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Integration of structural health monitoring in life-cycle performance assessment of ship structures under uncertainty

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ABSTRACT

In this paper, an approach for integrating the data obtained from structural health monitoring (SHM) in the life-cycle performance assessment of ship structures under uncertainty is presented. Life-cycle performance of the ship structure is quantified in terms of the reliability with respect to first and ultimate failures and the system redundancy. The performance assessment of the structure is enhanced by incorporating prior design code-based knowledge and information obtained by SHM using Bayesian updating concepts. Advanced modeling techniques are used for the hull strength computations needed for the life-cycle performance analysis. SHM data obtained by testing a scaled model of a Joint High-speed Sealift Ship is used to update its life-cycle performance.
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1. Introduction

Efficiently ensuring the adequacy of the life-cycle performance of ship structures is fundamental for their safe use and can only be attained by integrating every valuable information gathered about the structural health into the assessment of this performance. Sustainment and life-cycle engineering of ships and ship systems represent major and fast growing challenges for the US Navy [1]. Structural health monitoring (SHM) is emerging as a very powerful technique in ship structures for collecting accurate information about the operational loads the ships are exposed to and detecting damages in the structure once they occur.

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In principle, among the potential direct applications of SHM, the following is essential in the performance assessment of ship structures. Monitoring the response of a ship structure to its exposure to wave loads provides a volume of valuable information that if used properly can provide a platform for predicting lifetime loads for design and assessment of structural performance. A common monitored response in structures is the strain inflicted by the various load effects experienced by the structure. Using proper calibration, the measured strains may be converted to global ship responses, such as vertical wave-induced bending moments. In the absence of monitoring information, design code formulas [2] are typically used for conservatively estimating the wave-induced load effect in the reliability analysis of ship structures. Even in this case, design codes do not provide formulas for estimating high frequency load effects for cases in which these effects are significant. Either way, incorporating the information obtained from SHM with the prior code derived information can enhance the established life-cycle assessment of ship structures.

The nature of SHM data dictates the fundamental need for accounting for uncertainty in the treatment of this data for integration in the performance assessment methodologies and only recently such research has emerged in the bridge engineering field [3 and references therein]. However, these studies have mainly focused on information related to the load effects that SHM provides, primarily using classical inference concepts in which prior information cannot be easily incorporated and, in fact, is neglected.

Ship reliability-based studies that account for optimum and safe design and life-cycle performance assessment have been conducted. Various studies investigated the reliability of ship structures with respect to their ultimate flexural failure [4–7]. On the other hand, Lua and Hess [8] analyzed the reliability of ship structures with respect to the first failure. Life-cycle redundancy of ship structures has also been recently investigated [9]. These studies provide a wealth of procedures for establishing the life-cycle performance prior to monitoring. Within the outline of these procedures, a methodology for updating the life-cycle performance with obtained SHM data is yet to be developed.

The objective of this paper is to present an approach for integrating the information obtained from SHM in the life-cycle performance assessment of ship structures under uncertainty. The resistances with respect to the ultimate and first failure vertical bending moments are determined such that the ultimate failure moment is computed using an optimization-based method [10] and the first failure moment is computed using the progressive collapse method [11]. The probabilities of failure are computed using a hybrid Latin hypercube sampling – SORM technique. This paper uses Bayesian inference concepts which enable the inclusion of necessary prior information with the SHM data for updating the load effects. The approach is illustrated on the Joint High-speed Sealift Ship (JHSS). SHM data obtained by testing of a scaled model of the JHSS ship is used to update its life-cycle performance.

2. First and ultimate strength

Being the most critical limit state in a ship structure, the longitudinal strength of the midship hull girder is of particular interest because the vertical bending moment is one of the highest load effects that a ship structure has to withstand [12]. Even though the complete failure of the ship hull will not be attained until the ultimate bending strength is reached, reaching the first failure moment (i.e., the moment at which the first plate or panel fails) serves as a crucial sign of warning against collapse.

The first failure moment is determined herein using a simplified progressive collapse method [11]. The method is designed to provide the ultimate strength of the ship hull. However, the sequence of failures preceding the ultimate failure is followed in the process. The first failure moment is found as the first encountered failure mode. In this method, an assumption is made where a stiffened panel is removed from the system once it fails (i.e., its post ultimate behavior is neglected). However, using this method only for the computation of the first failure omits the need for this assumption and it has no bearing on the computation of the first failure moment. Decò et al. [9] integrated this method in a sampling technique to obtain a probabilistic distribution for the first failure moment.

The ultimate failure moment of the hull girder is typically determined using well-documented simplified methods for predicting the load-shortening curves of steel plates and panels considering the effects of initial imperfections that are used in a systematic incremental curvature procedure to determine the ultimate bending moment of the ship hull. However, Okasha and Frangopol [10] made use of optimization search algorithms to speed up the process of finding the ultimate failure moment

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