New Higher Strength Coiled Tubing Developed to Extend Coiled Tubing Operating Envelopes

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NOV Quality Tubing™

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The Need for Higher Strength

- Well depths are increasing, many with long horizontal sections.
  - Operations cannot be performed with existing coiled tubing grades due to axial load limitations.
- Wellhead pressures are increasing
  - Require significantly higher pumping pressure while cycling tubing from reel to well and back.
  - Existing grades dilate rapidly and encounter physical restrictions.

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Design Requirements

- 130,000 psi min specified yield strength.
- Maximum difference between actual tensile and yield strengths.
- Consistently exceed fatigue cycle life of comparable size QT-1000.

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High Strength Design Requirements

- ❑Be able to consistently manufacture and service with existing equipment.
- ❑ Strip-to-strip bias welds – must be weldable by current process.
- ❑ Tube-to-tube welds – must be weldable by current process.

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High Strength Requirements

Physical Property	**Value**
Minimum Yield Strength	130,000 PSI (125,000 PSI @ Bias)
Minimum Tensile to Yield Difference	4,000 PSI
Minimum Elongation	$750{,}000\ A^{0.2}/U^{0.9}$
Maximum Hardness	Rockwell “C” 37

Notes on Elongation:

A = Cross Sectional Area of Tubing

U = Specified Minimum Tensile Strength of Tubing

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Tubing Mechanical Properties

Diameter (in)	Wall Thickness (in)	Yield Strength (psi)	Tensile Strength (psi)	Elongation (%)
1.75	0.134	138,500	143,600	24.5
1.75	0.156	145,800	150,200	22.5
1.75	0.175	146,200	151,600	22.0
1.75	0.188	141,600	147,400	22.5
1.75	0.203	144,700	150,000	27.5
2.00	0.134	141,200	146,200	24.5
2.00	0.156	143,600	149800	23.5
2.00	0.188	134,700	140,500	22.5
2.00	0.203	140,500	149,600	24.5

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Burst Testing

Diameter (in)	Wall Thickness (in)	Length (in)	Estimated Burst (psi)	Actual Burst (psi)
2.000	0.134	96.00	18,860	21,437
2.000	0.134	96.00		20,233
2.000	0.156	96.00	22,620	25,431
2.000	0.156	96.00		24,273
2.000	0.188	96.00	27,377	32,297
2.000	0.188	96.00		32,542

Estimated burst = Barlow's formula using actual tensile strength

No actual burst failures in the weld seam

Collapse Testing

Diameter (in)	Wall Thickness (in)	Calculated Ovality (%)	Estimated Collapse (psi)	Actual Collapse (psi)
2.000	0.134	0.650	11,200	16,790
2.000	0.134	0.400	11,900	16,641
2.000	0.156	0.299	17,500	22,008
2.000	0.156	0.150	18,600	22,338
2.000	0.188	0.399	22,100	28,923
2.000	0.188	0.448	21,800	28,937

Estimated collapse = API 5C3 using actual wall and zero axial load

Function Testing

- Tubing has been successfully shear tested
  - By Texas Oil Tools
  - Also by multiple customers

- Tubing is currently being tested for behavior in injectors
  - By HydraRig
  - By Customer

