APPLICATION STUDY OF POST-TREATED HIGH-STRENGTH STEEL JOINTS IN INDUSTRIAL CRANE FRAMEWORKS

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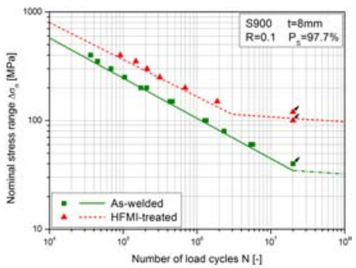
Introduction

Experimental fatigue tests



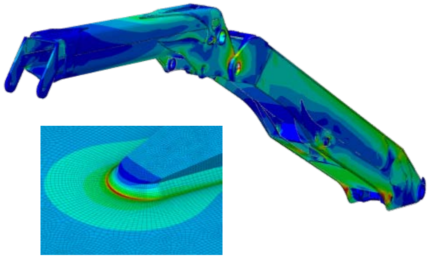
- Evaluation of fatigue strength increase by post-treatment methods
- Statistically verified data

Service load measurements

$$\begin{pmatrix}F_X(t)\\F_Y(t)\\F_Z(t)\end{pmatrix} = Pseudoinv\begin{bmatrix}\varepsilon_{1,X} & \varepsilon_{1,Y} & \varepsilon_{1,Z}\\ \varepsilon_{2,X} & \varepsilon_{2,Y} & \varepsilon_{2,Z}\\ \varepsilon_{3,X} & \varepsilon_{3,Y} & \varepsilon_{3,Z}\end{bmatrix}\cdot\begin{pmatrix}\varepsilon_{1,measurement}(t)\\ \varepsilon_{2,measurement}(t)\\ \varepsilon_{3,measurement}(t)\end{pmatrix}$$

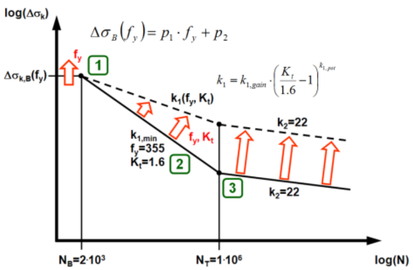
- Built-up of methodology to measure the service loads during operation
- Classification of results

Numerical analysis of structural details



- Numerical analysis of complete structure and critical details by solid, shell and submodels

Local fatigue assessment



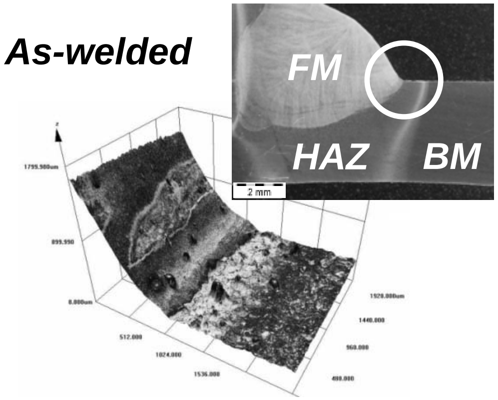
- Local fatigue behaviour of as-welded and post-treated condition
- Lifetime assessment

Light-weight crane frameworks

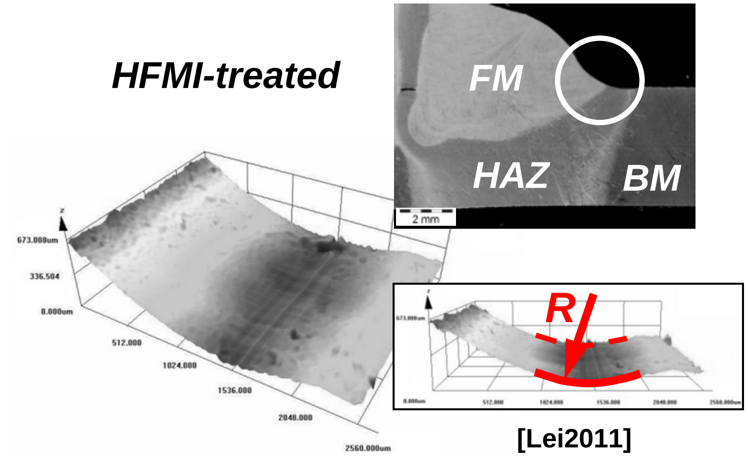
HFMI (High Frequency Mechanical Impact) as post-treatment

