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Time–variant reliability analysis of novel deck and bottom panels

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ABSTRACT

There has been an increasing interest in using reliability–based approaches in ship structural design. The methods and numerical tools presently available to solve structural reliability problems are capable of representing in a rational manner the uncertainties involved in the design of structures and their consequences on the safety level. With these methods, the uncertainties in the design variables involved in a given strength requirement can be rationally quantified through probabilistic models. As a result, the probability of failure, or the probability of violation of the strength requirement can be computed and used as the safety measure.

The objective of the present paper is to use novel longitudinals of Y–stiffener profiles instead of the conventional T–stiffeners profile in double hull oil tanker's bottom and deck panels under axial compressive loads considering the structural degradation due to corrosion effects. The Y–stiffener profile is a fabricated section and simply can be produced by attaching the lower end the conventional stiffener's web to the top of the hat part. The Y–stiffener utilizes the advantages of having more effective plate that allows increasing the stiffener spacing, which in turn drops the required number of stiffeners. Time–variant reliability analyses were performed using VaP (Variable Processor) software via applying the Second–Order Reliability Method (SORM) for both conventional and novel Y–stiffener profiles. The ultimate strength and the applied load formulations were derived based on the International Association of Classification Societies–Common Structural Rules (IACS–CSR) for oil tankers. With the Y–stiffeners, a significant improvement in the panel's safety level was achieved in comparison with the conventional profiles in terms of providing higher safety index, larger safety index to weight ratio over the vessel entire lifetime and more structural weight saving.

1. Introduction

The structural safety of ships at sea has always been an important aspect of ship operations. In order to be able to assess the structural safety of the ship, it is necessary to evaluate the strength of the ship and to define probabilistic models which can characterize the variability expected from the structural strength estimates. Ship structures are designed to possess enough load–carrying capacity to sustain extreme environmental and operational loads in their service life without structural failure. It is, therefore, natural that usually the analysis of the structural reliability of ships concerns only the resistance to extreme loads.

In typical tanker ship structures, deck and bottom panels are reinforced by longitudinals (stiffeners) in the longitudinal direction and transversely supported by widely spaced transverse structures (such as transverse bulkheads, deck beams and bottom floors). The conventional longitudinals are usually tee, angle, bulb or flat bar profiles. Generally, plates, stiffeners and main supporting members of ship hulls may fail by yielding, buckling or fatigue.

To properly deal with the pertinent uncertainties in the structural capacity and load effects, a structural reliability analysis is preferred rather than a deterministic analysis. Structural reliability analysis aims at estimating the implied probability of failure of structural components or structural systems with a rational assessment of the normal variability and uncertainty that affects both load effects and resistance.

Many ship casualties, especially in older ships, can be attributed to age–related structural degradations such as corrosion wastage, fatigue or brittle fracture. As a result, research of aging ships has drawn attention of several researchers including Akpan et al. (2002), Ivanov et al. (2003, 2004), Paik et al. (2003a, b, c) and Saad-Eldeen et al. (2015a, 2013, 2015b). The time–dependent reliability analysis provides a measure of the safety probability of a structure as it ages with time. It is easy to understand that the reliability of a vessel without maintenance decreases with age. Therefore, risk and reliability

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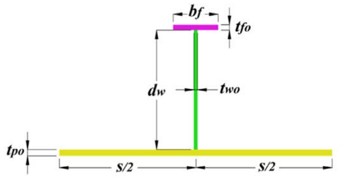
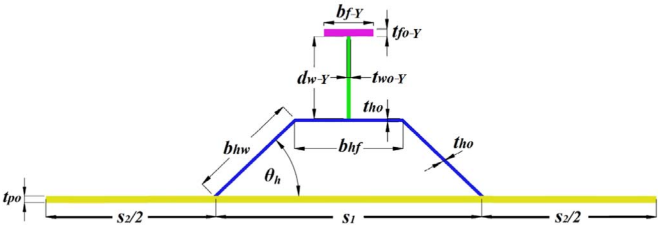
approaches are increasingly popular with designers and owners as they give them a qualitative indication of the sea–worthiness of their vessel at any point of their design life. Such a design procedure includes uncertainties in the strength of various structural elements, in loads, load combinations, variability of material properties, and modeling errors in analysis procedures.

