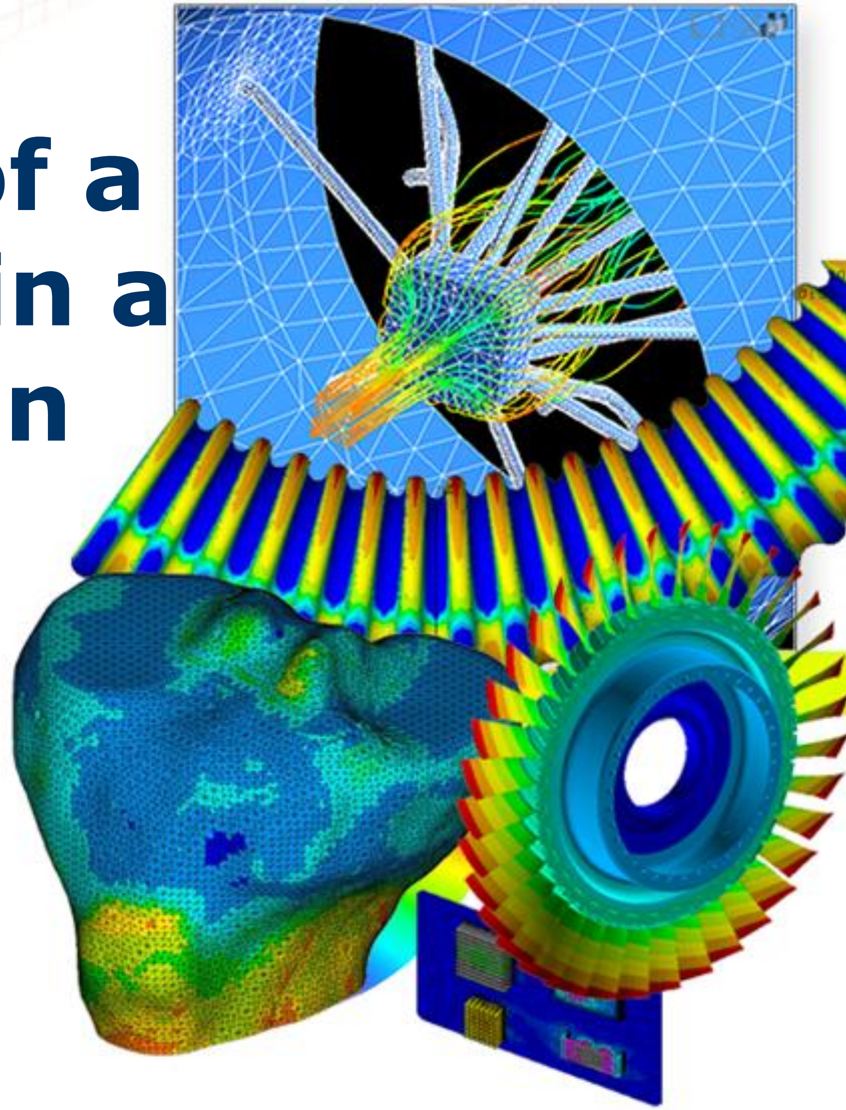
CAE ASSOCIATES

ENGINEERING ADVANTAGE

Fatigue Analysis of a Welded Structure in a Random Vibration Environment



ANSYS Users Conference

Framingham, MA

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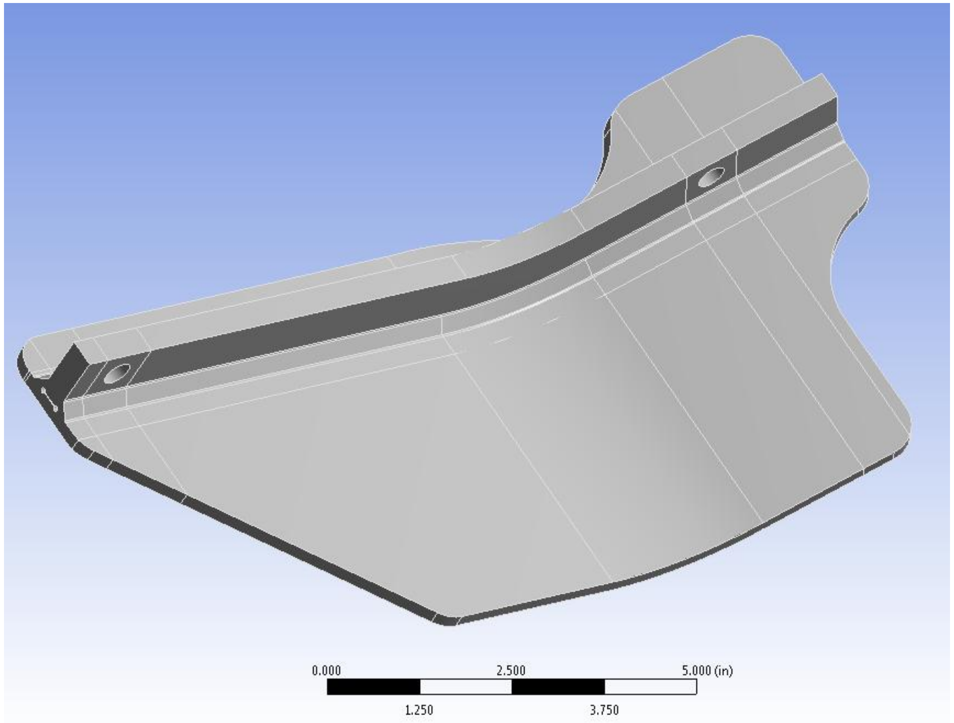
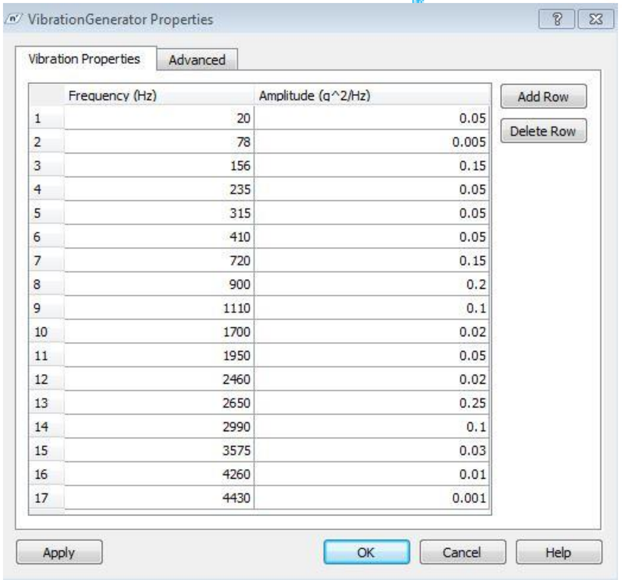
Outline

- Problem description:
  - Life assessment of welded bracket subjected to random vibrations.
- Background:
  - Stresses in welds.
  - Methods for calculating critical weld stresses.
  - Random vibration fatigue analysis.
- Analysis description:
  - Selection of weld stress approach.
  - Using ANSYS Mechanical and nCode DesignLife to perform random vibration fatigue of welded structure.

Problem Description: Welded Bracket

- Welded bracket with base excitation:
  - Input Power Spectral Density (PSD) provided.
  - Supported and excited at two holes.
  - Fillet welds along intersection of components.



