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Strength assessment of an intact and damaged container ship subjected to asymmetrical bending loadings

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ABSTRACT

The objective of this work is to analyse the effect of structural damage and associated neutral axis translation and rotation of the residual load carrying capacity of a container ship hull subjected to asymmetrical bending loading. The assessment is performed by a finite element analysis (FEA) and a formulation based on the Common Structural Rules (CSR). A container ship is analysed in intact and damaged conditions. The position of the neutral axis of the mid-ship section of the container ship is identified at each load step based on FEA and CSR. An update to the progressive collapse approach stipulated by CSR is proposed and compared with the finite element solution. Finally, some conclusions are presented.

1. Introduction

Ships are subjected to severe very complex loading conditions and due to the complexity of the ship hull structures different failure modes may occur. Among these, the longitudinal strength is identified as the most important governing factor to ensure structural safety.

A method for analysing the ultimate strength of ship hull was firstly suggested by Smith [1] based on the progressive collapse, where the hull girder cross-section is divided into structural components that are composed of plating with their stiffener, assuming that the cross-section remains plane as it is progressively loaded and deformed. The stiffened plates are assumed to follow their stress-strain curve during the applied axial load, accounting for the yielding and post-buckling effect before the ultimate limit state is achieved.

Dow et al. [2] developed an incremental curvature procedure, which allows the derivation of a moment-curvature relationship for a complete hull and this procedure was correlated with experimental data derived from the collapse tests of three box girders and ultimate longitudinal strength test carried out on the destroyer ship. Valsgaard and Steen [3] used a nonlinear super element approach within the framework of a general nonlinear shell program. A comparison between the numerical strength predictions obtained and the test results of a large-scale box girder and VLCC has been carried out. A series of finite element analyses were conducted to simulate the behaviour of tested box girders.

Several damage case scenarios were adopted by different class societies [4,5]. When the damage occurs, the ship strength is reduced, which leads to changes in the ship cross-section structural descriptors. Therefore, as a result of that asymmetrical bending moment, the neutral axis translates and rotates. Predicting the ultimate strength of a ship's hull girder, in damage scenarios and when it is subjected to asymmetrical bending is a very important issue to be analysed. Several research works have been reported dealing

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with the theoretical and experimental aspect of this problem.

Hussein and Guedes Soares [6] have studied the damage and intact ship cases for double hull tankers based on IACS [7] rules. Guedes Soares et al. [8] also evaluated the ability of using simplified methods based on the progressive collapse to predict the ultimate strength of a damaged ship. The results of the approximate methods agreed well with each other for both conditions, damaged and intact. The simplified methods were more conservative than the finite element analysis in hogging while it seems to give a good approximation to the result of sagging with some overestimation.

Yoshikawa et al. [9] studied the damage strength for bulk carriers after the ship grounding using a different approach in that the damage parts were not removed but considered in the load-displacement relation of the damaged panel, independently of the fact that the ultimate strength of the damaged panel is so small when the damage occurs between two neighbouring transverse frames. Kim et al. [10] studied damage cases for several container ships that are of different size, in order to establish a damage index diagram for rapid salvage and escape schemes and Wang et al. [11] have provided a state-of-art research on ship collision and grounding focusing on accident scenarios, evaluation approaches and acceptance criteria.

Ozguc et al. [12] investigated the collision resistance and residual strength of single skin and double skin bulk carriers. The dynamic impact analysis has been conducted to define several damage scenarios. They found that the damage caused by the collision reduces the ship strength, which is governed by the damage location and extent and they also found that the ultimate load carrying capacity in sagging for intact and damage case is considerably less than hogging condition. Fujikubo et al. [13] discussed the influence of the rotation of the neutral axis on the residual strength of bulk carriers and double-hull hankers having collision damages at the side structures. The progressive collapse analysis was applied, applying the Smith's approach for a biaxial bending problem. The reduction of the ultimate strength was investigated for different damage locations and extends. Nam et al. [14] studied the ultimate longitudinal strength of the hull girder of a VLCC considering probabilistic damage extents due to collision and grounding accidents based on IMO Guideline [15]. Damage indices were estimated for all heeling angles due to any possible flooding of compartments from 0° to 180°, including sagging to hogging conditions. The analysis revealed that minimum damage indices show different values according to heeling angles and damage levels.

