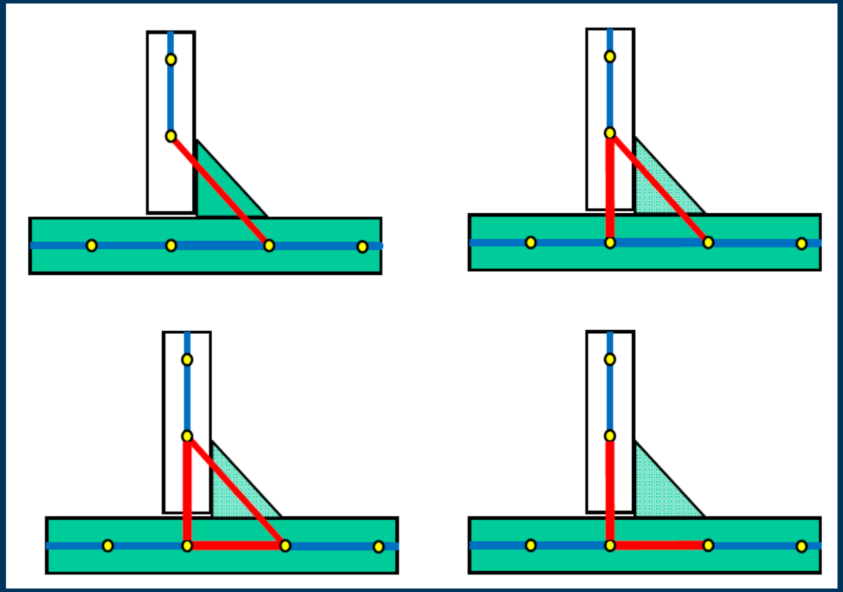
Virtual Seminar Series – Tuesday 2, 9, 16 November



Fatigue Life Prediction of Welds from Finite Element Results

Presented by Mr. Jeff Mentley
Prenscia (HBK)

Tuesday, November 2, 2021

Fatigue Life Prediction of Welds from Finite Element Results

Abstract

Welding is a commonly used and effective method for making structural joints between metal parts. However, the nature of the welding process means that these welds generally have a fatigue strength that is inferior to that of the parts being joined together. The result is that, even in a well-designed structure, the welded joints are likely to fatigue. Any evaluation of the durability of a welded structure must therefore place a high priority on a fatigue assessment of the welded joints.

This presentation examines multiple approaches for the fatigue life prediction of welds from finite element results. Mesh insensitive structural stress techniques are discussed for spotweld, shell seam weld and solid seam weld modelling. These stresses can be obtained from quasi-static analyses, or from dynamic analyses in either the time or frequency domains enabling the correct loading environment to be accurately represented. Corrections applied to the stresses and material definitions for seam weld analysis will be examined, and their application in the fatigue life prediction process discussed.

About the presenter, Mr. Jeff Mentley, Prenscia (HBK)

Jeff Mentley has been involved with finite element analysis for the past 43 years. He has been with Prenscia (formally nCode) as an application engineer for the last 20 years, working in the areas of virtual durability prediction. Prior to joining Prenscia, Jeff held positions in product development, engineering consulting, training, and support at Rasna Corp, PDA Engineering, Physics International and Control Data Corporation. Jeff graduated with a master’s in civil engineering from SUNY at Buffalo.

Fatigue Life Predictions of Welds from Finite Element Results

Presenter: Jeff Mentley

Agenda

1. Introduction to fatigue of welds
2. Structural stresses
3. Shell seamwelds
4. Solid seamwelds
5. Summary
6. Questions

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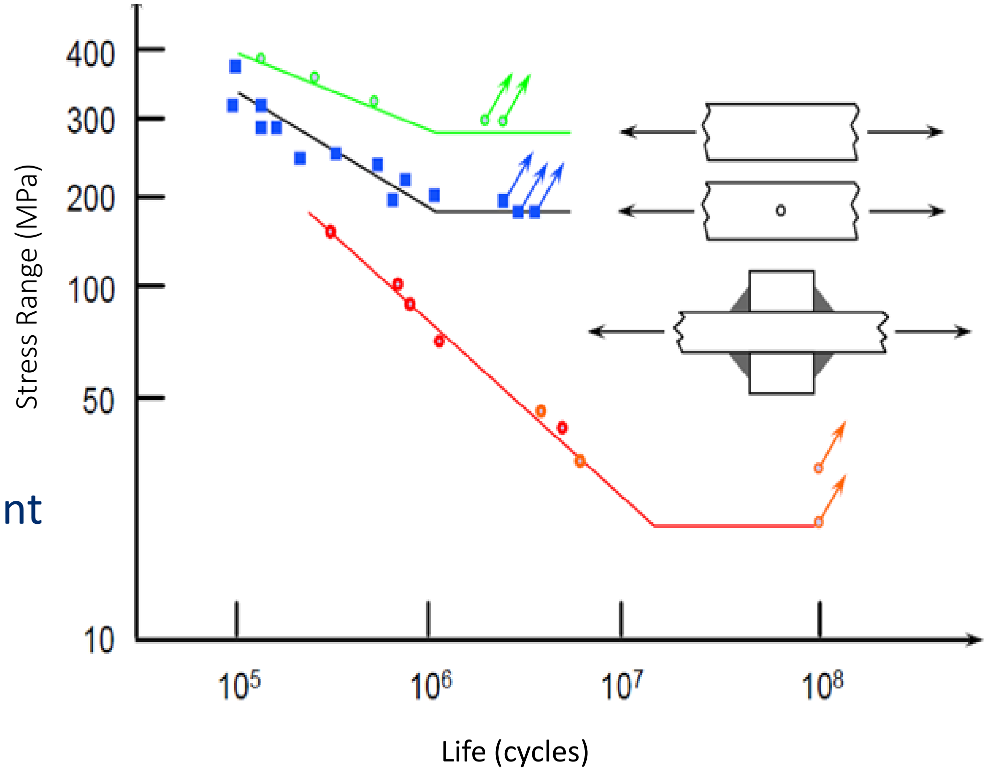
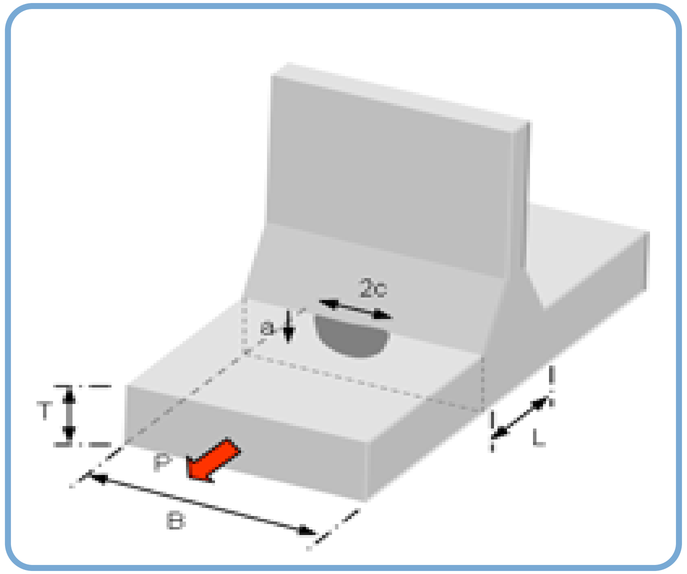
Observations on the Fatigue Behavior of Welds

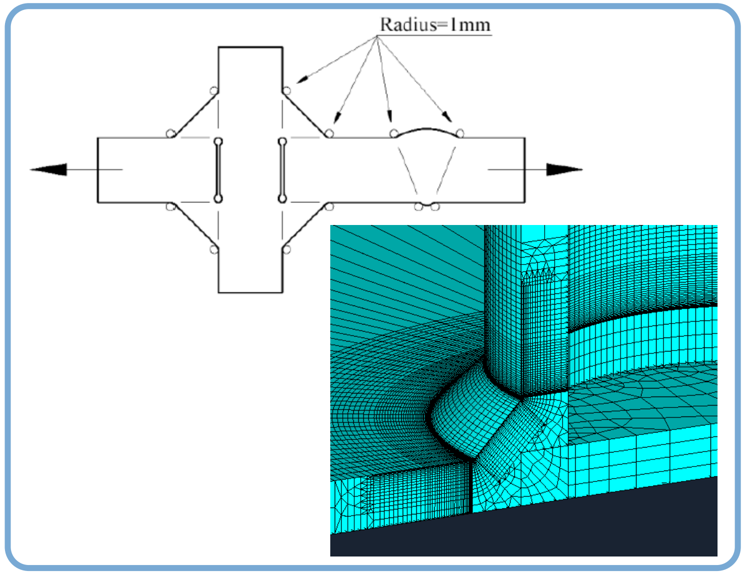
- The fatigue properties of a welded joint are quite different from those of the parent plate due to:
  - Weld geometry usually has
    - Large stress concentrations factors
    - Existing crack initiation sites
  - High tensile residual stresses
  - Non-uniform material distribution
    - Deposited weld metal
    - Heat-affected zone in parent metal
- Fatigue properties of welds are much lower than those of the parent
- Parent metal strength not reflected in the weld fatigue strength
- Weld fatigue behavior is primarily crack growth

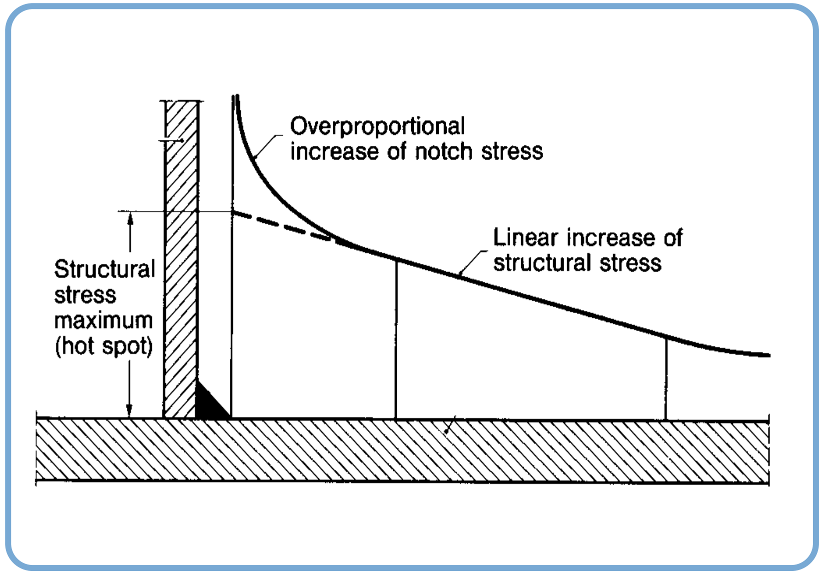


There are several approaches used to predict the fatigue life of welds

- Fracture mechanics, crack growth
- Local notch stress , R1
- Structural stresses

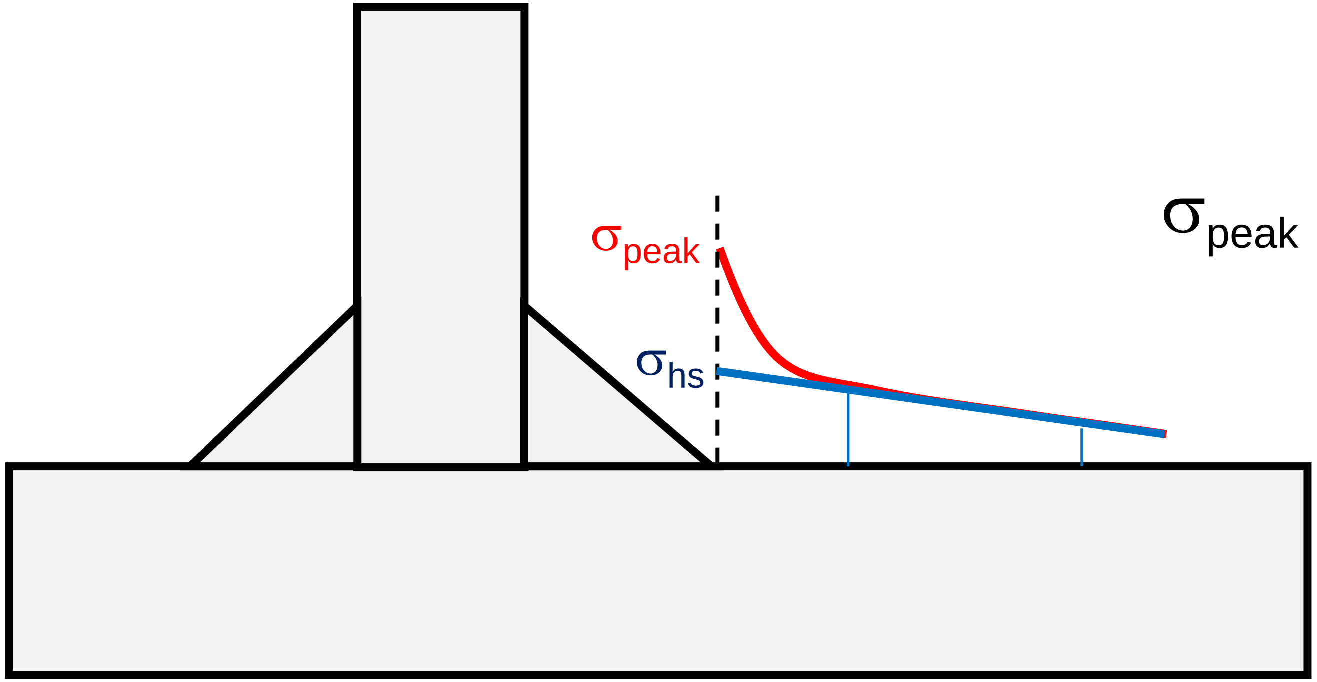






Structural stress method

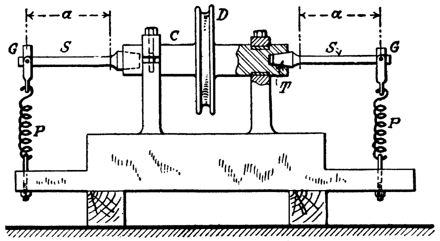
- The ***structural stress*** is the stress at or near the weld toe, excluding the effect of the stress concentration
- It can be measured or calculated analytically
- For a calculated structural stress, the less dependence on modelling approaches, the better
- The actual stress at the toe is K_t times the structural stress



