Quench and tempered technology in challenging CT shale operations

October 24th, 2018

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Improved Reliability in Shale Plays

1. What is the current performance of Q and T?
2. What failure modes continue to shorten life?
3. What are the improvements?
4. What do we need to focus on?

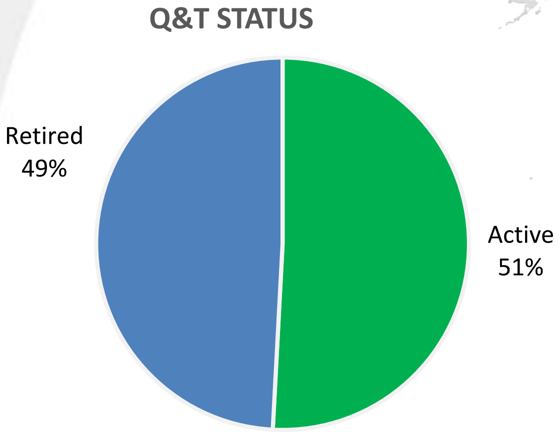
Improved Reliability in Sealy Wells
How do we Evaluate Quality in Every Pull?

1. What is the current performance of Q and T?
2. What failure modes continue to shorten life?
3. What are the improvements?
4. What do we need to focus on?

Q&T Shipments

As of **October 2018**:

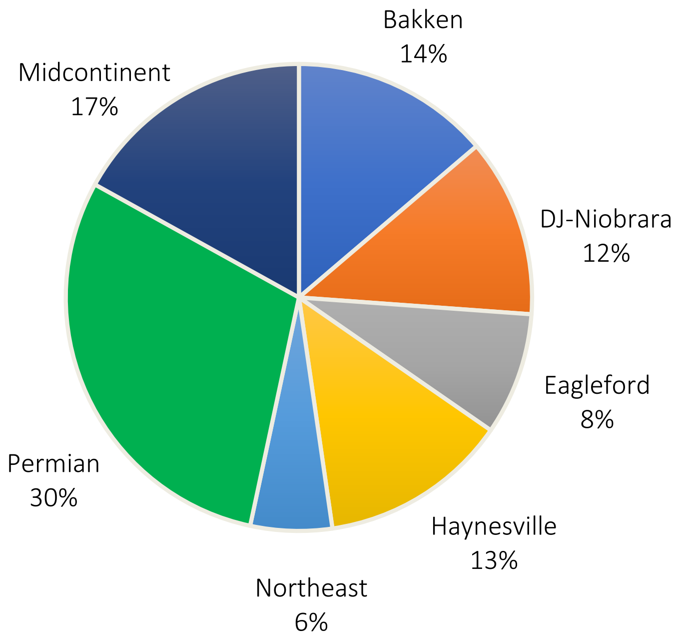
9.8 million feet (3000 km) of Q&T shipped worldwide



Q&T Commercial Release

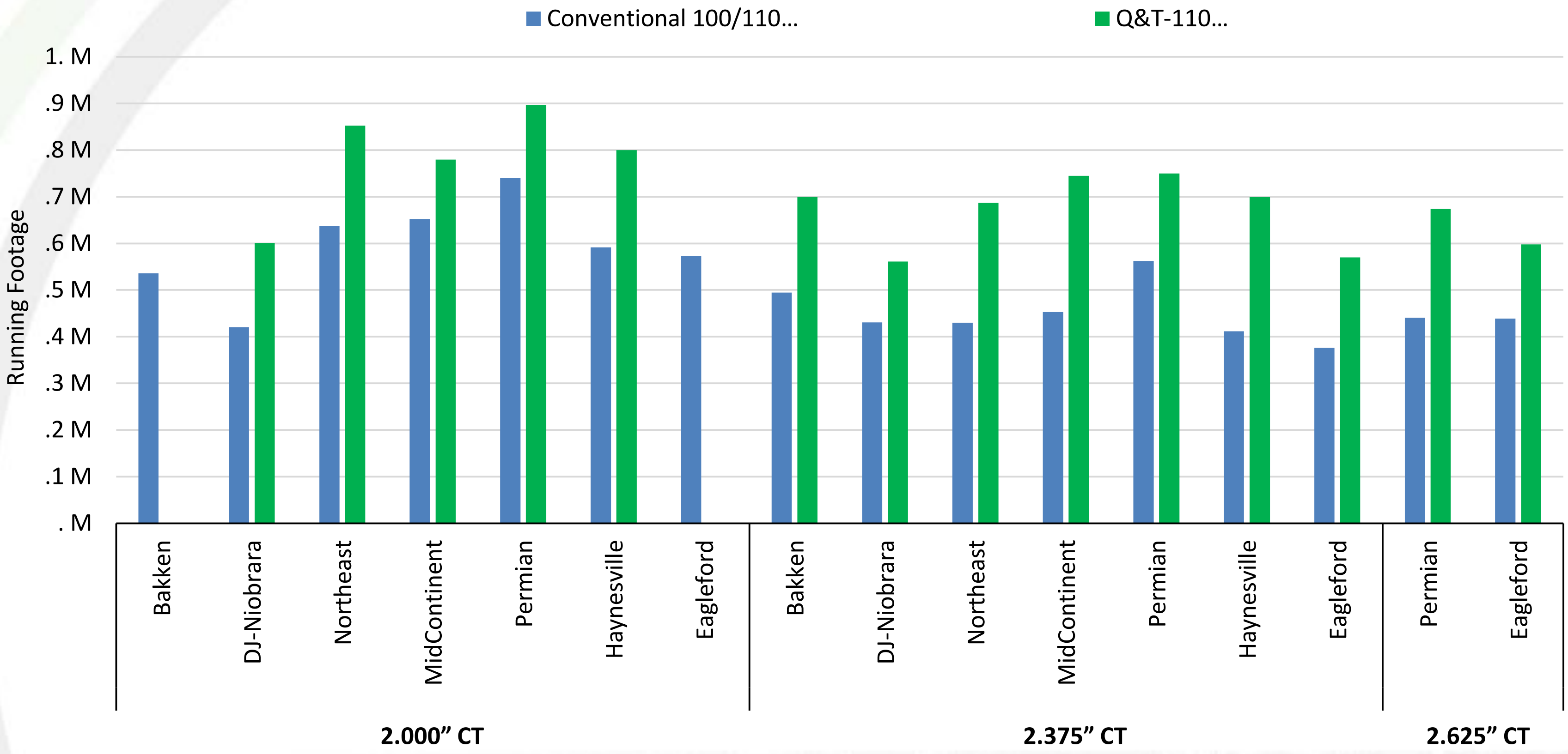
90% of US orders converted to a Quench and Tempered Product

