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Why Coiled Tubing Fails and How to Avoid Failure on Your Job ... in Your Well

or

Why Coiled Tubing Works and How to Make Sure it Works on Your Job ... in Your Well

Steven M. Tipton
The University of Tulsa

Society of Petroleum Engineers
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The Oilfield is a Rough Place

Outline

- Introduction / Mechanics Primer
- CT Fatigue Research
  - TU Coiled Tubing Mechanics Research Consortium
- Surface Defects
- Analytical Modeling
  - FlexorTU5
- Inspection
  - 3D laser imaging

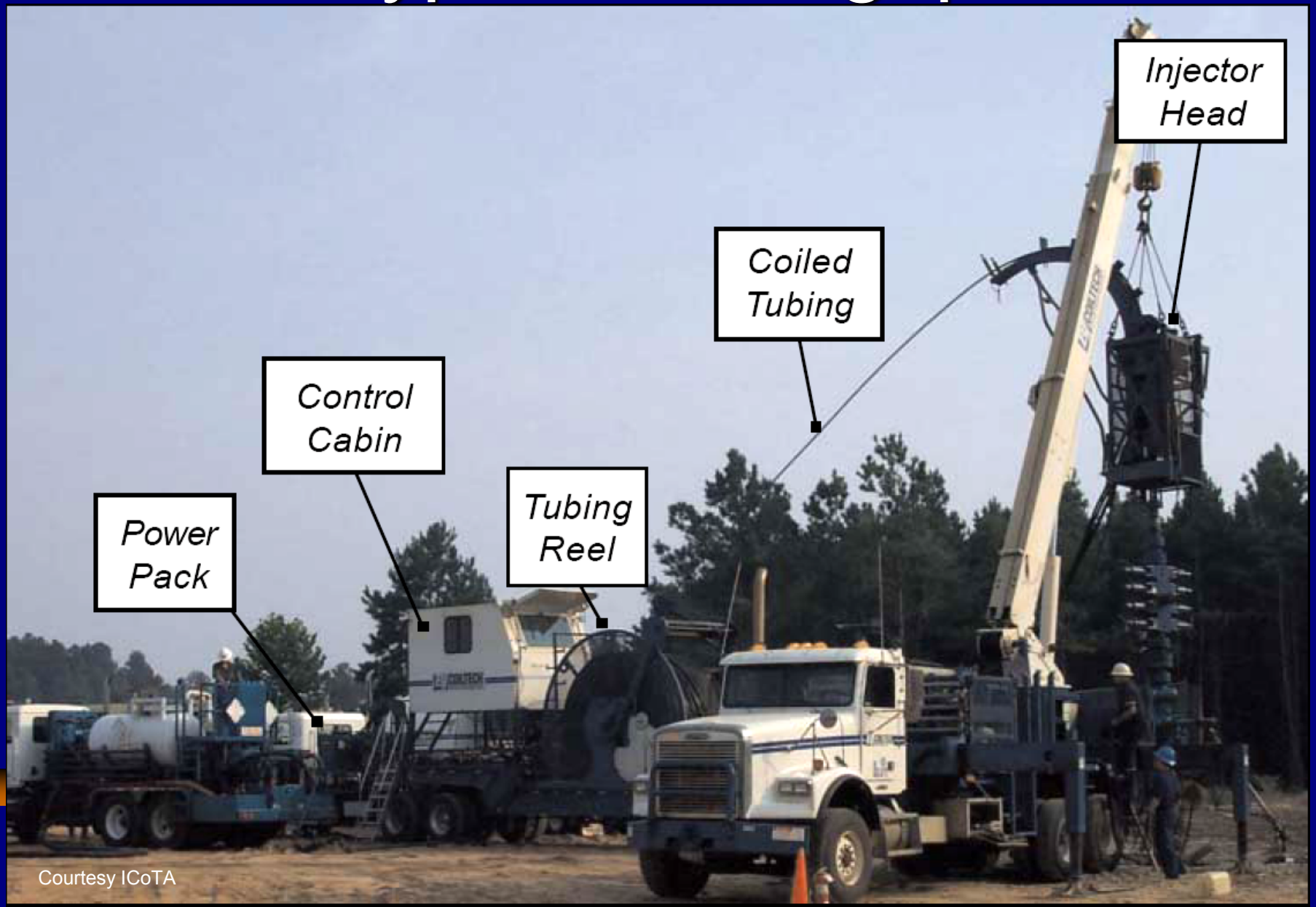
Background

- 1989 - developed CoilLIFE – Schlumberger
- 1994 - JIP to revise CoilLIFE and develop CT test machine
- 1995 - developed coiled tubing fatigue module for NOV-CTES (Achilles)
- 1996 - 2000 University of Tulsa JIP's to study CT mechanical and fatigue behavior
- 2000 – present: University of Tulsa Coiled Tubing Mechanics Research Consortium

What is “Coiled Tubing”

- Exactly what it sounds like
- Continuously Milled Tubing
- Rolled from Flat Strip
  - Resistance Welded Seam
  - HSLA (High Strength Low Alloy)
    - 55-120 KSI
  - CRA
    - Chrome Alloys, Titanium
- Diameters: 0.75” – 4.5”
- Thicknesses: up to 0.25”
- Lengths > 30k ft
  - 10K – 20k ft most common

Typical CT Rigup



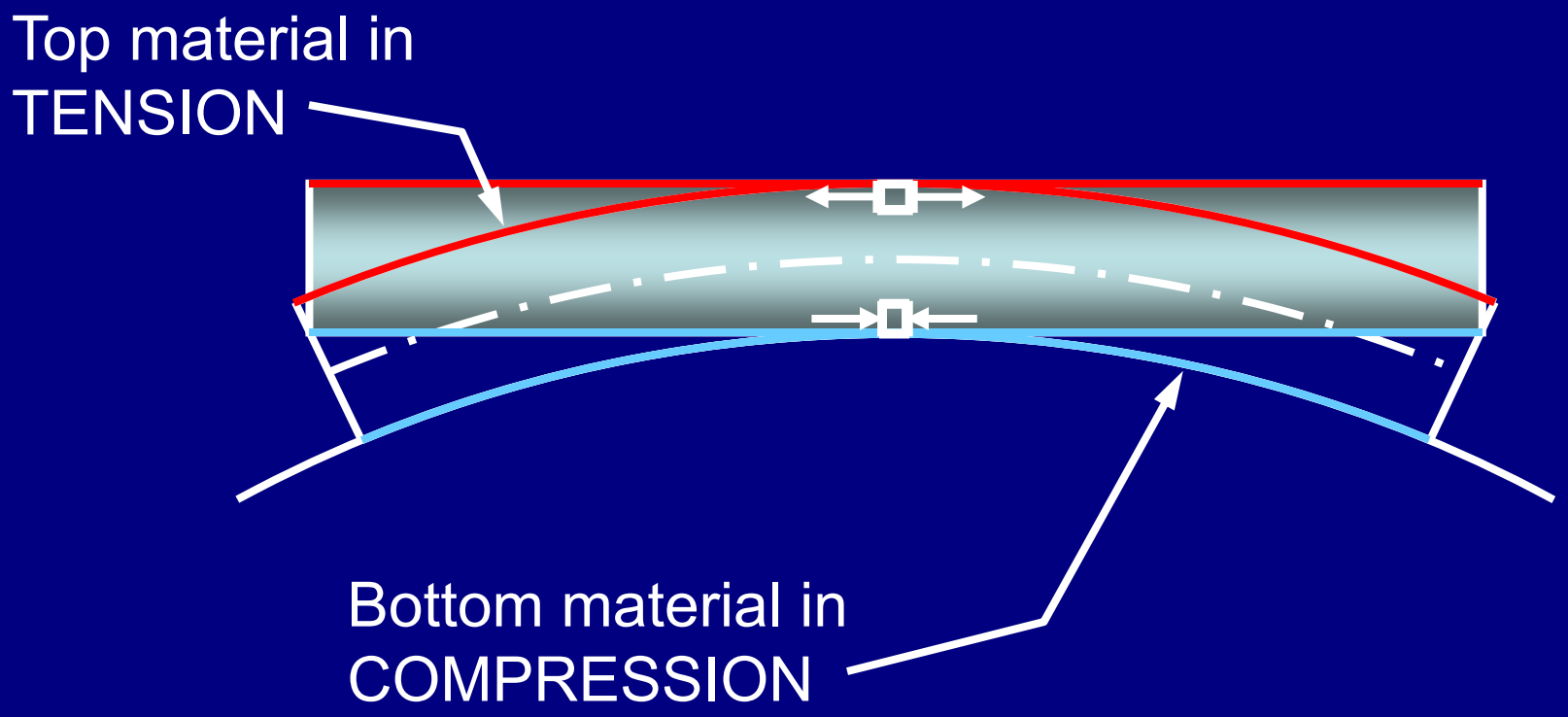
Courtesy ICoTA

Coiled Tubing Units

Coiled Tubing

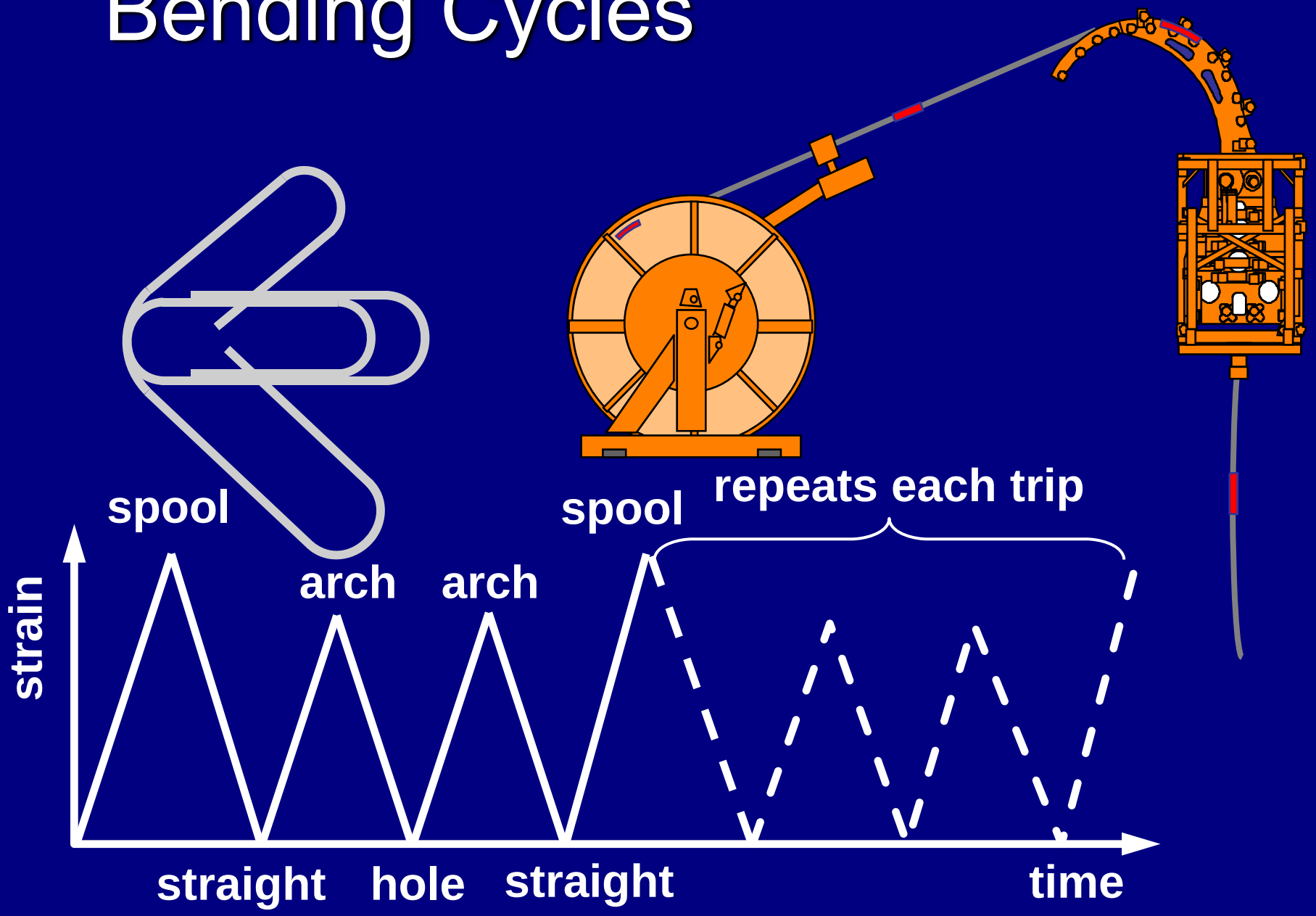
2009 SAE Baja Vehicle

Bending Strains



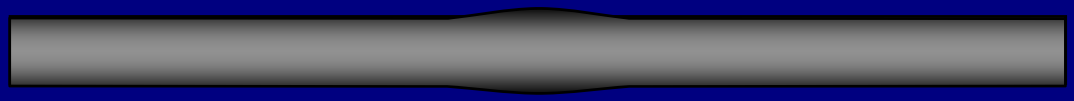
"Strain" defined as % material stretches in Tension or shortens in Compression

Bending Cycles



Bending Strains Lead to

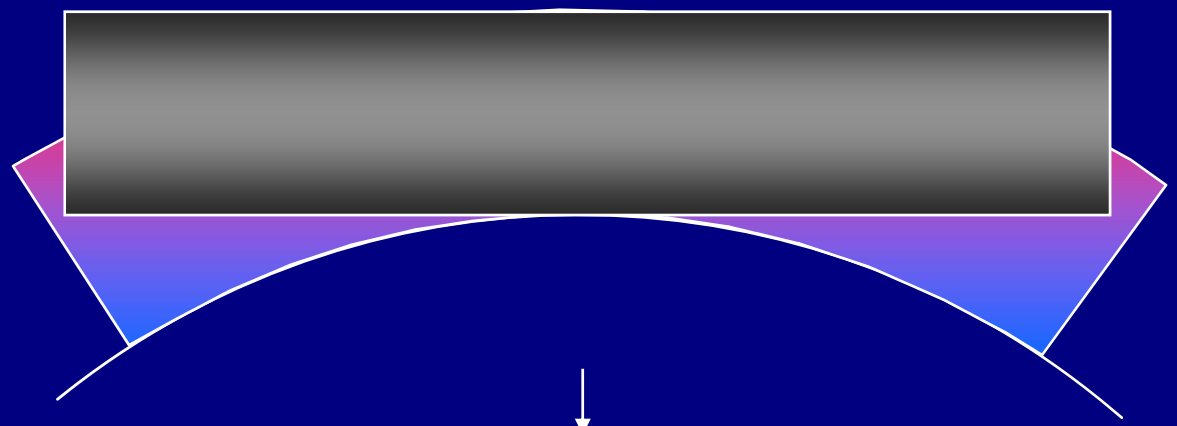
- ULTRA-Low Cycle Fatigue
  - e.g., lives ≈ 10 – 100 cycles to failure
    - Normal Low Cycle >10^3 Cycles to Fatigue
    - Engine Parts >10^6 Cycles to Fatigue
- Ballooning



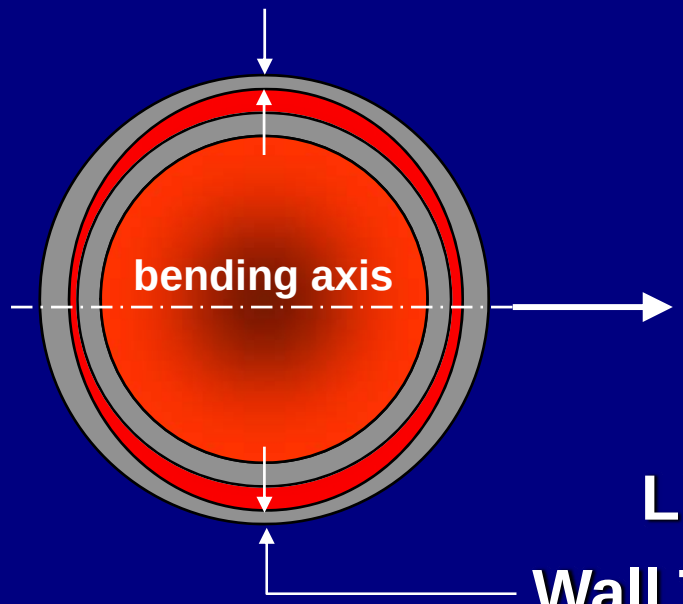
  - >30% even when pressure is <50% yield
- Permanent Elongation
  - 6-10 ft per 10,000 ft trip, even for axial loading well below yield

Bending Strains

Huge Cyclic Plastic Strains (>2%!)



