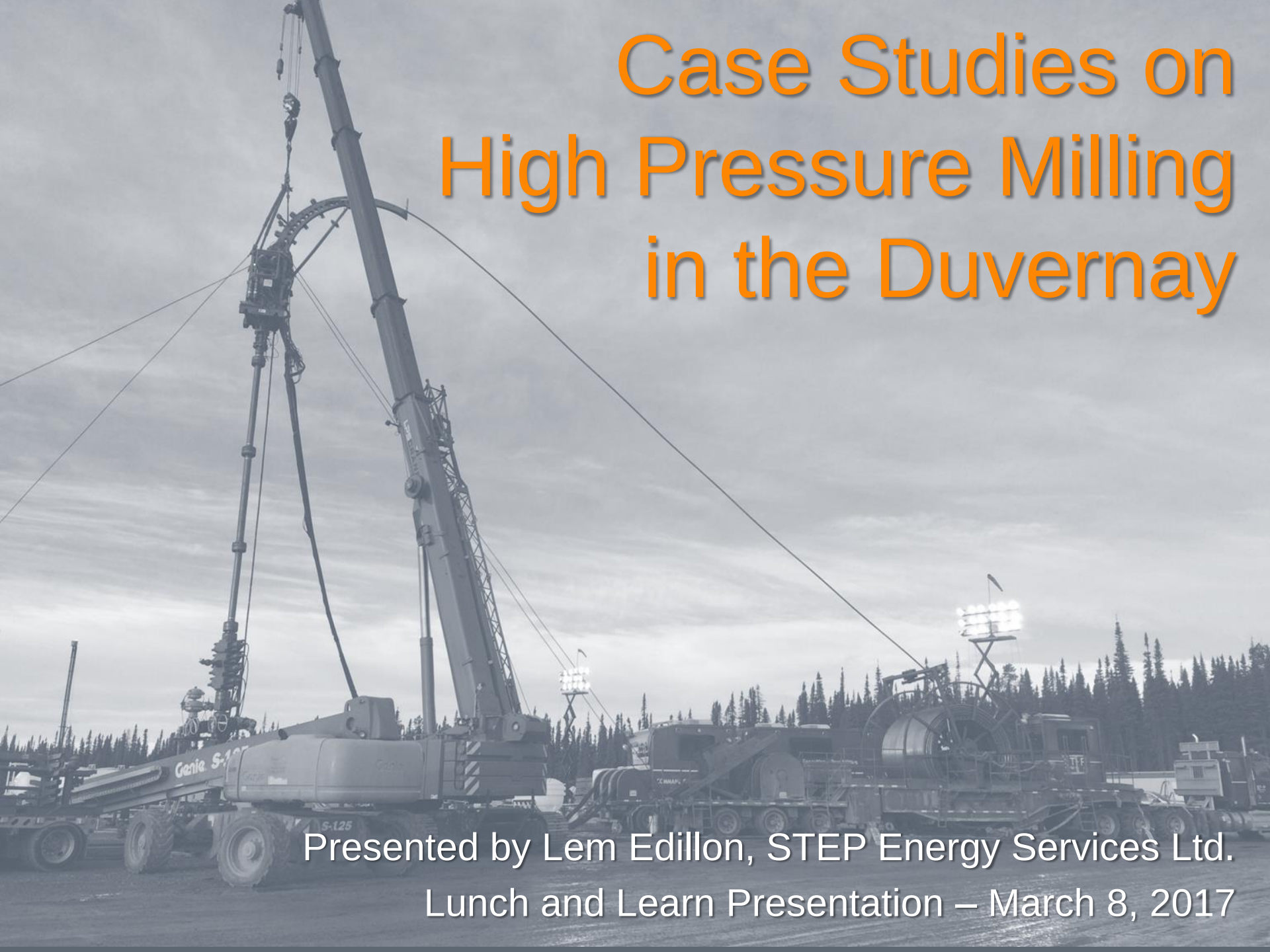


Case Studies on High Pressure Milling in the Duvernay

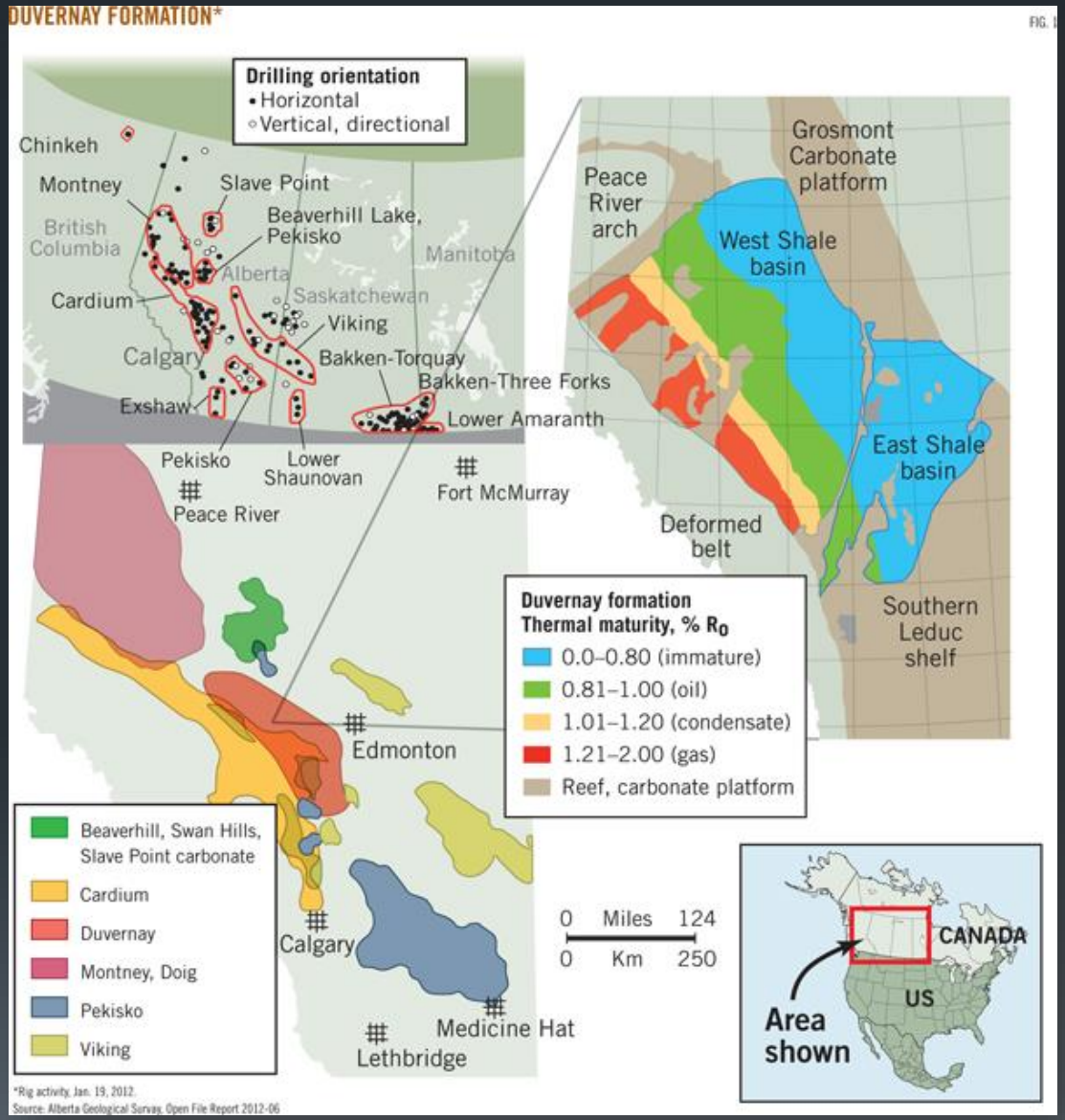
Presented by Lem Edillon, STEP Energy Services Ltd.

Lunch and Learn Presentation – March 8, 2017

Presentation Outline

- The Duvernay Play
- Project Outline
- The Challenge
- Preliminary Design Work
- Initial Coiled Tubing Operations
- String Failure and Analysis
- Further Case Studies
- Conclusions and Recommendations

The Duvernay Play



- World-class emerging play in west central Alberta
- Oil, condensate, and dry gas formation
- Similar to the Eagle Ford of Texas: over-pressured reservoirs
- A majority of the acreage held by large companies focused on long-term growth
- Deeper play with some of the most expensive wells onshore.

Source: Oil & Gas Journal, 2014

Project Timeline

2014

- Preliminary simulations, string designs, equipment considerations.

2015

- Ordered first CT strings, initial operations on an 8-well pad.