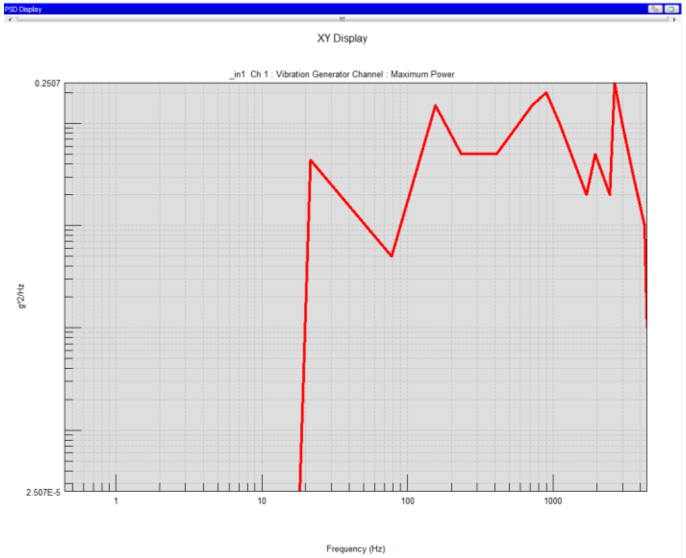


VibrationGenerator Properties

Vibration Properties | Advanced

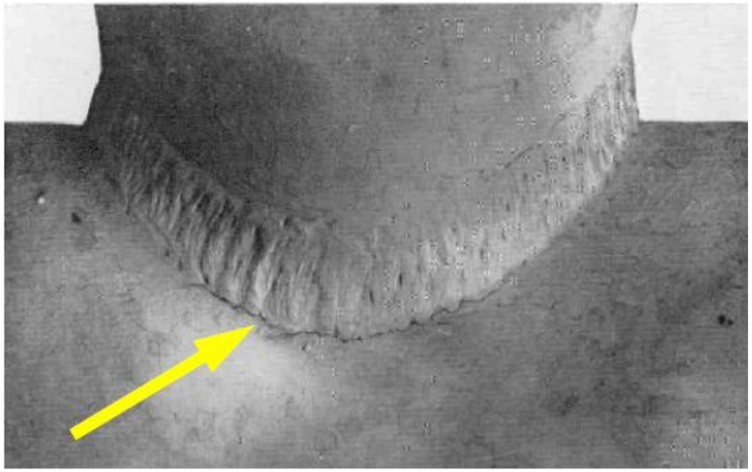
	Frequency (Hz)	Amplitude (g^2/Hz)
1	20	0.05
2	78	0.005
3	156	0.15
4	235	0.05
5	315	0.05
6	410	0.05
7	720	0.15
8	900	0.2
9	1110	0.1
10	1700	0.02
11	1950	0.05
12	2460	0.02
13	2650	0.25
14	2990	0.1
15	3575	0.03
16	4260	0.01
17	4430	0.001

Add Row | Delete Row | Apply | OK | Cancel | Help

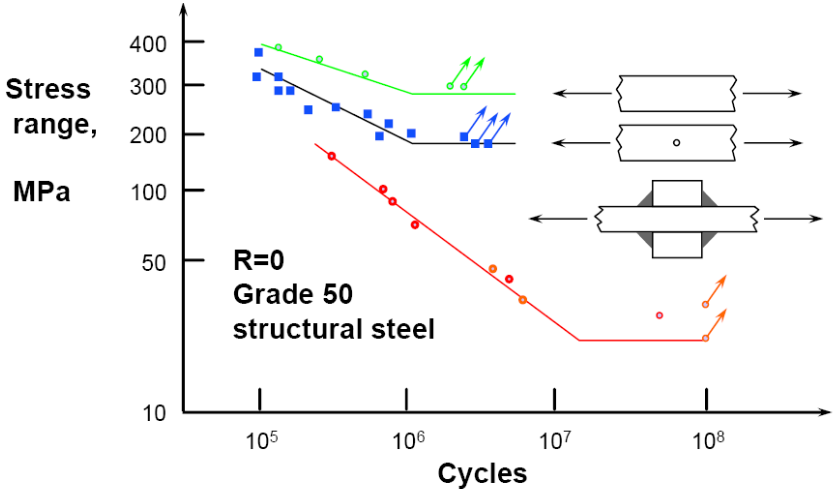


The Importance of Weld Stress Prediction

- Key features of welds:
  - Sharp section changes.
  - Local discontinuities.
  - High tensile residual stresses.
  - Crack initiation sites.
  - Material properties vary over weld cross section.
  - Geometry of weld cannot be modeled in detail.

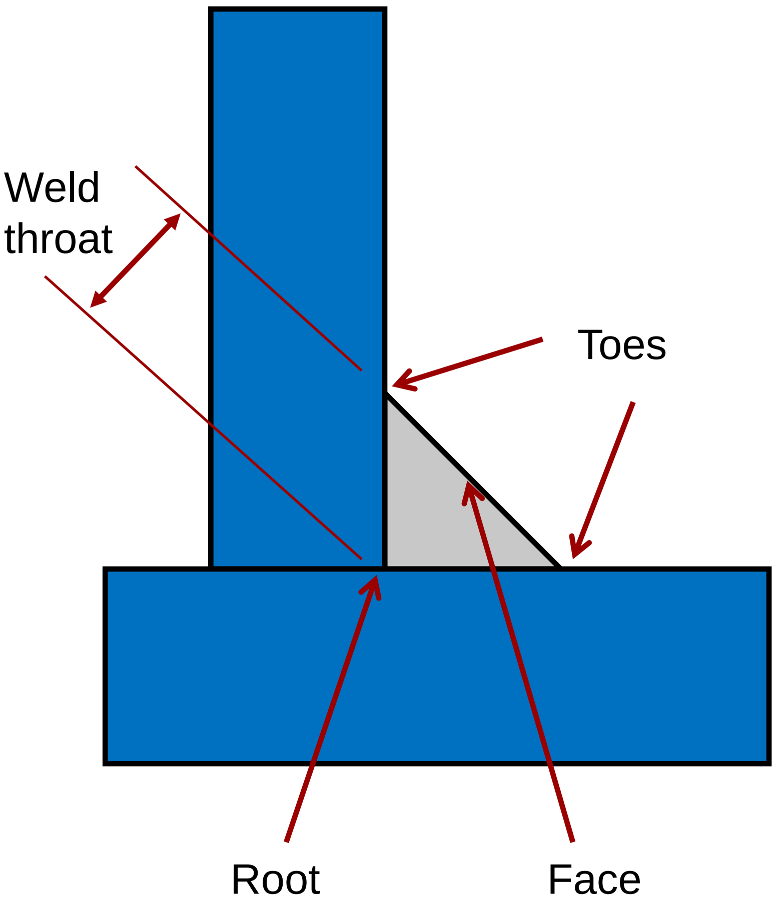


- Consequences:
  - Relatively low fatigue strength.
  - Dominated by fatigue crack growth.
  - Fatigue life not increased by use of higher strength material.



Weld Geometry and Terminology

- Weld features.
  - Face:
    - The exposed surface of the weld.
  - Toe:
    - The point or line where the face meets the parent material.
  - Root:
    - The point in the weld joint where the weld metal ends.
  - Weld throat:
    - The minimum distance from the root to the face of the weld.
    - It is the minimum load bearing section and considered the effective area.