Even with pressure below 50% of yield



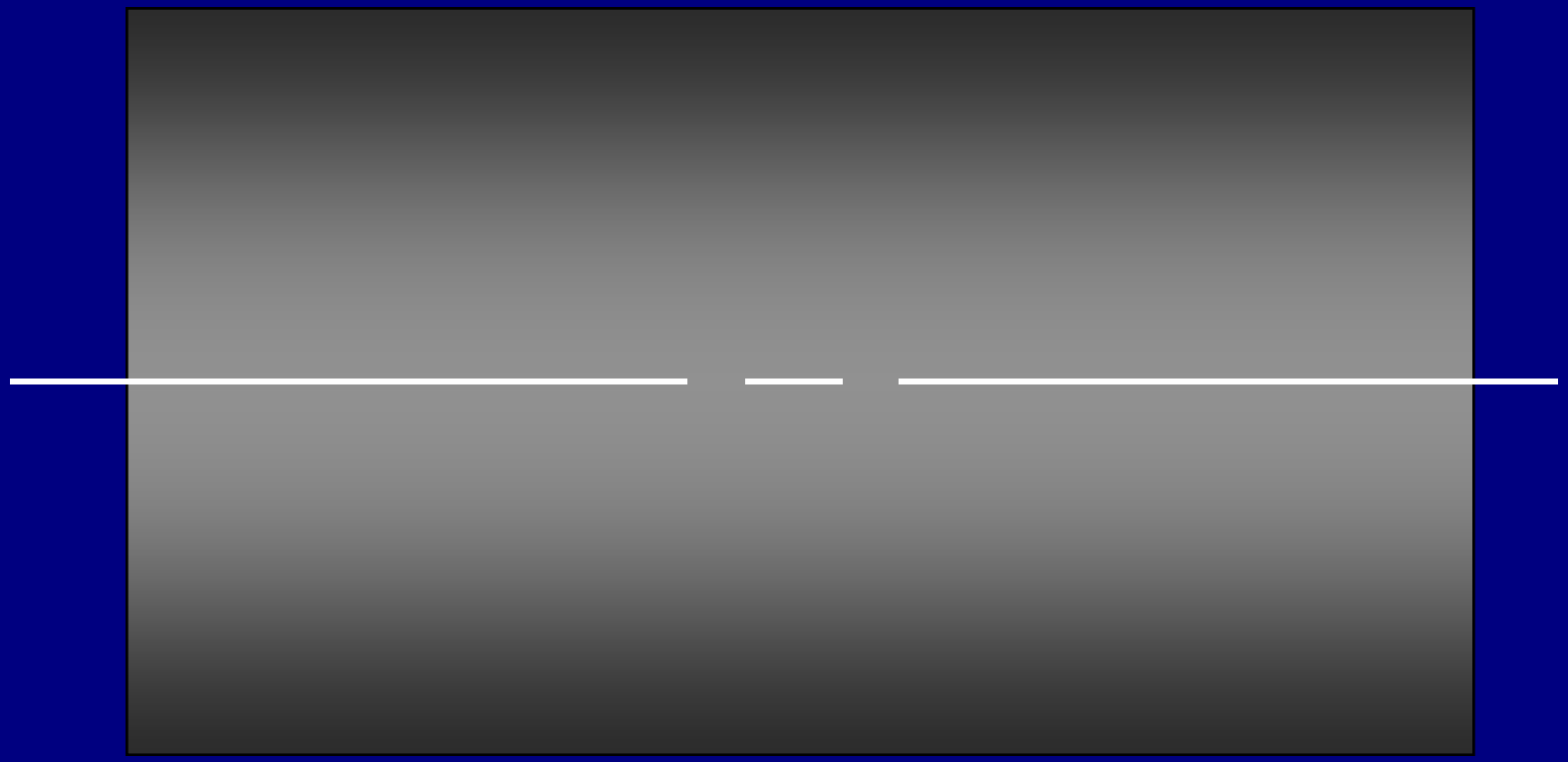
"Ratcheting"

Incremental diameter growth >30%

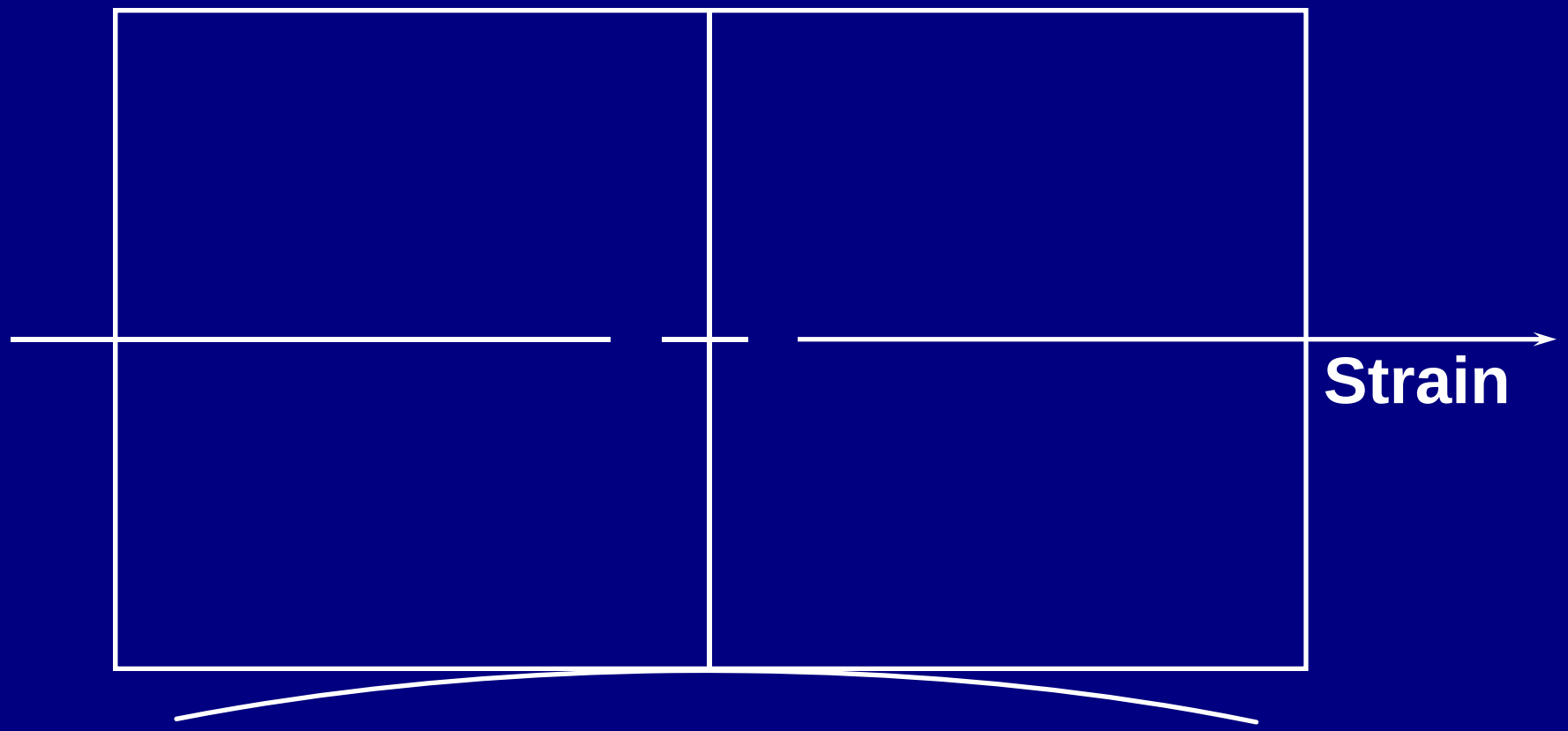
Lives < 10 cycles!