2016

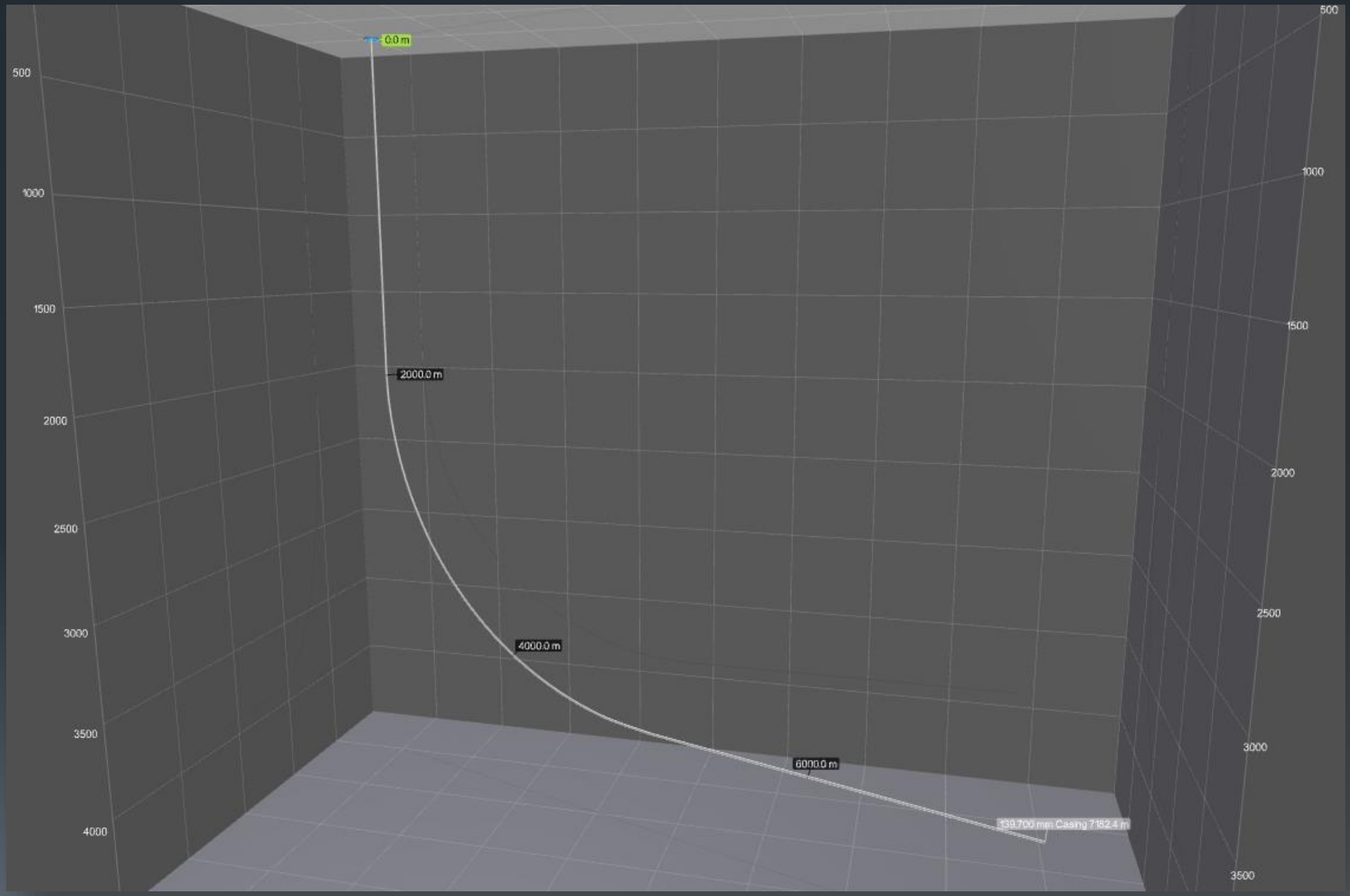
- Ran more than ~690,000 cumulative running meters with 3rd, 4th, and 5th strings.

2017

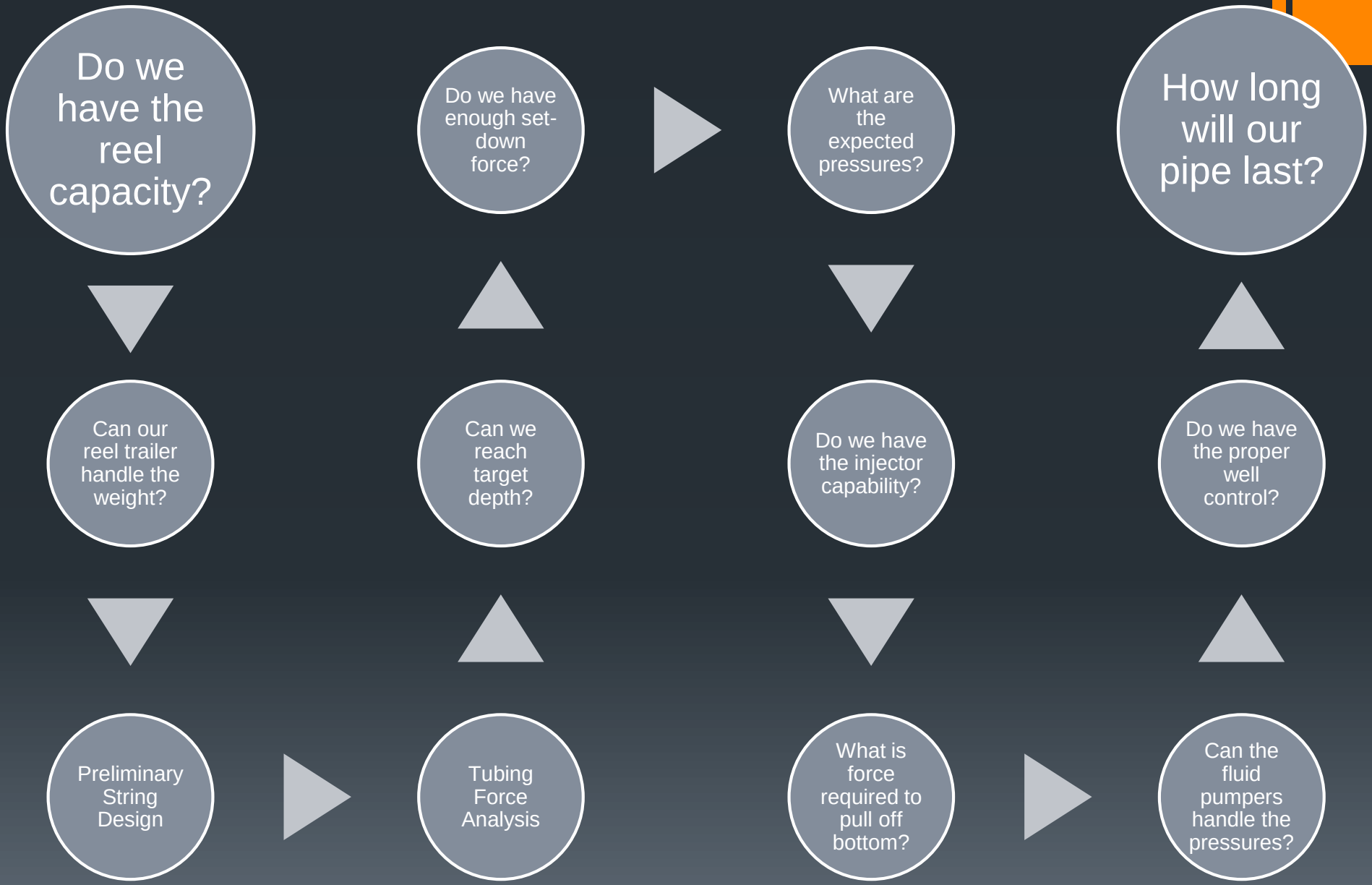
- Continuing operations w/ 6th string. Achieved depth record of 7,200m

The Challenge

- August, 2014: Duvernay oil and gas operator requests modeling for coiled tubing operations in a 7,200m well.



Preliminary Analysis



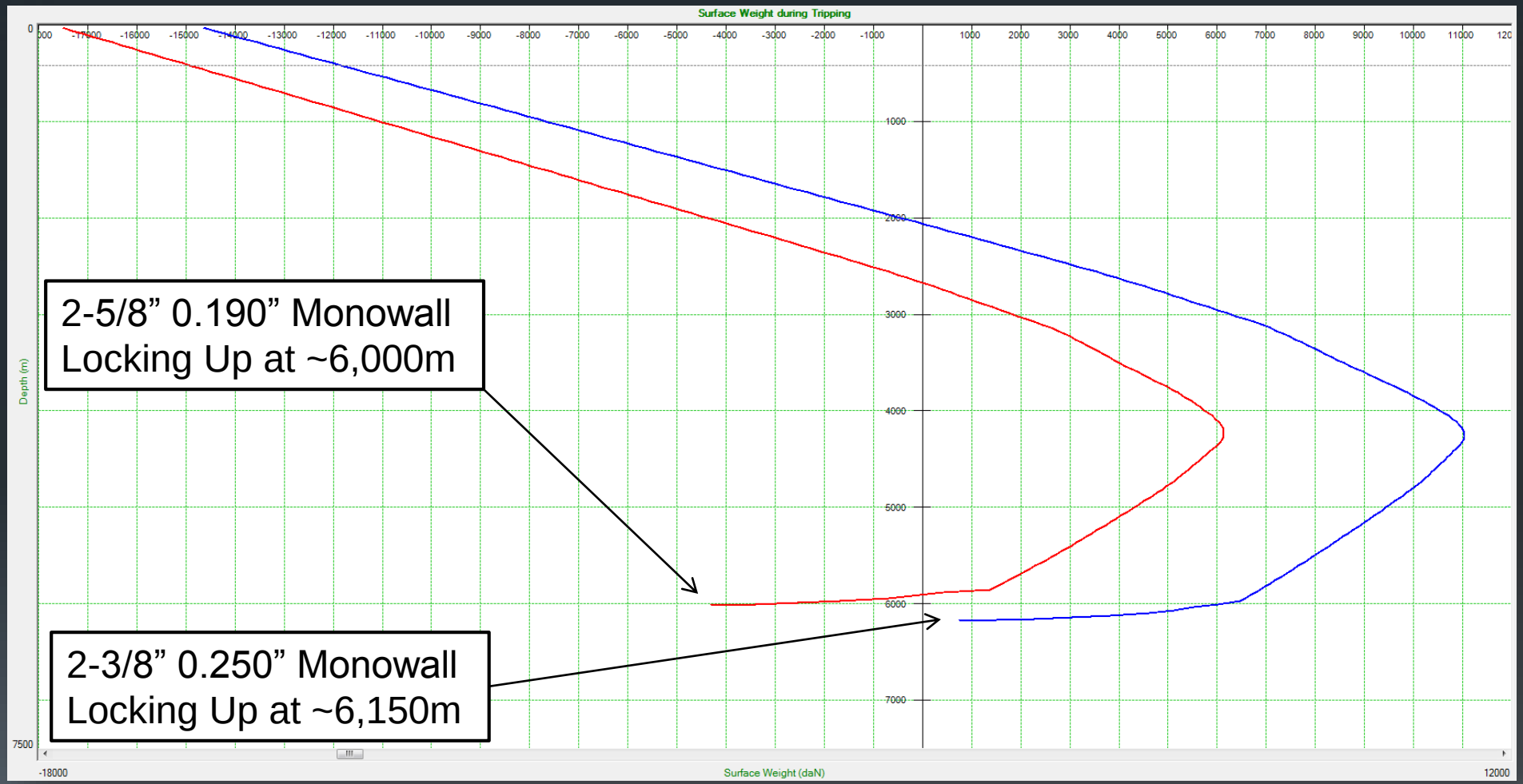
Reel Capacity

- 12’ wide reel trailer
- 96” Core, 182” Flange, 110” Wide
- 2-3/8” CT Capacity = 9,900m (Cerberus)
- 2-5/8” CT Capacity = 7,900m (Cerberus)
- Maximum Lifting Weight Limitation = 180,000 lbs.
- Target Maximum String Weight = 168,000 lbs.

