Marine Structures 39 (2014) 438–462

Contents lists available at ScienceDirect

Marine Structures

journal homepage: www.elsevier.com/locate/marstruc

# Statistical properties of bulk carrier longitudinal strength

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ARTICLE INFO

*Article history:*
Received 8 July 2014
Received in revised form 5 September 2014
Accepted 3 October 2014
Available online 30 October 2014

*Keywords:*
Longitudinal strength
Bulk carrier
Corrosion
Taylor series expansion method
Monte Carlo simulation

ABSTRACT

The paper focuses on time-variant longitudinal strength of bulk carriers under corrosion wastage, applying both Taylor series expansion method and Monte Carlo simulation. Hull girder section modulus and ultimate bending moment capacity are determined, by classical beam theory and the commonly applied incremental-iterative approach, respectively. Two main aspects are fully discussed and investigated, according to the final recommendations of last ISSC Report. The former regards the covariance between annual corrosion rates of individual structural members, commonly assumed as uncorrelated. Really, as it is conceivable that a certain correlation exists, three different cases are investigated: uncorrelated variables, fully correlated variables, full correlation between structural members belonging to the same category of compartments. The latter investigates the probability density function of both hull girder section modulus and ultimate bending capacity, because the Central Limit Theorem cannot be applied when correlation among random variables exists. Finally, as a test example, the bulk carrier section, presented in the last ISSC benchmark study, is analysed.



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http://dx.doi.org/10.1016/j.marstruc.2014.10.007
0951-8339/

## 1. Introduction

Ship structures are continuously exposed to age-related damages such as corrosion, fatigue cracking and localized dents, which may affect the ship structural capacity up to loss of life, property damage and environmental pollution [14]. Corrosion wastage effects can be monitored, or at least mitigated and delayed, by means of ad hoc detail design and proper preventing measures [4], although appropriate thickness reductions have to be always considered, especially for those vessels operating beyond the expected service life, such as bulk carriers, tankers and floating production storage and off-loading units, designed for continuous offshore operations [16].

Corrosion wastage has not been explicitly considered up to the 1980s, since the scantlings of merchant ships were determined by more or less empirical formulas, implicitly accounting for corrosion safety margins, derived by experience and individually developed by each classification body. To harmonize relevant standards and safety margins for double hull oil tankers and bulk carriers, in June 2003 IACS decided to prioritize the development of common structural rules (CSR), that became effective on 1st April, 2006 [9,10]. The CSR are based on the so-called "net scantling approach", as far as corrosion additions for each structural element are derived independently from the net scantling requirements, to address corrosion wastage that is likely to occur during the ship-in-operation phase. In this respect, the method takes into account the corrosion effect, based on explicitly defined corrosion additions for one side of each structural element, depending on both compartment category and structural member (platings, ordinary stiffeners or primary supporting members). Scantling compliance in relation to rules depend on considered structural requirements (i.e. local strength, hull girder strength, fatigue assessment) and analysis type (thickness, buckling and collapse capacity, hull girder section properties). In the review period of CSR, industry stakeholders urged IACS to harmonize the key technologies used to derive the rules [14], developed independently for double hull oil tankers and bulk carriers. In order to harmonize relevant standards, IACS was committed to create the common structural rules for bulk carriers and oil tankers (CSR-H), issued on 1st January 2014 and expected to become effective on 1st July 2015. In any case, the "net scantling approach" has been entirely preserved with no relevant variations, as regards the CSR approach.

The "net scantling approach" is very easy to be applied in the ship design process, but it doesn't consider explicitly the corrosion probabilistic behaviour in terms of mean value and variance of the annual corrosion rate. In this respect, more refined corrosion models were developed in the last years [17]. proposed a corrosion wastage model with some initial nonlinearities due to the activity of the anaerobic sulphate-reducing bacteria (SRB), adopting five phases of corrosion, namely kinetic (actual), kinetic (linearized), oxygen diffusion, SRB growth and SRB steady state [19]. developed a time-dependent corrosion wastage model, presenting three different phases, namely coating life, transition time and corrosion wastage, furnishing a wide variety of data, in terms of expected annual corrosion rate and coefficient of variation [7]. proposed a corrosion model based on three subsequent phases, namely no-corrosion period (coating life), signal damage of corrosion coating period (corrosion occurrence) and decrease in the corrosion rate period [21]. presented a similar corrosion model, but different in the second phase, assuming that the coating gradually deteriorates, thus allowing pitting corrosion. The last ISSC Final Report 2012 [12] has also emphasized the need for a corrosion wastage model, based on a full statistical approach, evaluating the ship ultimate strength capacity by means of a probabilistic format, accounting for uncertainties due to thickness wastage.

Only recently, the impact of ageing effects on the ultimate strength of hull girder and its components has been considered in the condition assessment of aged ships and offshore structures. In this respect, few advances have been reached in the main degradation modes of ship structures due to corrosion, fracture and mechanical damages. Wang et al. [27] carried out a statistical investigation of time variant hull girder strength of ageing ships and coating life, based on data from ships in service, taken from the measurement of section belts during CAP surveys. Although some difficulties in identifying plate renewals that probably slightly affected the analysis, the authors identified uncertainties in the decrease of tankers' hull girder section modulus and derived some formulas for the relevant strength assessment. Ivanov [13] focused on both hull girder loads and section modulus degradation due to corrosion, determining relevant geometric properties in a probabilistic format as annual distribution for any given lifespan. Probabilistic models of corrosion were combined with as-