Fatigue assessment of threaded riser connections

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Abstract

Threaded connections as found in applications like rigid riser, drillstrings, and workover riser are manufactured with sharp notches. Subjected to cyclic loading, those notches lead to high stress concentrations, which increase the risk of fatigue crack initiation significantly. A common connection type that has been the basis for extensive studies is the API Line Pipe connection. Fatigue assessment of threaded riser connections (TRC) is commonly based on a local stress methods. This is the prescribed method in standards and recommended practices such as DNV- RP-C203, BS 7608 or ASME B31.3. For this purpose, the peak stress at the root of the last engaged thread (LET) is found by finite element analysis (FEA). Subsequently, a given design curve is corrected for the notch effect of the thread root and the fatigue life of a connection can be calculated by means of linear damage accumulation. It was shown in different research projects that fatigue assessment of TRC based purely on the peak stress lead to overly conservative lifetime estimates.

In order to achieve more precise lifetime estimates, alternative fracture mechanics methods based on ASME BPVC VIII-3-App. D have been applied. The intention was to establish stress- life diagrams for design purposes of threaded riser connections based on alternative methods. Moreover, comparison of the chosen approach and test results was included to review the obtained results.

It was found that the chosen approach yields unconservative results, when compared with test data, common stress - life design curves and other methods based on the peak stress approach.

About API Line Pipe connection

The basic API thread type consists of truncated triangular threads. In order to tighten the connection the male and female part or pin and box are assembled by applying a make-up torque. This process already leads to stress in the connection that exceed the material yield strength at the roots of the threads. Subjected to cyclic loading a complex stress state arises at the thread roots of both parts of the connection. From screwed connections it is known that approximately half of the axial load is carried by the last engaged thread. Consequently, fatigue cracks develop at this location.

Project aim

This project aims on improving fatigue assessment procedures for TRC by testing different fatigue assessment methods.

Peak stress method

1. Finding peak stress from FEA
2. Calculating stress concentration factor

$$K_t = \frac{\sigma_{\max}}{S}$$

3. Correction of chosen design curve by stress concentration factor

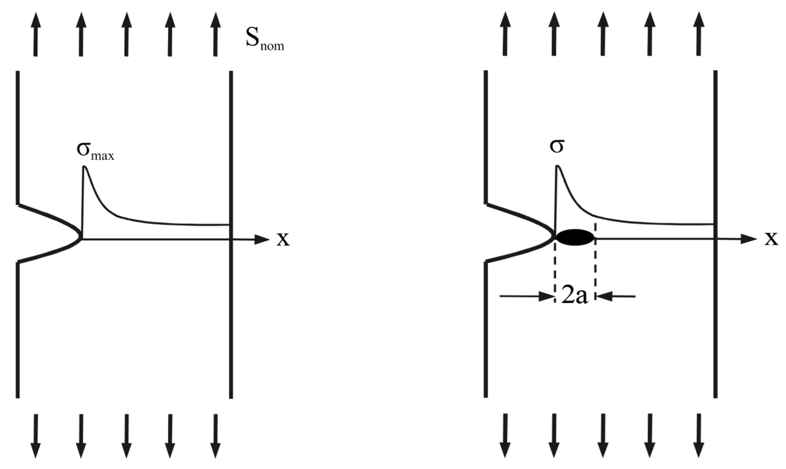

Fig. 1. Illustration of peak stress and ASME FCG method based on [3]

ASME FCG method

1. Assumes a annular flaw at the root of the LET
2. Fitting of 3rd order polynomial to stress field
3. Calculation of stress intensity factor

$$K = F\sqrt{\pi a}$$

4. Numerical integration of Paris law to find crack growth

$$\frac{da}{dn} = C * \Delta K^m$$

5. Establishing of design curve by repetition on different load levels

Weight function method & pfat

1. Finding suitable weight function for crack shape
2. Calculation of stress intensity factor by superimposing stress field on crack body and integration of:

