



Computational Mechanics of Welds and Fatigue Life

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A Multiscale Analysis & Extension of an Energy Based Fatigue Life Prediction Method

for high, low, and combined cycle fatigue, Casey M. Holycross, Ph.D thesis , 2016

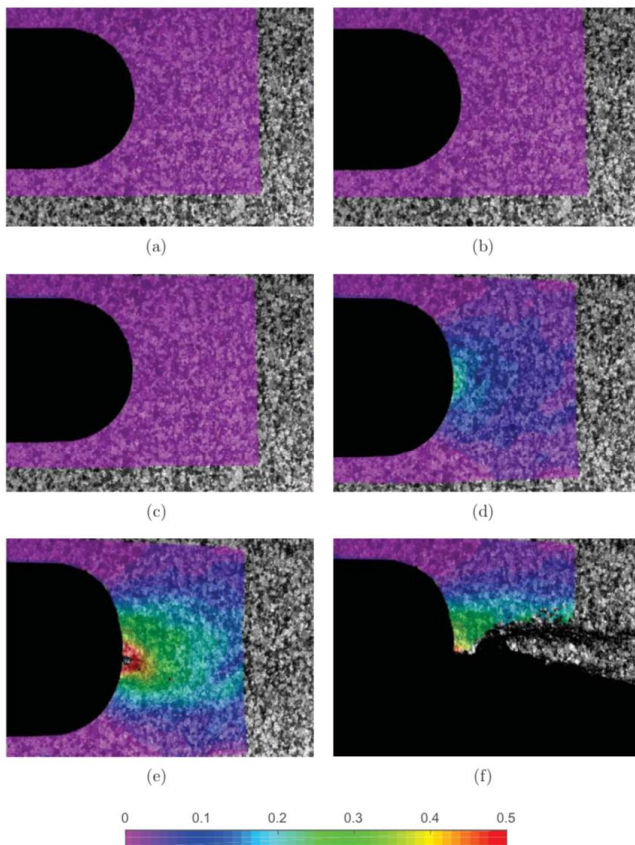


Figure 5.15: Strain in the y direction of static test at subsequent loads until failure

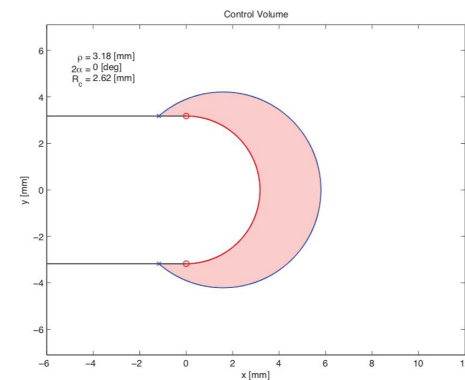


Figure 6.14: Control volume determined from material properties and notch geometry of the U-shape notched panels.

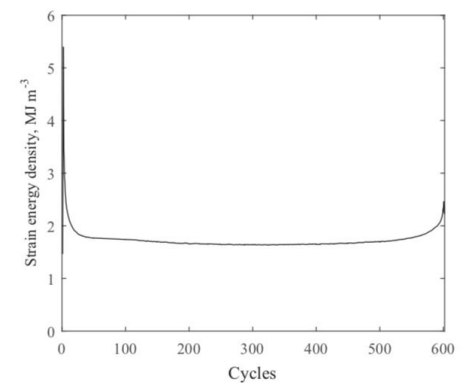
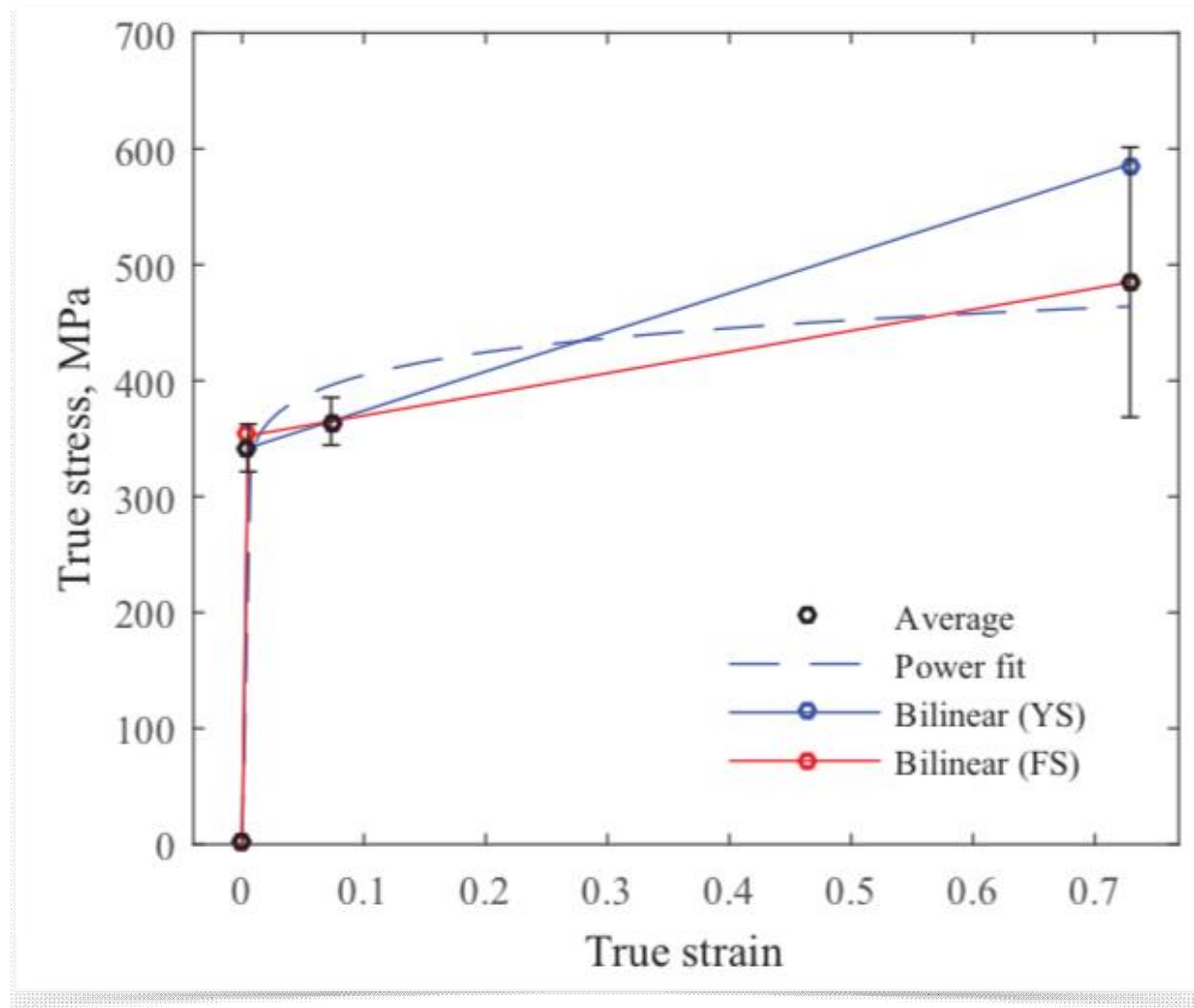


Figure 5.6: Cyclic energy evolution during an LCF lifetime

DIC measurements of strain in each load cycle in a beam with a U-groove. Associates the failure with a critical value of average damage in a representative volume. Another form of Miner's rule.

