International Journal of Offshore and Polar Engineering
Vol. 12, No. 2, June 2002 (ISSN 1053-5381)

Hot-Spot Stress Design Curves for Fatigue Assessment of Welded Structures

S. J. Maddox
TWI Limited, Great Abington, Cambridge, UK

ABSTRACT

Fatigue design rules for welded structures have not kept pace with computing developments in design, notably the increasing use of finite element stress analysis (FEA). In this respect, a design approach based on the hot-spot stress is expected to be the most suitable for treating welded joints in which weld toe cracking is the likely mode of failure. As part of a recent JIP addressing the fatigue design of FPSOs, available hot-spot S-N data obtained from structural weld details, including results obtained as part of the JIP, were evaluated as the basis for hot-spot stress design S-N curves.

INTRODUCTION

Fatigue is a vitally important design criterion for welded components and structures because of the relatively poor fatigue performance of many weld details compared with unwelded material. Considerable effort has been put into the production or improvement of fatigue design rules in recent years, particularly in Europe (BSI, 1993; DNV, 1998; DNV, 2000) but also on a more international level (Hobbacher, 1996). In view of the broad level of agreement regarding the significance of key factors, very good agreement exists between the approaches contained in such rules and the design data presented (Maddox, 1997). It is anticipated that the basic approach in current fatigue design rules will remain in use, with incremental improvements, for many years to come, but a feature that is increasingly regarded as a disadvantage is that these are based on the use of the nominal applied stress. This proves to be a problem in the design of some structural configurations because of the difficulty of defining nominal stresses. The same problem frequently arises when stress information is obtained by finite element analysis (FEA). In view of this, there is growing interest in the use of hot-spot stresses for fatigue design.

While the hot-spot stress approach has been in routine use in the design of steel tubular structures for over 25 years (HSE, 1995), the approach is not yet fully developed for application to plate structures. Two issues still need to be addressed:

- The definition of the hot-spot stress and how it is derived from stress analysis of the structure.
- The choice of hot-spot stress design S-N curves.

Both issues were addressed in a major Joint Industry Project (JIP), *FPSO—Fatigue Capacity*, directed at the design of floating production, storage and offloading (FPSO) units. This included extensive FEA and fatigue testing of typical FPSO weld details (Lotsberg, 2001). This paper addresses the second issue, partly on the basis of fatigue test results obtained in the JIP (Kim, 1999), but mainly on the basis of relevant, published fatigue test data for a wider range of structural connections and dimensions. Thus, although FPSO design was the focus of attention, the findings of the work presented are applicable to other steel-plate welded structures.

Received October 12, 2001; revised manuscript received by the editors January 22, 2002. The original version (prior to the final revised manuscript) was presented at the 11th International Offshore and Polar Engineering Conference (ISOPE-2001), Stavanger, Norway, June 17–22, 2001.
KEY WORDS: Fatigue, fillet welds, butt welds, welded structures, hot-spot stress, finite element analysis, design, FPSO.

BASIS FOR HOT-SPOT STRESS DESIGN S-N CURVES

The hot-spot stress fatigue design approach is applicable only to situations where the potential mode of failure is by fatigue crack growth from the toe of a weld. In general, 3 types of weld toe failure can be identified (Fricke, 2001), as illustrated in Fig. 1. In 2 cases, types (a) and (c), it is generally accepted that the stress distribution approaching the weld toe depends, amongst other things, on the plate thickness. Consequently, the hot-spot stress is either the stress at a point that is some proportion of plate thickness away from the weld toe, or it is obtained by extrapolation from stresses located at distances that are some proportions of plate thickness away from the toe. But in the case of type (b)—edge cracking from a weld toe or end—the stress distribution approaching the weld toe does not usually depend on the plate thickness. Consequently, the methods used to address hot-spot types (a) and (c) are not appropriate; alternatives are still under investigation. The present review, then, is confined to types (a) and (c) hot-spots.

By definition, the hot-spot stress includes all the stress-concentrating features of a welded joint *except* that due to the local weld toe geometry. Thus, the most logical basis for the hot-spot stress design S-N curve is that for transversely loaded butt welds. In such details, the only source of geometric stress concentration is the weld itself.

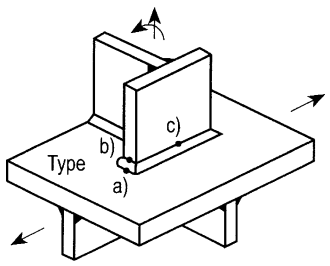

Fig. 1 Types of hot-spot in welded structures: (a) Weld at end of longitudinal attachment (weld toe or end on loaded plate surface); (b) Weld on or around a plate edge (weld toe on plate edge); (c) Weld transverse to loading (weld toe on loaded plate surface).