# Fatigue of Welds

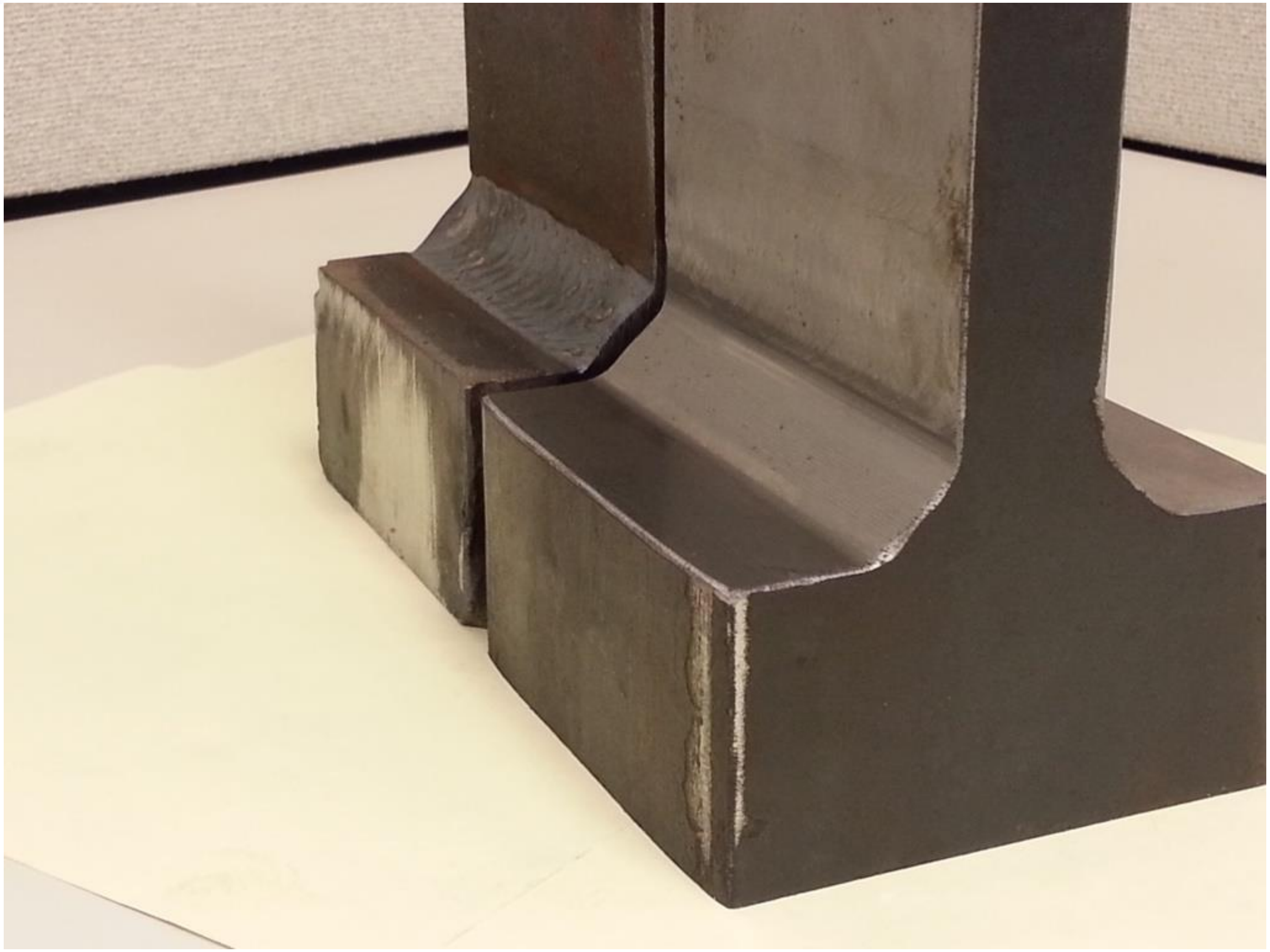
Professor Darrell F. Socie

# Weld Fatigue Problems


# More Problems

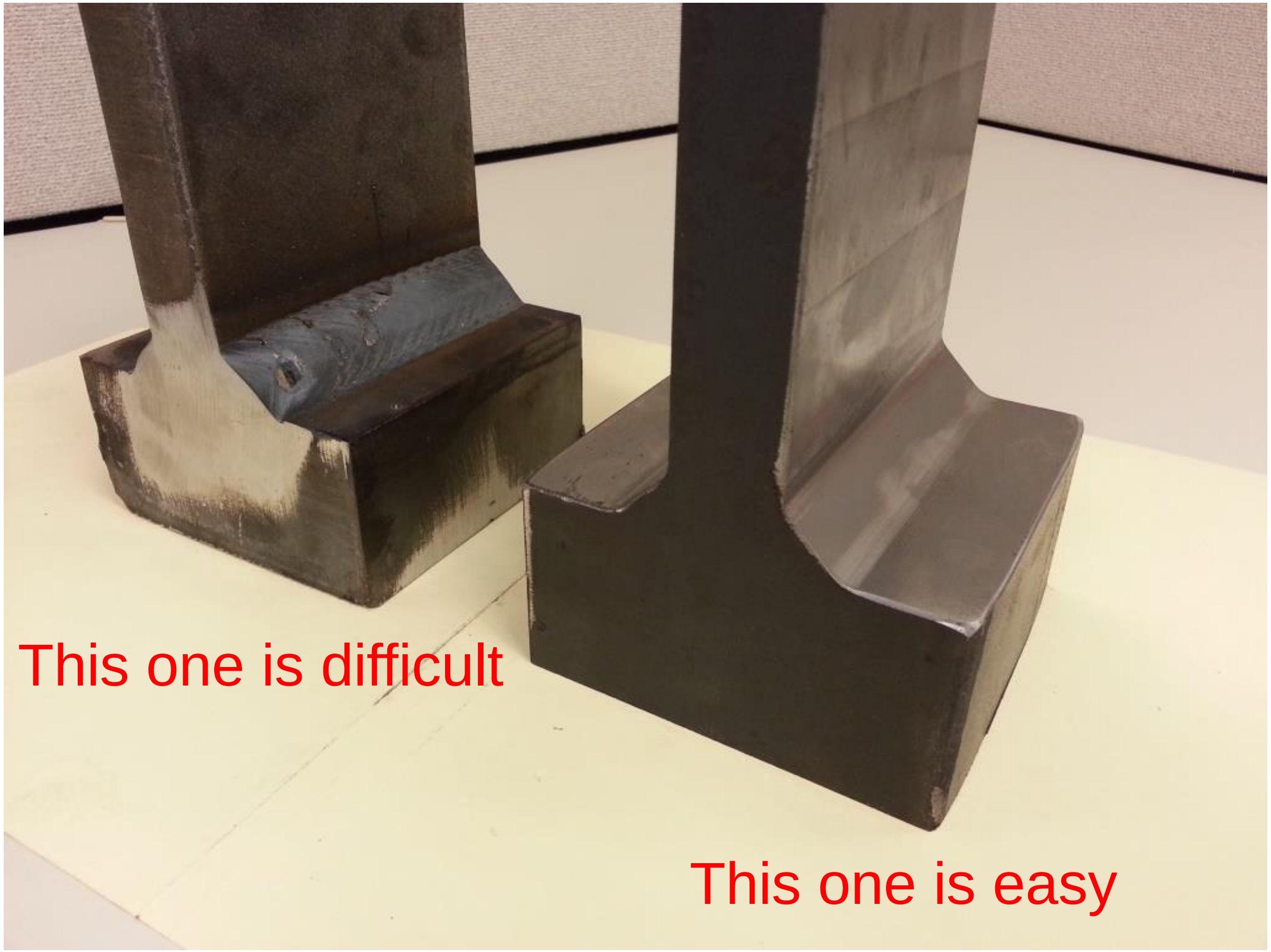

  

# Two Similar Shapes



# Fatigue Analysis



# Fatigue Analysis

Material Data

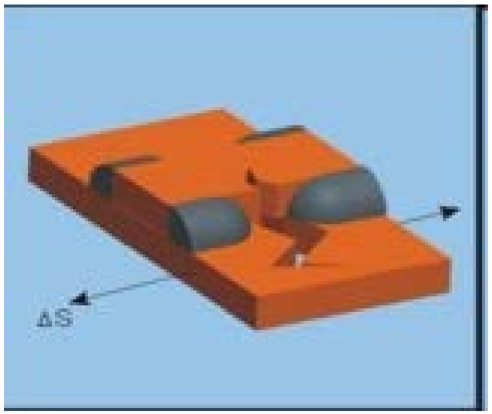
Component Geometry

Service Loading

Analysis

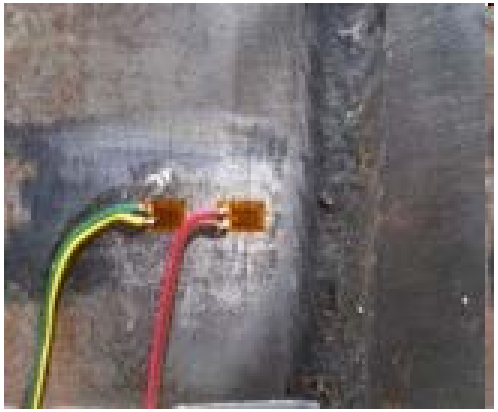
Fatigue Life Estimate

# Nominal Stress



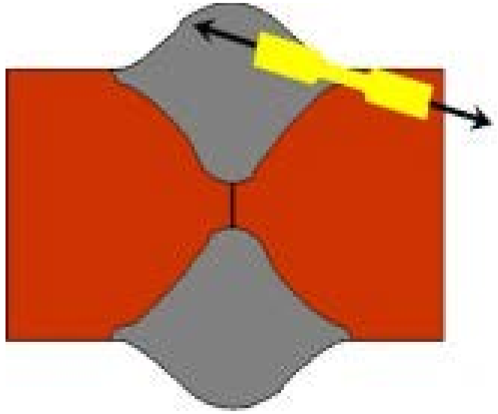

Nominal stress approaches are based on extensive tests of welded joints and connections. Weld joints are classified by type , loading and shape. For example, a transversely loaded butt weld. It is assumed and confirmed by experiments that welds of a similar shape have the same general fatigue behavior so that a single design SN curve can be employed for any weld class. The designer need only determine the nominal stress and select a weld class. There is no need to directly consider the stress concentration effects of the weld.

# Structural Stress



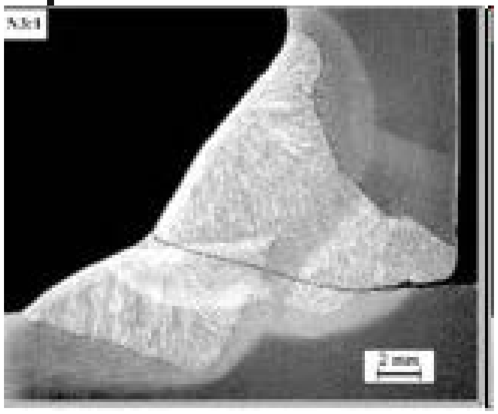
Structural stress approaches are often referred to as "hot-spot methods". The structural stress includes the macroscopic stress concentrating effects of the weld detail but not the local peak stress caused by the notch at the weld toe. There are various methods used to determine the structural stress. They involve extrapolating the computed or measured stresses from two points near the weld to a structural stress at the weld toe. This method works in situations where there is no clear definition of the nominal stress.

# Local Stress Strain



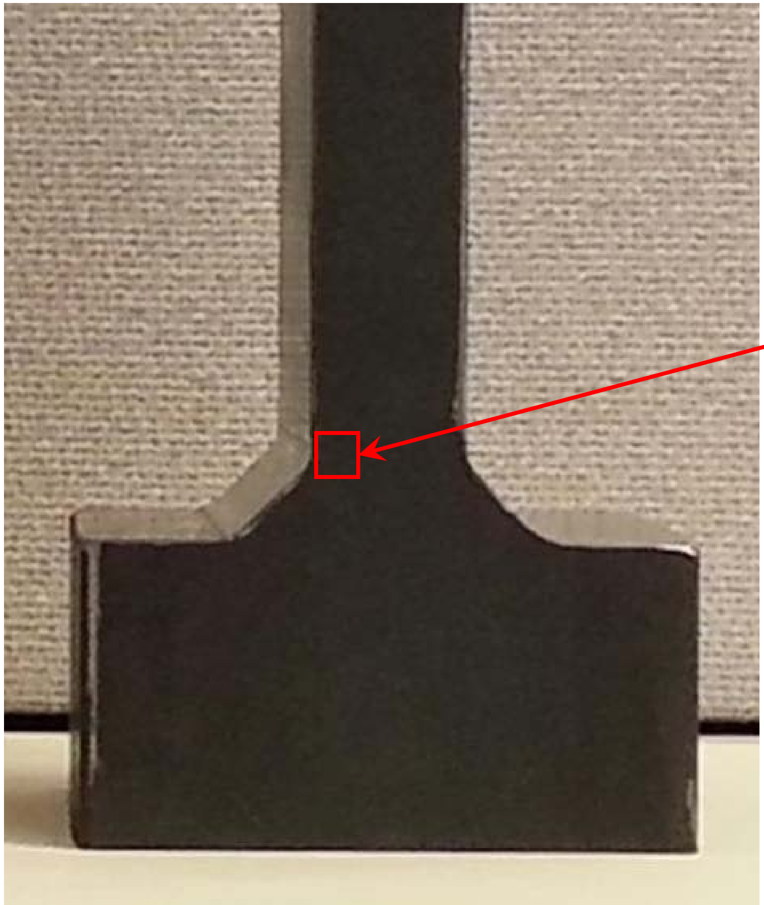
Local stress or strain approaches include both the macroscopic stress concentration due to the weld shape and the local stress concentration at the weld toe. To apply traditional methods of fatigue analysis to welds, an appropriate value of the stress concentration factor and residual stress must be selected. Although the smallest radius produces the largest stress concentration factor, its effect in fatigue is smaller because of the gradient effect. As a result there is a critical radius for fatigue that can be used to compute the fatigue notch factor.

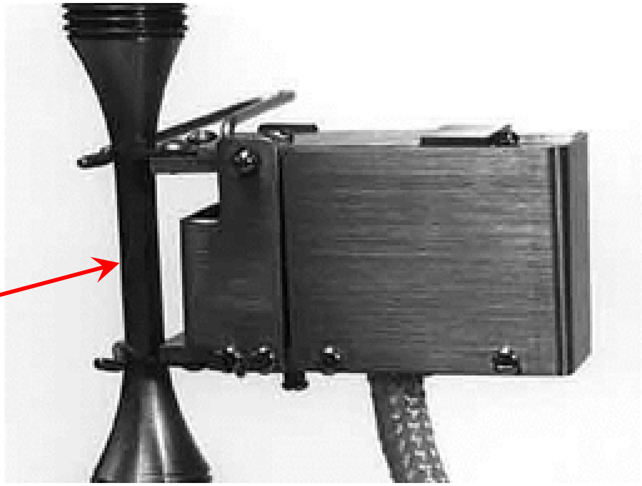
# Crack Growth



Many weld details have planar lack of fusion defects. This is particularly true of fillet welds. In this case fracture mechanics models for crack growth are the most appropriate fatigue technology.

# Similitude



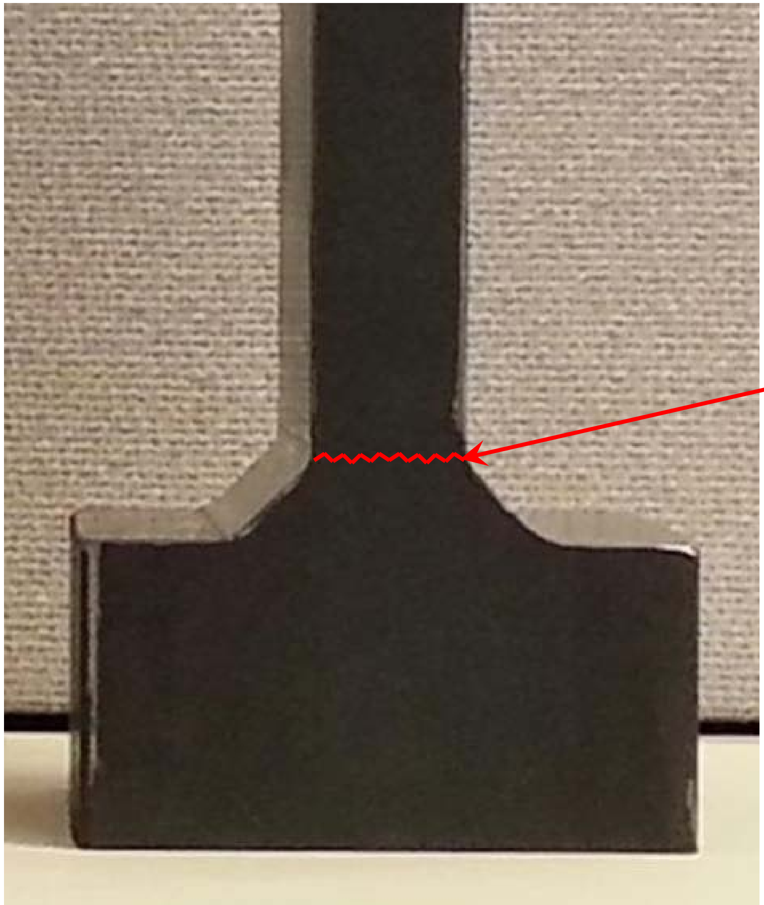


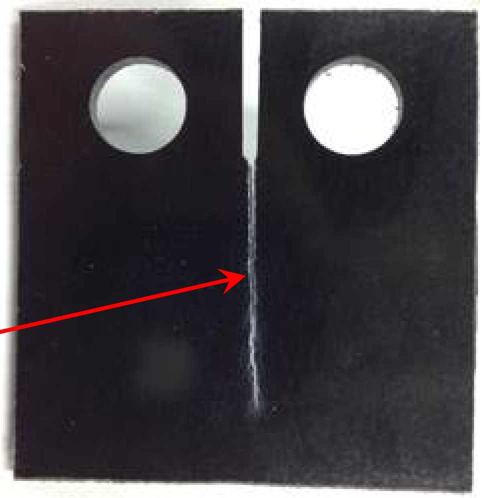
Local stresses and strains control the fatigue life