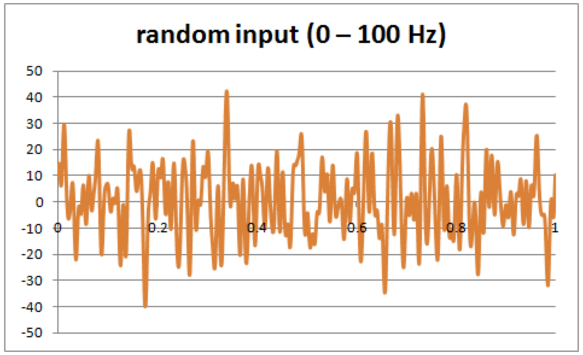


Fatigue Failure in Welds

- The primary failure mechanism in welds is fatigue.
  - Fatigue is failure from cyclic loading.
  - The underlying mechanism in fatigue is the propagation of cracks.
  - Cracks are present from the welding process.

- Fatigue is typically assessed based on time-based loading.

- However, if random loading occurs:
  - Evaluation of fatigue is performed in the frequency domain.
  - Statistical approach is used.
  - Random loading characterized by Power Spectral Density function.



Methods for Calculating Stress in Welds

- There are four methods generally used for calculated stress in welds:
  1. Nominal stress method.
  2. Structural hot spot stress method.
  3. Effective notch stress method.
  4. Stress intensity at a crack tip.

- The method used in assessing welded structure life depends on:
  - The nature of the problem.
  - If the method is valid for approval of a particular component.
  - If the welded design is catalogued in a welding standard.
  - The ability to create detailed finite element analyses of local weld regions.

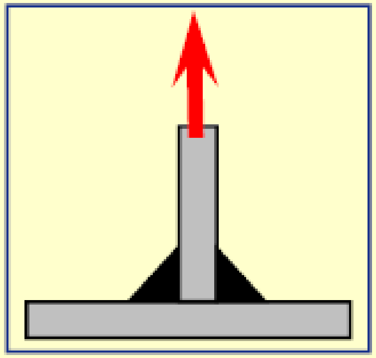
- International Institute of Welding (IIW) has defined S-N curves for welds in aluminum and steel.

- The S-N curve selected must match the method used to extract the stresses.

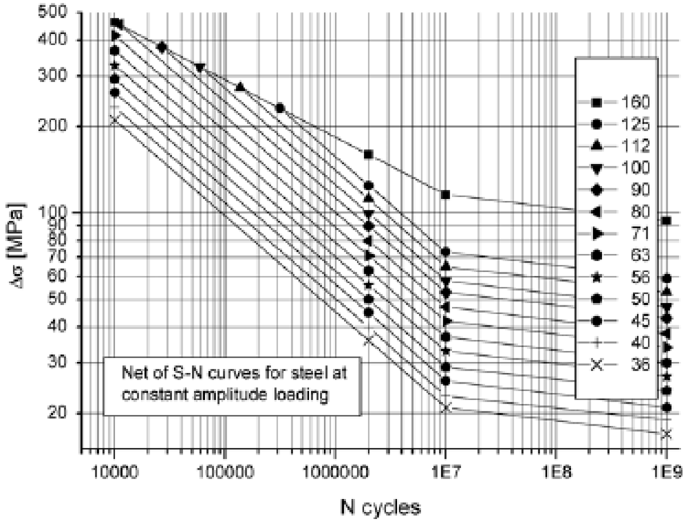
Nominal Stress Method

- Nominal stress method.
  - Classical analysis or hand calculation approach.
  - Stress calculated as section loads divided by net sections and bending moments divided by section moduli.
  - The focus of most welding standards.
  - Life prediction found using S_N-N fatigue curves for the weld class.
    - More than 70 weld classes.

$$S_N = F/A$$

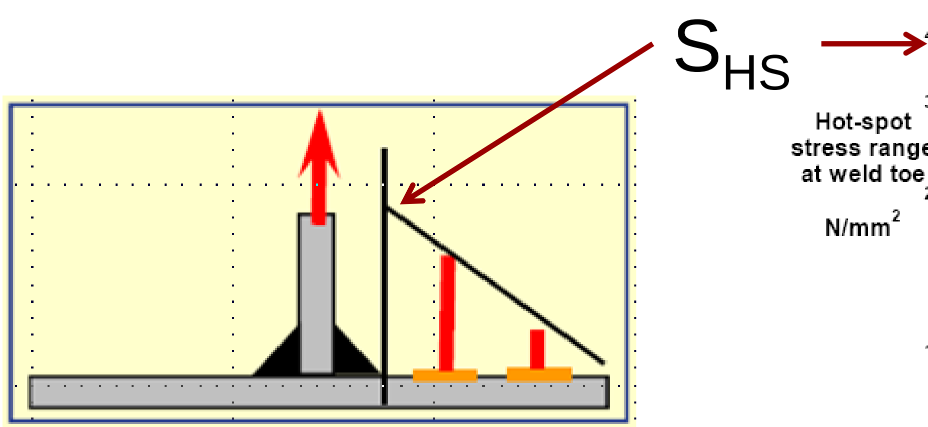


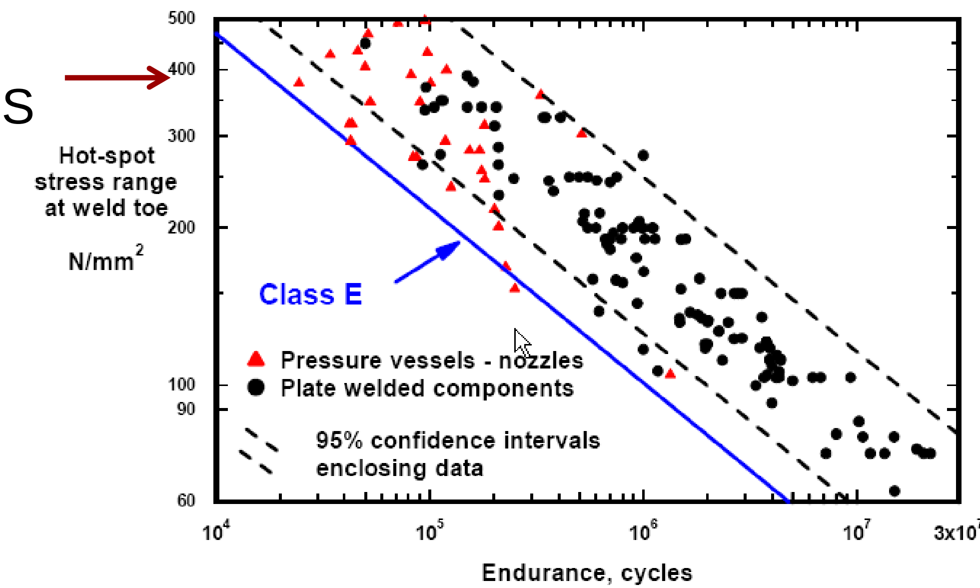
S_N



Structural Hot Spot Stress Method

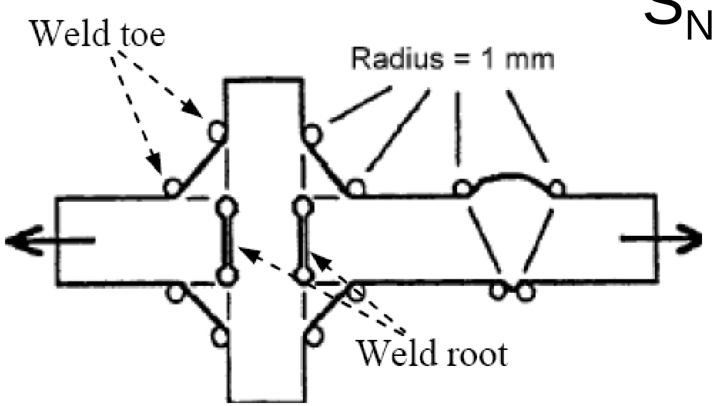
- Structural hot spot stress method.
  - Accounts for stress concentration effects, ignores the local notch effect of the weld toe.
  - Hot spot stress found by linearly extrapolating stress from adjacent region to weld toe from FE analysis.
    - Various methods for extrapolating, such as along surface or through thickness.
  - S_{HS}-N fatigue curves based on hot spot stress range exists for some weld designs.