Wall Thinning

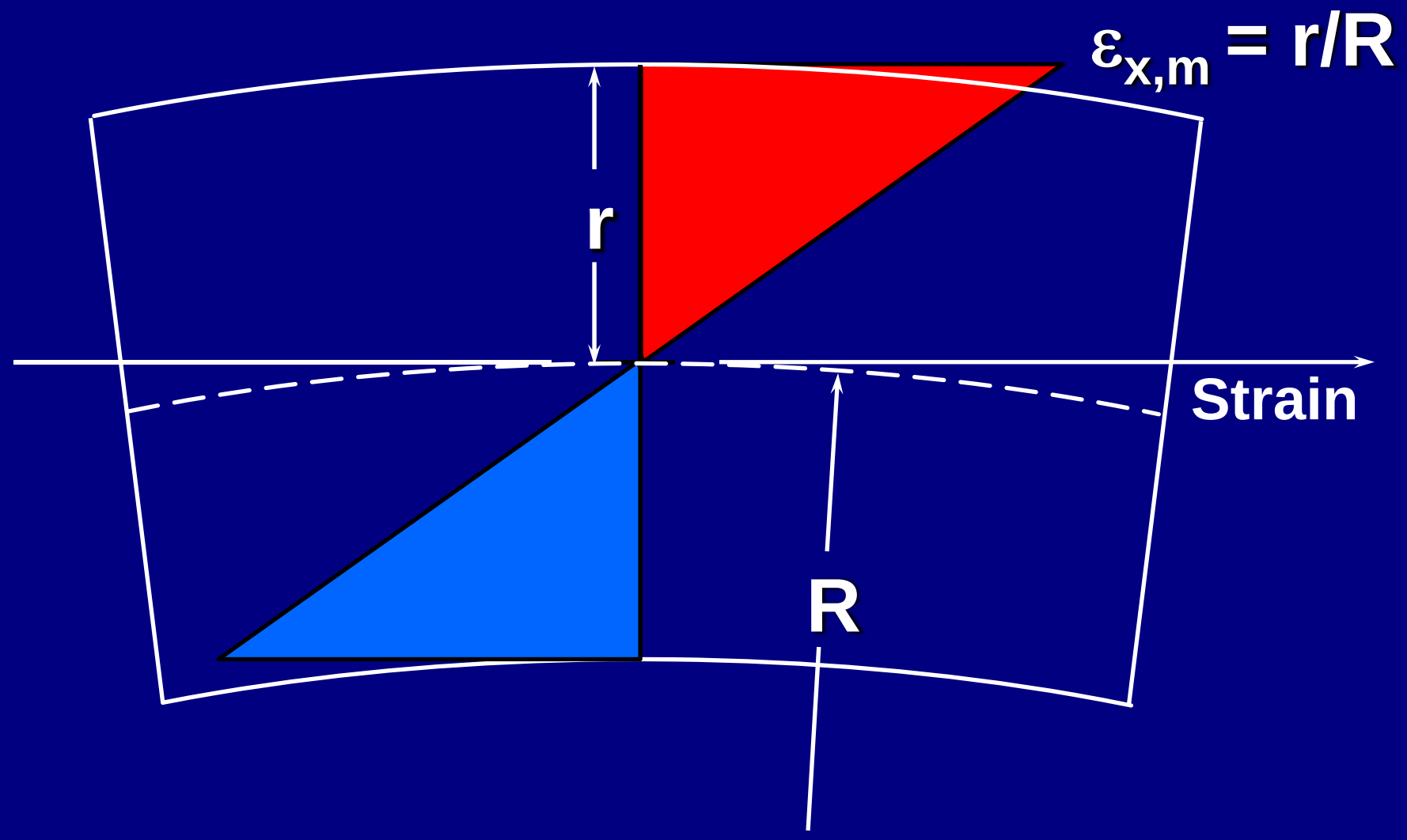
Permanent Elongation



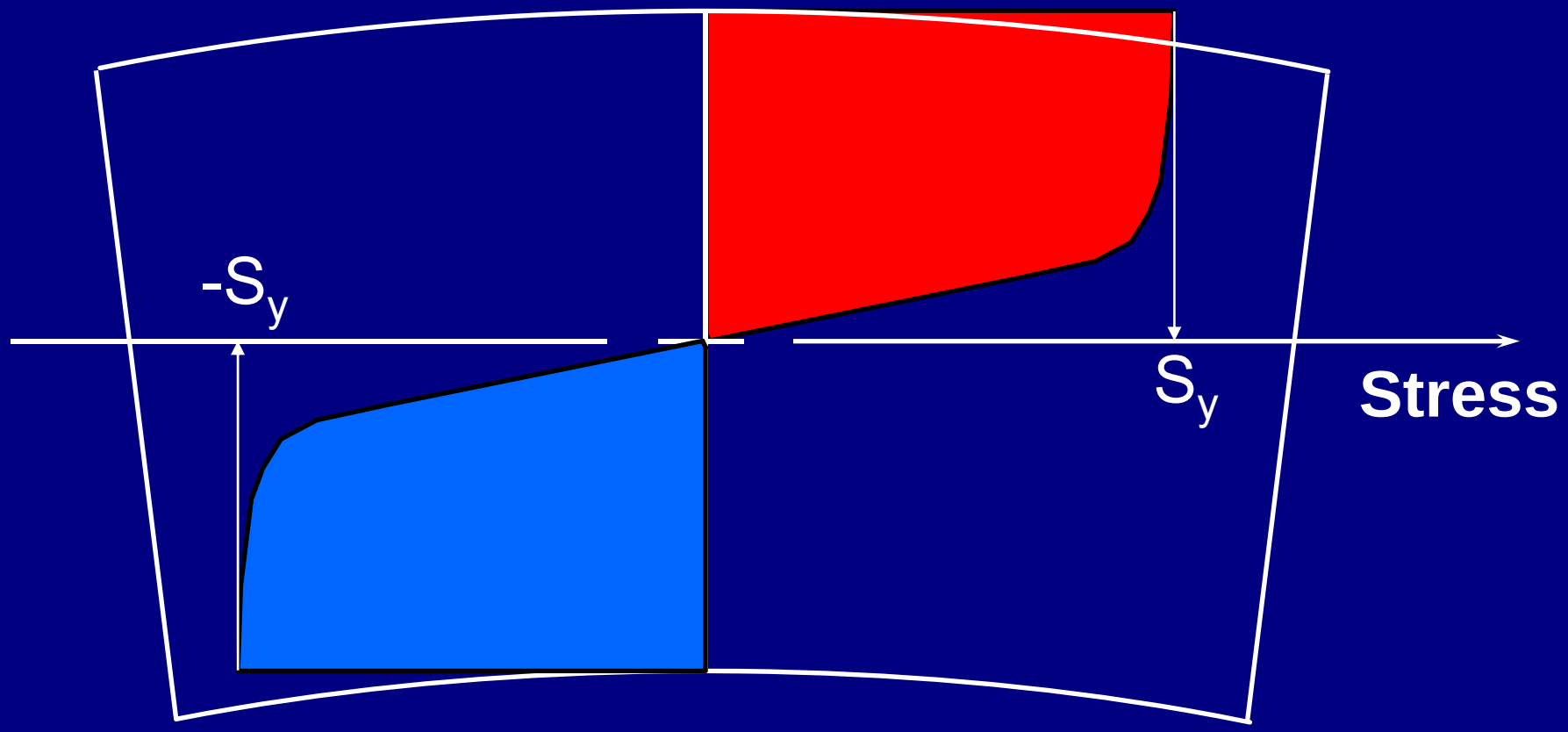
Bending Strain Distribution



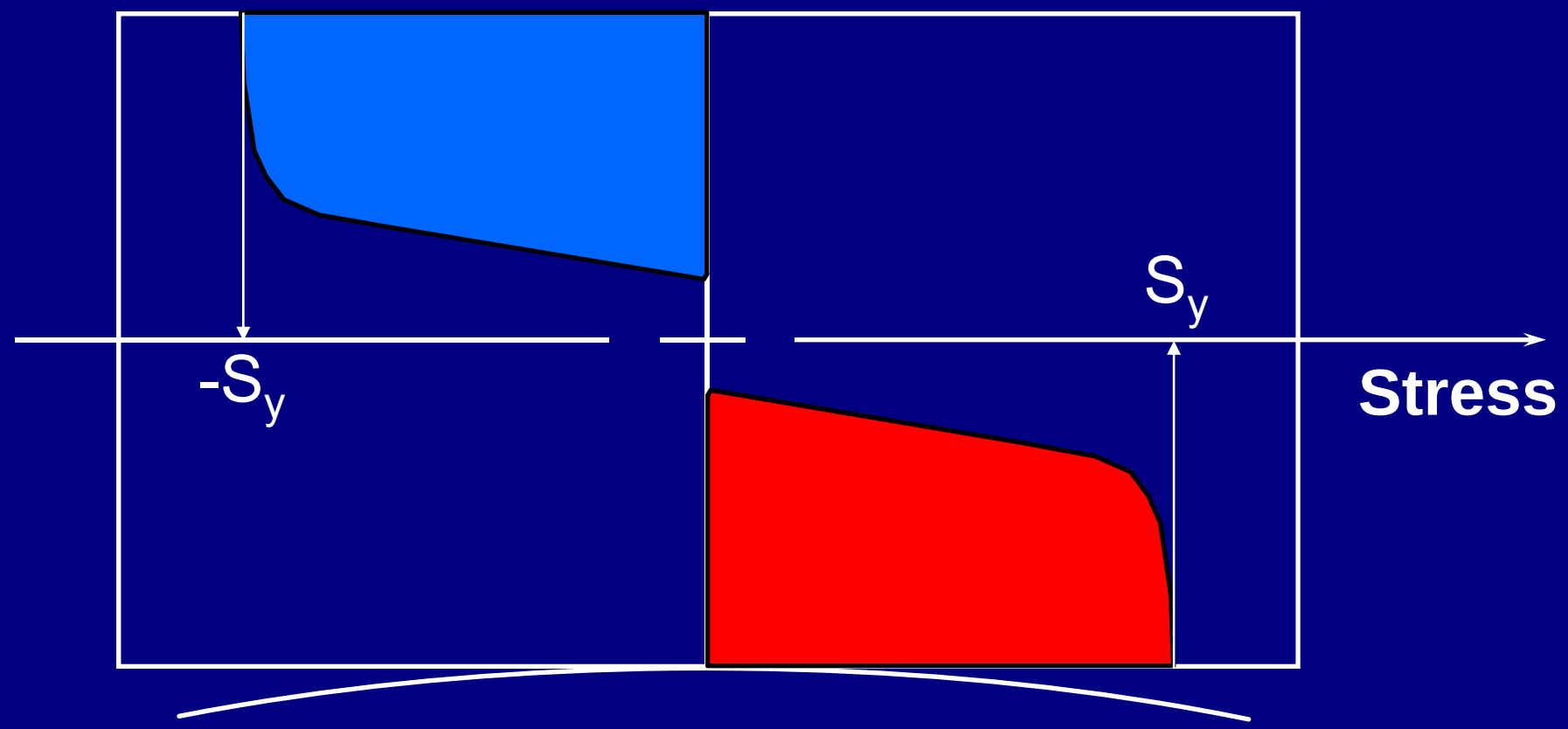
Bending Strain Distribution



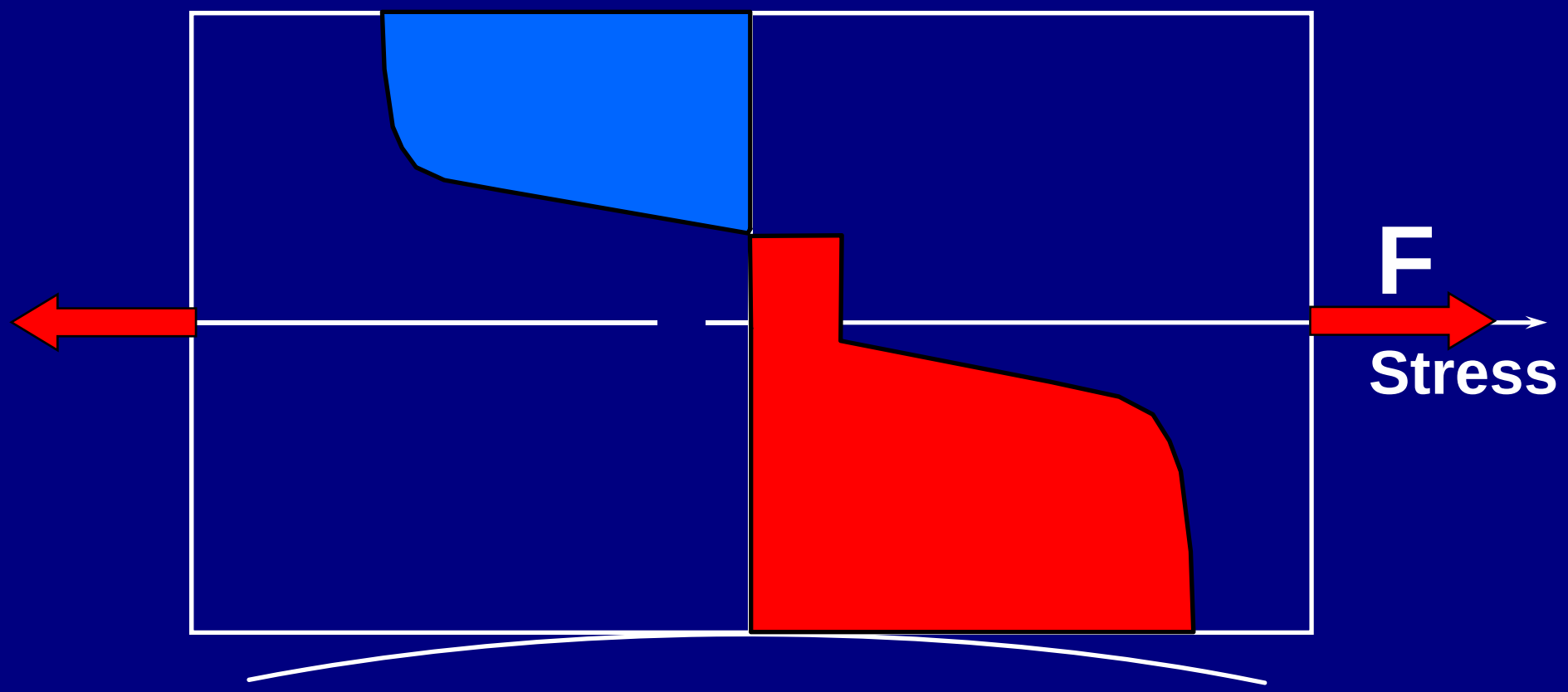
Bending Stress Distribution



Bending Stress Distribution

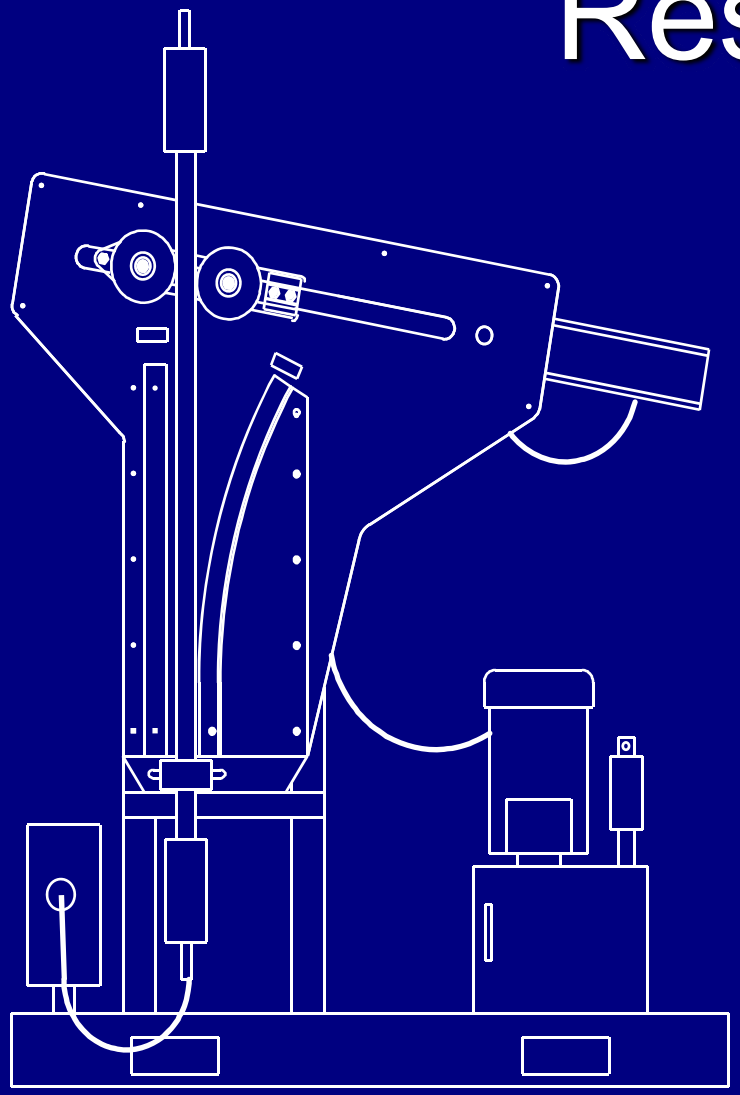


Causes Permanent Elongation



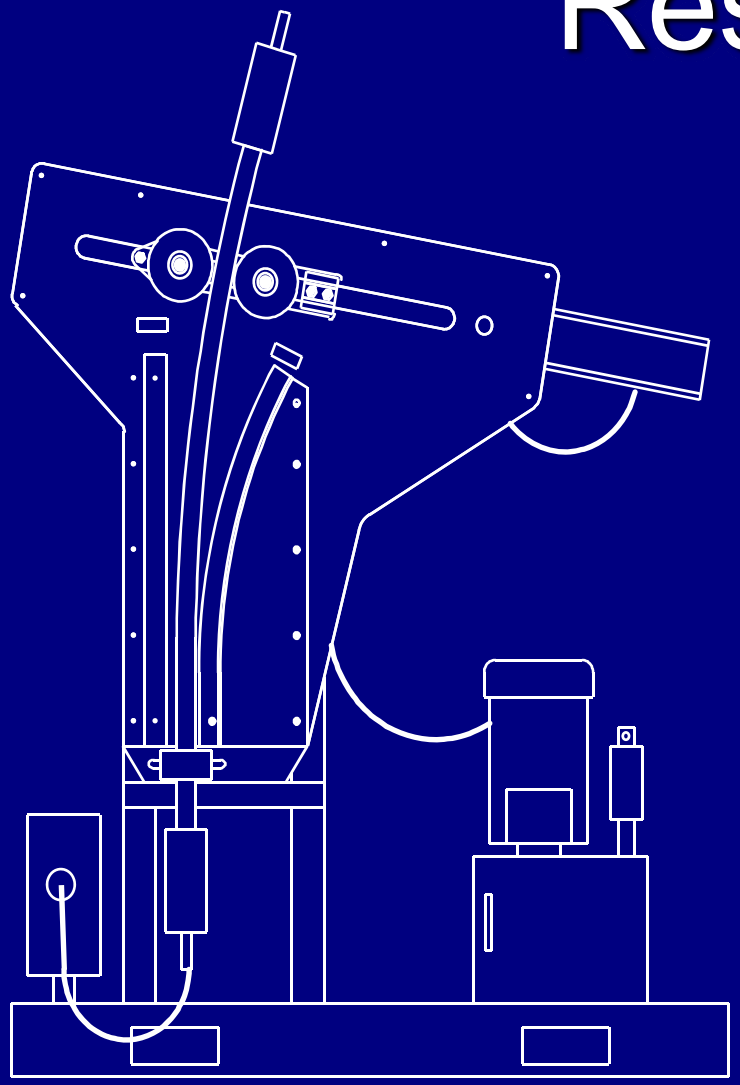
CT Fatigue Research

CoilLIFE Fatigue Test Machine



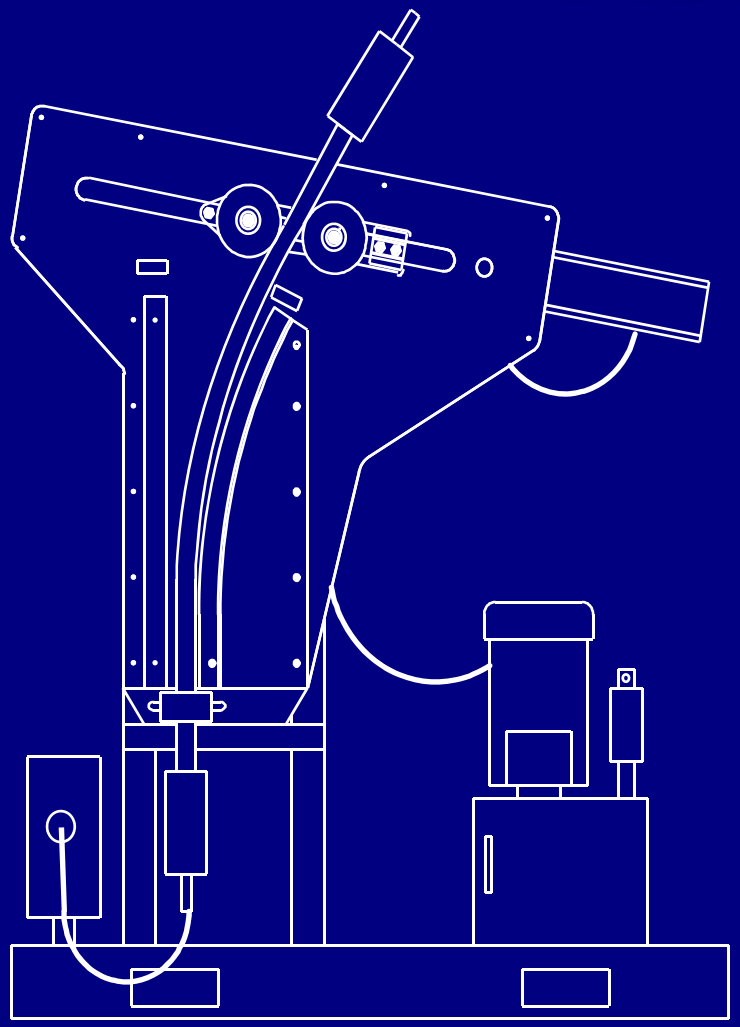
CT Fatigue Research

CoilLIFE Fatigue Test Machine



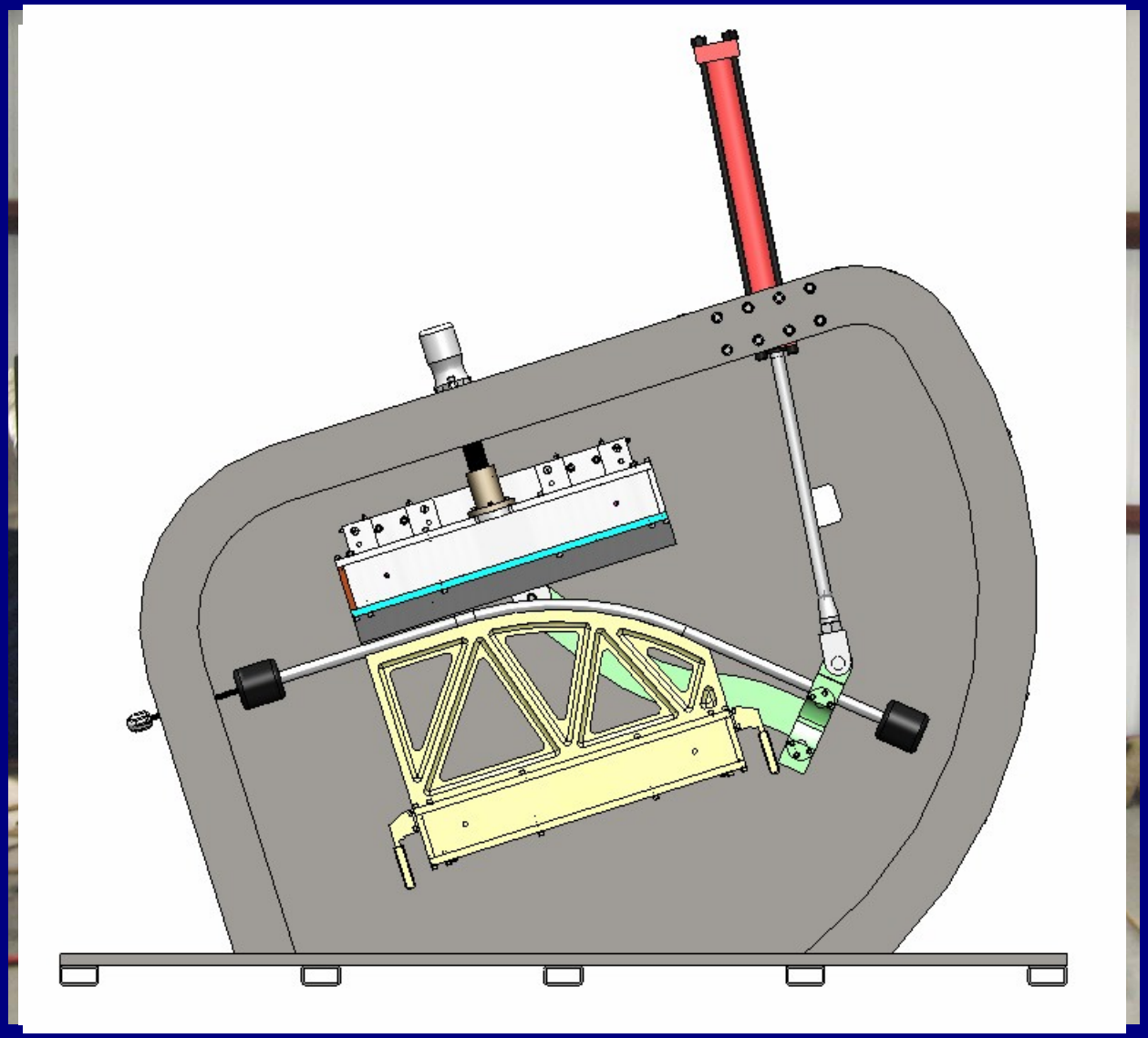
CT Fatigue Research

CoilLIFE Fatigue Test Machine