Improvement of notch topography

As-welded

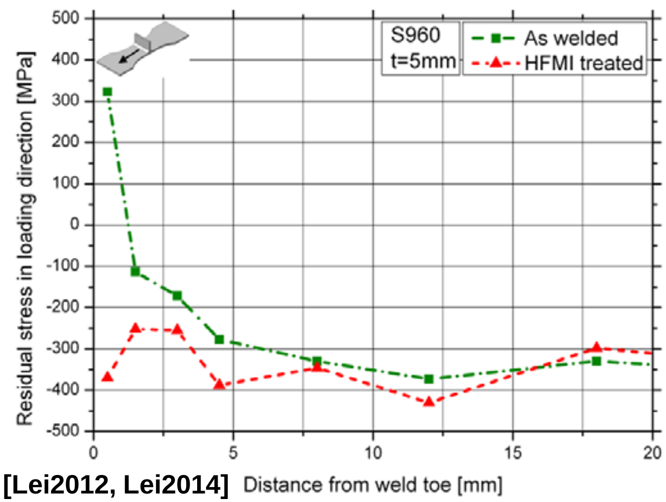


HFMI-treated



[Lei2011]

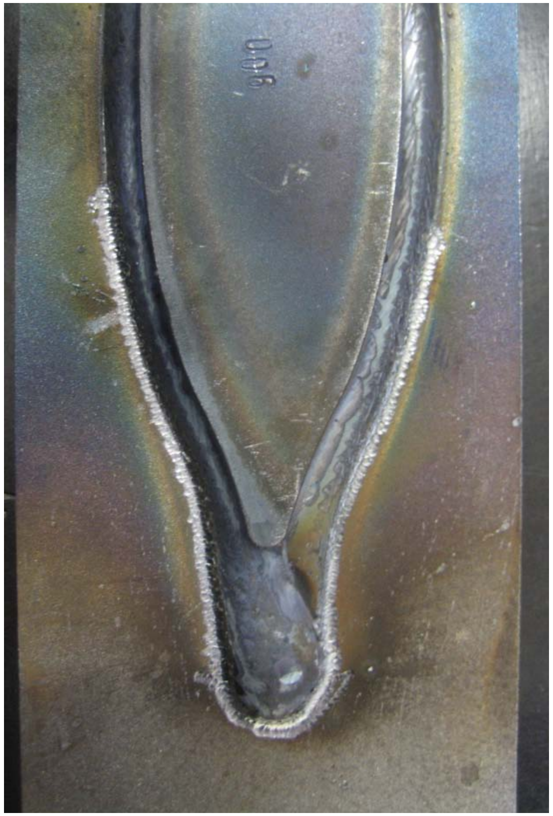
Change of residual stresses

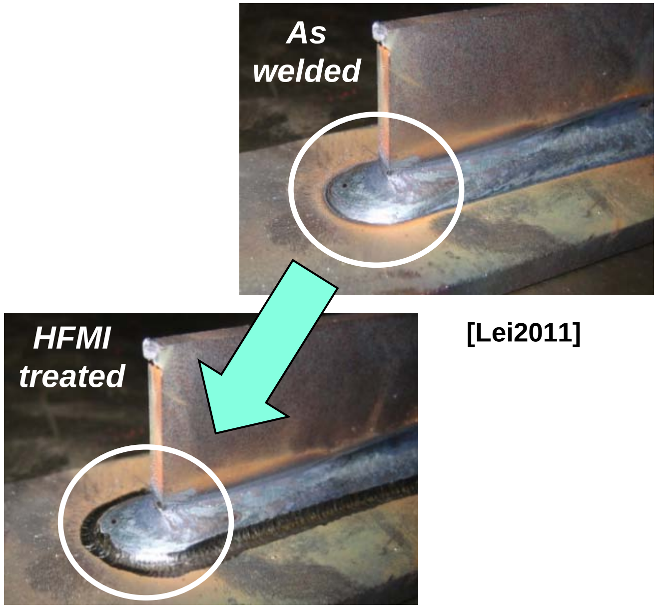


[Lei2012, Lei2014]