Lifetime to about a 1mm crack

Crack initiation

# Similitude (continued)





Nominal stresses and crack
Length control the fatigue life

Crack propagation

# Vehicles Are Frequently Overloaded

Occasional plastic deformation → strain life analysis

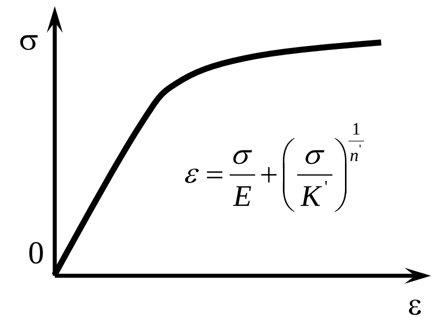
# Strain-Life Fatigue Analysis

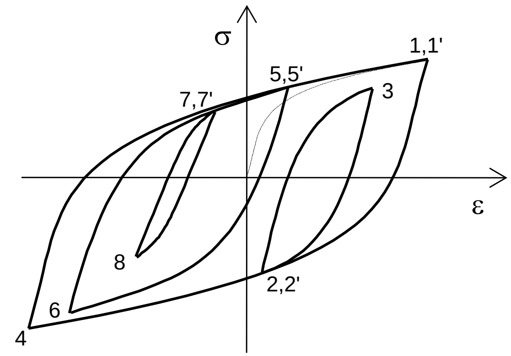
Material Data

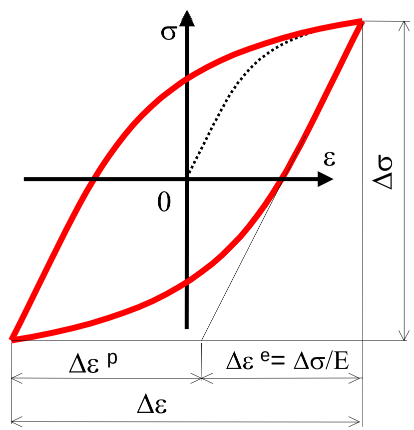
Component Geometry

Service Loading

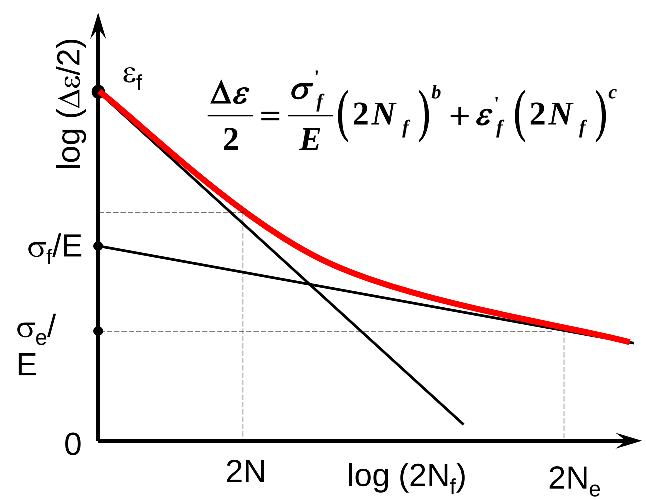
## Cyclic stress strain curve




## Strain-life curve

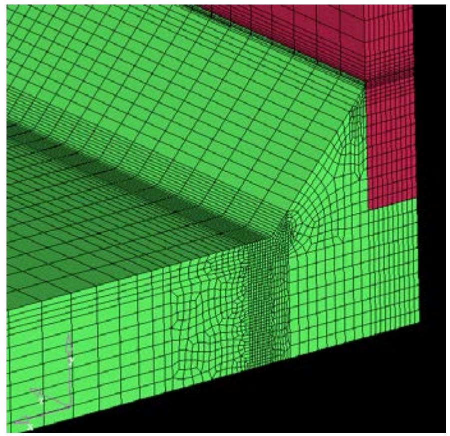


# Strain-Life Fatigue Analysis

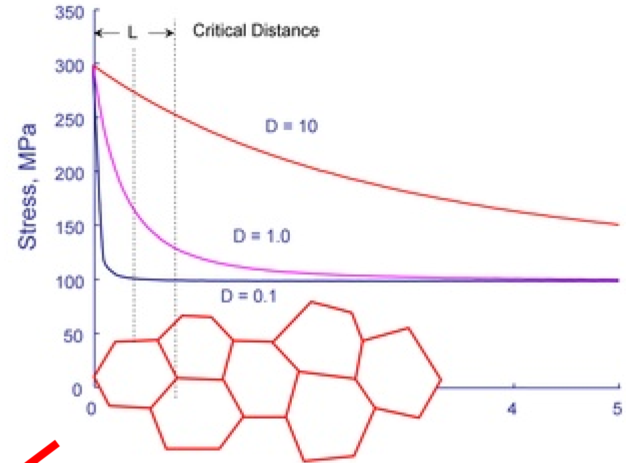
Material
Data

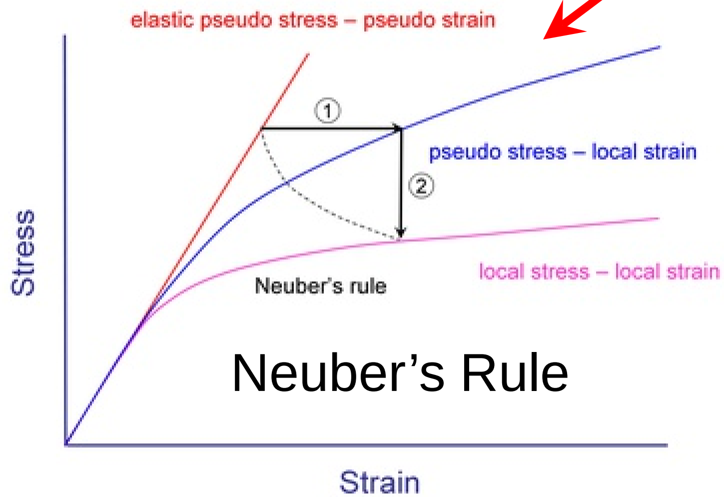
Component
Geometry

Service
Loading



Gradient Effects




Neuber's Rule

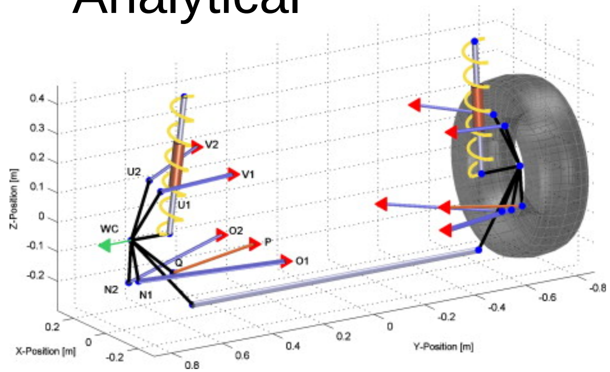
# Strain-Life Fatigue Analysis

Material Data

Component Geometry

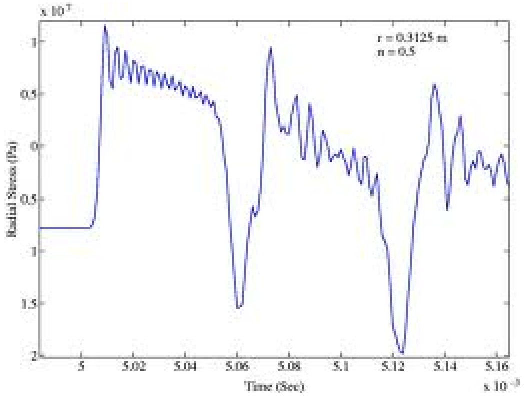
Service Loading

Analytical




Experimental

Structural Loads

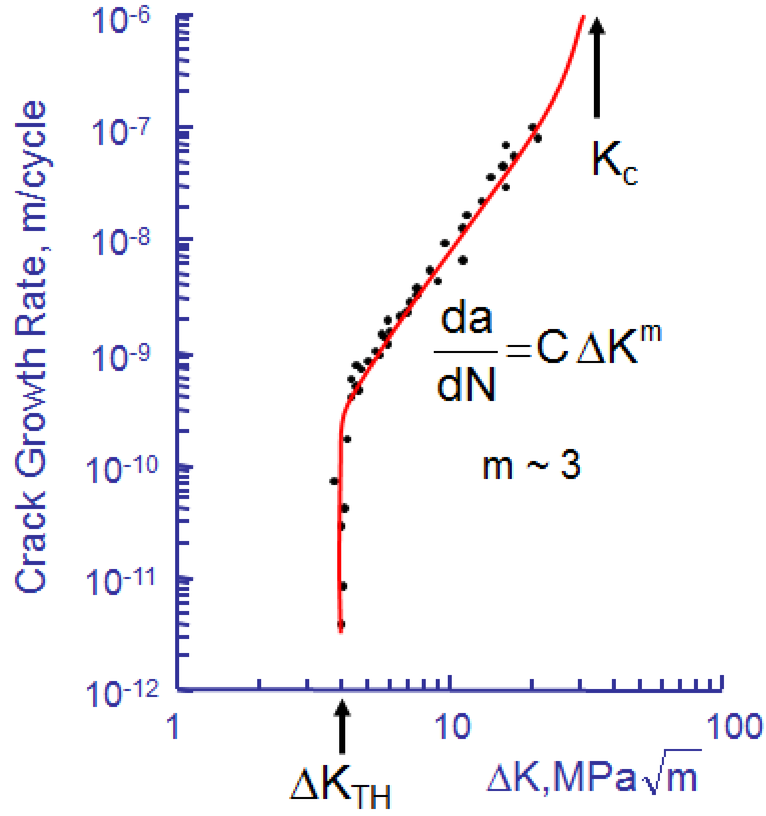


# Crack Growth Fatigue Analysis

Material
Data

Component
Geometry

Service
Loading

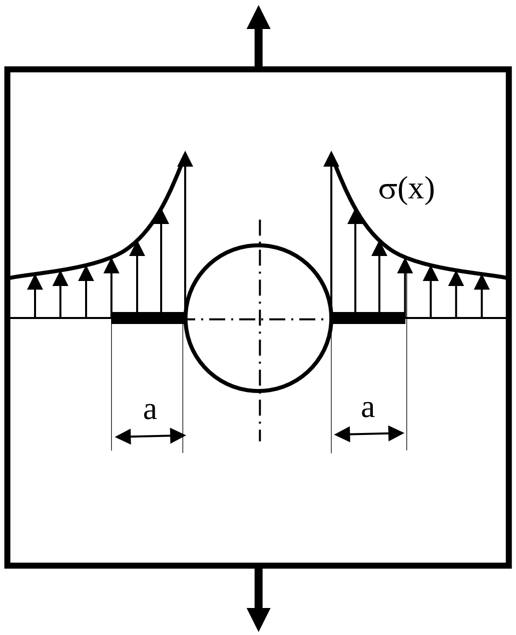


# Crack Growth Fatigue Analysis

Material
Data

Component