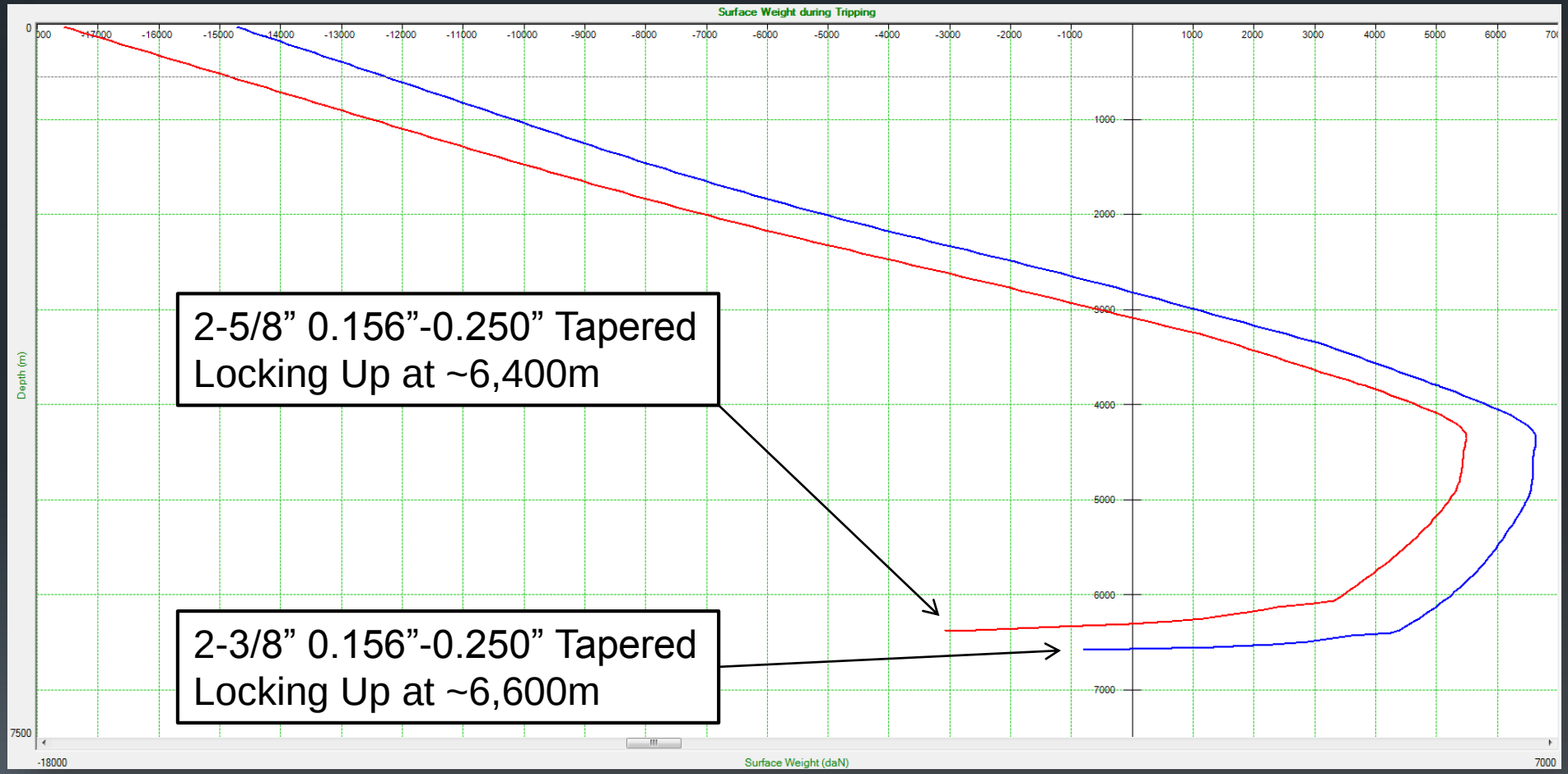
Preliminary String Design and Tubing Force Analysis

- Performed TFAs on the deepest well and most challenging well in the proposed pad
- 7-5/8” Casing to ~4000m, 4-1/2” Production ~4000m-7100m
- 42 MPa expected WHP during milling operation
- Used 0.27 friction coefficient
- 450 L/min fluid rate
- Modeled with an extended reach vibrational tool

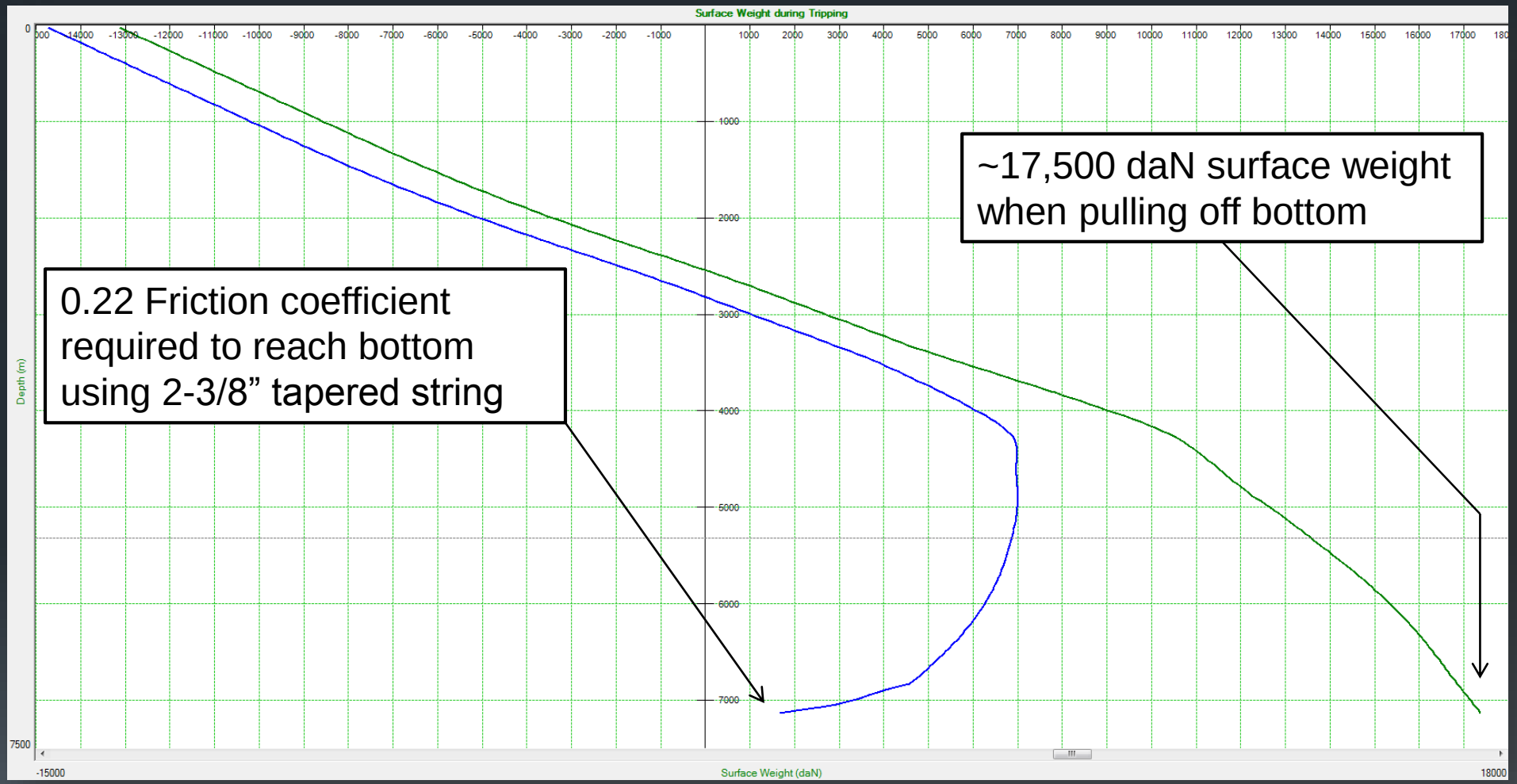
Tubing Force Analysis
Monowall String Design – RIH



Tubing Force Analysis
Tapered String Design - RIH



Tubing Force Analysis
Tapered String Design – 0.22 FC



- Max. pick-up force (80% yield): 23,200 daN end of CT, 55,800 daN surface
- Injector capability: 130,000 lbf. (57,800 daN)

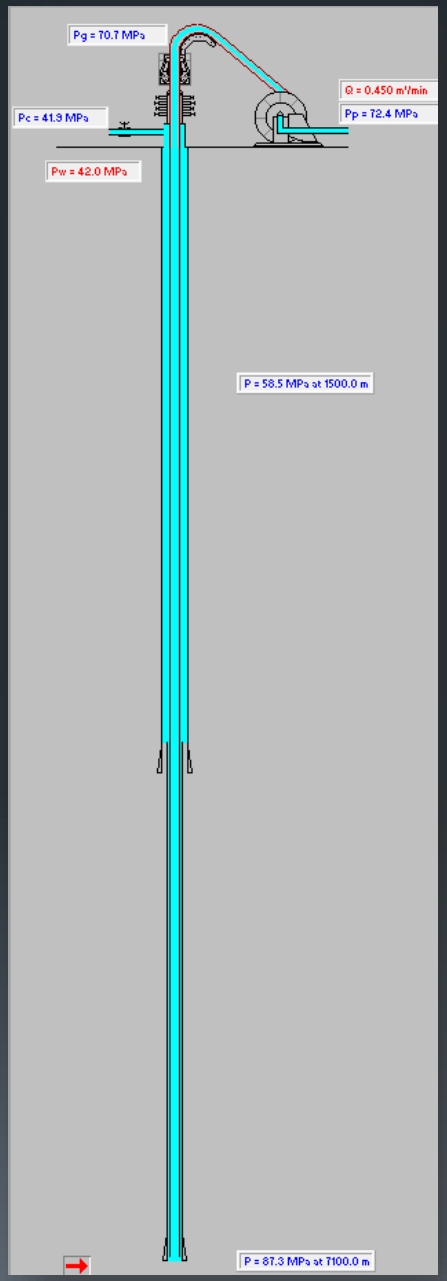
Preliminary String Design and Tubing Force Analysis

