FATIGUE LIFE OF TUBULAR JOINTS IN OFFSHORE STEEL STRUCTURES

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1. Introduction

In the North Sea, a large number of offshore steel structures have been constructed over the last two decades. Soon after oil and gas exploration and production began in the North Sea in the mid 1960'es, it became apparant that the steel structure design developed for offshore activities in the Gulf of Mexico was not adequate, when transferred to the more rigorous North Sea environment. In particular fatigue cracks evolved as a result of wave action during severe winter storms. Thus, it was evident that there was a great need for better understanding of the fatigue phenomenon, so that safer structures could be built.

The lack in the understanding of the fatigue behaviour of offshore steel structures has resulted in comprehensive investigations carried out both in Scandinavia and on a wider European basis, involving all the countries located around the North Sea.

The results obtained in the investigation on the full-scale joints may be found in (1). A summary of these test results are presented herein.

One of the special topics that is dealt with is the fatigue life of tubular joints that have been repaired. The fatigue life of such repair-welded tubular joints is studied, and compared with the original fatigue life of the joint.

2. Experimental investigation

With the dimensions that have been chosen for the tubular joints, these correspond to a large number of joints in the platforms of the Tyra Field in the North Sea. Compared to the largest joints in these platforms, the actual test joints are approximately half size. The Tyra Field is one of the biggest Danish oil and gas fields with 9 fixed platforms.

The test specimens are carried out as double T-joints. This gives for each test specimen four critical areas with respect to fatigue cracks, since these may be expected to develope at the edges of the weld between the main tube (chord) and the secondary tube (branch), in or near the symmetry plane of the specimen. The test joint is loaded in in-plane bending, as may be seen in Figure 1.

In the fabrication of the tubular joint test specimens, it has been emphasized that fabrication procedures, dimensions, materials, welding and quality control correspond as precisely as possible to actual structures constructed recently. This means that the tubular joints tested can be considered to be representative for a large number of the platforms built recently in the North Sea.

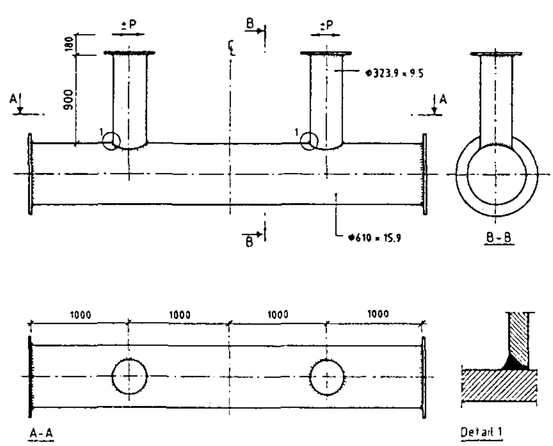

Figure 1 Test specimen from investigation on full-scale, double T-joint

The test specimens have been fabricated from seamless tubes. The yield stress of the material used is $f_y = 370$ MPa and the ultimate strength is $f_u = 525$ MPa. After the first series of tests, the tubular joints were repair-welded, and the fatigue tests were repeated.

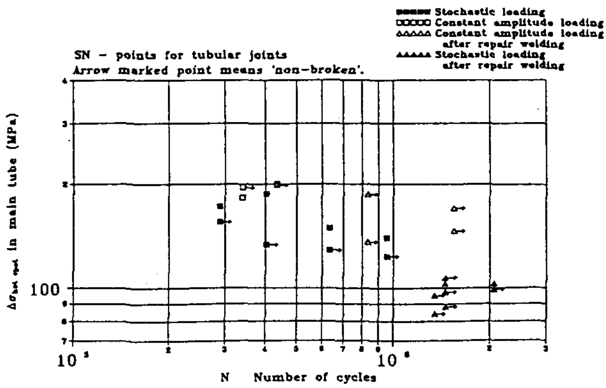

Fig. 2 Results obtained in tests on tubular joints. Stresses in chord.

In the repair-welding, it has been emphasized that the welding procedures correspond as precisely as possible to procedures used presently in the North Sea in repair-welding of fatigue cracks in tubular structures.

The tubular joints have been loaded under constant and variable amplitude loading. In the fatigue tests under variable amplitude loading, a one-step Markov model is used in the load simulation. No lower truncation to avoid cycles below the fatigue threshold level has been introduced in the load simulation algorithm. The spectrum used is based on the Pierson-Moscowitz wave elavation spectrum.

In the results from the variable amplitude tests, the stress parameter used is the equivalent constant amplitude stress range, defined as

$$\Delta\sigma_e = \left[\frac{\sum_i (n_i \Delta\sigma_i^m)}{N}\right]^{1/m}$$

where

n_i = number of cycles of stress range $\Delta\sigma_i$
$\Delta\sigma_i$ = variable amplitude stress range
N = total number of cycles ($\sum_i n_i$)
m = slope of corresponding constant amplitude S-N line

Stress ranges in the variable amplitude tests are equivalent constant amplitude stress ranges, using a value of m = 3. Stresses in the tubular joints are determined as hot spot stresses according to the ECSC-definition, (ECSC = European Coal and Steel Community).

The difference in fatigue life can be quantified by the Miner sum M, defined as the number of cycles to failure at variable amplitude loading, N_{va}, divided by the number of cycles to failure at constant amplitude loading, N_{ca}, at the same stress level.

3. Main findings and conclusions

The number of tests on the full-scale tubular joints that has been carried out in the present investigation is insufficient to make possible a statistical treatment of the test data. However, some of the results are shown in the S-N diagram in Figure 2. From the investigation on the full-scale tubular joints the following conclusions can be drawn :

- Assuming a slope of m = 3 for constant amplitude loading, Miner sums of M = 0.6 - 0.8 are found. The variable amplitude tests on the repair welded joints give the lowest Miner sum.
- The repair welded joints have fatigue lives of 1.9 - 5.0 times the life of the original joints under the same loading conditions. Furthermore, the fatigue crack initiation in general moved from the chord wall in the first series of tests to the branch wall in the test series on the repair-welded joints. The main reason for these observations is assumed to be the differences in weld shape and thus also in stress concentrations in the two cases.

References

1. Ibsø , J.B. and Agerskov, H., "Fatigue Life Prediction of Offshore Tubular Structures under Stochastic Loading", Proceedings of a Nordic Conference on Fatigue. Edited by A.F. Blom. EMAS Publishers, West Midlands, England, 1993.