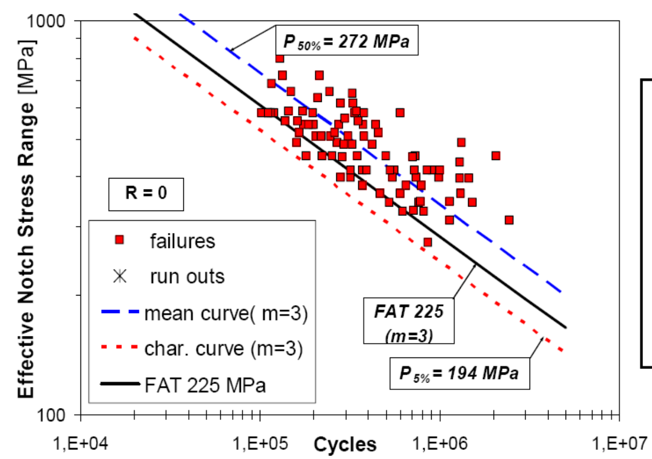


Effective Notch Stress Method

- Effective notch stress method:
  - The effective notch stress is the stress at the weld toe radius obtained assuming linear elastic response.
  - Real weld contour variations are approximated by an effective notch root radius of 1 mm.
  - For thin structures (under 5 mm), an effective notch radius of 0.05 mm is recommended.
  - A single S_{NS}-N curve is used for all welds depending upon the effective notch radius used.



S_{NS}

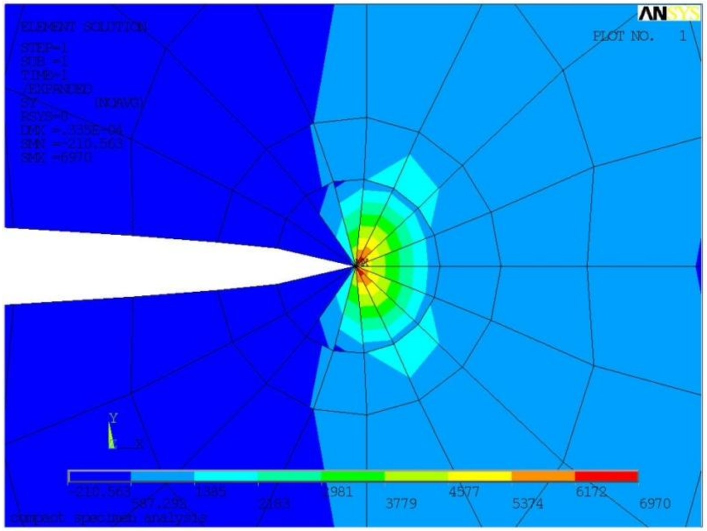


$R_{effective}$ = 1 mm (K_t=2.5)
R_{mean} = 1.4 mm
$R_{(strd.deviation)}$ = 1.2 mm
$\theta_{mean} = 46^\circ$
$\theta_{(strd.deviation)} = 6.8^\circ$
Log C_{mean} (m=3) = 13.6
Log $C_{(strd.\ deviation)}$ = 0.23
Nr of strd. Deviations = 1.92
$FAT_{Pf50\%}$ = 272 MPa
$FAT_{Pf5\%}$ =194 MPa

Stress Intensity at a Crack Tip

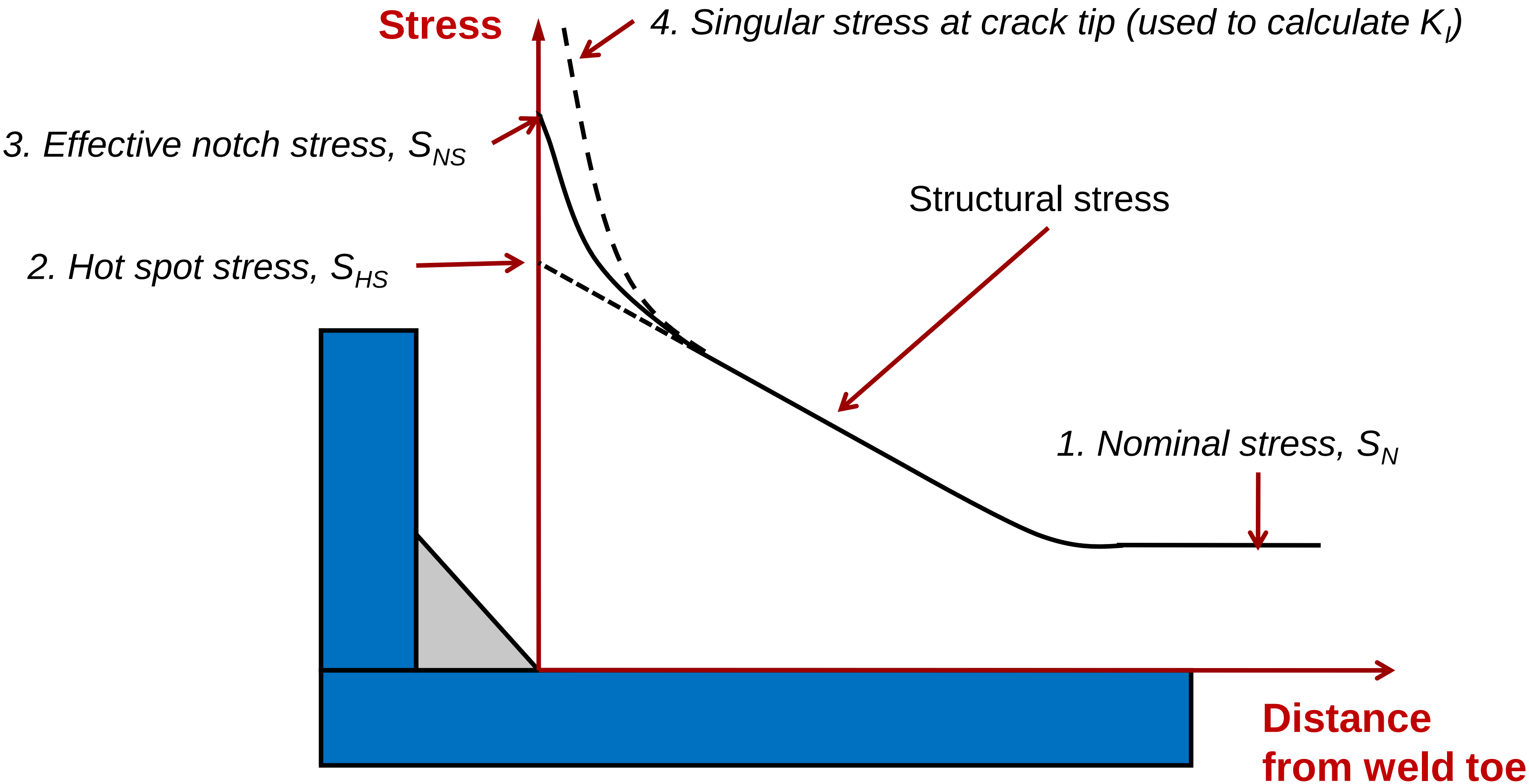
- Stress intensity at a crack tip:
  - Models a known crack size and location.
  - Requires a fine mesh near the crack tip.
  - Calculates stress intensity at the crack tip using fracture mechanics approaches.
  - Analysis is repeated by extending crack perpendicular to the 1st principal stress a small distance and recalculating stress intensity.

$$\sigma_{yy} = \frac{K_I}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 + \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right)$$



Comparison of Stress Techniques

- An illustration of the comparison of the different stress calculation techniques:



Random Vibration Fatigue Analysis

- Random vibration fatigue analysis is performed by defining the amplitude of the applied loading as a function of frequency.
  - This is called the input Power Spectral Density, or input PSD (g^2/Hz).