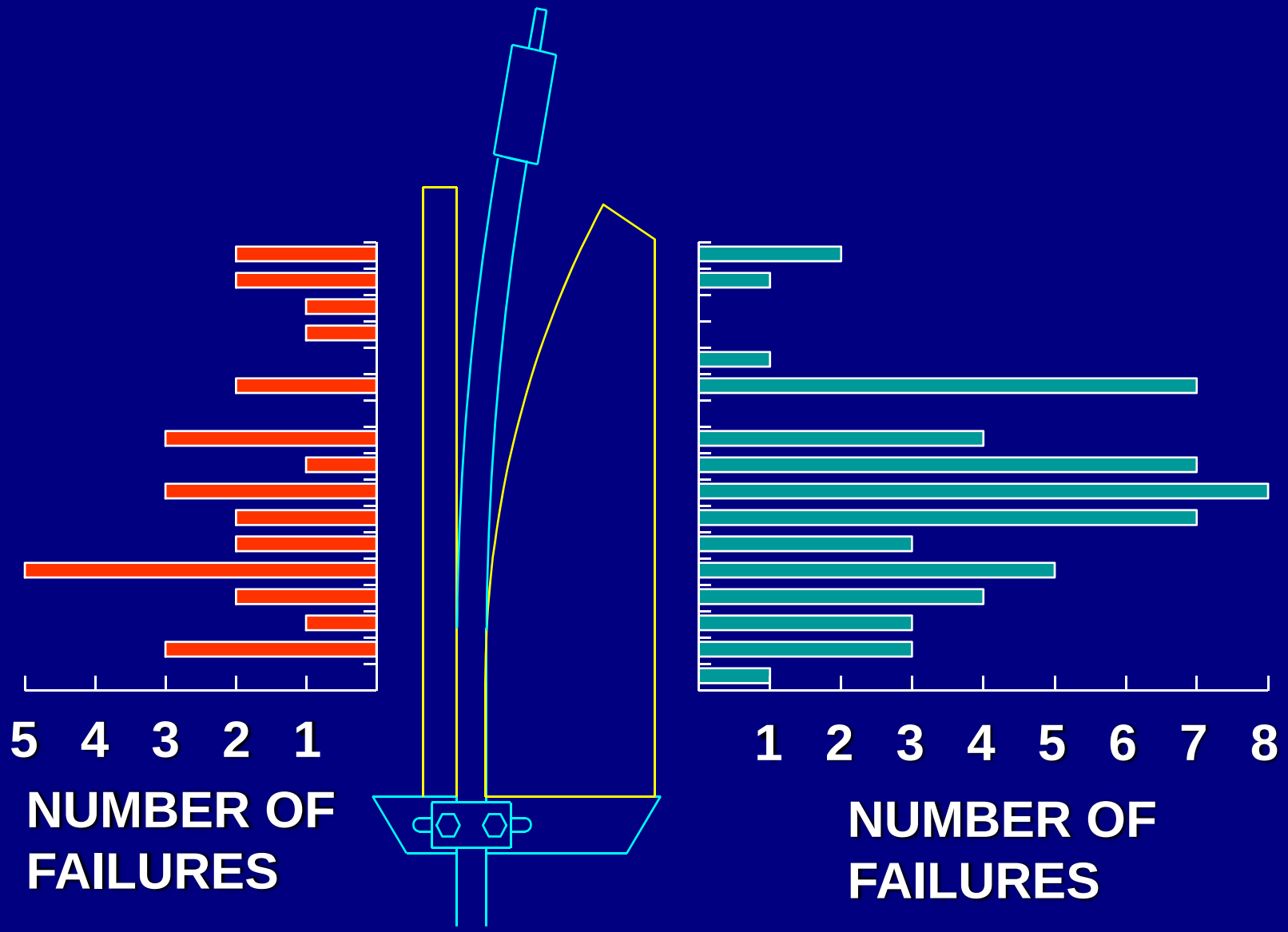


TU CT Fatigue Test Facility

Accelerated CT Fatigue Test Machine

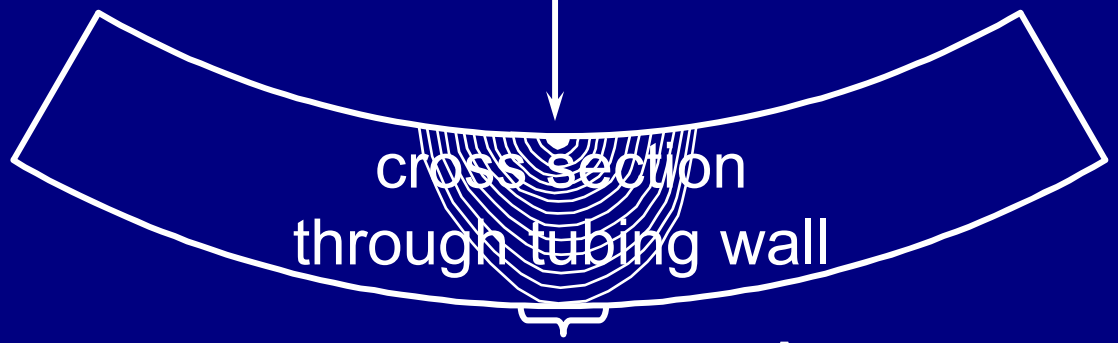


Fatigue Crack Development



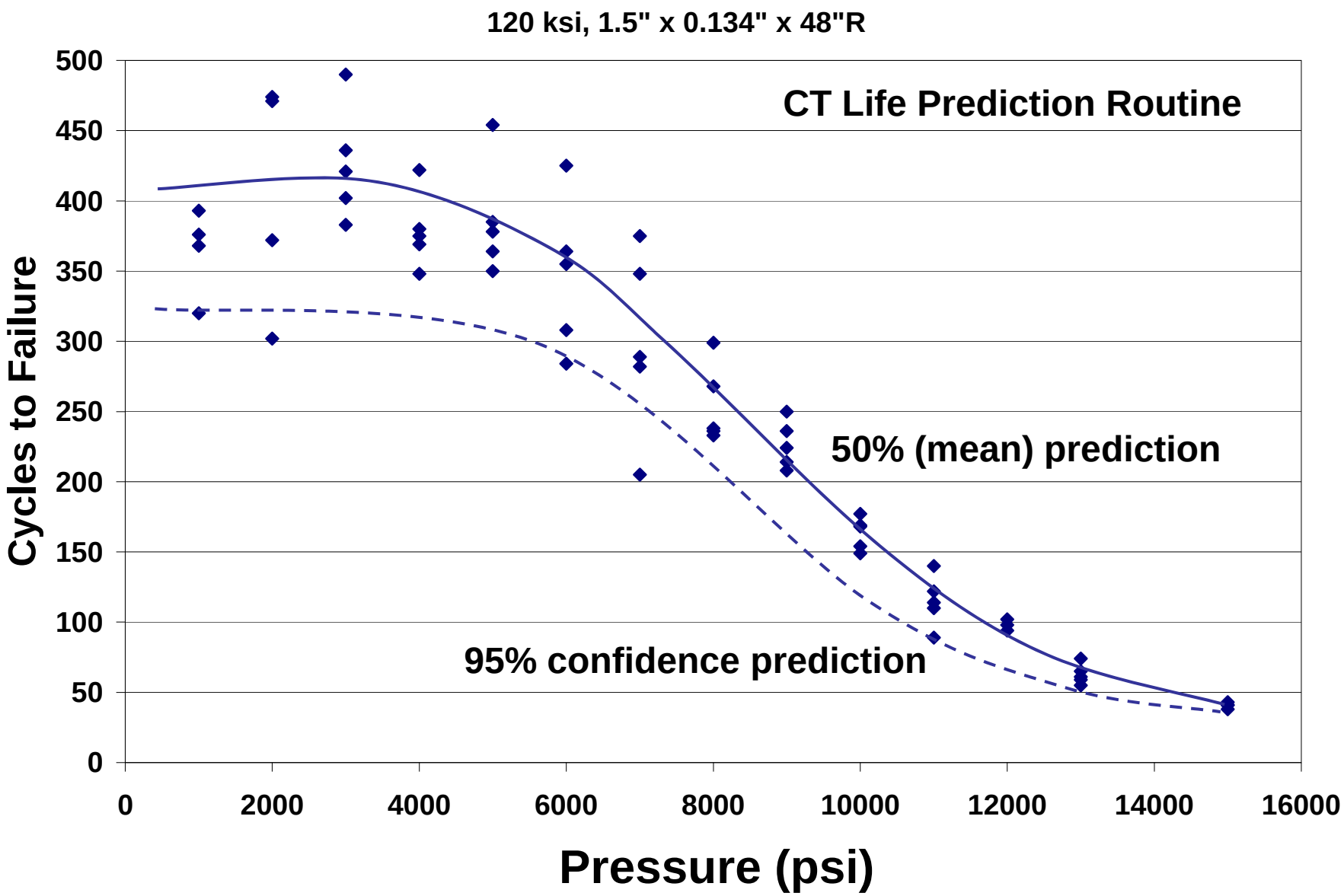
Fatigue Crack Development

MOST fatigue cracks initiate at the inner surface



Appears as a “pinhole” failure

Fatigue behavior of CT defies engineering logic!

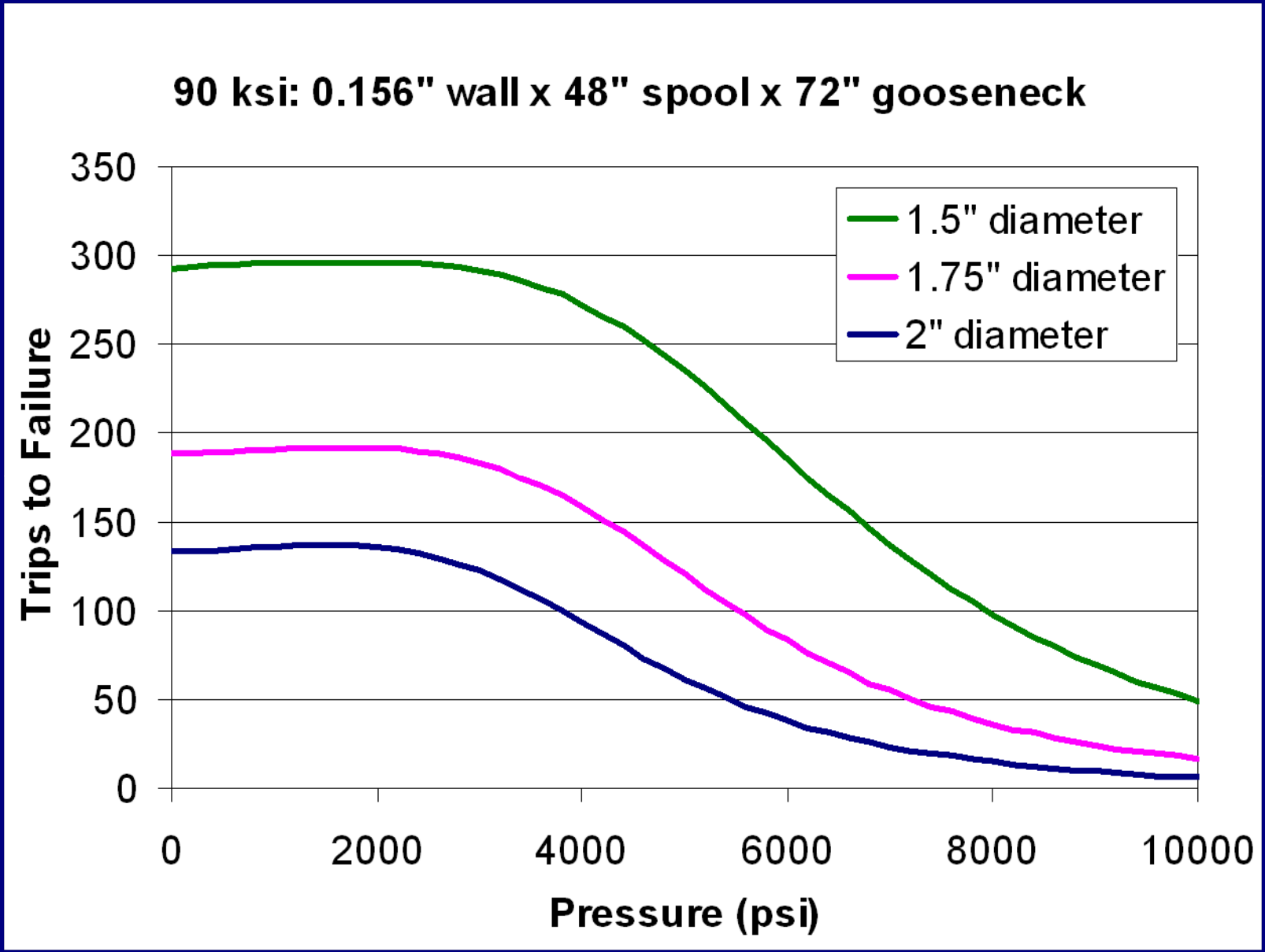

120 ksi, 1.5" x 0.134" x 48"R
CT Life Prediction Routine
50% (mean) prediction
95% confidence prediction
Cycles to Failure
Pressure (psi)
0
50
100
150
200
250
300
350
400
450
500
0
2000
4000
6000
8000
10000
12000
14000
16000