In the 2000s, many efforts were done to study the reliability–based analysis of ship structures. Debek and Konieczny (2006) carried out a complete reliability evaluation of a bulk carrier hull structure. Parunov et al. (2007) investigated comparative hull–girder reliability for a new generation oil tanker, which is characterized by shallow draught and low length–to–beam ratio, using vertical wave bending moments obtained by direct hydrodynamic and statistical analysis and CSR for tankers. The reliability assessment was performed for the ship in “as built” and “corroded” conditions, assuming 20–year corrosion. Results of the analysis of as–built and corroded ships showed that the structural reliability of the new generation oil tanker is higher than the reliability of the “rule” oil tanker. The sensitivity analysis showed that for various ships, even of the same type, the relative impact on the structural safety of still–water and wave–induced bending moments may be quite different. While for the new generation tanker the calculated reliability index is very sensitive to the still water bending moment in ballast loading condition, the reliability of the “rule” tanker is almost completely insensitive to this variable. The sensitivity analysis shows that the uncertainty of the ultimate bending moment capacity is generally the most important variable in reliability assessment. Parunov and Soares (2008) investigated changes in notional reliability levels that result from redesigning an existing Aframax tanker to comply with CSR for double–hull oil tankers. It was shown that the hull–girder failure probability of an Aframax tanker was reduced several times due to reinforcements according to CSR. The results of the performed reliability analysis indicated that the probability of structural failure in sagging is reduced about five times based on CSR requirement. From the reliability analysis, it was further shown that the safety index in sagging is much lower than in hogging. This is expected since the sagging failure mode is more important for these ships. Hussein and Soares (2009) carried out a study to evaluate the reliability and residual strength after damage of double hull tankers designed according to the new IACS common structural rules. The sensitivity analysis showed that the ultimate strength and the corresponding uncertainty have the highest importance. This importance does not change from one damage scenario to the other. The still water bending moment and the wave–induced bending moment have almost the same importance. Shi et al. (2014) proposed a method that combines the First–Order Reliability Method (FORM) and Kriging interpolation models, as response surface of a ship–stiffened plate with initial imperfections.

The influences of general corrosion on ultimate strength were specifically emphasized and the sensitivity factors of the failure probability were provided. Soares and Teixeira (2000) calculated the time–variant failure probability of two bulk carriers using the long–term loading formulation and analytical hull girder ultimate strength formulation. A sensitivity study on the effects of the variables in different loading conditions was performed. Sun and Bai (2000) and Akpan et al. (2002, 2003) modeled corrosion as a time–dependent random function and used Second–Order Reliability Method (SORM) to calculate the instantaneous reliability of the primary hull structure. The procedures to assess the time–variant reliability of tankers, bulk carriers and floating production storage and offloading (FPSO) structures subjected to degradations due to corrosion and fatigue–induced cracking were presented by several authors such as Paik et al. (2003a, b, c), Sun and Bai (2003), Hu and Cui (2004), Hu et al. (2004) and Moatsos and Das (2005). In such research, different models for corrosion wastage were applied and the hull girder ultimate strength was estimated. Timelines presenting vessels relating the probability of hull girder failure to ship age were obtained. The effects of various repair schemes on reliability were also discussed.



(a) T-stiffener profile



(b) Y-stiffener profile

Fig. 1. Conventional and novel stiffener profiles; (a): Conventional T–stiffener and (b): Novel Y–stiffener.

As an initial platform towards improving the ship panel's ultimate strength to weight ratio, deterministic studies on using the Y–stiffener as an alternative to the conventional stiffener profiles have been previously performed. Examples that are most relevant to the present study include El-Hanafi et al. (2013) who provided a new methodology to generate the Y–stiffener dimensions from the original as–built T–stiffener in the midship section (see Fig. 1). Badran et al. (2013) studied the effect of three levels of initial imperfection on the ultimate strength of Y and T–stiffeners subjected to lateral loads. Recently, Leheta et al. (2015) developed a mathematical model based on IACS Common Structural Rules to calculate the ultimate strength of longitudinally stiffened panels supported by Y–stiffeners under axial compression and combined in–plane and lateral pressure loads. Utilizing this model, Leheta et al. (2015) carried out an extensive campaign of analytical tests comparing different Y profiles against the conventional ones in both deck and bottom stiffened panels. They concluded that using the Y–stiffener can provide higher section modulus and significant improvement in the panel safety margin (defined as the ultimate strength minus the applied compressive stress) to weight ratio.

The present study aims to implement Second–Order Reliability Method (SORM) to compare the reliability safety index of tanker's longitudinally stiffened panels supported either by conventional or novel Y–stiffener profiles along the vessel lifetime taking into account the structure degradation caused by corrosion effects. VaP (Variable Processor) software is utilized in order to perform the required time–variant reliability analysis.

Only deck and bottom panels are considered in the present study, these panels are situated amidships of a very large crude carrier (VLCC) under two different loading conditions:

- Loaded condition (sagging vertical bending moment).
- Ballast condition (hogging vertical bending moment).

Both deck and bottom panels experience large in–plane compression or tension primarily in the ship's longitudinal direction caused by the hull girder bending moment. Generally, the lateral pressure applied on the tanker's deck structure is negligible. While outer bottom panels are subjected to additional bending moment due to lateral pressures from the seawater and ballast water, inner bottom panels are subjected to additional bending moment resulting only from the cargo lateral pressure (during the loaded condition). The vertical sagging bending moment causes the deck panels to be in compression and bottom