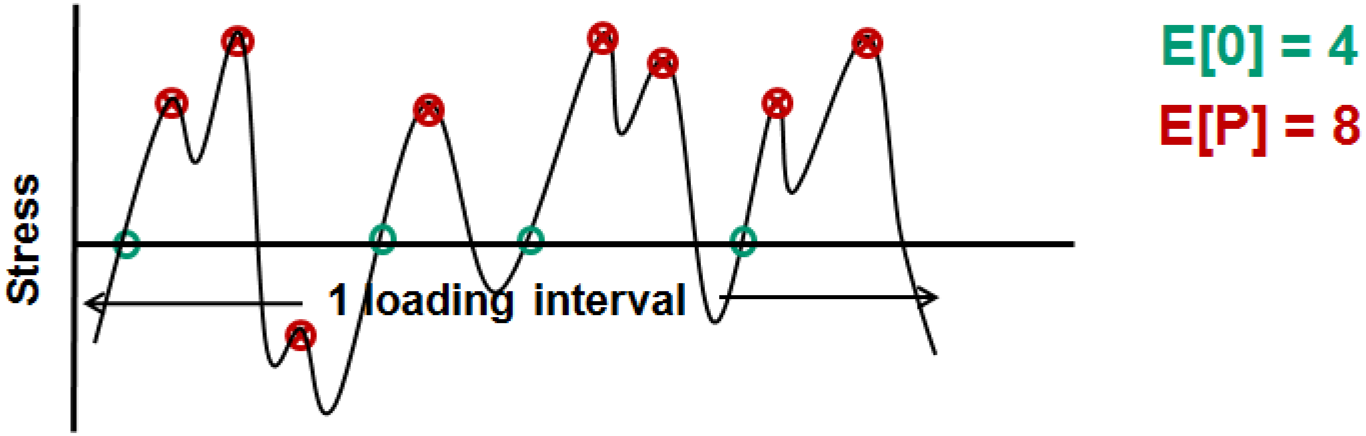
- Random vibration fatigue is determined using:
  - Statistical parameters that describe the PSD loading.
  - Miner's Rule to accumulate total damage.
  - The appropriate S-N data based on weld stress method chosen.
  - A PSD cycle counting method.

- nCode DesignLife PSD cycle counting methods:
  - Narrow Band – original technique, rarely used.
  - Steinberg – simple approach based on Gaussian distribution.
  - Dirlik – general purpose technique.
  - LaLanne – general purpose, default in DesignLife.

Random Vibration Fatigue Analysis

- The output or response PSD is obtained by multiplying the input PSD by the square of a transfer function.
  - The transfer function is obtained from the results of a harmonic analysis.

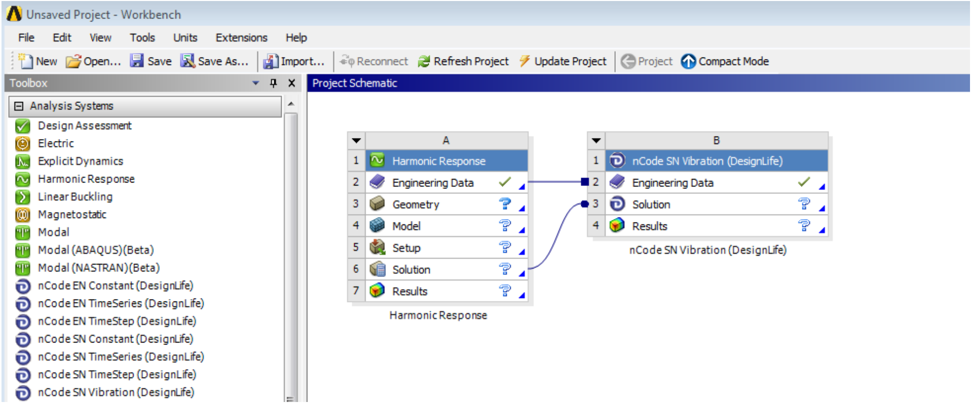
- Statistical parameters from the random loading are determined:
  - No. of upward zero crossings (E[0])
  - No. of local peaks (E[P])
  - Irregularity factor (γ = E[0]/E[P])



Application to Bracket Problem

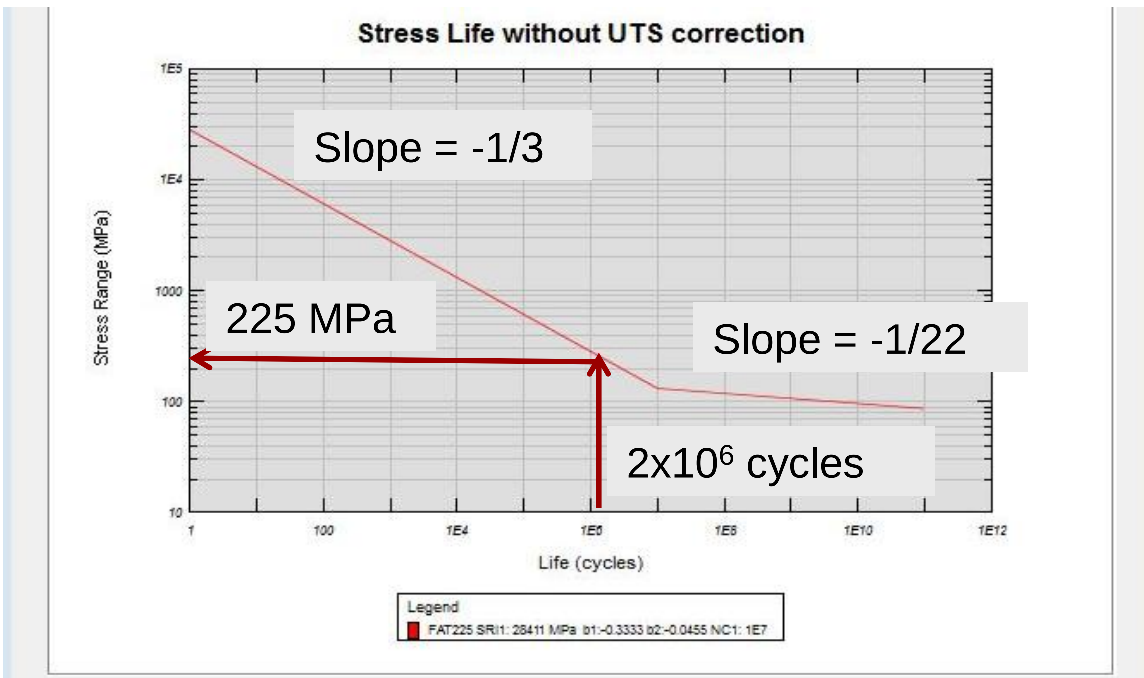
- What tools are available in nCode DesignLife?
  - nCode DesignLife has a random vibration module to perform vibration fatigue.
  - nCode also has two weld modules:
    - Spot weld, used to model welding of thin metal sheets.
    - Seam weld, for more general welding approach.
      - The seam weld is analogous to the hot spot weld stress approach.