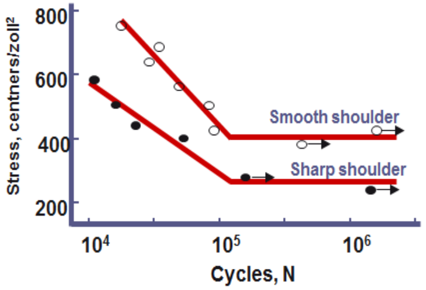
$$\sigma_{peak} = Kt^*\sigma_{hs}$$

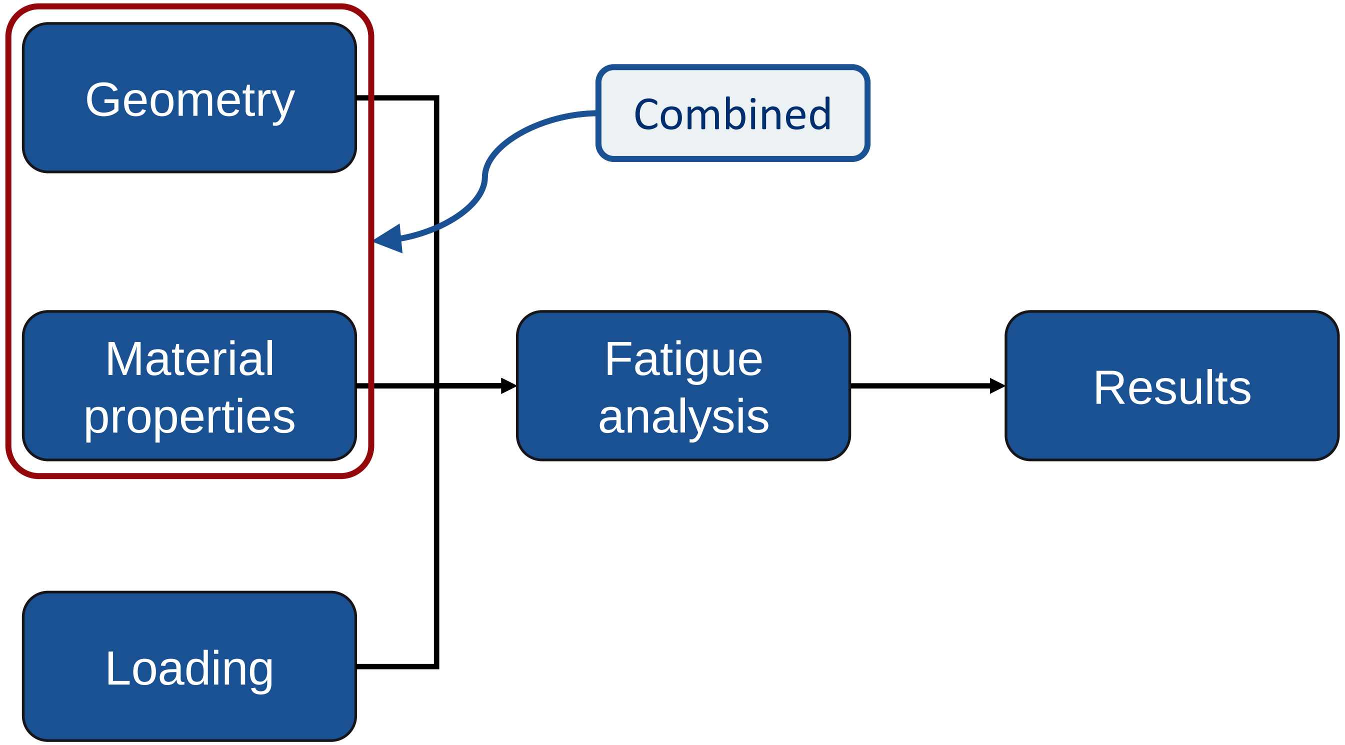
Fatigue analysis process using Structural Stresses

- Typical fatigue process requires detailed material and geometry data
- Geometry, surface finish, manufacturing effect, etc. are taken into account when fatigue properties are characterized for components
- Using structural stresses, weld is treated as a component
- Component fatigue curves represent the weld, not the weld material



Wöhler circa 1850





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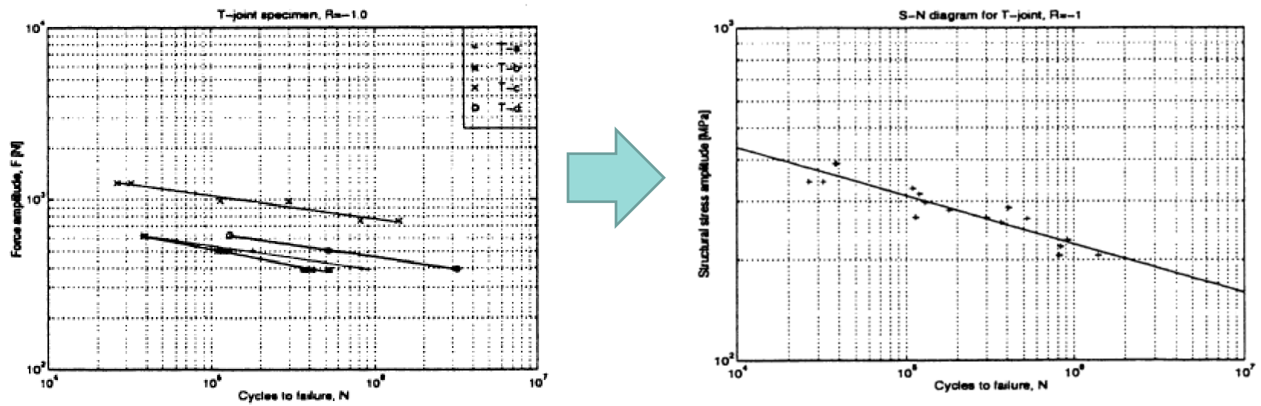
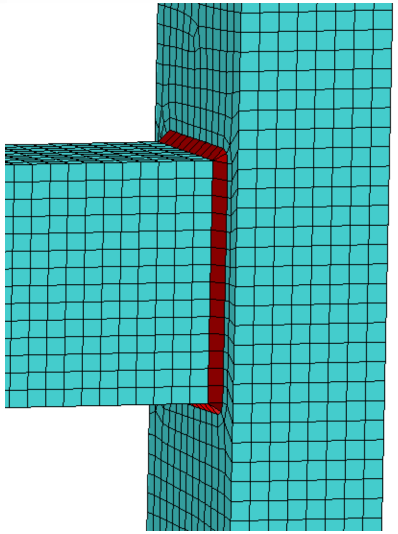
How Structural Stress Approach is Applied

- Load life curves from physical fatigue tests
- Finite element models of test specimens
- Structural stresses calculated from FE models
- With appropriate corrections load life curves can be collapsed to single structural stress life scatter band
- The resulting structural stress curve represents the typical behavior of the welds in the specimens tested





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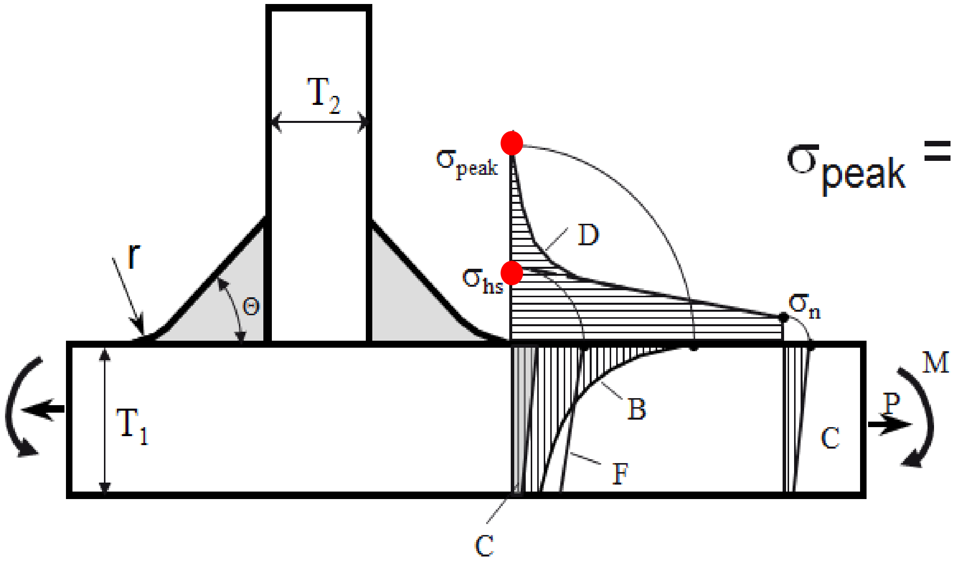
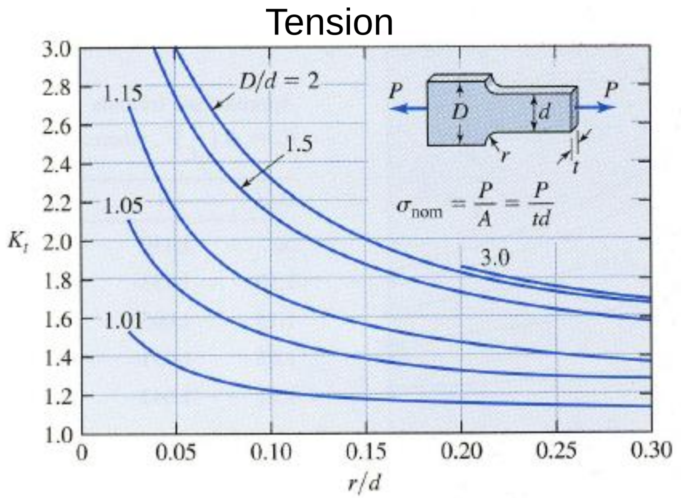
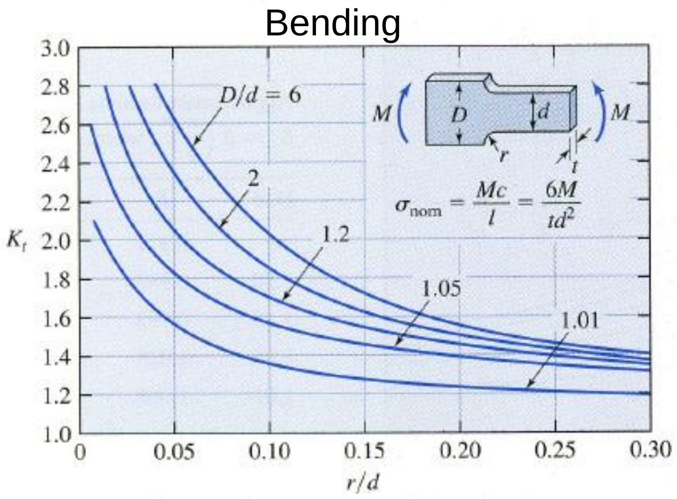
- The component SN curves include the stress concentration factor at the weld toe
- Stress concentration factors are a function of the loading condition



$$\sigma_{peak} = K_t * \sigma_{hs}$$





Shell Element Seamwelds

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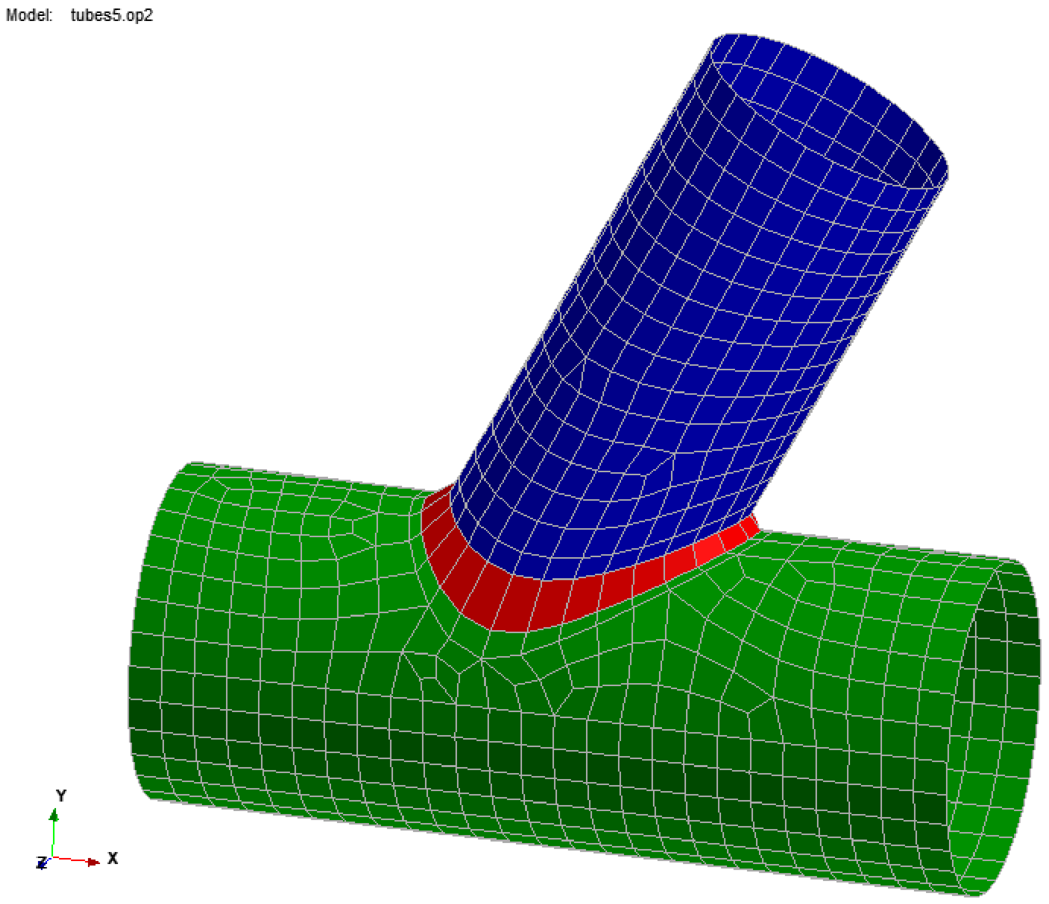
Seamwelds in Shell Models