$$K = \int_0^a \sigma(x) m(x,a)\, dx$$

3. Numerical integration of Paris law to find crack growth

$$\frac{da}{dn} = C * \Delta K^m$$

4. Establishing of design curve by repetition on different load levels

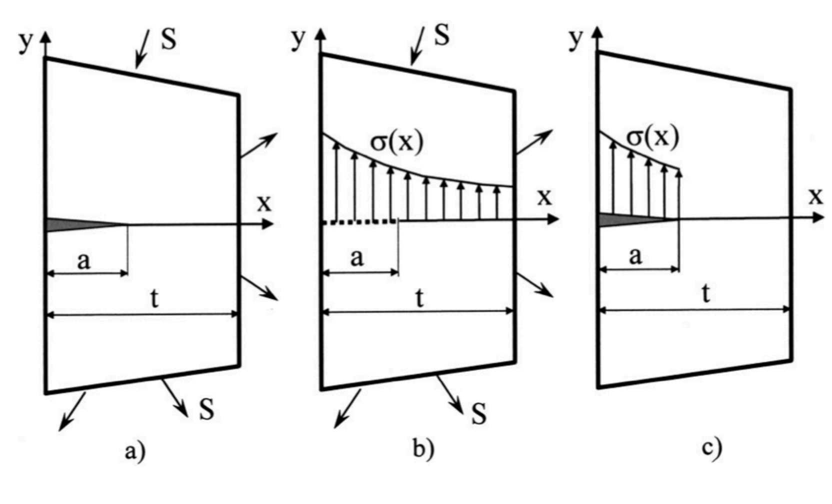

Fig. 2. Weight function method based on superposition principle taken from [4]

Project Objectives

1. Stress analysis of TRC, for which test data are available
2. S-N based fatigue assessment
3. Calculation of final crack size from a failure assessment diagram
4. FCG based fatigue assessment

FE models

- Different fatigue assessment methods require different FE models
- 2D axisymmetric model with elastic-plastic material model for Peak stress method
- 2D axisymmetric model with elastic material model for ASME FCG methods
- 3D model for 3D FCG simulations