CT Life Prediction

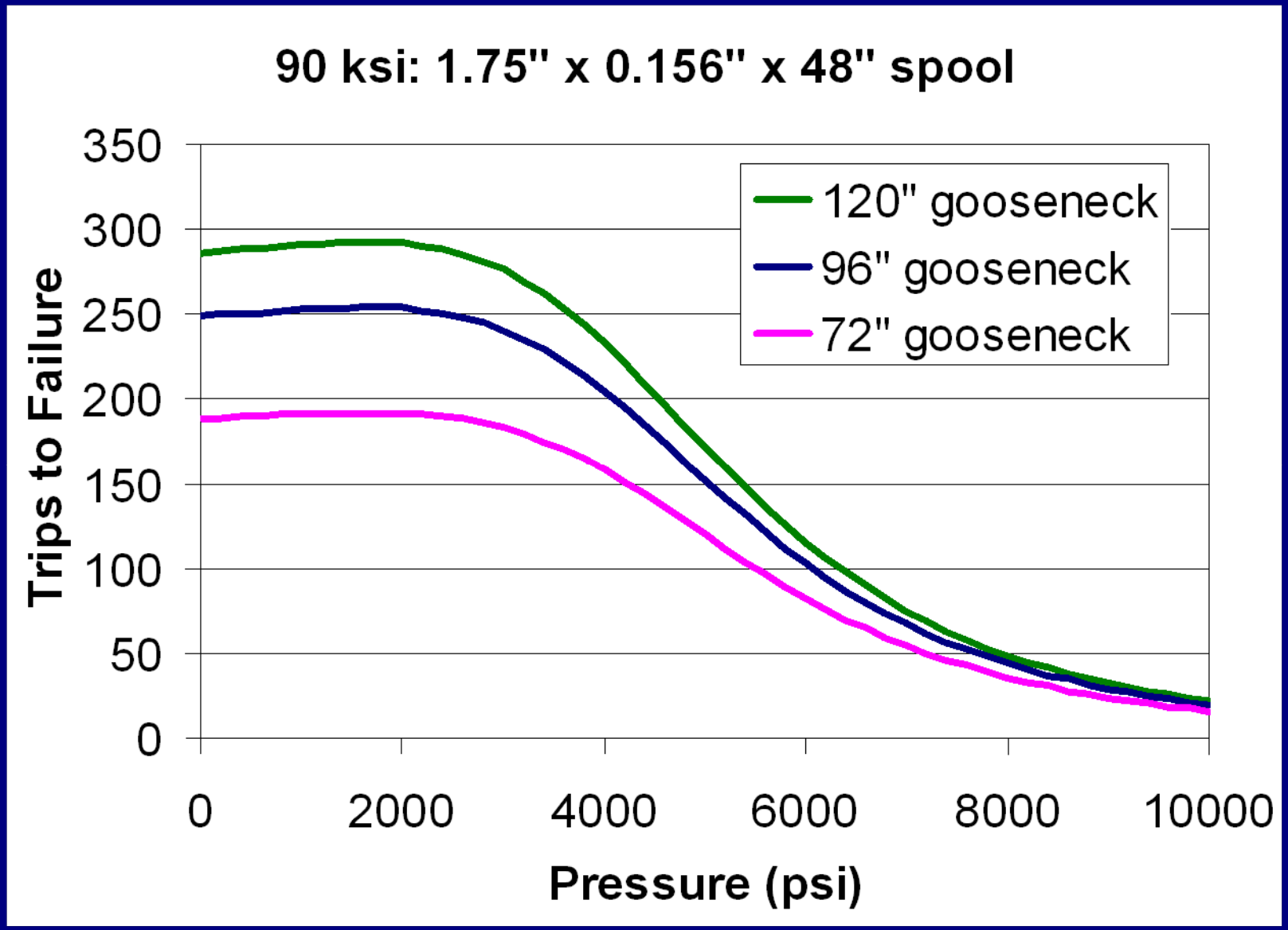
- Factors that influence life:
  - Diameter — Larger diameter – larger bending strains
  - Pressure — Higher pressure – higher tangential stresses
  - Wall Thickness — Thinner walls – higher tangential stresses
  - Bending Radius
    - Spool
    - Gooseneck

    Smaller radius – larger bending strains
  - Material Grade — 70 – 120 ksi

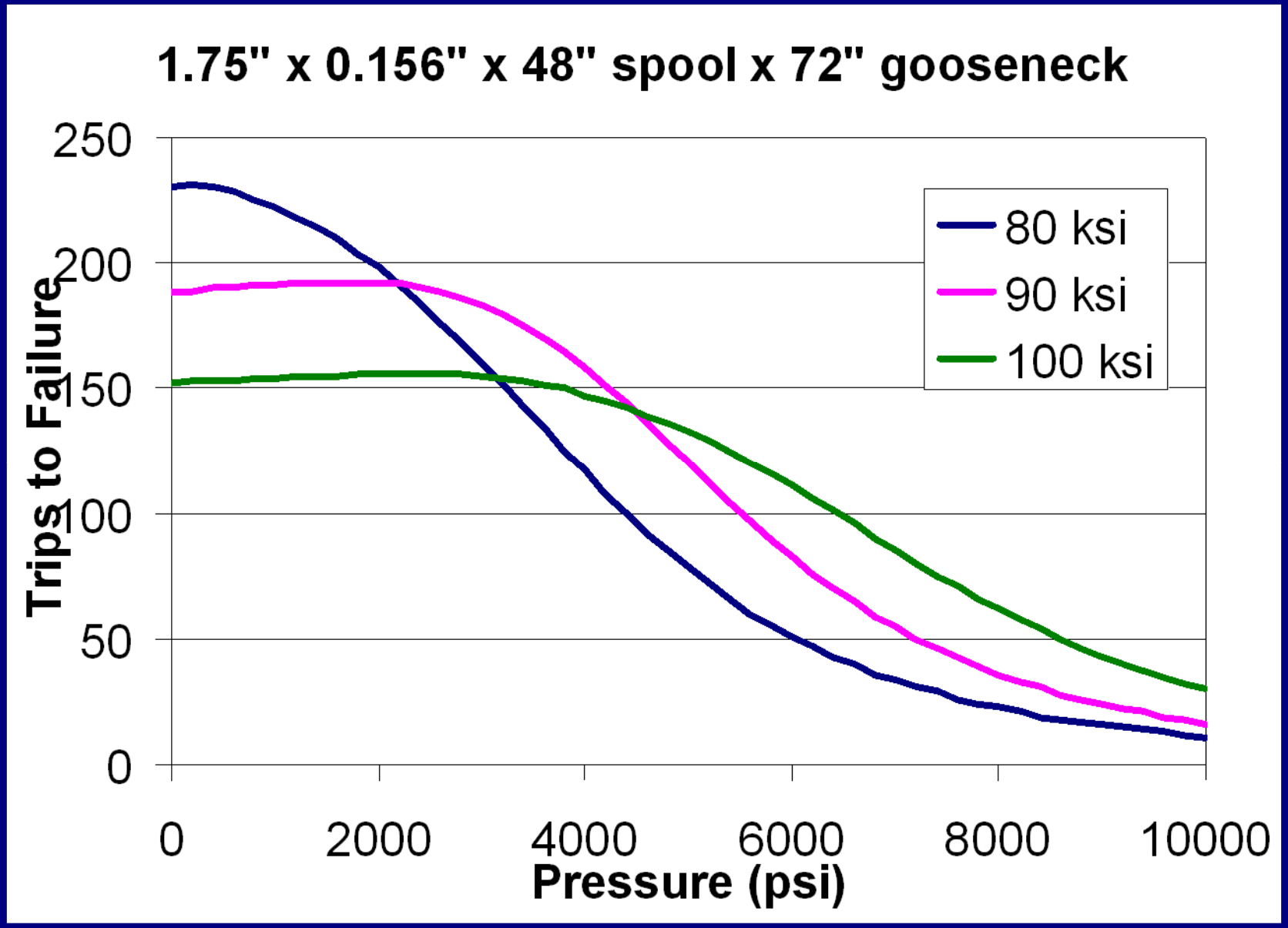
Effect of Tubing Diameter



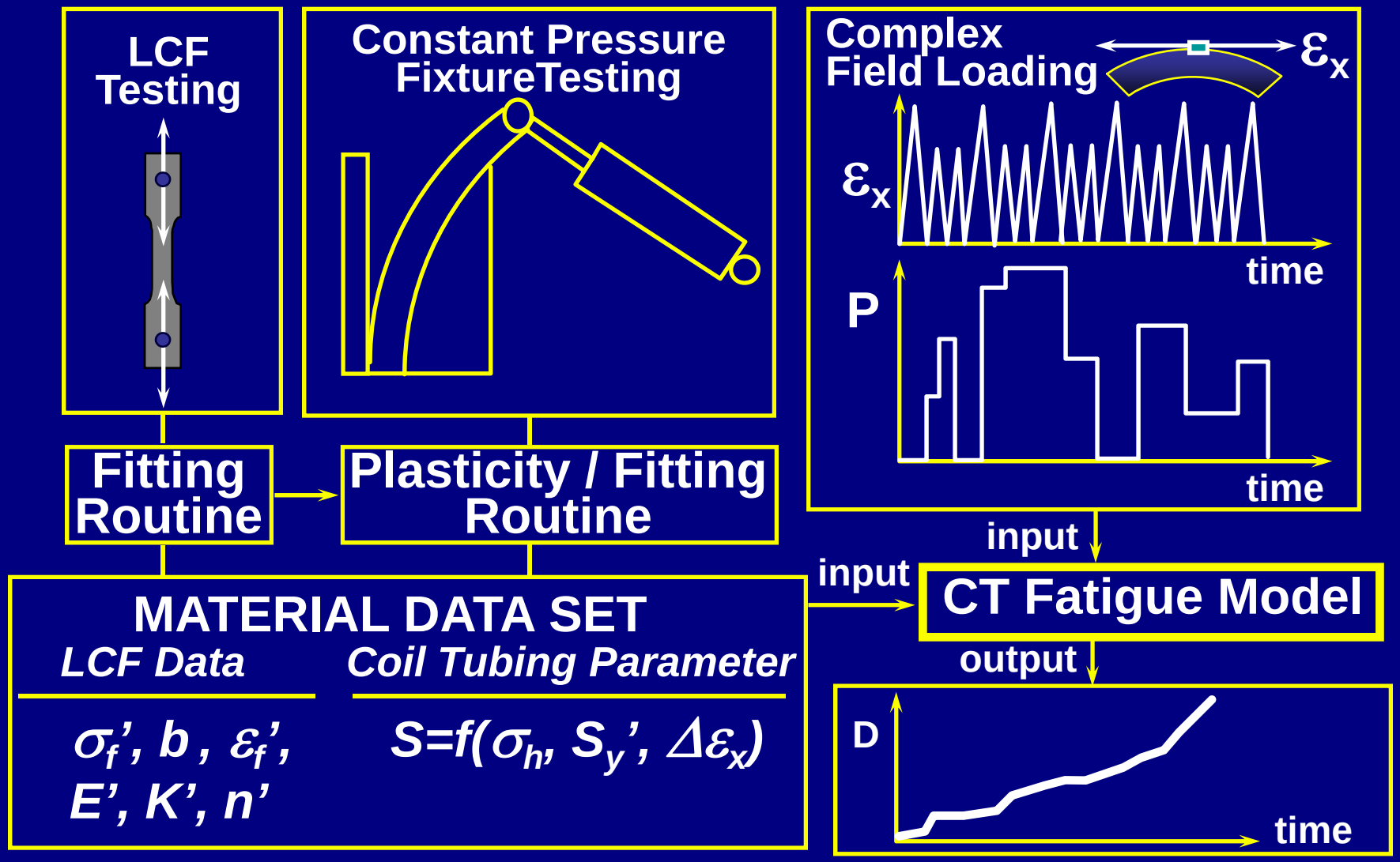
Gooseneck Radius of Curvature



Material Selection

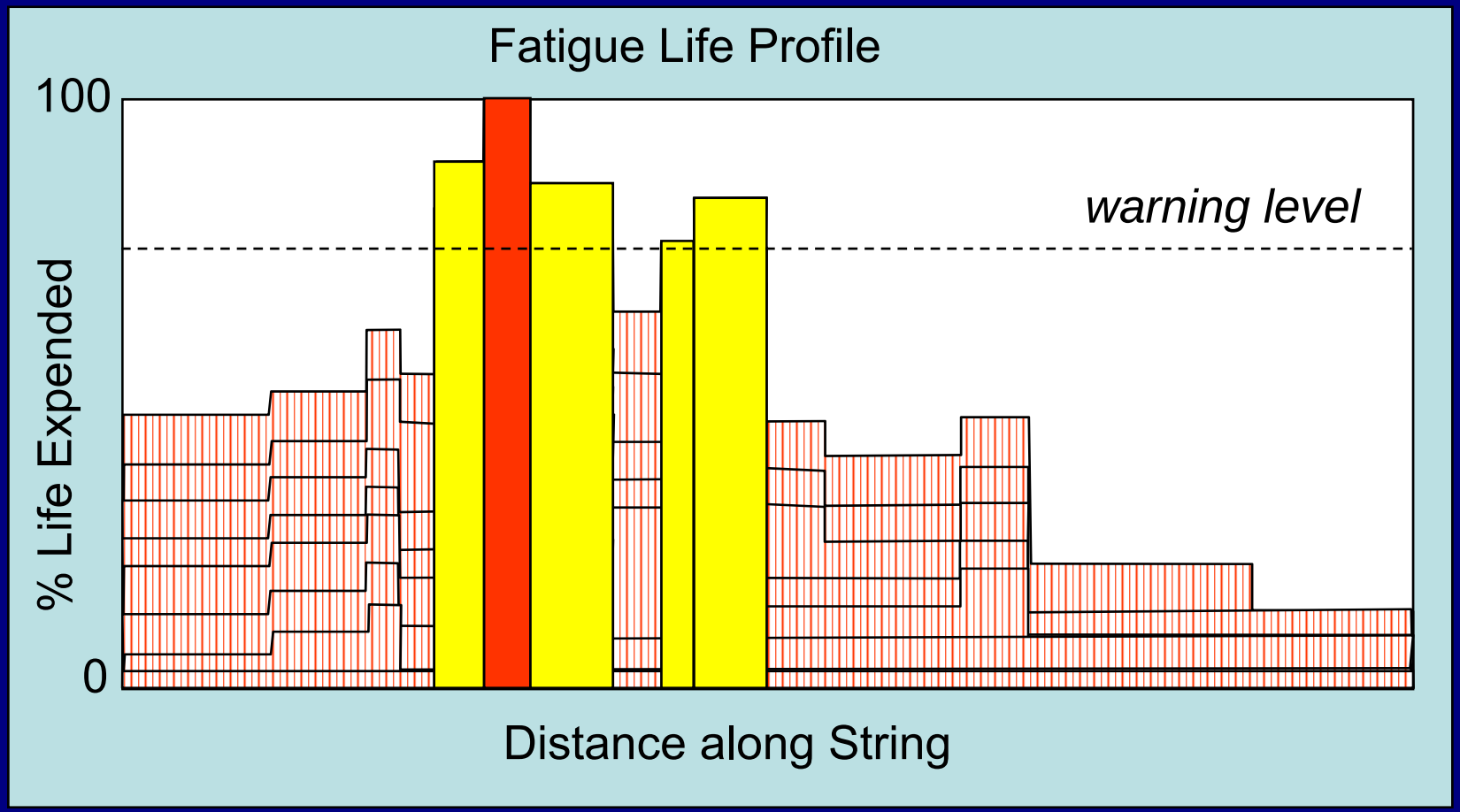


Fatigue Life Estimation



CT Life Prediction

- Implemented with String Management Software:

