extreme waves. Several studies were conducted in the past on the effect of bow flare on the motions and vertical bending moment, among which only a few of them deals with ship responses in abnormal waves. However, to the knowledge of the authors, none of them analysed the effect of bow flare on the hydrodynamic coefficients and the radiation forces, in particular, and the dependency of the vertical responses on the radiation forces which in turn depends on the bow flare angle. In this paper, the extreme responses of three ships (bulk carrier, containership and passenger ship), categorized based on their bow flare angle, measured in a wave tank are compared with the numerical results. A detailed study is conducted in order to understand the dependency of the hydrodynamic coefficients and the radiation forces on the hull geometry and the bow flare angle. The experimental results are represented by the acronym ‘Exp’ in the following figures.

The time domain codes proposed by Fonseca and Guedes Soares (1998a, 1998b) and Rajendran et al. (2013, 2014, 2015a) are used for the numerical calculations. The numerical methods were developed in order to facilitate faster computation of extreme statistics of ship responses. The short-term statistics of the vertical response of a cruise ship and a containership in extreme sea conditions were calculated and presented in Rajendran et al. (2013, 2016a, 2016b). Nowadays, high fidelity hydrodynamic numerical methods and techniques, like 3D panel methods, (Kring et al., 1997, Lin et al., 2008; Kim et al., 2011) and computational fluid dynamics (CFD) (Oberhagemann et al., 2012), are extensively used, particularly by the researchers and the classification societies, for the calculation of ship responses. They give promising results for the responses of ships with high Froude number riding over small to moderate waves. The ship responses in extreme seas are highly nonlinear and one of main sources of nonlinearity is associated with the geometry of the ship. This demands re-gridding of the whole domain at each instant of time and re-calculation of the potentials in the aforementioned 3D time domain methods, which is highly time consuming, particularly, when it comes to the calculation of the short-term distribution of loads acting on ships. However, it is easier to accomplish this task using simplified theories like strip theory within the accuracy acceptable for the practical engineering applications.

Fonseca and Guedes Soares (1998a, 1998b) proposed a body nonlinear time domain method based on strip theory. The radiation forces were calculated based on Cummins formulation. The Froude–Krylov and the hydrostatic forces were calculated for the exact wetted surface and the radiation and diffraction forces were linear and calculated for the mean water level. The results from this method will be called as ‘partially body nonlinear’ in the following sections and will be denoted by the acronym ‘TDPNL’ in the following figures. This method has already been applied to analyse the response of ships to normal (Fonseca and Guedes Soares, 2004a, b) and abnormal waves (Guedes Soares et al., 2008), showing good results from comparisons with model tests (Fonseca et al., 2006; Guedes Soares et al., 2006).

Rajendran et al. (2013, 2014, 2015a) further improved the method with a body nonlinear radiation and diffraction forces and systematically validated the numerical method by comparing the ship responses in small amplitude waves with the frequency domain results. A practical engineering approach was followed for the calculation of the radiation and diffraction forces for the exact wetted surface area. This method will be called as ‘fully body nonlinear method’ in the following sections and will be denoted by the acronym ‘TDFNL’ in the following figures. Apart from these two nonlinear methods, the linear results are also presented for the passenger ship which is represented by the acronym’ TDLIN’ in the following figures. It has been known that other physical effects such as slamming, whipping and nonlinear wave propagation are relevant for ships in extreme seas. Slamming is an important phenomenon, which can produce large impact forces for a very short duration and set the ship in vibration, which can lead to whipping. This becomes a matter of utmost concern while considering the elastic behavior of ships. However, in this paper, ship is considered as a rigid body and it was assumed that slamming has little effect on rigid body motions and loads. Nonlinear wave propagation is computationally intensive and beyond the scope of the present study.

2. Theory

2.1. Equation of motion

Two kinds of nonlinear numerical methods are used for the calculation of the ship responses in extreme seas and classified as partially body nonlinear and fully body nonlinear methods. The

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