Geometry

Service
Loading




Stress distribution along crack path
in an un-cracked body

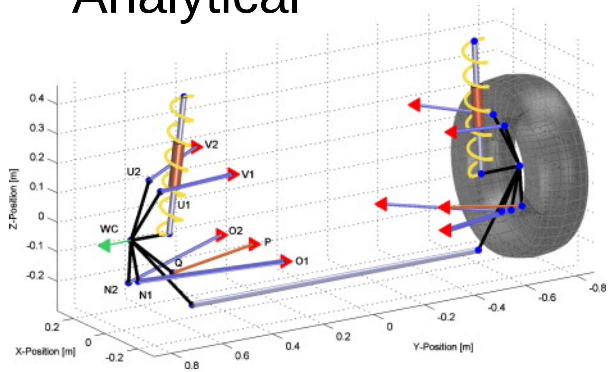
# Crack Growth Fatigue Analysis

Material
Data

Component
Geometry

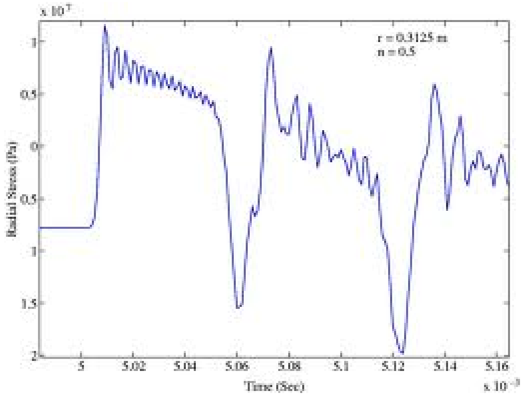
Service
Loading

Analytical

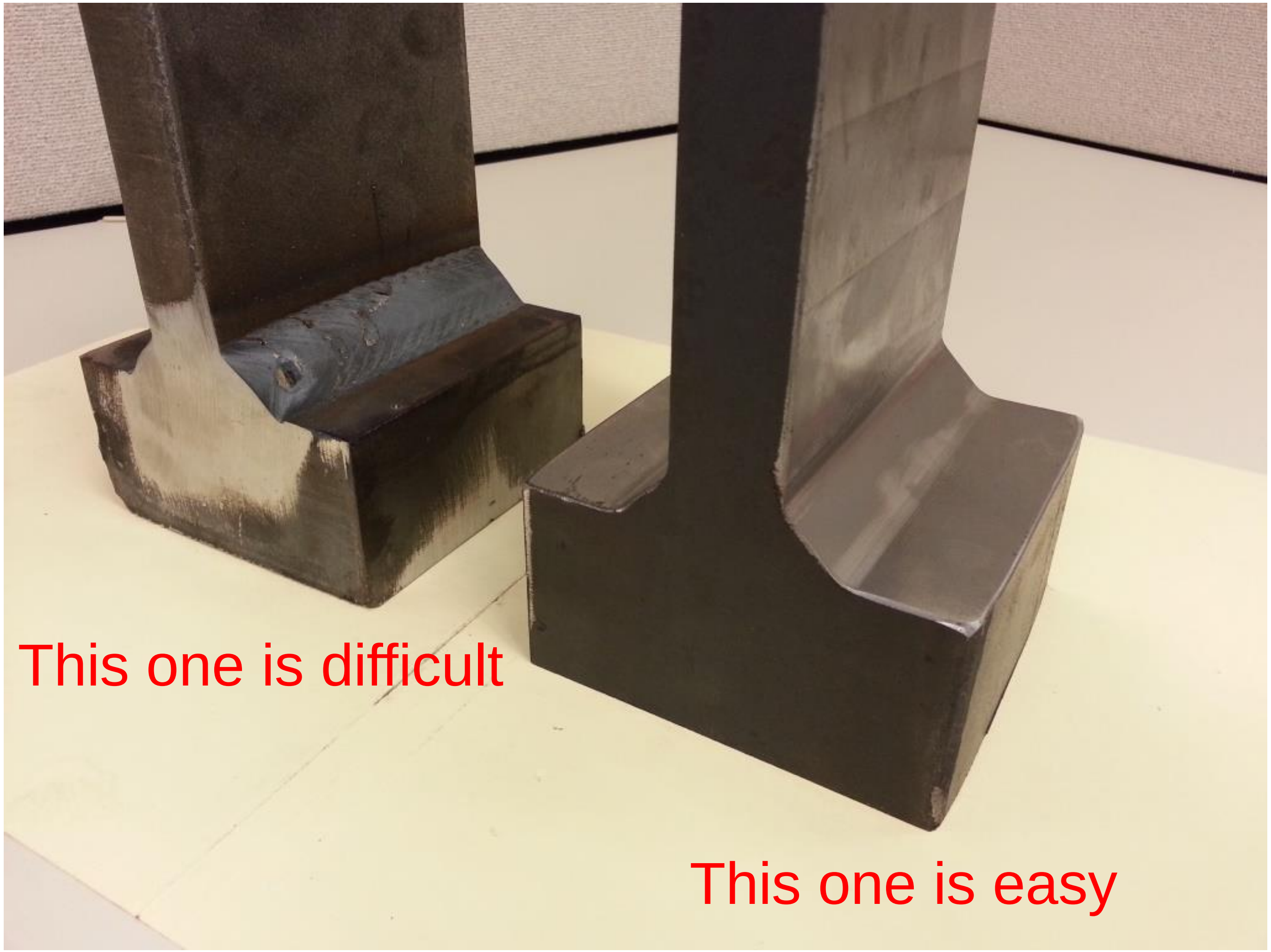


Experimental

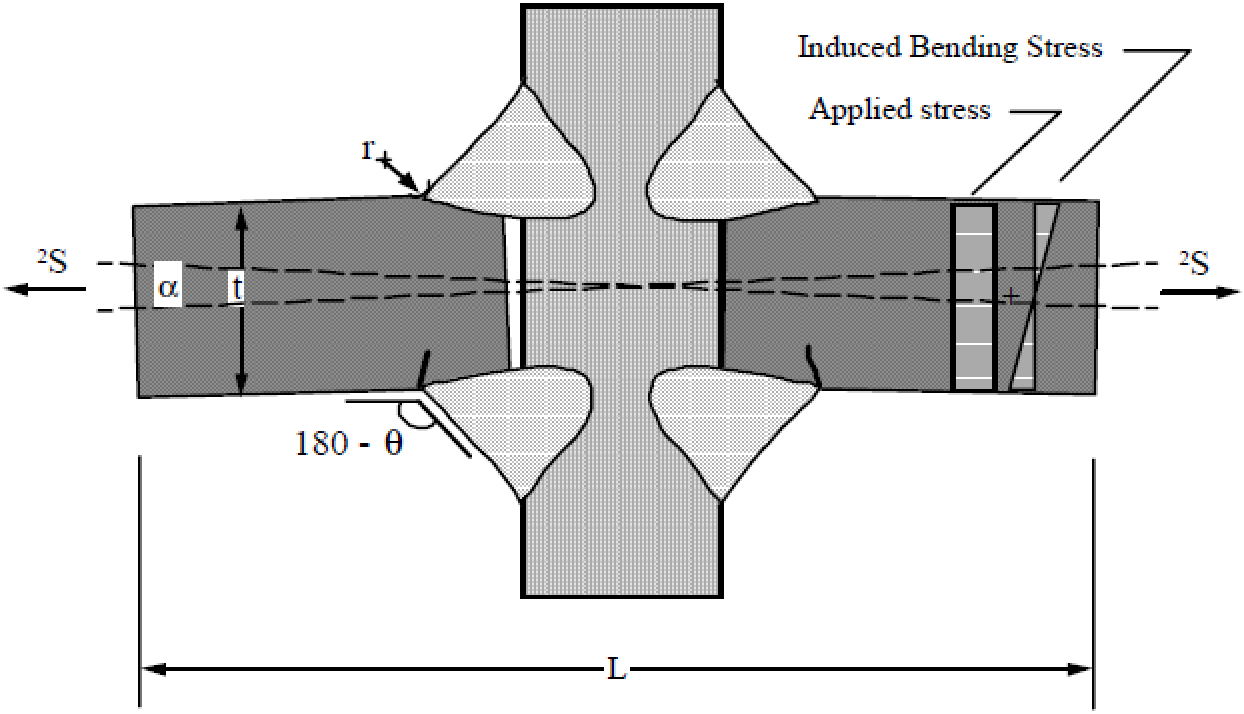
Structural Loads



# Why Are Welds Difficult to Analyze?



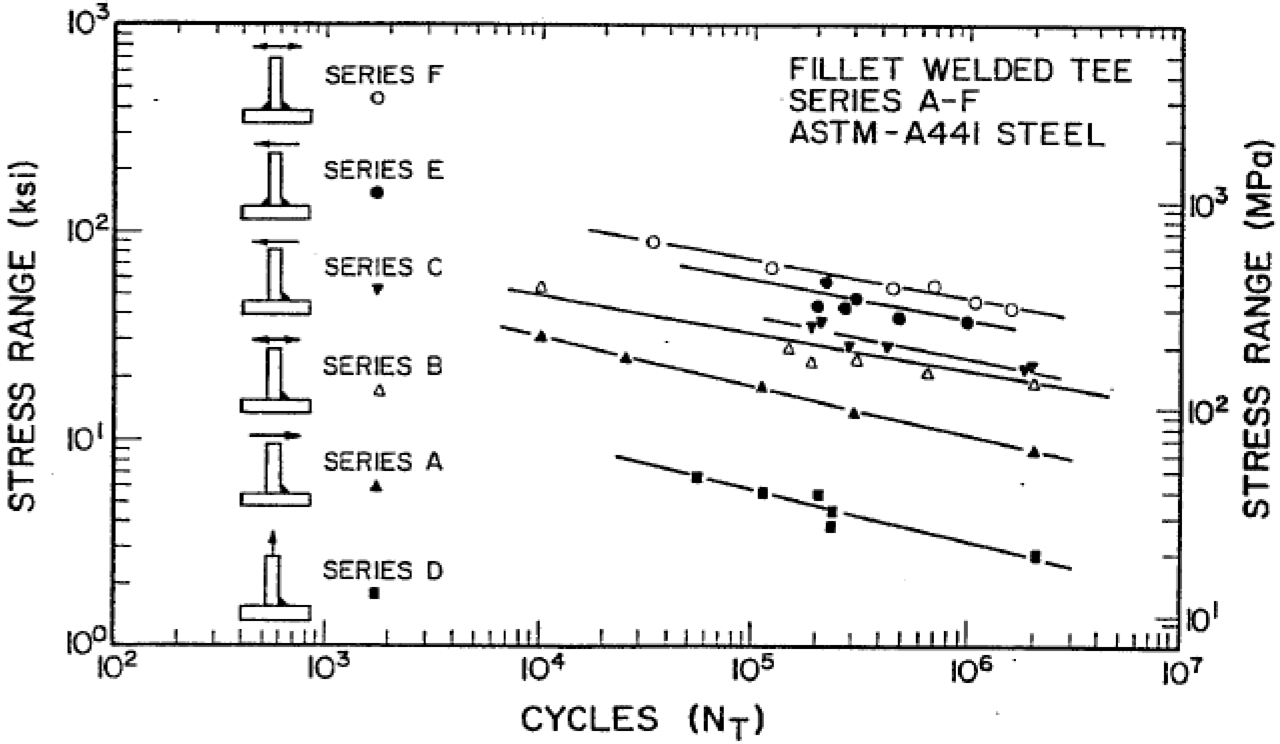
# Welds Have Distortions




What is the real stress at a weld toe?

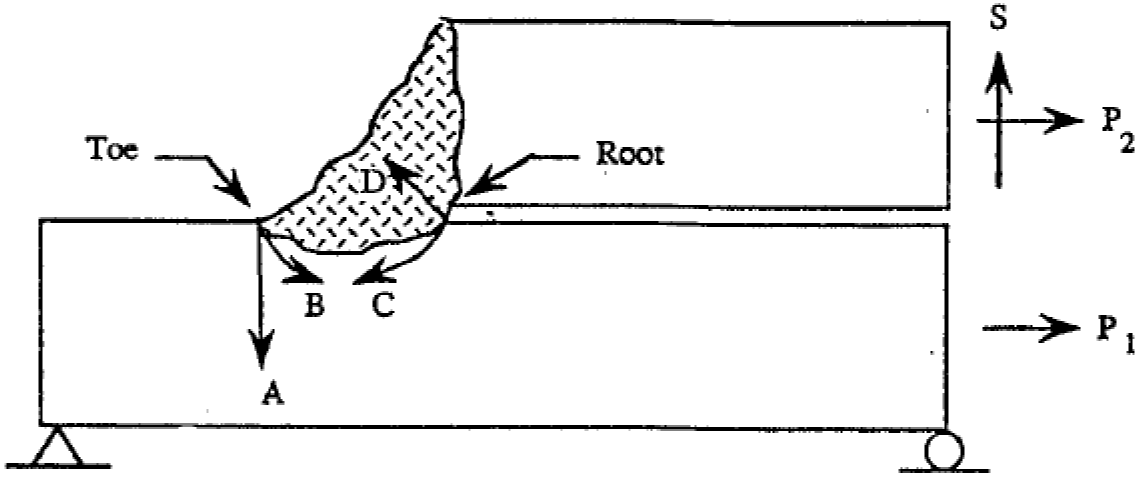
  

# Loading Conditions

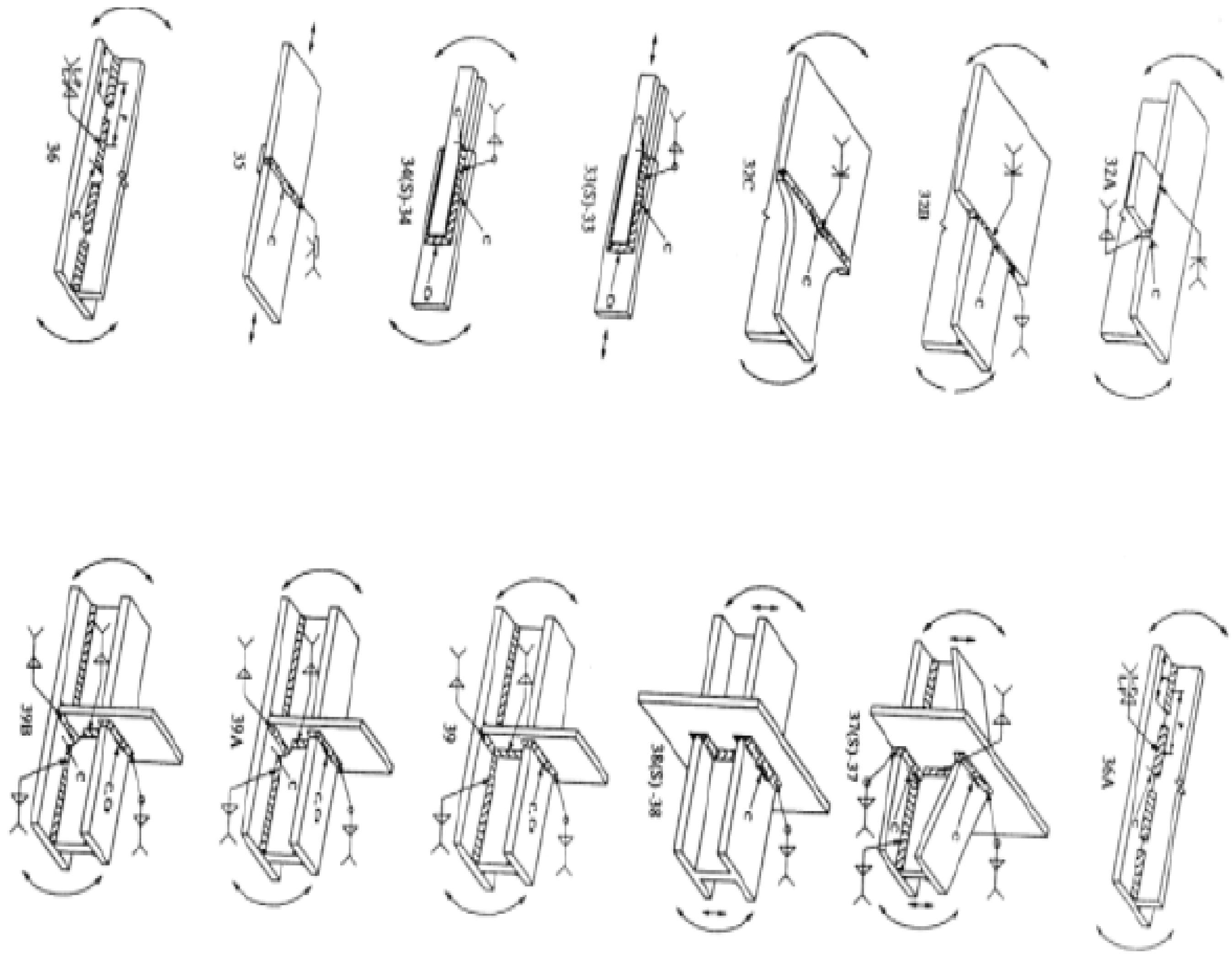



How is the weld loaded ?

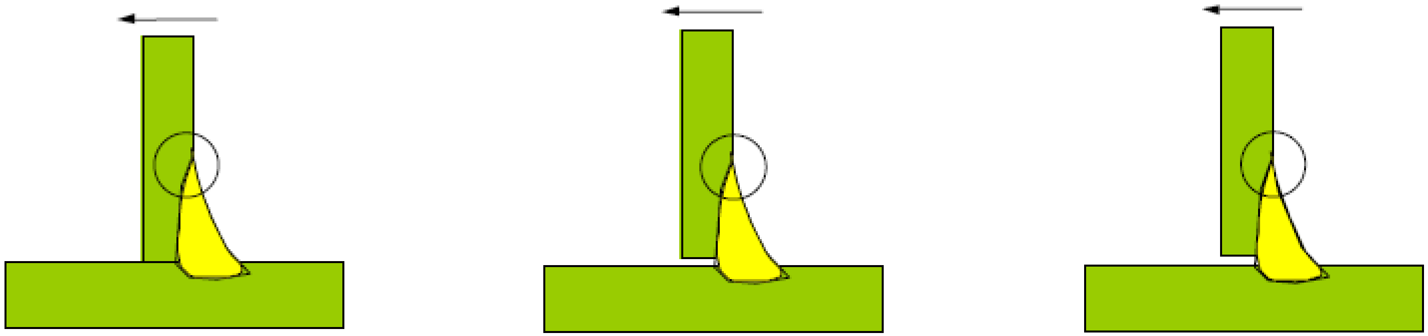
# Many Possible Failure Locations



# So Many Possibilities !



# What is $K_T$?

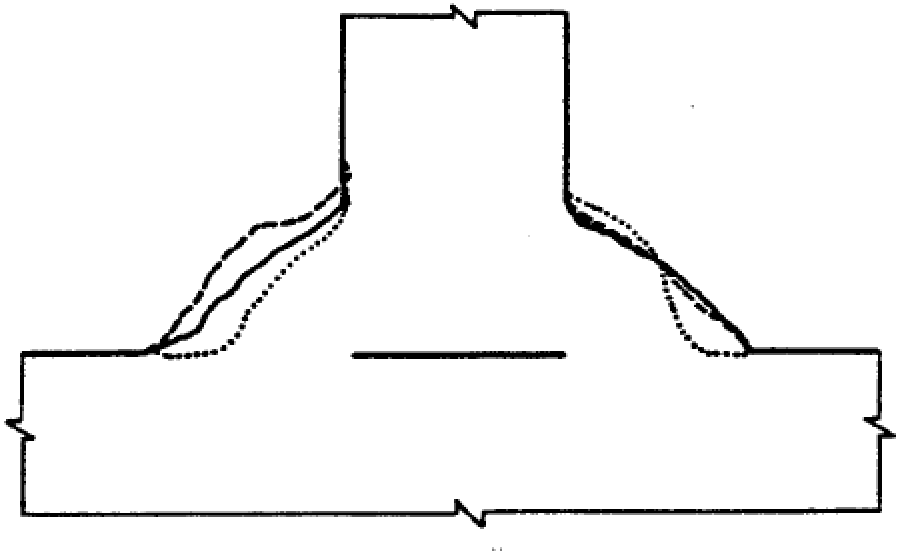


Tight fit-up
$K_T = 3$

?

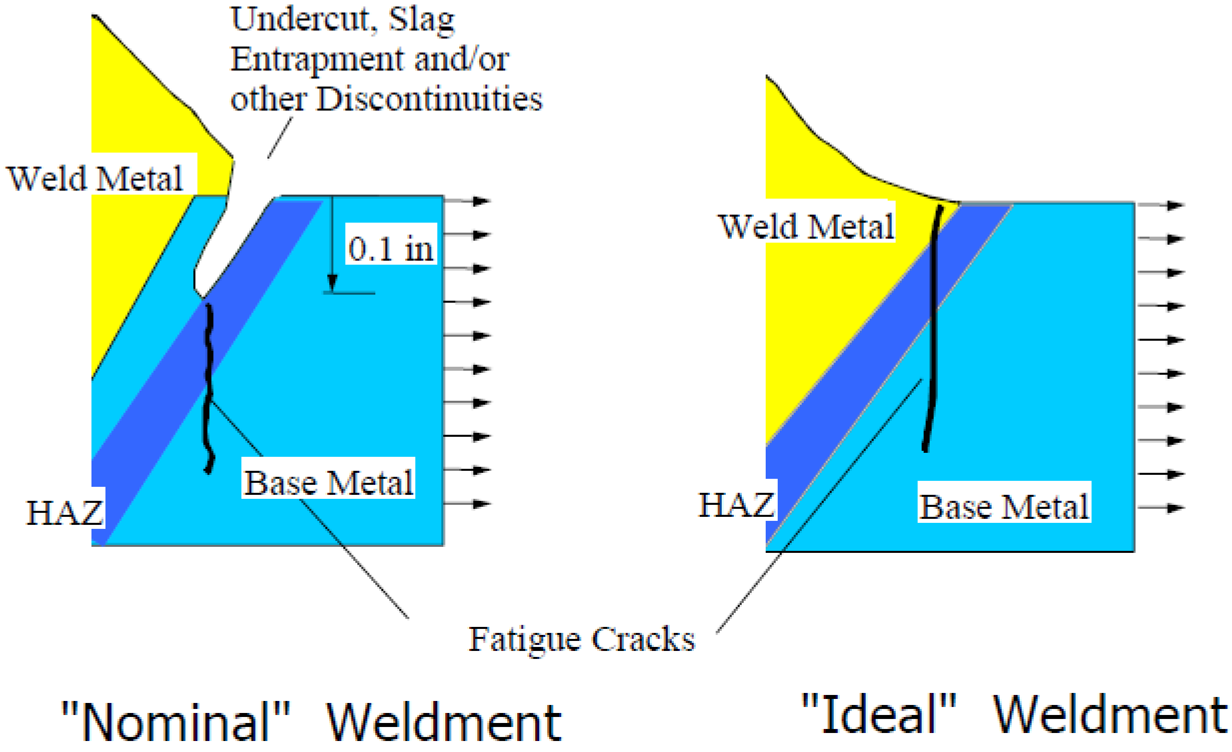
Loose fit-up
$K_T = 7$

# What Is The Weld Shape ?

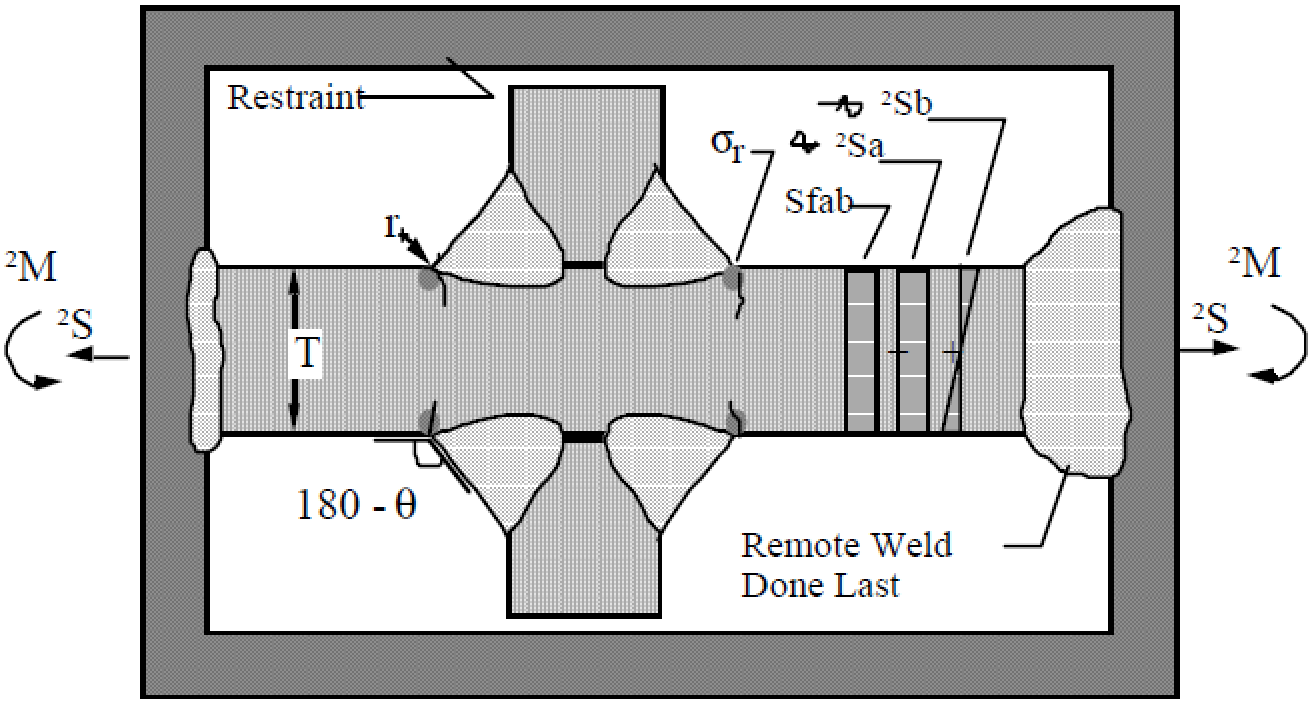


# Weld Quality ?

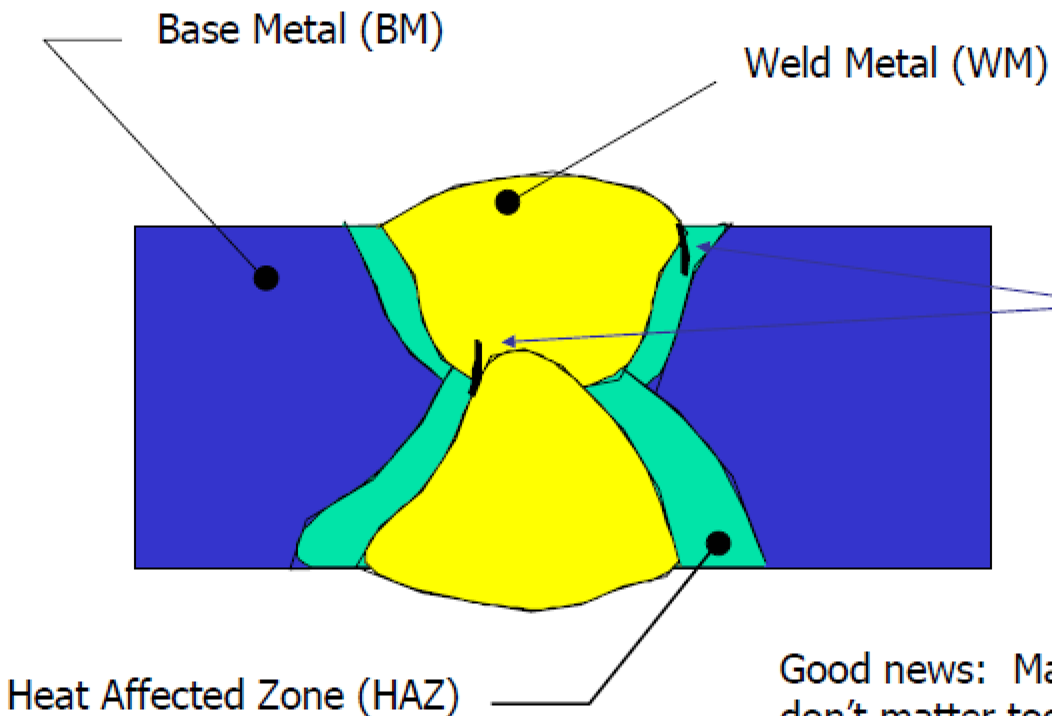


# Mean Stress ?




Applied mean stresses, welding residual stresses, and fabrication residual stresses

# Material Properties ?




Fatigue cracks begin in WM or HAZ not in BM!

