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Residual ultimate strength of a very large crude carrier considering probabilistic damage extents

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ABSTRACT: *This paper provides the prediction of ultimate longitudinal strengths of the hull girders of a very large crude carrier considering probabilistic damage extent due to collision and grounding accidents based on IMO Guidelines (2003). The probabilistic density functions of damage extent are expressed as a function of non-dimensional damage variables. The accumulated probabilistic levels of 10%, 30%, 50%, and 70% are taken into account for the estimation of damage extent. The ultimate strengths have been calculated using the in-house software called Ultimate Moment Analysis of Damaged Ships which is based on the progressive collapse method, with a new convergence criterion of force vector equilibrium. Damage indices are provided for several probable heeling angles from 0° (sagging) to 180° (hogging) due to collision- and grounding-induced structural failures and consequent flooding of compartments. This paper proves from the residual strength analyses that the second moment of area of a damage section can be a reliable index for the estimation of the residual ultimate strength. A simple polynomial formula is also proposed based on minimum residual ultimate strengths.*

KEY WORDS: Collision; Grounding; Residual ultimate strength; Probabilistic damage extent; Damage index; Moment plane; Neutral axis plane.

INTRODUCTION

Collision and grounding accidents occur at sea in spite of continuous efforts to prevent them. The collision and grounding accidents of liquid cargo tankers such as crude oil carriers and chemical tankers cause the structural damage of ships and pollute the ocean environment. Therefore, regulations for ship structural design against the severe accidents have been developed to reduce ocean pollution and the loss of human safety.

The goal-based standard (GBS) being developed by the international maritime organization (IMO) requires the longitudinal strengths for both intact and damaged ships with major damages due to collision and grounding accidents. The compartments of a ship can be flooded due to the failure of shell plating, forcing the ship to heel at a certain angle. The damaged ship should be able to withstand the heeling without any catastrophic hull girder collapse until it reaches the closest harbor. Therefore, the identification of the residual longitudinal strength is very important.

Many studies have focused on predicting the residual longitudinal strength of damaged vessels. A simple procedure for hull girder strength estimation after collision and grounding damage was proposed by Paik et al. (1998). The procedure is regarded as suitable in the early design stage. Prediction formulas based on the hull girder section modulus were suggested

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for the prediction of the residual longitudinal strengths (Wang et al., 2002). The combined loading effect on the ultimate strengths of a bulk carrier under alternate hold loading conditions using nonlinear FEA was studied by Amlashi and Moan (2008). The ultimate vertical bending moment capacity was studied by nonlinear FEA (Paik et al., 2008). But it should be noted that far too many resources for modeling and computing are required for nonlinear FEA. The idealized structural unit method (ISUM) has been taken as one of the alternative methods. Paik et al. (1996) insisted that ISUM substantially reduces modeling efforts, especially for initial imperfections and residual stresses. The hull girder residual strengths of four double-hulled tankers, three bulkers, and one single hull very large crude carrier (VLCC) with assumed grounding damages were proposed using ISUM (Wang et al. 2000). The iterative-incremental method (IIM) which is also called progressive collapse method (PCM), based on the principles of the Smith method (Smith, 1977), has primarily been applied to estimate the hull girder strengths of intact ships (Gordo and Guedes Soares, 1996; 1997; Gordo et al. 1996; IACS, 2010). Nielsen (1998), Cho and Lee (2005), Smith and Pegg (2003), Fang and Das (2004), Jia and Moan (2009), Khan and Das (2008), and Hussein and Guedes Soares (2009) tried to apply PCM to the asymmetrically-damaged sections, but they failed to provide a relationship between heeling angle (or moment acting plane) and angle of rotated neutral axis. Using PCM, Choung et al. (2012) derived the ultimate hull girder residual strengths of a VLCC in which mechanically perfect convergence criterion for neutral axis rotation was proposed.

For the calculations of the residual ultimate strengths, this paper will basically apply new PCM by Choung et al. (2012). IMO Guidelines (2003) provide probabilistic damage extent of oil tankers to estimate the amount of oil spilled from the 52 collision and 63 grounding accidents of oil tankers, chemical tankers, and ore carriers of 30,000*tons* and above. The probabilistic damage extents are provided in terms of probabilistic density functions (PDFs), which are of form of non-dimensional damage variables. Even though Pedersen and Zhang (2000) pointed out the IMO Guidelines (2003) could underestimate the grounding damage extent of the large-sized vessels, this paper principally introduced non-dimensional damage PDFs by IMO Guidelines (2003).

In this paper, a VLCC designed according to the CSR for Tankers (IACS, 2010) is chosen as a target vessel to calculate the residual longitudinal strengths. Probability levels of 10%, 30%, 50%, and 70% are taken into account for defining the extent of the damage. The residual longitudinal strengths are presented for all possible heeling angles with 15° increments from sagging to hogging conditions.

A NEW PROGRESSIVE COLLAPSE METHOD

The progressive collapse method assumes that a hull girder failure is the result of an inter-frame collapse of the ship structure. The key assumption is based on Navier's hypothesis. In the design calculation of beams, it states that the stress at any point due to bending is assumed to be proportional to its distance from the neutral axis. This implies equivalently that the plane of the cross-section is assumed to remain a plane under continuous curvature or moment increase. A hull girder section is subdivided into small structural units, which are often called stiffened panels and are assumed to behave independently. The neutral axis plane (NAP) of the cross section should be located at an equilibrium position of the axial forces. The total moment resistance of the section is determined by the summation of the unit forces times their perpendicular distance to the neutral axis.

The limit of the classical principle of PCM is that it can't be applied to the asymmetric section, because it is impossible to recognize how much NAP simultaneously rotates and translates during inelastic deformation of the structural units such as yielding and post-buckling. Asymmetry of the section can be easily produced by heeling of the section or collision-induced shell damage. Many researchers have tried to apply classical PCM to the asymmetrically-damaged sections due to collision or groundings. Smith and Pegg (2003) assumed that the angle of NAP was same as the angle of the moment-acting plane. However, it is apparent that even the angle of elastic NAP deviates from the angle of the moment-acting plane. Cho and Lee (2005) assumed that the angle of elastic NAP remained during inelastic deformation. This assumption is also mechanically incomplete.

In order to produce mechanically complete solution, Choung et al. (2012) proposed a new convergence criterion for the angle of NAP rotation with several new definitions of moment planes (MPs) and elastic and inelastic NAPs. Hereafter, this is called INAP.