Several other interesting studies with respect to the residual strength of damaged hulls have been performed in Refs. [16–18] and reliability of damaged ships after collision and grounding in Refs. [19,20]. Recently, very intensive studies have been performed by different authors using box structures that simulate the mid-ship section of ship subjected to different type shape and size of damage, including dents, cracks, corrosion degradation and opening leading to asymmetrical bending loads in Refs. [21–25].

Tekgoz et al. [26] analysed the ultimate load carrying capacity of ship shaped structures subjected to asymmetrical longitudinal bending moments based on FEM and the approach stipulated by CSR. The effect of the shape of initial imperfections and of the shape of the transverse net section on the ultimate strength was evaluated for five different net sections. An update on the existing progressive collapse analysis on the cross-section subjected to asymmetrical bending and a new interaction curve accounting for the asymmetric response of the studied structures are proposed. The triangular net sectional shape showed a better structural capacity than the square shape when the structures are subjected to asymmetrical bending moment in hogging conditions. The net sectional shape sensitivity analysis demonstrated that the minimum ultimate bending moment is achieved at a different heeling angle for the different net sectional shapes.

Tekgoz et al. [27] presented an analysis of the effect of the neutral axis movement, translation and rotation, of the mid-ship section on the ultimate load carrying capacity of an intact container ship subjected to asymmetrical bending moment. It has been found that, for this particular ship, the neutral axis rotation may lead to as much as 10% strength difference as a function of heeling angle. In the hogging condition, the neutral axis translations become negligible whereas it may lead to as far as 17% strength difference in the sagging condition.

Tekgoz et al. [28] studied also the compressive strength of a single hull damaged tanker ship subjected to asymmetrical bending loading. It was concluded that the structural damage leads to the maximum bending capacity shift and reduction as a function of the heeling angle degree. The maximum bending moment occurred for the damage case at around 55 and 65° of the heeling angle in the hogging condition and around 70 and 80° of the heeling angle in the sagging condition, whereas it occur at around 80 and 90° of the heeling angle of the intact structure. In fact, these heeling angles are outside of a normal range of a ship operation and a ship may have those angles only in the process of capsizing. As for the neutral axis rotation was found that the neutral axis rotates in the damaged and intact cases. As the ship heeling increases, it generally gives rise to the neutral axis rotations. In the damaged and also intact structures, the neutral axis rotates in the sagging condition more than in the hogging condition, which may experience as far as 18° of the heeling angle.

Choung et al. [29] studied the residual strength of an asymmetrically damaged tanker considering rotational and translational shifts of the neutral axis plane. A new criterion defined as the force vector equilibrium condition was proposed for defining the translational and rotational location of the neutral axis plane. The force vector equilibrium suggests that the bending moment related force centres above and under the neutral axis in each increment of the curvature, acts on the moment producing shearing plane, which must be perpendicular to the applied external bending moment in both linear and non-linear stages. This in turn leads to the neutral axis rotation changes if not satisfies this criterion and a convergence criterion was developed in order to account for the neutral axis translations and rotations.

However, the proposed method, developed here, suggests that the external bending moment and internally developed bending moment vectors must act on the same plane and both of which act on the cross-sectional principle planes of the ship in each increment of the curvature. In each curvature, the response bending moments are calculated based on their action on the vertical and horizontal principle planes. The integral vector of these bending moments points to the plane on which the external bending moment vector is subjected. This accounts for the neutral axis rotations and for this, a new equilibrium criterion related to the global bending