

Damage Tolerance Assessment of Welded Joints Subjected to Fatigue Crack Growth

T. Lassen

Agder University College

Grimstad, Norway

ABSTRACT

The present paper suggests a probabilistic damage tolerance supplement to the design S-N curves for welded joints. The reliability levels are derived from extensive testing with fillet welded joints (F-class detail) for which the entire crack growth history is measured, not only the final fatigue life. The statistics in time to reach given crack depths are determined. A Markov model is fitted to the data base and scaled to in-service conditions. Results for some frequent cases occurring in practice for offshore structures are readily derived and presented. The scope is to provide the practising engineer with simple graphical aids that predict the reliability against fatigue fracture during service life. The impact of chosen fatigue design factors and uncertainty in applied stresses is revealed. The effect of an in-service inspection program is also predicted. The graphical tools are suggested for use in support of decision-making at the design stage, without any advanced fracture mechanics modelling and stochastic simulation.

Key Words: Offshore structures. Welds. Fatigue. Crack Growth. Inspection. Uncertainty. Reliability. Decision making.

1 INTRODUCTION

Fatigue durability and inspection planning have for a long time been important issues in the design and scheduled inspection of welded components and structures. For welded structures subjected to cyclic repetitive loading, the admissible stresses in the vicinity of welded joints are relatively low due to the joints vulnerability to fatigue damage. The susceptibility to fatigue damage is due to stress concentrations, microscopic initial flaws and residual welding stresses. Even large complex structures may often be divided into a relatively low number of elementary joints. To verify the fatigue life and control the fatigue damage during service of such structures, it is necessary to study in detail the fatigue behaviour of these simple joints. It has been recognised that the fatigue process is a random phenomenon. Fatigue laboratory tests exhibit considerable scatter. Additional uncertainties are introduced by crack growth modelling, service loading and in-service inspection. Normally, the structures have to be designed for a finite life with an accepted probability of failure based on the S-N approach. Hence, cracks may propagate and become critical during the predicted "safe-life", unless discovered in time and repaired. If fracture

is unacceptable, additional safety measures must be taken through in-service inspection requirements specifying Non Destructive Inspection (NDI) methods, inspection intervals and repair procedures. This leads to the damage tolerance concept; a joint containing a crack has to withstand the service loading for some time. During this time there must be a large probability that the crack be detected before it becomes critical. To verify this probability, the reliability against such a failure must be calculated explicitly as a function of service time in support of the inspection strategy. A combination of elements from fracture mechanics and stochastic modelling provide the necessary tools for these reliability calculations. This so-called probabilistic fracture mechanics approach has lately been widely used on welded tubular joints which often are the primary structural joints in fixed structures in the North-Sea. The analysis is often carried out using the First Order Reliability Method (FORM), which has become a standard method in structural reliability. A limit state function is formulated by applying Linear Elastic Fracture Mechanics (LEFM). The uncertainties of all the influencing parameters can be taken into account by treating them as basic random variables. One problem which usually arises is that the necessary statistical information (mean value, standard deviation and distribution type) for these variables is not known. It is therefore of interest to carry out an investigation on some supplementary stochastic methods which are more direct and easily applicable. An alternative is to assume an evolutionary probabilistic structure from the start, based directly on test results, thus avoiding any fracture mechanical modelling. One of these methods is the Markov Chain approach where crack depths are treated as damage states. A basic element of the model is the concept of a Duty Cycle (DC) which is a repetitive period of operation in which damage can accumulate. During a DC there is a given probability that the damage will remain in the state occupied at the start of the DC and a complementary probability that the damage will reach the next higher state. This is a "bulk statistical" assumption which circumvents the problems with detailed statistical information for each crack growth rate parameter involved in LEFM. The model was first set forward by Bogdanoff and Kozin (1985). The present paper presents results for a fillet welded joint which is the most widespread configuration in ships and offshore structures. The scope is to provide the practising engineer with a tool for decision making regarding the Fatigue Design Factor and a scheduled inspection program.