- The effective notch weld stress approach was selected for this application.
  - Build model with 1 mm radius fillets at weld toe and root.
  - Perform harmonic analysis in Mechanical.
  - Feed the harmonic solution to nCode, perform vibration fatigue within nCode.



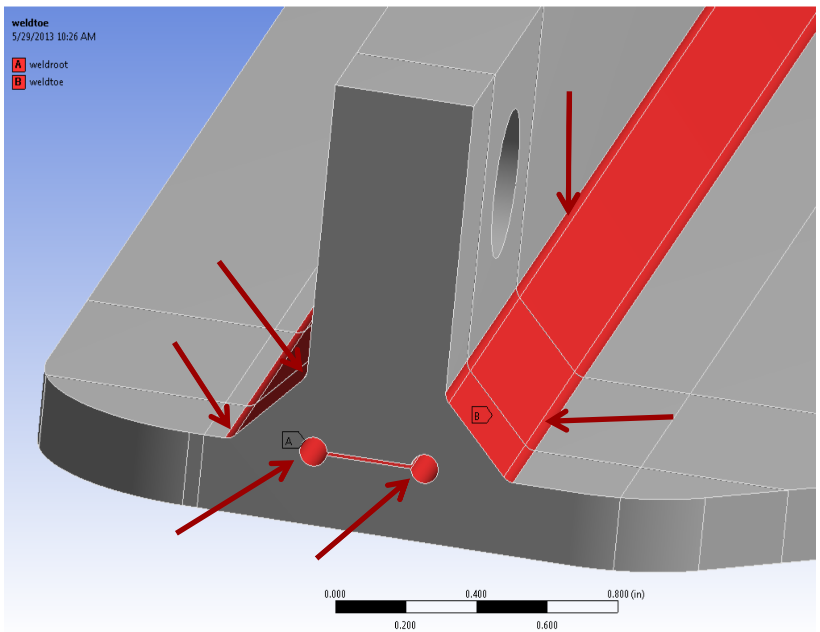
S-N Data

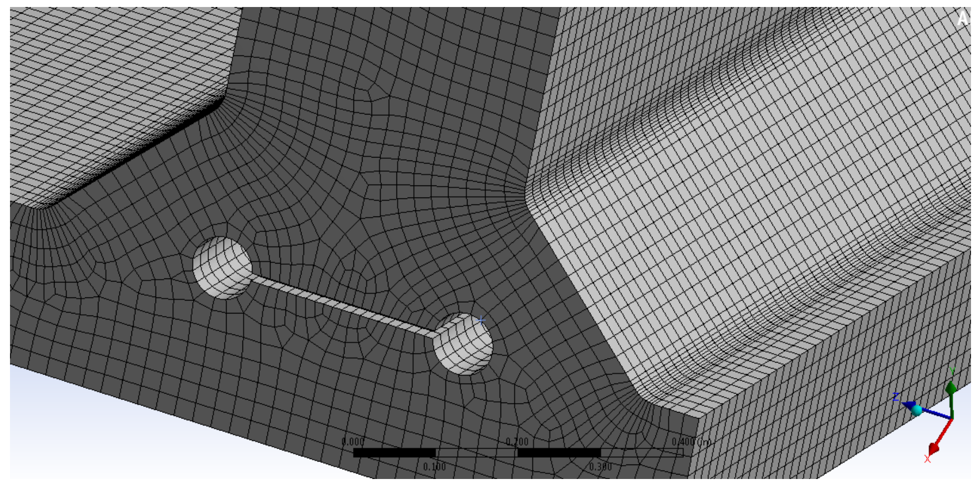
- FAT 225 is the recommended S-N curve if using the effect notch stress approach with welds in steel.
  - The fatigue strength at 2×10^6 cycles is 225 MPa.
  - The curve represents a survival probability of 97.7% and a standard deviation of log N = 0.206.
  - Can adjust this S-N curve to the required survival probability level.



Effective Notch: 1 mm Fillet Radii

- Weld regions modeled with 1 mm fillet radii at toe and root.
- Fine mesh in weld regions required for effective notch method.
- Weld geometry created using standard procedures in DesignModeler.