Measured True Stress - Strain & Ramberg-Osgood Curve



Casey Holycross' Cyclic SED Data Summary

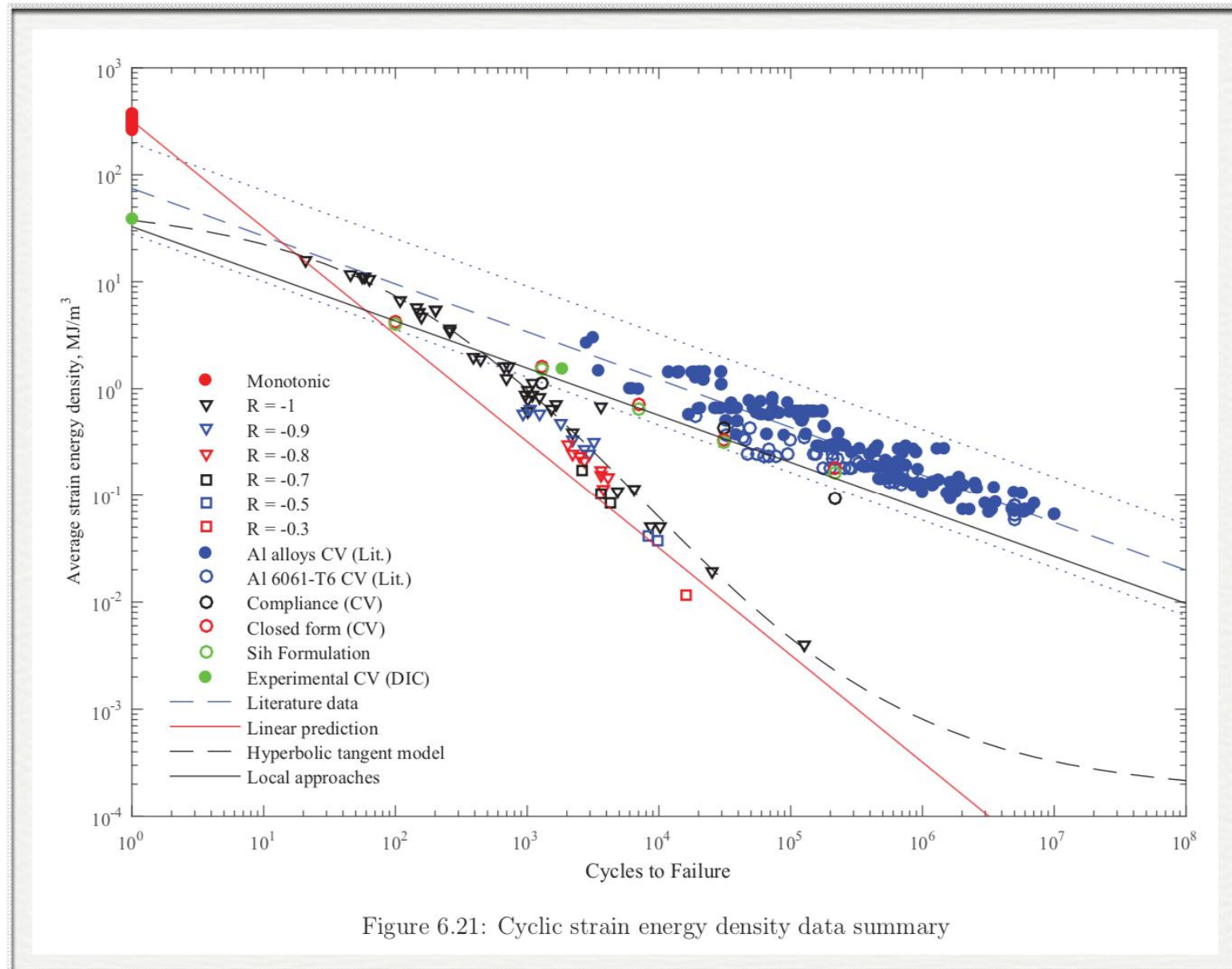
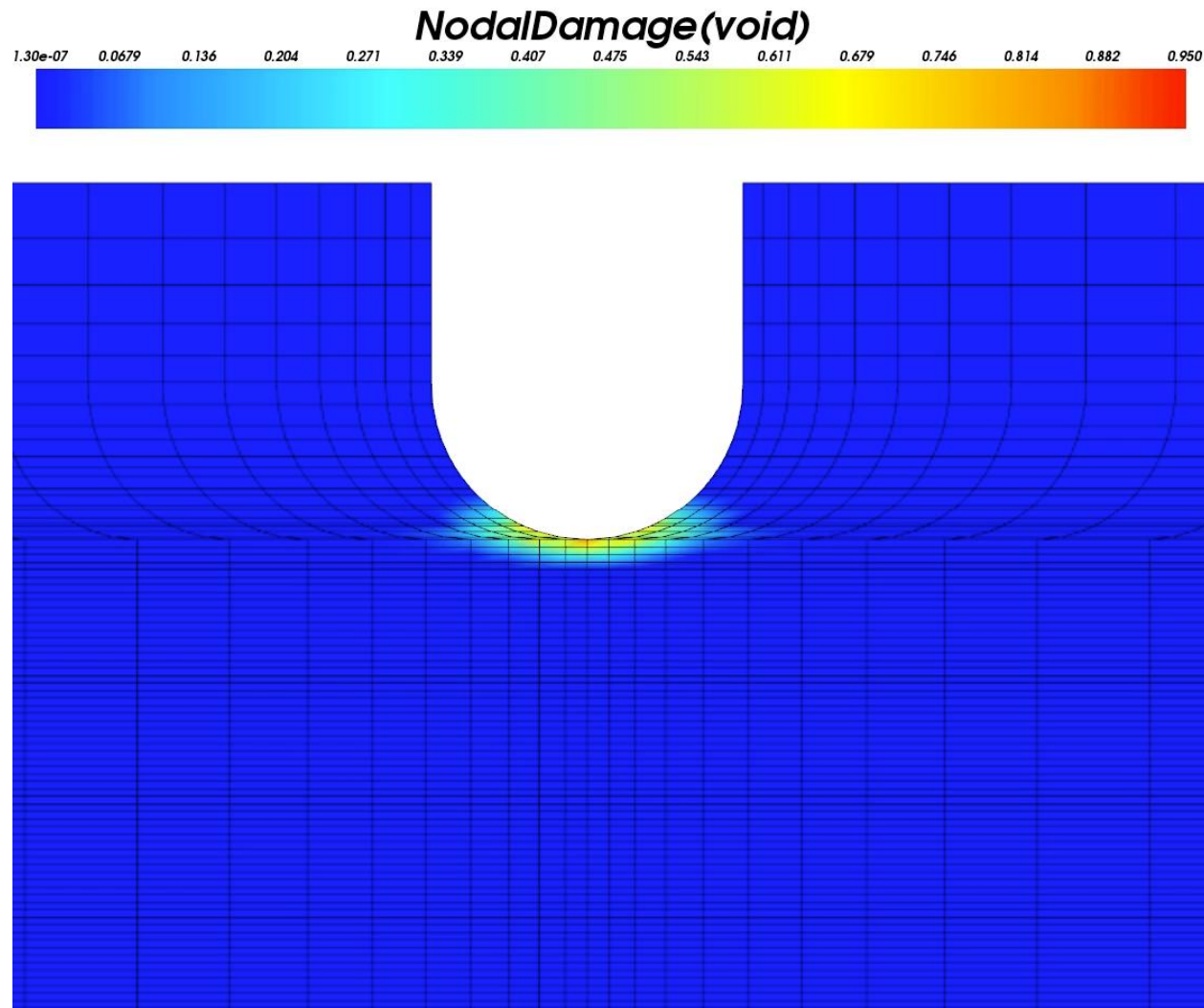


Figure 6.21: Cyclic strain energy density data summary

A numerical model to simulate Casey Holycross' Experimental Methodolgy

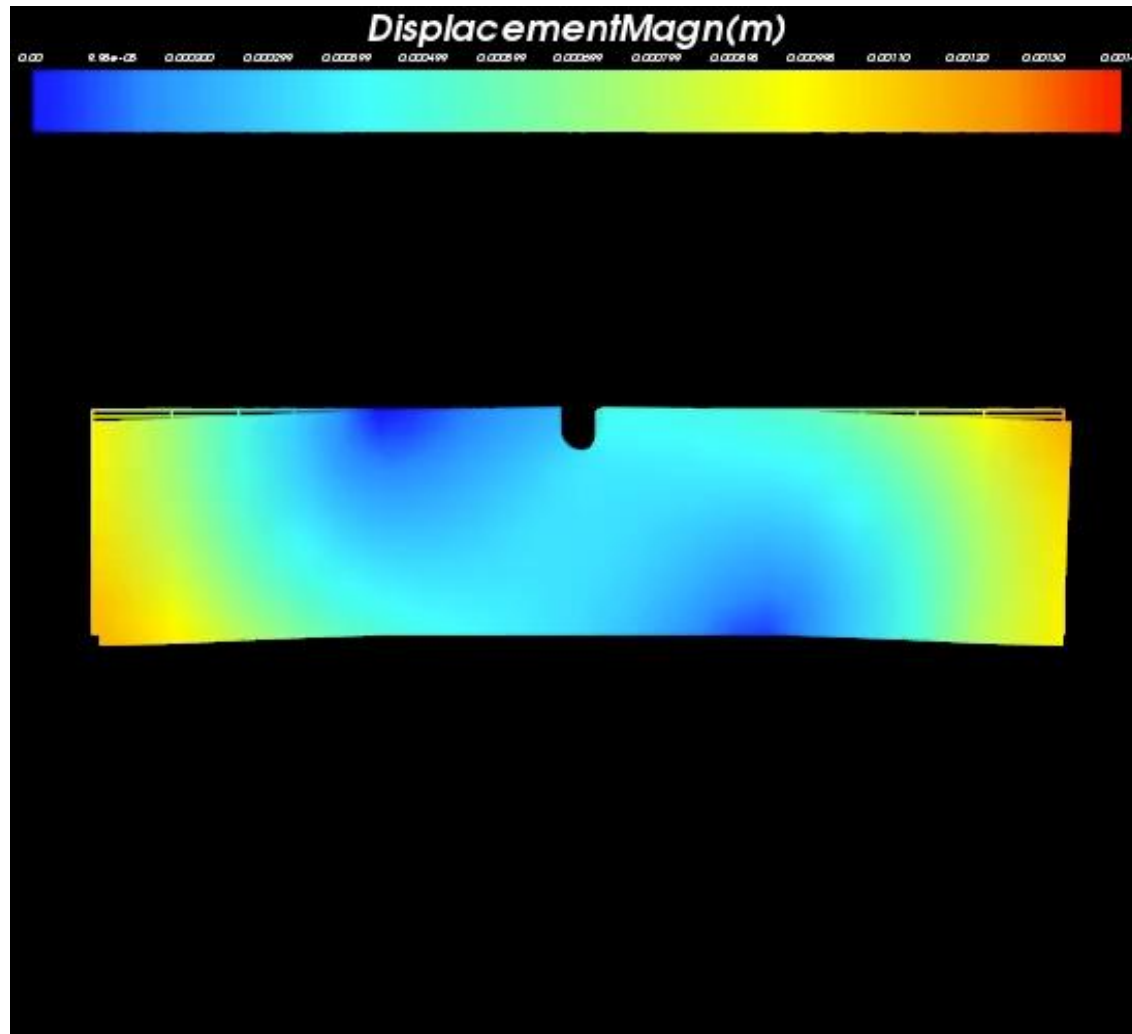
- Compute 3D transient temperature, microstructure, displacement, strain and stress in welds
- For an expected or probable distribution of in-service loads, compute plastic strain and damage evolution.
- Identify areas at high risk of fatigue failure based on effective stress I2, hydrostatic stress and damage evolution.