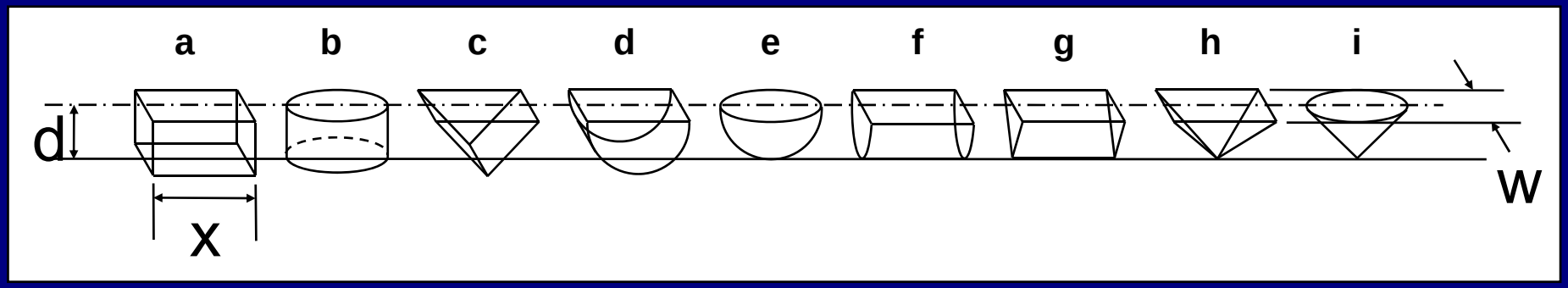


- Fatigue eliminated as a primary failure mode!

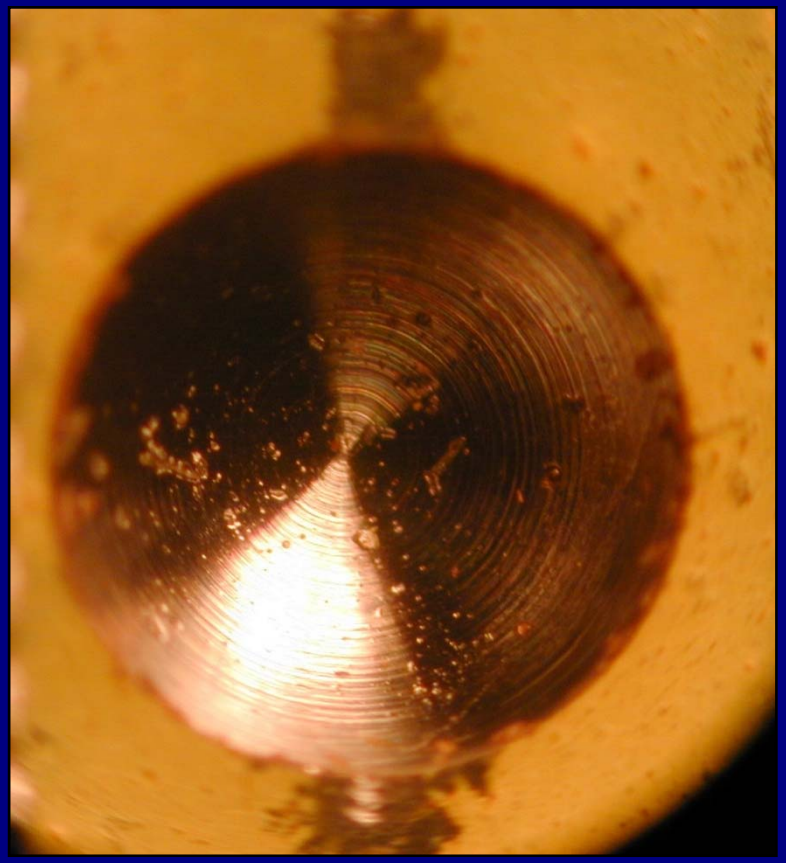
What About Defects?

Means of Imposition

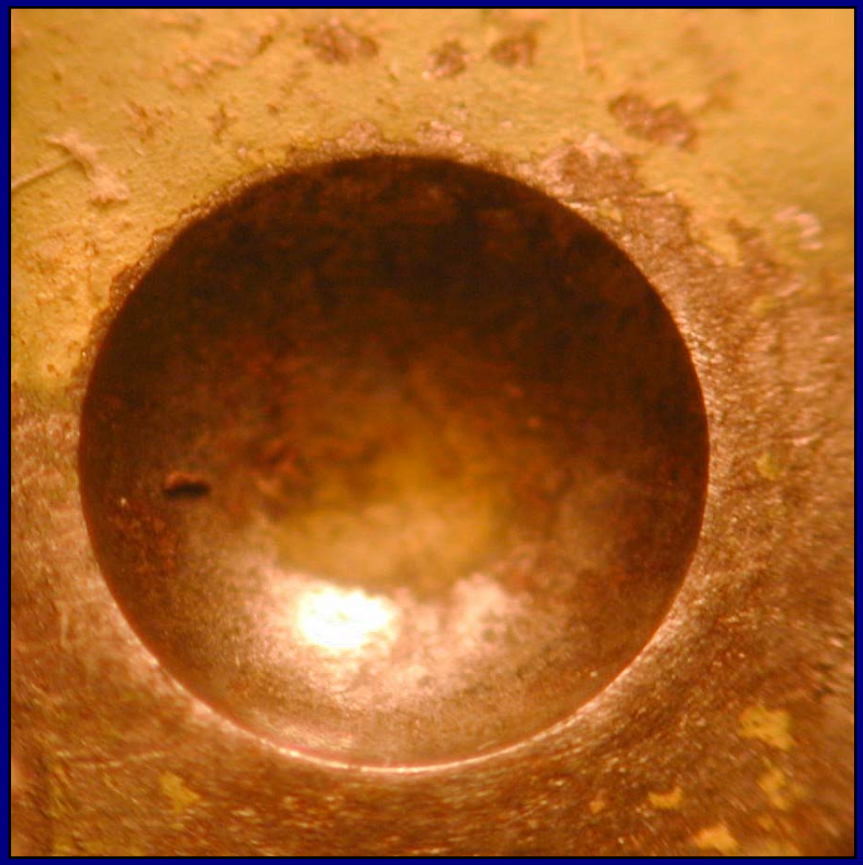
- Milling (cut into surface)
- Impressing
- Corrosion Pits (chemical milling)
- EDM – Different shapes possible



Means of Imposition

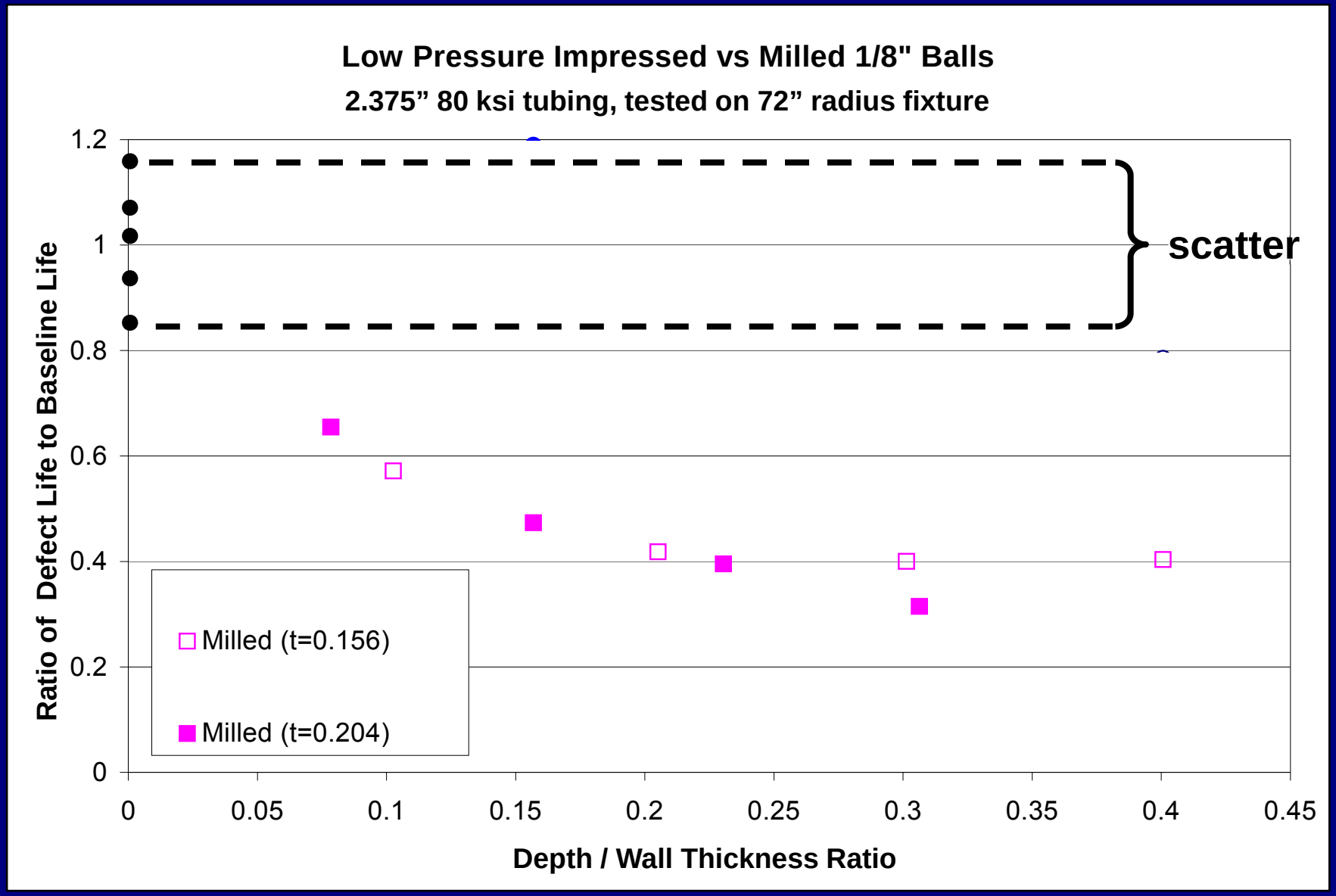


Milled Ball



Impressed Ball

Influence of Surface Defects

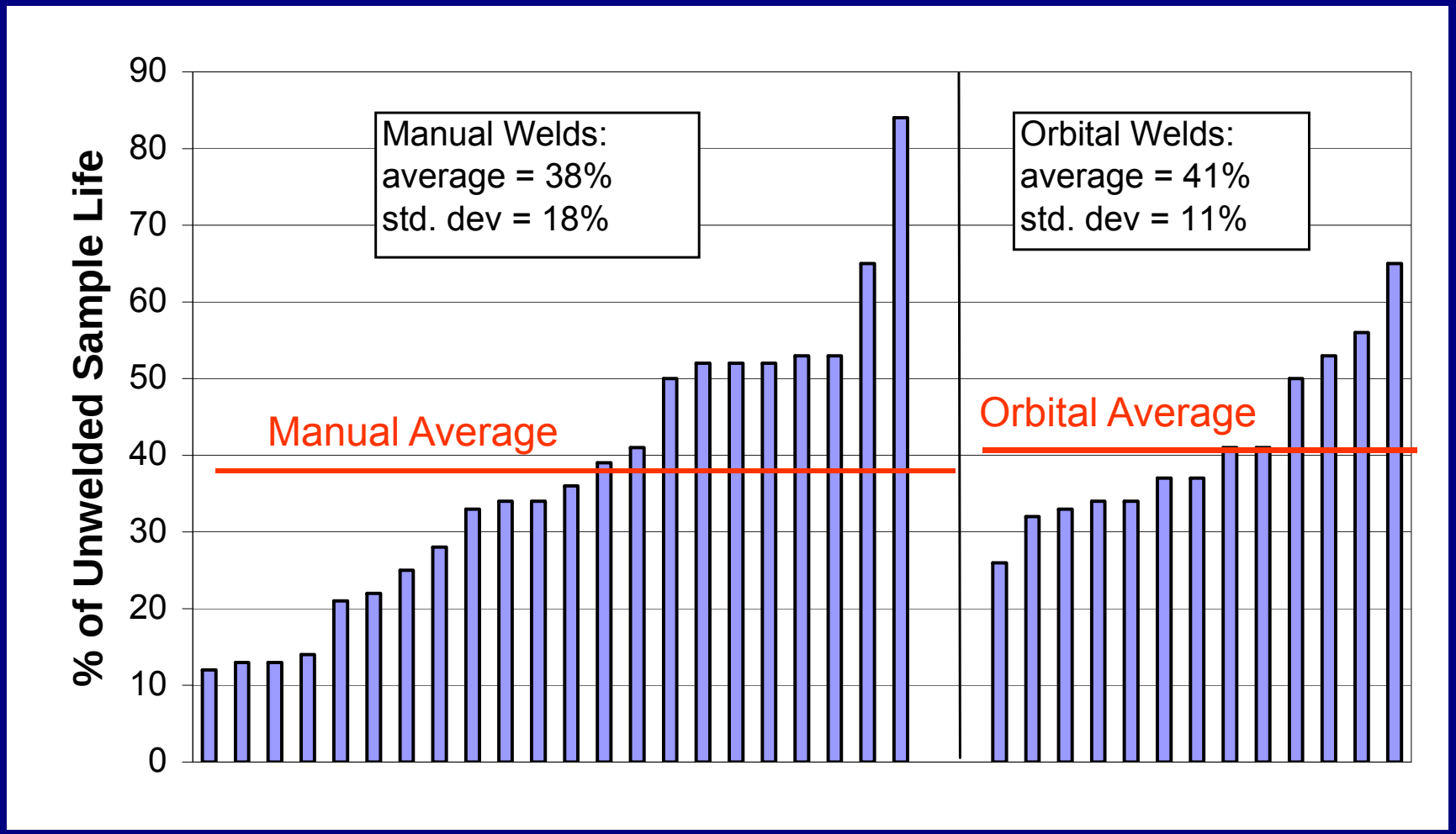


Repairing Defects

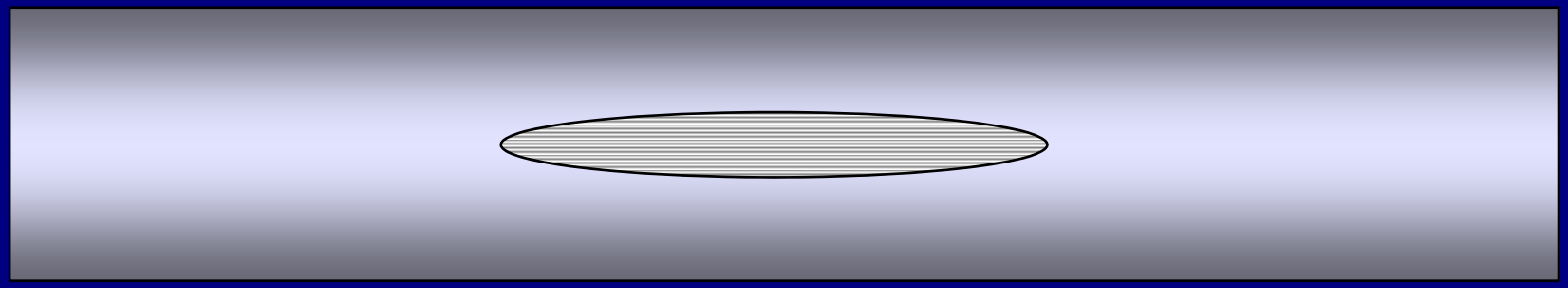
- What happens after a defect is discovered?
  - Scrap / Replace string (expensive)
  - Cut and splice (welding – expensive)
  - Grind repair