Modeling

- Mesh requirements
  - List of elements that represent the weld
    - Weld element normals facing outward
  - Elements attached to weld elements
    - Quads
    - Minimal distortion
    - Have results

Stress recovery

- Calculated using nodal forces and moments
  - Weld toe normal and shear stresses
- Stress combinations
  - Weld Normal, AbsMax Principal, Critical Plane



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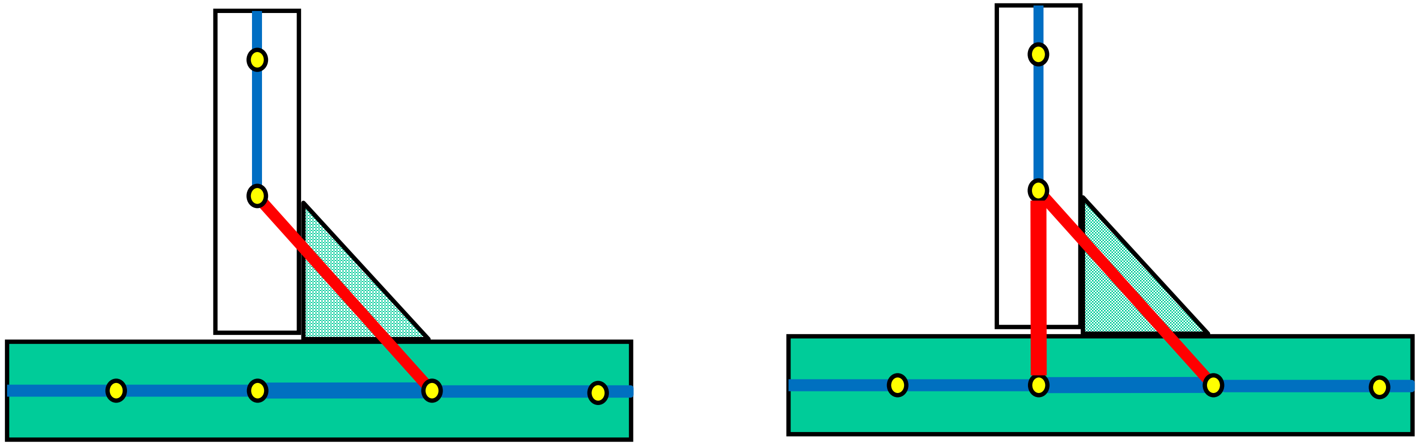
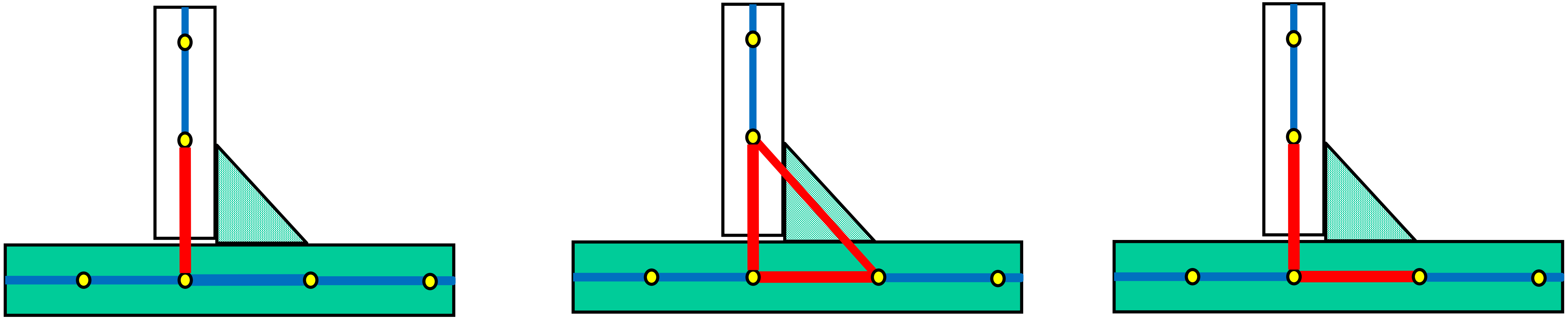
Various Shell Seamweld Connections

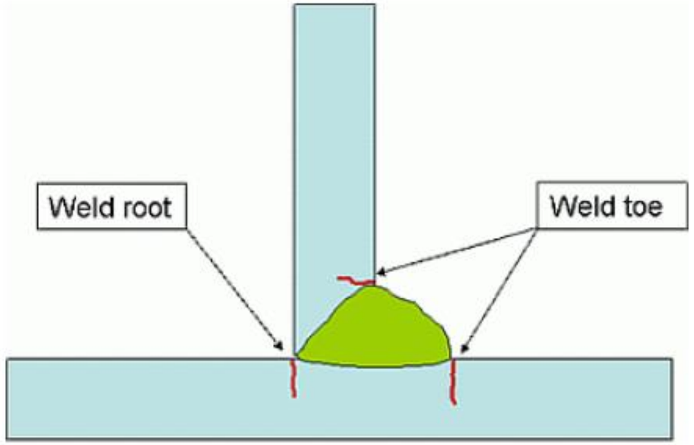
- Shell elements
- Beam elements
- Rigid beams
- Multi-point constraints

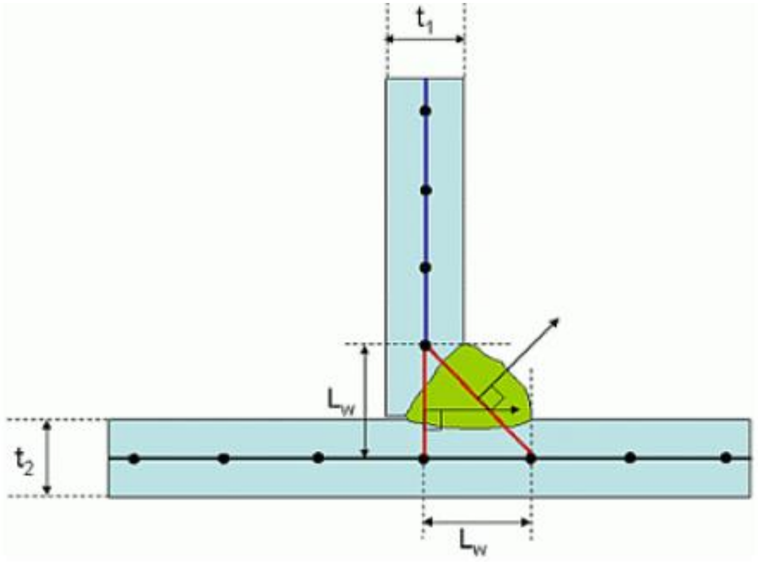




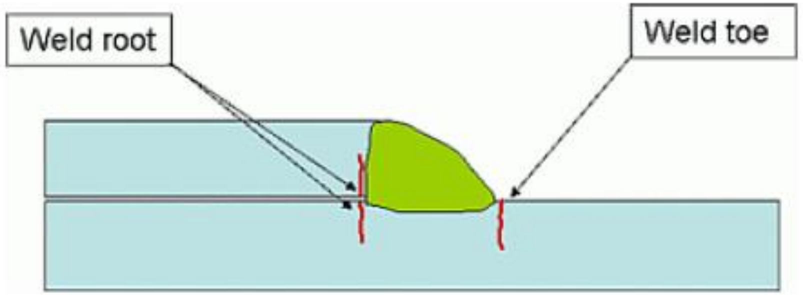
Weld configurations and modelling guidelines

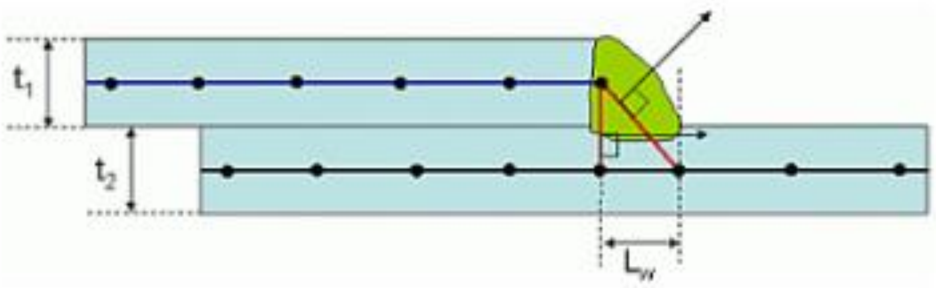
Fillet





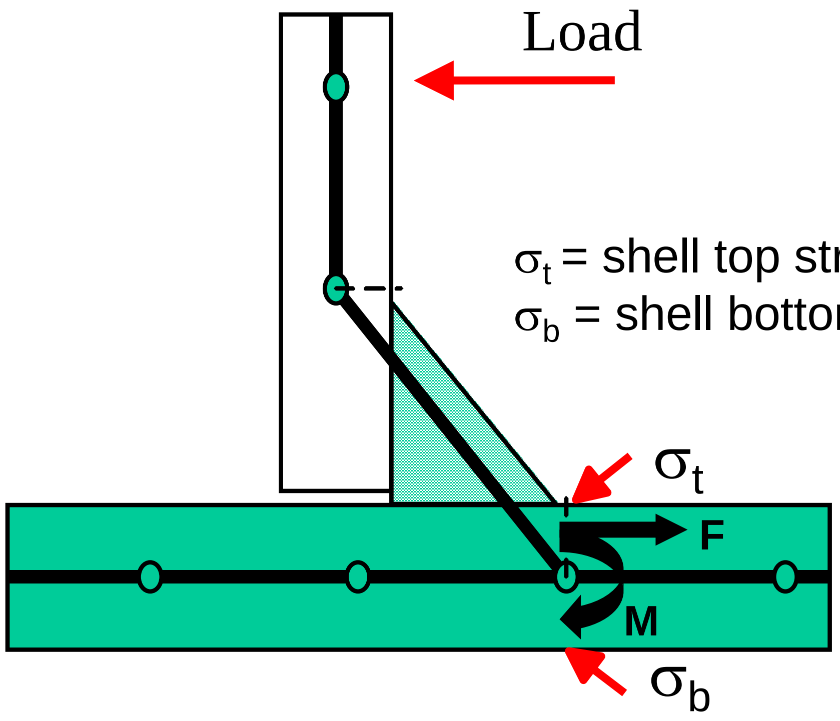
Overlap





Shell Seamweld Stress Calculations

- Axial and bending stresses at the weld toe calculated using the weld toe element results
  - Nodal forces and moments
  - Cubic stresses
- Fatigue calculation requires shell top stress and the bending ratio



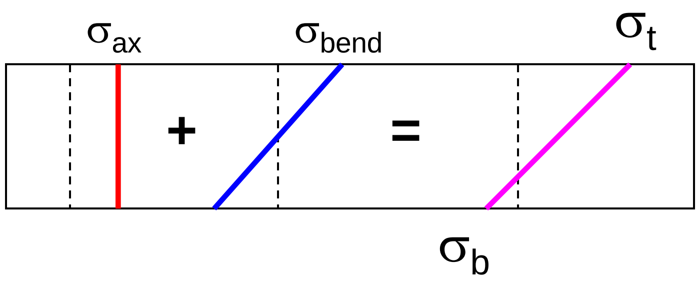
σ_t = shell top stress
σ_b = shell bottom stress

$$\sigma_{ax} = ½\,(\sigma_t + \sigma_b)$$

$$\sigma_{bend} = ½\,(\sigma_t - \sigma_b)$$

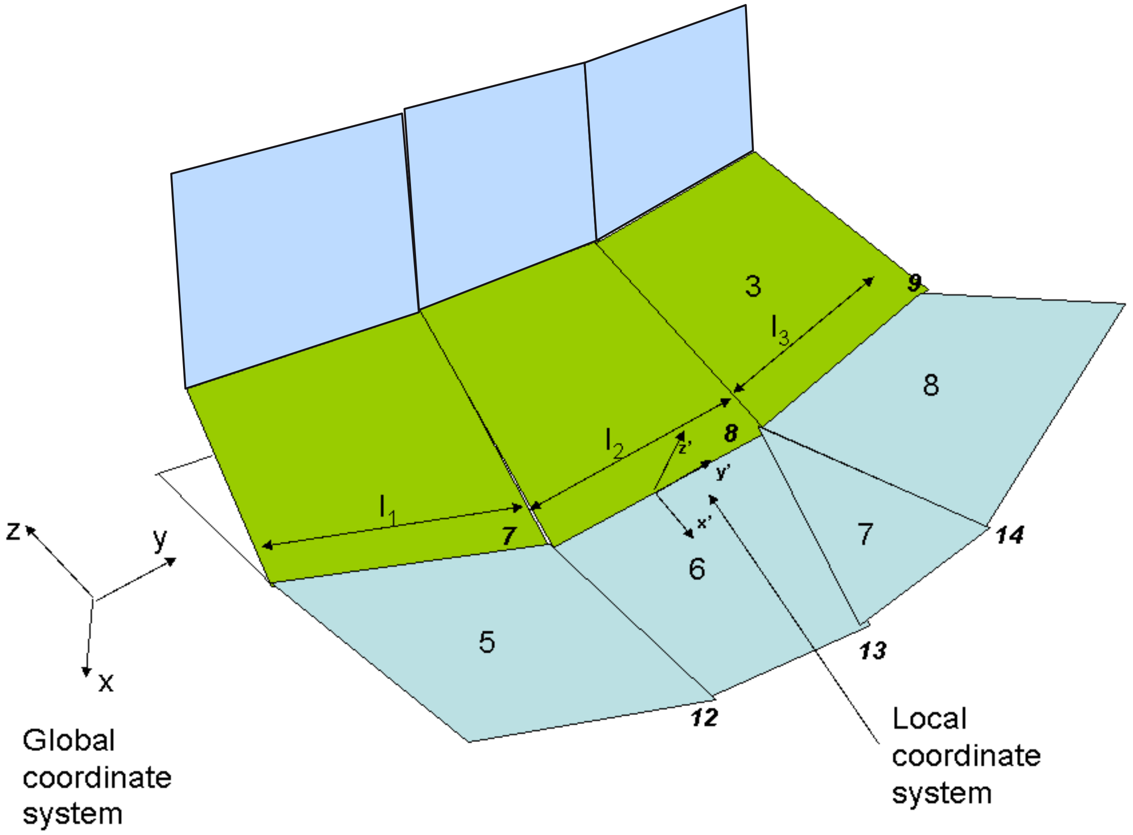
$$\sigma_t = \sigma_{ax} + \sigma_{bend}$$

$$br = |\sigma_{bend}| \,/\, (\,|\sigma_{ax}| + |\sigma_{bend}|)$$



Membrane and bending stresses are calculated for the weld toe and weld root elements