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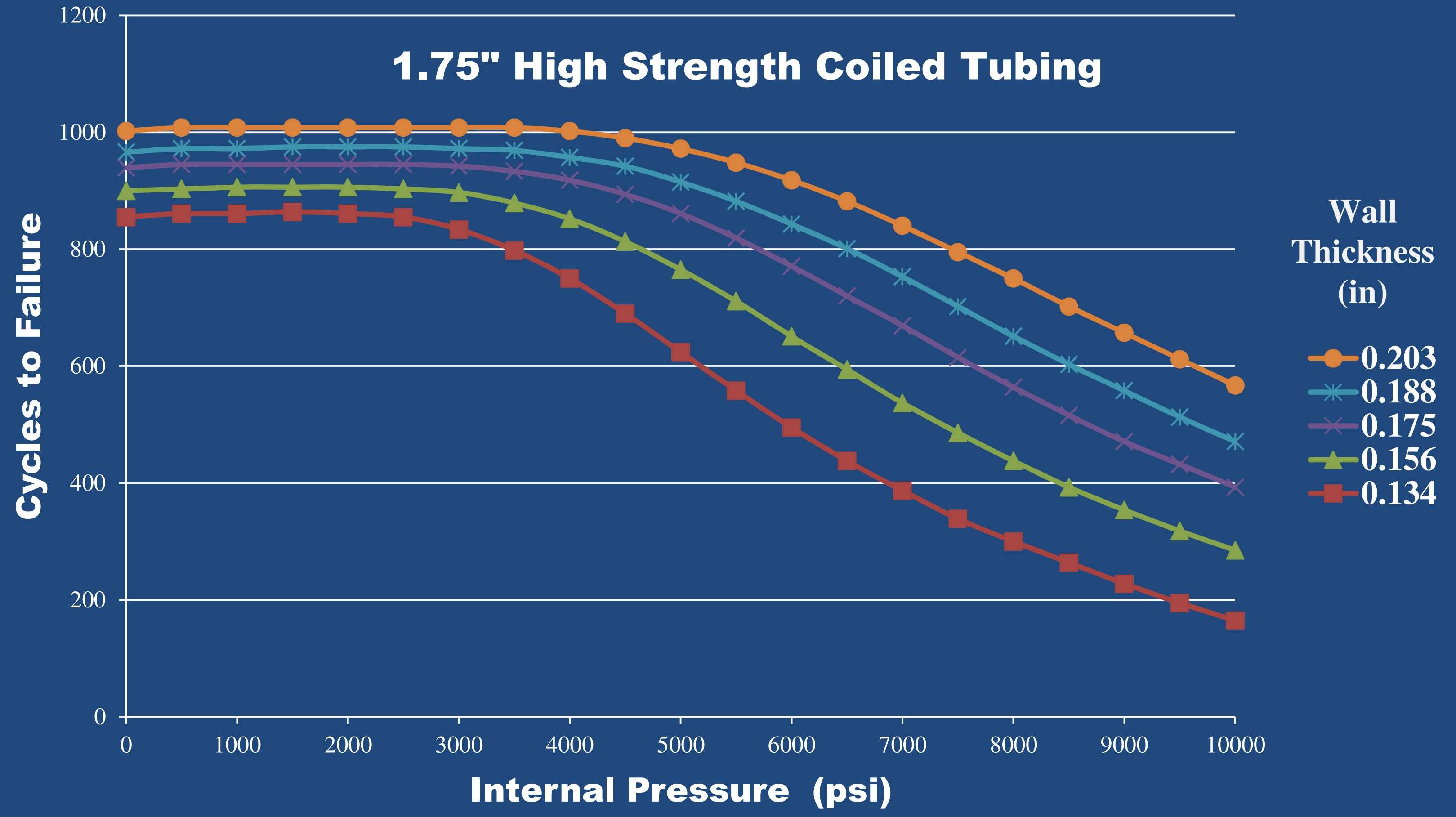
Fatigue Performance Evaluation

- Fatigue testing on Standard Fatigue test Machine
  - In excess of 350 samples tested over 72” radius
  - 36 samples tested over 48” radius
- Standard set of ASTM E606 strain controlled fatigue tests
- Used to develop algorithm for Flexor and Cerberus models