Repairing Defects
One Option: Butt Welding

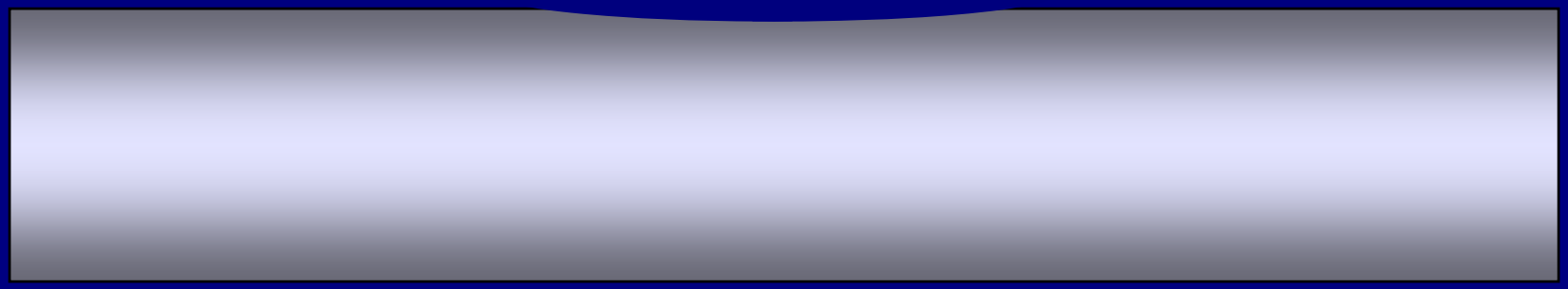
Butt Welding Fatigue Data



Grind Repairing

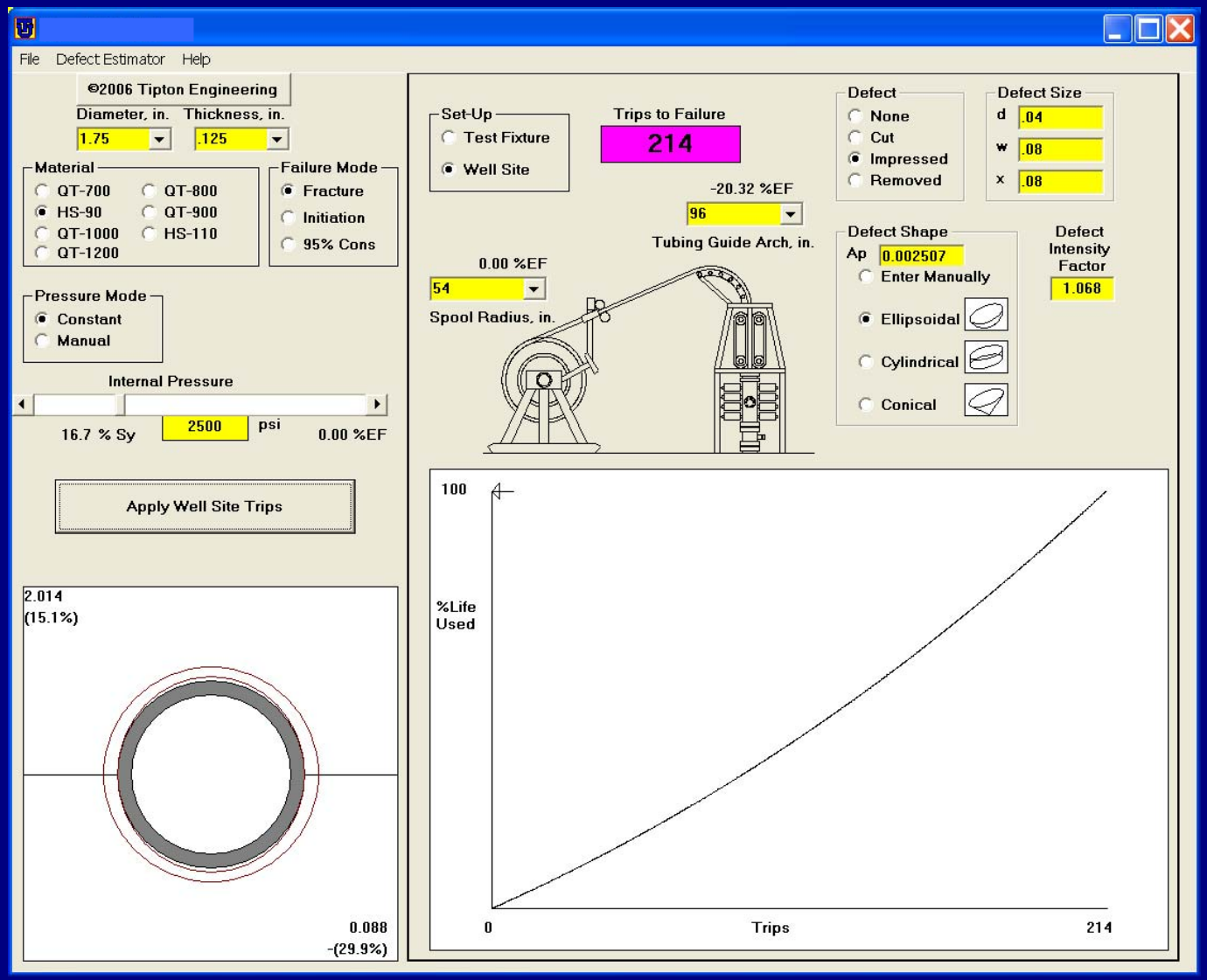


replaced with
Abrupt, localized discontinuity
smooth, gradual thickness change



Technique is important and grind repair guidelines have been developed

Fatigue Life Predictive Model



No defect: 229

Cut defect: 76

Repaired: 129

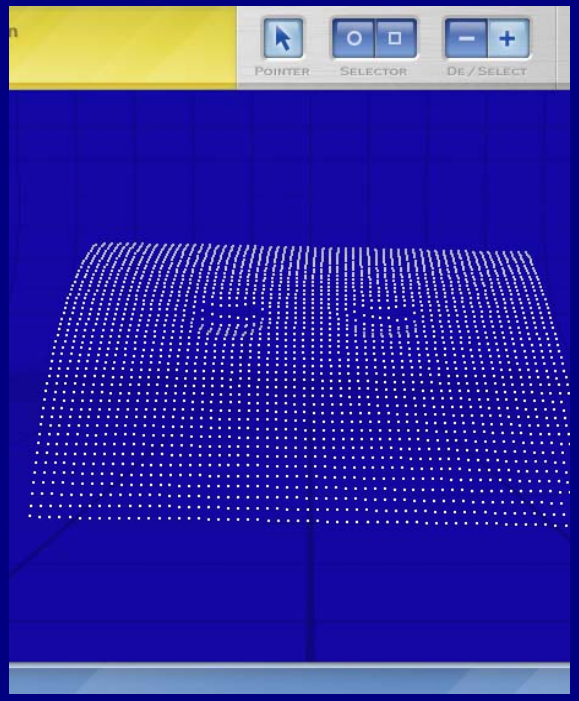
Impressed: 214

Defects Must be FOUND

- Visual Inspection
- Magnetic Flux Leakage
  - Most popular approach for CT inspection
  - MFL can only DETECT defects
  - Can’t provide any information about defect size or severity
- 3D Laser Imaging for NDE
  - Complete geometry of defect is captured digitally

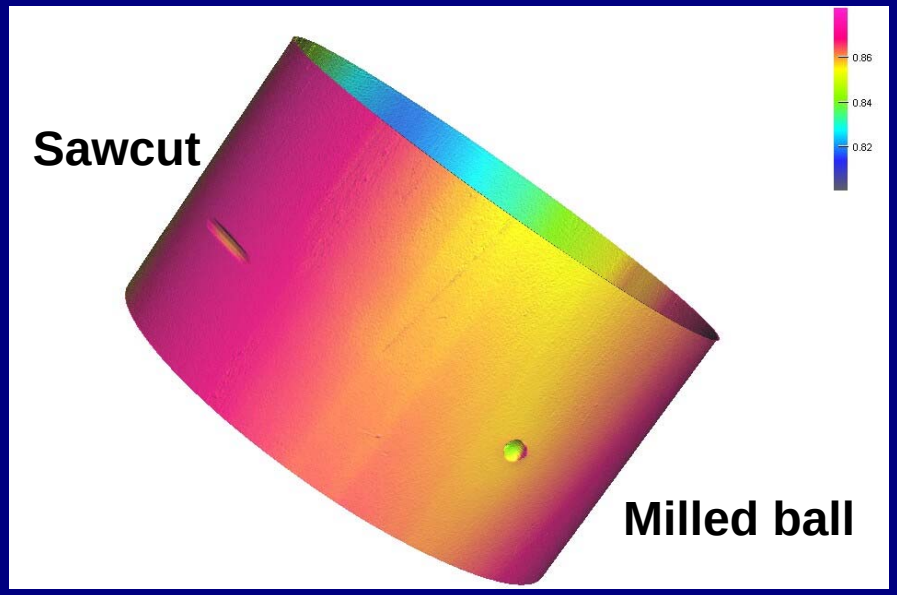
3D Laser Imaging System

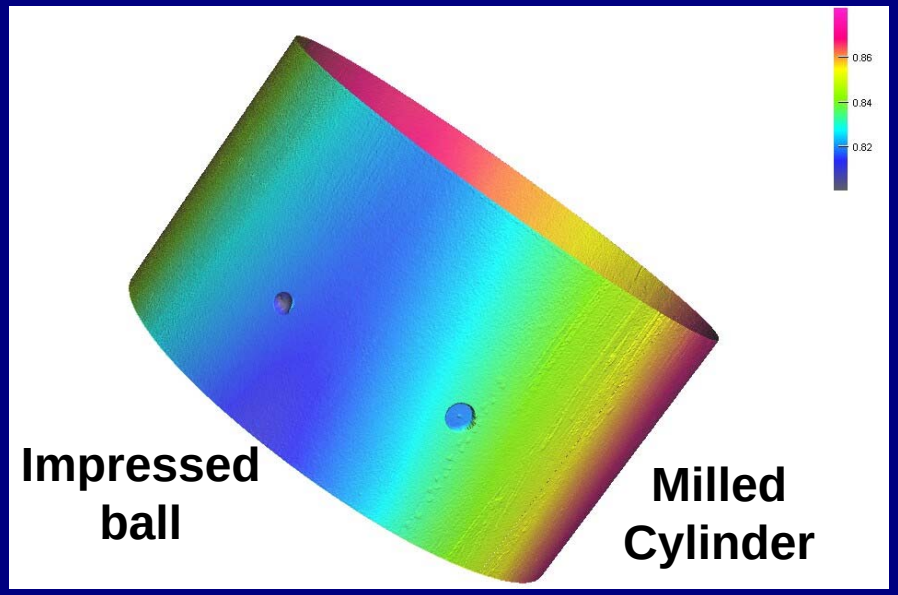
(Low-Cost)



