Proceedings of the Eighth (1998) International Offshore and Polar Engineering Conference
Montréal, Canada, May 24-29, 1998

ISBN 1-880653-34-6 (Set); ISBN 1-880653-38-9 (Vol. IV)

Prediction of Fatigue Crack Growth in Offshore Structures Using a Sea State Equivalent Stress Concept

L.S. Etube, F.P. Brennan and W.D. Dover
University College London
London, United Kingdom

Abstract

Fatigue testing under simulated service conditions has advantages over constant amplitude tests. For example the variability in both amplitude and frequency content of service loading can be reproduced by carrying out tests under simulated service conditions. This means that the complex interactions between environment and loading which govern fatigue crack growth mechanisms in offshore structures are taken into account.

Existing fracture mechanics models and fatigue crack growth prediction methods generally rely on using the overall equivalent stress range with a suitable crack growth law for fatigue crack growth prediction under variable amplitude loading. For S-N type analysis this method is by far the best when dealing with variable amplitude sequences. However, for fracture mechanics (FM) crack growth prediction employed after an in-service inspection schedule, the use of the overall sequence equivalent stress range will not allow for sequence effects to be accounted for. These effects can be significant under service loading conditions as crack growth is largely dependent on the stress intensity factor range-which is a function of stress range and crack size. It is possible that the use of the overall sequence equivalent stress concept in a fracture mechanics analysis procedure may not be robust enough to handle the high degree of variability observed in service as crack growth acceleration and retardation can not account for. A different and more realistic fracture mechanics based approach is required.

This paper presents a new fracture mechanics based model for predicting fatigue crack growth in offshore structures. The model relies on the use of measurable sea state properties to determine crack growth associated with each sea state over its duration. It uses the principle of equivalent stress range but limited to a sea state. This approach is more representative of fatigue damage under service conditions and has the added capability of allowing the inclusion of any sea state interaction effects which may be anticipated.

Introduction

Fatigue is the main source of structural degradation of structures in the North Sea and has been the focus of many major research programmes. Due to the fact that fatigue is sensitive to many factors, extrapolating fatigue behaviour, obtained by studying crack growth under constant amplitude loading conditions, to in-service loading is not easy. The latter has for example, both variable amplitude and frequency content. Thus it is also possible that under realistic loading conditions, sequence effects can be significant, resulting in both fatigue crack acceleration and retardation which can neither be reproduced nor predicted from the understanding available from constant amplitude tests.

The process of signal generation and cycle counting is often a very lengthy one. Theoretical equations such as Wirsching [5, 6], Chaudhury and Dover [7], Hancock [8] and Kam and Dover [9] have been proposed which have made it possible to avoid this lengthy signal generation and cycle counting process. These however have been limited to discrete spectra where only the equivalent stress for a particular sea state for example can be obtained. This paper presents a methodology that can be used to calculate the crack growth associated with any particular sea state by using these theoretical methods. It then illustrates how a proposed probability distribution function can be used together with fast assessment equations to predict the behaviour of cracked offshore structures under service loading conditions. This approach relies on the use of a sea sate probability distribution function together with a sea state equivalent stress concept to characterise fatigue crack growth in offshore structures.

This paper gives details of how the sea state equivalent stress concept can be applied to offshore structures using a conventional cycle counting methodology. It further introduces a sea state probability distribution function and illustrates how it can be used to calculate equivalent stresses for typical offshore loading for use in fatigue assessment.

Sea state Probability Distribution Model

A detailed examination of oceanographic data for the North Sea, observed over a period of several years has shown that the distribution of significant wave height, H_s, is accurately described by the Gumbel distribution. The Gumbel distribution is given as;

$$P(x) = 1 - \exp[-\exp(-x)] \quad (1)$$