Good news: Material properties don't matter too much!

# Summary

- The variables influencing weldment fatigue life can be thought of as being only two:
  - the magnitude of the notch root stresses.
  - the properties of the notch root material.

- In this sense, the applied stresses, the degree of bending, the welding residual stresses, the fabrication residual stresses, the applied mean stresses, the weldment geometry, the notch root weld defects, and the weldment size all influence the magnitude of the notch root stresses.

# Summary (continued)

- The fatigue behavior of a weldment is controlled by the local (notch root, hot-spot) stress-strain history.

- For structural steel weldments: material properties are of minor importance except (as we shall see) to the degree that they determine and limit the value of the residual stresses.

# Fatigue Analysis of Welds

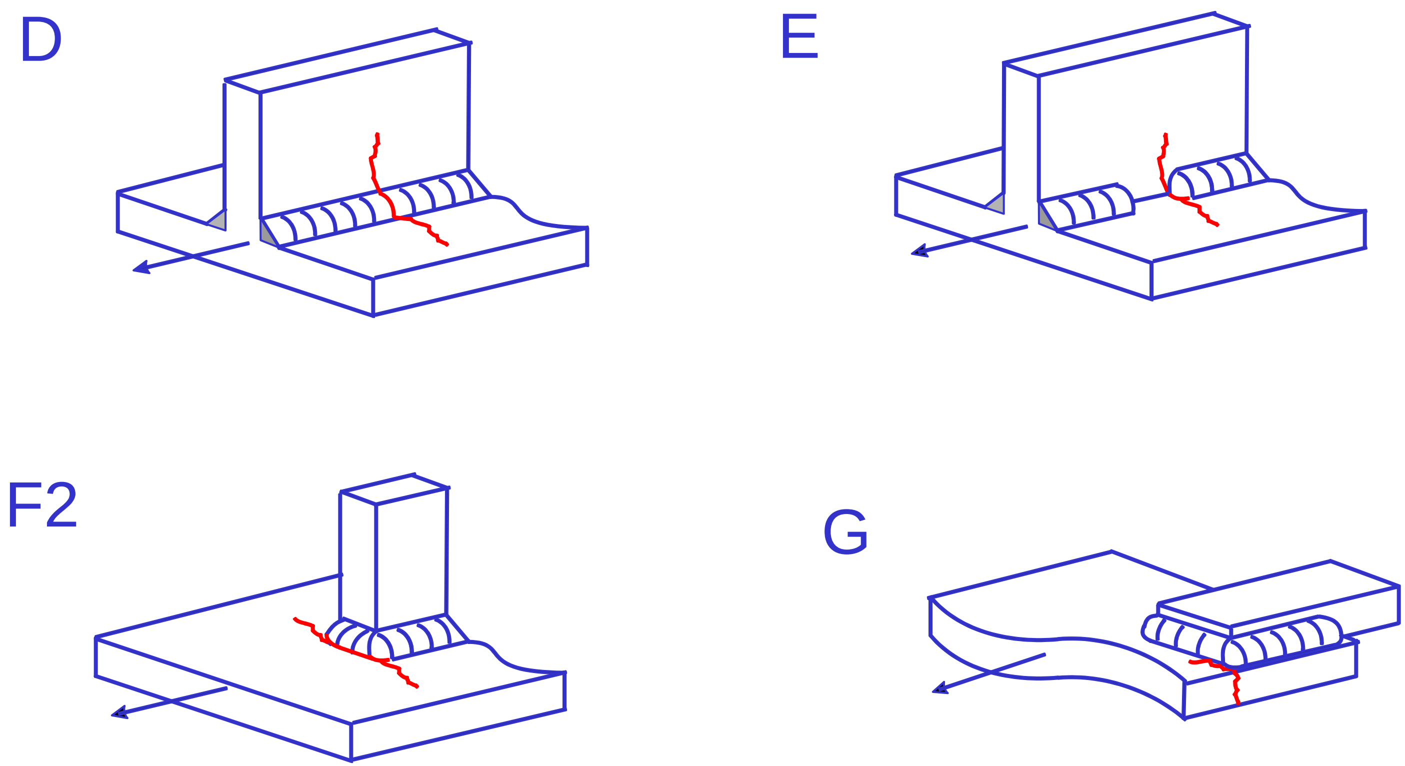
| | |
|---|---|
| Material Data | Uncertain, but unimportant |
| Component Geometry | Uncertain, but very important |
| Service Loading | Uncertain, but important |

How do we deal with these uncertainties?

# Analyzing Welds

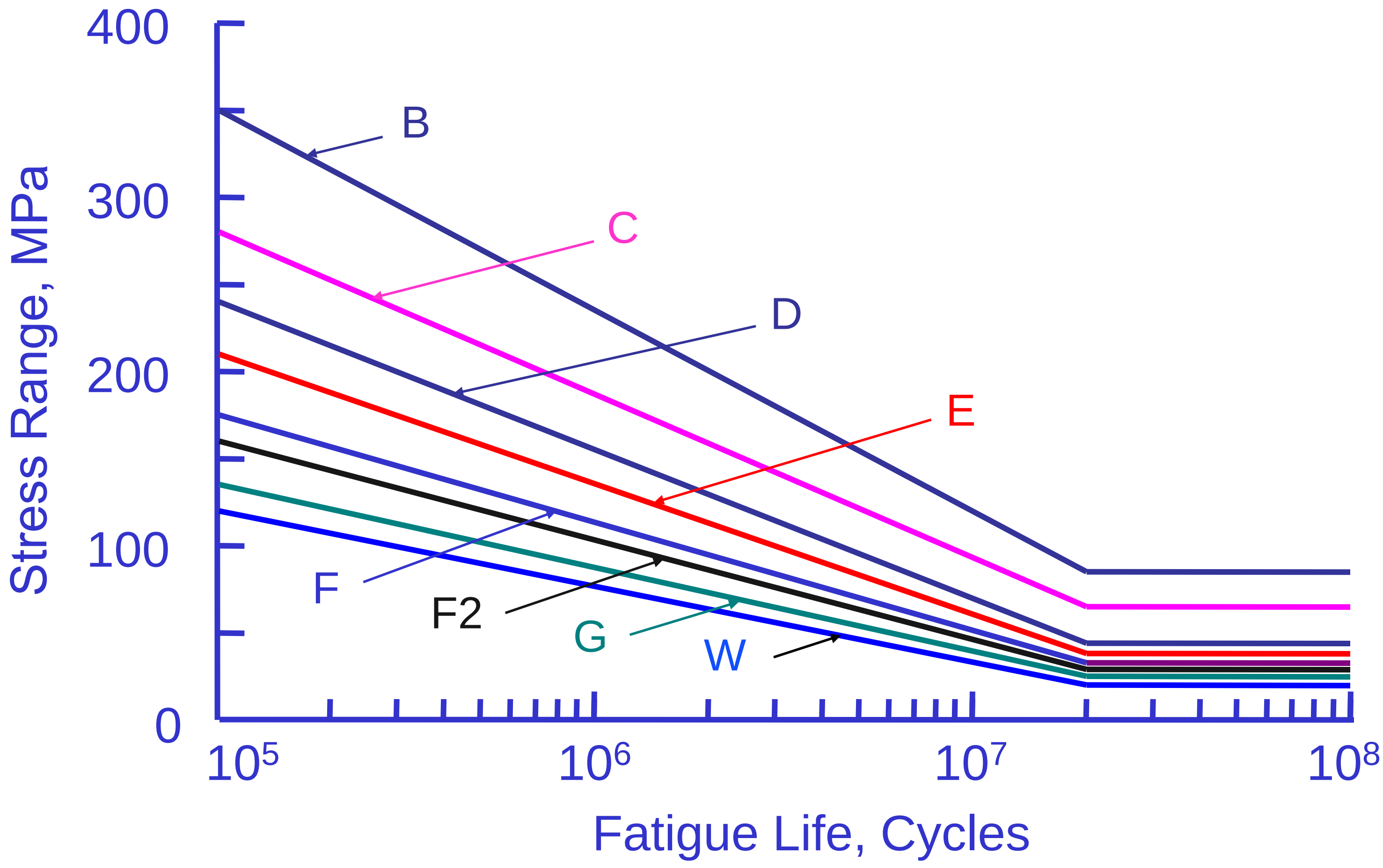
- Nominal Stress
- Structural or Hot Spot Stress
- Local Stress Strain
- Crack Growth

# Nominal Stress Weld Classifications

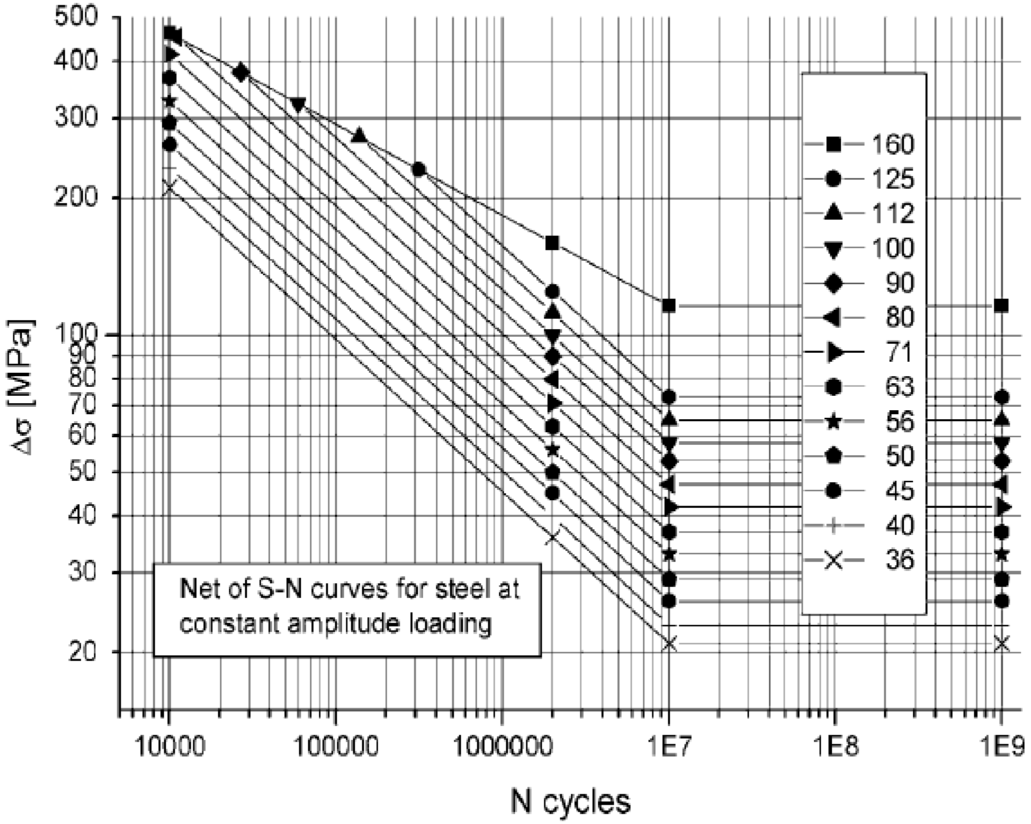


# BS 7608 - Steel



# IIW Classification




$$\Delta\sigma^{m} N = C$$

$$C = (FAT)^{m} 2\times10^{6}$$

$$m = 3$$

$$\Delta\sigma = C^{\left(\frac{1}{m}\right)} N^{\left(-\frac{1}{m}\right)}$$

$$\Delta\sigma = FAT\left(\frac{2\times10^{6}}{N}\right)^{\left(\frac{1}{m}\right)}$$

# Japan Society of Steel Construction

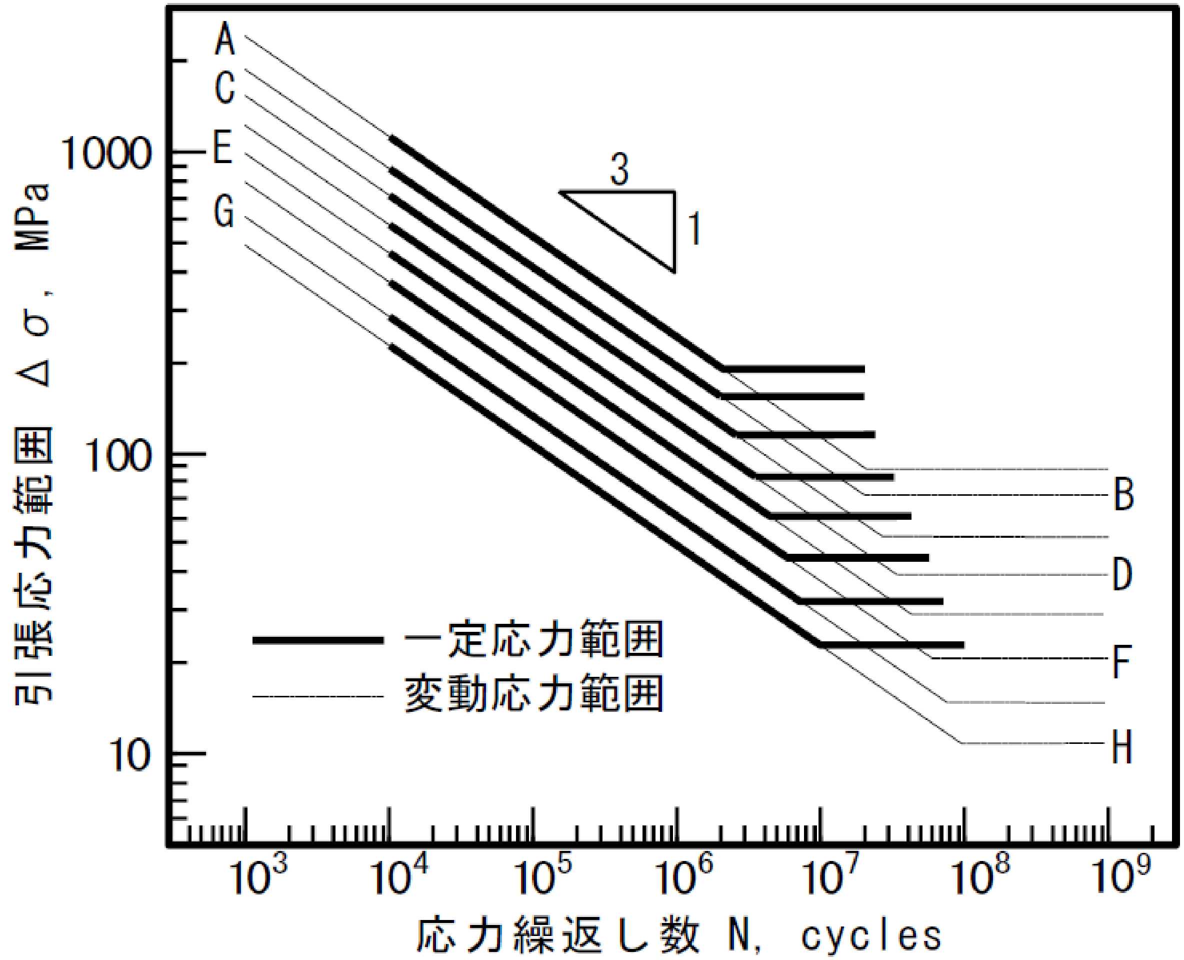
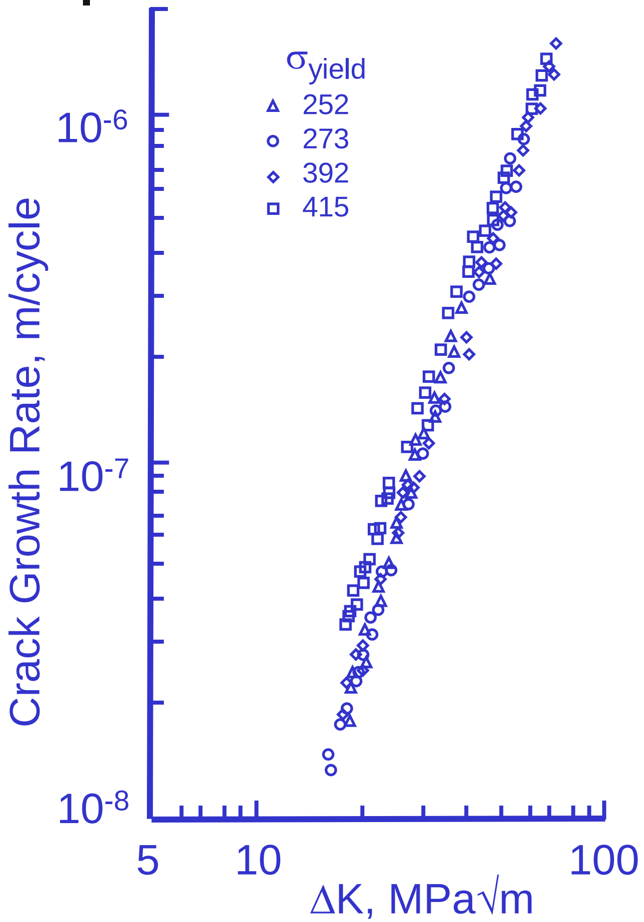