- **Surface residual stresses in transversal (load) direction (T-joint, *S960*)**
  - **As-welded: High tensile residual stresses at weld toe region (+*300MPa*)**
  - **HFMI-treated: Superposition of compressive residual stresses → Reduction down to *-350MPa***

End-of-seam specimens – HFMI-treatment



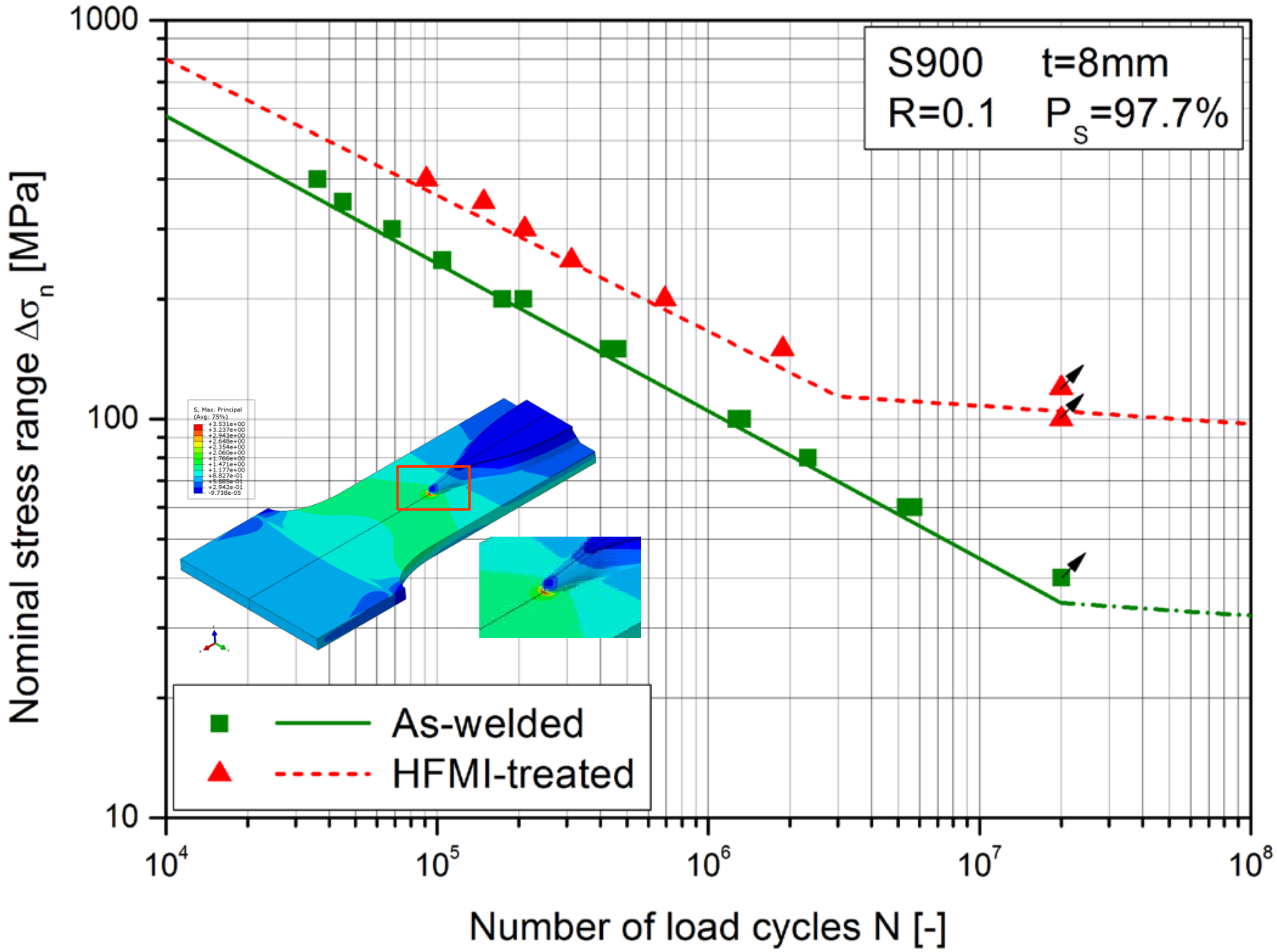


[Lei2011]