SHALE PLAY DISTRIBUTION

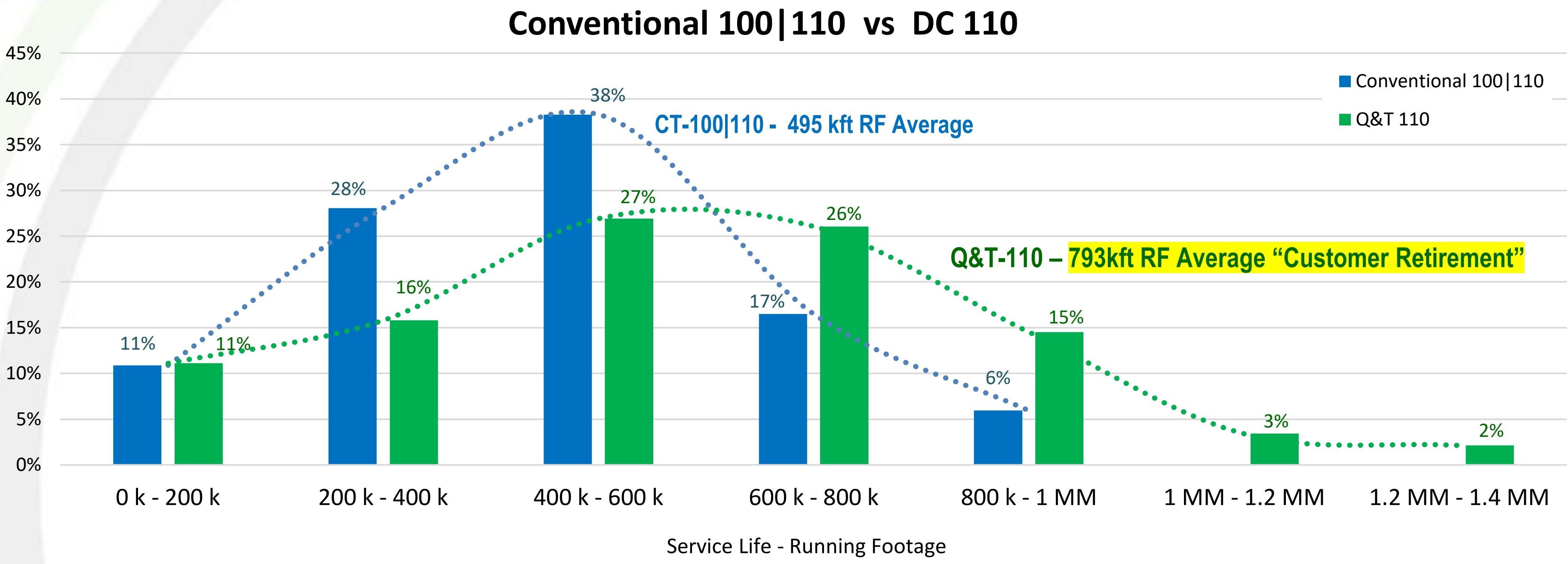


Q&T North America Field Performance

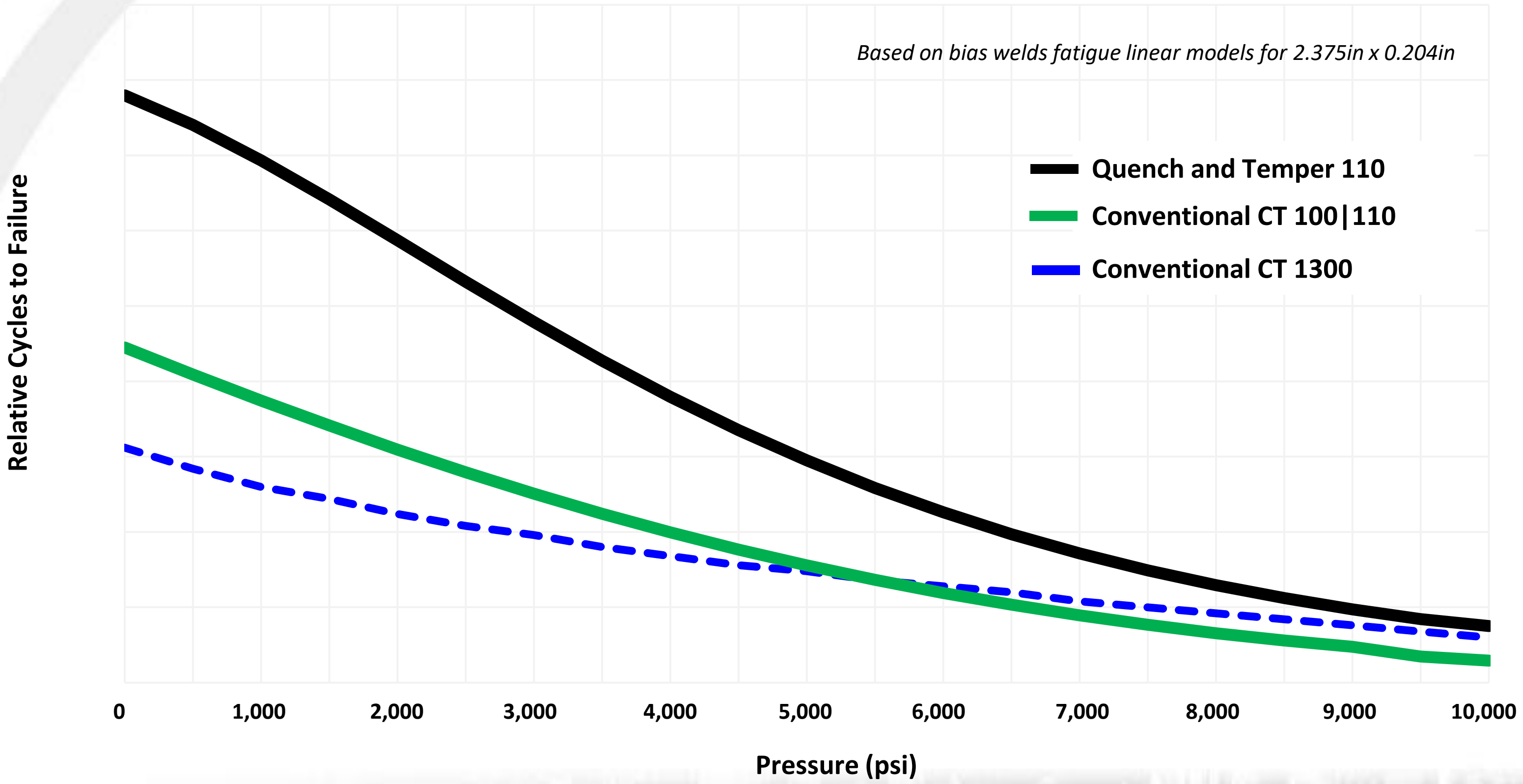
Avg. 54% RF increase NAM



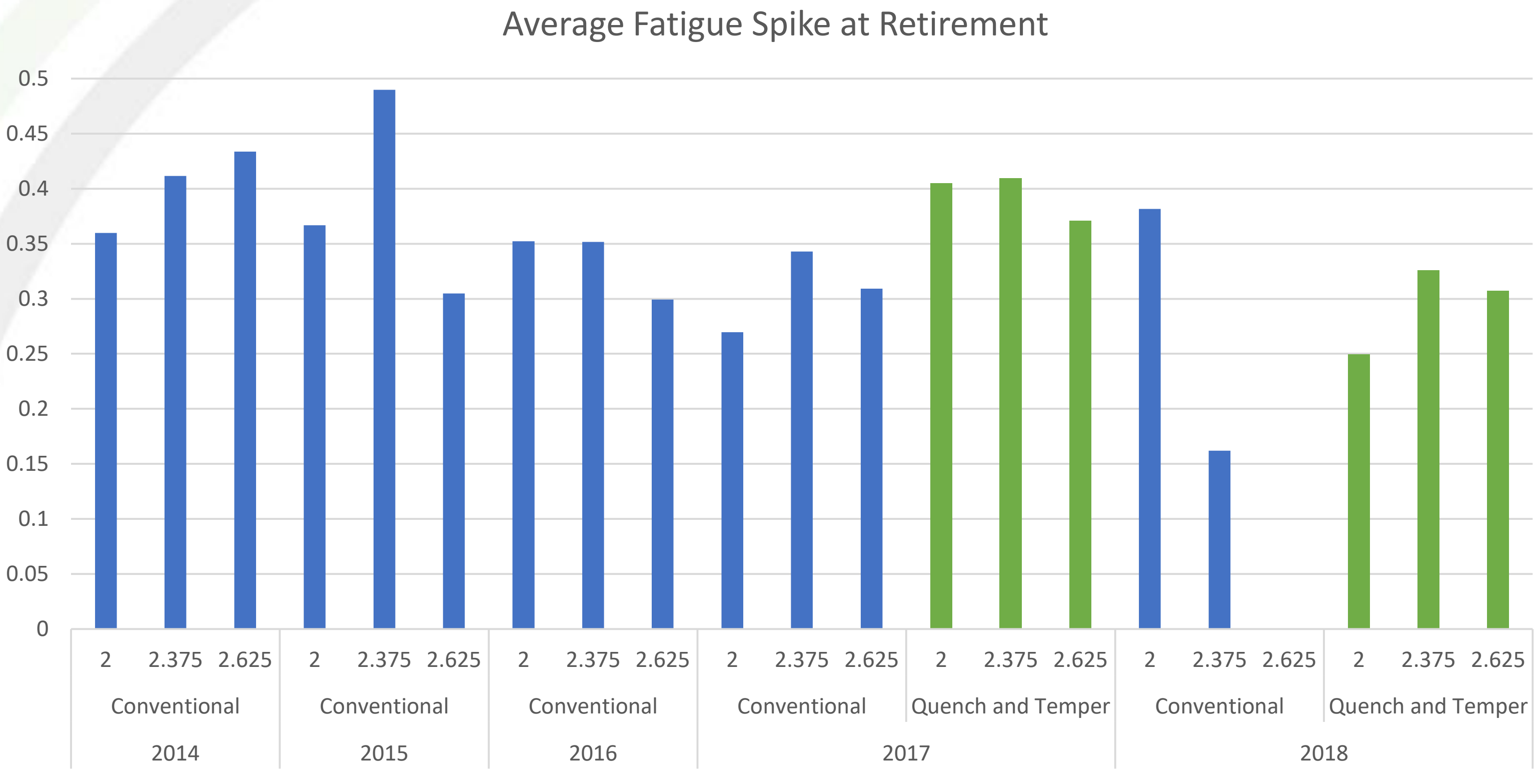
Quench and Temper-North America Field Performance