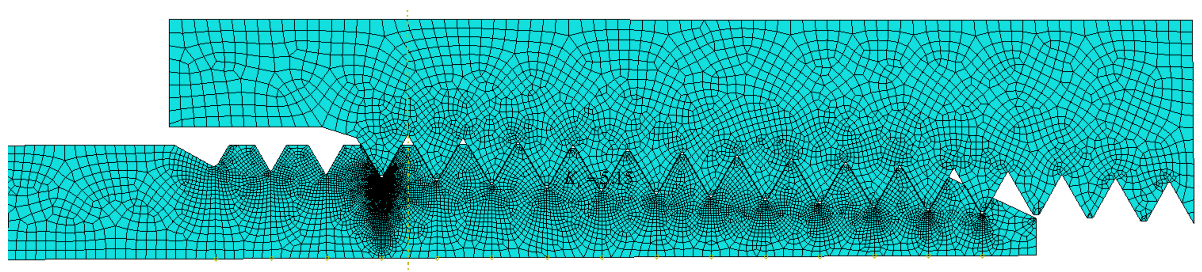

Fig. 3. 2D axisymmetric model

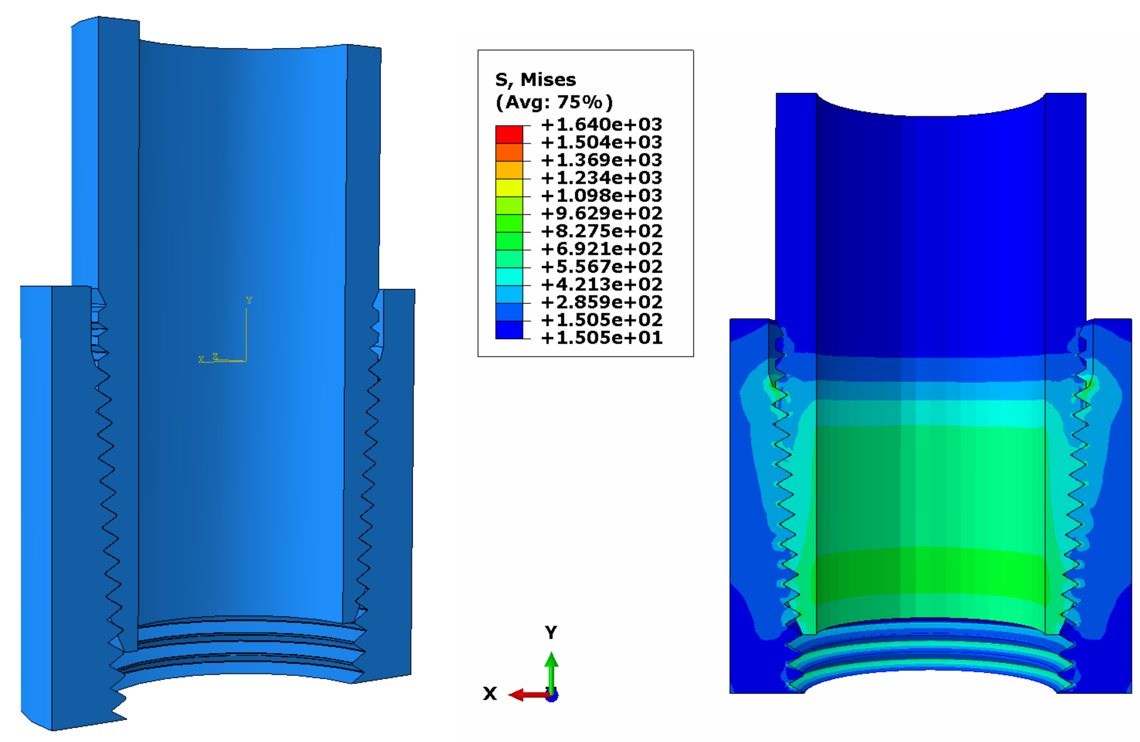

Fig. 4. 3D model

FE simulation

- Simulation of make-up process by using interference fit option in ABAQUS
- Cyclic load cycle applied
- Export of results at thread root and anticipated crack growth path
- Submodelling of 3D model for more accurate results

