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Probabilistic methods for planning of inspection for fatigue cracks in offshore structures☆

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ABSTRACT

Due to the nature of the fatigue phenomena it is well known that small changes in basic assumptions for fatigue analysis can have significant influence on the predicted crack growth lives. Calculated fatigue lives based on the S–N approach are sensitive to input parameters. Fracture mechanics analysis is required for prediction of crack sizes during service life in order to account for probability of detection after an inspection event. Analysis based on fracture mechanics needs to be calibrated to that of fatigue test data or S–N data. Calculated probabilities of fatigue failure using probabilistic methods are even more sensitive to the analysis methodology and to input parameters used in the analyses. Thus, use of these methods for planning inspection requires considerable knowledge and engineering skill. Therefore the industry has asked for guidelines that can be used to establish reliable inspection results using these methods. During the last years DNV GL has performed a joint industry project on establishing probabilistic methods for planning in-service inspection for fatigue cracks in offshore structures. The recommendations from this project are now included in a Recommended Practice. The essential features of the probabilistic methods developed for this kind of inspection planning are described in this paper.

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1. Introduction

Fatigue is an important design criterion for offshore structures in extratropical waters. In general large uncertainties are associated with fatigue analyses of offshore platforms. Fatigue design of offshore structures is normally based on S–N data (test data) established by constant amplitude testing. In-service inspection to detect fatigue cracks is normally performed in order to assure that potential cracks in the structure, which may have been present from the initial delivery or have arisen at a later stage during the service time, do not exceed a critical size. The reliability of a non-destructive testing (NDT) is described by the ability to detect an existing crack as a function of the crack size and by the uncertainty associated with the sizing of an identified crack. Regardless of the inspection outcome (detection or no detection of a defect), each inspection provides additional information to that available at the design stage. Thus, this information can be utilised to update the estimated fatigue reliability.

For the S–N fatigue approach, the inspection results cannot be used directly to update the estimated fatigue reliability, as no direct relationship between the crack size and the damage accumulation in the S–N approach is available. A calibration of the fracture mechanics fatigue approach to the S–N approach is therefore required to take the reliability of the inspection method into account as probability of detecting fatigue cracks is presented as a as function of crack size. The resulting amount of required in-service inspection is dependent on how this calibration is performed. Therefore, an analysis methodology with calibrated initial defects is presented to make inspection planning less time consuming and less complex to perform.

The basis for this methodology goes back to 1981–83 when DNV performed a joint industry project on cost optimal inspection and maintenance of offshore structures, Ref. [39]. The concept of probability of detection curves was introduced together with crack growth analysis based on fracture mechanics. The effect of inspection was included in reliability analysis using a Bayesian updating approach. Itagaki et al. [16] presented updating of variables based on inspection of ship structures. Updating of variables was also presented by Deodatis et al. [47] and Ito et al. [48]. Updating of fatigue failure probabilities based on events was presented by Madsen [22]. This methodology has later frequently been used for evaluation of inspection results with respect to fatigue cracks; see e.g. Ref. [23]. A similar methodology has later been used by a number of other researchers; reference is e. g. made to Lotsberg and Kirkemo [19]; Moan et al. [26]; Vårdal and Moan [43]; Lotsberg and Marley [20]; Moan et al. [25]; Cremona [6]; Moan and Song [27]; Lotsberg et al. [21]; Vårdal et al. [44]; Sigurdsson et al. [38]; Moan [28,29]; Dalsgaard Sørensen and Ersdal [7] and Lassen and Recho [18].

In the period 2011–2013 DNV performed a joint industry project on use of probabilistic methods for planning of inspection for fatigue cracks in offshore structures. This work included assessment of this method for jacket structures, semisubmersibles and floating production ships. The recommendations from this project are now included in a DNVGL Recommended Practice. The main background for this document is presented in this paper.

Inspection planning was earlier based on engineering assessment of fatigue utilization and consequence of failure of the considered detail. Without a well-defined relation between calculated fatigue damage, consequence of failure and an acceptance criterion, the resulting inspection plan became very much dependent on the engineer's background and experience. With use of a probabilistic approach a proper relation based on the same units can be established with respect to utilization, consequence of failure and target safety level which makes the assessment methodology more robust and less dependent on engineering judgment. By using this methodology also the actual crack growth characteristics of different types of connections and the reliability of the inspection method used to detect fatigue cracks can be more correctly accounted for.

2. Inspection philosophy

Degradation of offshore structures is caused mainly by corrosion and fatigue crack growth. The effect of corrosion is normally designed for by corrosion allowance or a protection system, which makes the corrosion development gradual and rather easy to control. The fatigue crack growth can be more critical because cracks can result in a sudden fracture. Moreover, cracks are hard to detect because they are rather small for a significant part of the crack growth time.