Computer Model for Casey Holycross' Fatigue Test



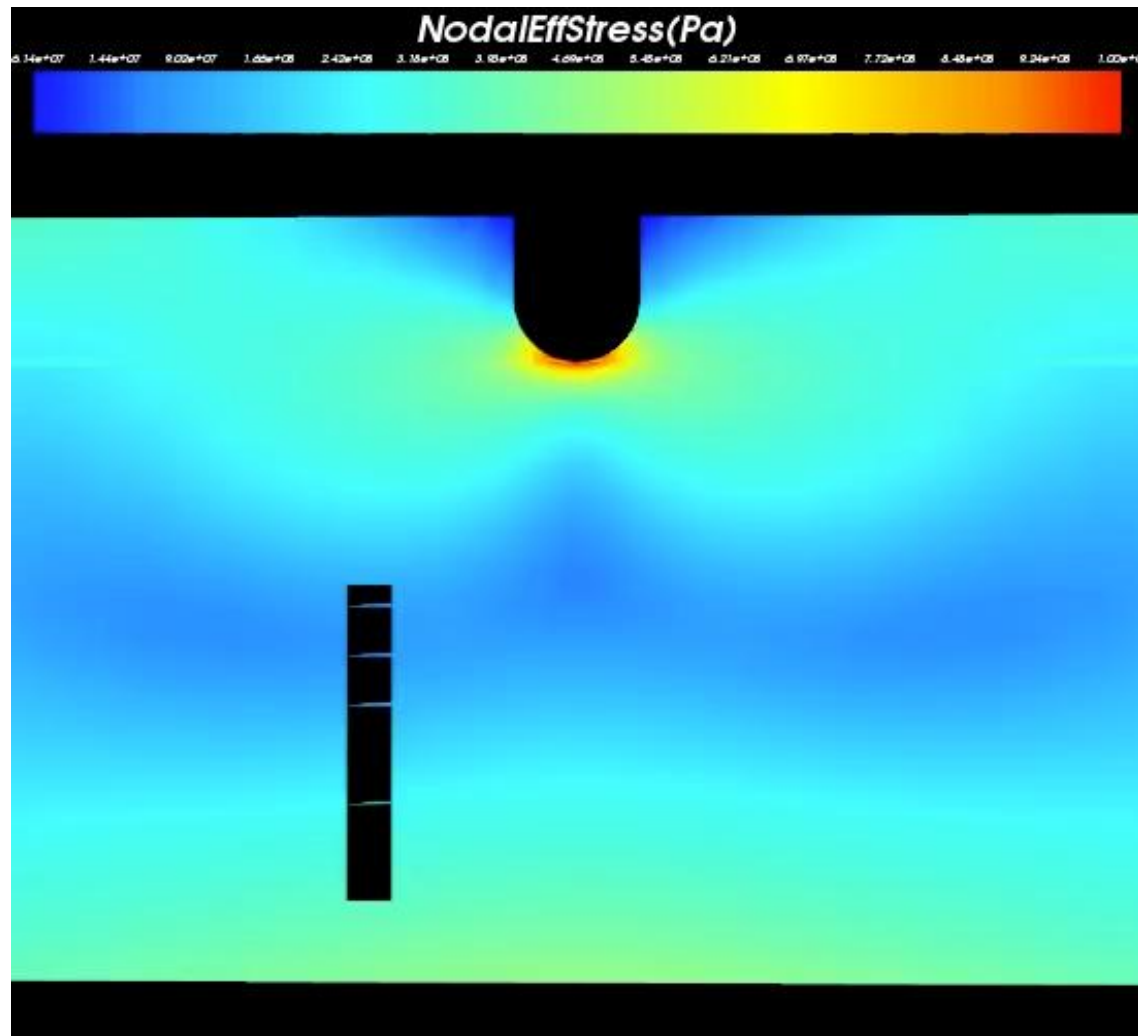
50 load cycles. Plane strain with maximum load is 3,500,000 N/m . The red colour is damage 0.95 that indicates it is broken, i.e., that a crack nucleated and grew.

Displacement of Casey Holycross' Fatigue Test



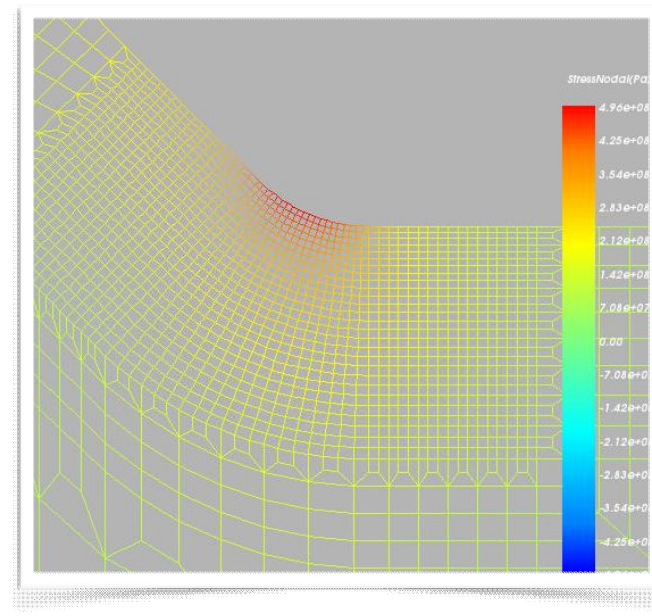
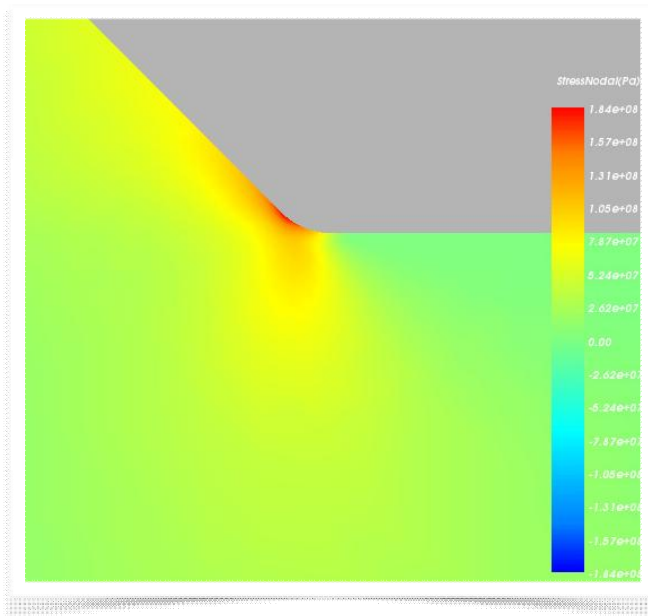
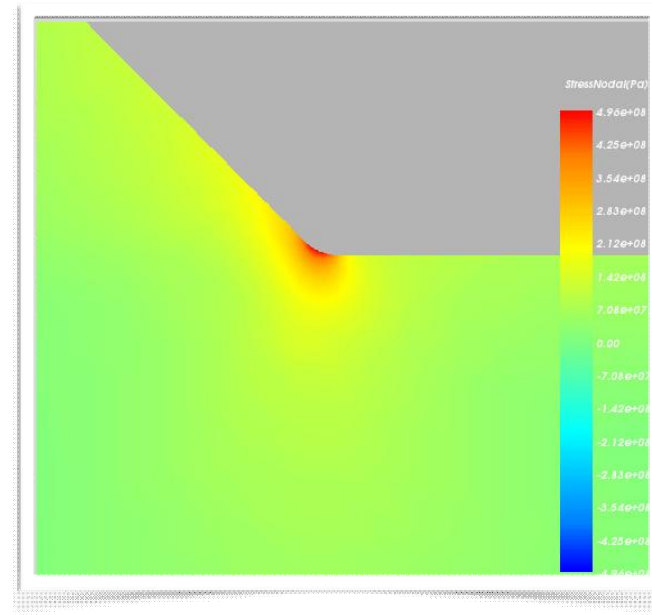
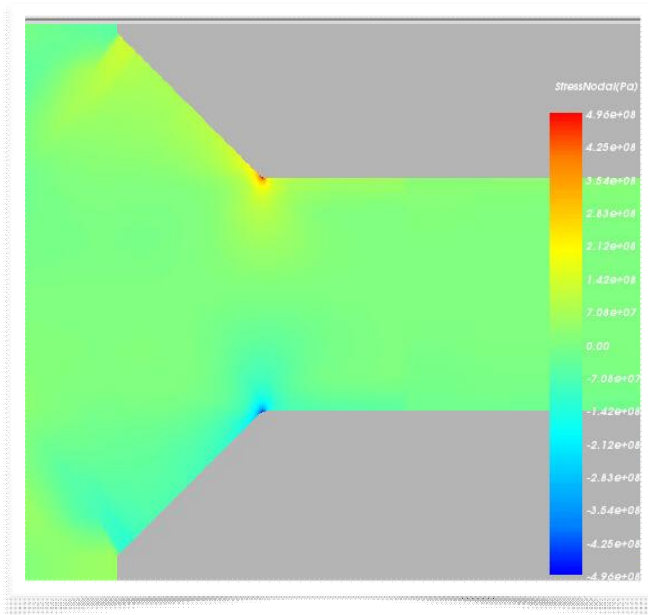
50 load cycles. Plane strain with maximum load is 3,500,000 N/m

