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Erkki Niemi
Wolfgang Fricke
Stephen J. Maddox

Structural Hot-Spot Stress Approach to Fatigue Analysis of Welded Components

Designer's Guide

Second Edition

INTERNATIONAL INSTITUTE OF WELDING
A world of joining experience

IIW Collection

Series editor

IIW International Institute of Welding,
ZI Paris Nord II, Villepinte, France

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ISSN 2365-435X ISSN 2365-4368 (electronic)
IIW Collection
ISBN 978-981-10-5567-6 ISBN 978-981-10-5568-3 (eBook)
DOI 10.1007/978-981-10-5568-3

Library of Congress Control Number: 2017946952

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

This 'Designer's Guide' follows previous recommendations published in 1995 by the International Institute of Welding (IIW), 'Stress Determination for Fatigue Analysis of Welded Components' edited by E. Niemi. It represents the latest product of the continuing joint-activity of Commissions XIII (Fatigue) and XV (Design) to develop better fatigue design and analysis procedures for welded structures. The Guide focuses on one particular aspect, namely the hot-spot stress approach. It is intended to provide practical guidance on the application of that approach, based on the current state-of-the-art. However, it is also hoped that it will promote wider use of the approach, assist code-writers in its introduction into design Standards and encourage further research.

A shortcoming of current fatigue design rules for welded components and structures is that they have not kept pace with computing developments in design, notably stress determination by finite element analysis (FEA). The basic design method embodied in the rules was actually developed over 30 years ago, when computers were something of a novelty and structural analysis relied mainly on the use of standard formulae and experience. Thus, it was entirely reasonable to base fatigue design on nominal stresses, as is currently the case. However, computer-based analyses like FEA are now used routinely and, with increased computing power, their capabilities are increasing. Thus, general guidance is needed on the determination of the stresses to be used in conjunction with the current nominal stress-based design rules. The IIW has been particularly active in developing such guidance, as noted above. However, this represents an interim solution in that there is also scope for new design methods that take more advantage of the potential output from FEA. One such approach, for designing weld details from the viewpoint of potential failure from the weld toe, is the so-called *hot-spot stress method*. This makes use of the stress adjacent to the weld that includes the stress concentration effect of the welded joint, but excludes the local notch effect of the weld itself. It is generally referred to as the structural, or geometric, stress and its value at

the weld toe is termed the *structural hot-spot stress.* It is then used in conjunction with appropriate S-N curves representing the notch effect of the weld toe.

The hot-spot stress approach should lead to increased accuracy in fatigue design. The current nominal stress-based design curves include some allowance for the stress concentration effect of the weld detail, but in a rather crude way. That stress concentration effect is known to depend on the dimensions and proportions of the weld detail, but the fatigue data used to establish the design curves were obtained from a variety of test specimens with varying geometry. FEA enables the actual geometry and dimensions to be modelled, leading to a more precise estimate of the stress concentration due to the weld detail.

Although in use for tubular structures for over 25 years, only tentative guidance is available on application of the structural hot-spot stress method to plate structures. Key requirements are:

(a) The definition of the structural hot-spot stress and how it is obtained from stress analysis;
(b) The choice of hot-spot stress design *S-N* curves.

Both issues are addressed in the present document, but especially the first, on the basis of the current state-of-the-art. It reflects the findings of major joint-industry research programmes, as well as deliberations by IIW and other standardizing bodies. However, research continues and it is anticipated that improvements to the procedures described will be made in future.

The document is the product of several years of study by IIW Commission XIII Working Group 3, 'Hot-spot stress method in fatigue analysis of welded components', initially under the Chairmanship of Prof. Erkki Niemi (Finland), but then under Prof. Wolfgang Fricke (Germany) when Prof. Niemi retired. Final drafting of the document was undertaken by Prof. E. Niemi, Prof. W. Fricke and Dr. S.J. Maddox (UK). Members of both Commission XIII and Commission XV have participated in the work, as well as practicing engineers from industry. However, special acknowledgement is made to the following:

Prof. G. Marquis—Finland
Dr. M. Huther, Dr. H-P. Lieurade, D. Turlier—France
Prof. A. Hobbacher, Prof. H. Petershagen, Prof. C.M. Sonsino—Germany
Prof. C. Miki, Mr. I. Kojima—Japan
Prof. P. Haagensen, Dr. I. Lotsberg, Dr. K.A. MacDonald—Norway
Prof. J. Samuelsson—Sweden
Dr. P. Dong—USA.

In 2013 it was decided to revise the document in order to consider recent developments in the field. In particular, more emphasis was placed on the structural stress determination by through-thickness stress linearization, on the alternative approaches by Dong, Yiao/Yamada and Haibach and on additional examples to

demonstrate the application of the recommendations. The revised version was finalized in early 2016, again with discussion and comments from the aforementioned Working Group and Commissions of the International Institute of Welding, which is highly appreciated.

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Contents