Q&T Fatigue Model Development vs. Competition



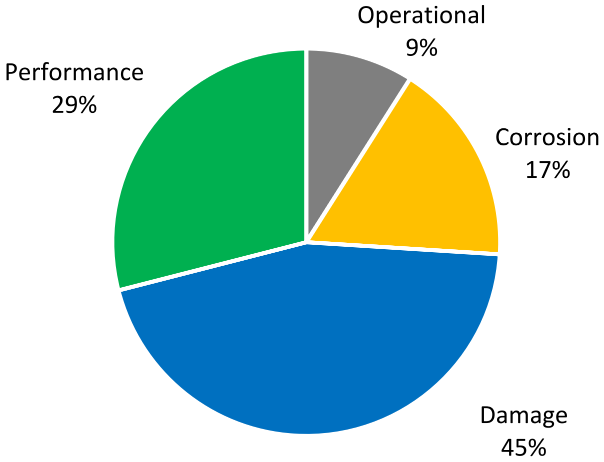
Q&T North America Field Performance



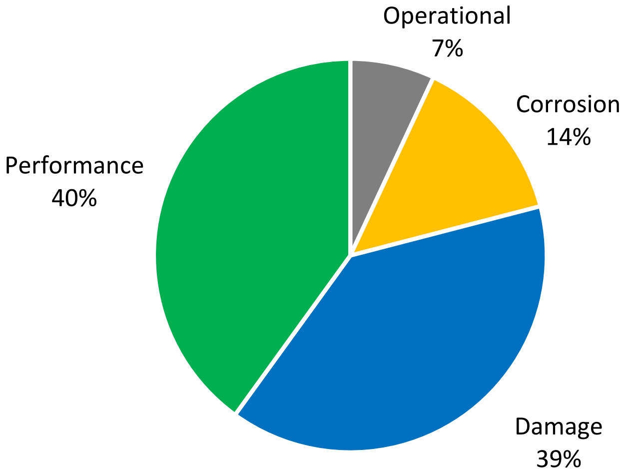
Failure Modes

Q&T Retirement Mechanisms

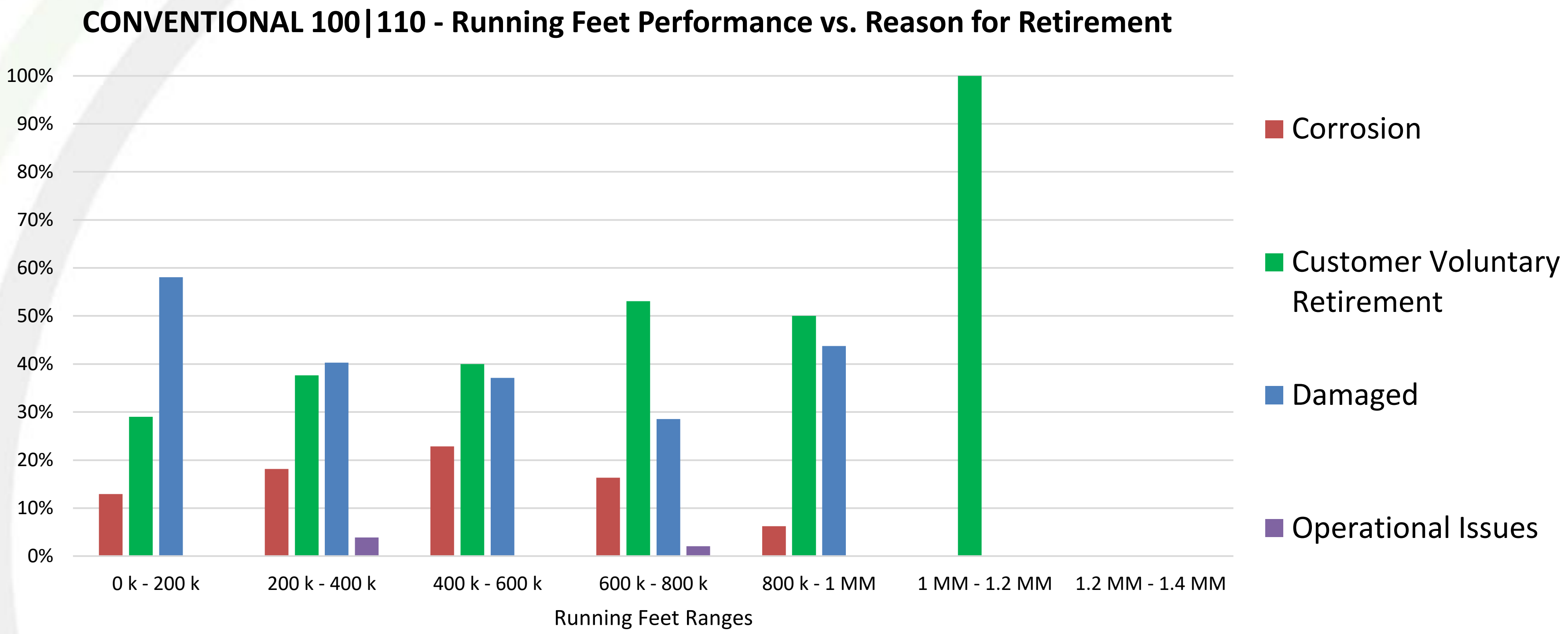
CONVENTIONAL GRADE



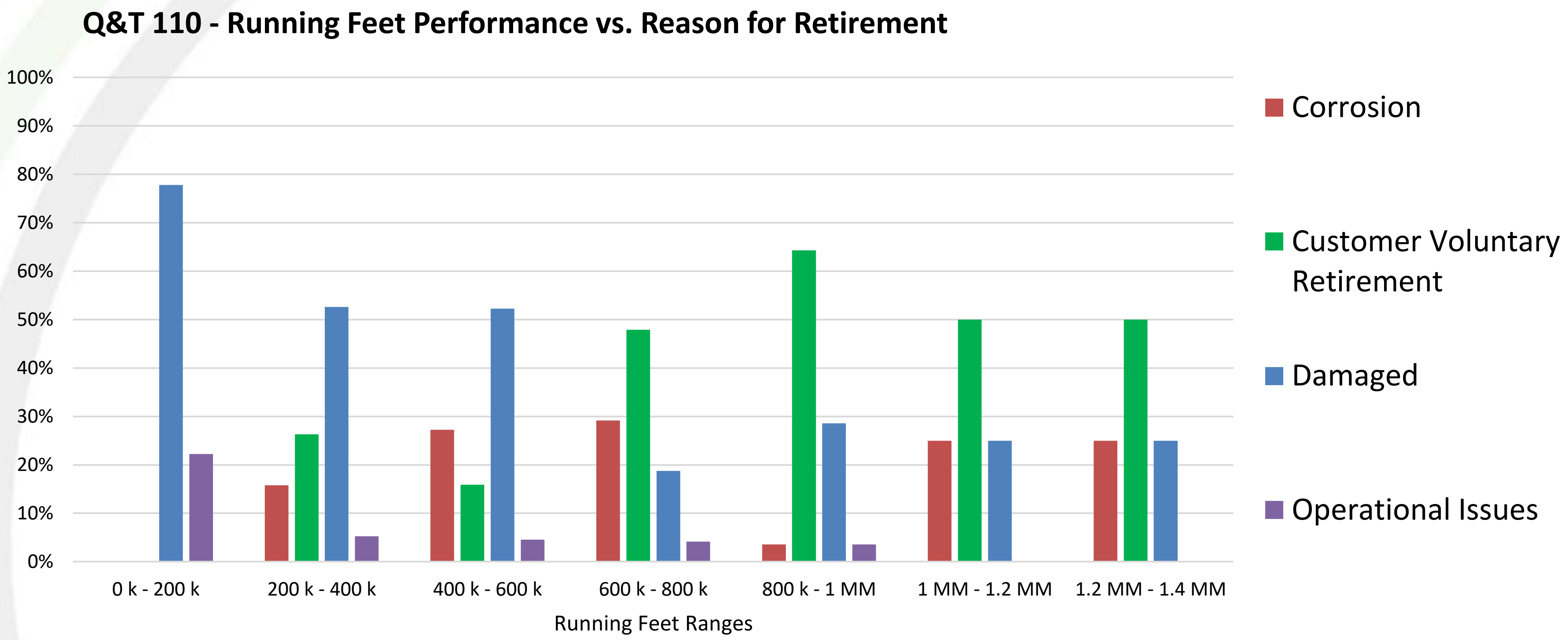
Q&T 110



Conventional Tube Retirement Mechanisms



Q&T Retirement Mechanisms



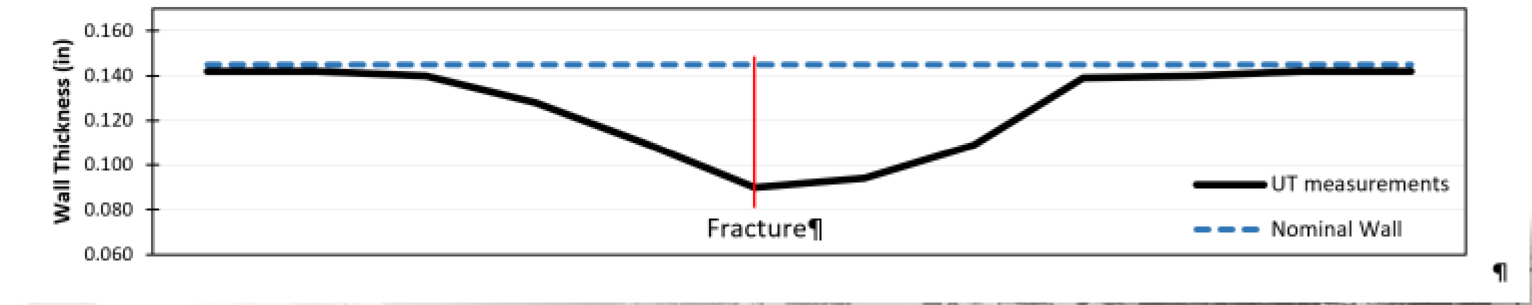
Mechanical Damage

Q&T Retirement Mechanisms-Mechanical Damage

Q&T Retirement Mechanisms-Abrasion

Abrasion:

- **An increase in hardness will yield better abrasion resistance, but the agitators currently being used are extremely aggressive, causing localized abrasion at multiple locations in the horizontal sections.**
- **Relaxing the helix with a short trip and the use of pipe on pipe friction reducers can help minimize damage**
- **Appropriate string design can also optimize reach while minimizing contact forces in the horizontal section**



Q&T Retirement Mechanisms

Mechanical Damage: Abrasion in the horizontal and possible High Cycle Fatigue Damage to the coil?

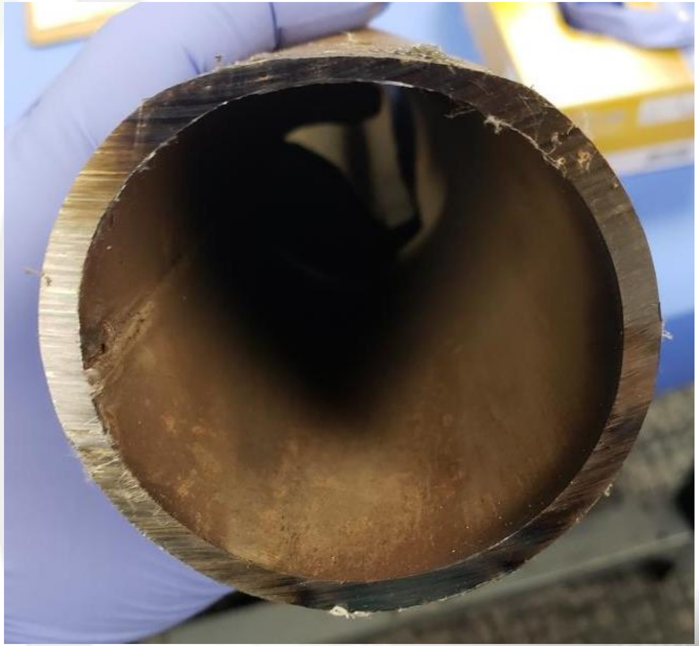
Credit: Scott McCracken with TTS via Linkedin

Q&T Retirement Mechanisms-Abrasion

Mechanical Damage: Abrasion in the horizontal near the BHA

Q&T Retirement Mechanisms-Abrasion

Mechanical Damage:
Abrasion in the horizontal at BHA and 500M UH



Q&T Retirement Mechanisms-HCF?

Mechanical Damage:
Ductile type failures near whip end-could this be attributed to agitators?