Effective Stress Casey Holycross' Fatigue Test

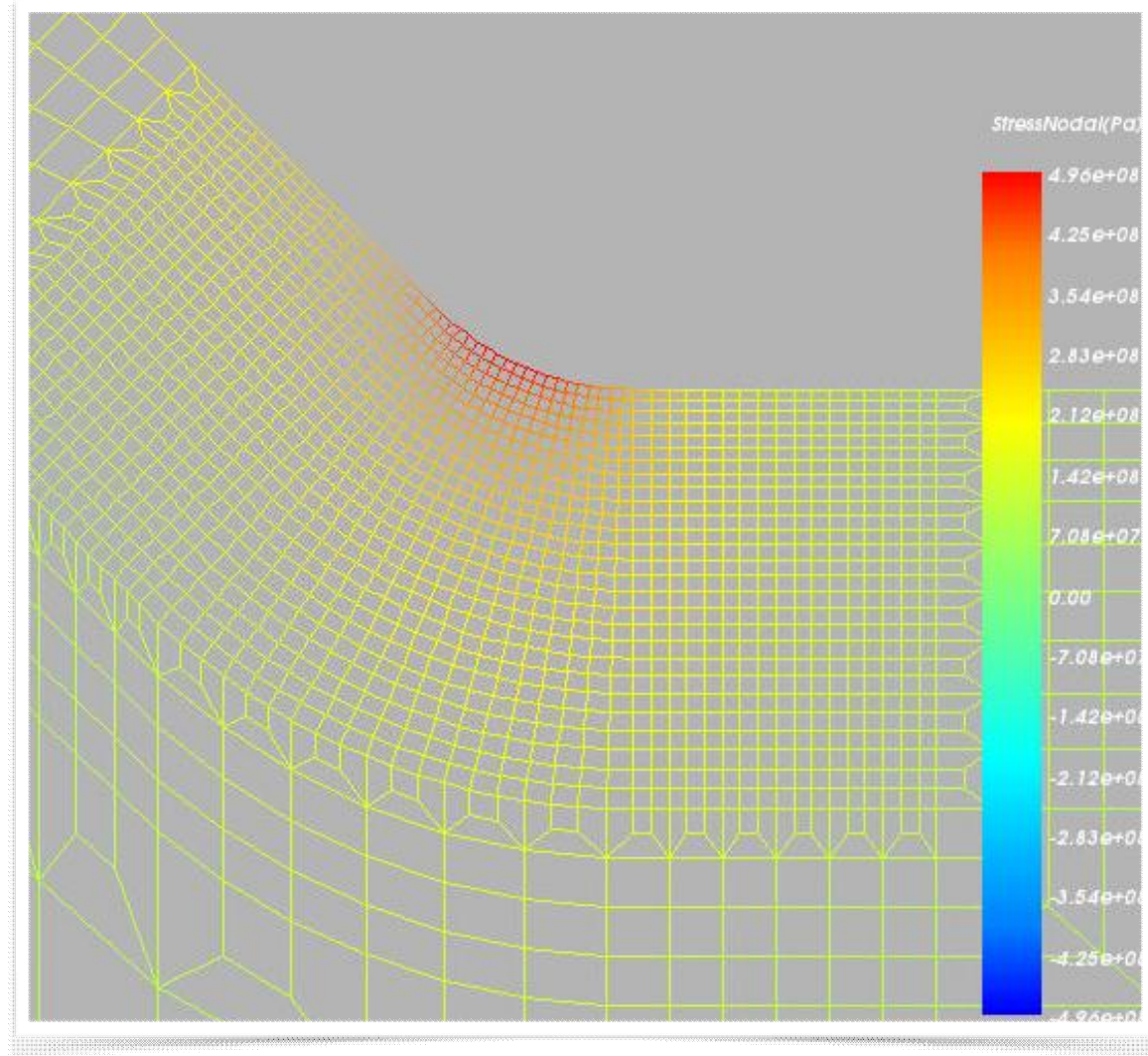


50 load cycles. Plane strain with maximum load is 3,500,000 N/m

Casey Gales' Test - Weld Toe Mesh

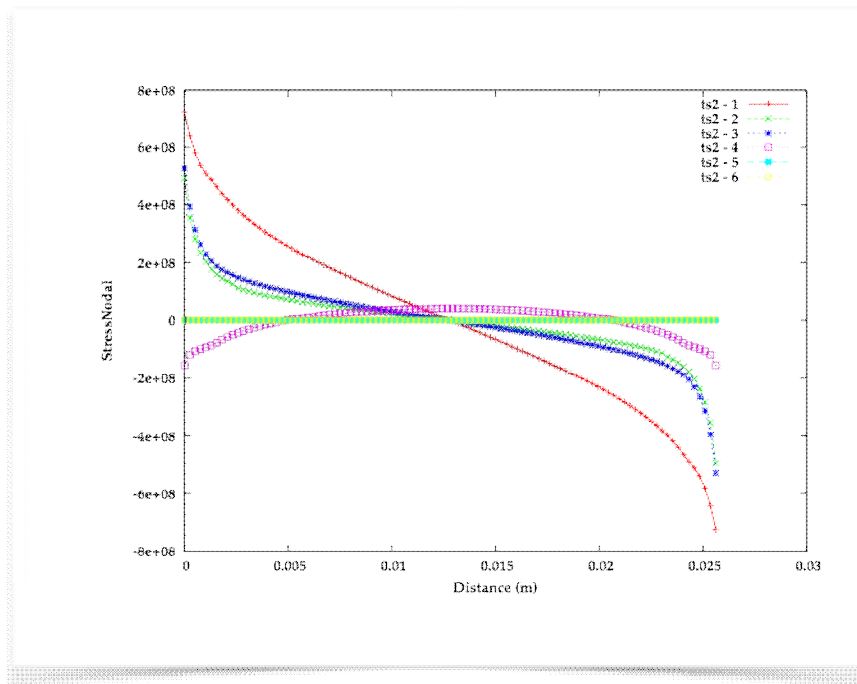


Parametric Mesher for Weld Toe Stress Distribution

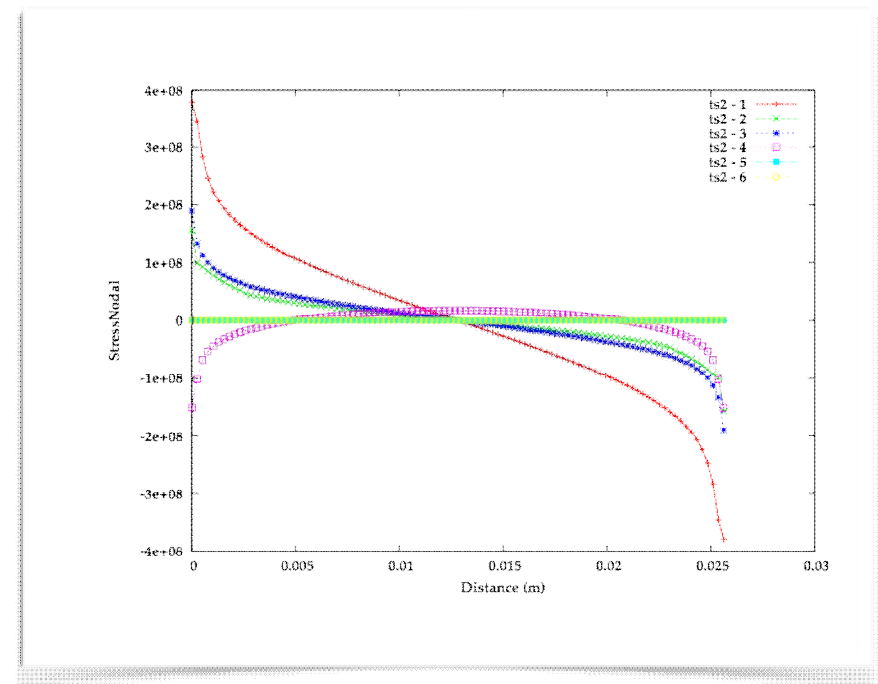


The parametric mesher for a weld toe creates a mesh for a specified weld toe radius. The stress analysis can be either elastic or plastic. There is no need to use a stress concentration factor. The weld toe can be identified automatically because VrWeld knows what is filler metal and what is base metal.