- Nodal forces and moments are collected at weld toe nodes and shared in proportion to the element edge length
- Line forces and moments are averaged to the midpoint of the edge and translated to the local coordinate system
- Forces and moments are converted into stresses normal to the weld toe for both surfaces of the shell
- Forces and moments are converted into steer stresses along the weld toe for both surfaces of the shell



$$\sigma_{top,normal} = \frac{f_{x\prime}}{t} + 6\frac{m_{y\prime}}{t^2}$$

$$\tau_{top,normal} = \frac{f_{y\prime}}{t} + 6\frac{m_{x\prime}}{t^2}$$

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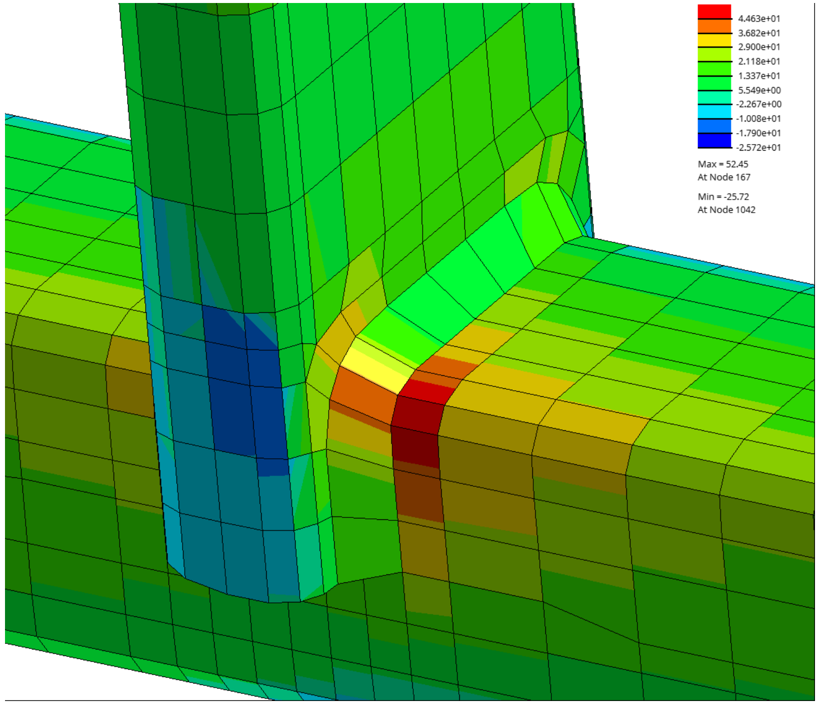
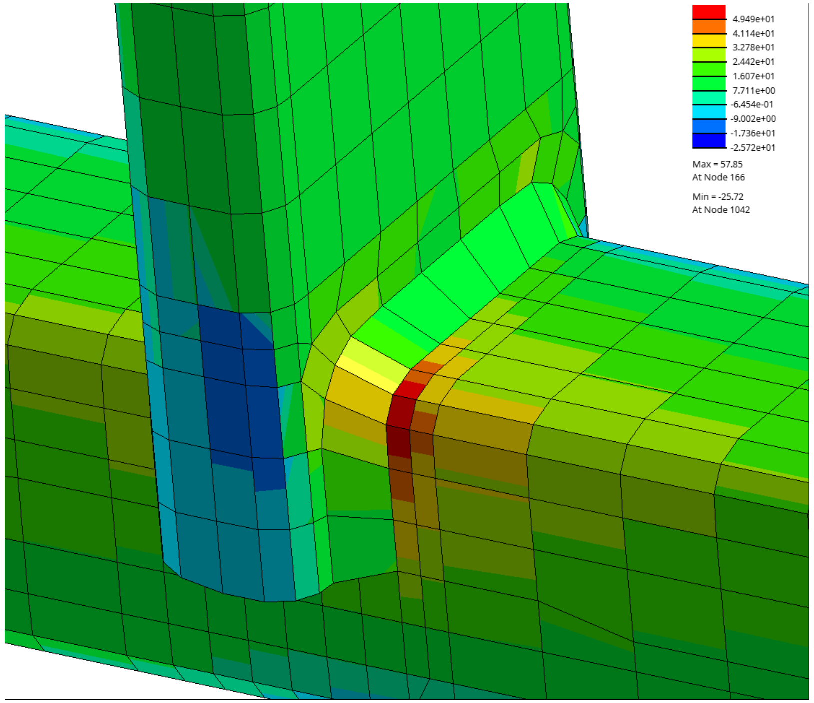
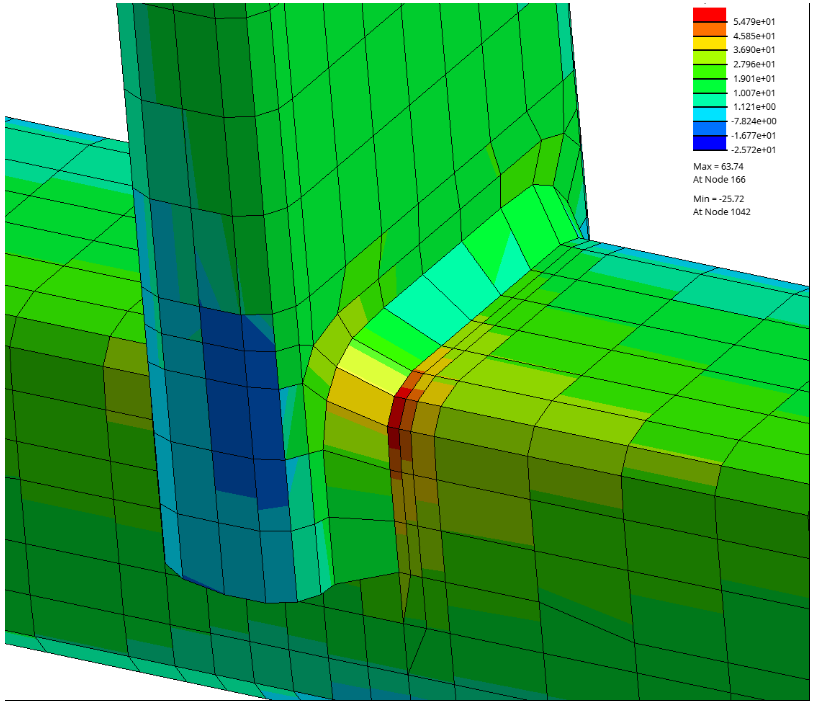
Standard Shell Stresses

52.5 MPa	57.9 MPa	63.7 MPa
(100%)	(110%)	(122%)







Structural Stresses from Nodal Forces and Moments

85.9 MPa

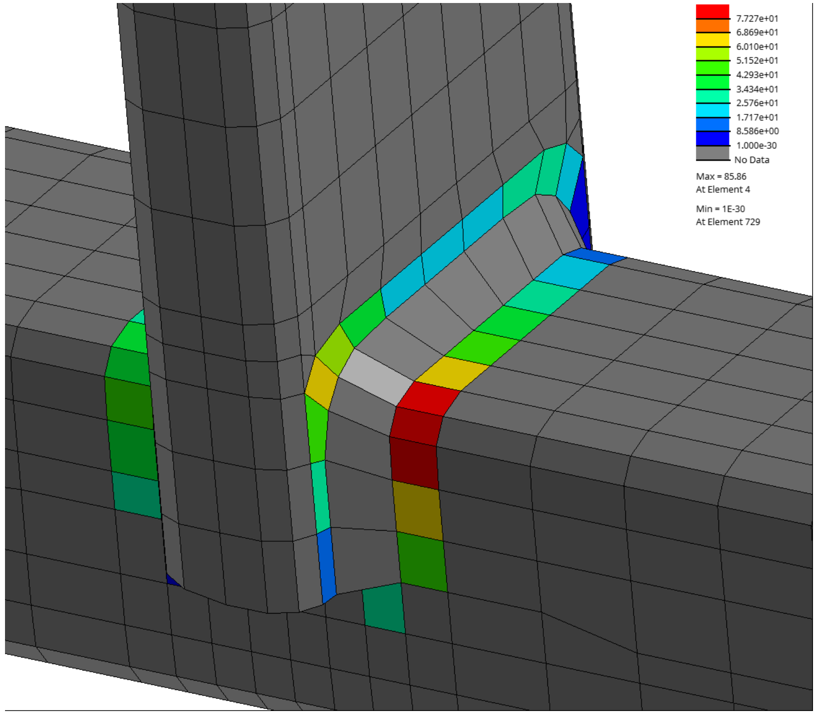
(100%)

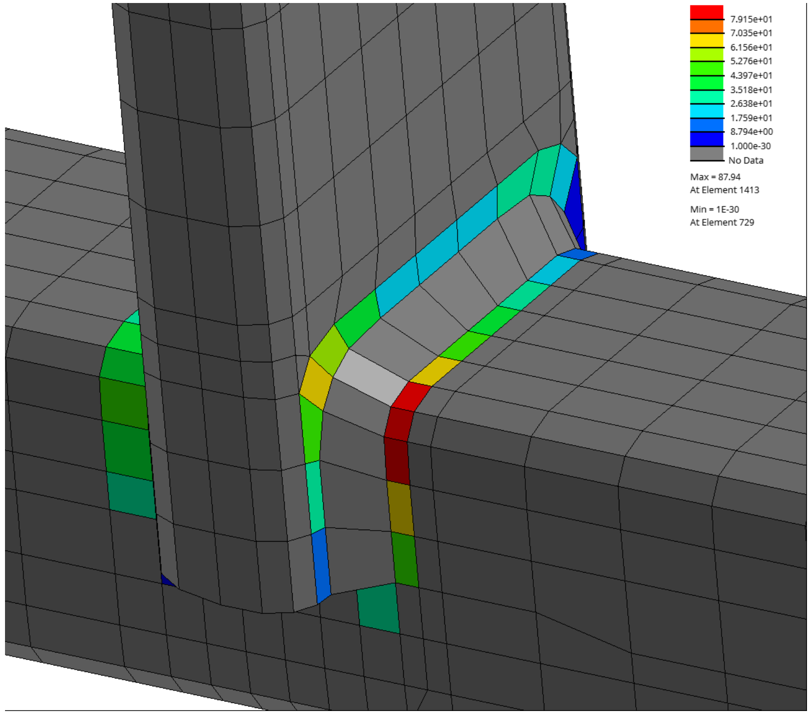
87.9 MPa

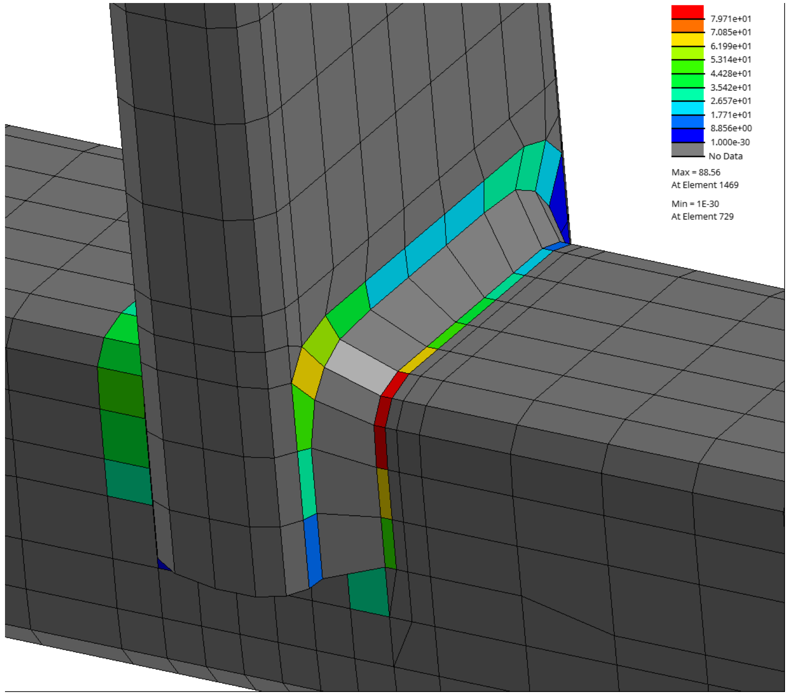
(102%)

