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Comparative analysis among deterministic and stochastic collision damage models for oil tanker and bulk carrier reliability

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Abstract

The incidence of collision damage models on oil tanker and bulk carrier reliability is investigated considering the IACS deterministic model against GOALDS/IMO database statistics for collision events, substantiating the probabilistic model. Statistical properties of hull girder residual strength are determined by Monte Carlo simulation, based on random generation of damage dimensions and a modified form of incremental-iterative method, to account for neutral axis rotation and equilibrium of horizontal bending moment, due to cross-section asymmetry after collision events. Reliability analysis is performed, to investigate the incidence of collision penetration depth and height statistical properties on hull girder sagging/hogging failure probabilities. Besides, the incidence of corrosion on hull girder residual strength and reliability is also discussed, focussing on gross, hull girder net and local net scantlings, respectively. The ISSC double hull oil tanker and single side bulk carrier, assumed as test cases in the ISSC 2012 report, are taken as reference ships.
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Keywords: Residual strength; Collision damage models; Oil tanker; Bulk carrier; Reliability analysis

1. Introduction

Hull girder residual strength check, following collision or grounding events, is generally based on Rule damage scenarios, providing penetration depths and heights, as a function of ship main dimensions. The first studies on hull girder resistance against collision were carried out at the beginning of the 1980s by Germanischer Lloyd, within the "Tanker Safety" research programme (Egge and Böckenhauer, 1991), funded by the German ministry of research and technology, and devoted to evaluate the absorbed plastic deformation energy in a ship−ship collision. In 1986 GL Rules included for the first time the additional class notation COLL, followed by a number ranging from 1 to 6 and indicating the ratio of deformation energy absorbed during collision by the vessel to the reference value of a similarly sized non-strengthened single side hull (Egge and Böckenhauer, 1991). Some years later, the American Bureau of Shipping published the first guidelines for the assessment of hull girder residual strength of oil tankers (ABS, 1995a) and bulk carriers (ABS, 1995b), following collision or grounding events, with the main aim of avoiding post-accident hull girder collapses, during towing or rescue operations. In the same year, the International Maritime Organization (IMO) provided the first international standard for the evaluation and approval of alternative methods of design and construction of oil tankers, embodied by MEPC.66(37) and, in a revised form, by MEPC.110(49) Resolution (IMO, 1995; IMO, 2003). The basic philosophy of guidelines consists of comparing the oil outflow performances of an alternative tanker design with reference values of a double-hull ship, complying with Regulation 13(F) of Marpol 73/78. In this respect, as calculation of oil outflow

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performances is mainly based on a stochastic approach, devoted to evaluate probabilities of zero, mean and extreme outflows, guidelines provide damage density distributions of transverse penetration, longitudinal/vertical location and extent of collision and grounding events. Hence, in the last decade, following Prestige's accident occurred in 2002, hull girder residual strength became a very popular topic and new strength checks were provided by Det Norske Veritas (DNV, 2011), that introduced the additional class notation CSA-2 for ships complying with enhanced fatigue and ultimate limit state criteria, including residual strength after collision or grounding events. Finally, the IMO Maritime Safety Committee adopted, at the 87th session in May 2010, the resolution MSC.290(87) that partly emended SOLAS requirements for structure, subdivision and stability of oil tankers and bulk carriers of 150 m in length and above, whose building contract is placed on or after 1st July 2016, making mandatory that ships have to be designed and constructed for a specified design life, to be safe and environmentally friendly in both intact and damage conditions, throughout their life. Hence, construction rules for bulk carriers and oil tankers of Classification Societies acting as IMO Recognized Organizations or National Administrations were checked to verify the conformity with the new goal-based ship construction standards for bulk carriers and oil tankers. In this respect, the International Association of Classification Societies (IACS) delivered the Common Packages 1 and 2, comprising various IACS requirements to support the requests from its member societies and embodied in the “Harmonized Common Structural Rules for Bulk Carriers and Oil Tankers” (IACS, 2015a) a mandatory residual strength check criterion for ships with length equal or greater than 150 m.