- Initial Pad: Performed Tubing Force Analyses (TFA) on a single well.
- 7-5/8” Casing to ~4000m, 4-1/2” Production ~7100m
- 45 MPa expected WHP
- Summary at 0.27 Friction Coefficient:

CT OD	Wall Style	Wall Thickness	String Weight	Lockup Depth
2-3/8”	Monowall	0.250”	167,000 lbs.	6,000m
2-3/8”	Tapered	0.156-0.250”	150,000 lbs.	6,600m
2-5/8”	Monowall	0.203”	168,000 lbs.	6,150m
2-5/8”	Tapered	0.156-0.250”	168,000 lbs.	6,400m

Note: The table above is an abbreviated version of several string designs, friction coefficients, and wellhead pressures simulated.

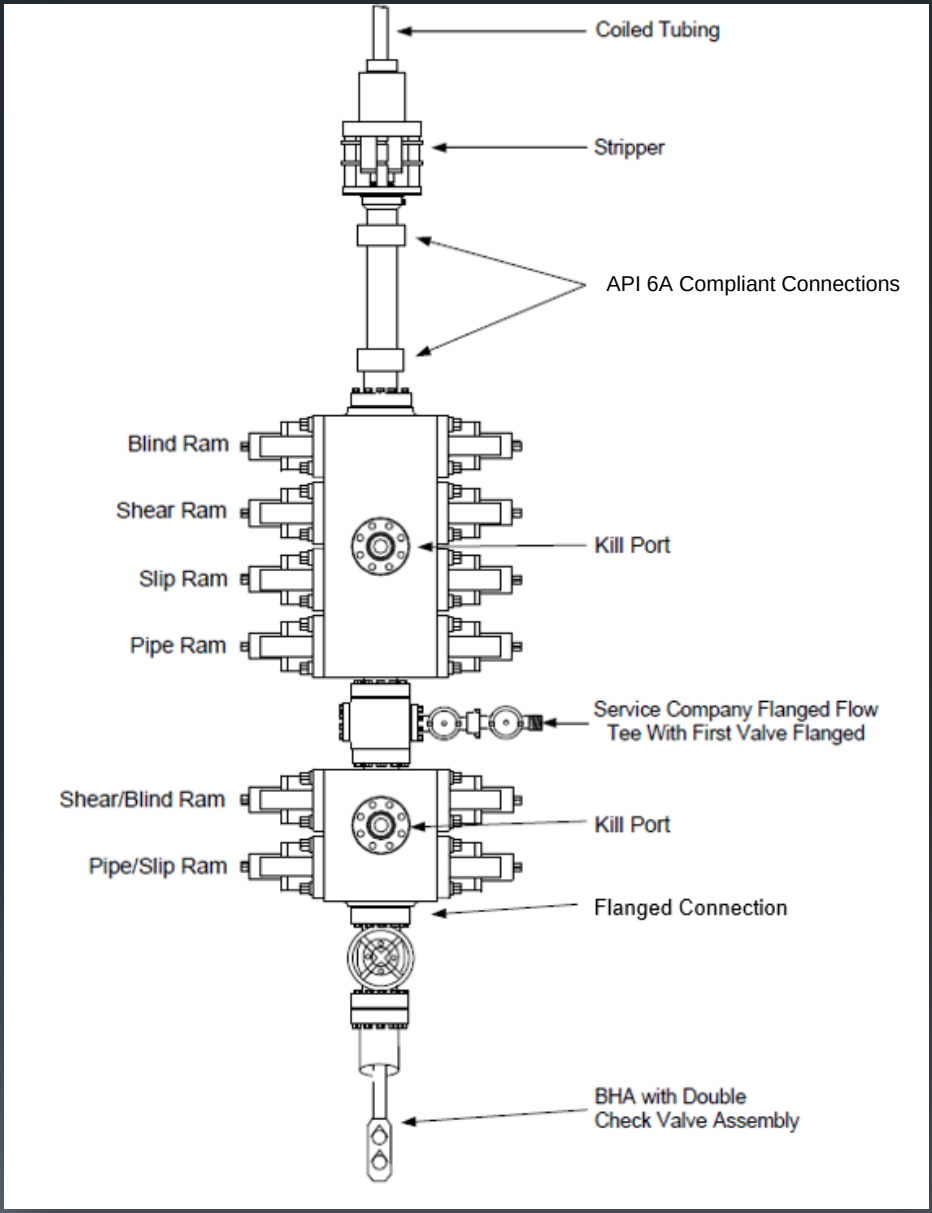
Hydraulic Analysis



	2-3/8”	2-5/8”
Wellhead Pressure	42 MPa	42 MPa
Circulating Rate	450 L/min	450 L/min
Pumping Pressure	72.4 MPa	62.7 MPa
Gooseneck Pressure	70.7 MPa	61.9 MPa
Annular Velocity in 7-5/8” Casing	27 m/min (87 ft/min)	28 m/min (91 ft/min)
Annular Velocity in 4-1/2” Casing	98 m/min (324 ft/min)	115 m/min (377 ft/min)

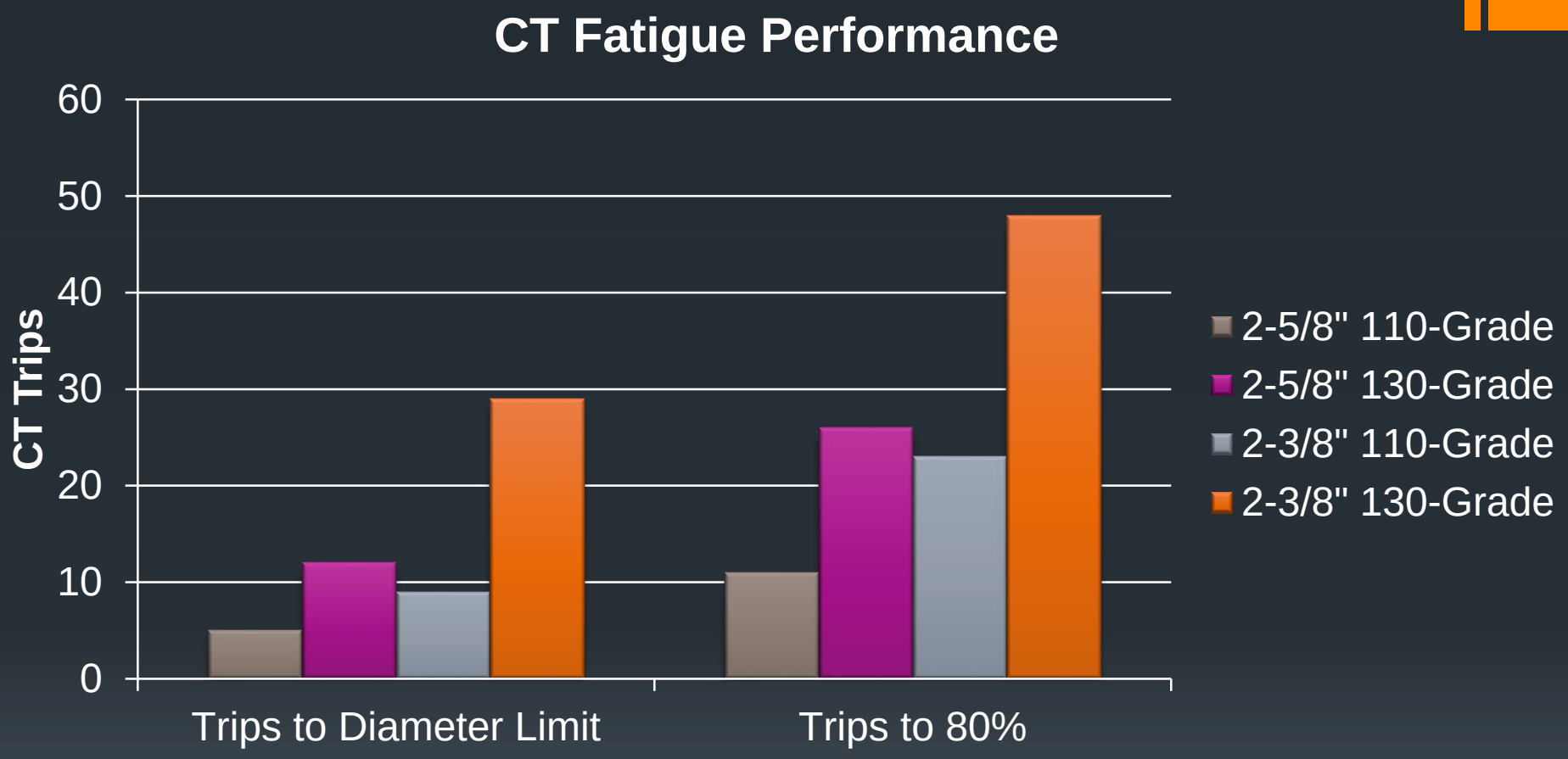
- Fluid pump specifications: 94 MPa rated operating pressure. 800 HP “true twin” quintaplex pumps
- Minimum two fluid pumper requirement
- Well Control: 15,000 psi (103.4 MPa) rated BOP, tandem stripper, lubricator and rotating joint required

