

Recommended Hot-Spot Analysis Procedure for Structural Details of Ships and FPSOs Based on Round-Robin FE Analyses

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ABSTRACT

As part of the Joint Industry Project *FPSO Fatigue and Fracture Capacity*, a Special Task Group of 9 participants performed investigations regarding finite element (FE) modelling and analysis of typical structural details in FPSOs (Floating Production, Storage and Offloading Units) as well as in ships. The purpose of this special effort was to develop recommendations on appropriate hot-spot stress methods and S-N data for fatigue strength design. In total, 5 details with different characteristics, from the perspectives of both geometry and fatigue loading, were selected, for which stress measurements and fatigue tests are available. Participants developed various FE models, using different types and sizes of elements, modelling and stress evaluation techniques as well as FE programs. Comparisons between the analysis results and measured stresses near the weld toes allow conclusions to be drawn. Three different stress extrapolation techniques for predicting hot-spot stresses at the weld toes were investigated. The resulting hot-spot stresses, together with the estimated fatigue lives, are compared against the existing design S-N curves published by the International Institute of Welding (IIW). It was concluded that the hot-spot stresses predicted using the 3 stress extrapolation techniques, where in most cases the element sizes and stress evaluation points are determined by the plate thickness, can be used with the current design S-N curves. One of the recommended methods requires no stress extrapolation, which is considered an attractive and practical alternative to the existing practices developed by classification societies.

INTRODUCTION

The hot-spot stress approach for the fatigue strength assessment of welded joints is based on the assumption that the local stress increase at the weld toe can be subdivided into 2 parts, one governed by the structural (i.e. macrogeometrical) stress increase, and the other created by the localized notch stress due to the weld toe itself, which is restricted to a region of 2 to 3 mm around the toe. Further, it is assumed that the fatigue assessment can be based on the first part, i.e. the structural stress at the hot spot, together with an appropriate S-N curve, which implicitly considers the effects of the localized notch and additionally is valid for a certain class of weld shapes and materials. Regarding the hot-spot stress, experimental and analytical procedures have been derived for its determination by extrapolating the structural stress outside the localized notch-affected zone to the weld toe. The approach was first applied in the 1970s to tubular joints of offshore structures, where the increase in structural stress can be very high due to local bending of the tubular shell close to the connection between brace and chord (Almar-Næss, 1985).

The hot-spot stress approach was later also applied to welded plate structures (Radaj, 1990), which are typical for ships and FPSOs (Floating Production, Storage and Offloading Units). Here, 3 different types of hot spots at weld toes can be identified (Fig. 1):

(a) at the weld toe on the plate surface of an ending attachment

(b) at the weld toe around the plate edge of an ending attachment

(c) along the weld of an attached plate (weld toe on attachment surface or on plate, if more highly stressed)

For weld toes on a plate or shell surface, i.e. types (a) and (c), the structural stress can be defined as the sum of the axial and bending part of the stress distribution in the thickness direction (Niemi, 1995). However, a unique definition of the structural stress at plate edges (weld toe type (b)), which can be used for fatigue strength assessment, is not possible. Thus, extrapolation of edge stresses is currently regarded as the only practical way for the determination of hot-spot stresses.

The hot-spot stress approach has often been criticized. In particular, the problem of defining appropriate reference points for the stress extrapolation has triggered many debates. Several codes and guidelines in various industrial sectors recommend different procedures for the determination of hot-spot stresses and S-N curves. Even in the shipbuilding and offshore industry, the procedures established by the classification societies and other authorities are diverging. Uncertainties about the suitability of the hot-spot stress approach have been raised by round-robin analyses such as ISSC (1997), showing large scatter and differences between analysis results and measured stresses.

The industry, however, considers the hot-spot stress approach a very practical approach, offering a better alternative than the traditional nominal stress approach for the assessment of individual joint geometries in ships and FPSOs, which vary from detail to detail due to different scantlings and geometrical configurations. As large differences in fatigue assessment procedures as well as underpredicted fatigue lives cannot be tolerated, much effort has gone into further investigations of the hot-spot stress approach within the Joint Industry Project (JIP) *FPSO Fatigue and Fracture Capacity*. Within this project, which has 18 partners and is coordinated by Det Norske Veritas, a special task group performed

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