図 6.2.6　疲労設計曲線(引張応力を受ける継手)

# Crack Growth Data




Ferritic-Pearlitic Steel:

$$\frac{da}{dN} = 6.9 \times 10^{-12} \left(\Delta K \, MPa\sqrt{m}\right)^{3.0}$$

Martensitic Steel:

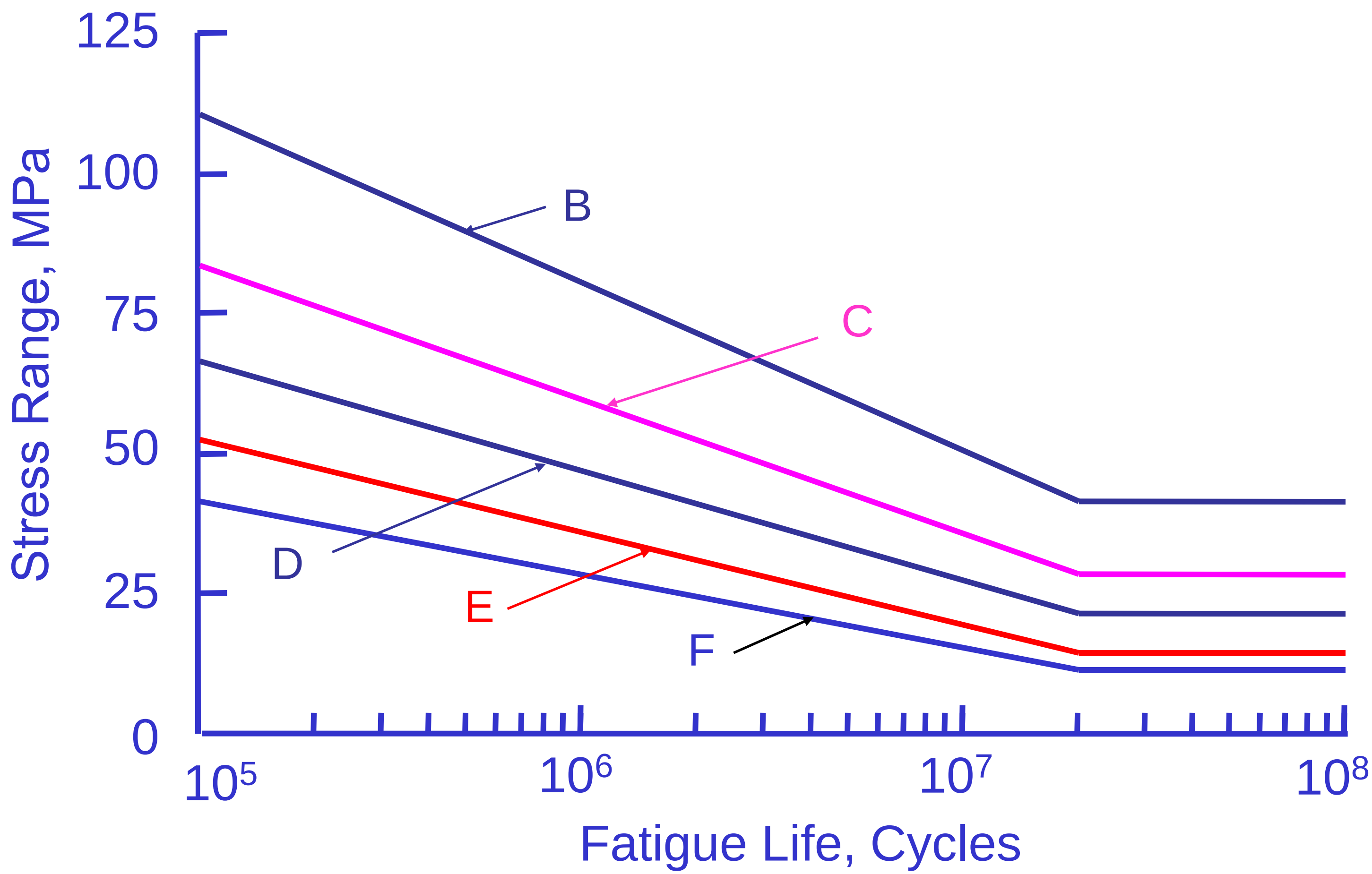
$$\frac{da}{dN} = 1.4 \times 10^{-10} \left(\Delta K \, MPa\sqrt{m}\right)^{2.25}$$

Austenitic Stainless Steel:

$$\frac{da}{dN} = 5.6 \times 10^{-12} \left(\Delta K \, MPa\sqrt{m}\right)^{3.25}$$

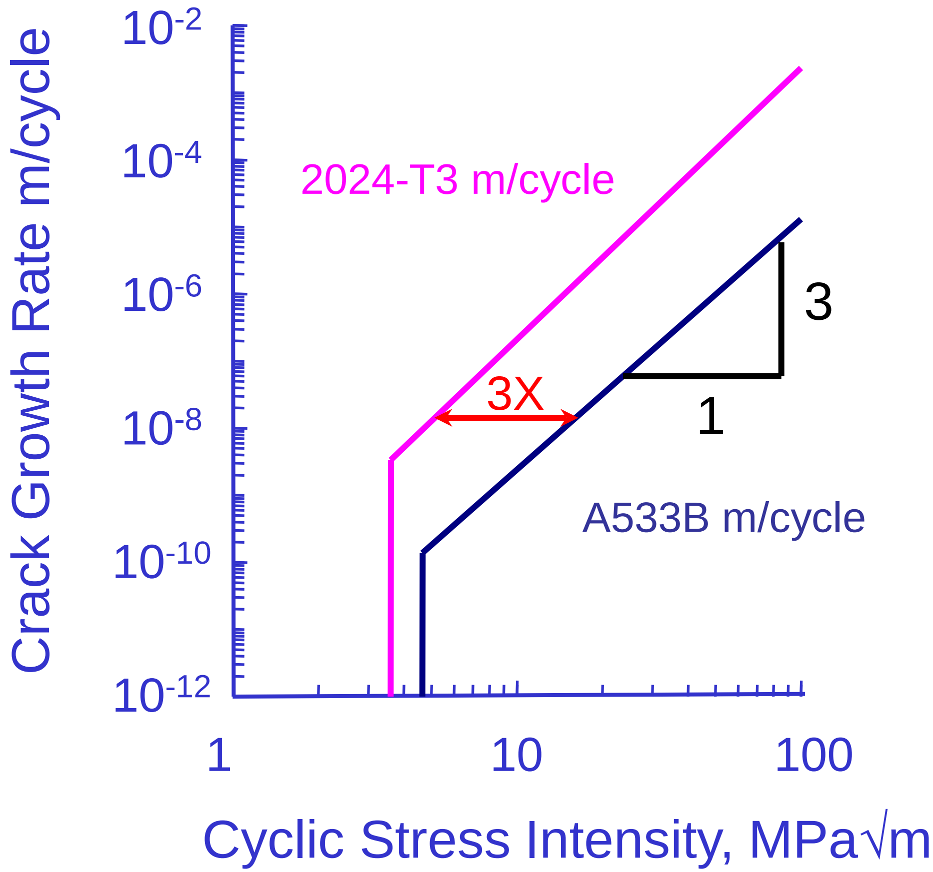
Barsom, "Fatigue Crack Propagation in Steels of Various Yield Strengths"
Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 93, No. 4, 1971, 1190-1196