[Pit2014]

- **HFMI-treatment at the weld toe as post-treatment method (PIT-System)**
  - **HFMI-Parameters: *p=6bar (~90psi), v=20-30cm/min, f=90Hz***
  - **Radius of the hardened pin: *R=2mm***

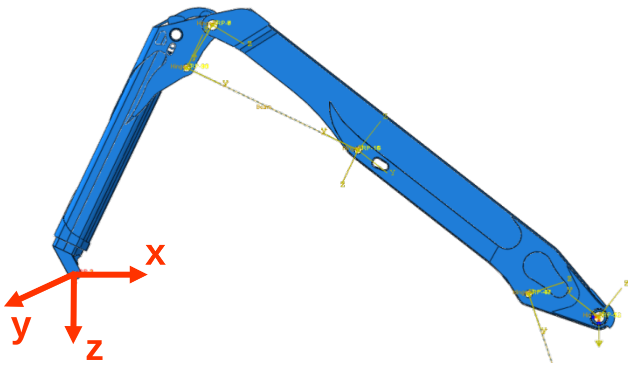
End-of-seam specimens – Nominal S/N-curves



- **Major increase of fatigue strength by HFMI-treatment at the weld toe due to high notch effect at weld toe region (small, highly stressed volume)**

Service load measurements

- **Evaluation of service loads at crane end based on pseudo-inverse approach**



$$F_X = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \rightarrow \varepsilon_X = \begin{pmatrix} \varepsilon_{1,X} \\ \varepsilon_{2,X} \\ \varepsilon_{3,X} \end{pmatrix}$$

$$F_Y = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \rightarrow \varepsilon_Y = \begin{pmatrix} \varepsilon_{1,Y} \\ \varepsilon_{2,Y} \\ \varepsilon_{3,Y} \end{pmatrix}$$

$$F_Z = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \rightarrow \varepsilon_Z = \begin{pmatrix} \varepsilon_{1,Z} \\ \varepsilon_{2,Z} \\ \varepsilon_{3,Z} \end{pmatrix}$$

$$\begin{pmatrix} F_X(t) \\ F_Y(t) \\ F_Z(t) \end{pmatrix} = Pseudoinv \begin{bmatrix} \varepsilon_{1,X} & \varepsilon_{1,Y} & \varepsilon_{1,Z} \\ \varepsilon_{2,X} & \varepsilon_{2,Y} & \varepsilon_{2,Z} \\ \varepsilon_{3,X} & \varepsilon_{3,Y} & \varepsilon_{3,Z} \end{bmatrix} \cdot \begin{pmatrix} \varepsilon_{1,measurement}(t) \\ \varepsilon_{2,measurement}(t) \\ \varepsilon_{3,measurement}(t) \end{pmatrix}$$

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Standard load cases F_X, F_Y and F_Z

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Strain gauge and cylinder displacement measurements in service

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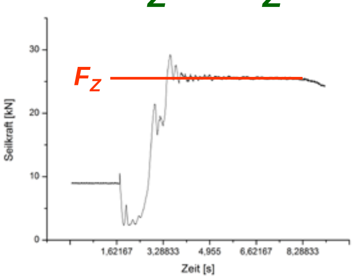
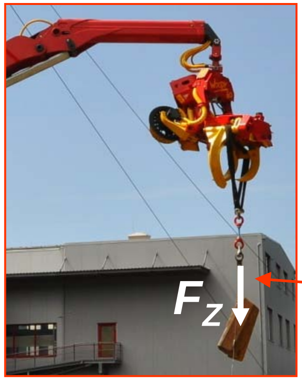
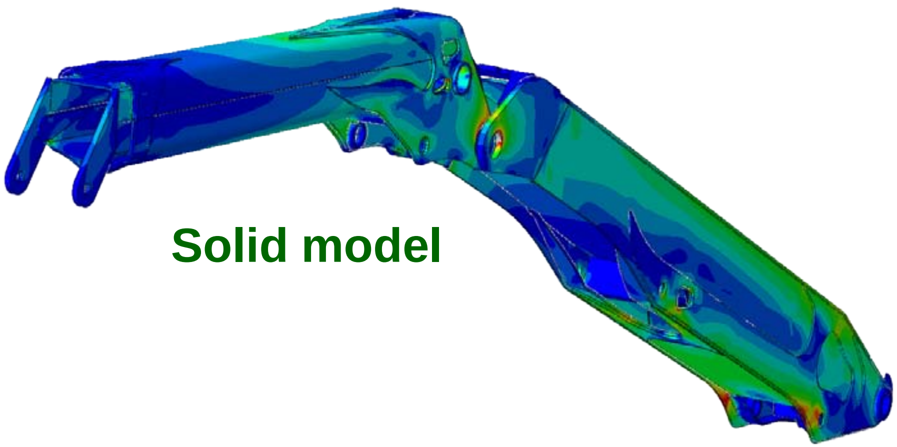
Service loads $F_X(t)$, $F_Y(t)$ and $F_Z(t)$