88.6 MPa

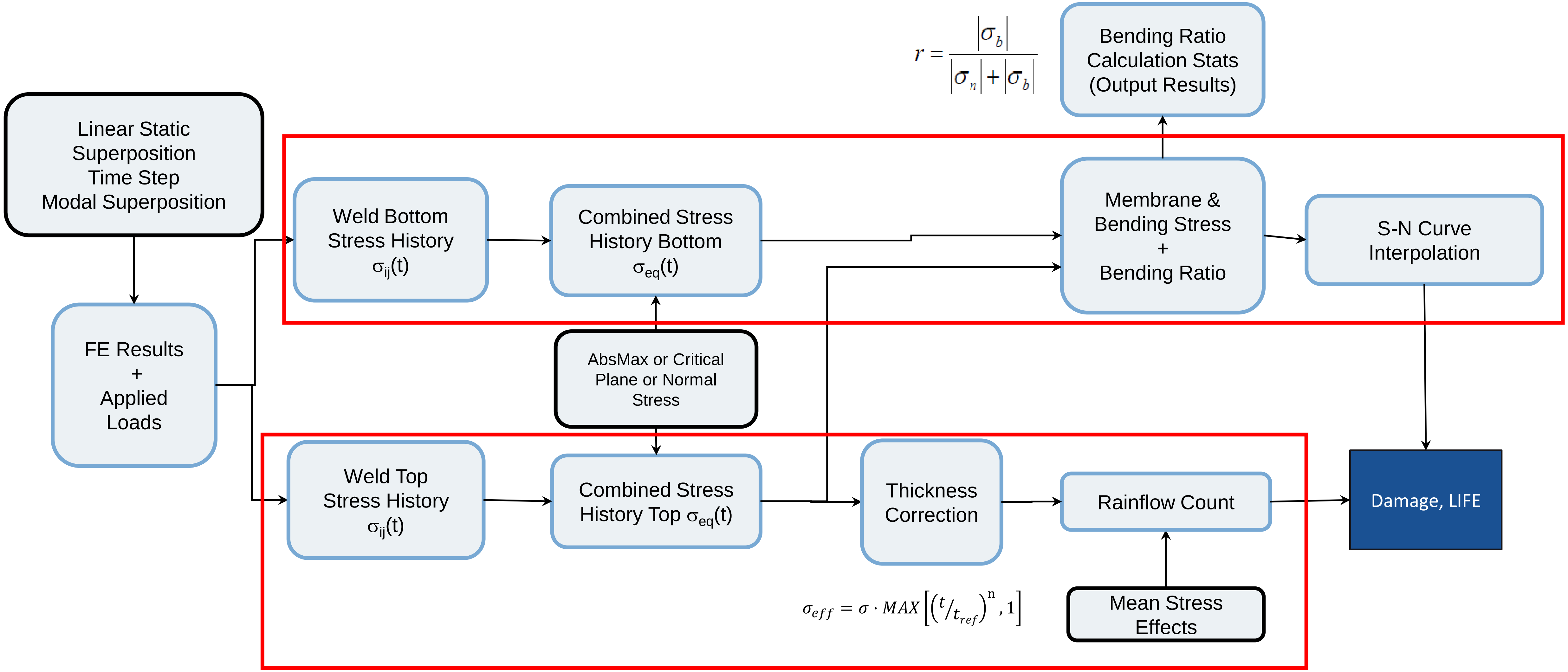
(103%)







Using the structural stresses in the seamweld solution process



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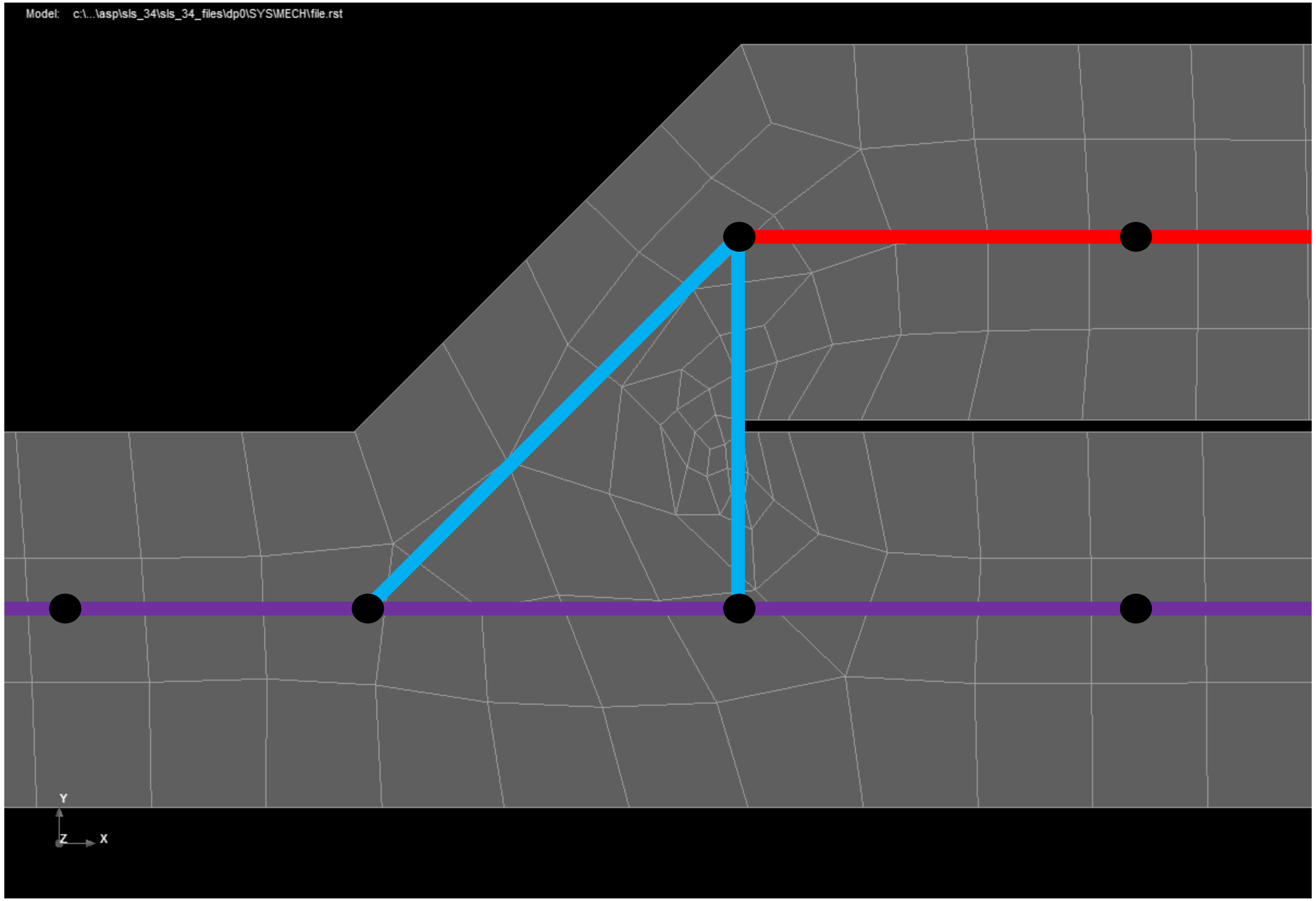
Solid Element Seamwelds

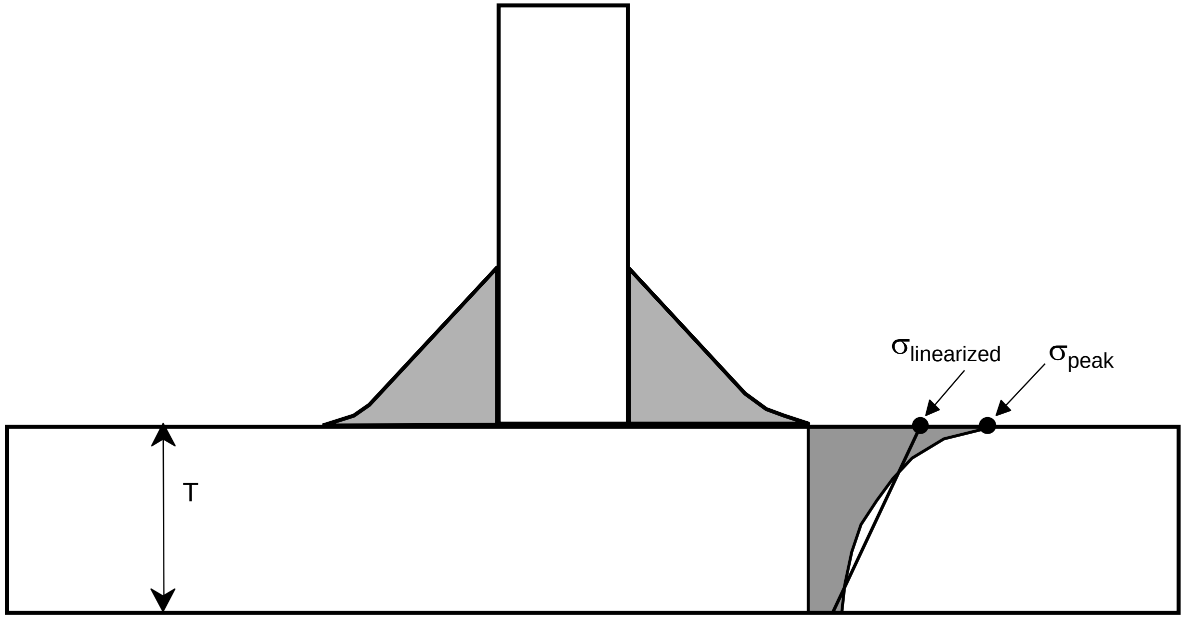
Solid vs Shell Weld Modeling

- Some structures are difficult or impossible to idealize with shells
- Solid element modeling allows more geometric detail to the weld
- Allows user defined failure locations



Structural Stress Calculation using Thru Thickness Integration

- Linearize the stress profile through the thickness of the plate
- Eliminates the impact of the stress riser at the weld toe and provides a structural stress, and bending ratio



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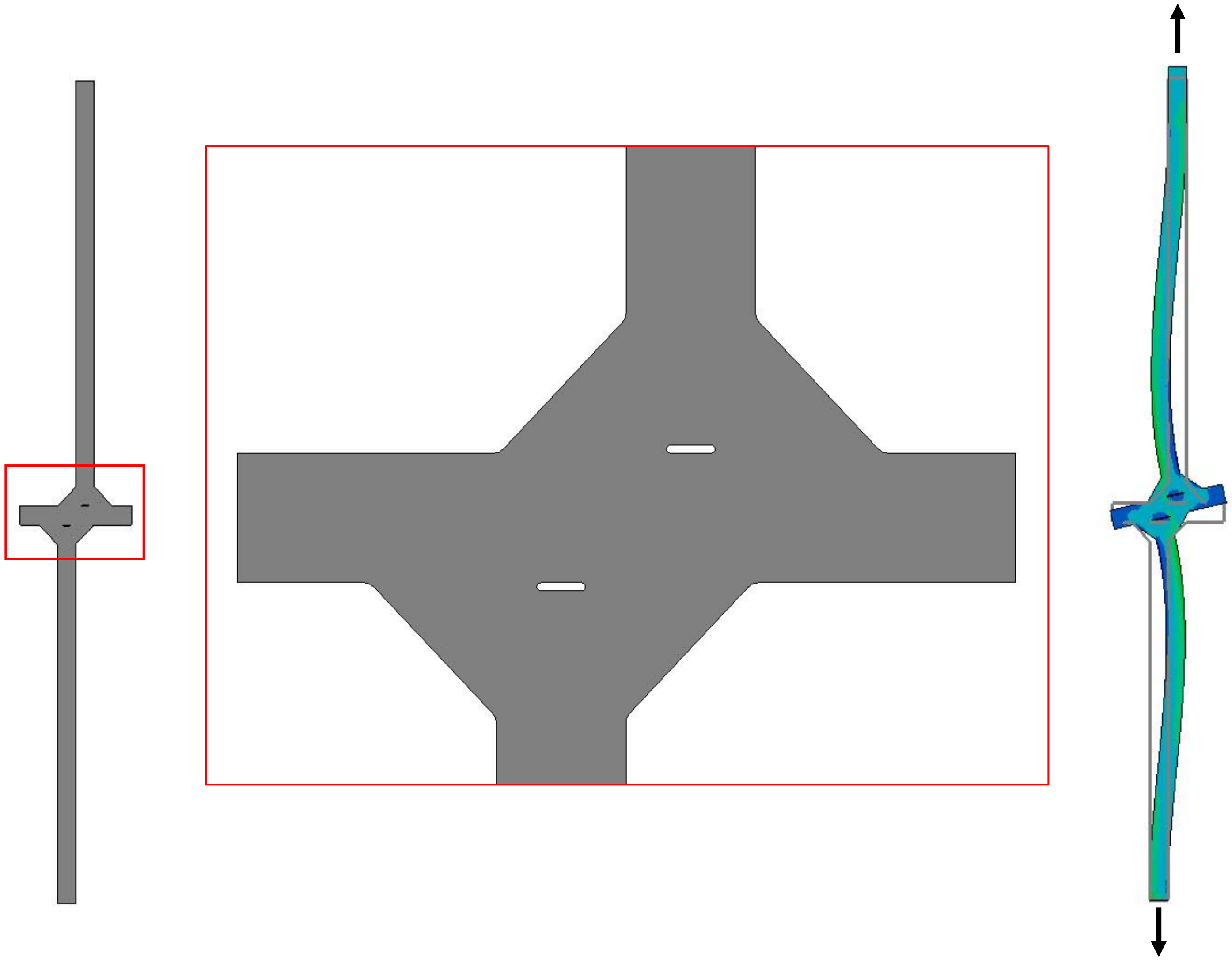
Example model