Casey Holycross' Cyclic SED Data Summary

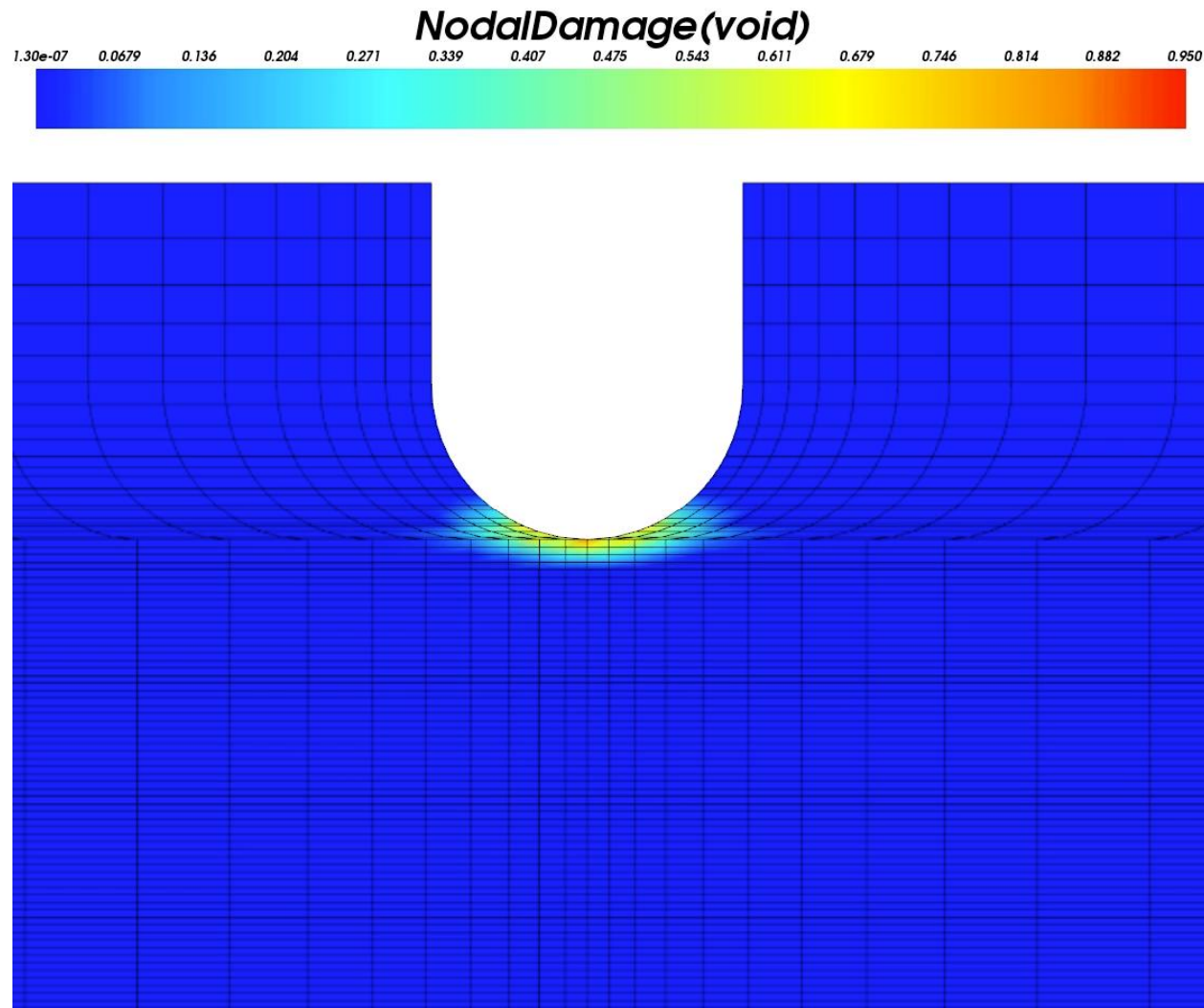


Maximum Load



Minimum Load

Computer Model for Casey Holycross' Fatigue Test



50 load cycles. Plane strain with maximum load is 3,500,000 N/m . The red colour is damage 0.95 that indicates it is broken, i.e., that a crack nucleated and grew.

In-service Life as Nonlinear Initial Value Problem

- Governing equations - 3D nonlinear, transient
- Conservation of mass, energy, momentum
- Geometry
- Initial State
- Material properties - constitutive equations
- Boundary conditions

Experimental Data - Evidence Based Reasoning

- Stochastic Probabilistic (Statistics)
- Constitutive equations, e.g., stress-strain
- Damage evolution equations
- Creep - visco-elasto-plasticity or viscosity
- Reversible and irreversible thermodynamic
- Microstructure
- Large plastic zones

Continuum Mechanics vs Fatigue Mechanics

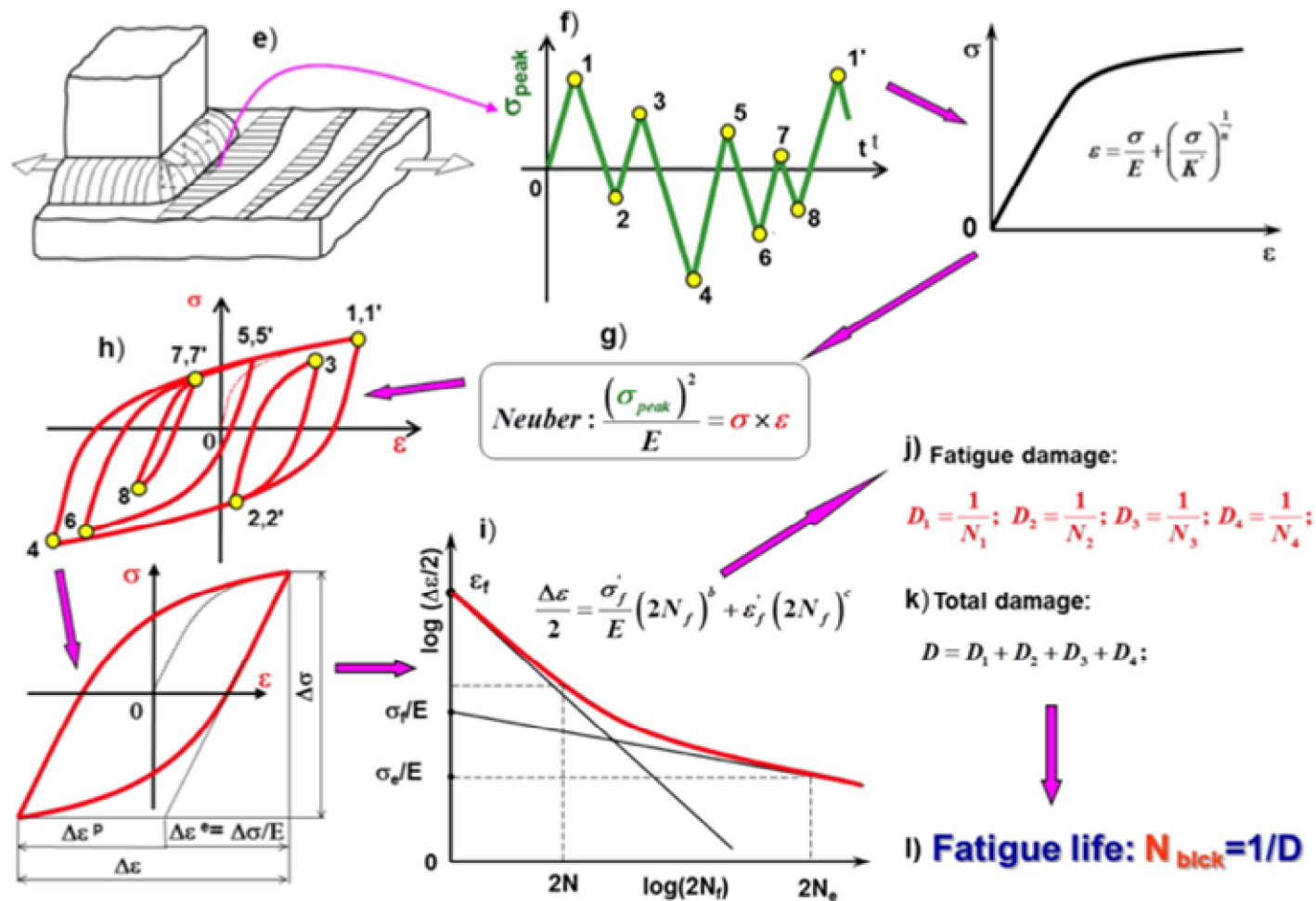
- **Continuum Mechanics**

- Smooth continuous functions: macroscopic: macroscopic
- No length scale
- Point-wise or non-local
- Conservation of mass, energy, momentum
- Constitutive equations

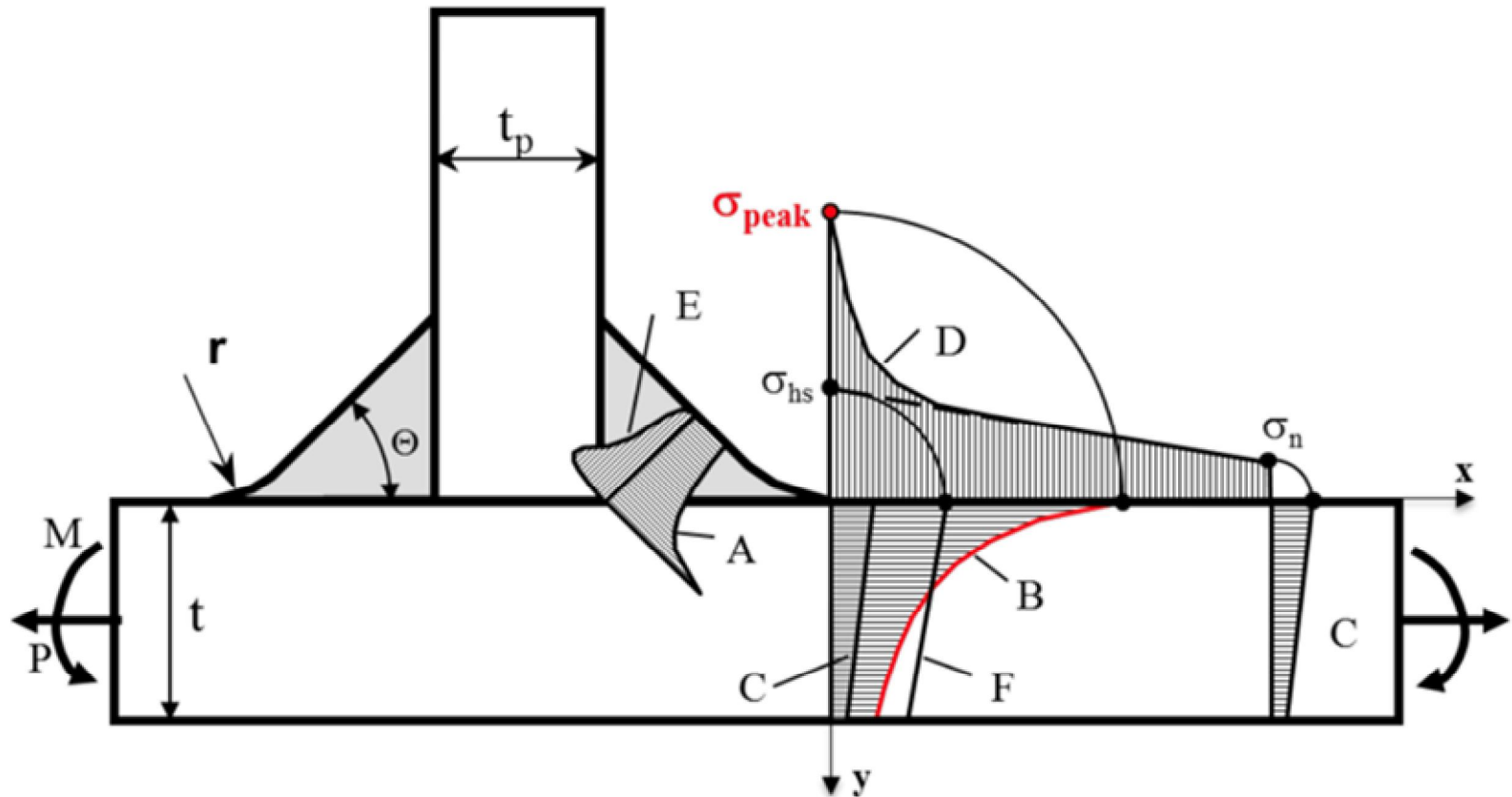
- **Fatigue Mechanics**

- Statistical, stochastic, regression equations
- Neuber rule, averages stress & strain at a notch
- Geometric Programming