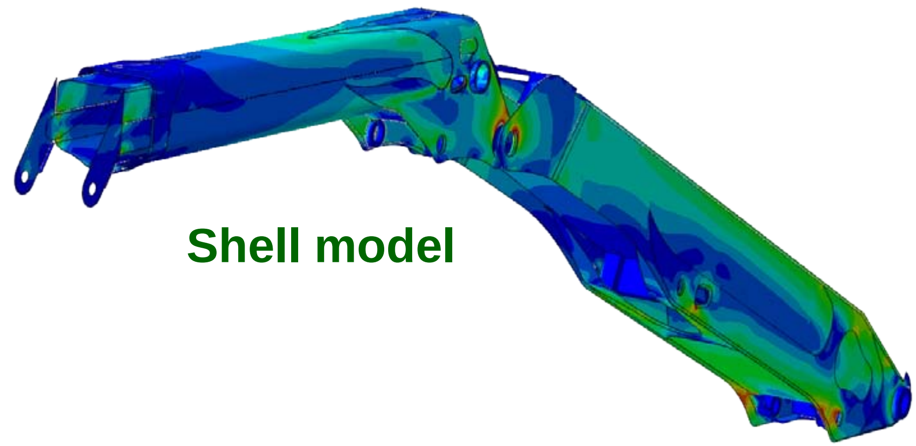
Measurement of $F_Z \rightarrow \varepsilon_Z$





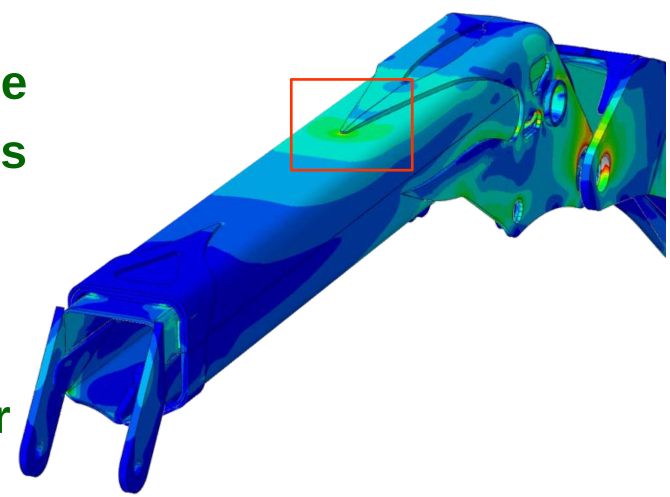
Numerical analysis – Complete model of framework





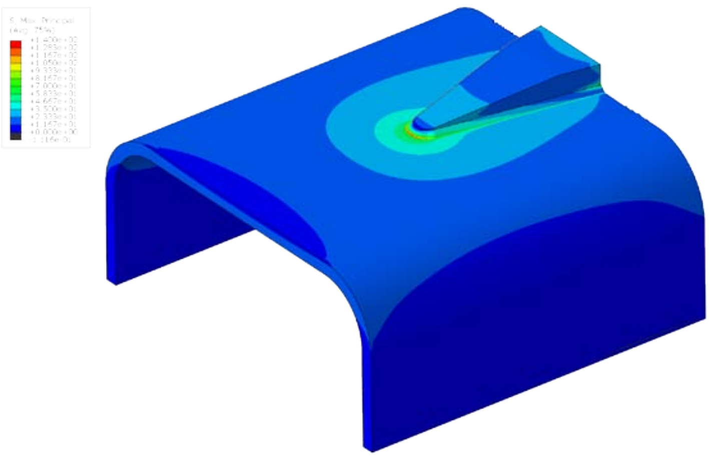
- **Built-up of solid and shell model of complete framework**
- **Good agreement of numerical results between both modeling techniques**
- **Selection of simulation method depends on**
  - **Pre-processing effort and computational time**
  - **Contact modeling between sheets and seams**