- Cruciform
- Load carrying
- 4 mm offset alignment
- Loaded in tension



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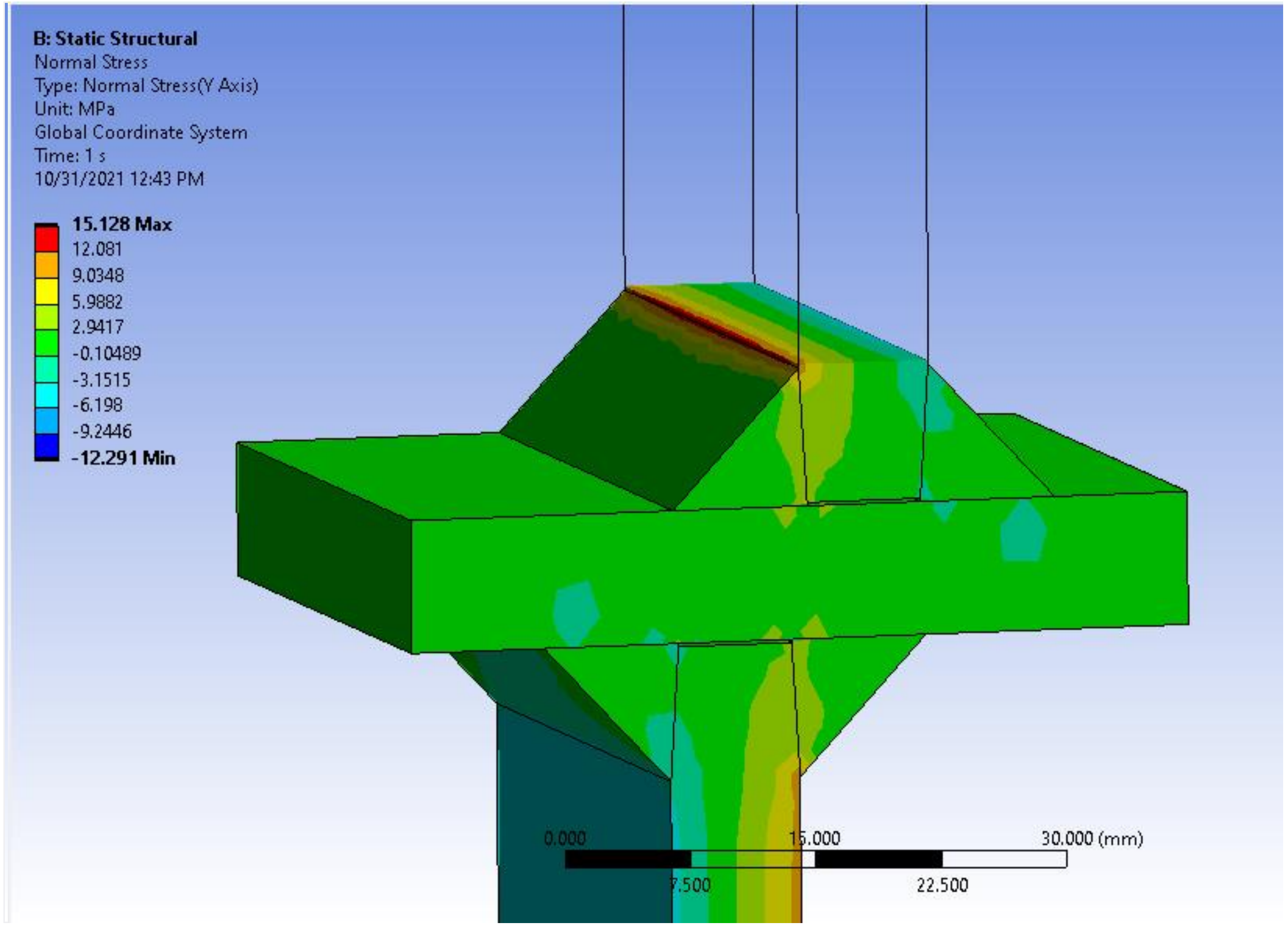

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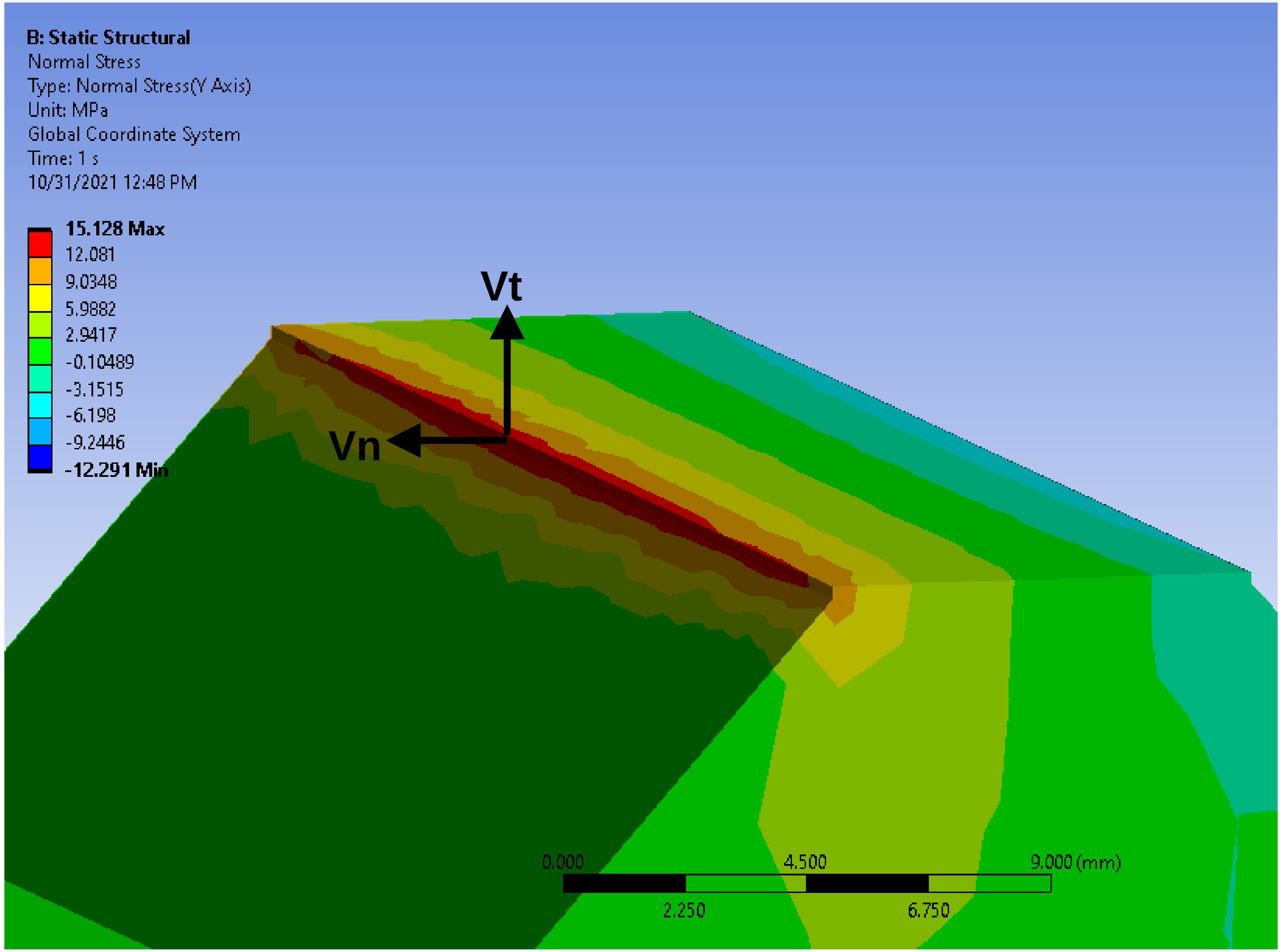
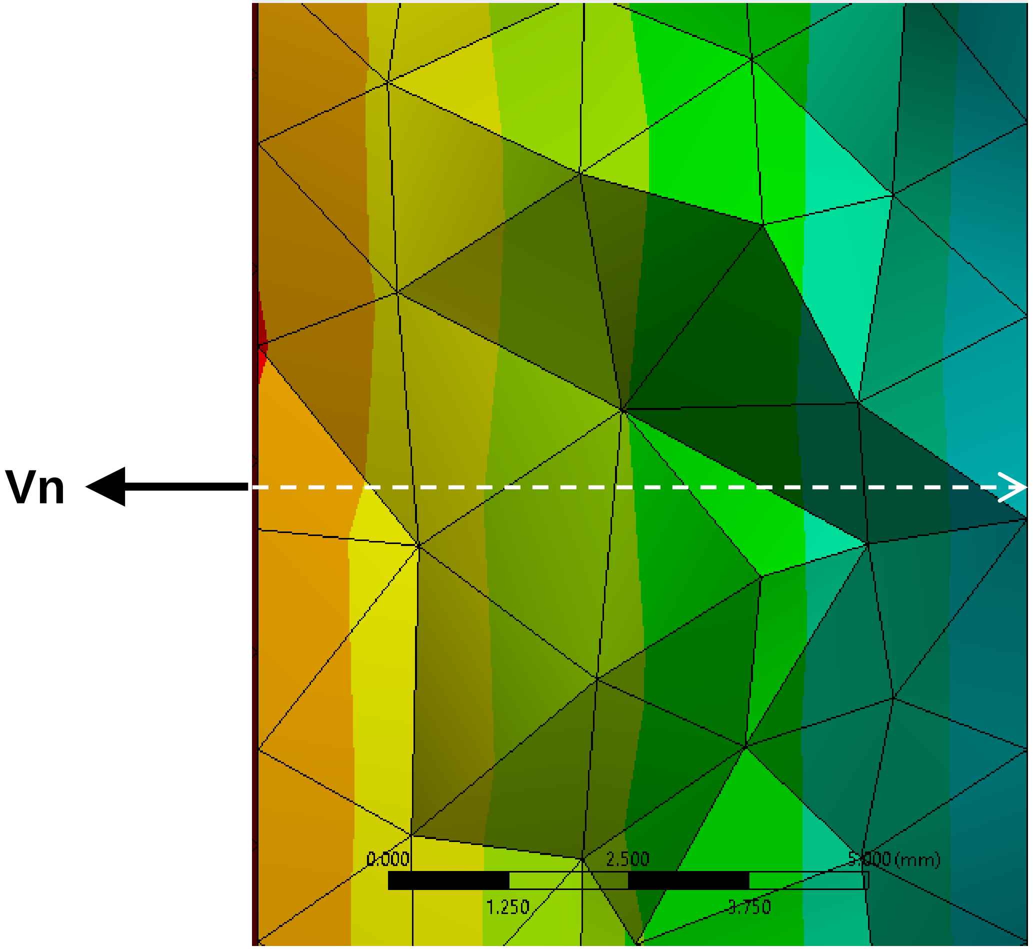
Solid weld definition

- Weld location
  - Geometric location
  - Independent of nodes and elements
- Outward normal – Vn
  - Weld crack path is in the opposite direction of Vn
  - Stresses calculated on 2D plane perpendicular to Vn
- Toe normal – Vt
  - Used to orient stress tensor
    - Sx along Vt
    - Sy along (Vn x Vt)



Thru Thickness Integration Process

- 5 weld layers (stress recovery locations)
- Minimum of 3 linear stress elements thru stress linearization path
  - Hex8 (full integration)
  - Tet10
  - Pyra13
  - Wed15
  - Hex20
- Use averaged nodal stresses
- Each location compute a 2D stress tensor on a plane perpendicular to linearization path



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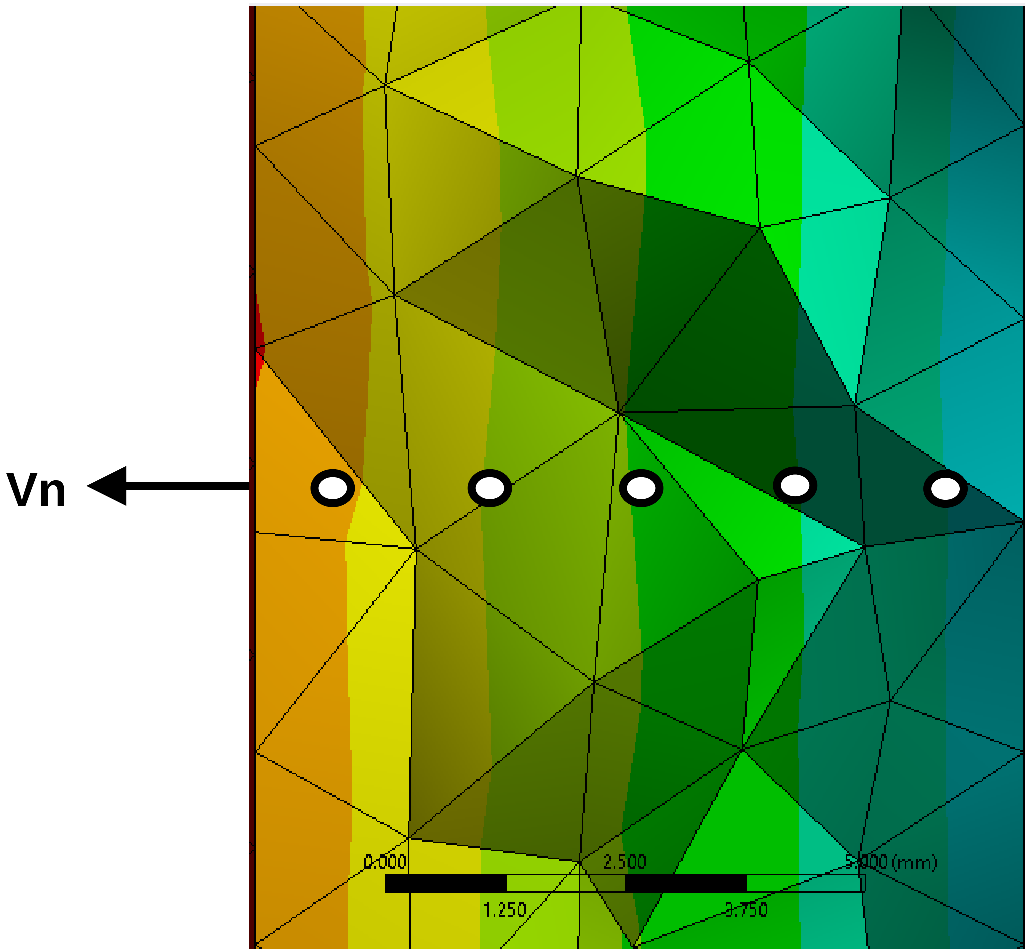