Fatigue Analysis of Specific Crack

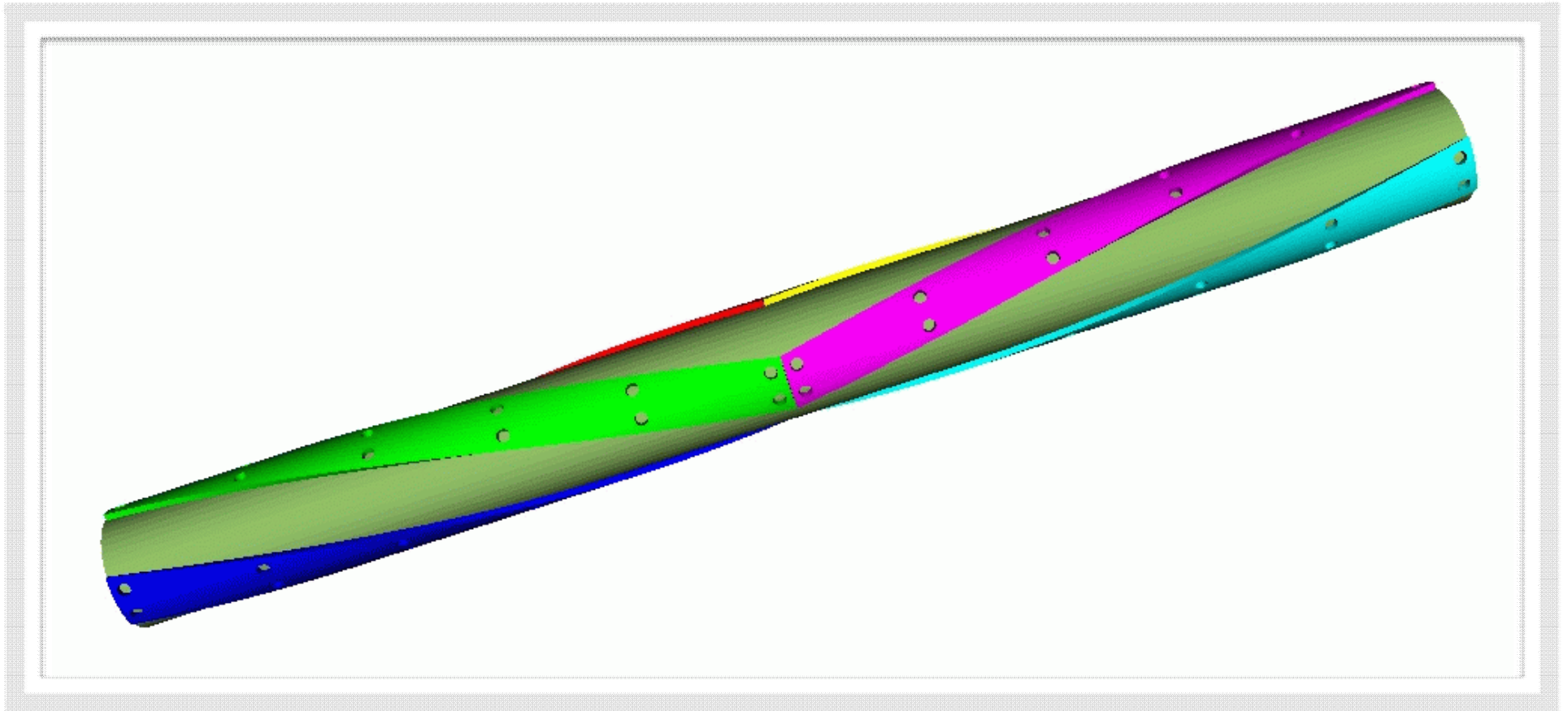


In-service Loads for Fatigue Analysis

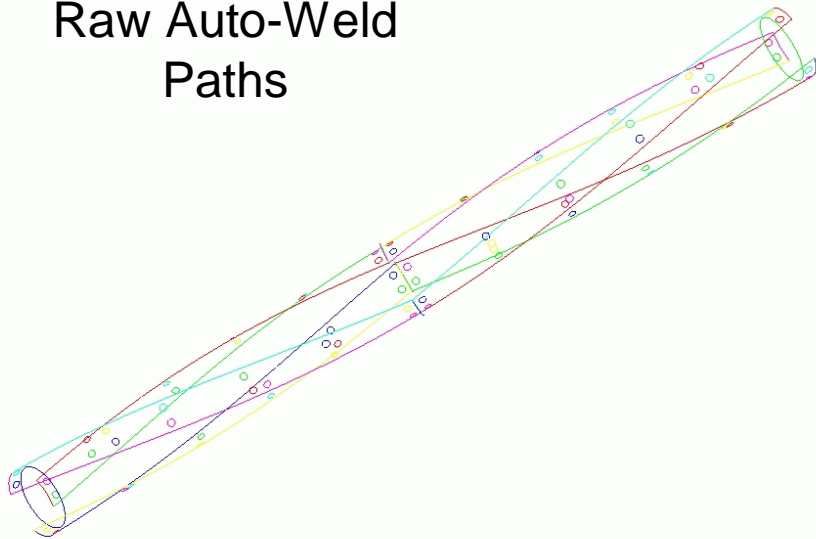


Instead of or in addition to applying membrane and bending loads apply in-service loads to the structure.