- **Detailed analysis of critical end-of-seam detail by submodeling technique**
  - **Fine mesh to evaluate local stress behaviour for fatigue assessment properly**

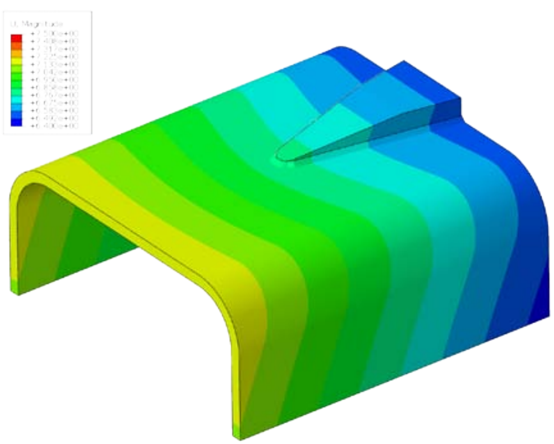


Numerical analysis – Submodel technique

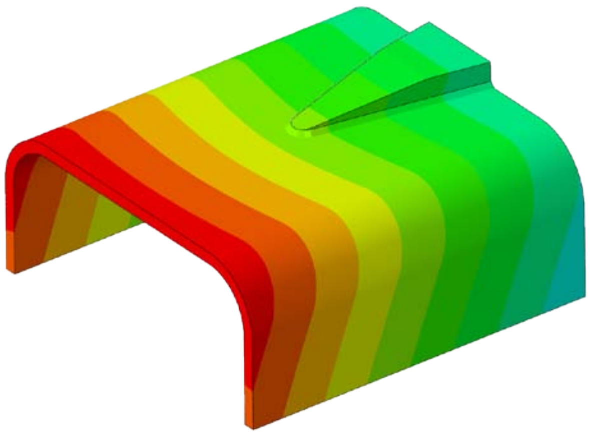
- **Solid submodel of specific framework detail**
- **Mesh according to IIW-guideline [Fri2009]**
- **Displacement data at cross-section points from complete solid and shell framework model**
- **Maximum principal stress at weld toe based on**
  - **Complete solid model: *110MPa***
  - **Complete shell model: *91MPa***
- **Difference caused by minor dissimilar displacements (solid/shell) for framework**