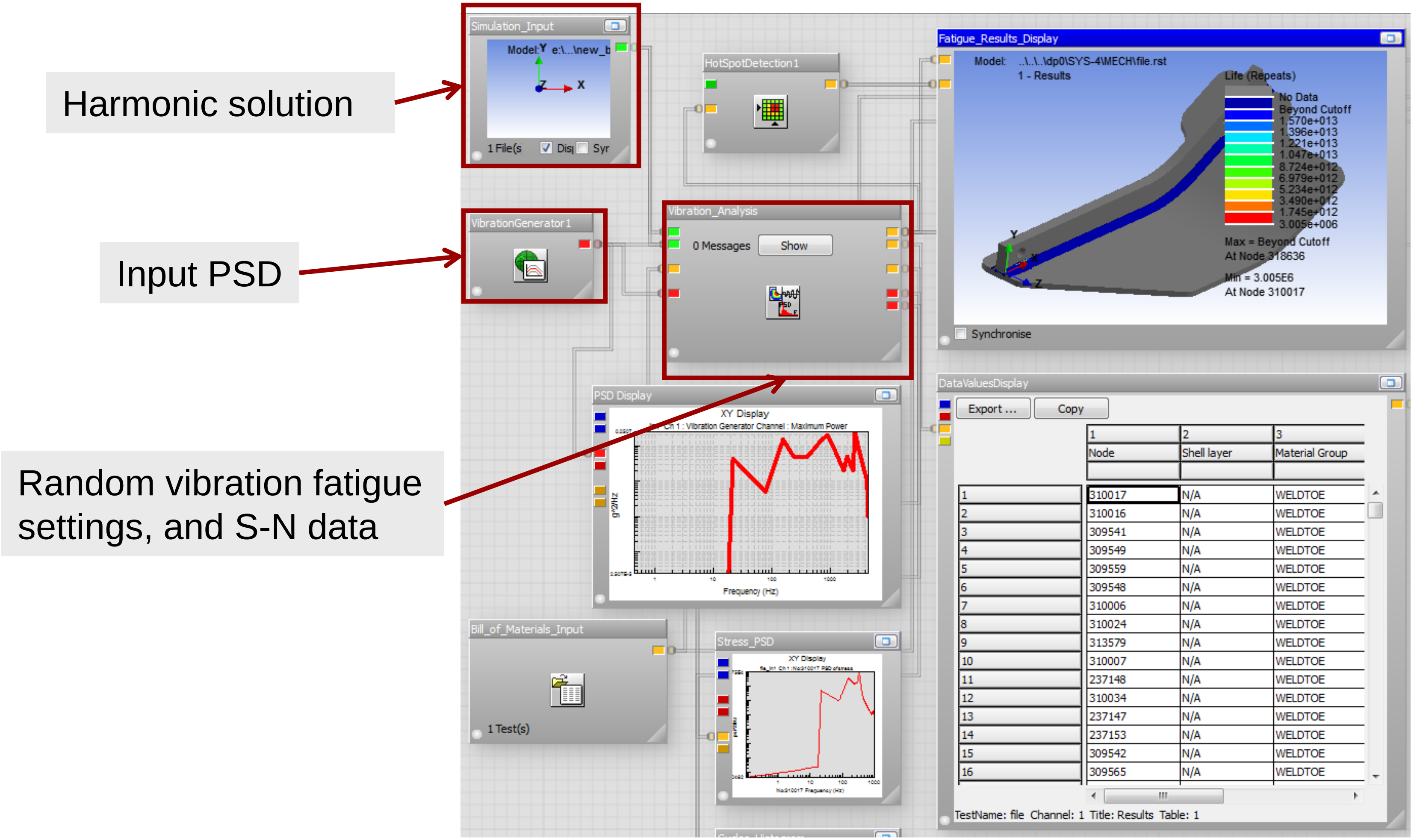
Analysis Settings/Assumptions

- Harmonic analysis used the following loading and solution settings:
  - Fixed supports in two holes.
  - Unit vertical acceleration = 1g = 386.4 in/sec^2
  - Frequency sweep from 0 to 7500 Hz.
  - Constant damping ratio = 0.05.

- Random vibration fatigue vibration analysis input:
  - Harmonic analysis fed to nCode as transfer function.
  - Input PSD and S-N curve defined.
  - Used Named Selections to limit fatigue calculations to weld regions.
  - Compare PSD cycle count methods.

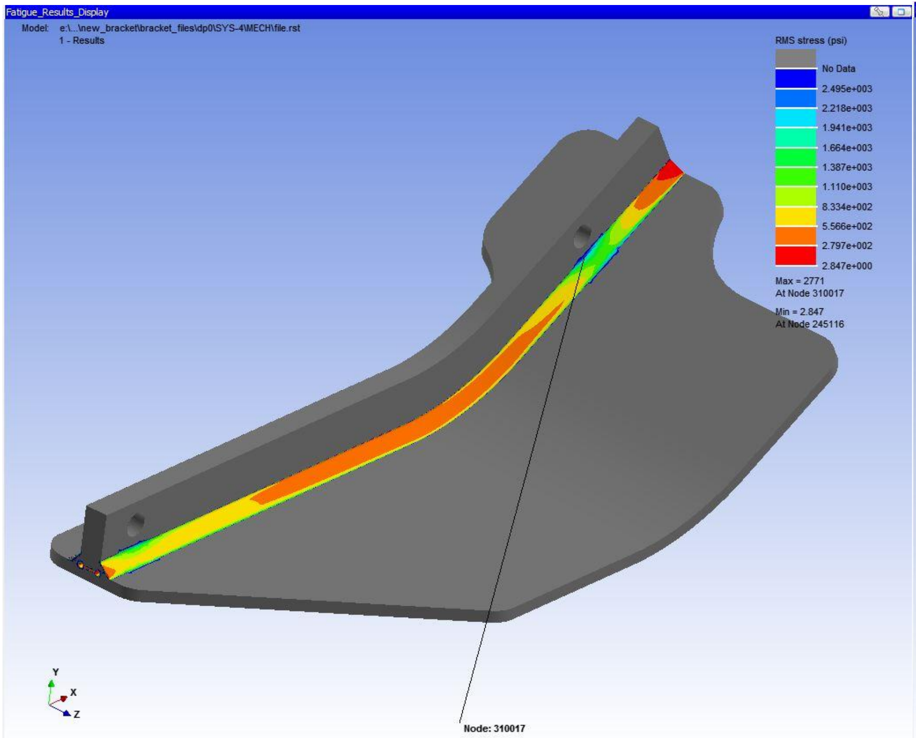
nCode DesignLife Setup

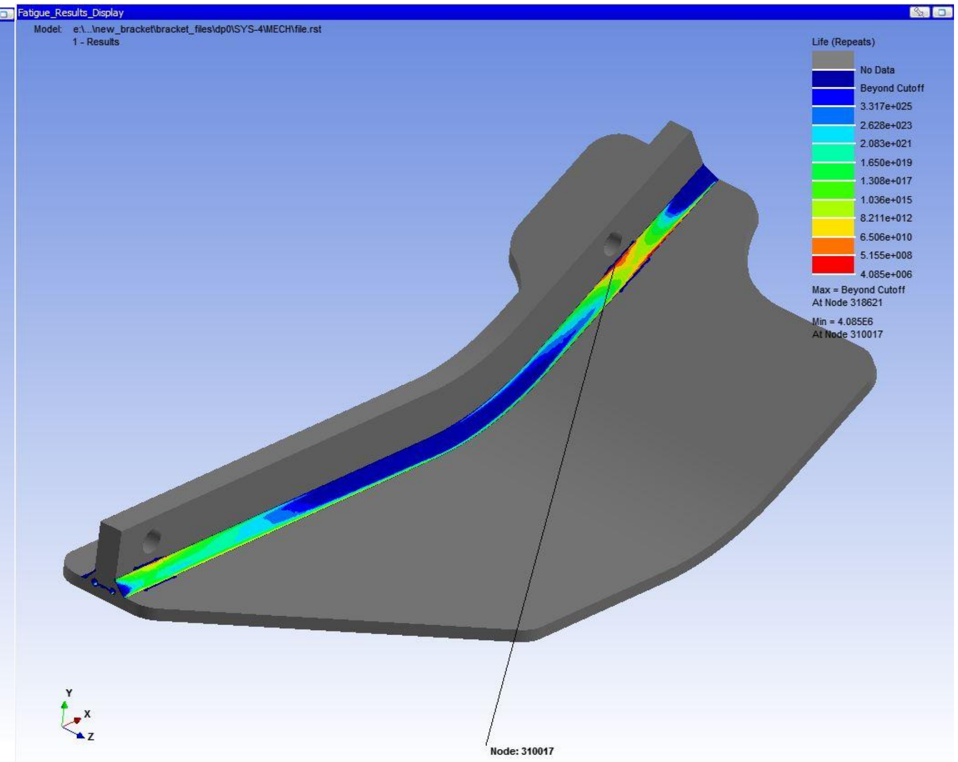
- nCode requires input of the harmonic solution, the definition of the random loading via a PSD definition, and the S-N data:



Vibration Fatigue Results

- RMS stress and life prediction results using the LaLanne cycle count method:



