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Time-variant bulk carrier reliability analysis in pure bending intact and damage conditions

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ABSTRACT

Time-variant reliability analysis of a corroded bulk carrier in intact and damage conditions is performed by First-Order (FORM), Second-Order (SORM) Reliability Methods and Importance Sampling simulation. Annual failure probabilities are determined up to 25-year ship lifetime, accounting for time-variant corrosion wastage of structural members contributing to hull girder strength. Statistical properties of hull girder capacity are determined by Monte Carlo simulation, applying three correlation models among corrosion wastages of structural members contributing to hull girder strength, namely no correlation, full correlation and full correlation among wastages of structural members belonging to the same category of compartments. A modified incremental-iterative method is applied, to account for instantaneous neutral axis rotation, in case of asymmetrical damage conditions, as for collision and grounding events. Incidence of intact/damage condition, as well as correlation among corrosion wastages, on annual sagging/hogging time-variant failure probability is investigated and discussed. Time-variant sensitivity analyses for intact and damage conditions are also performed, to investigate the incidence of random variables' uncertainties on the attained failure probability. Finally, the bulk carrier section scheme, benchmarked in the last ISSC Report, is applied as test case.

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1. Introduction

Ship structural design was traditionally based on deterministic analysis till the 1970s, when the first attempts of applying probability-based methods were undertaken by Mansour [44,45] and Mansour and Faulkner [47]. Early efforts focused on developing reliability analysis methods for ship structural design. In this respect, Ang [6] emphasized the importance of risk and uncertainty evaluation in ship structural design, describing practical methods for risk assessment, in terms of failure probability, to develop the first reliability-based design criteria. Load and hull girder capacity uncertainties were analysed, focussing on the explicit use of failure probability as a measure of risk and safety level in ship structural design. In the same years, Ang and Cornell [7] outlined the main probability means, for properly modelling and analysing all uncertainties connected with ship structure safety and serviceability. Assumptions for implementing probability concepts, as well as practical design criteria and code provisions, were explained and discussed, with the main aim of developing safety factors for ship structural design. Stiansen et al. [65] focused on hull girder strength statistical properties, discussing all factors affecting the as-built ultimate capacity and furnishing approximate formulations of relevant coefficients of variation. Ayyub and Haldar [9] reviewed the commonly applied structural reliability analysis methods, discussing relevant advantages and limitations, with reference to both First-Order-Second-Moment method and simulation techniques, focussing on the Conditional Expectation plus Antithetic Variates variance reduction method, to speed up Monte Carlo simulations.

The earliest applications of reliability analysis to ship structures were carried out applying the Mean Value First-Order Second-Moment Method (MFOSM) and the First-Order Reliability Method (FORM), while advanced techniques were applied after the 1990s. Among others, Mansour [46] determined reliability indexes of several oil tankers and bulk carriers, to develop new hull girder longitudinal strength check criteria. Uncertainties associated with random variables were taken into account and quantified by their coefficients of variation. Guedes Soares [26] proposed a model to estimate the time-variant hull girder reliability, resulting from degrading effects due to corrosion. Reliability function was determined at discrete points during the ship lifetime and example calculations were carried out for a tanker. Ostergaard [52] performed the reliability analysis of a containership, to assess partial safety factors for vertical wave bending loads. The hull girder capacity distribution was determined by nominal sagging/hogging values, coupled with relevant coefficients of variation; still water and wave vertical bending moments, instead, were derived by statistical data and hydrodynamic analysis, including long-term statistics. In the same years, the first attempts of deriving probabilistic values of hull girder strength were performed by Monte Carlo simulation [64]. Relevant results were expressed in terms of nominal mean values, coefficients of variation and distribution types, after carrying out several goodness of fit tests. Subsequently, Wirsching et al. [71] focused on time-variant reliability analysis of a tanker experiencing structural degradation, due to corrosion wastage, in order to provide information to ship designers and owners, for general risk assessment with reference to corrosion margins, as well as steel replacement during the ship lifetime. Anyway, the first applications of advanced reliability analysis methods have been carried out only recently. Paik et al. [54] applied the time-variant Second-Order Reliability Method (SORM) on a double hull oil tanker and a bulk carrier, accounting for corrosion wastage, with 1 and 20-year reference time. Akpan et al. [3] focused on the risk assessment of aging ships, degraded by corrosion and fatigue, based on time-dependent models for corrosion growth and fatigue cracks. Time-variant annual failure probabilities were determined by the Second-Order Reliability Method, estimating the hazard function at discrete points during the ship lifetime, with 1-year step. Sun and Bai [66] focused on the time-variant reliability assessment of a Floating Production, Storage and Offloading (FPSO) vessel, applying a modified Smith method and accounting for both corrosion and crack propagation, by Paris-Erdogan equation. Zhu and Frangopol [73] presented a new approach for reducing uncertainties in performance assessment of ship structures, updating the wave-induced load effects by Bayesian methods with data acquired from structural health monitoring (SHM). Time-variant reliabilities, before and after updating, were determined and compared. Zayed et al. [72] investigated the time-variant reliability of ship structures, focussing on fast integration techniques, to estimate long-term vertical wave bending moments.