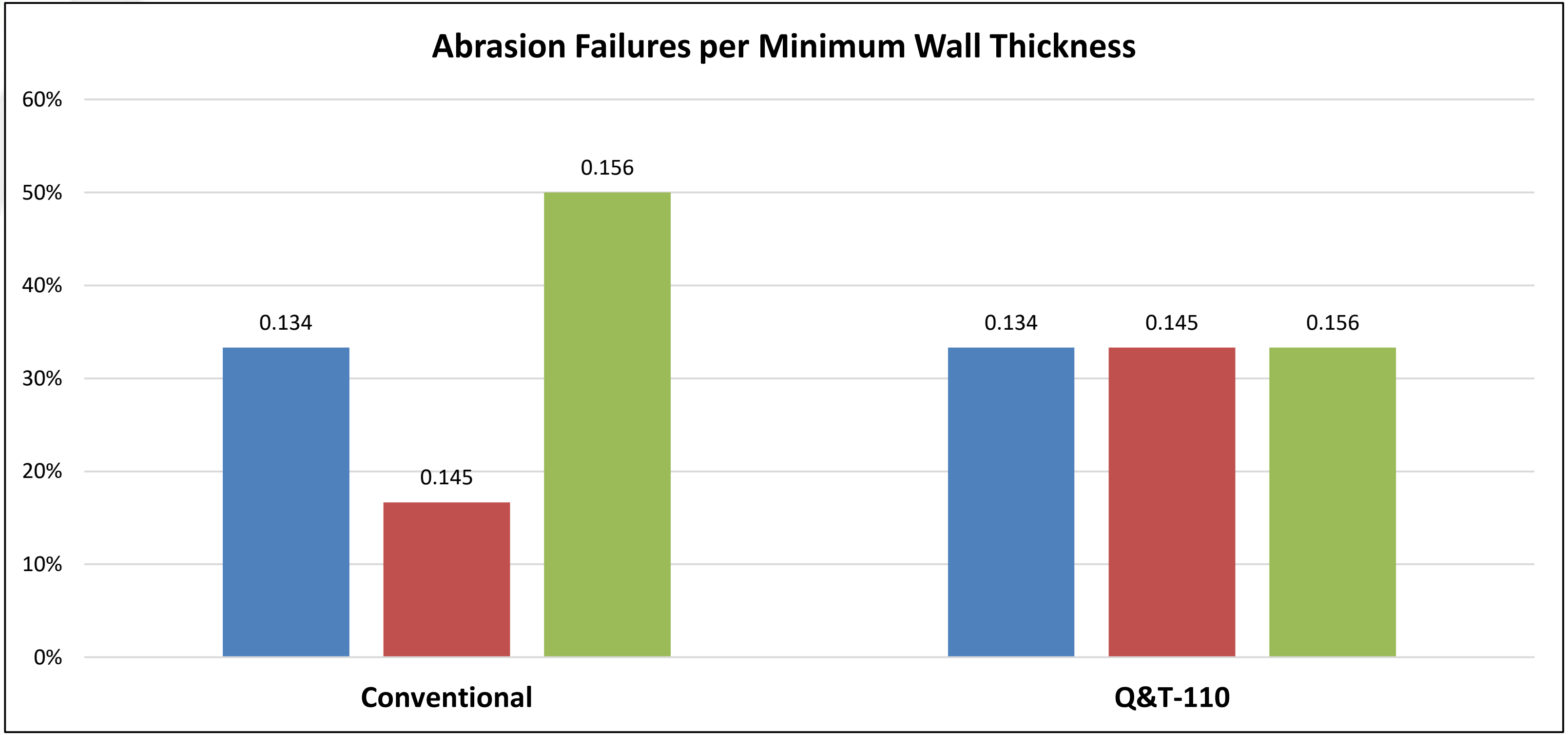
Can We Prevent Mechanical Damage?

Can We Prevent Mechanical Damage?

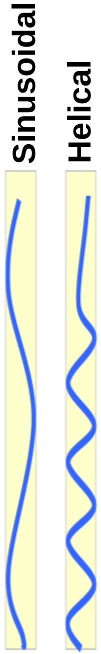
- Pipe on Pipe FR
- Resetting the Helix with short trips
- String Design

Q&T Retirement Mechanisms-Abrasion

Whip End Geometry?



Refresher: Theory Of Buckling



Helical buckling load at a point along the tubing inside the wellbore.

$$F_{\text{helical buckling load}} = -\sqrt{1+\mu}\,\sqrt[4]{\left(\frac{8EI}{r_c}\right)^2\left[\left(Fd\theta + dW_b \sin\theta\right)^2 + \left(Fd\gamma \sin\theta\right)^2\right]}$$

Force friction due to helical buckling.

$$F_{\text{buckling friction}} = \frac{\mu r_c F^2}{4EI}\,dL$$

Wall contact force over the section of the tubing inside the wellbore.

$$WCF = \sqrt{\left(d\gamma^2 \sin^2\theta + d\theta^2\right)F^2 - 2W_b \sin\theta\, d\theta F + \left(W_b \sin\theta\right)^2}$$

dW_b	*Derivative of buoyant weight*
$d\gamma$	*Derivative of azimuth*
$D\theta$	*Derivative of inclination*
E	*Young's Modulus of the CT material (30 x10^{-6}psi)*
F	*Effective axial force in the CT at a position of interest in the wellbore*
I	*Area moment of inertia of CT cross-section*
L	*Length of the section*
r_c	*Radial clearance of the CT in the Annulus*
WCF	*Wall contact force*
θ	*Inclination at a point in the well*
μ	*Friction coefficient*

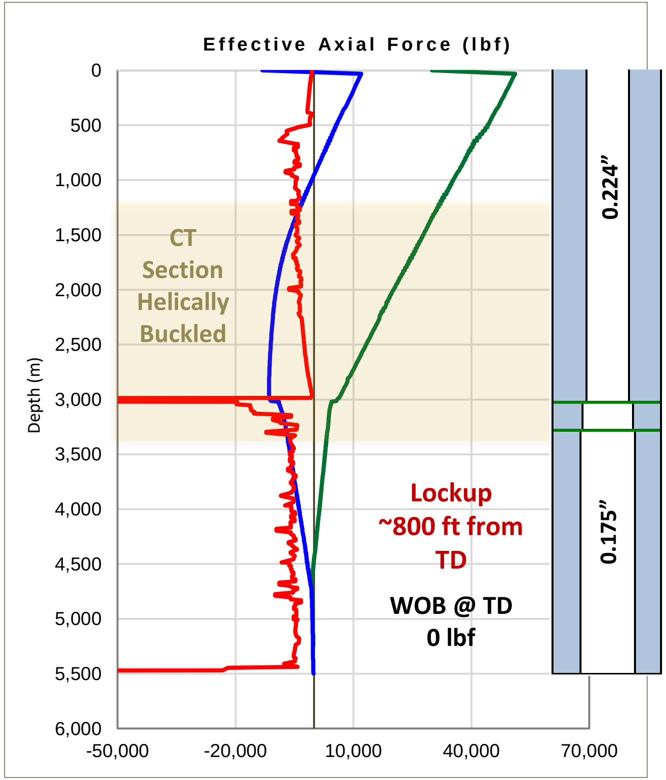
Reference: SPE-168235

CT Engineered Design Example 2⅜” CT

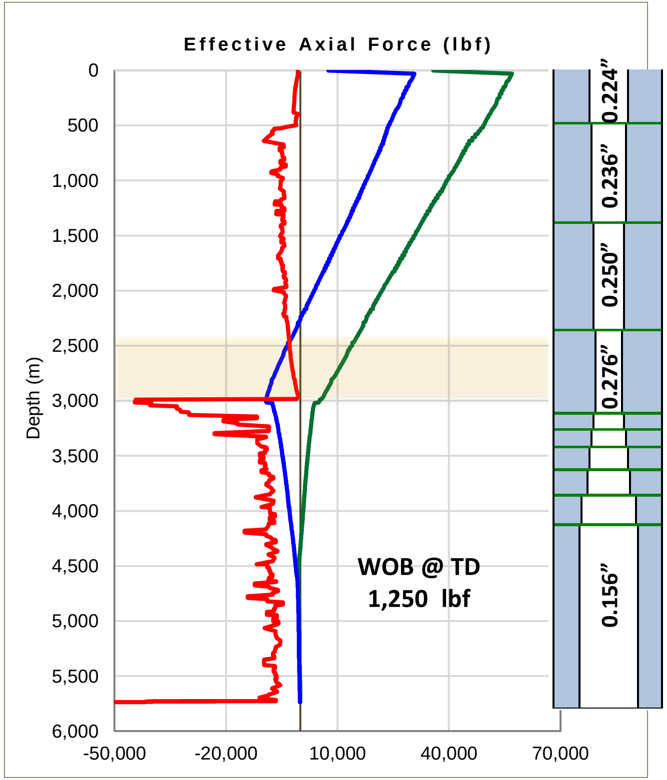
- ☑ Friction Reducer
- ☑ Lubricants
- ☑ Vibration tool @ 3.5 BPM

Effective Force POOH
Effective Force RIH
Helical Buckling Load Limit (lbf)

Previous Conventional Design



Engineered CT Solution



Pictures not to scale

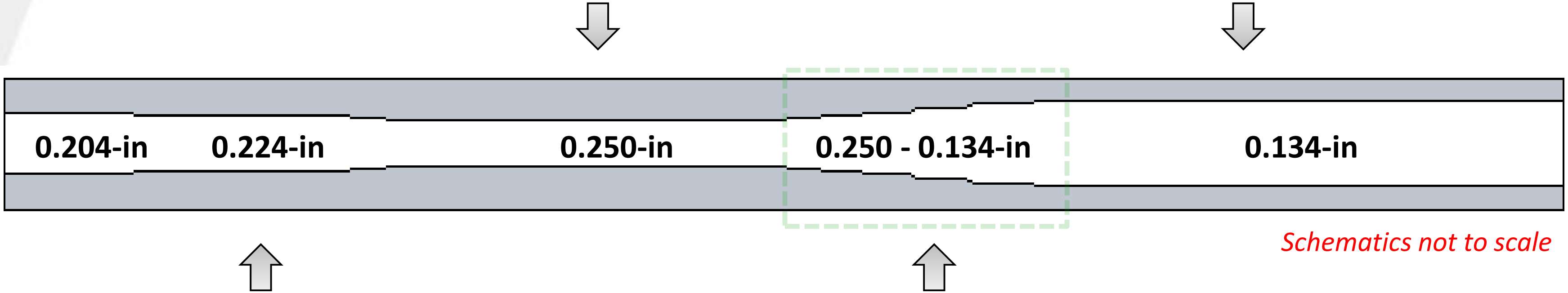
Hourglass CT Configuration

Extended Reach

Heavy wall is strategically placed to maximize reach and durability

Proper Section Length of Minimum Wall Thickness

The thinnest wall thickness would never be at surface while working in the lateral of the wells



Schematics not to scale

Weight & ID Frictional Pressure Loss Management

Overall weight and frictional pressure loses can be manage with a hourglass configuration