At the same time, several efforts have been undertaken to harmonize damage stability regulations among different vessel typologies and investigate the impact of a probabilistic approach on safety levels of existing and new ships. In this respect, two EU-funded projects, namely HARDER and GOALDS, were launched in March 2000 and September 2009, as a consortium of 19 and 18 Organizations from industry and academia in Europe, respectively. The main aim of HARDER project was to collect and analyse collision events occurred from 1944 to 1999, updating the IMO database, initially developed for A.265(VIII) Resolution (IMO, 1973). In this respect, based on the newly developed probability distributions of non-dimensional damage location, length, penetration and vertical extent of collision events, new probabilistic damage stability regulations were developed and embodied in SOLAS 2009 (IMO, 2009). Following the main outcomes of HARDER project, the recently launched one, namely GOALDS, rechecked previous results and extended the probabilistic framework of damage stability regulations to grounding events. Particularly, HARDER casualty statistics were updated, including collision and grounding events from 2000 to 2009, mainly based on Lloyd's Register Fairplay database, increasing the overall number of registered accidents up to 1016 collision and 476 grounding events (IMO, 2012). In this respect, the newly performed statistical analyses not only confirmed the main outcomes of HARDER project, but also provided new data on collision and grounding statistical properties for different vessel typologies, namely passenger and ro−ro ships, containerships, general cargo vessels, oil tankers and bulk carriers.

In the same years, due to the growing interest in evaluating ship response in damage conditions, more refined structural models, capable of accurately predicting hull girder sagging/hogging residual strength, following collision or grounding events, were developed by several researchers (Smith and Pegg, 2003; Özgüç and Barltrop, 2008; Choung et al., 2012; Alie et al., 2012; Kim et al., 2013; Choung et al., 2014; Campanile et al., 2015, among others), with the main aim of providing a structural model, based on classical incremental iterative method, but capable of satisfying the horizontal bending moment equilibrium equation, in case of asymmetrically damaged cross-sections. At the same time, hull girder reliability in damage conditions was investigated, focussing on limit state functions after collision events (Fang and Das, 2005), operational conditions and hull girder deterioration (Saydam and Frangopol, 2013), incidence of welding residual stresses and material properties on hull girder reliability (Campanile et al., 2015, 2016a).

Nevertheless, in all cases statistical properties of hull girder residual strength have been determined on the basis of deterministic Rule damage scenarios, neglecting the incidence of damage variability. In this respect, as some concerns arise when applying deterministic damage scenarios to assess the hull girder residual strength statistical properties and perform reliability analysis in damage conditions, the paper provides a comparative analysis among deterministic and stochastic collision damage models for oil tanker and bulk carrier reliability, following collision events. Particularly, the IACS deterministic model, actually embodied in the “Harmonized Common Structural Rules for Oil Tankers and Bulk Carriers” (IACS, 2015a) is compared with two stochastic collision damage models, the former based on the main outcomes of the recently developed GOALDS statistics (IMO, 2012), the latter derived by MEPC.110(49) Resolution (IMO, 2003). Particularly, the paper focuses on three main aspects:

(i) Statistical properties of hull girder residual strength, based on net scantling approach (IACS, 2015a), are investigated by Monte Carlo simulation, accounting for uncertainties due to material properties and deterministic/random damage dimensions, depending on the applied collision damage model.
(ii) Reliability analysis is performed by Monte Carlo simulation, to investigate the incidence of randomness due to collision penetration depth/height on sagging/hogging failure probabilities.
(iii) The incidence of corrosion on residual strength statistical properties and hull girder reliability, following a collision event, is investigated focussing on three hull girder corrosion wastage conditions, namely gross scantlings, hull girder net scantlings and local net scantlings, respectively.

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