Fatigue Performance



Source: Cerberus

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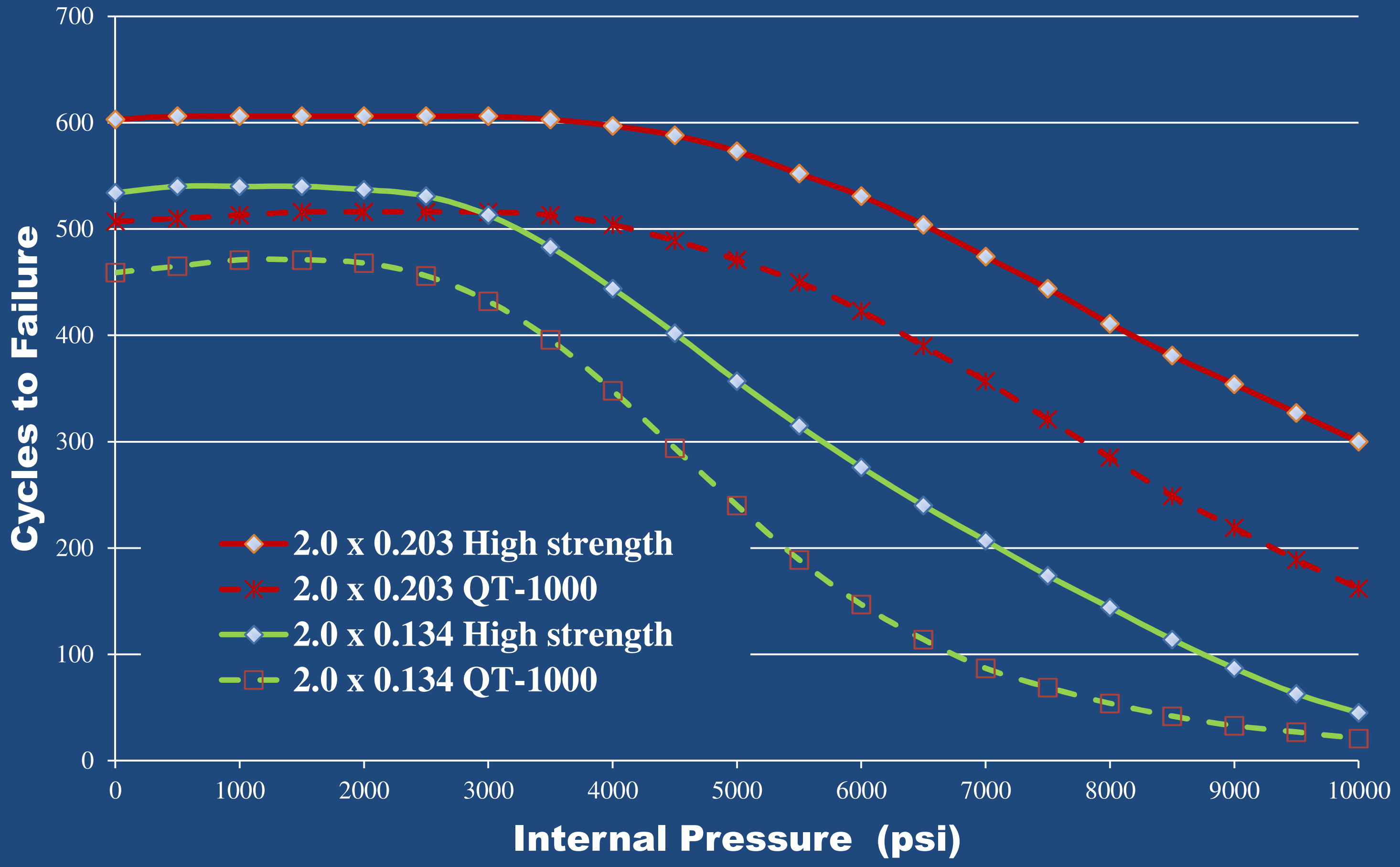
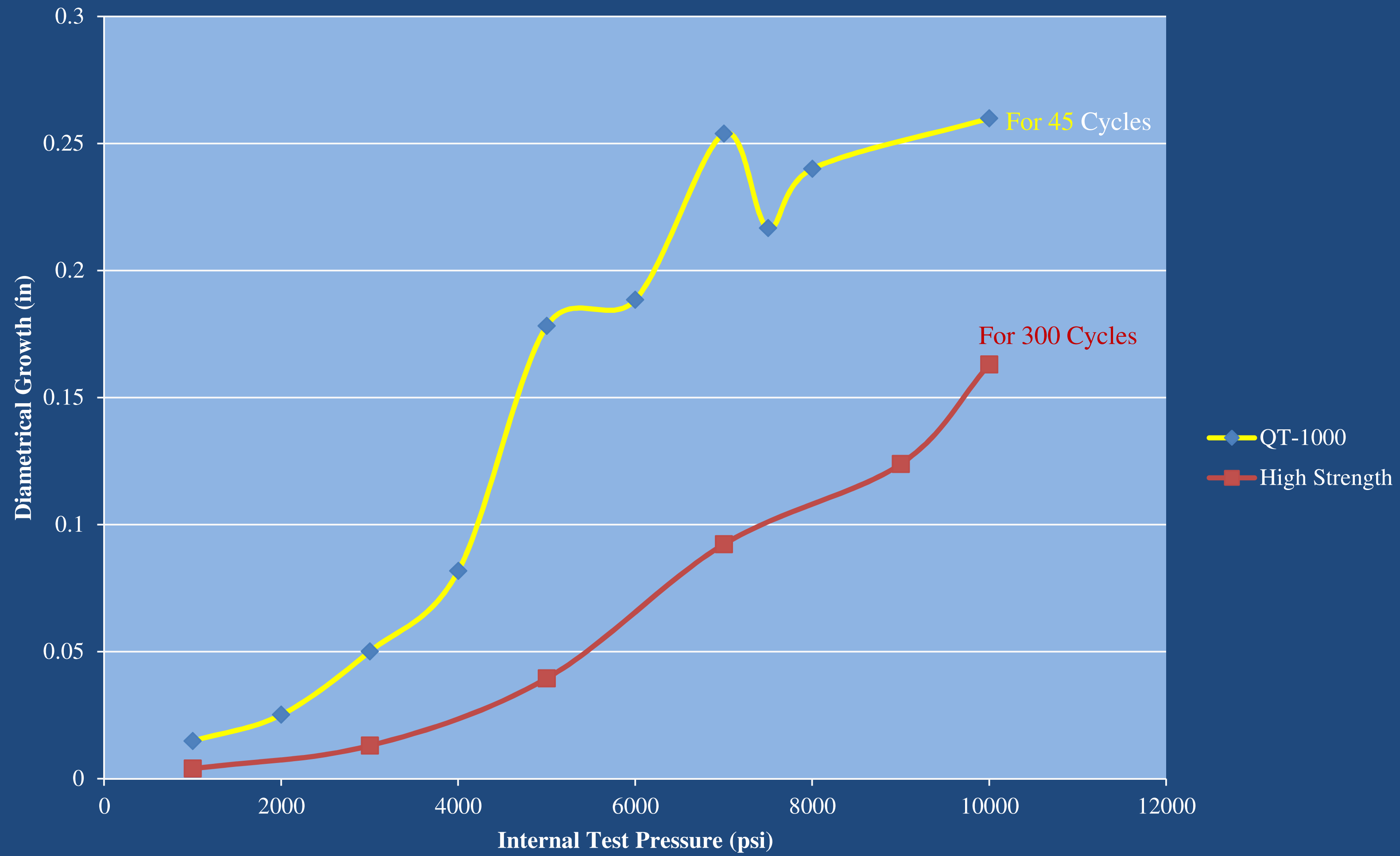
Fatigue Comparison to QT-1000



