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Risk-based framework for ship and structural design accounting for maintenance planning

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ABSTRACT

This work develops a risk-based framework for a ship and structural design accounting for maintenance planning. The risk analysed here covers structural failure where, it is deemed as a failure when the structural capacity is less than the subjected loads, reducing the stipulated margin of safety. The risk in this context also includes hazards such as accidental spills, loss of cargo, ship and crew members during the operations stage. For structural failure, time profiles of performance, which will incorporate structural degradation in conjunction with ship hull strength to predict the expected behaviour in terms of structural integrity is analysed. The profiles are envisaged to be approximate as they are based on the limited data available during the early design stage. The risk-cantered maintenance methodology is applied for determining the maintenance plan of a ship hull structural system and permits the developed framework to be used in the early stage of design, accounting for different hazard scenarios, specific economic environment and degradation severity along the service life.

1. Introduction

Nowadays, two fundamental risk-assessment approaches are employed, qualitative and quantitative ones (Guedes Soares and Teixeira, 2001; Apostolakis, 2004). The qualitative risk approach identifies the risk, employing a pre-defined rating scale. The risk is scored based on the probability or frequency of occurring. A quantitative risk analysis, which is a more advanced approach is employed here to develop a probabilistic analysis accounting for the existing uncertainty.

The approach, presented here, enables the risk mitigation actions in the early ship design stage, accounting for the fact that the ship design and operation are predominantly governed by the ship owner's specification and applicable Regulations and Classification Rules.

The owner's specification covers the ship performance and minimizes the capital, CAPEX and operational costs, OPEX and the Regulations and Classification Rules cover the fundamental design, safety, environmental and operational requirements.

The International Maritime Organization, IMO implemented the Formal Safety Assessment, FSA (IMO, 2005, 2006a, b, 2007, 2008, 2013, 2015) to improve the maritime safety and was used to create new rules as shown in (Psaraftis, 2012; Montewka et al., 2014) and designing of ships in the degradation condition in (Papanikolaou et al., 2009). Recently the Formal Safety Assessment was employed (Guia et al., 2016) to perform a sensitivity analysis on the hull girder safety level of a tanker ship and in (Garbatov and Sisci, 2018) for a risk-based conceptual ship design of a multipurpose vessel subjected to shipbuilding constraints, risen due to the limitation of SME shipyard in building new ships as it was discussed in (Garbatov et al., 2017b; Atanasova et al., 2018; Damyanliev et al., 2018).

However, what nowadays is observed is that in the environment of small and medium shipyards, the basic planning and the initial design are done outside of the shipyards and outfitting, and detailed designs are performed in the shipyards. In this perspective, to enhance the capacity of SME shipyard in the design process the internet environment can be used to enable remote design and information exchange between SMEs and design agents. The implementation of the available software, including in-house developed one may support the development of a low budget integrated design framework for SMEs.

The objective here is to develop a framework, capable to perform ship and structural design accounting for the risk-based life cycle assessment and maintenance in a very early stage of ship design, where limited information is available and at the same time permits to account for a specific measure related to the future maintenance and repair to be considered. The study is performed in three consecutive stages related to conceptual ship design, risk-based structural assessment, and risk-based maintenance as can be seen from Fig. 1.

The first stage addresses the risk related to the owner's specification requirements considering aspects including lightweight, dead weight,

