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Fatigue assessment of welded joints in API 579-1/ASME FFS-1 2016 - existing methods and new developments

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Abstract

The 3rd Edition of API 579-1/ASME FFS-1 2016 *Fitness-For-Service* includes a new Part 14 dedicated to fatigue assessment. An important section in this part covers the fatigue assessment of welded joints. In this paper, an overview of the fatigue methods for welded joints is provided and extensions are recommended. First, an overview is given of the classical fatigue method used in the ASME B&PV Code based on smooth bar fatigue curves in conjunction with a fatigue strength reduction factor. In addition, the mesh insensitive structural stress method is outlined using an equivalent stress parameter based on fracture mechanics considerations in conjunction with a master S-N curve based on the analysis of over 2000 high and low cycle S-N test data. The resulting master S-N curve approach is applicable to high cycle fatigue and low cycle fatigue if a Neuber correction is introduced. In this paper, a new structural strain method is presented to extend the early structural stress based master S-N curve method to the low cycle fatigue regime in which plastic deformations can be significant while an elastic core is present. With this new method, some of the inconsistencies of the pseudo-elastic structural stress procedure can be eliminated, such as its use of Neuber's rule in approximating structural strain beyond yield. The earlier mesh-insensitive structural stress based master S-N curve method can now be viewed as an application of the structural strain method in the high cycle regime, in which structural strains are linearly related to traction-based structural stresses according to Hooke's law. Thus, both low cycle and high cycle fatigue behavior can now be treated in a unified manner. In the low-cycle regime, the structural strain method characterizes fatigue damage directly in terms of structural strains that satisfy a linear through-thickness deformation gradient assumption, material nonlinear behavior, and equilibrium conditions. A PVRC Joint Industry Project is currently sponsoring work on the structural strain method that will lead to its incorporation in the next edition of API 579-1/ASME FFS-1.

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1. Introduction

In a previous paper, Osage [1] provides an overview of the third edition of API 579-1/ASME FFS-1 *Fitness-For-Service* that was published in 2016. The 2016 Edition includes a new Part 14 covering fatigue assessment procedures for in-service components. Fitness-For-Service (FFS) assessments are quantitative engineering evaluations that are performed to demonstrate the structural integrity of an in-service component that may contain a flaw or damage, or that may be operating under a specific condition that might cause a failure. The API 579-1/ASME FFS-1 Standard was specifically written to cover in-service pressurized equipment typically found in the refining and petrochemical industries as well as the fossil utility industry. Part 14 provides methods used to estimate the time to crack initiation using a strain-life approach and is written as a multi-level approach covering screening, current design code methods, and advanced methods that take into account the latest in technology. The advanced methods include fatigue assessment of welded joints using the equivalent structural stress and Master S-N Curve Method and a new smooth-bar fatigue assessment method that incorporates a multi-axial fatigue criterion with a critical plane approach. Cycle counting methods for both welded joint and smooth-bar fatigue methods are also provided. Methods to evaluate fatigue in the subcritical crack-growth regime in API 579-1/ASME FFS-1 using a fracture mechanics approach are also covered.

In this paper, an overview is given of the fatigue analysis methods in Part 14 of API 579-1/ASME FFS-1 2016, pertaining to the assessment of welded joints, as listed below. The fatigue analysis of welded joints may be performed using smooth bar fatigue curve methods or fatigue analysis methods based on welded joint fatigue curves. Cycle counting and plasticity correction procedures are provided for each method in reference [2].

- Level 2, Method A – Fatigue assessment using elastic stress analysis and equivalent stresses: the fatigue damage and remaining life are computed based on an effective total equivalent stress obtained from a linear elastic stress analysis, and a smooth bar fatigue curve.
- Level 2, Method B – Fatigue assessment using elastic-plastic stress analysis and equivalent strain: the fatigue damage and remaining life are computed based on an effective strain range obtained from an elastic-plastic stress analysis, and a smooth bar fatigue curve.
- Level 2, Method C – Fatigue assessment of welds using the equivalent structural stress: the fatigue damage and remaining life are computed based on an equivalent structural stress range parameter obtained from a linear elastic stress analysis, and a welded joint fatigue curve.
- Level 3 – Fatigue assessment using elastic or elastic-plastic stress analysis and shear and normal strains: a multiaxial strain-life method is used with a critical plane approach. Fatigue damage is calculated on each candidate plane using a strain-life equation, the plane with the maximum damage identifies the critical plane and the overall fatigue damage for a given point. The strain-life equation is based on Brown-Miller adjusted for mean stress effects.

A new structural strain method is presented to extend the early structural stress based master S-N curve method to the low cycle fatigue regime in which plastic deformations can be significant while an elastic core is present. The loading conditions which satisfy this criteria are derived via the Bree diagram. In the late 1960's, Bree developed a theory and corresponding diagram plotting the primary membrane stress versus the cyclic thermal stress which delineates the various zones of plastic behavior. The zones include elastic cycling, plastic cycling, elastic cycling after initial plasticity, and ratcheting leading to incremental growth. In this paper, the Bree diagram is extended to four different cyclic loading cases that also account for the ratio of the yield stress at the operating extremums of the cycle. These four cyclic loading cases can be used to determine the appropriate structural stress range to be used in a fatigue assessment using the structural strain method.

The new structural strain method is then presented to extend the early structural stress based master S-N curve method, i.e. Level 2 Method C, to the low cycle fatigue regime in which plastic deformation can be significant

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