Rapid Taper Technology

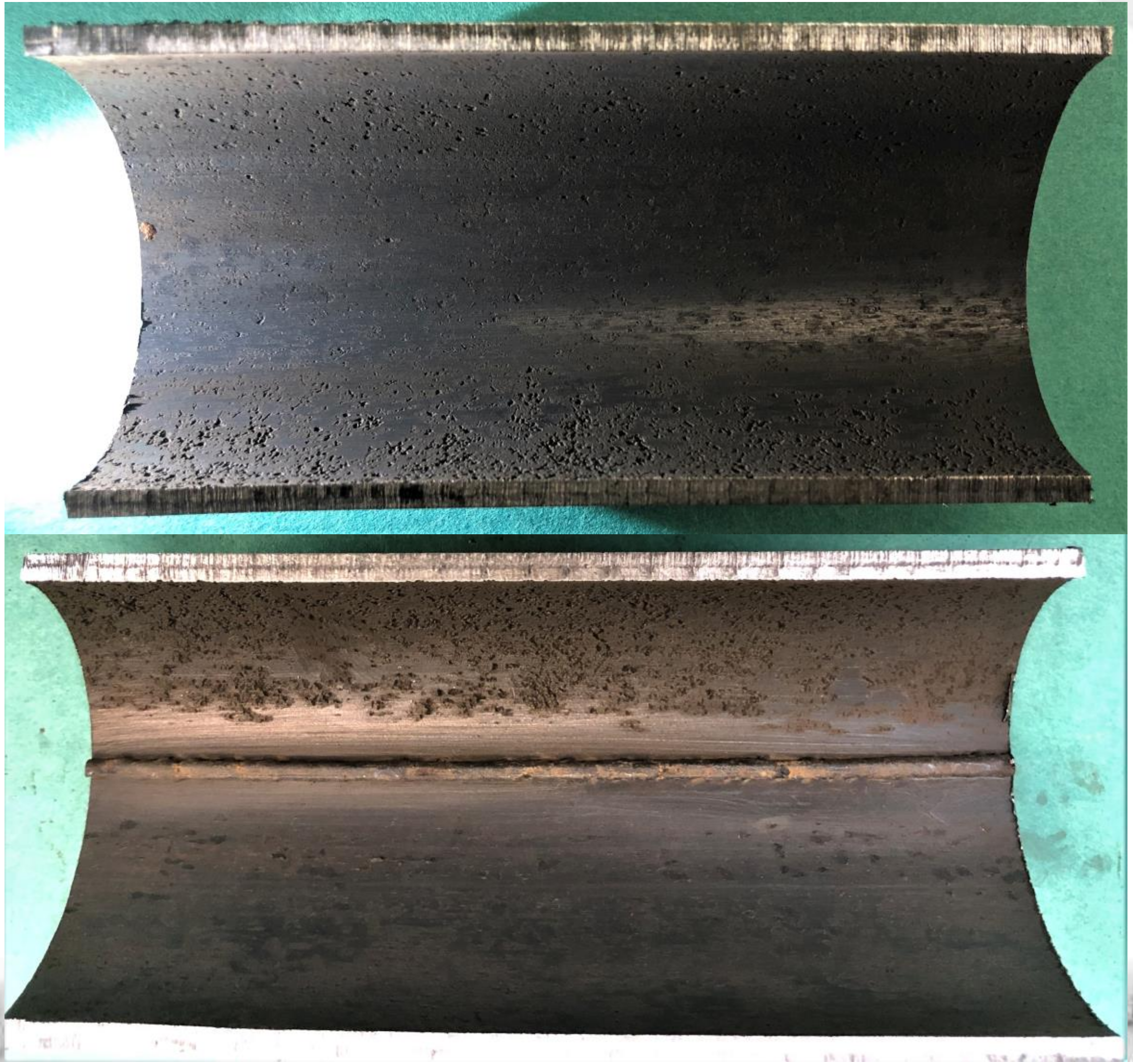
~4,000 ft (1,200 m) transition 9 wall thicknesses without step welds

Corrosion

Q&T Retirement Mechanisms- Corrosion

- A comparison of the full circumference often shows preferential to one side or the other

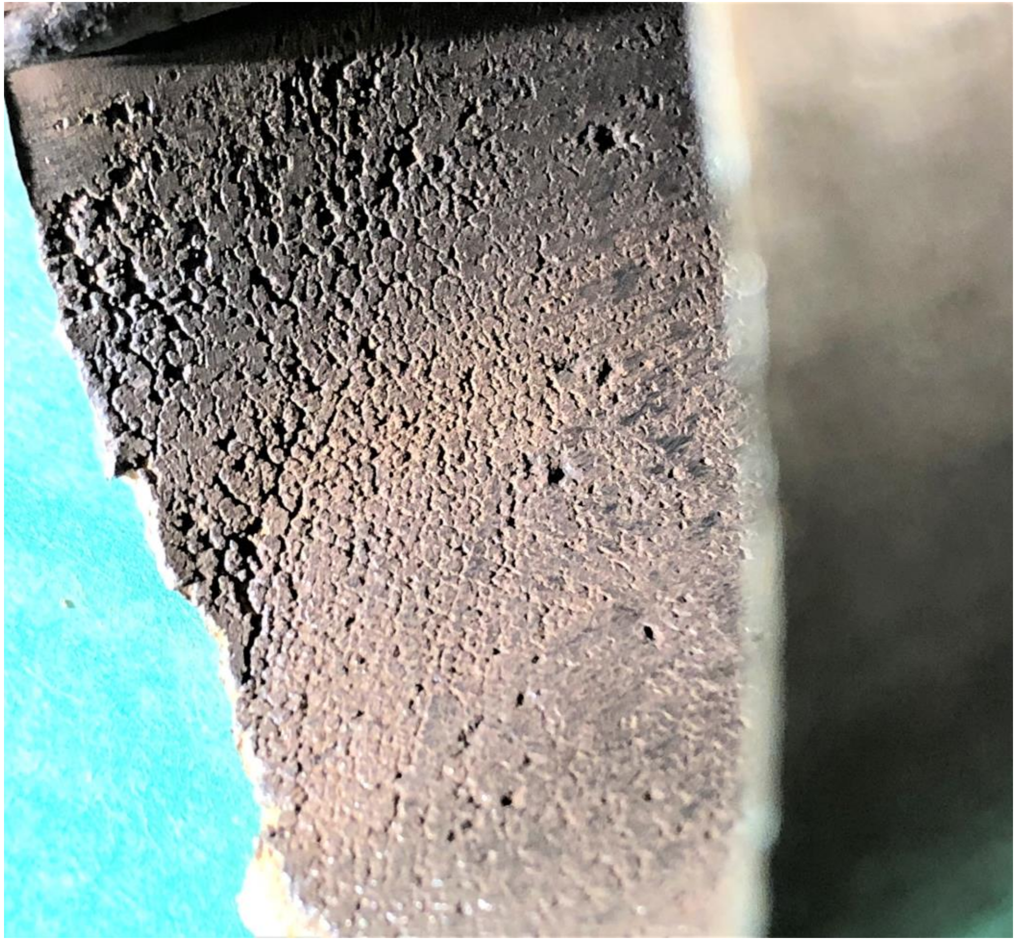
- This would suggest the corrosion may be happening between jobs



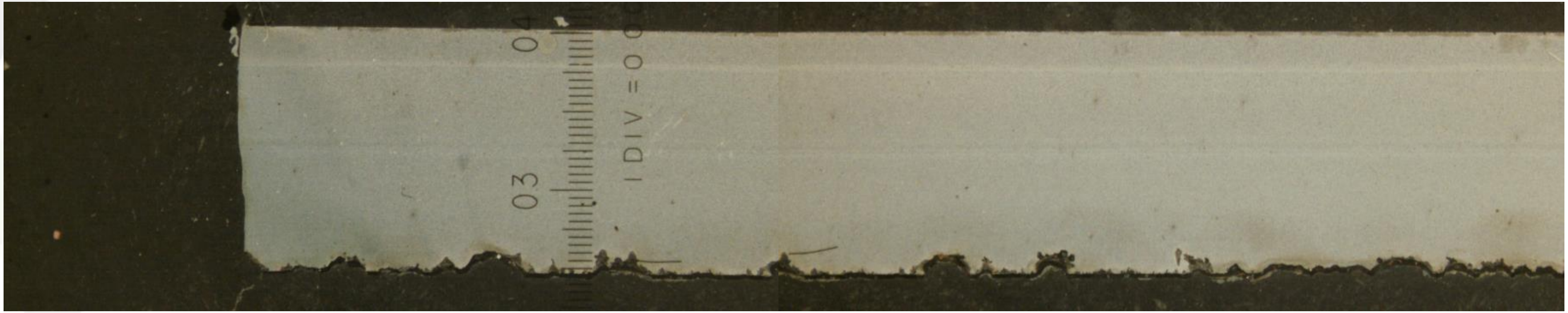
Q&T Retirement Mechanisms

Corrosion:

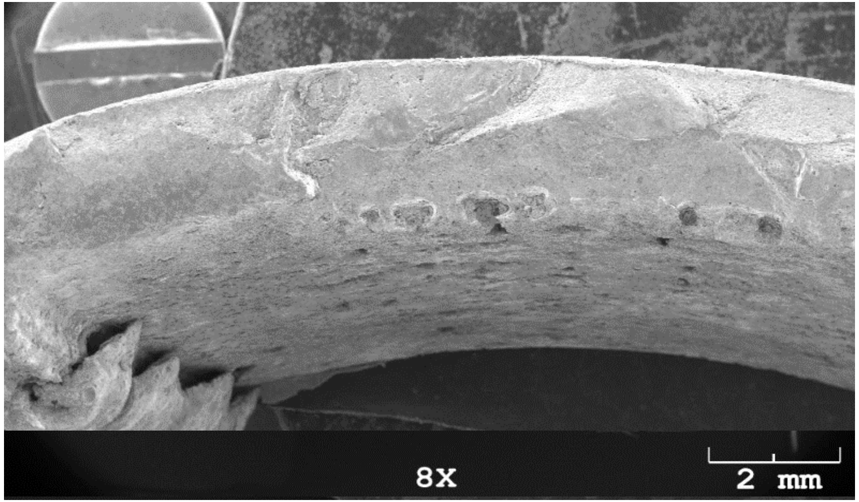
- An improvement in microstructure still requires us to manage fluids

