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Correction of prediction model output for structural design and risk-based inspection and maintenance planning

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ABSTRACT

This paper presents a new methodology to calibrate structural reliability models output. The methodology combines data from experience and prediction models to correct the structural reliability models. The paper gives an overview of the techniques used for model calibrations, summarises the methodology in an overall discussion, and proposes data processing to sanitise sensitive information. The proposed methodology is inherently adaptable and can be applied to many other fields that require cost effective maintenance, as well as providing data for calibrating methods and codes.

1. Introduction

Setting standards for designing, building, maintaining, inspecting and repairing ships have become increasingly difficult. Most of these vessels experience varying degrees of corrosion and fatigue cracking which represent the most pervasive types of structural and joints problems.

In terms of inspection, periodic inspections are used to check for degradation of coatings, corrosion and cracking and other material deteriorations (IACS, 2013). Each of the damage modes, if not properly monitored and corrected, can potentially lead to unanticipated out-of-service time or even catastrophic failure. These problems are significant risks to operations of vessels, such as tanker and bulk carriers.

In risk based inspection planning understanding the degradation mechanism of the structure plays an important role in the ability to identify critical failures which can have in some cases disastrous health and environmental consequences.

Prediction model for ship structural defects and deteriorations approximates the way the structure, under certain conditions, will be affected in the future. The prediction is often based on experience or knowledge.

The importance of predicting, monitoring and mitigating structural degradation has been recognised by classification societies, ship owners and authorities.

The development of such prediction models is important in areas such as: corrosion, fatigue design of structural details, reliability based design, and risk based life cycle management. For example, Yamamoto and Ikegami (1998), proposed a general corrosion model assuming that the phenomena is a result of three sequential processes: degradation of paint coatings, generation of pitting point, and progress of pitting point. Guedes Soares et al. (2009) proposed a corrosion wastage model based on a non-linear time-dependent corrosion model whereas Melchers (2010) proposed a quantitative models for marine immersion which included the effect of microbiological influences in the prediction of corrosion loss for a maximum pit depth.

Wirsching et al. (1990) describe fatigue crack growth by a fracture mechanics model in which parameters and other design factors are considered as random variables and the "*probability of failure estimates are used for an economic value analysis to establish optimal strategies for design and for a maintenance schedule*". The integrity of structural systems can then, be ensured through a programme that coordinates design, inspection and repairs to minimise total lifetime costs. Ayala-Uraga and Moan (2007), see, in relation to the design of welded structures, the application of the reliability methods as a tool for making decisions about the balance between design criteria and optimal plan for inspection and repair costs, considering inherent uncertainties.

Motivated by the need to optimise maintenance expenditure and achieve better safety level at a lower cost, there have been significant developments in the area of reliability-based inspection planning for complex structures, such as offshore structures, ships and bridges (Guedes Soares and Garbatov, 1996a, 1996b; Lagaros and Tsompanakis, 2007). Various tools and methodologies were developed for fatigue reliability analysis and inspection updating (Moses, 1977, 1982; Cramer and Bea, 1991; Enevoldsen and Sørensen, 1994; Garbatov and Guedes Soares, 2002). The methods were used for developing optimum inspection plans for individual structures.

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Following the developments for fixed steel platforms, further research work addressed the development of methodologies for optimised inspection of floating structures and tankers (Ma et al., 1995; Garbatov and Guedes Soares, 1998; Riahi et al., 2011). Several studies have addressed the application of these techniques to jack-ups (Barltrop, 1991; Veldman and Lagers, 1997). For ships, methods for structural inspection and maintenance and repair planning, have been proposed (Skjong, 1985; Madsen et al., 1987; Ayyub et al., 2002; Straub and Faber, 2005), and are being applied to outline Risk Based Inspection (RBI) plans.

It is recognised that reliability based inspections and repair strategies not only improve the cost effectiveness of the maintenance of ship structures but also enable the risk associated with inspections and repairs to be determined quantitatively (Hifi et al., 2008).

In order to maintain a high standard of structural integrity, inspection, maintenance and repair scheduling need to be carefully planned (Barltrop et al., 2008). For example, the importance and influence of inspection and repair at different points in time on the reliability of the hull girder has been demonstrated by Guedes Soares and Garbatov (1996a, 1996b).

RBI is also used for offshore and ship structure where risk analysis is performed in order to quantify degradations, using structural reliability approach, and identify an inspection strategy (Boon et al., 2009; Garbatov and Guedes Soares, 2009).