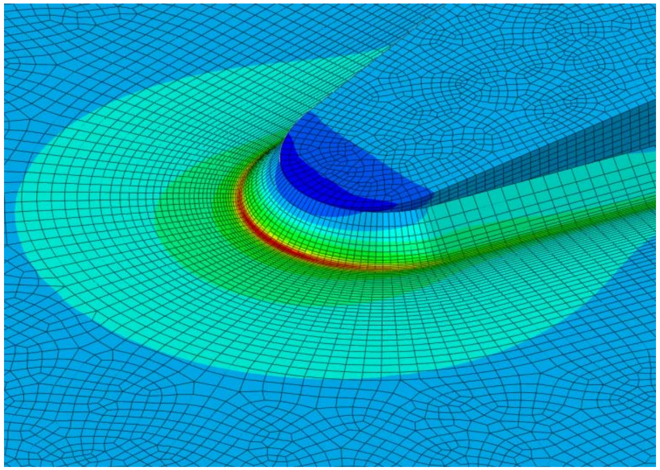
Displacement from complete solid model



Displacement from complete solid model

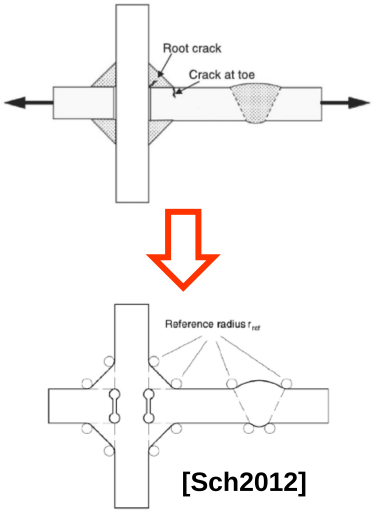


Displacement from complete shell model

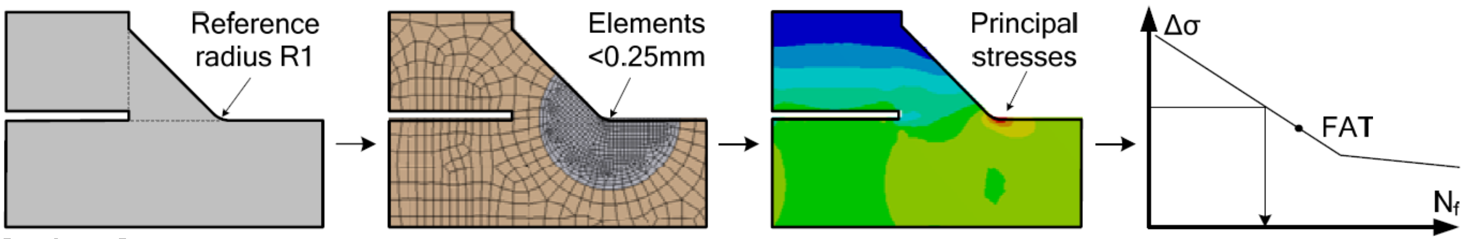


Local fatigue assessment

- **Effective notch stress concept according to IIW-recommendation [Hob2009]**
  - **Reference radius of ρ_f=1mm based on [Neu1968, Rad1996]**
  - **Slope in finite lifetime region for as-welded condition: *m=3***

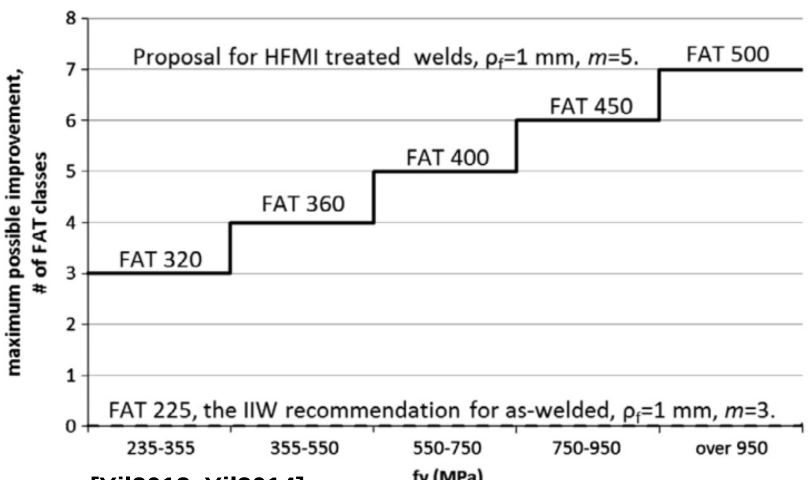


[Sch2012]