# Nominal Stress - Aluminum



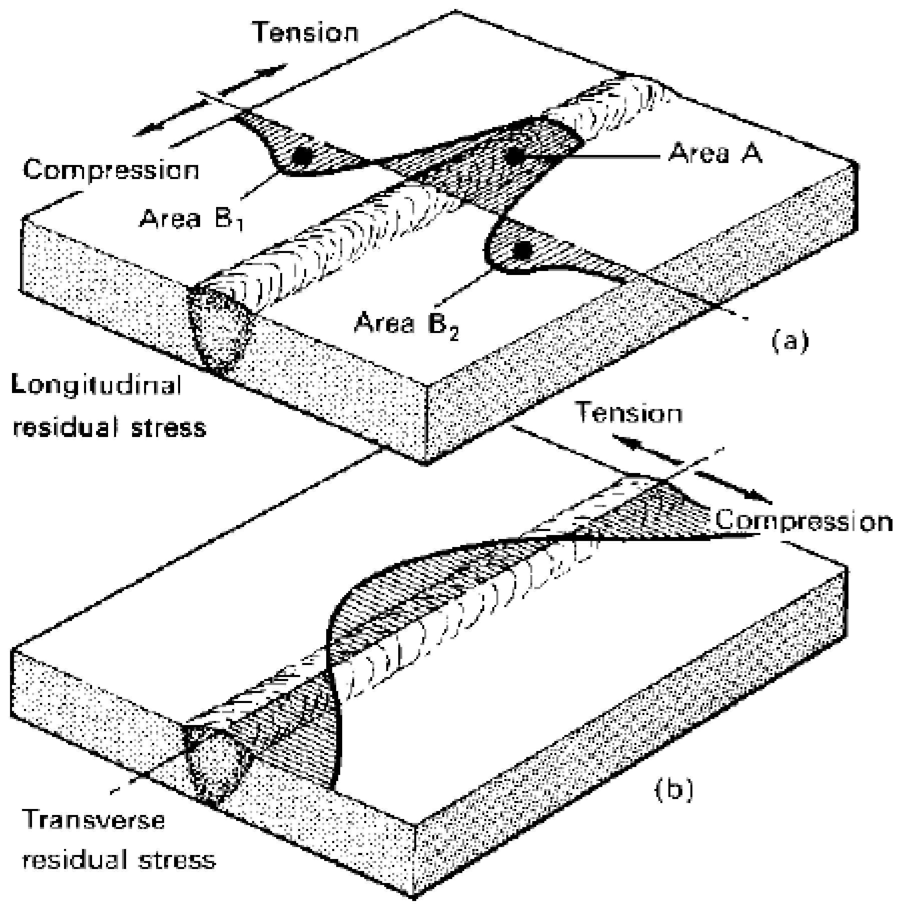

Sharp, “Behavior and Design of Aluminum Structures”,McGraw-Hill, 1992

# Crack Growth Data



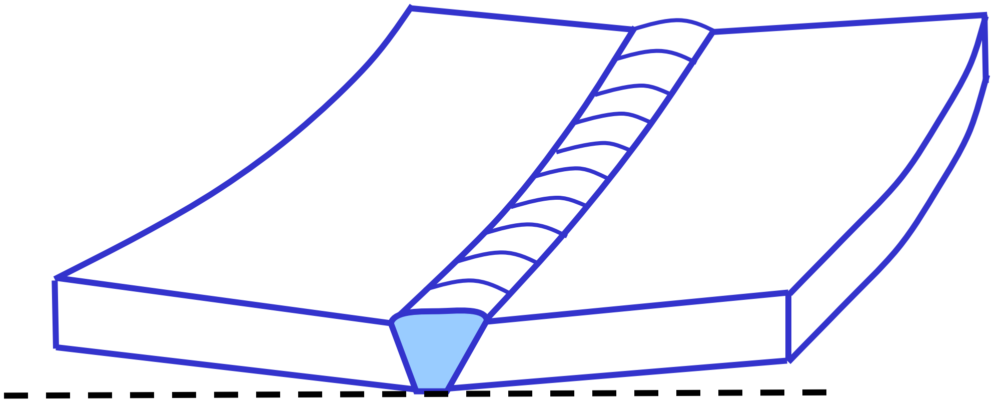

Steel welds are 3 times stronger than aluminum

# Residual Stress from Welding

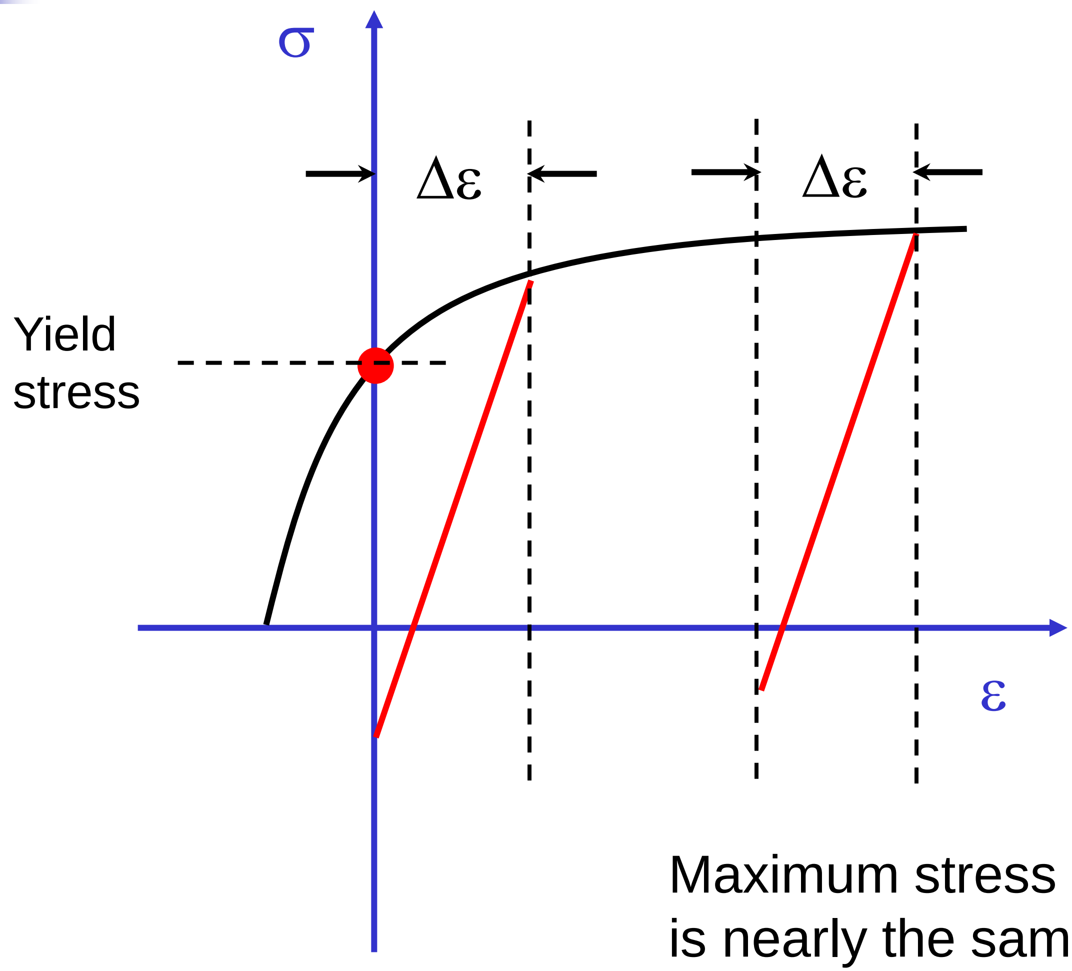


# Weld Distortion



# Weld Toe Residual Stress

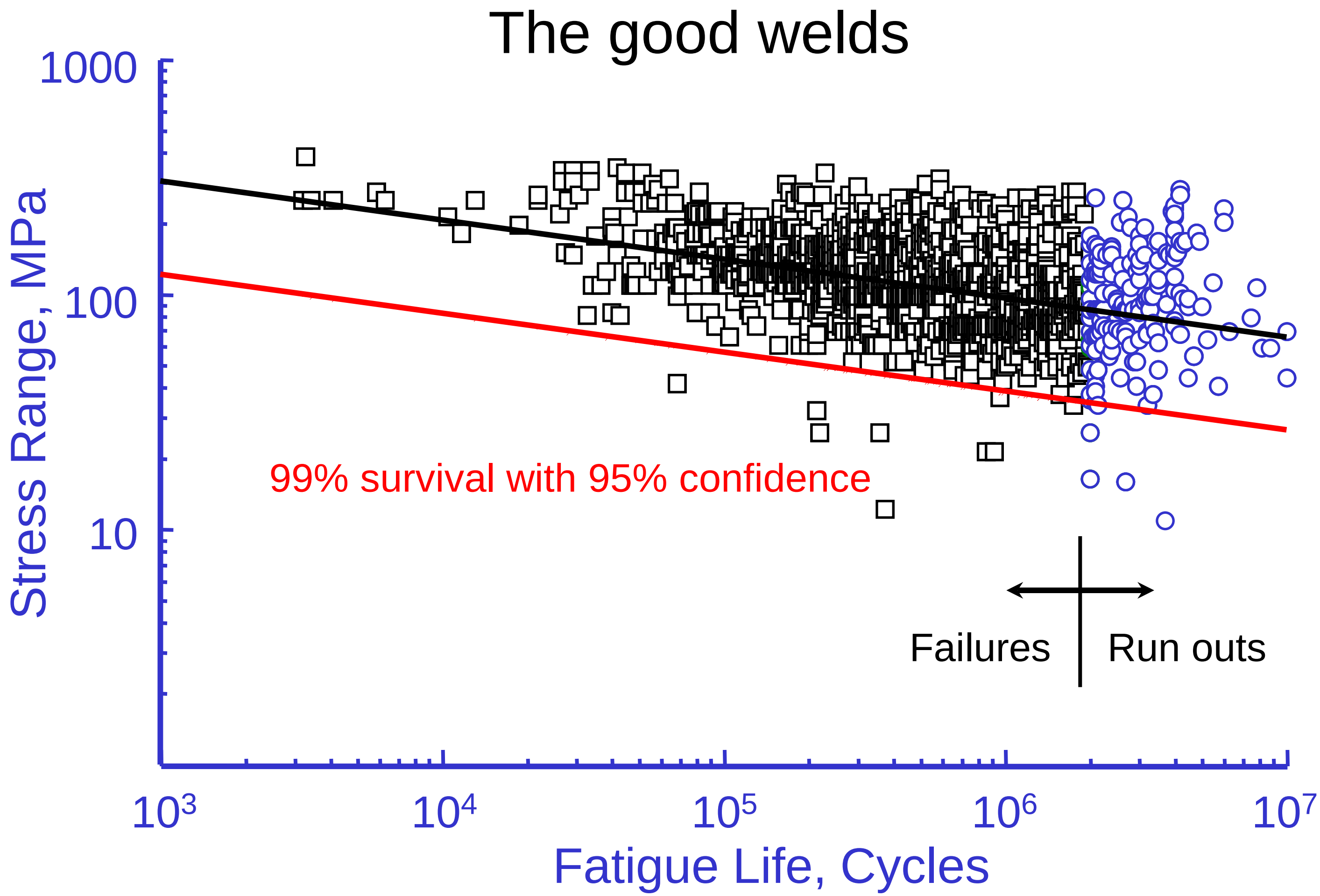



Maximum stress at the weld toe is nearly the same for any cycle

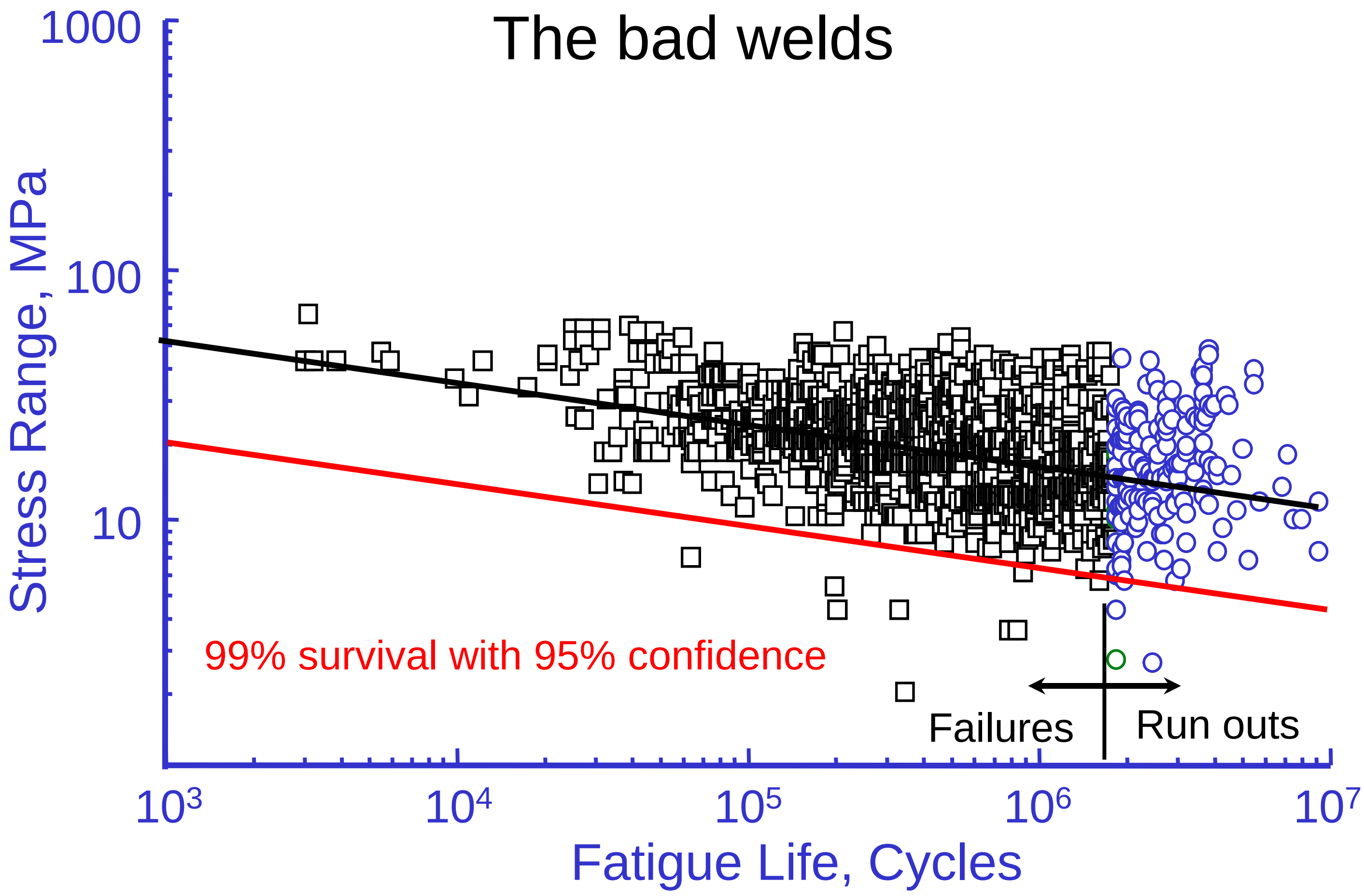
# Mean Stress Effects

- As welded structures usually have the maximum possible mean stress
- Stress relief, peening, etc. will have a substantial effect on the fatigue life

# Butt and Fillet Weld Test Data



# Weld Terminations



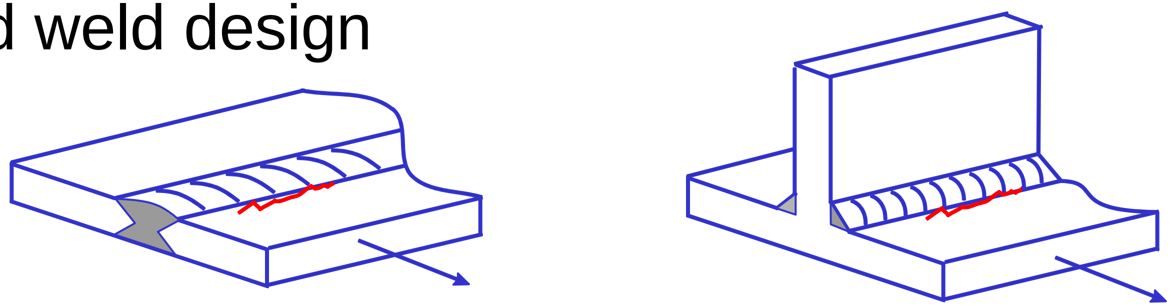
# Sources of Inherent Scatter

- Weld quality
- Mean, fabrication and residual stresses
- Stress concentrations (geometry)
- Weldment size
- Material properties

Opportunities for Improvement !

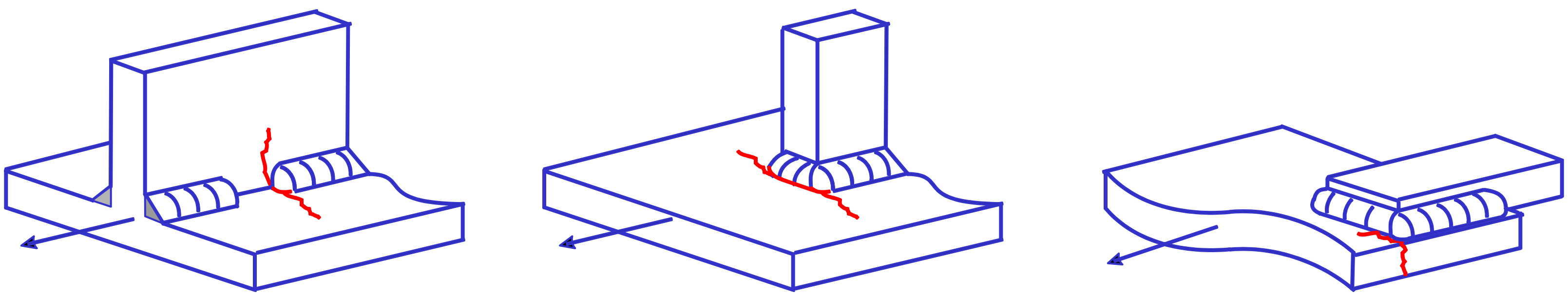
# The Good and Bad

Good weld design



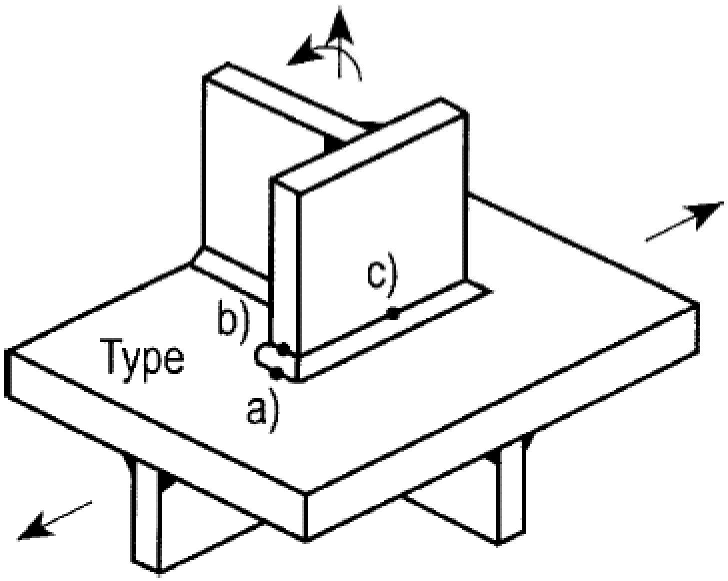
Local stress concentration from weld toe

Poor weld design



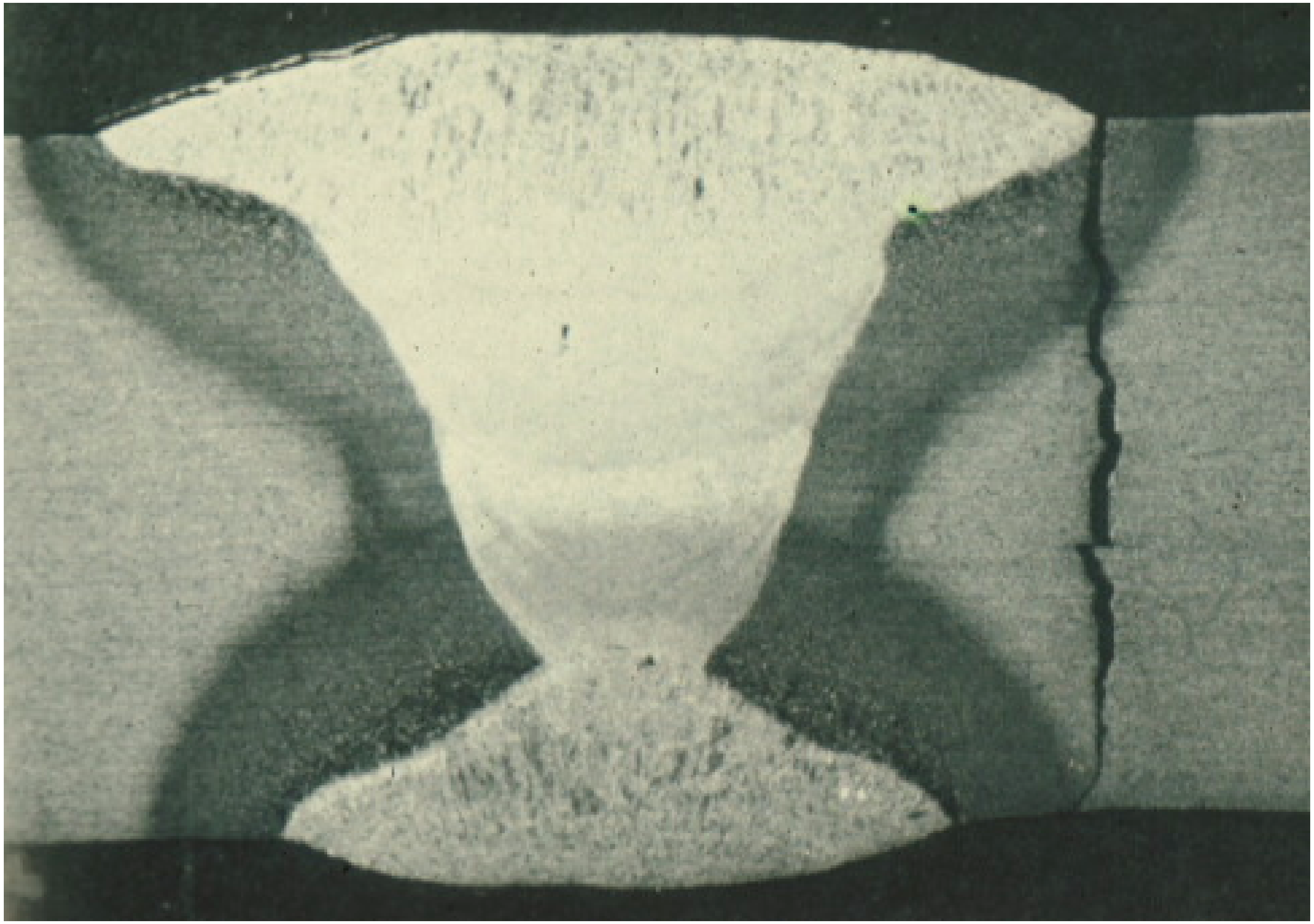
Macroscopic stress concentration from a geometry change

