Low Cycle Fatigue of T-tubular Joints under Axial Loading

Marie Hochman¹, Marte Madshus² and Stig Berge
Department of Marine Technology, Norwegian University of Technology
Trondheim, Norway

¹ Presently with Det Norske Veritas, Oslo ² Presently with Aker Solutions, Oslo

ABSTRACT

Fatigue of tubular T-joints under axial loading was investigated. Five models were tested, three with R-ratio R=-1 and two with R=0. Hot spot stress was evaluated for the brace and the chord based on strain measurements using the ECSC linear extrapolation procedure. Fatigue loading was applied in load control, to obtain through thickness cracking at a number of cycles in the range 5000 - 10 000 cycles. In addition, finite element analyses were carried out on the same geometries. The experimental data and the FE results were analysed and compared. Results were also compared with published data. Finally, an assessment was made on fatigue design criteria for tubular joints in the low cycle range.

KEY WORDS

T-tubular joint; stress concentration factor; finite element analysis; fatigue testing; low cycle fatigue; fatigue design.

INTRODUCTION

During the operational life time of offshore structures, waves represent the main fatigue loading. Consequently fatigue damage is mostly caused by cyclic loads with small amplitude, and fatigue damage accumulation occurs in the high cycle range, i.e. from 10⁵ to 10⁶ cycles. However, low cycle fatigue may be of interest in specific cases, such as transportation of jacket structures on a barge from shore to field. Low cycle fatigue failures have been reported by the industry during such operations. One refers to low cycle fatigue when the major contribution to cumulative fatigue damage is from stress ranges corresponding to a constant amplitude life less than 10⁶ cycles.

Because most fatigue failures occur in the high cycle range, SN curves for tubular joints are based on high cycle fatigue data (Health and Safety Executive (HSE), 1992). In recent design codes and guidance documents, e.g. UK Department of Energy (1995) and Det Norske Veritas/NORSOK (2004), SN curves were extrapolated by log-linearization from the high cycle to the low cycle range. Both British Standard (1993) and HSE (2004) have set a limitation to this procedure. The SN curve may be extrapolated up to a cut-off stress range equal to twice the material yield stress. However, the data base to support this method is small and inconsistent (UK Department of Energy, 1991), and more data is needed to validate the procedure.

The present work is aimed at generating more data in the low cycle fatigue region, for assessment of design criteria in this range. Five T-tubular joint models with axial loading were tested in the low cycle range. The same geometry was also analysed using a finite element method, in an attempt to numerically determine stress concentration factors at the hot spot of tubular joints. The work presented herein is a continuation of the work reported by Waalen and Berge (2005) on T-tubular joints tested with in-plane bending, and by Boge et al. (2007) on T-tubular joints subjected to out-of-plane bending.

TUBULAR JOINT MODELS

The tubular joint models used in the experimental part of the present work were produced by the offshore yard Aker Verdal, to normal specifications for jacket tubular joints. The mean as-built dimensions and the corresponding non-dimensional parameters were as follows:

- Chord diameter: \( D = 325.3 \text{ mm} \)  \( d/D = \beta = 0.52 \)
- Chord thickness: \( T = 16.2 \text{ mm} \)  \( D/2T = \gamma = 10.4 \)
- Chord length: \( L = 1520 \text{ mm} \)  \( t/T = \tau = 0.79 \)
- Brace diameter: \( d = 168.9 \text{ mm} \)
- Brace thickness: \( t = 12.8 \text{ mm} \)
- Brace length: \( l = 500 \text{ mm} \)

The brace and chord members were rolled seamless pipes. The steel was of type X52 PSL2-HN, with the following strength properties:

- Yield strength: \( S_{YS} = 442 \text{ MPa} \)
- Ultimate stress: \( S_{UTS} = 580 \text{ MPa} \)
- Young’s modulus: \( E = 2.1\times10^5 \text{ MPa} \)