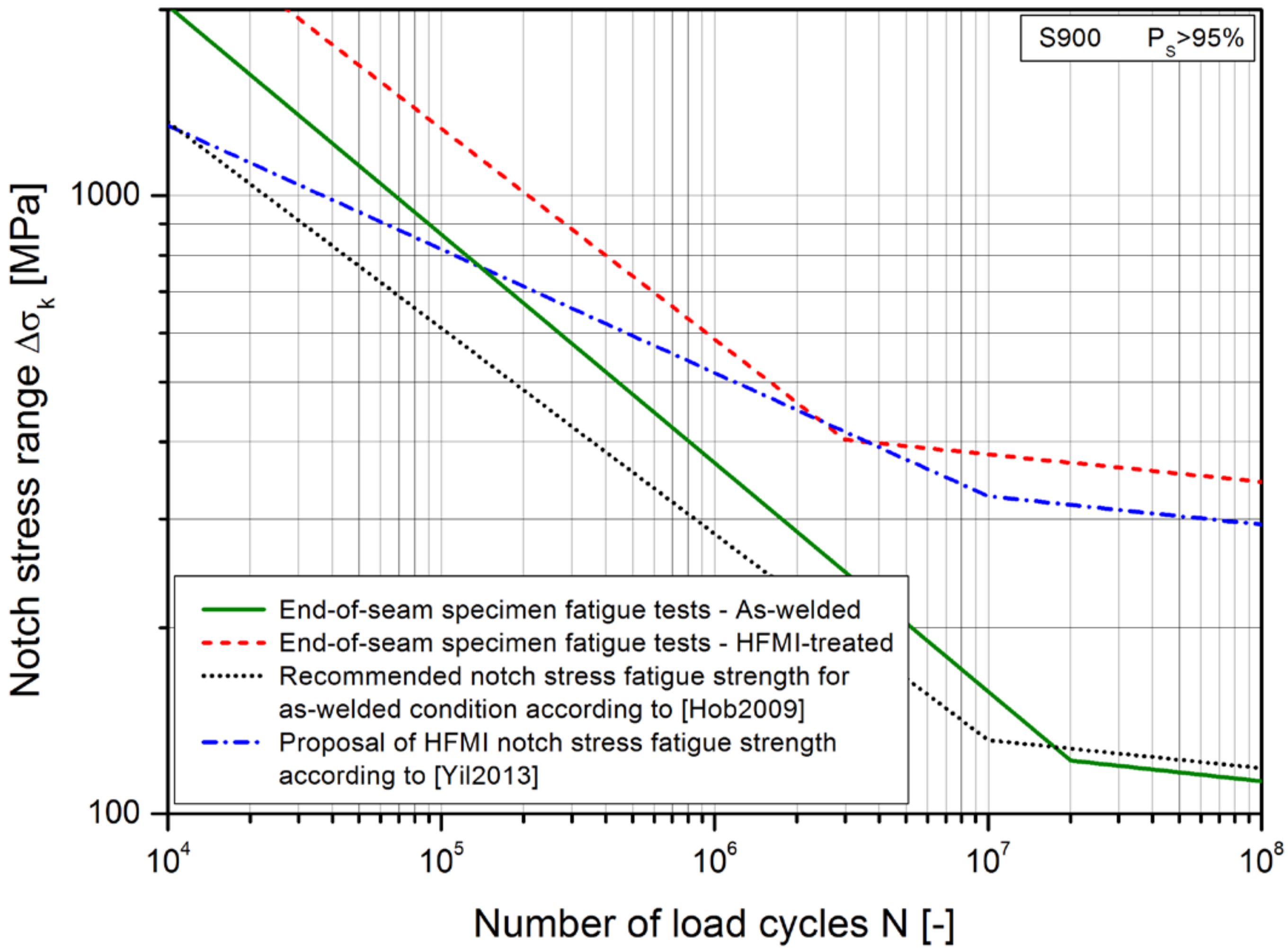
[Ped2010]

- **Proposal of HFMI notch stress fatigue strength according to [Yil2013]**
  - **Reference radius: ρ_f=1mm**
  - **Slope in finite lifetime region: *m=5***
  - **One fatigue class (about *12.5%*) increase in fatigue strength for every *200MPa* increase in ultimate base material strength f_y**



[Yil2013, Yil2014]

Local fatigue assessment



- **Notch stress fatigue assessment shows a good accordance of the fatigue tests and the recommended (as-welded) and proposed (HFMI-treated) values**

Summary and Outlook

- **Presentation of comprehensive methodology to assess the lifetime of crane frameworks based on experimental fatigue tests, service load measurements, numerical analyses and local fatigue behaviour**
- **Nominal S/N-curves of investigated HFMI-treated end-of-seam specimens show a significant beneficial increase of the fatigue strength especially in the high-cycle fatigue region up to *250%* compared to the as-welded condition**
- **Numerical analyses involving solid, shell and submodel technique demonstrate the advantages and drawbacks of each method**
- **Results of the comparative local fatigue assessment are in good agreement to the proposed HFMI-treatment fatigue guideline**

Outlook

- **Influence of applied shell elements to study numerical effects**
- **Determination of stress gradient effect for HFMI-treated joints**
- **Enhancement of variable amplitude HFMI fatigue test data and implementation in recent guidelines [Mik2013]**

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