Though a number of techniques have been developed, they are rarely used, and a little work has been done on compiling and processing the information from analyses and inspections to help ship inspectors, repairers, ship owners and designers and the crew to control these problems.

This paper discusses a methodology developed to calibrate the prediction models of structural defects and degradations using data from inspections and expert judgment (experience-based methods) to be used at the design stage and for inspection planning as a decision support system to improve the ship structural performance and make the inspections cost-effective.

2. Inspection planning

Stakeholders (owners/managers) need an inspection regime to help, systematically examine and assess the hull structure and to identify and record any defects or anomalies. This will need a holistic approach for a preventative maintenance scheme for the ship, considering the following issues:

- Identification of potential problem areas, so that preventive measures can be taken to remain in conformance with the applicable Classification Rule requirements,
- focused inspection and condition reporting on structurally critical areas,
- detection of anomalies or maintenance trends across fleet,
- potential to minimise disruption of normal ship operations, and,
- improved efficiency in the use of inspection results to satisfy the inspection requirements of other stakeholders (such as Class society).

Inspection can be categorised into two types, the '*Mandatory inspections*' those required by classification societies or flag administration, and the '*Owner's voluntary inspections*' those performed by owner for their own purpose. Class Society requirements, in fact, include periodical ("*special*") detailed surveys to be carried out every 5 years, the level of the damage severity increasing as the ship's age increases (IACS, 2013). Special surveys are supplemented by annual bottom/docking surveys aimed at checking the ship's status. If damage or other defects occur in the course of ship operations, which the owner is expected to report to the Class Society, additional occasional surveys are usually performed.

Inspection planning may be based on experience (determined by Class Society guidelines), which generally treat all ships with the same inspection programme, or based on a risk-based maintenance planning programme (Barltrop et al., 2010; Hifi and Barltrop, 2012). In the first case, inspection planning is based on general guidelines and engineering judgement which is prescriptive and does not take into account the structure specific characteristics or make optimum use of the observed performance data. In this approach, the various inspection criteria are combined in a qualitative manner to produce the inspection plan. Such criteria include fatigue lives, member criticality, stress levels, past inspection data, previous experience and cost considerations (Shama, 1991; Garbatov and Guedes Soares, 2001, 2011). Only some of the knowledge that could be used to predict structural problems, in the case of ship-to-ship variation (construction or use) is gained from the data gathered.

In the second case, risk based maintenance methods can deal with any individual structural component or with overall ship structural integrity.

To bridge the gap between these two approaches, the methodology proposed in this paper combines the knowledge gained from current practice in ship inspection and maintenance and from risk-based methods which have already been proven as a good practice in several industrial applications.

After an inspection is performed on a ship structure, the results can be classified as "no defect recorded" or "defect recorded". In the latter case the defect type and measured size define the defect. Each inspection result gives additional information on the in-service condition of the ship structure. It is therefore, necessary to update models' predictions (reliability models) with the additional information as the latter leads to changes of the predicted values and the basic random variables affecting the reliability.

The proposed methodology will gather the inspection data and information recorded through life and will calibrate the reliability models (prediction models for anodes, coating, corrosion, crack, etc.) to help produce better inspection and maintenance strategies and so improve the durability of new and existing ships.

3. Updating predicting models

Calibration and validation of prediction models is one of the most challenging phases in modelling processes. A deep understanding of modelling, data acquisition but also basic notions and procedures of mathematics and statistics are needed (Hangos and Cameron, 2001; Zimmerman, 2004).

A serious problem in computing predicted data is the model-data incompatibility caused by systematic model errors or potential biases. The calibration and recalibration of the model predictions are important aspects of obtaining good quality and reliable process data. Without an effective method to reduce the model-data mismatch, assimilating real data into the initial state of the model could result in initialisation shock, which would prevent the model from achieving its optimal predictive capability. In order to make full use of the inspection data without much initialisation shock, and to predict data, it is necessary to correct the systematic model biases. However, not much attention has been paid to this problem in the past.

Two approaches could be considered to effectively reduce these biases, with a simple statistical correction and the bias-correction, models can have a more realistic internal variability as well as an improved prediction performance.

The first approach for model calibration is to modify or update the individual model parameters using inspection data for a given set of assumed conditions with observed data for the same conditions until the output from the model matches the observed set of