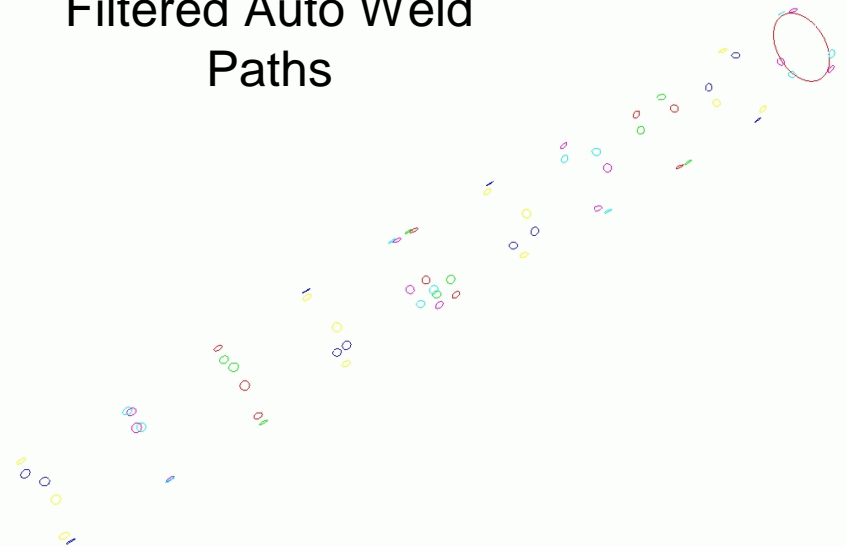
STL from CAD



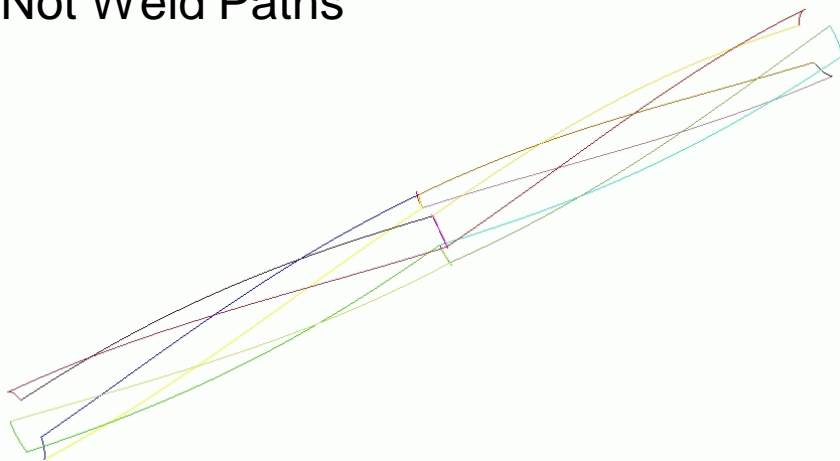
Raw Auto-Weld
Paths



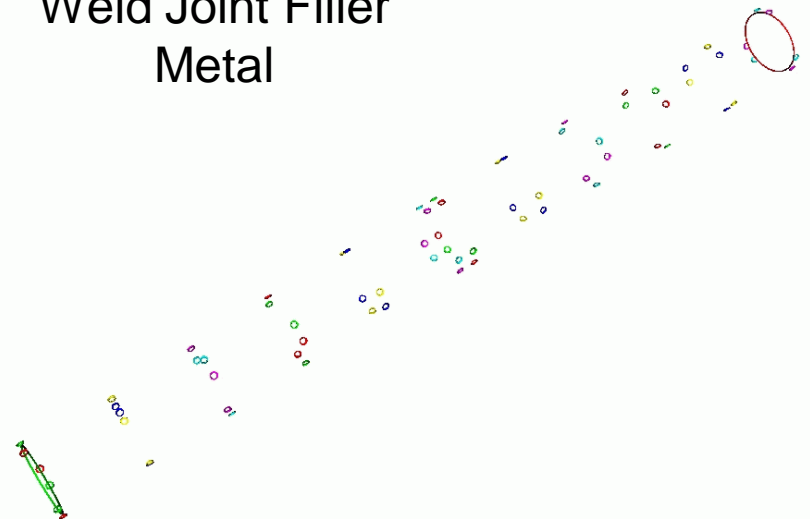
Filtered Auto Weld
Paths



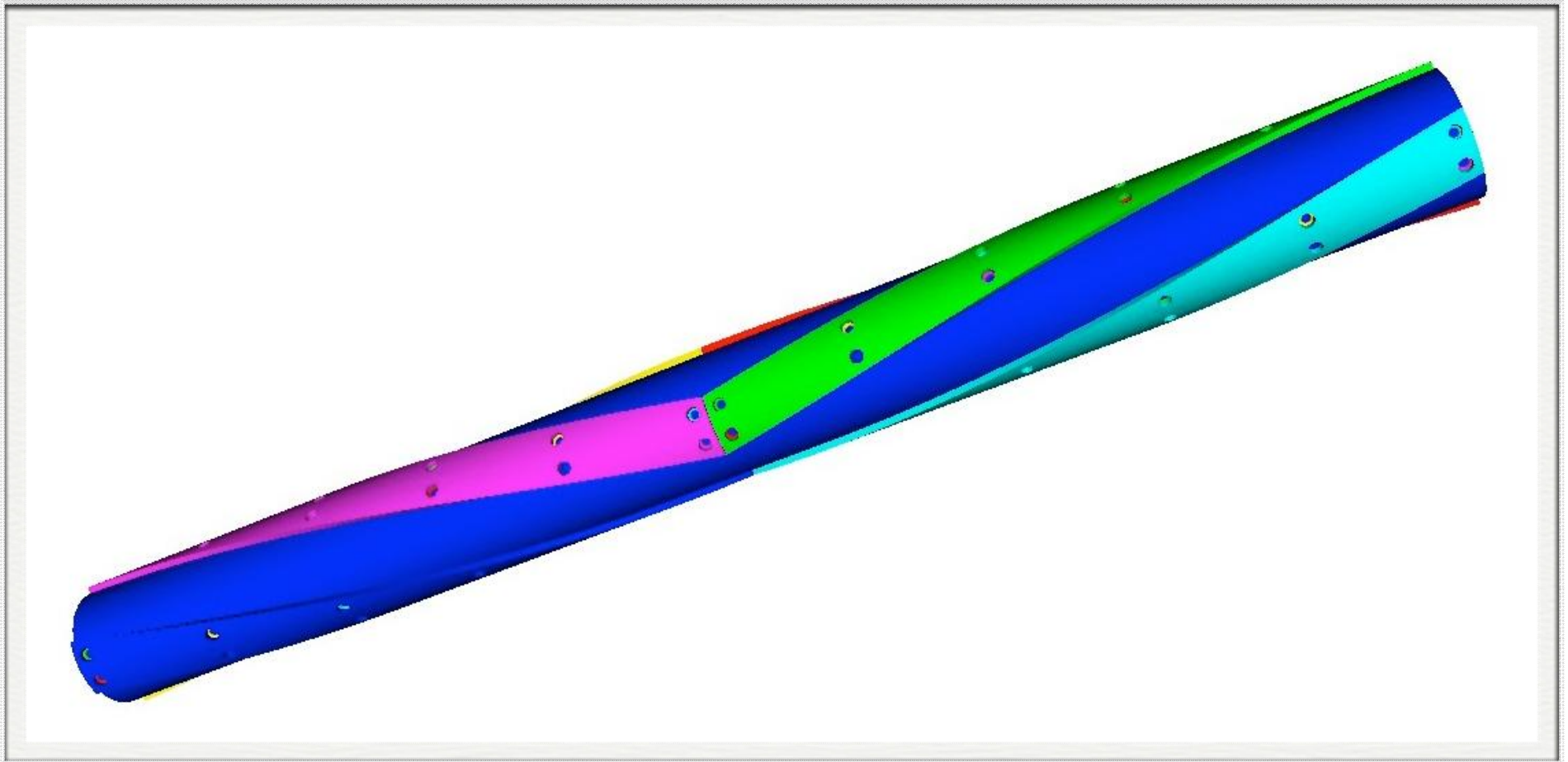
Not Weld Paths



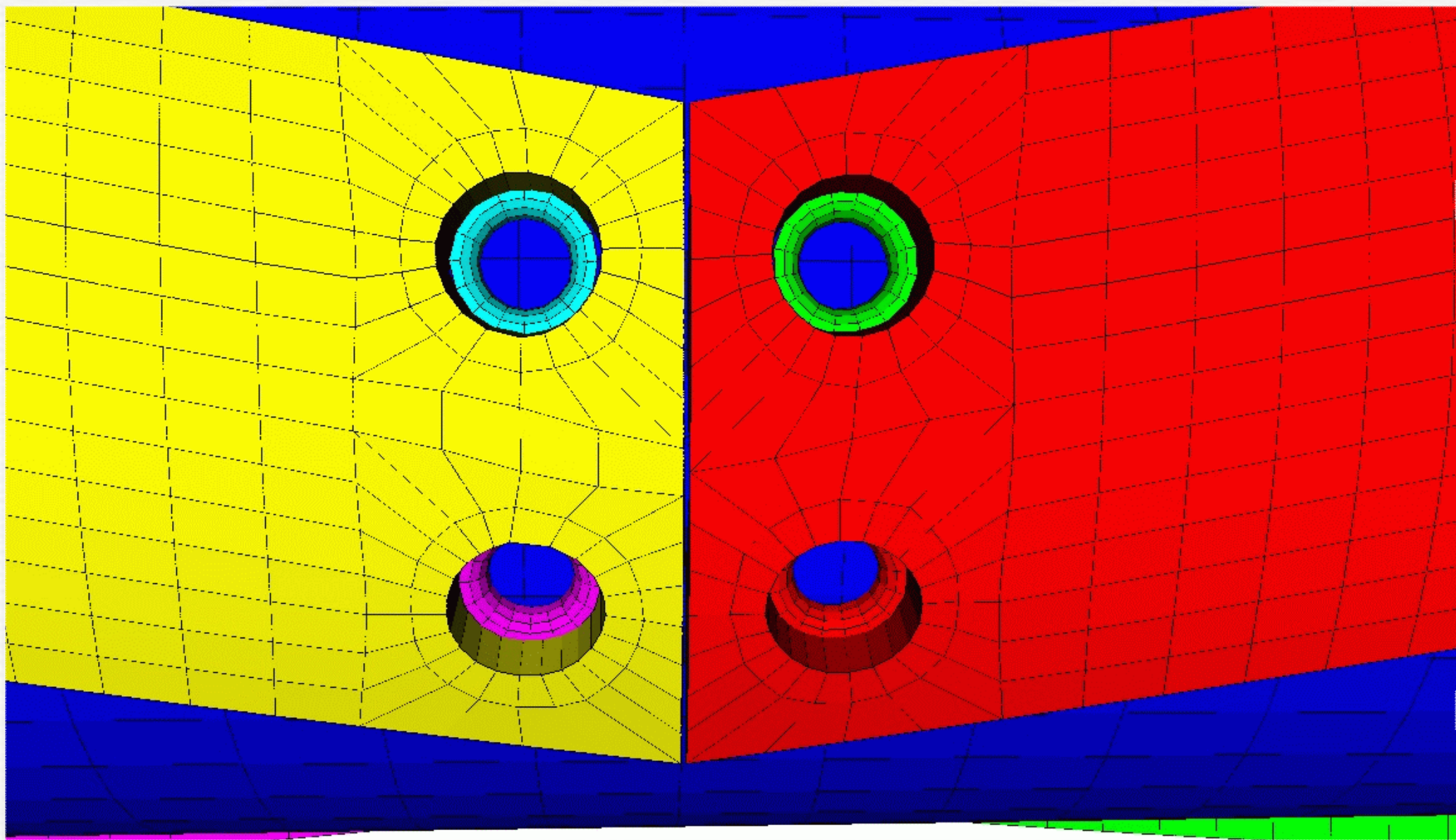
Weld Joint Filler
Metal



FEM Mesh

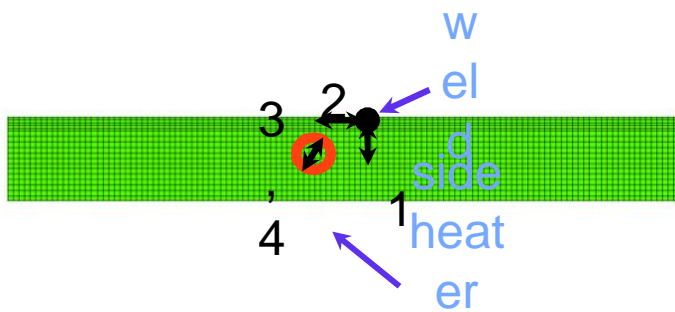


FEM Mesh



Zero Distortion - Zero Residual Stress Welds???

Is this possible?