Well Control Equipment



- Recommended Category 4 BOP stack and accumulator specification as per recently proposed IRP 21 revision.
- 15,000 psi (103.4 MPa) rated BOP, tandem stripper, lubricator and rotating joint required.
- Minimum two blanking elements, two shearing elements, two slip rams, and two pipe sealing elements in addition to CT stripper.
- API 6A compliant unions above the BOP

Fatigue Analysis

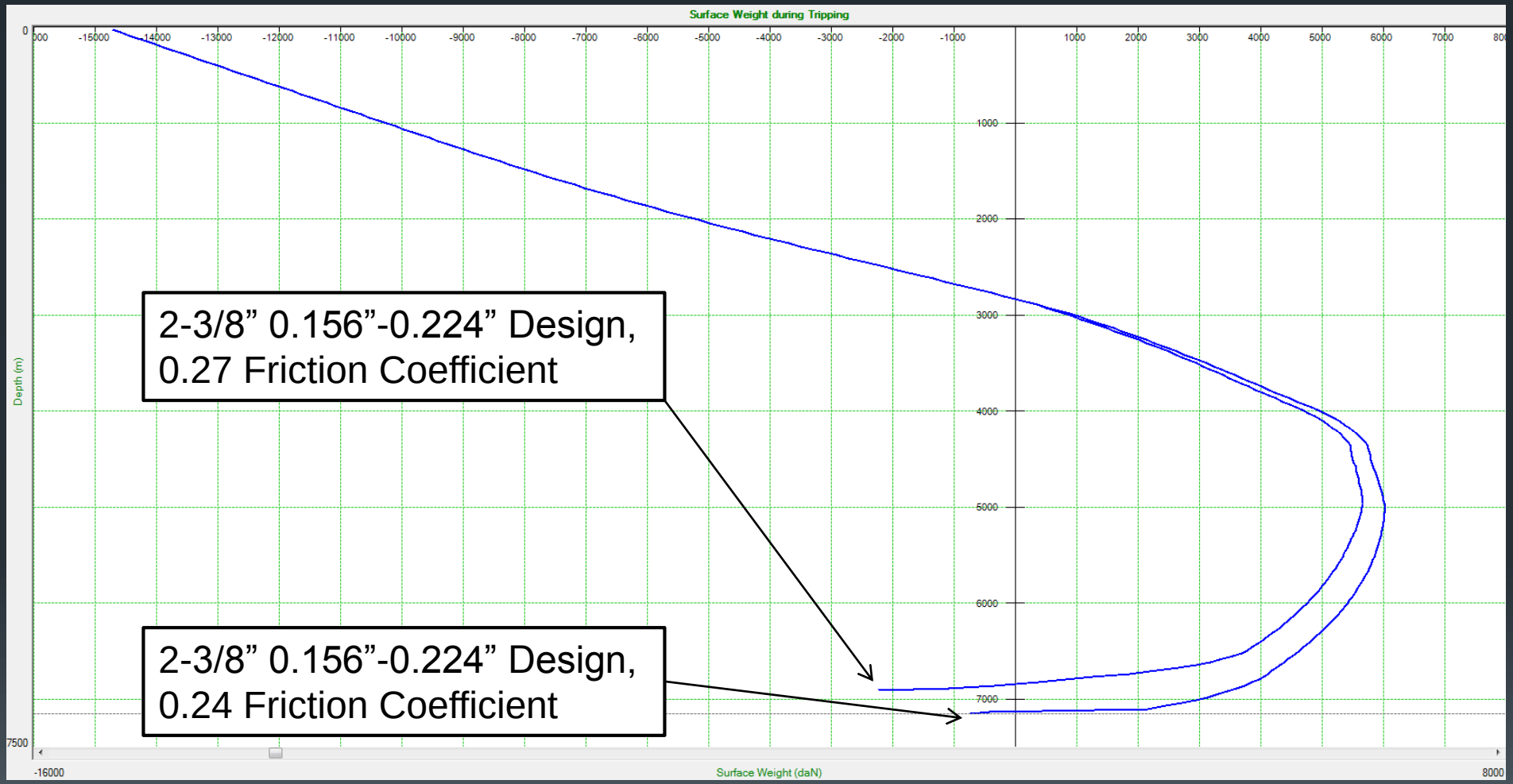


- Fatigue model: Achilles 5.0
- Simulated circulating pressure: 70.7 MPa
- 244 cm reel diameter, 279 cm arch radius
- Diameter limit = ~103% original (e.g. 62.4 mm for 60.3 mm CT)

Preliminary Conclusions

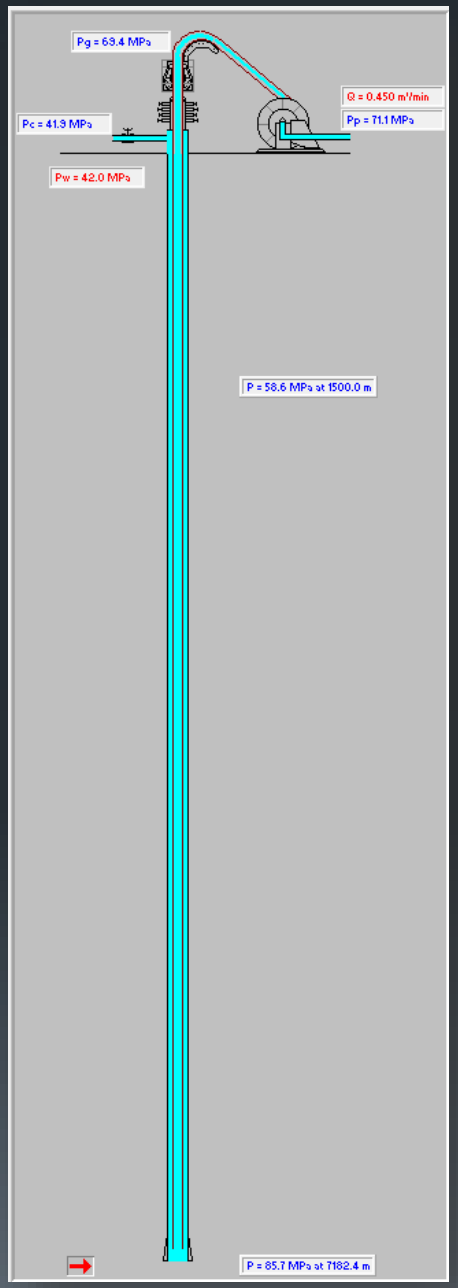
- 2-3/8” 0.156”-0.250” can reach TD with a 0.22 friction coefficient
- >70 MPa circulating pressures required 130-grade material
- Low annular velocity in the 7-5/8” casing
- CT operation would be challenging 7-5/8” to 4-1/2” casing
- Operator revisited job design options in May, 2015
- 8-well pad, repeated analysis on deepest well ~ 7200m
- 5-1/2” casing transition to 4-1/2” production.

TFAs / Hydraulics / Fatigue v2

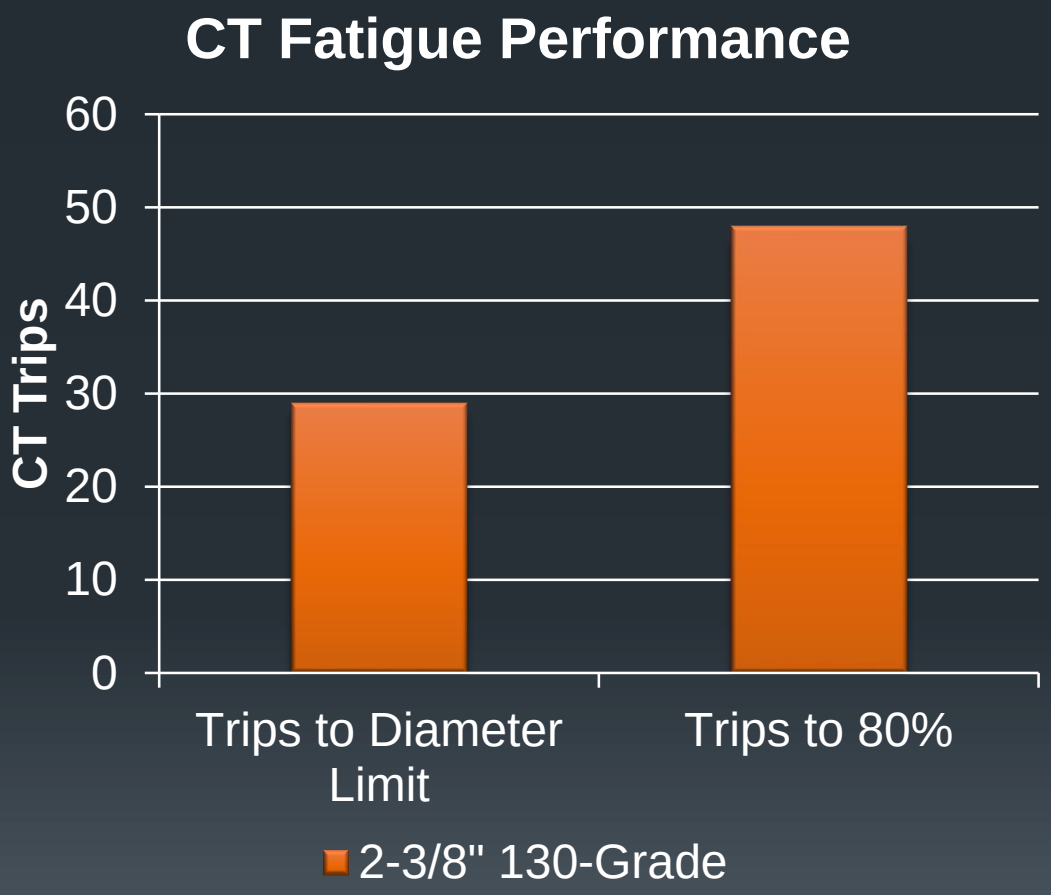


TFAs / Hydraulics / Fatigue v2

	2-3/8”
Wellhead Pressure	42 MPa
Circulating Rate	450 L/min
Pumping Pressure	71.1 MPa
Gooseneck Pressure	69.4 MPa
Annular Velocity in 5-1/2” Casing	54.9 m/min (180 ft/min)