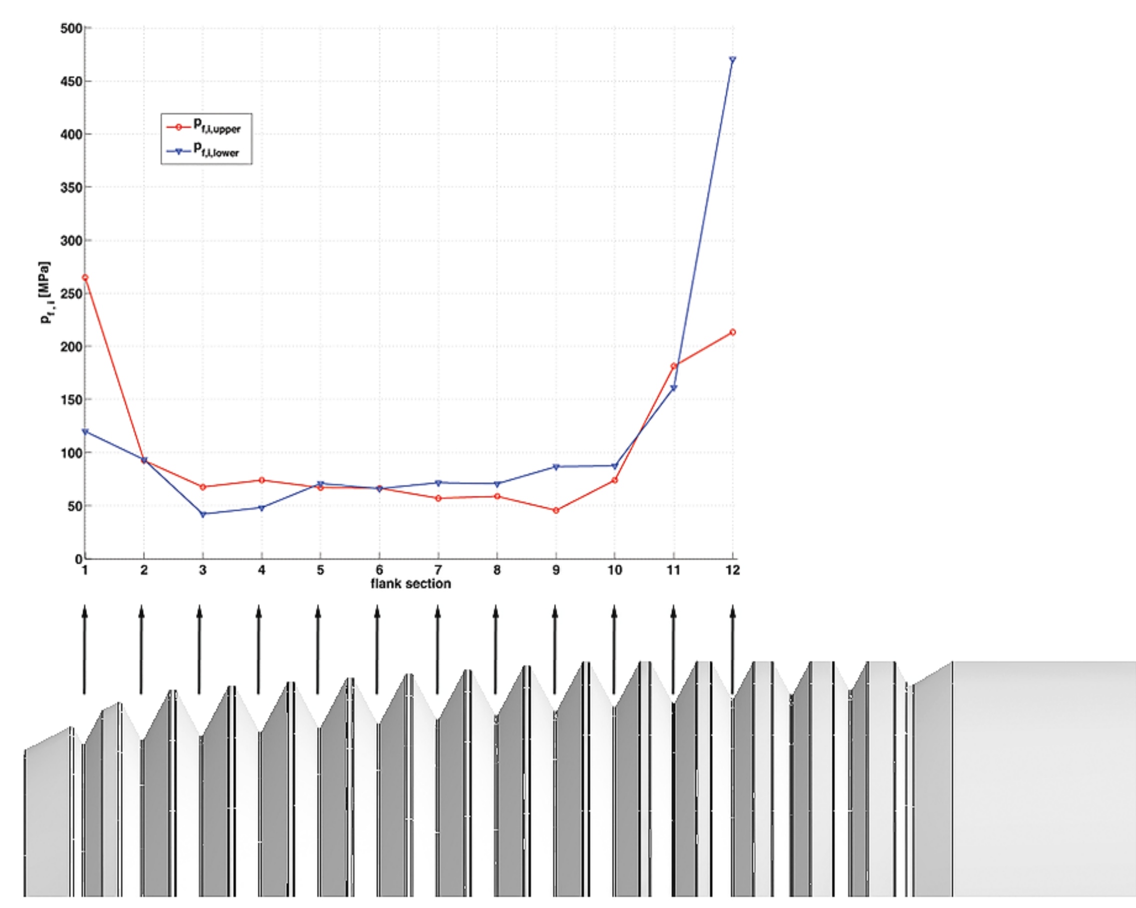

Fig. 5. Contact pressure distribution

Results

1. Peak stress method: $K_t = 5.15$
2. Weight function method:

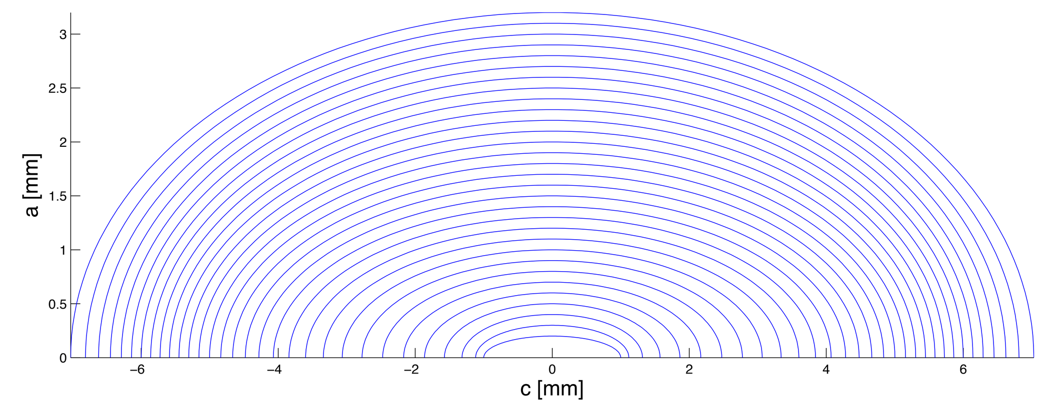

Fig. 6. Crack growth stages from weight function method

3. 3D crack growth simulation with LINKpfat:

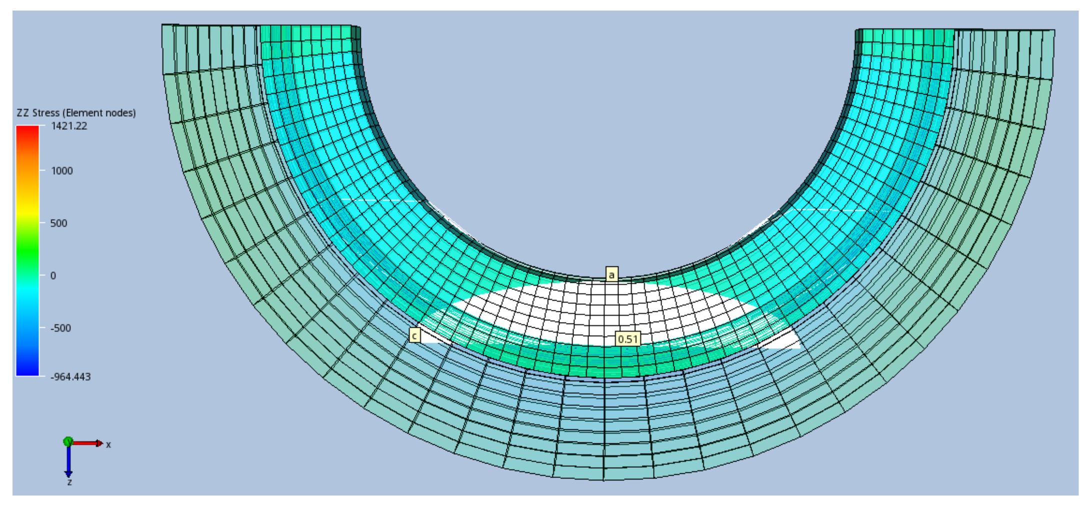

Fig. 7. Final crack size

4. Comparison of resulting SN curves:

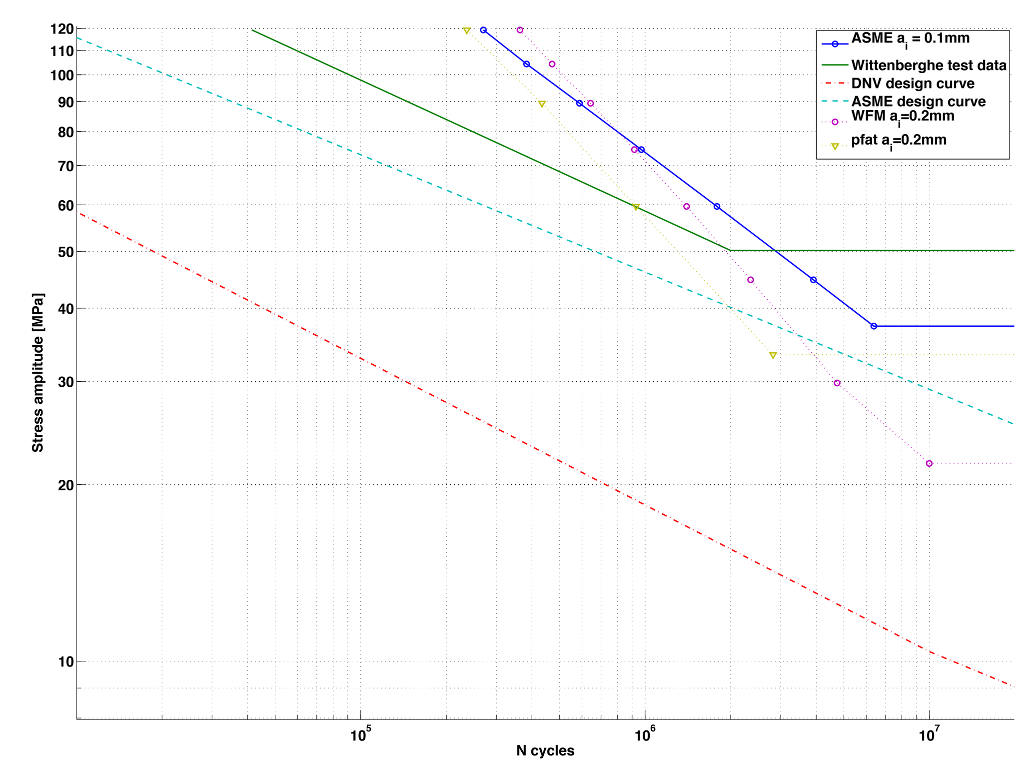

Fig. 8. SN curves

Conclusions

- *Peak stress method yields overly conservative results as expected*
- *Crack growth methods tend to be unconversative*
- *Results are difficult to assess, since test specimen couldn't be reproduced exactly*
- *SN test stopped before real fatigue limit was reached*
- *Important to perform own tests*
- *Industry standards are not well suited for structures with high stress concentrations*

References

1. DET NORSKE VERITAS. RECOMMENDED PRACTICE DNV-RP-C203 - Fatigue Design of Offshore Steel Structures, October 2011
2. A. Kiciak, G. Glinka, and D.J. Burns. Calculation of stress intensity factors and crack opening displacements for cracks subjected to complex stress fields. Journal of Pressure Vessel Technology, 125(3):260 – 266, 2003
3. Van Wittenberghe. Experimental Analysis and Modelling of the Fatigue Behaviour of Threaded Pipe Connections. PhD thesis, Ghent University, Gent, Belgium, November 2011
4. A. Kiciak, G. Glinka, and D.J. Burns. Calculation of stress intensity factors and crack opening displacements for cracks subjected to complex stress fields. Journal of Pressure Vessel Technology, 125(3):260 – 266, 2003
5. A. Fjeldstad, F. Kirkemo, and A. Wormsen. Fatigue assessment of threaded segment speci- mens based on the weakest link theory. In Proc. of OMAE2013, volume 32 of International Conference on Ocean, Offshore and Arctic Engineering, Nantes, France, 2013.
6. ISO 13628-7:2005 Petroleum and natural gas industries -- Design and operation of subsea production systems -- Part 7: Completion/ workover riser systems
7. J.R. Sims, Jr. Section VIII, Div. 3, Alternative rules for the construction of high-pressure vessels. Companion Guide to the ASME BPVC.