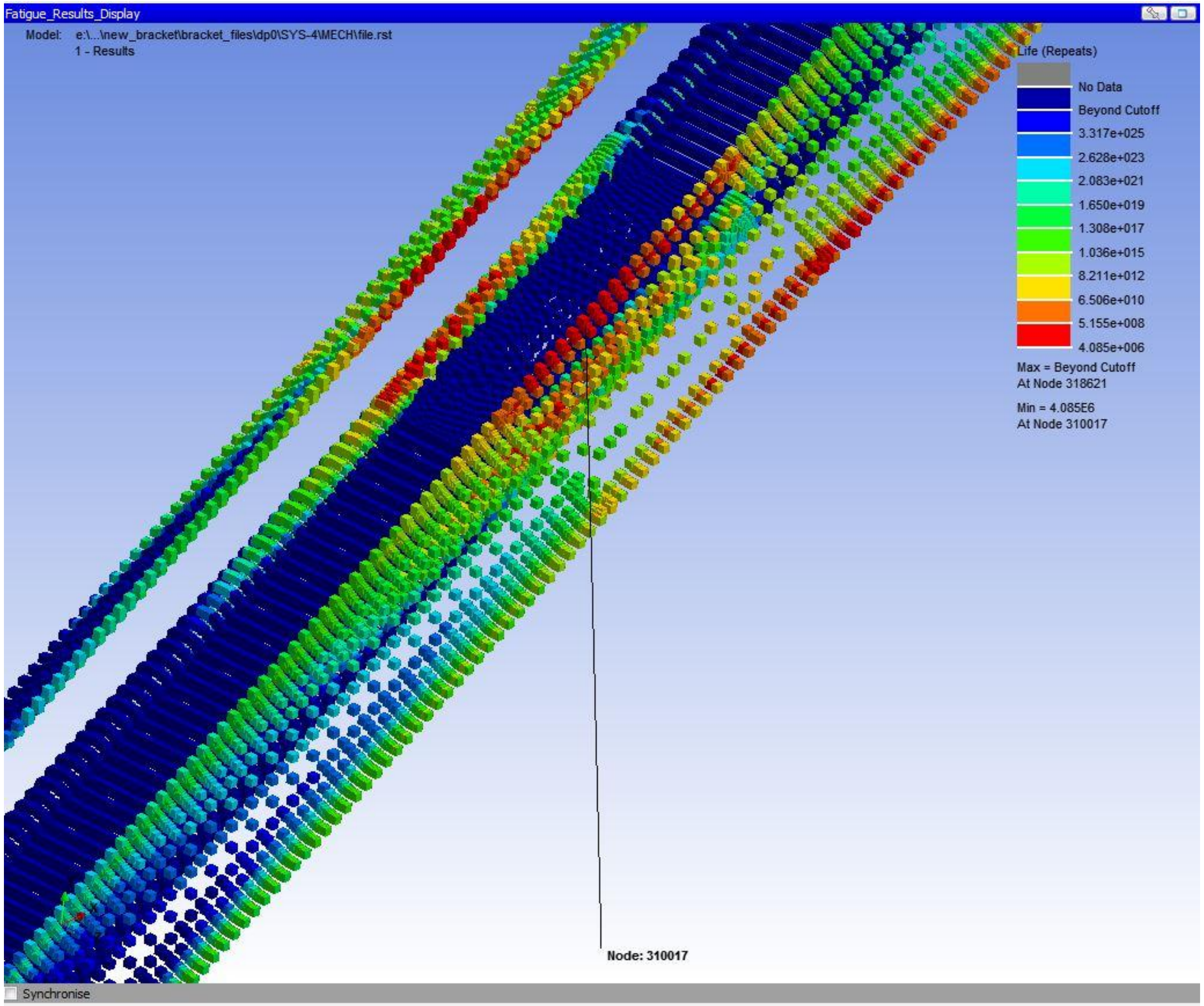


Max RMS stress = 2771 psi = 19.1 MPa

Min life = 4.085e6 sec = 1135 hrs

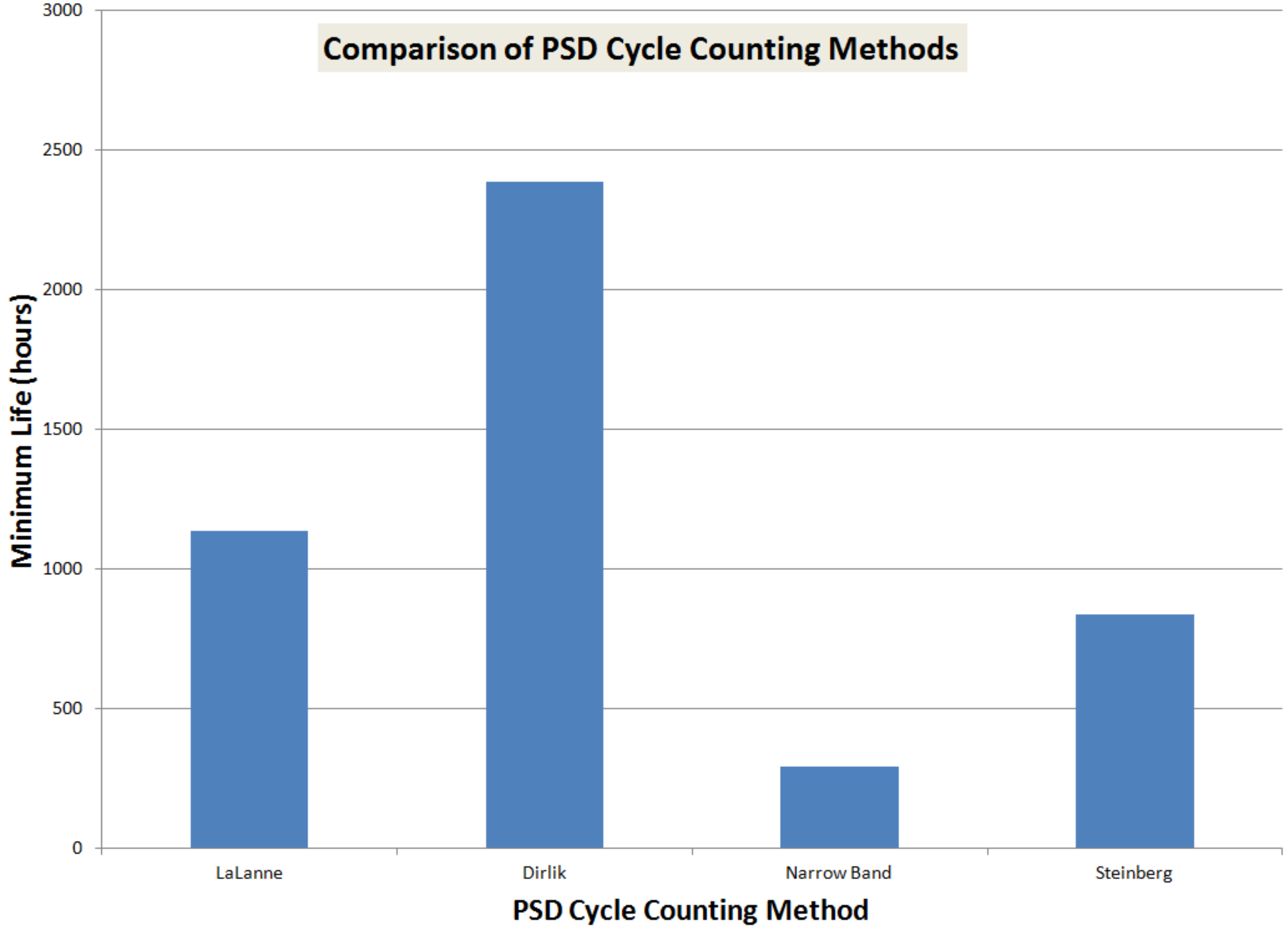
Vibration Fatigue Results

- To view inside the weld root region, plot results using the nodal point feature:



Vibration Fatigue Results

- Comparison of PSD cycle count methods:



Summary

- Used the effective notch weld stress approach with the nCode DesignLife vibration fatigue module to estimate the life of a welded bracket.
- Approach requires detailed modeling of weld regions and mesh refinement.
- For steel welds, this method only requires the FAT 225 S-N curve.
- Efficient solution technique, particularly taking advantage of Named Selections to limit fatigue analysis to weld regions.