# Nominal Stress ?

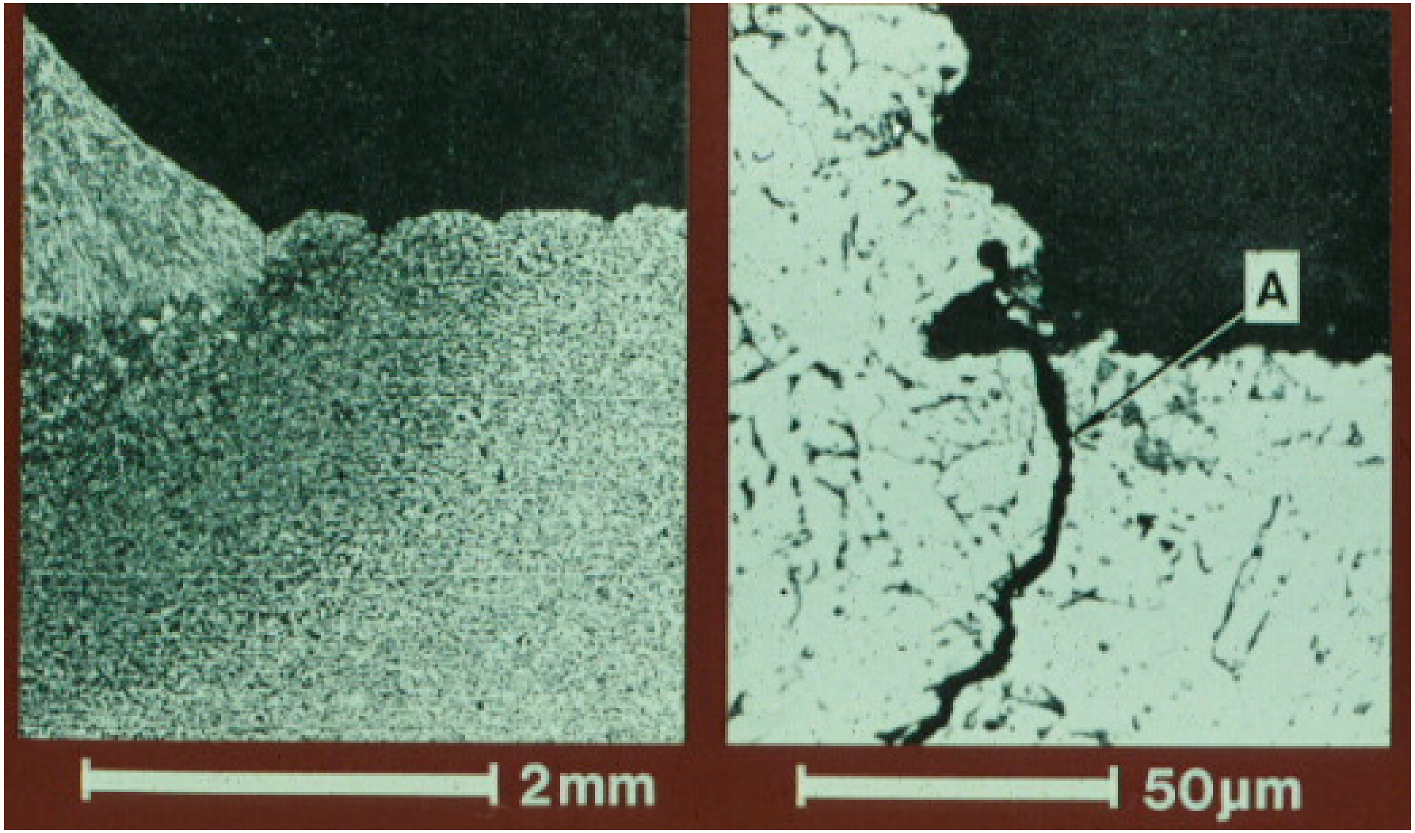



Solution: use structural stress approach

# Typical Butt Weld



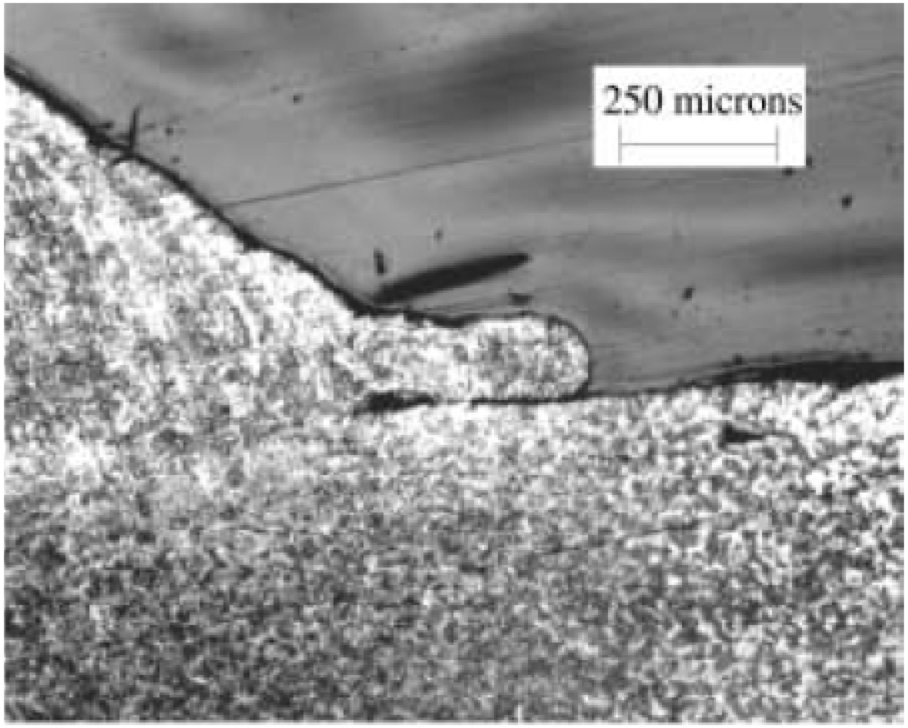
# Weld Toe



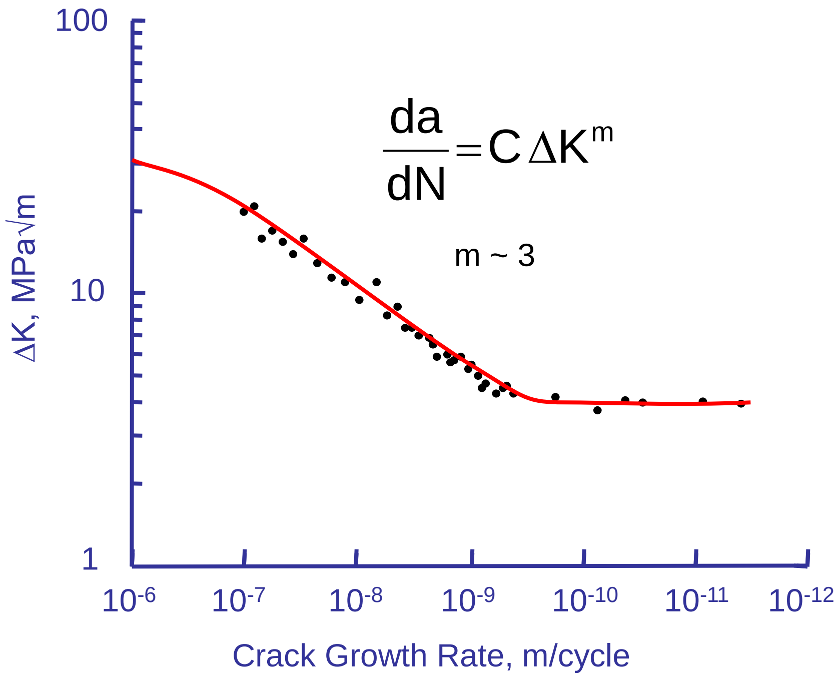

Microcracks form during welding process

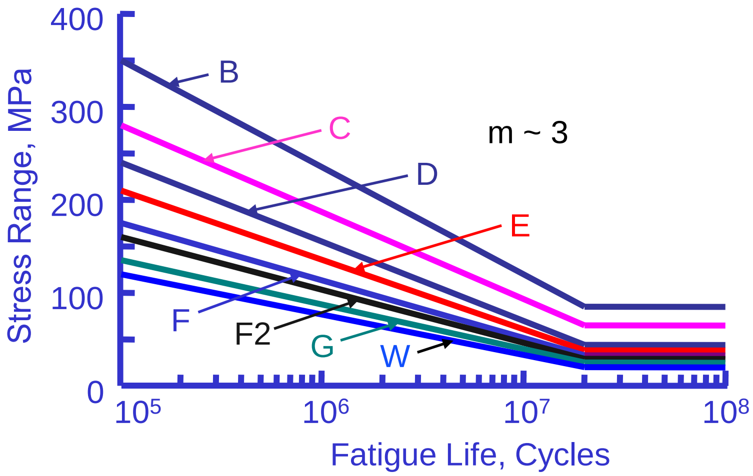
  

# Cold Lap



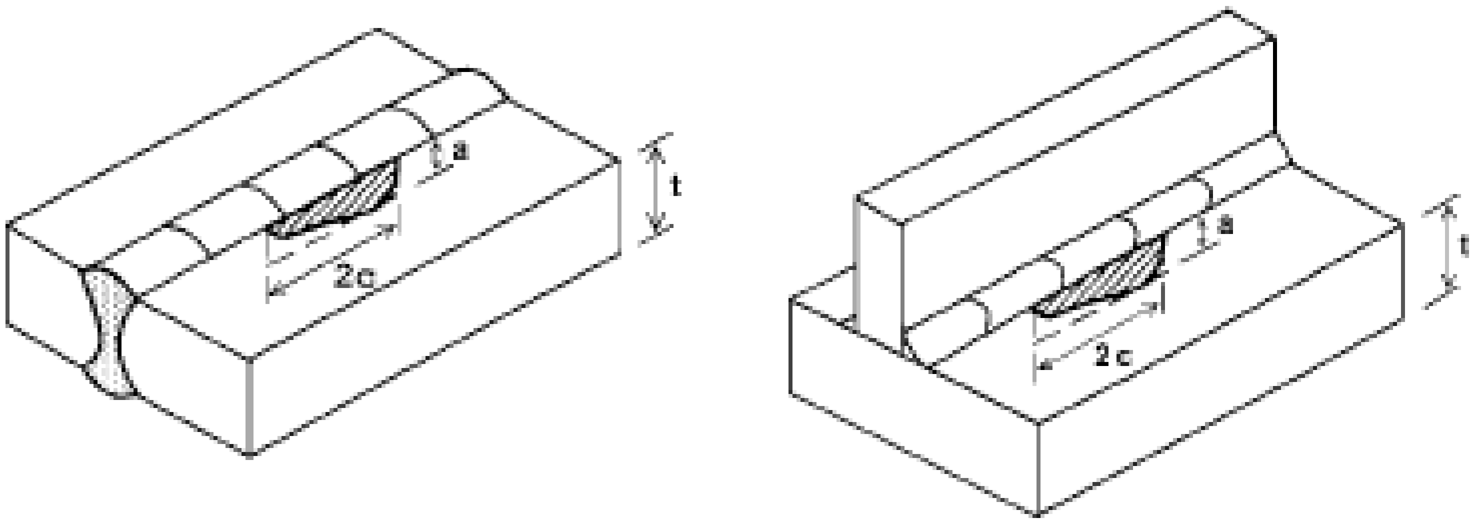
# All Welds Contain Microcracks



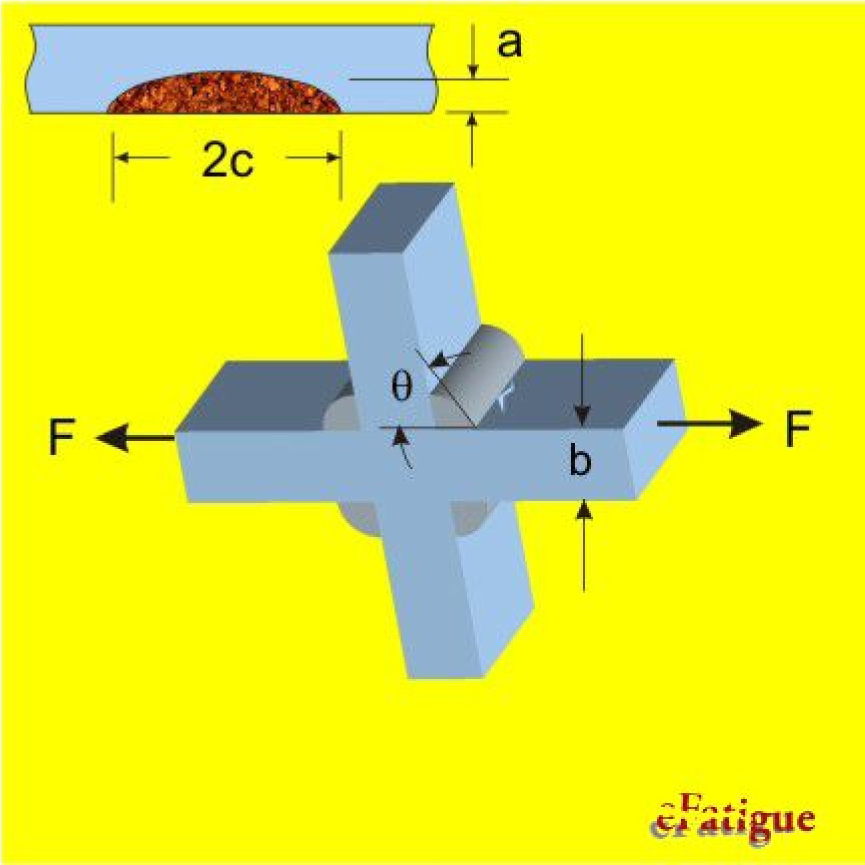

Same slope means same mechanism, crack growth

# Fracture Mechanics Modeling




Driving force is crack depth, a, not length, c

# Stress Intensity Solution

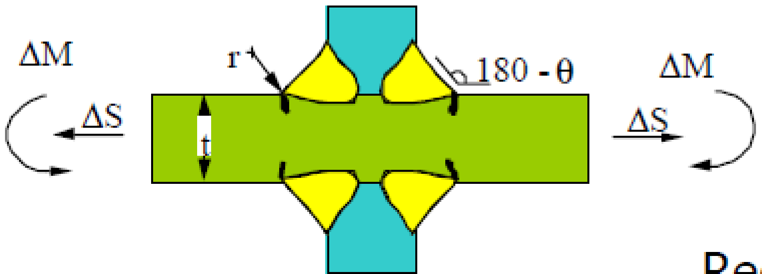



$$N = \int_{a_o}^{a_f} \frac{da}{C\left(\Delta K\right)^m}$$

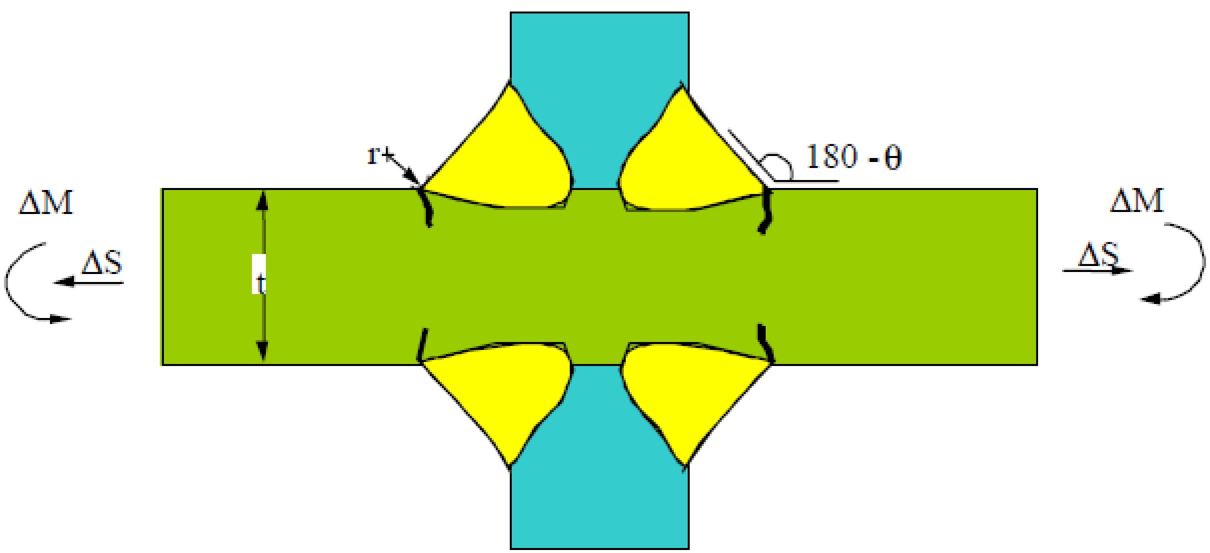
$$\Delta K = K_{max} - K_{min}$$

$$K_{max} = K_{applied} + K_{residual}$$

# Size Effects

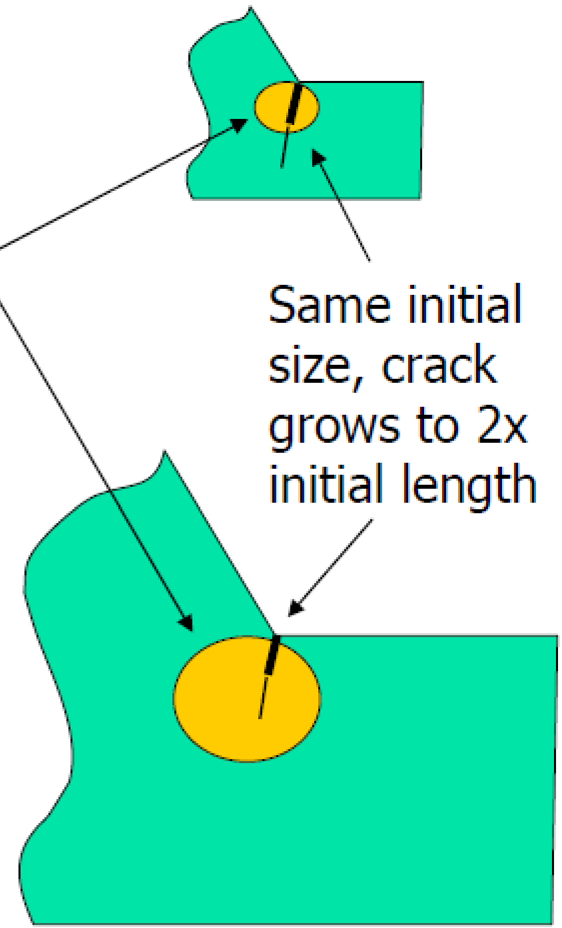



Longer Fatigue Life




