ABSTRACT

This paper addresses challenges in fatigue management of marine structural assets with a holistically approach, by jointly considering fatigue design, inspection and maintenance decisions, whilst taking into account sources of uncertainties affecting life cycle performance. A risk-informed and holistic approach is proposed for jointly optimizing fatigue design, inspection and maintenance based on the same fatigue deterioration model. The optimization parameters are fatigue design factor (FDF) and inspection intervals, while the objective is to minimize expected life cycle costs (LCC). The framework is to guide design process as well as to formulate optimal maintenance strategies. The proposed approach is exemplified for the marine industry through a fatigue-prone detail in a ship structure to obtain the life cycle optimal management solution that achieves a best compromise between structural safety and life cycle costs.

KEY WORDS: Integrity management; risk-based inspection; maintenance optimization; uncertainty management; probabilistic design optimization; decision analysis; life cycle engineering

INTRODUCTION

Marine structures are designed, constructed and managed to provide a variety of functions in support of transportation, production, leisure, etc. With the development of technology, functional requirements, budgeting control, safety and reliability are increasingly paramount. Local failures and structural collapse are normally avoided by design analysis and in-service inspections and maintenance, to achieve an acceptable failure probability. Deterioration factors, excessive deformations and vibrations are controlled so that structures are durable and serviceable within the required service lives. Other safety-related structural requirements concern redundancy, robustness and resilience (Faber, 2017). Besides, it is required that engineering design, inspection and maintenance activities are viable and sustainable, both economically and the environmentally. In order to ensure that structures meet the performance requirements, it is becoming normal practice to develop and identify safety check lists and formats to avert potential threats and failure modes in the design stage (HSE, 2001).

Fatigue crack growth is one of major threats for marine structures exposed to the sea environments, in which cyclic wave loading lead to deterioration in terms of crack initiation and growth in structures and if undetected lead to failure. Compared with other threats, fatigue cracks are safety-critical, as they can cause sudden rupture of structural cross-sections, leading to losses to human lives, commercial assets and the environment (Fricke, 2003). Crack initiation can be caused by several mechanisms, e.g. cyclic loading, local stress concentrations, corrosion, imperfections in materials, etc. Fatigue cracks are very common in marine assets operating at seas, and detecting and repairing fatigue cracks represent a substantial and expensive task. According to the characteristics of crack development, fatigue cracks are typically very small during a significant part of the service life, and therefore the time is usually very short for cracks to develop from a detectable size \( a_0 \) to the critical size \( a_c \) (Fig. 1). This poses a real challenge for detecting cracks reliably before they may cause catastrophic failures.

Figure 1. Crack initiation and propagation

Another challenge is that fatigue failures are difficult to predict accurately with existing analytical, numerical and experimental approaches. Fatigue resistance is affected by many factors that are only partially controllable, e.g. stress ranges, mean stresses, stress concentration factors, loading sequence, material properties, fabrication and welding techniques, environments, etc. (Fricke, 2003). Fatigue deterioration is associated with a high degree of uncertainty, e.g. those associated with fatigue loading, stress calculation, material properties, fatigue resistance data, fatigue accumulation model and crack growth...