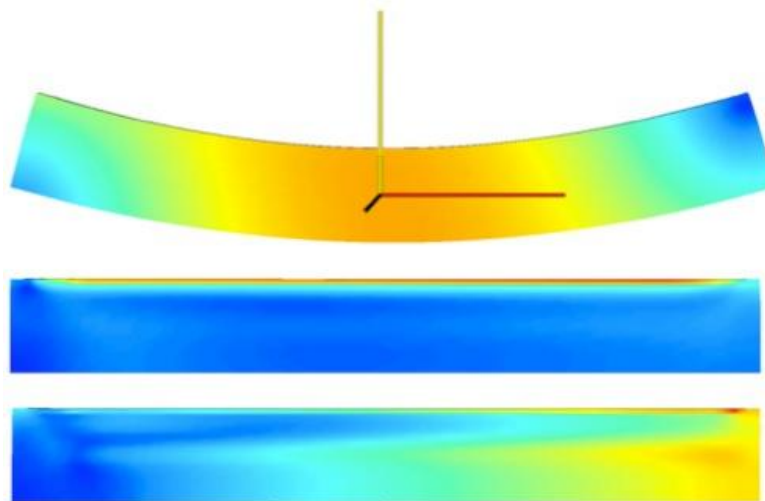
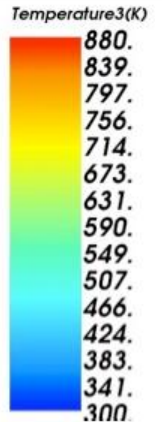
No Side Heaters



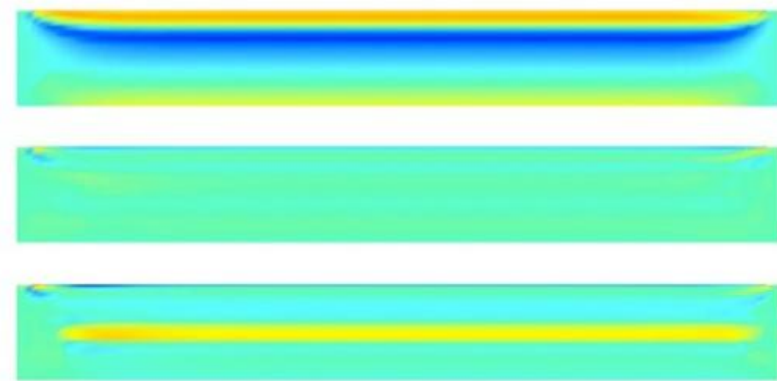
Trailing



Leading



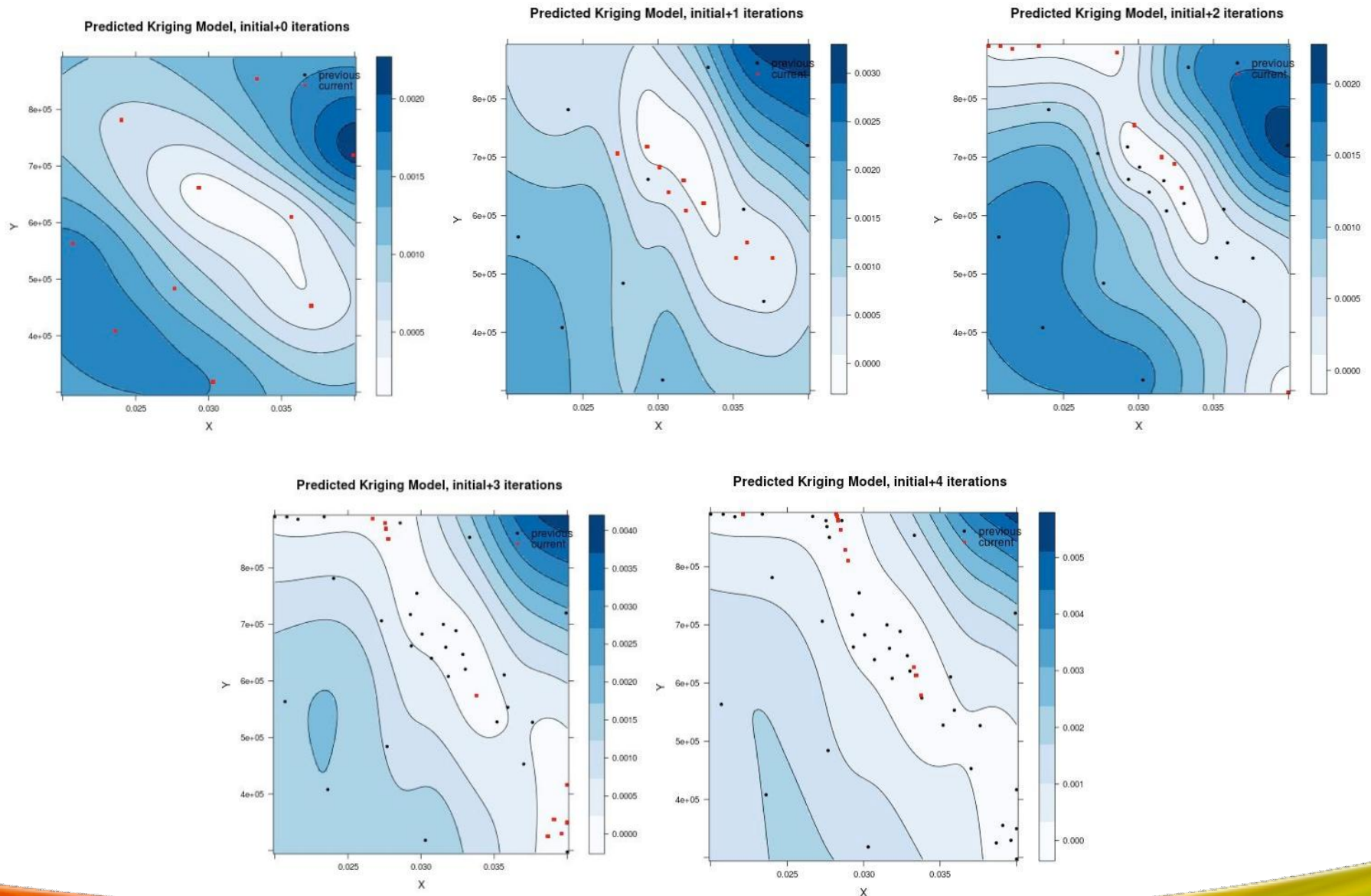
Distortion



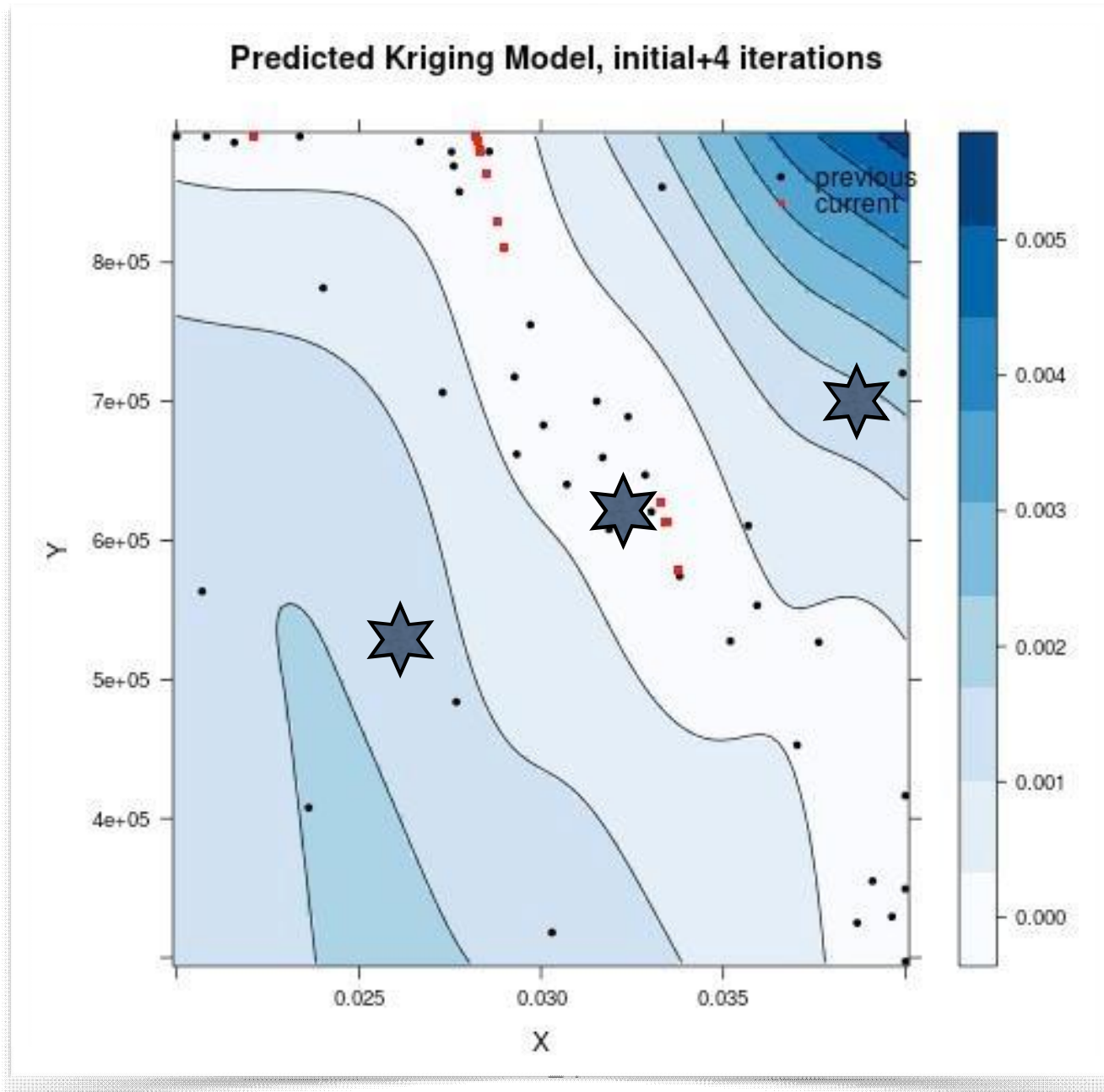
Residual Stress

Global Optimal Design - Kriging

Design Space for Radius and Flux



Optimal Designs for Physical Experiments



Some Thoughts



- 'Nature and Nature's laws lay hid in night: God said, Let Newton be! and all was light.'
Alexander Pope
- "There is a crack in everything, that's how the light gets in."
Leonard Cohen's "Anthem"
- If we are to achieve things never before accomplished, we must employ methods never before attempted.
Francis Bacon 1626