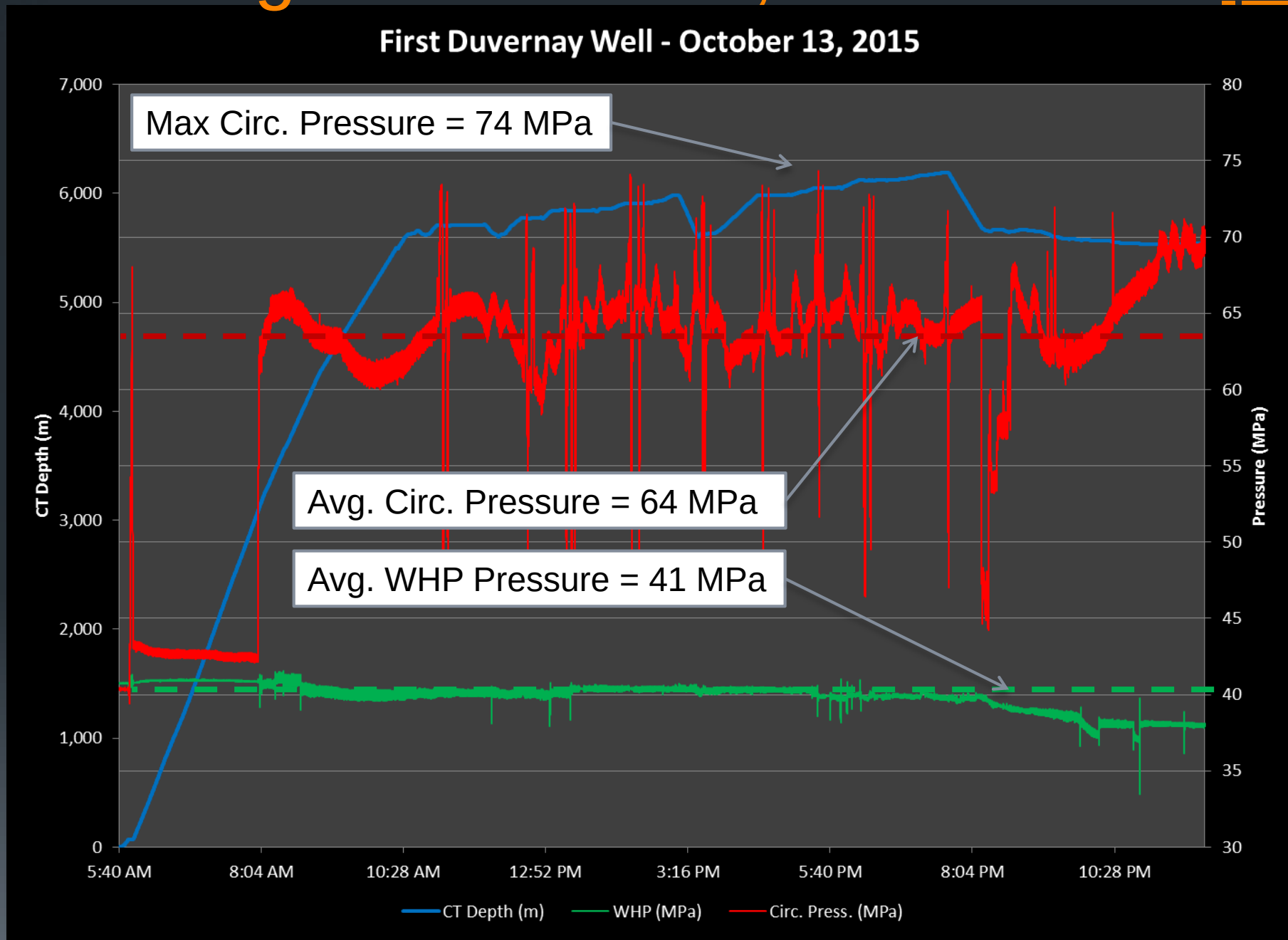


Fatigue Analysis

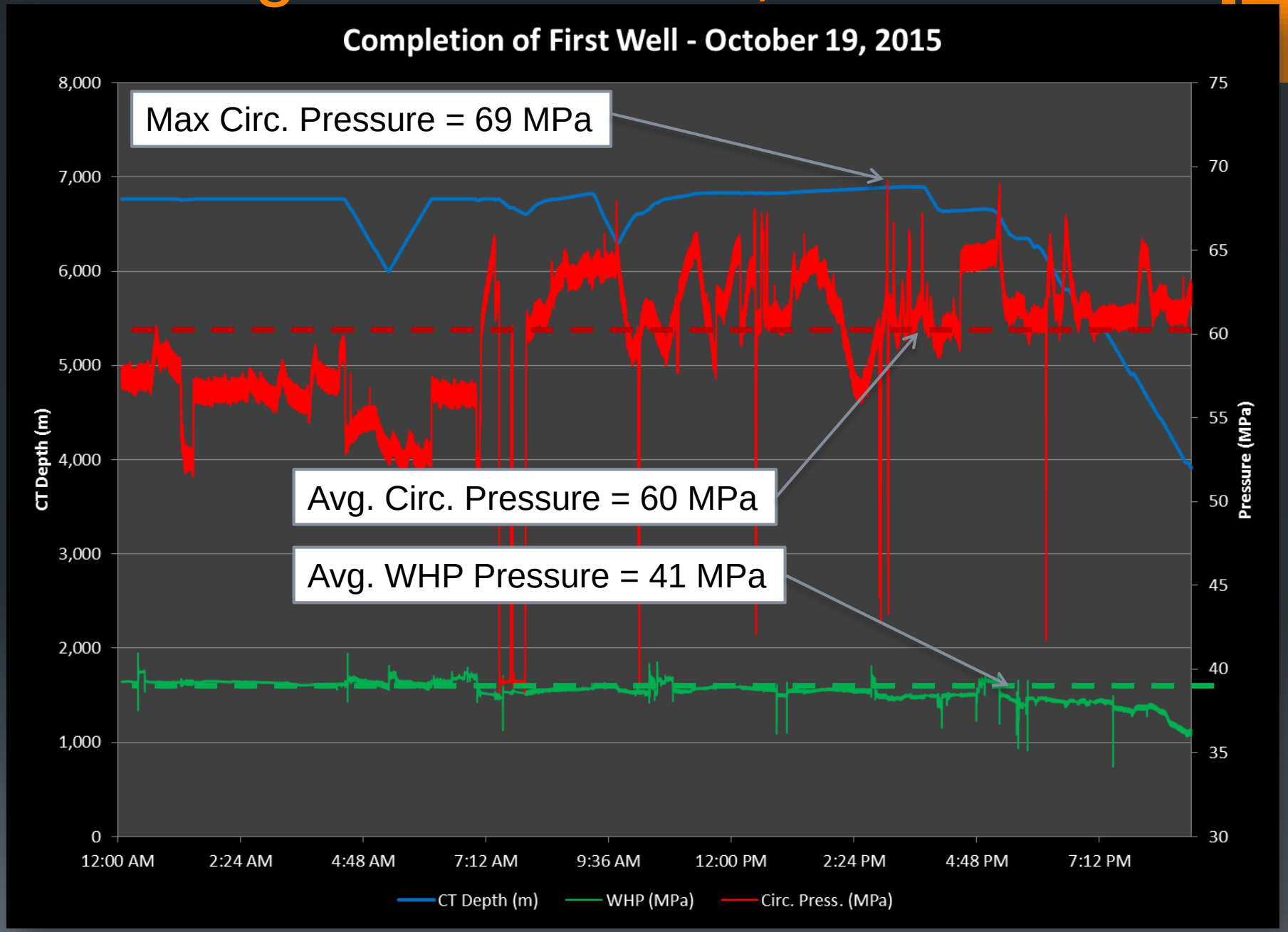


- Fatigue model: Achilles 5.0
- Simulated circulating pressure: 69.4 MPa
- 244 cm reel diameter, 279 cm arch radius
- Diameter limit = ~103% original (e.g. 62.4 mm for 60.3 mm CT)