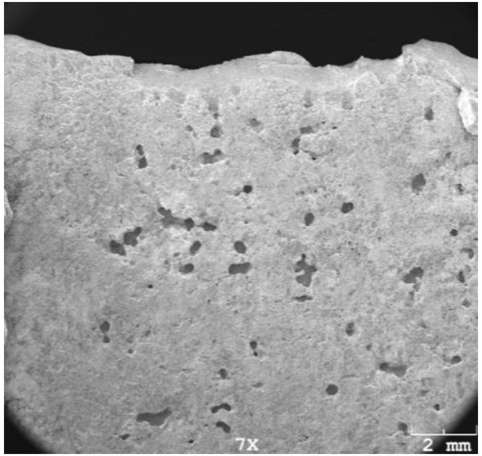


Q&T Retirement Mechanisms-Corrosion



MIC related corrosion still prominent



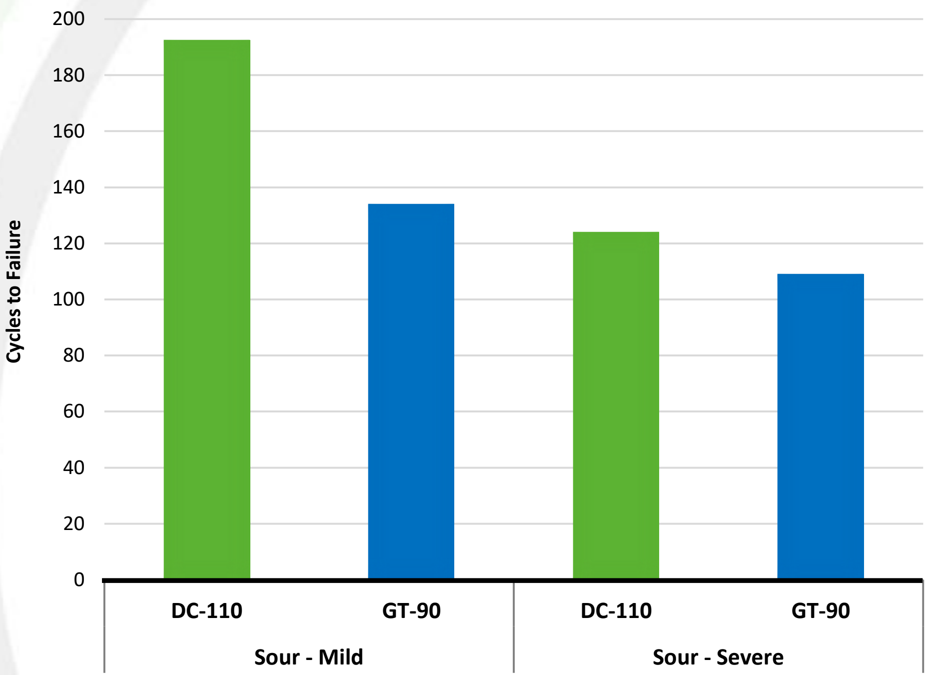


Can we prevent corrosion?

Can we prevent corrosion?

- Biocides- During job or after completion?
- Pigging/flushing programs- Circulate ball to flush fluids
- Inhibitors- After job
- Careful attention to H_2S mitigation- Q&T is not the silver bullet and all CT needs careful inhibition and mitigation in sour environments

Q&T 110 Sour immersion testing results compared to CT-90



Test Solution	Test Gas	Temp (ºF)	Duration (Hours)
NACE MR0175/ISO 15156-2 Table B.1 5% mass fraction NaCl + 0.4% mass fraction CH_3COONa with a starting pH of 3.7	1.4% H_2S|CO_2	77º ± 5º	> 168
Modified NACE MR0175/ISO 15156-2 Table B.1 23.4% mass fraction NaCl + 3% mass fraction CH_3COONa with a starting pH of 3.7	7% H_2S|CO_2		

- Fatigued testing using 60” Radius at 5,200 psi.
- Combination of base and bias welds

Improvements!

Q&T™ Diametral Growth: Prediction vs. Reality

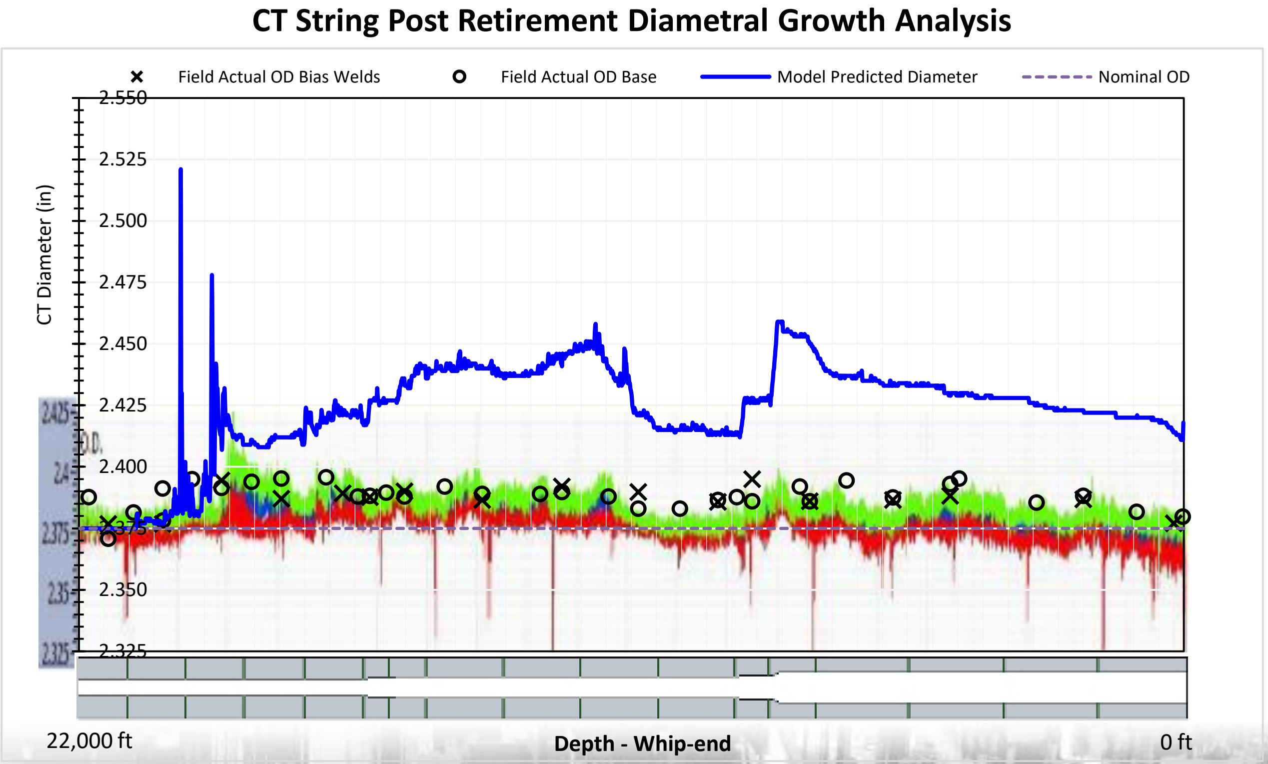
Performance of Q&T with 2⅜" [60.33mm] CT

Challenges

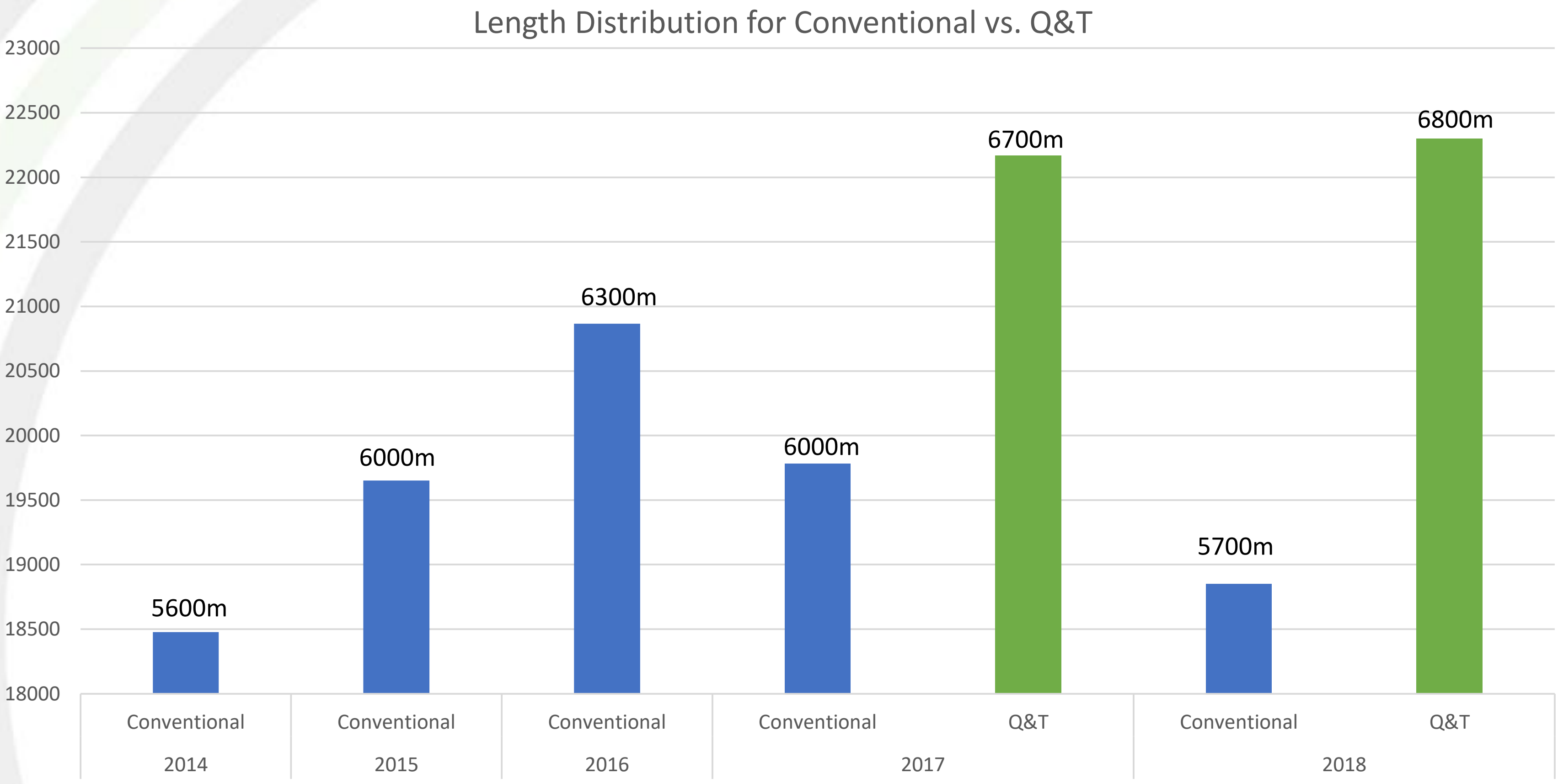
- Working Pressures:
  6,500 psi – 8,500 psi
  [45 Mpa – 59 Mpa]