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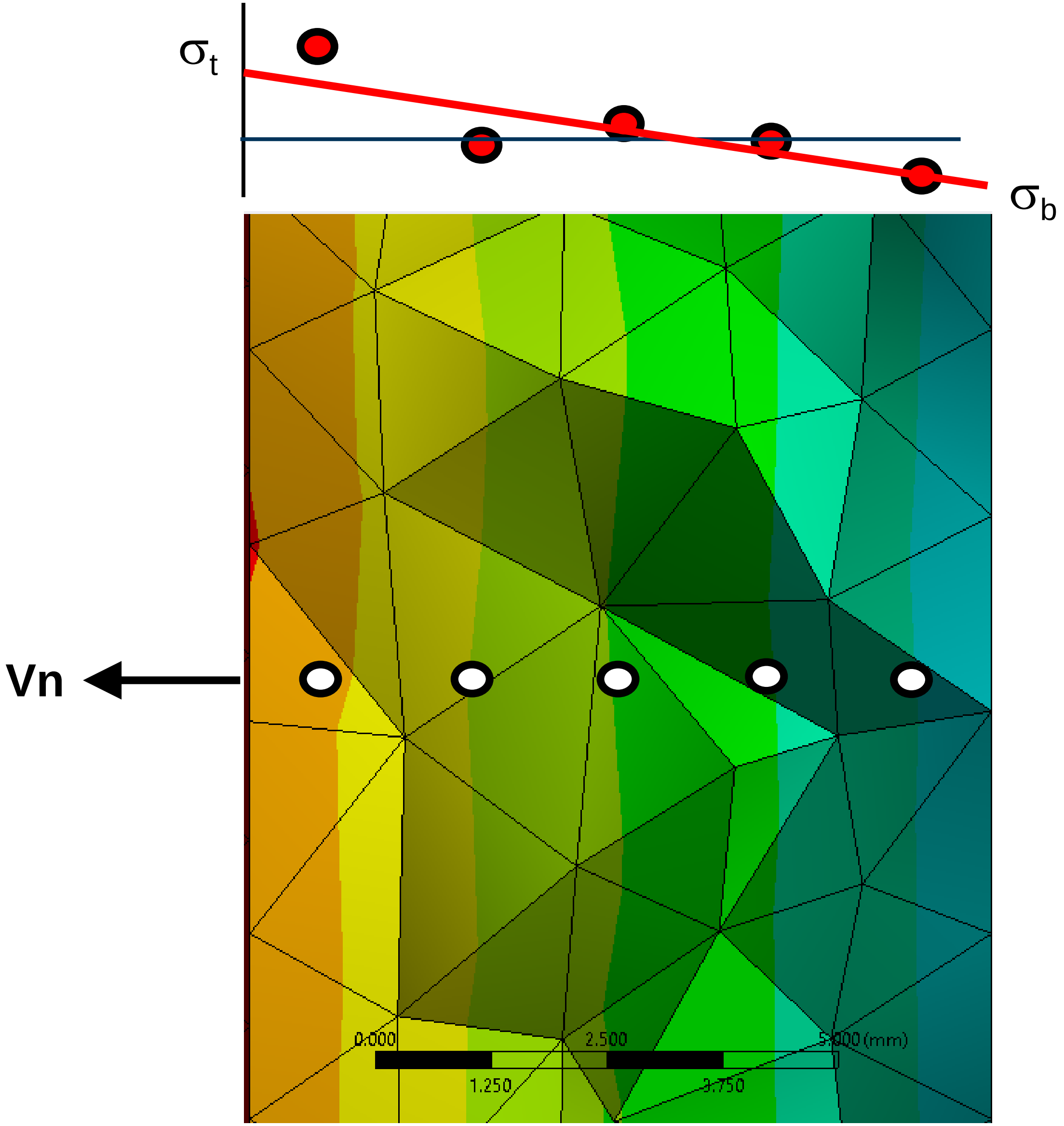

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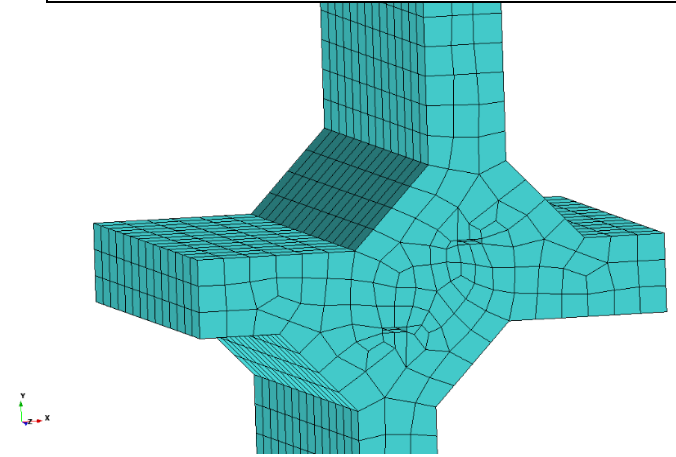
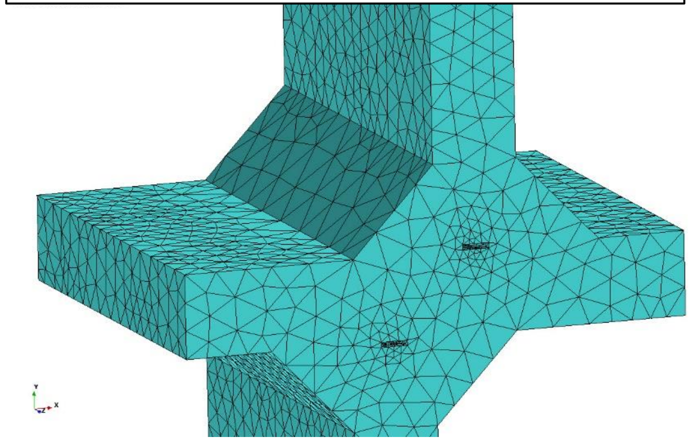
Effects of FE Element Type and Mesh Density on Stresses