Longitudinal Milled Defect

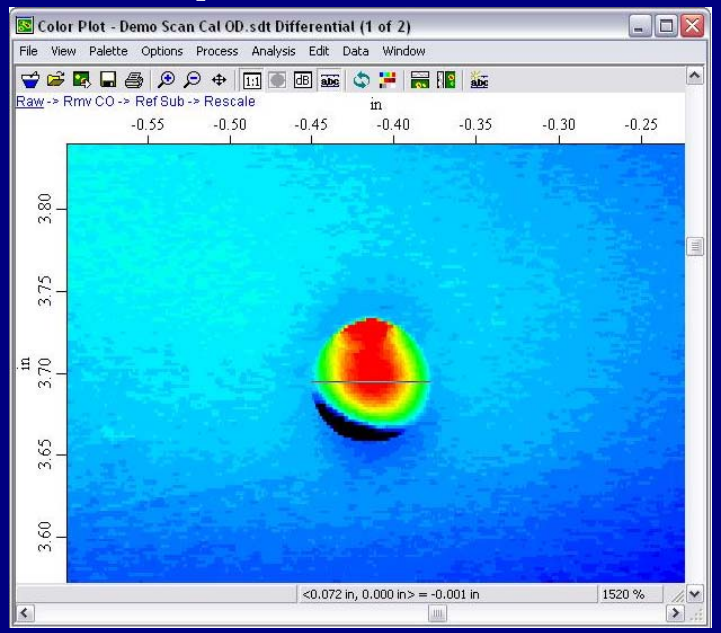
Commercial Laser System



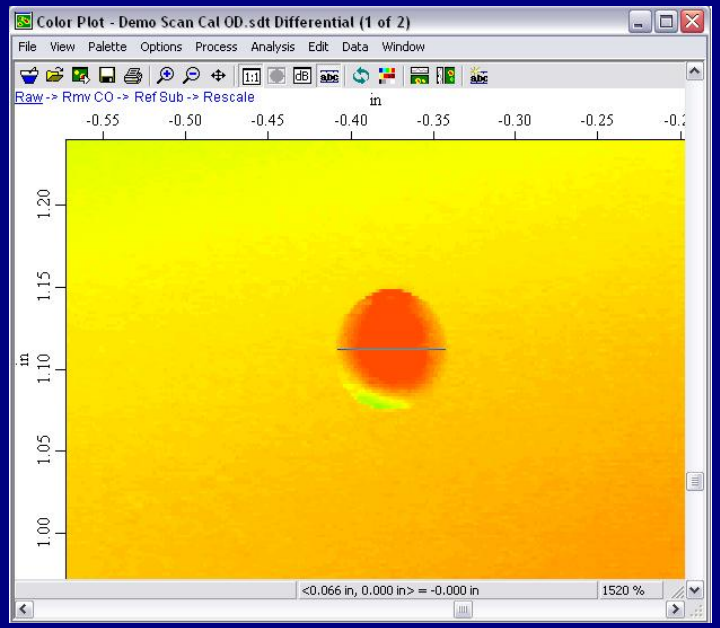


Color-coded Digital Data

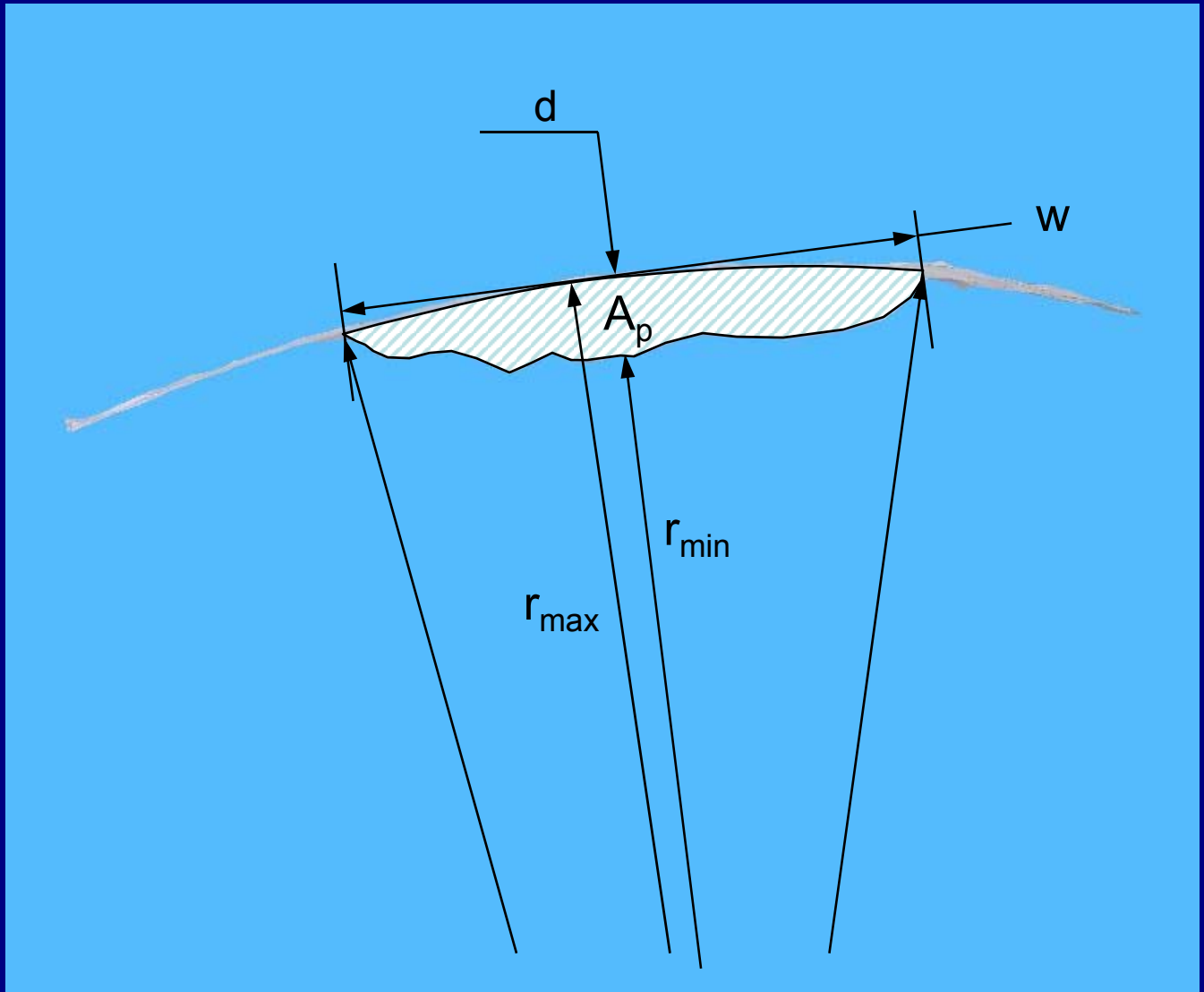
Impressed ball



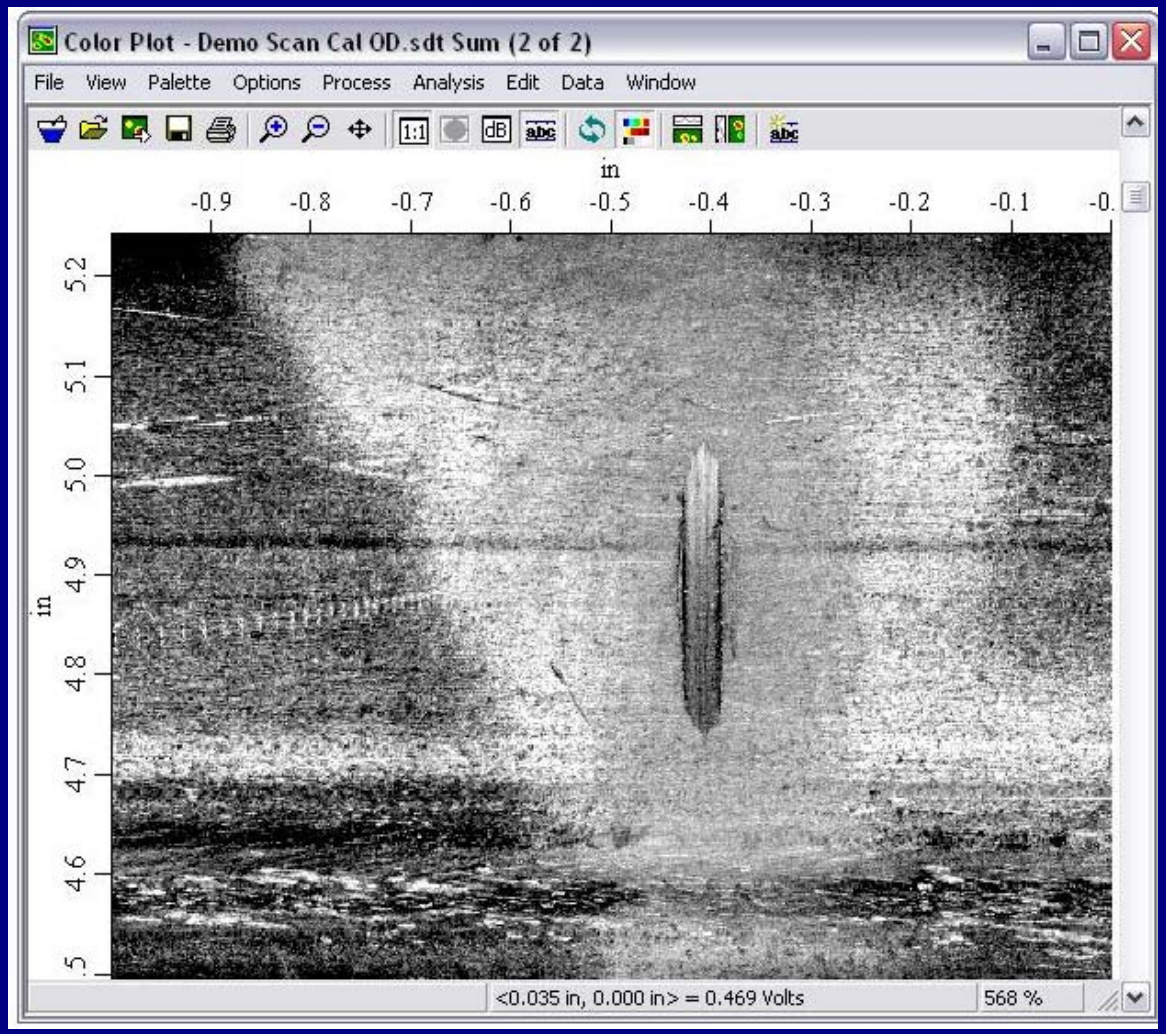
Machined ball



Automated Defect Measurements



Color-coded Digital Data & Photographic Image



Useful to distinguish cut or impressed

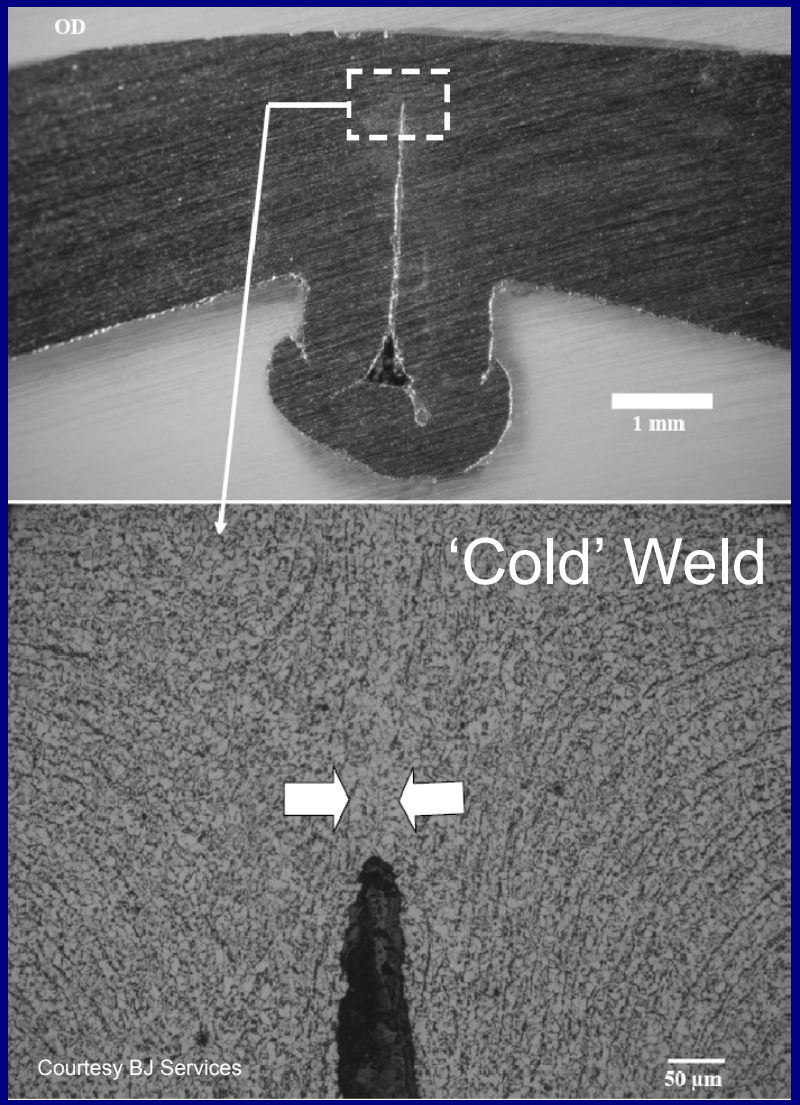
Sour and Corrosive Environments

- Similar effects: CT to Pipe
  - H2S
    - HIC (Hydrogen Induced Cracking)
    - SSC (Sulfide Stress Cracking)
  - SCC (Stress Corrosion Cracking)

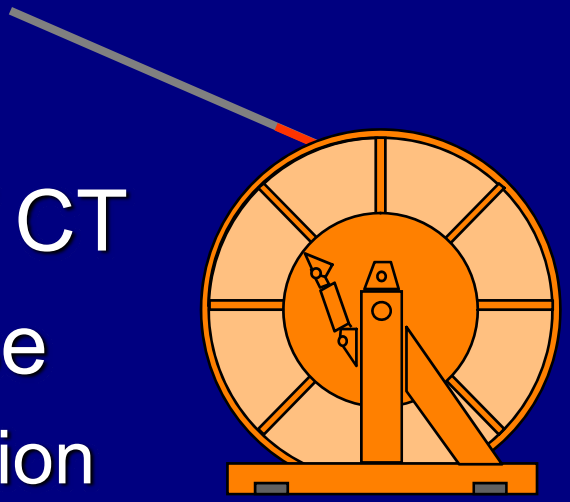
- Residual Stresses
  - Accelerates Corrosion

Manufacturing and Materials defects/flaws

- From 7 to 20 reels per 1,000 reels (~last 3 yrs)
  - –0.7 to 2%
  - –Only Those Reported
- Failures occur that are not fully investigated
  - –Especially later in CT Life



Conclusions



- Fatigue is inherent to the use of CT
- Large CT Bending Strains Cause
  - Fatigue, diameter growth, elongation
- Scatter is Associated with Fatigue Data
- Fatigue Software can Predict Influence of
  - Material, diameter, wall thickness, bending radius, internal pressure, statistical scatter, defects, grind repairs
- Field Monitoring Software used to Assess Every Section of Tubing Along the Entire String – Avoids failures in the field

Conclusions

- Defects can have first order influence (cut)
  - Or negligible influence (impressed)
- Repairing by Grinding is a viable option
- Software helps to quantify defect severity (and effectiveness of a grind repair)
- 3D Laser Scanning
  - Holds the potential to detect defects
  - Capable of measuring every detail about their geometry

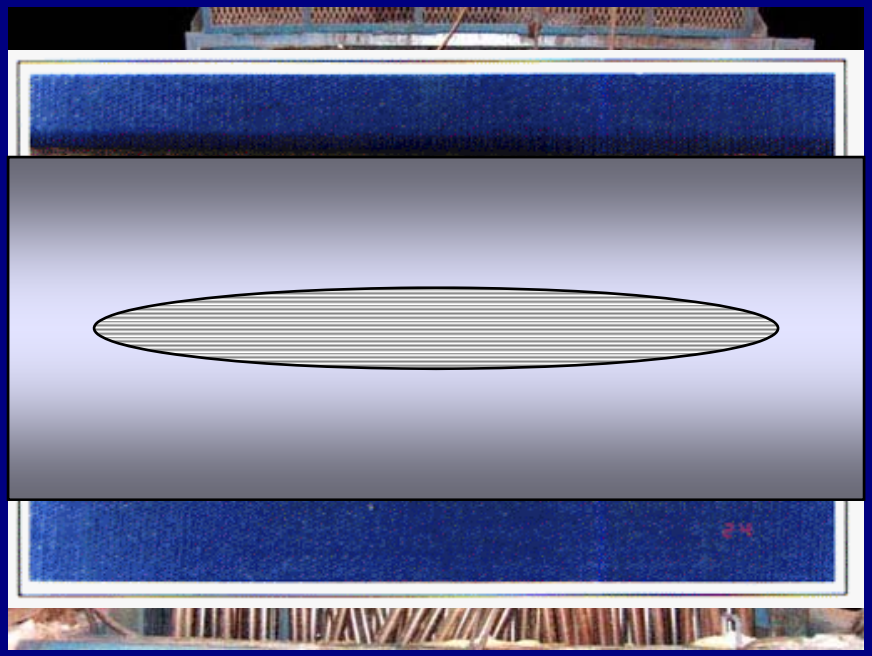
Conclusions

To Avoid Failures on Your Job .... or In Your well:

- Control the Factors that Contribute to Fatigue Damage Accumulation
  - Minimize tubing diameter
  - Maximize spool and gooseneck sizes
  - Select material most suited for application
  - Minimize tripping
  - Minimize tubing movement with high pressure

Conclusions

- Avoid Defects
  - Eliminate sources of defects - handling, injector debris…
  - Monitor/Inspect
  - Environmentally Induced Cracking
    - Storage corrosion
  - Repair shallow defect using grind repair techniques



Why Coiled Tubing Succeeds and How to Assure Success on Your Job ... in Your Well

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