Q&T Results

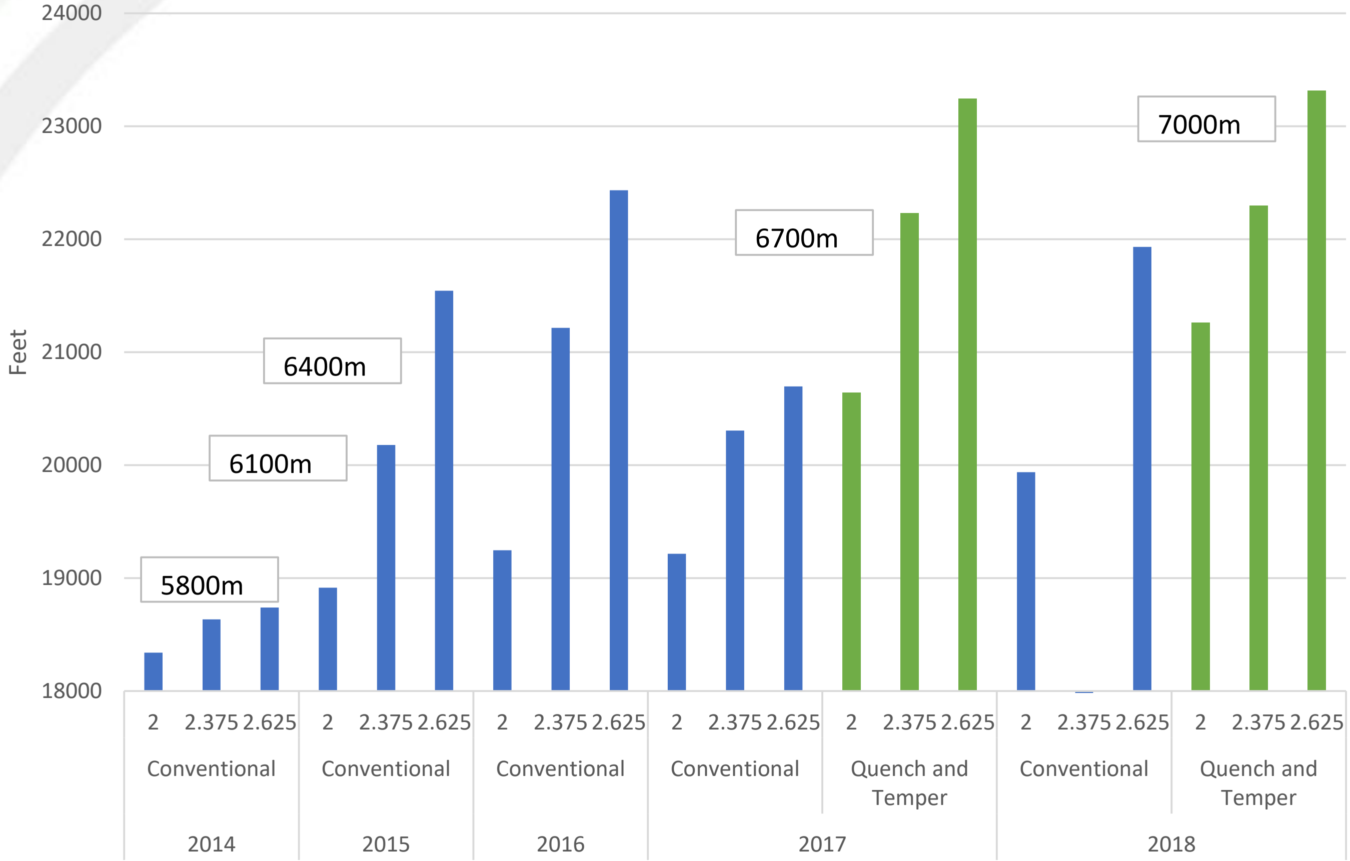
- Substantial reduction in ballooning compared to predicted model



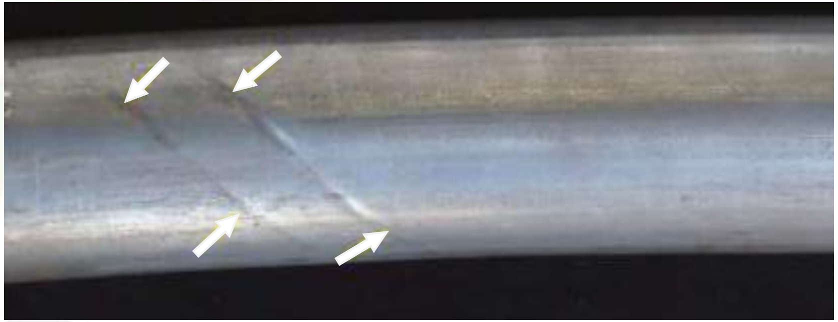
Q&T Improvements in Reach

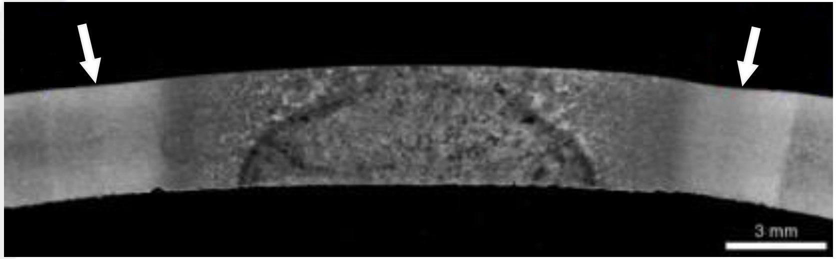


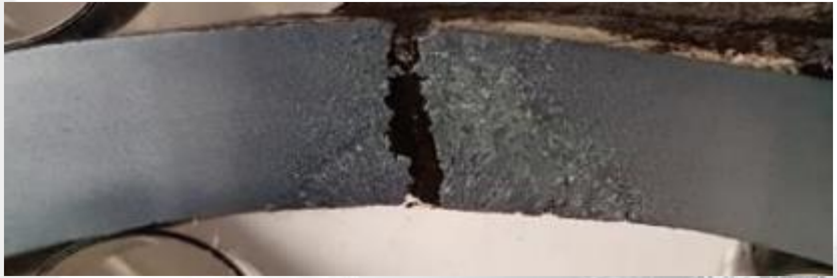
Q&T Increases in Diameter and Length



Conventional Coiled Tubing Manufacturing Process



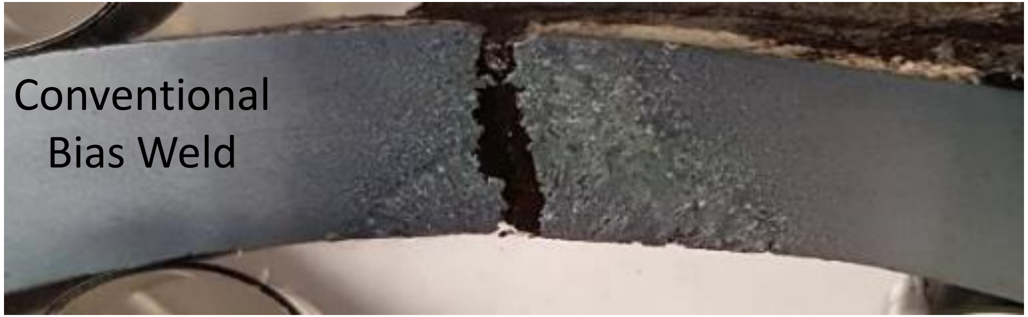




Bias welds in conventional coiled tubing:

- Inherently contain discontinuities in the microstructure
- Are susceptible to heat affected zone deformation during cycling
- Can fracture quickly through coarse grained microstructure

Q&T Microstructural Improvement



**Tube samples tested to same conditions to same fatigue machine cycles*

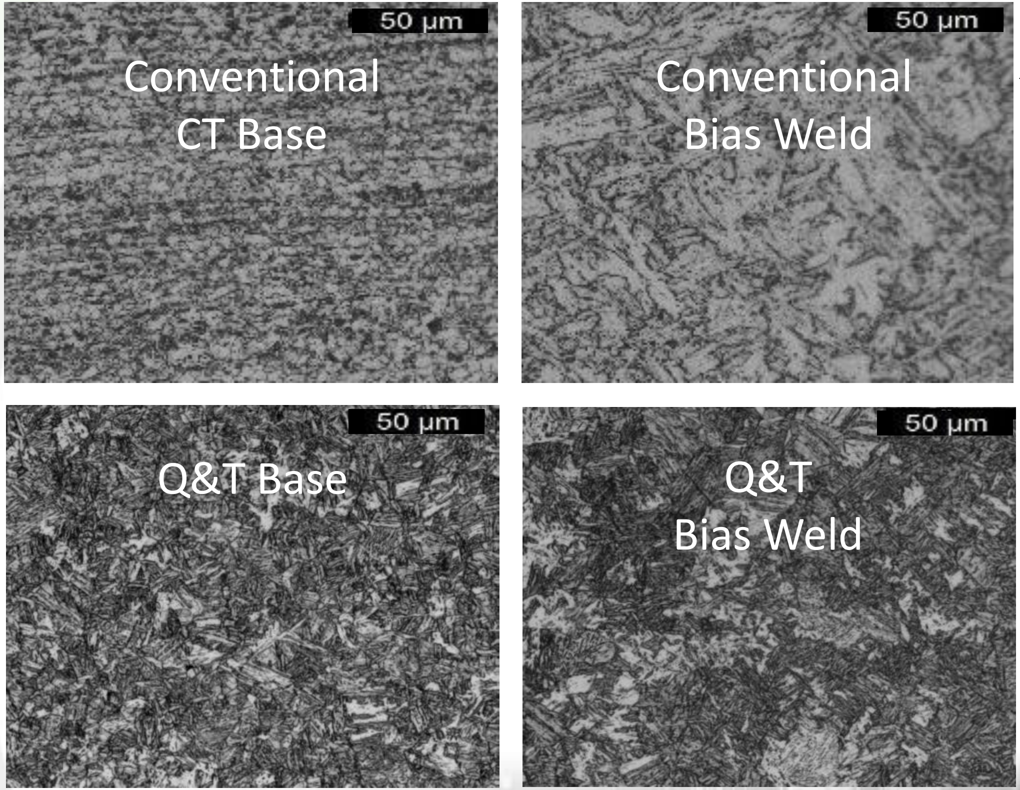
2.375” CT x 0.204” Metallography

After the same number of fatigue machine cycles:

- Microstructure of Q&T bias weld is superior to traditional CT manufacturing methods
- Fine grained structures improve fatigue and corrosion resistance