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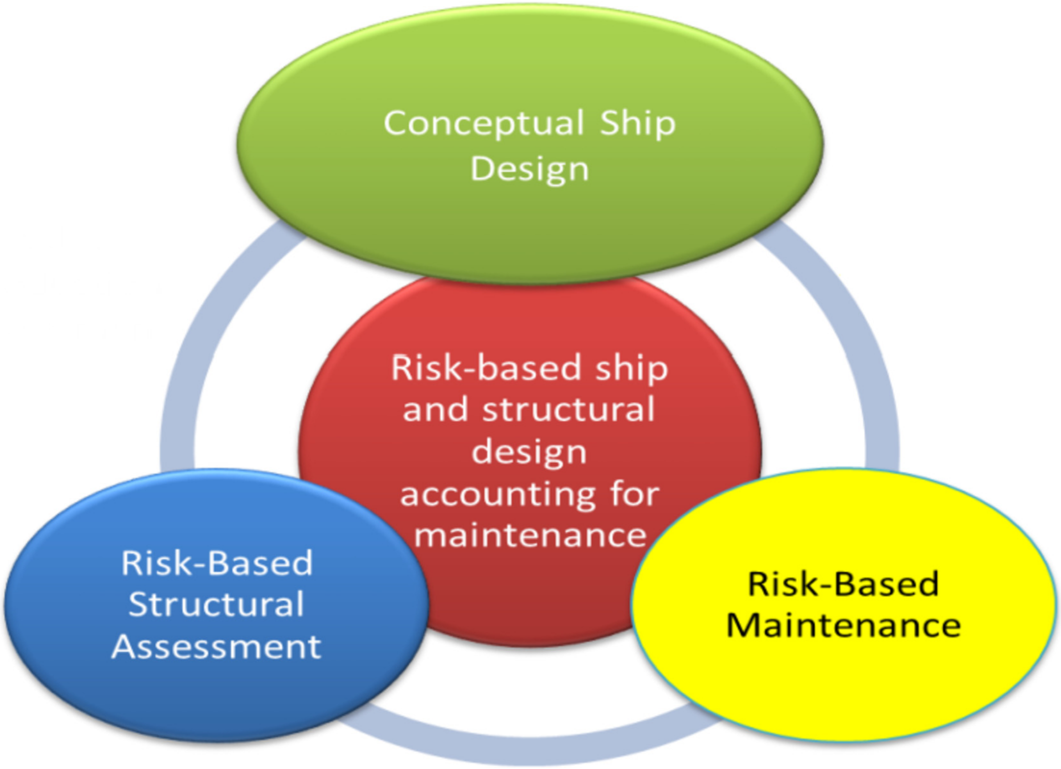

Fig. 1. Risk-based ship and structural design.

cargo capacity, freeboard, initial stability, seakeeping etc. Due to a large number of items that need to be considered, a Pareto optimisation algorithm is employed to conclude on the best design choice. The details about this stage were already discussed in (Damyanliev et al., 2017; Garbatov and Sisci, 2018) and here, only a brief description will be presented.

Based on the output from the first stage, the mid-ship section scantlings of an MPS are determined and a risk-based analysis with emphasis on the lifecycle cost and ultimate strength assessment is carried out. The analysis focuses on the progressive collapse and related probability of structural failure as well as the cost of progressive collapse, structural measures, human life, loss of cargo, accidental spills, where the last two are related to the environmental impact. The output will be a target structural reliability to which the designed structure needs to comply.

In the last stage, the risk-based maintenance planning is performed. The severity of structural degradation is defined in probabilistic terms and the different hypothesis of structural degradation consequences are studied. The cost of preventive and corrective maintenance is estimated with the aim to optimise the maintenance. The output is a maintenance plan that will aim to reduce the cost of the ship operation. It is noted that the maintenance planning could result in a redesign of the ship structure.

2. Risk analysis of ship hull structural system

The formal safety assessment formulation is applied here, which includes five steps, commonly used in a risk analysis methodology, including the identification of hazard, risk control options, risk analysis, cost-benefit analysis and decision-making and sensitivity analysis.

The risk associated with the ship in operation is estimated based on the probability of failure and the consequences of failure. The scope of the present study includes only the ship hull structural system with the failure that may lead either to the loss of the ship hull structure, loss of cargo, loss of human life or environmental pollution. Therefore, the failure consequence is related to the ship hull structure, cargo, human life loss and environmental pollution. The risk is driven by the failure probabilities and their consequence and the objective is to estimate the time-dependent probability of failure as a measure of the risk of a ship in operation.

The hazard that reduces the ship hull structural integrity is identified and the model that defines the global structural performance is based on the progressive collapse of the ship hull structure regarding the midship section of the ship hull girder. The impact of corrosion degradation on the primary structural components is included in the formulations.

2.1. Ship hull structural system

A ship hull structural system is defined as an assembly of structural components, including plates, stiffened panels, platforms, decks, etc., joined to satisfy a specific structural capacity and functionalities of the designed ship.

To define the ultimate limit state of failure, failure rates and consequences, information related to the ship operation, maintenance and repair during the service life needs to be collected. A non-failure state of the ship hull structural system is defined as a state when the ship hull structural system can perform its designed functions by meeting measurable requirements defined by an acceptable reliability or risk level. However, the ship hull structural system may function by only satisfying partially the acceptable level, which is not considered a successful performance.

In this work, a quantitative risk-based life cycle structural integrity assessment of a multipurpose ship in operation is performed. The multipurpose vessel is subjected to the progressive ship hull structural collapse and corrosion degradation during the service life.

The structural system is defined during the conceptual ship design, formulated as a compromise decision support problem with multiple goal constraints given the owner's requirements about the cargo deadweight/containers, speed, range, regulations and data on similar ships