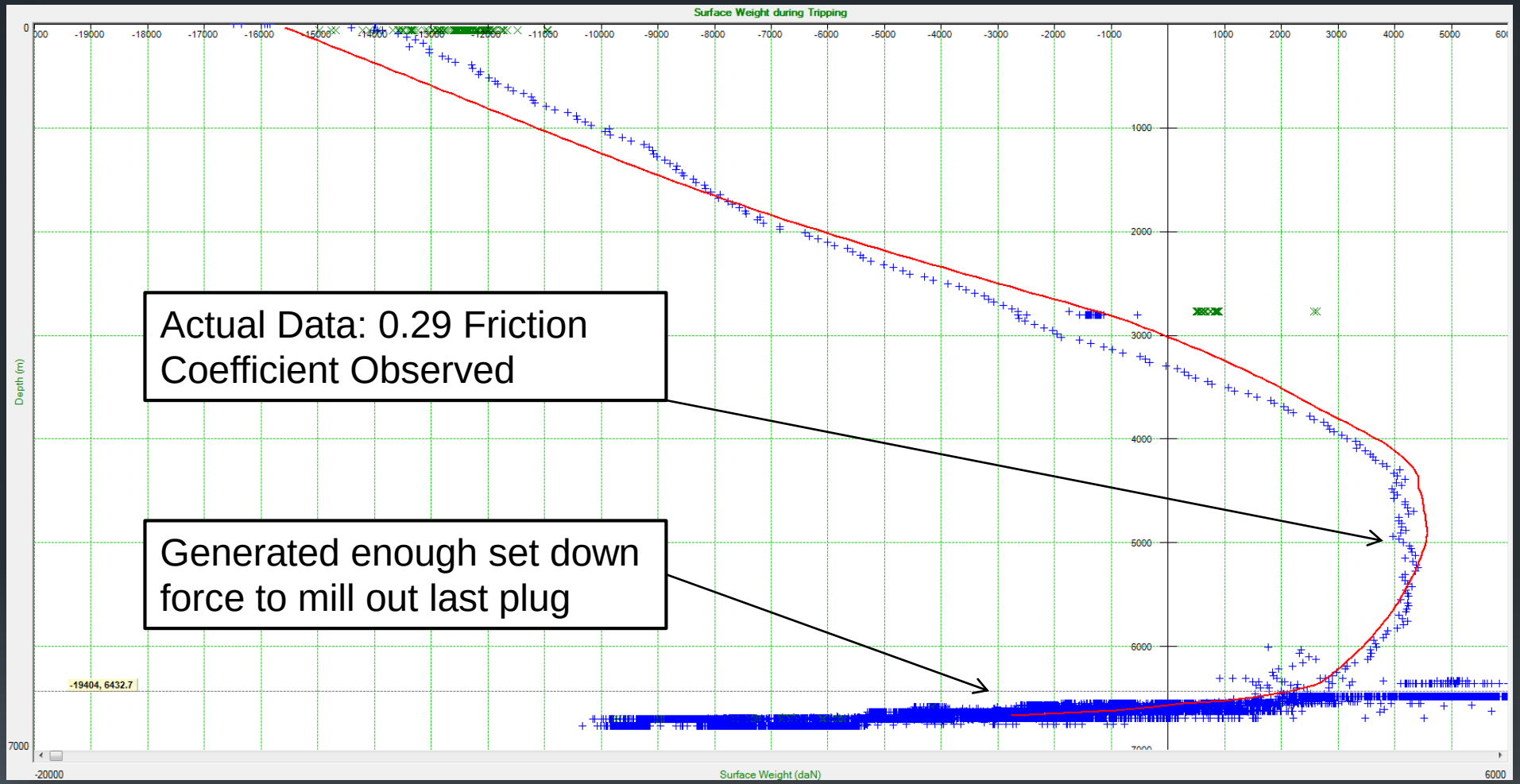
CT String #1 – October, 2015



CT String #1 – October, 2015



Friction Match – First well



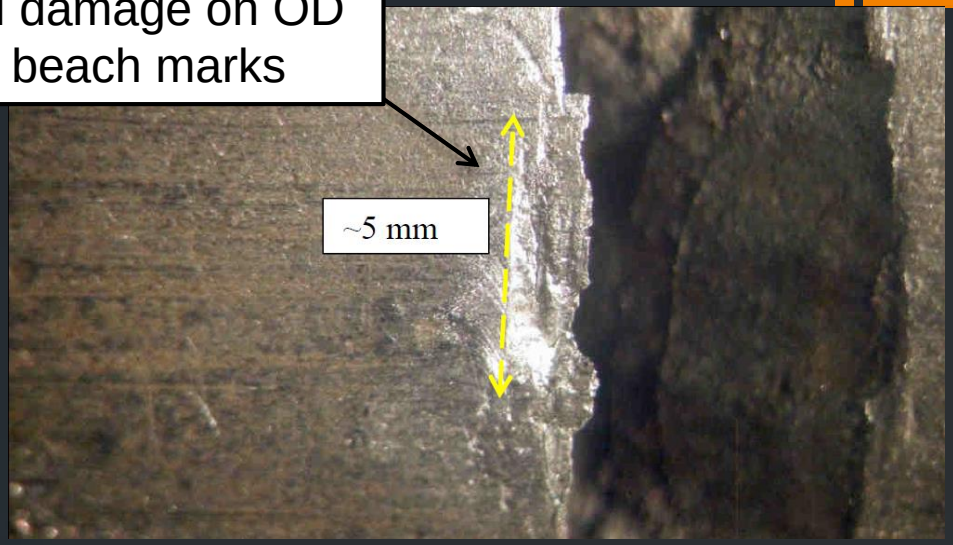
First Well Summary

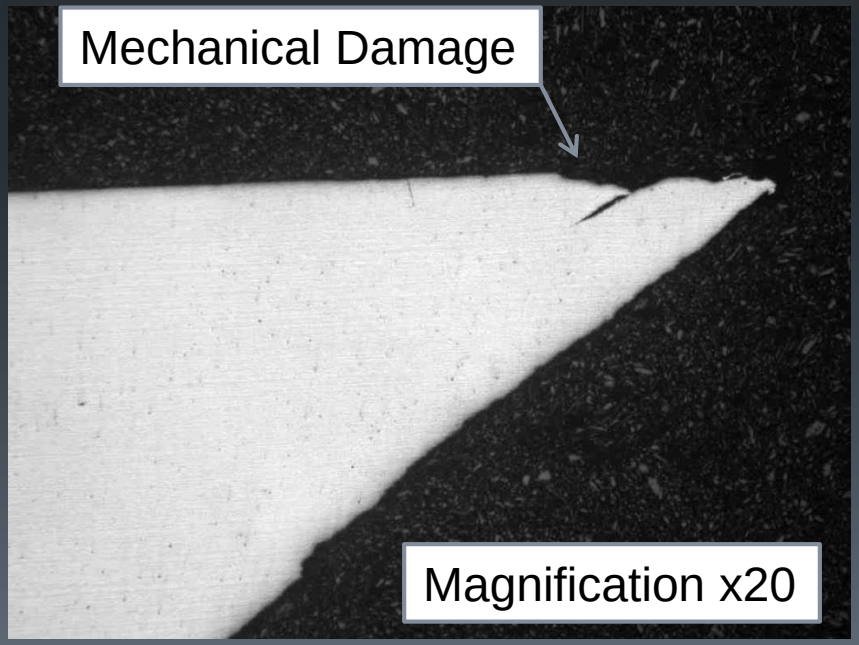
- Casing damage – difficulties milling, multiple trips performed.
- Operations included cleanouts, venturi runs, and fishing.
- Generated 162,322 running meters and then experienced a string failure.

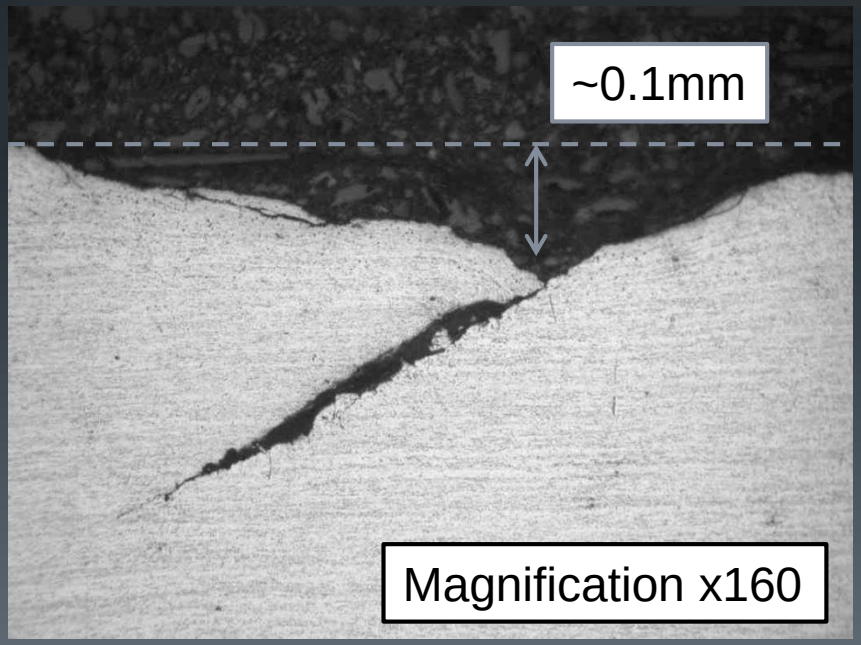
String Failure

- Occurred at 3,957m from the whip end. 30% fatigue (using a 1.2 application factor).
- Performed an ultrasonic and MFL inspection on the entire string
- Third party failure analysis: fracture occurred due to a high stress, low cycle, crack on the CT OD initiated shallow mechanical damage.
- No evidence of substandard material supported by a tensile test performed by the manufacturer.