Q&T Microstructural Improvement

Conventional vs. Q&T

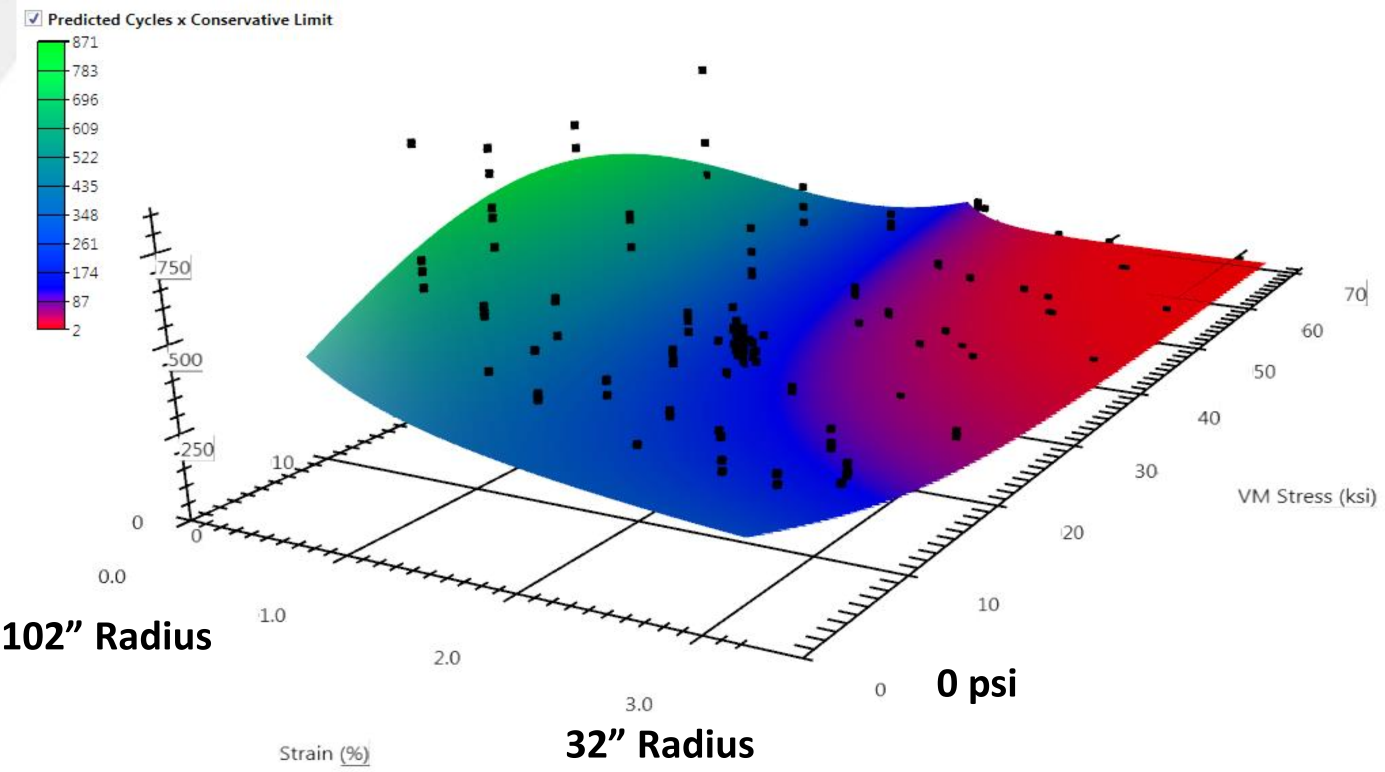


← Conventional CT microstructure has fine banding longitudinally and a cast bias weld microstructure

← Quench and Tempered CT microstructure is martensitic which improves mechanical properties and creates a more uniform microstructure

Q&T Modeling Improvements

3D view of our fatigue tests that span the ranges of stresses and strains seen during CT operations



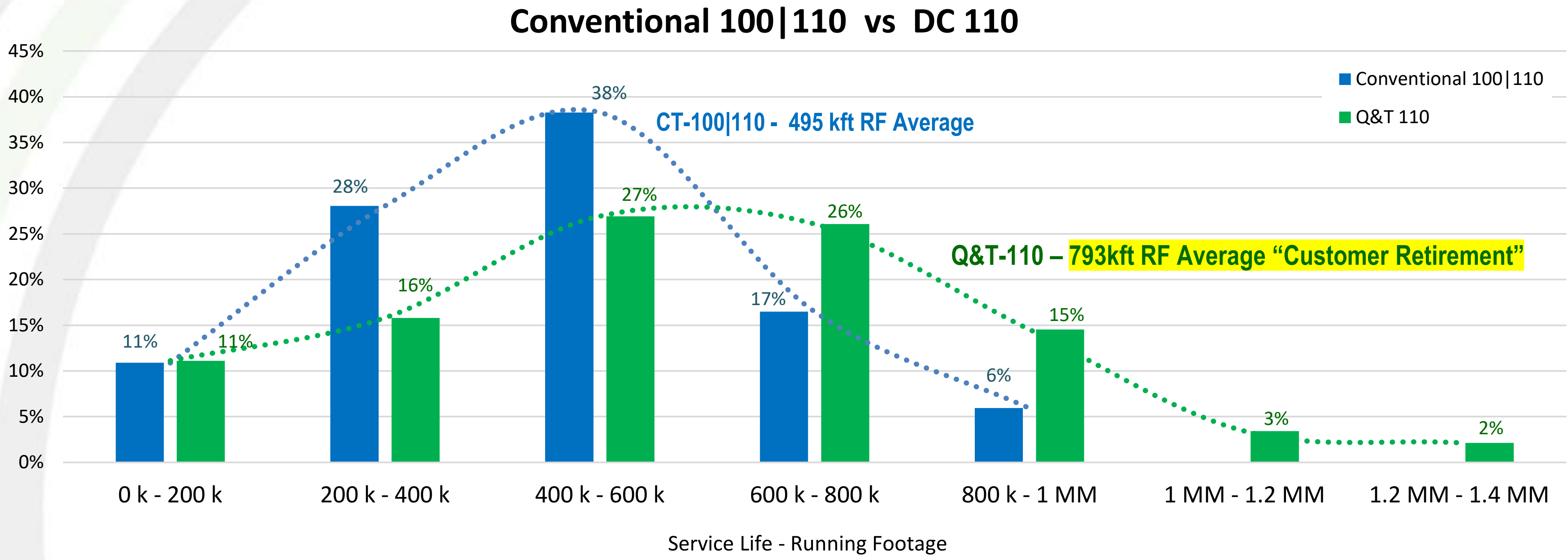
15,000 psi

0 psi

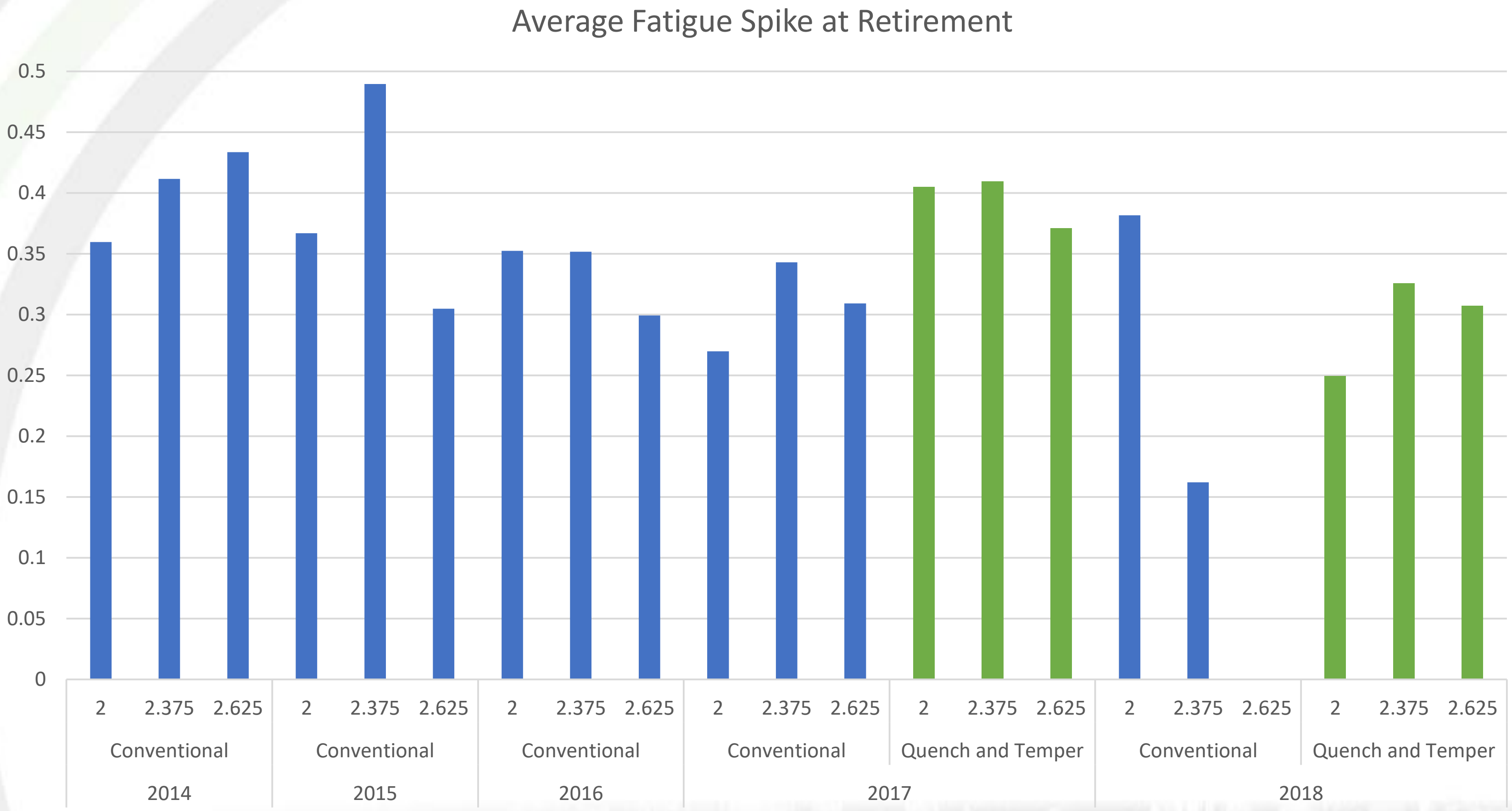
102" Radius

32" Radius

Quench and Temper-North America Field Performance



Q&T Modeling Improvements



Mechanical Damage

Abrasion

Corrosion

HCF

How do we put coil in every well?

Thank You.
Any Questions?

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Improvements!