Source: Cerberus

High Strength versus QT-1000
Diametrical Growth for 2.000" x 0.156"



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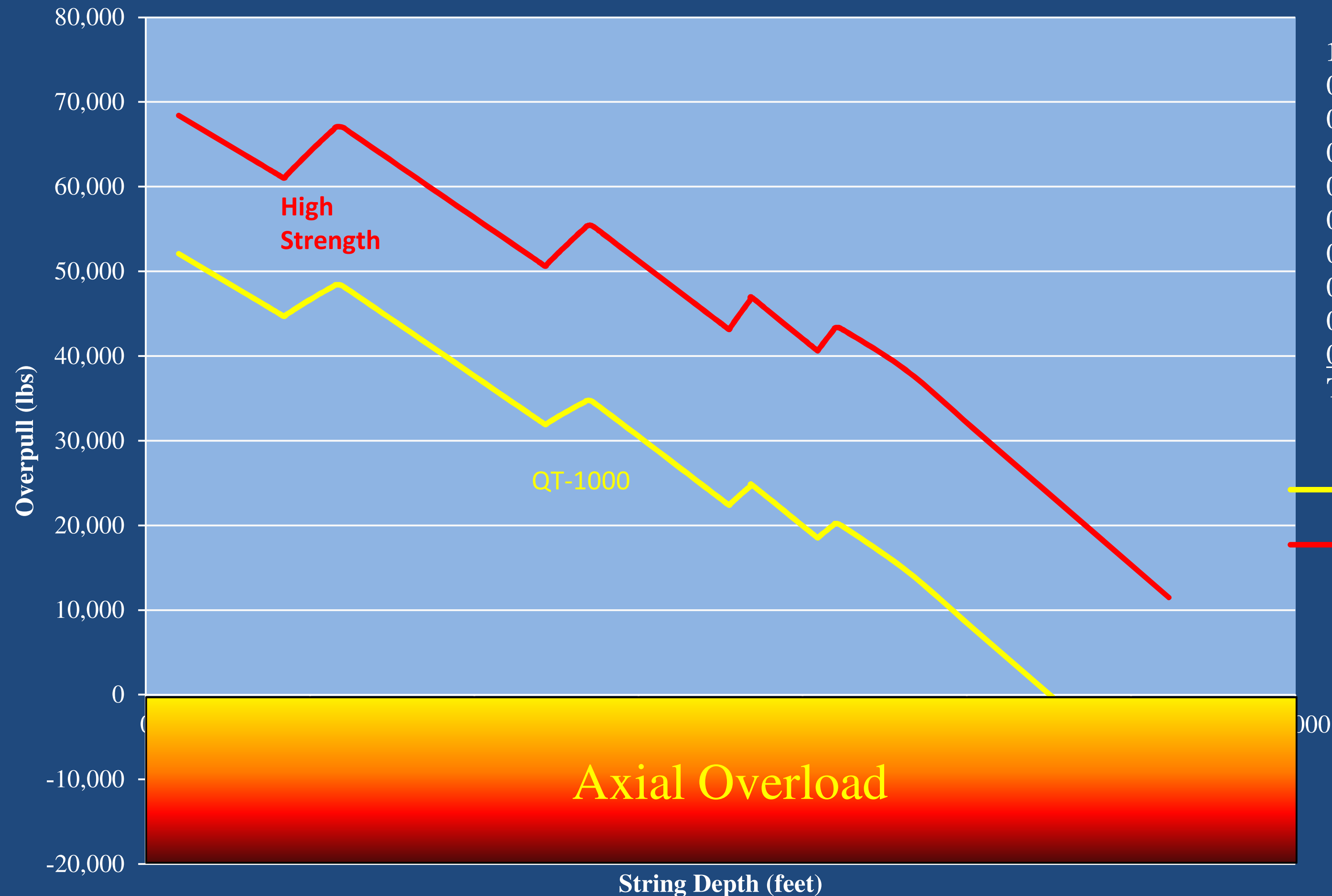
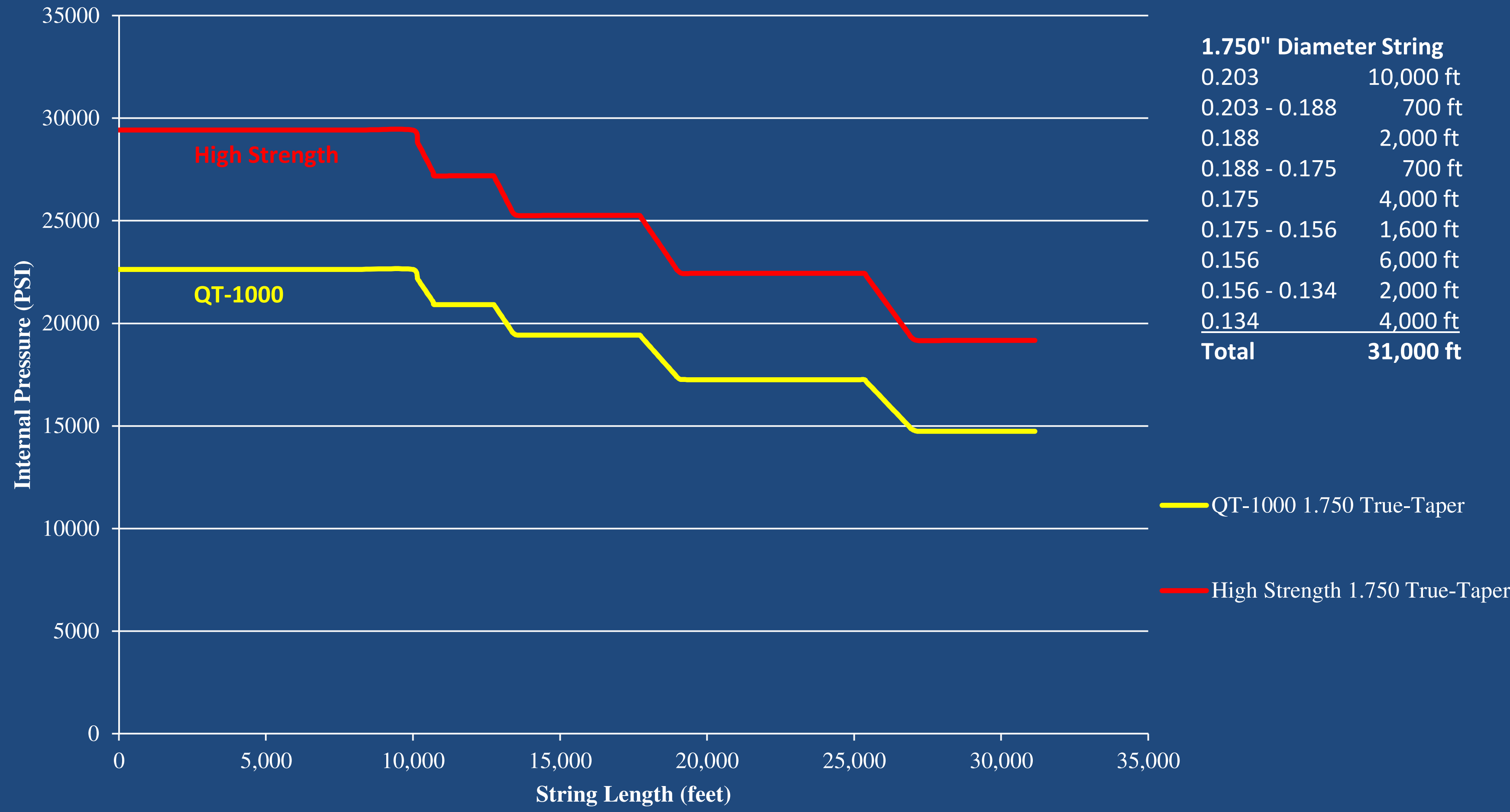
Overpull Comparison of QT-1000 to High Strength



1.750" Diameter String	
0.203	10,000 ft
0.203 - 0.188	700 ft
0.188	2,000 ft
0.188 - 0.175	700 ft
0.175	4,000 ft
0.175 - 0.156	1,600 ft
0.156	6,000 ft
0.156 - 0.134	2,000 ft
0.134	4,000 ft
Total	**31,000 ft**

Internal Yield Pressure Comparison of QT-1000 and High Strength



1.750" Diameter String	
0.203	10,000 ft
0.203 - 0.188	700 ft
0.188	2,000 ft
0.188 - 0.175	700 ft
0.175	4,000 ft
0.175 - 0.156	1,600 ft
0.156	6,000 ft
0.156 - 0.134	2,000 ft
0.134	4,000 ft
Total	**31,000 ft**

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Next Development Goals

- Further develop the Bias Welding process to capture a higher percentage of the parent material's strength

- Additional fatigue and mechanical properties testing to verify product performance in additional sizes

- Fully develop a tube-to-tube welding procedure for the manufactured tubing

Thank You For Your Attention

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