Shorter Fatigue life

Region of high stress

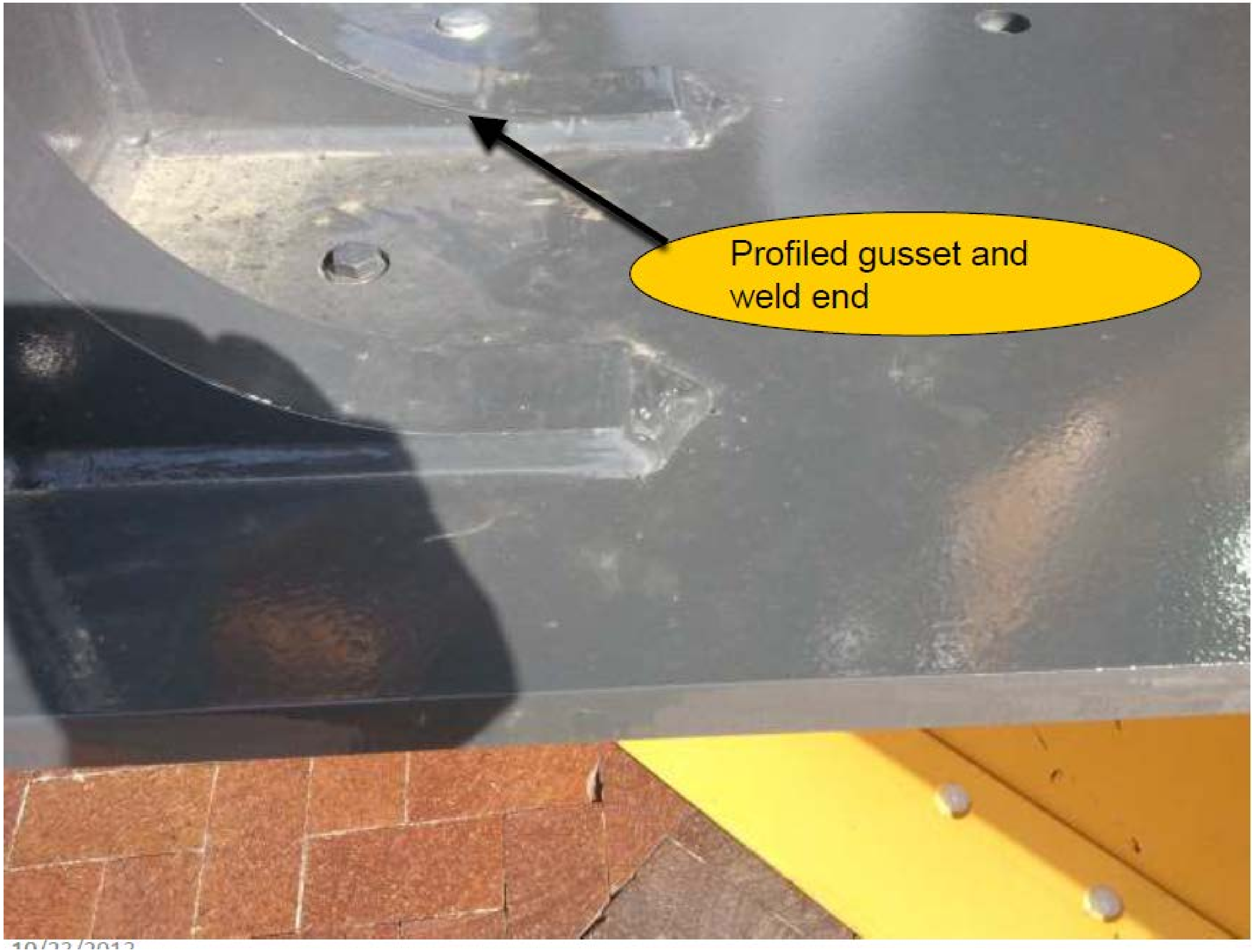


Same initial size, crack grows to 2x initial length

# Weld Improvement

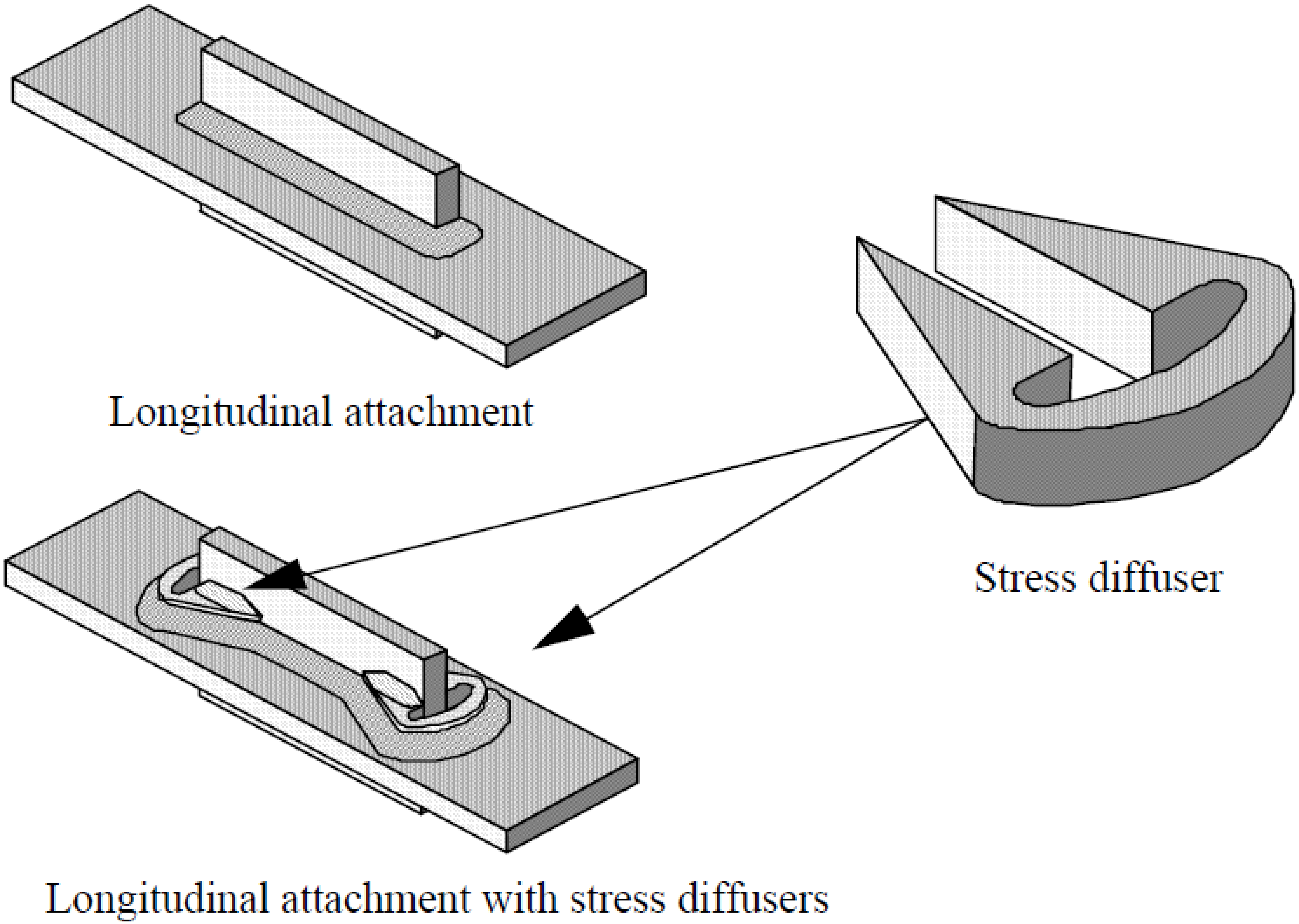
- Reduce stresses
  - Residual
  - Distortion
  - fabrication
- Reduce $K_T$
  - Weld toe
  - Macroscopic Shape
  - Weld starts and stops

# Gradual Change in Stiffness



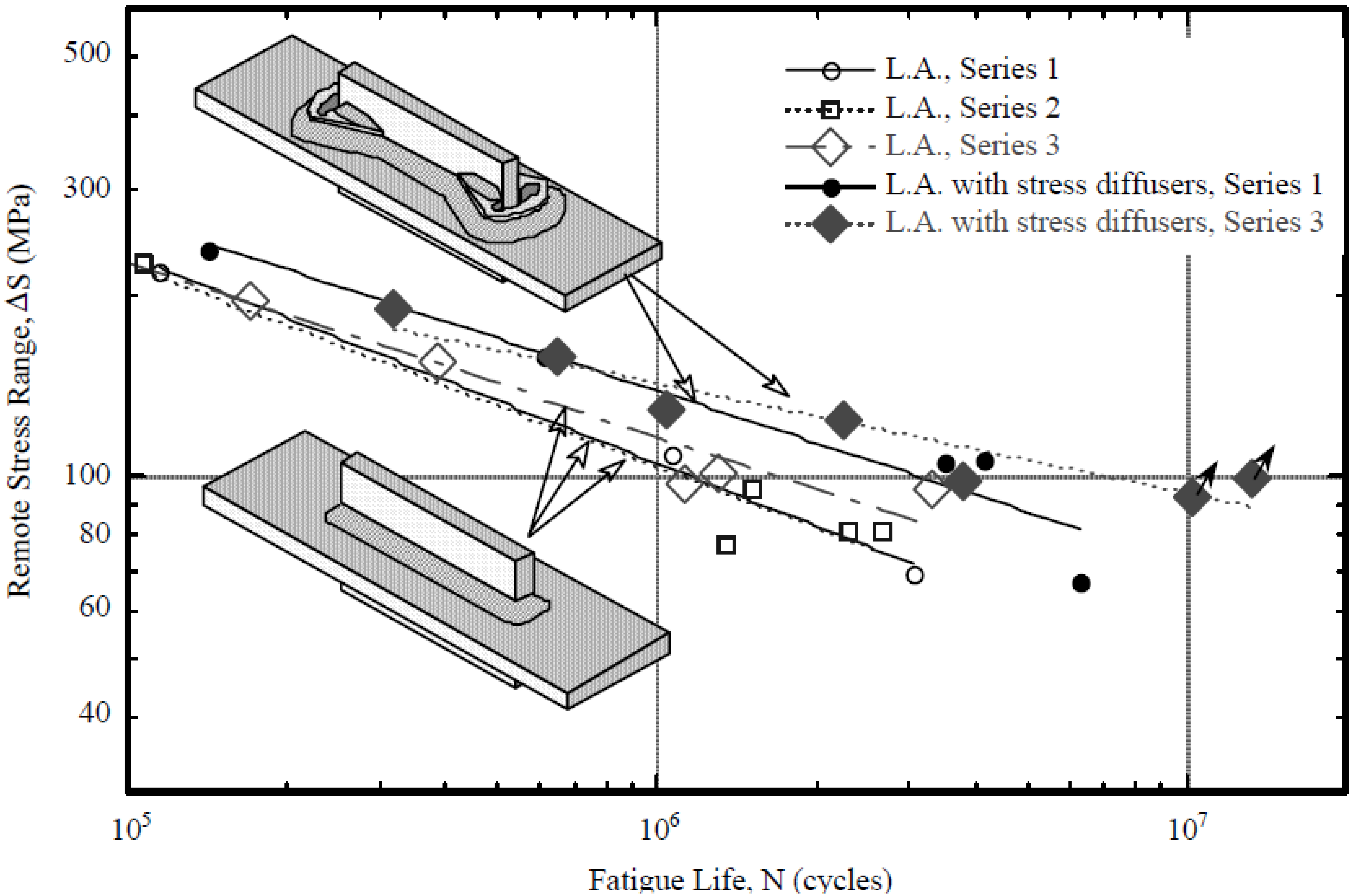
# Weld Terminations

# Stress Diffuser



# Stress Diffuser Improvement

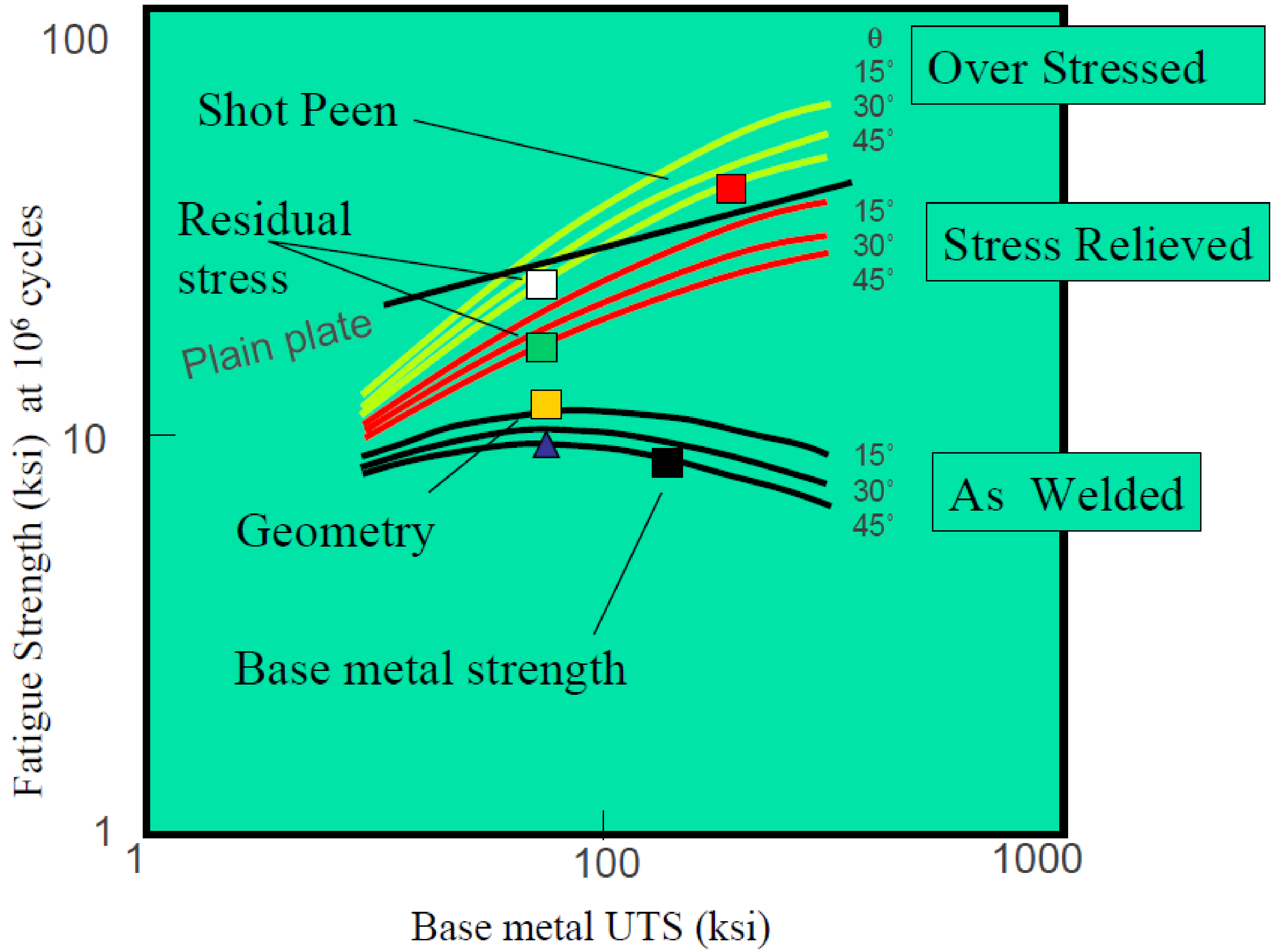


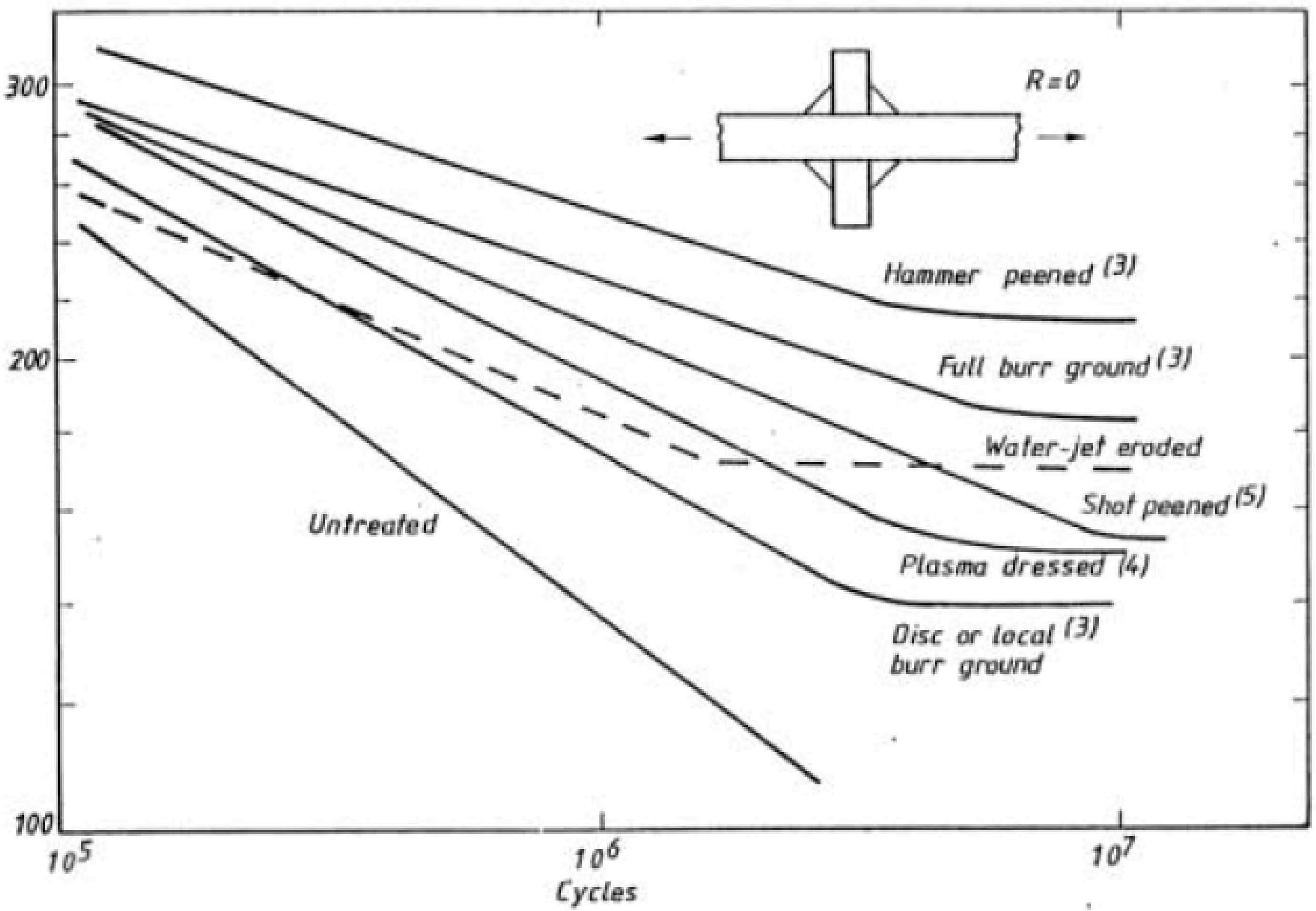
# Shape

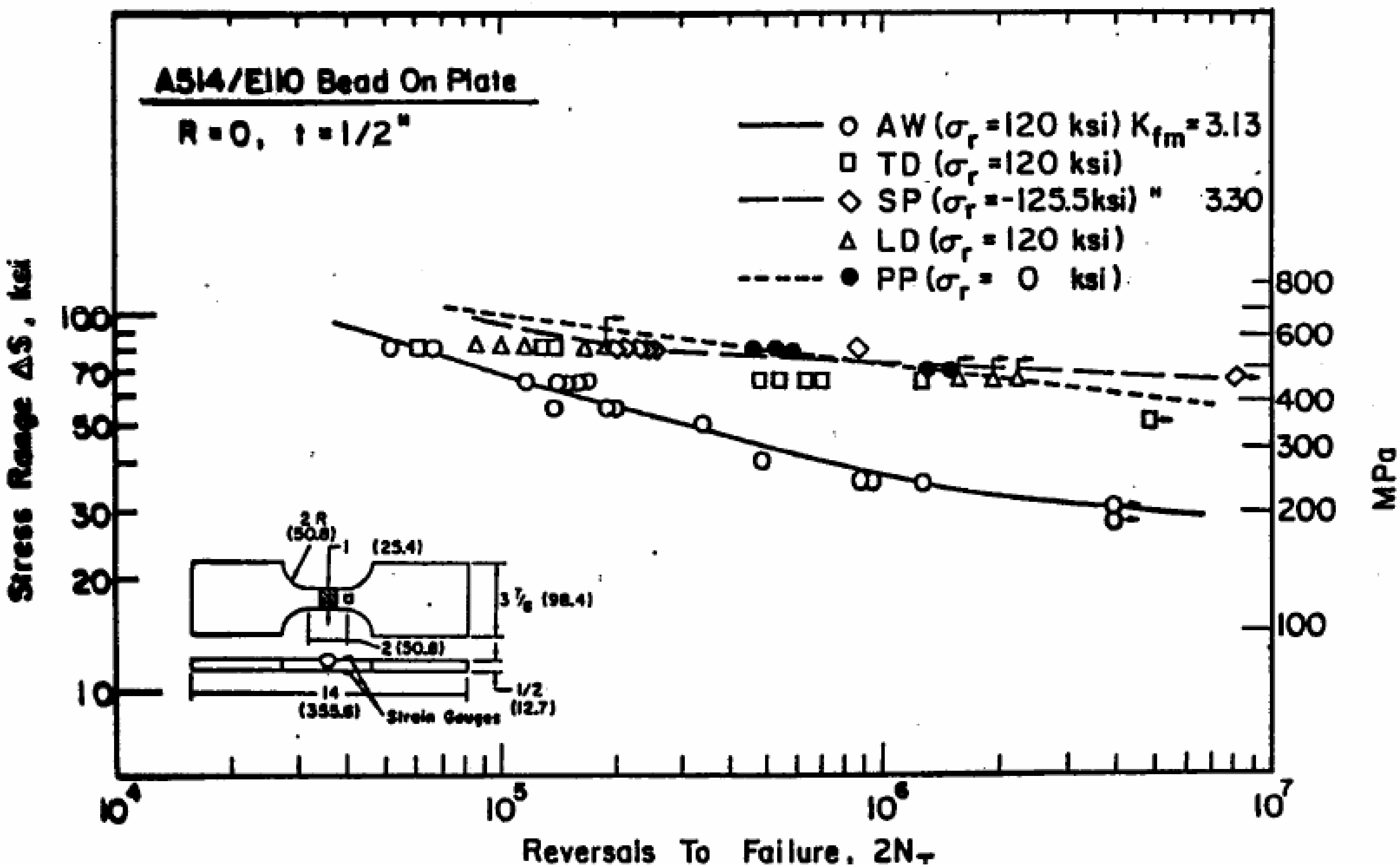
# Improvement Strategies



# TWI Suggestions



# Experimental Results



# Things Worth Remembering

- Local weld toe stresses, geometry and flaws control the life of weldments
- There are many ways to improve the fatigue strength of welded structures.

# Fatigue of Welds