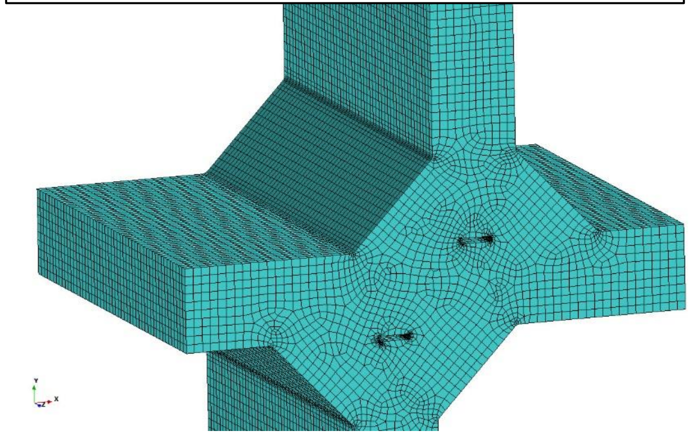
HEX8,   6230 elements



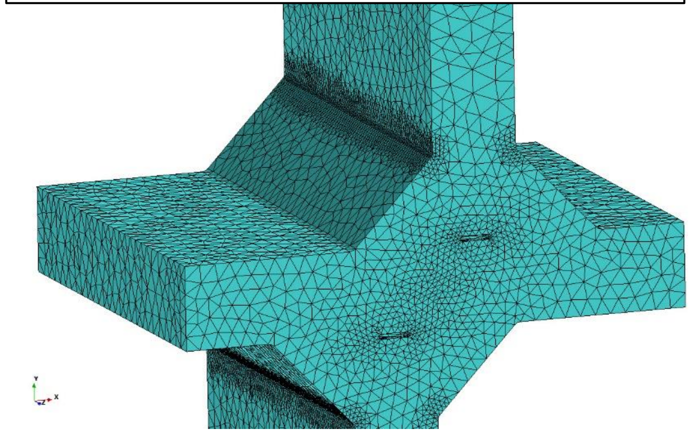
TET10,   137000 elements



HEX20,   294000 elements

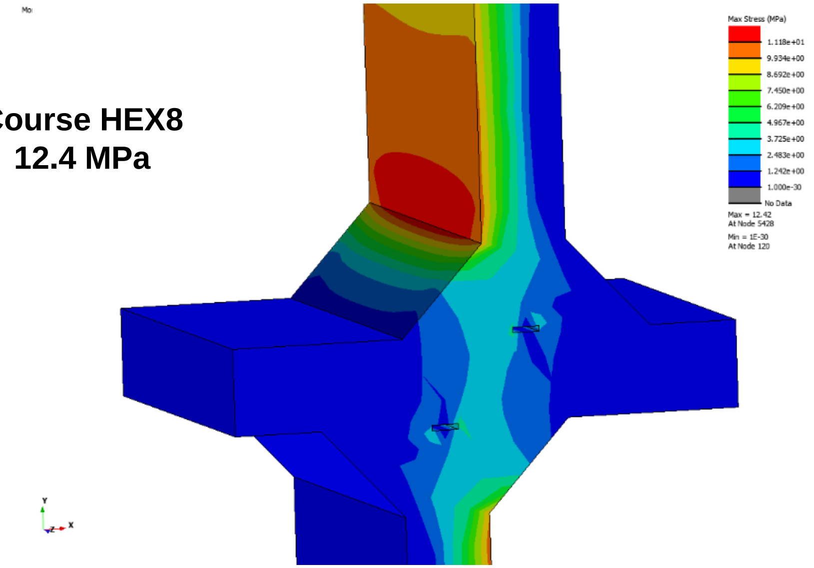


TET10,   425000 elements

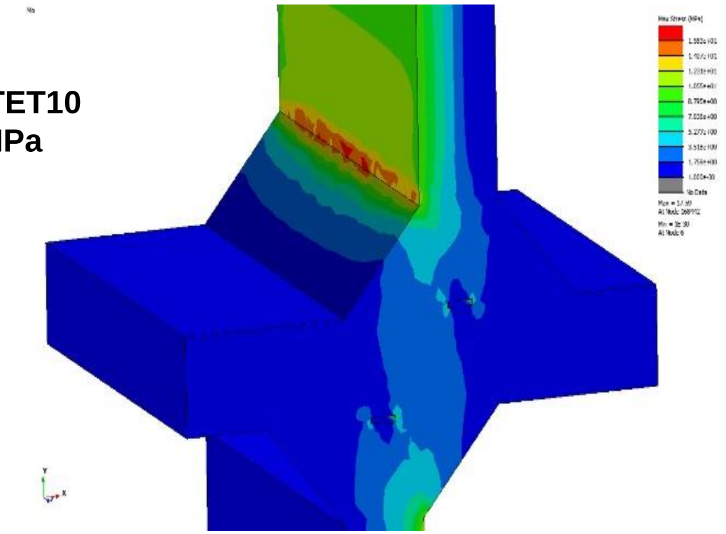


Maximum Stresses from FE Results

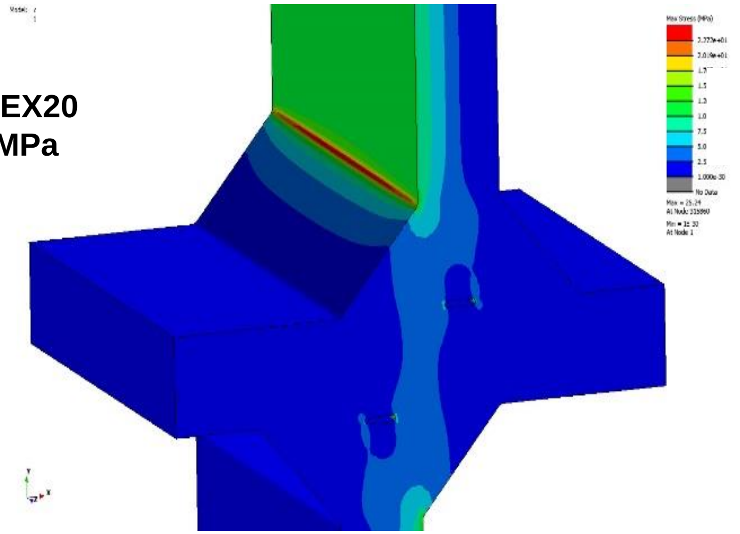
Course HEX8
12.4 MPa



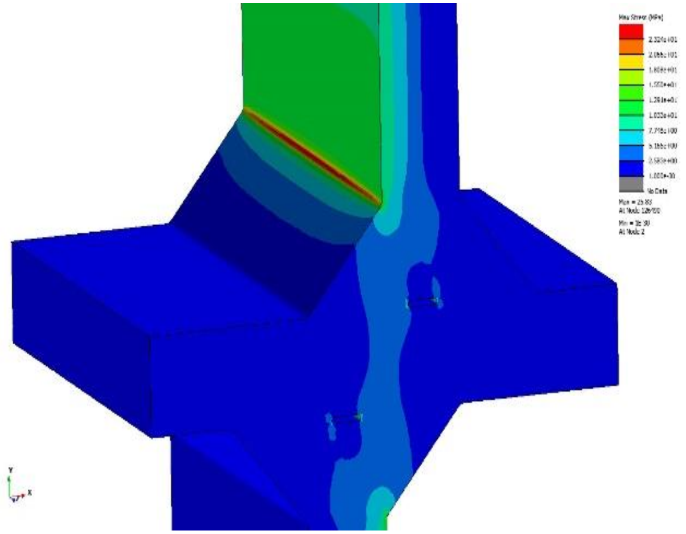
Course TET10
17.6 MPa



Fine HEX20
25.2 MPa

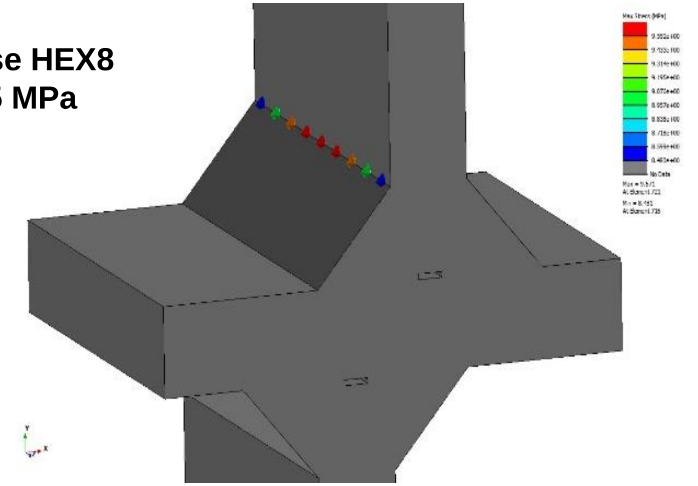


Fine TET10
25.8 MPa

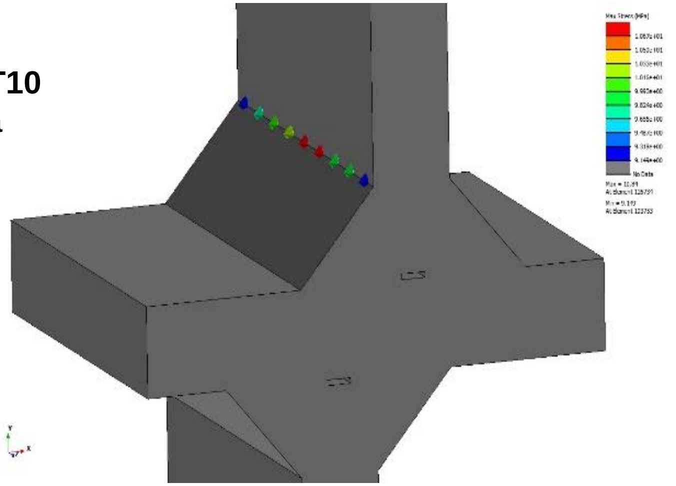


Mesh Insensitive Structural Stresses from TTI on FE Results

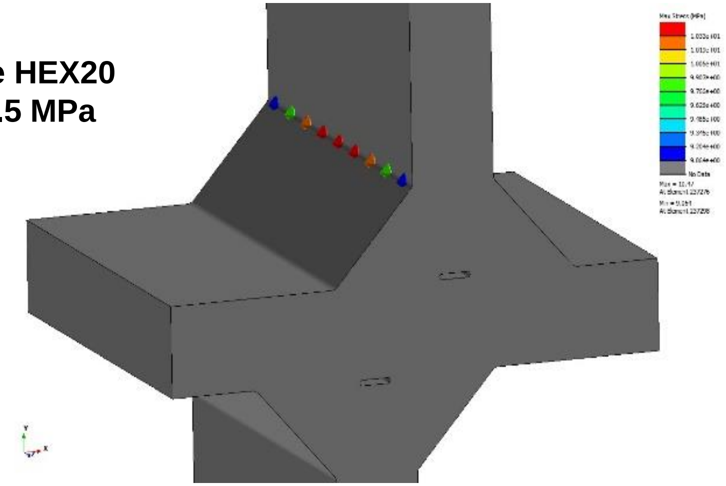
Course HEX8
9.5 MPa



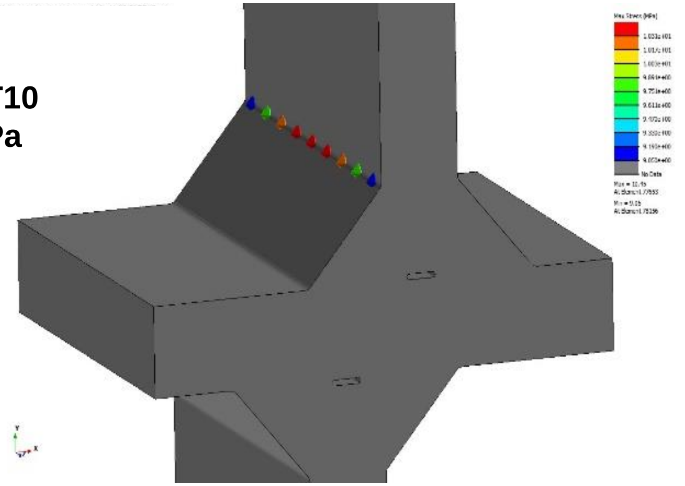
Course TET10
10.8 MPa



Fine HEX20
10.5 MPa

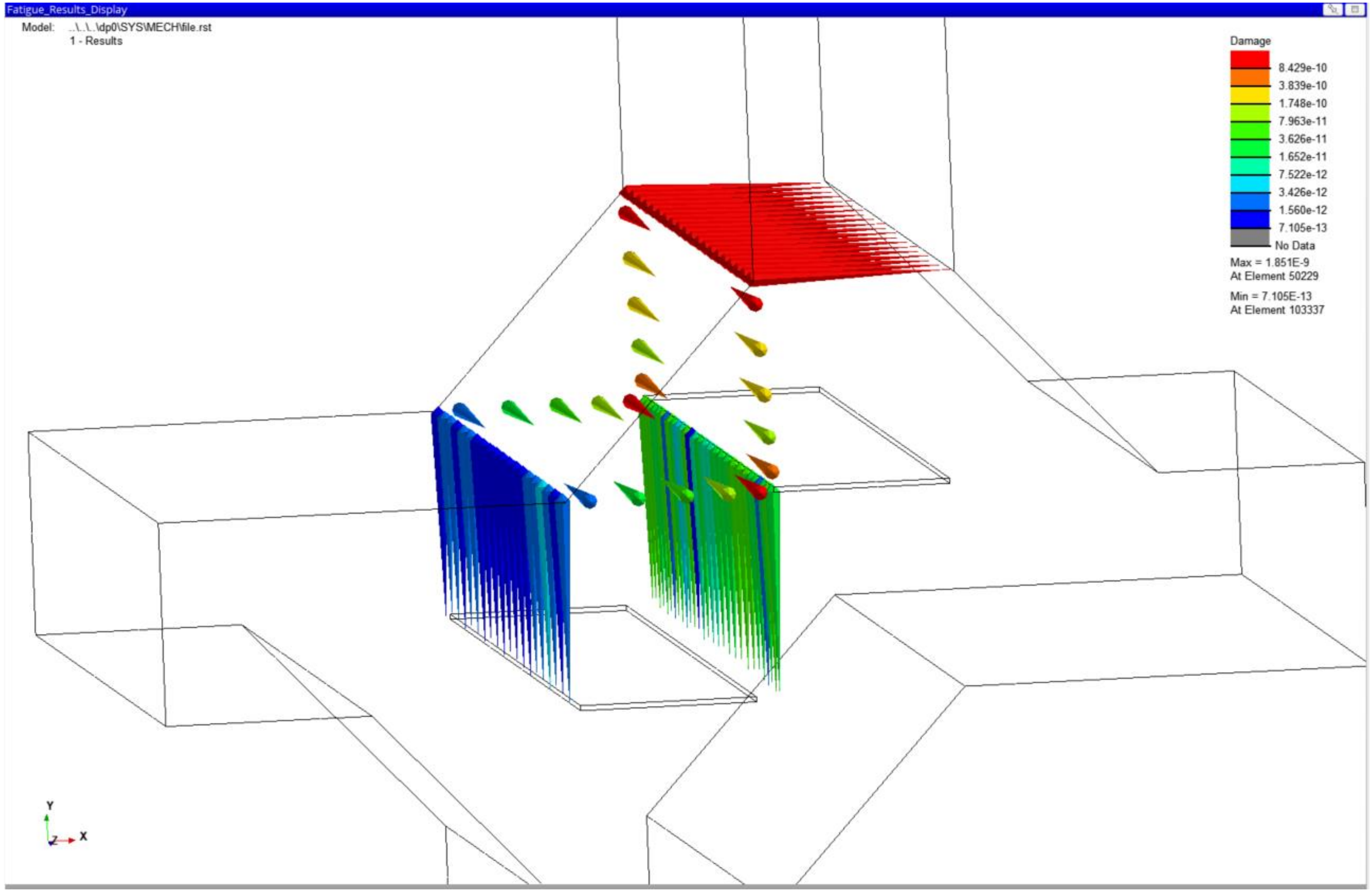


Fine TET10
10.5 MPa



Defining solid element welds

- AutoConfigure
  - Select element group(s) modeling the weld
- Preprocessor utilities
  - Ansys Workbench
  - Hypermesh
  - Abaqus CAE



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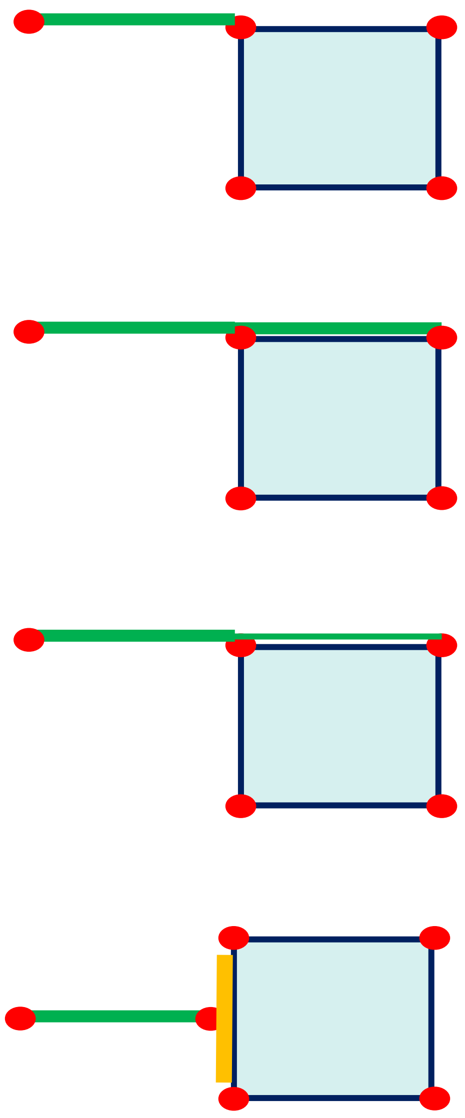
Method of welding shells to solids

- Load transfer from shells to solids
  - Meshing to transfer moments
  - Impact of joining technique on stresses in both the shells and solids
  - Thin skins of shells do not transfer moments
- My recommendation
  - Keep joint all shell or all solids
  - Make shell/solid connect away from weld
- Exceptions
  - Only interested in the failure in shells
    - Apply modeling to transfer moment of shell to a couple of forces on the solid
  - Ideal joining of shells to solids
    - Full transfer of force & moments
    - Stresses in shells and solids are valid



Summary

- Welds are difficult to analyze at the detailed material and geometry level
- Multiple methods available
- Structural stress approaches provide a solution to use component SN curves
- Shell seamweld models can use nodal forces and moments to calculate a structural stress
- Solid seamweld models use thru thickness integration to calculate structural stresses
- Both modeling approaches use the same solution process

Q & A

HOTTINGER BRÜEL & KJÆR

Thank You

Jeff Mentley| Application Engineer

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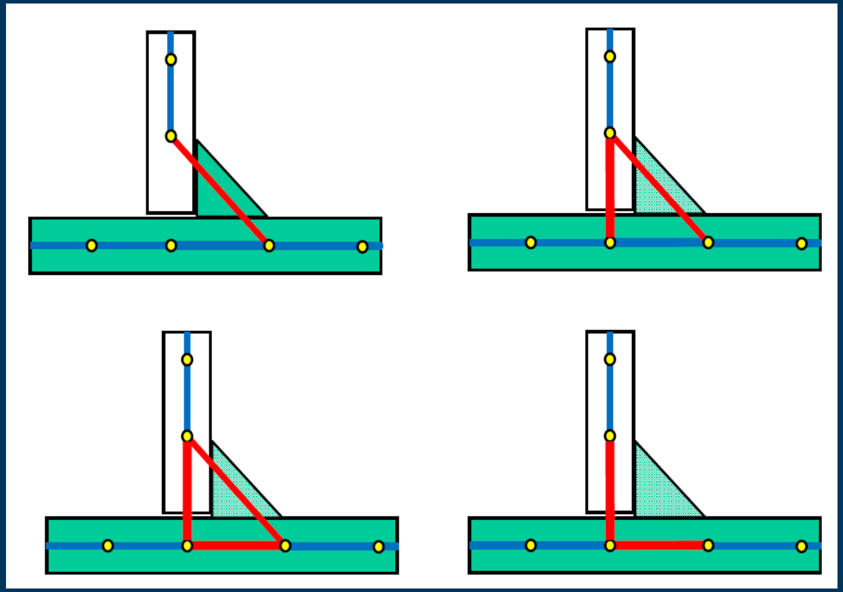
Q&A

- (no questions)

Virtual Seminar Series – Tuesday 2, 9, 16 November



Fatigue Life Prediction of Welds from Finite Element Results

Presented by Mr. Jeff Mentley
Prenscia (HBK)

Tuesday, November 2, 2021