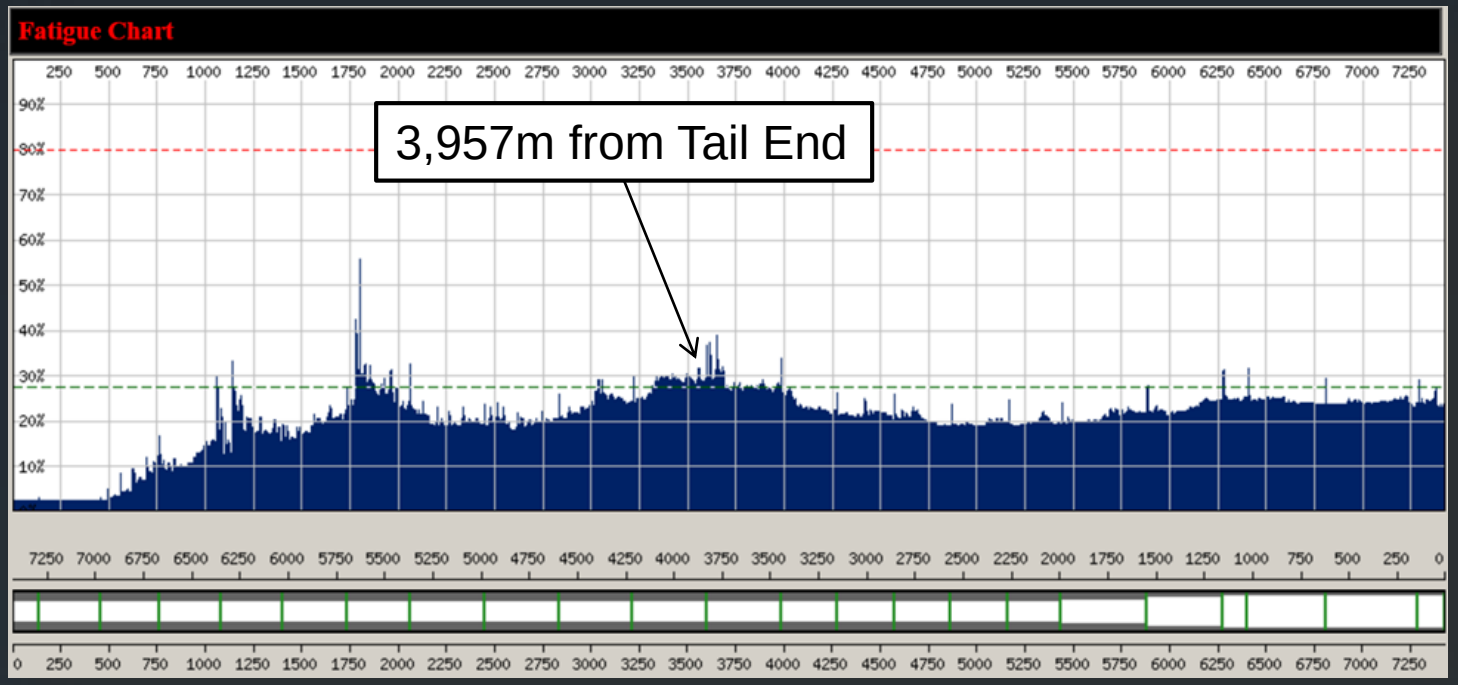
Failure Investigation

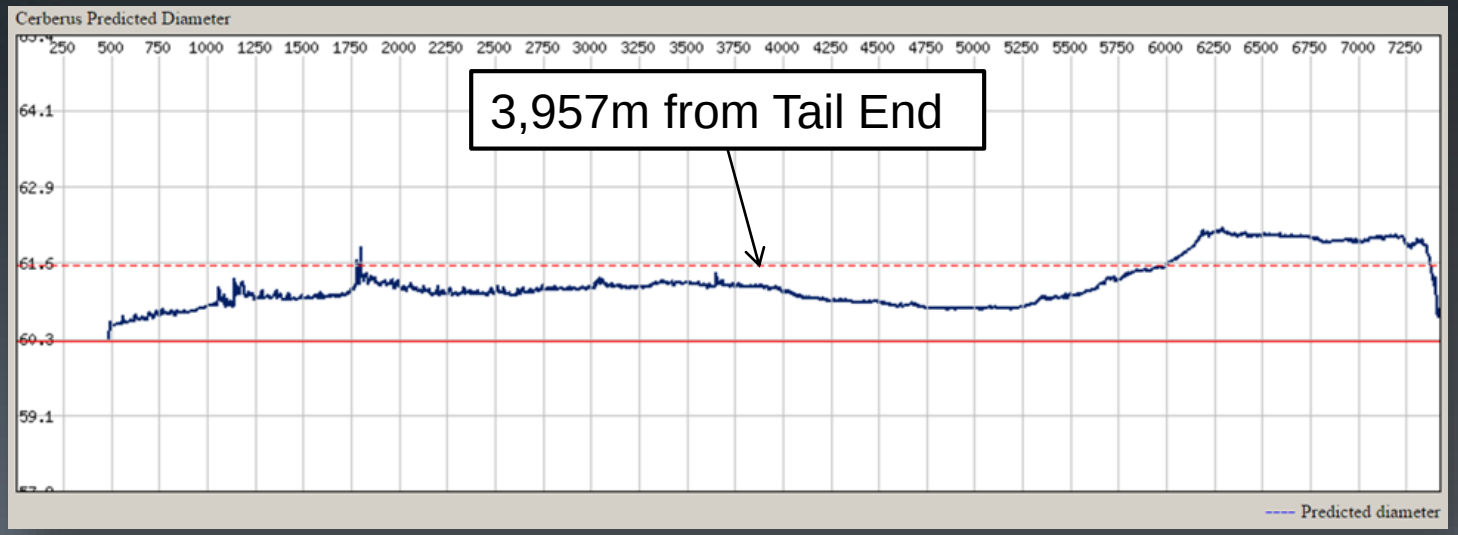




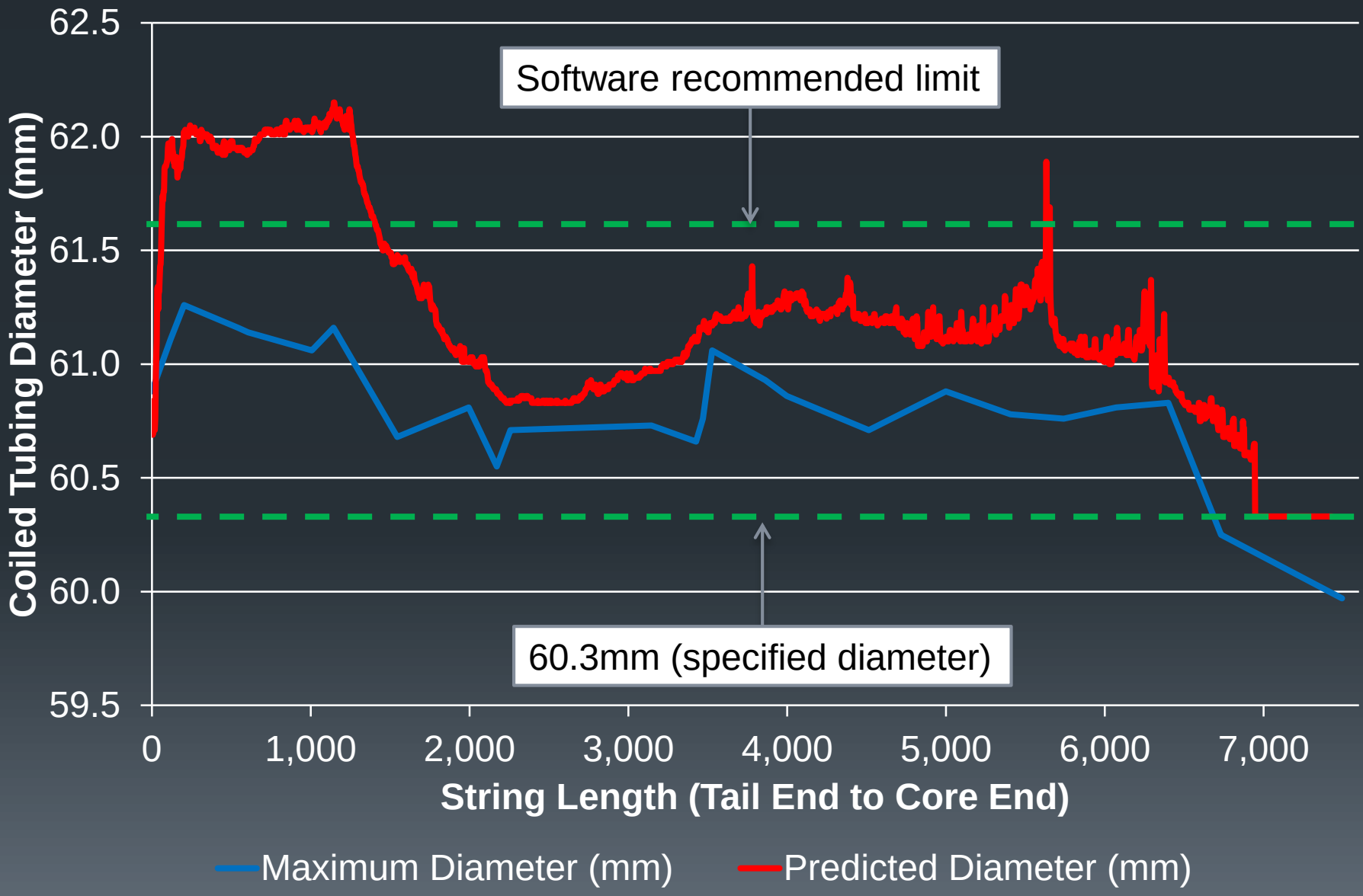


Fatigue and Diameter Analysis

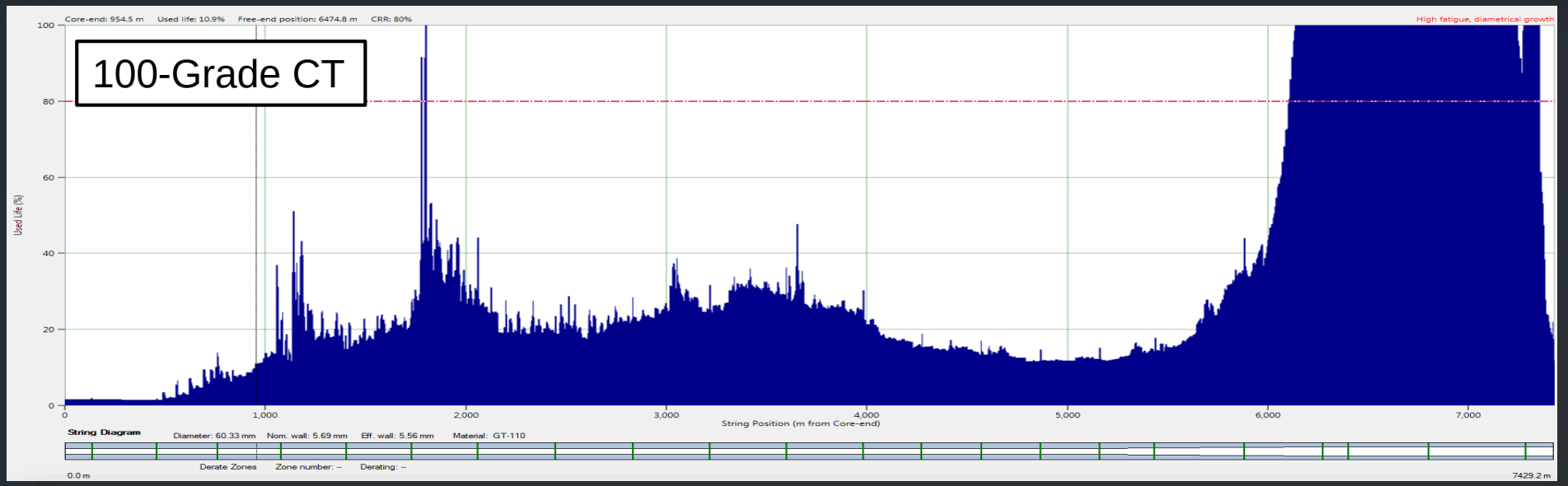


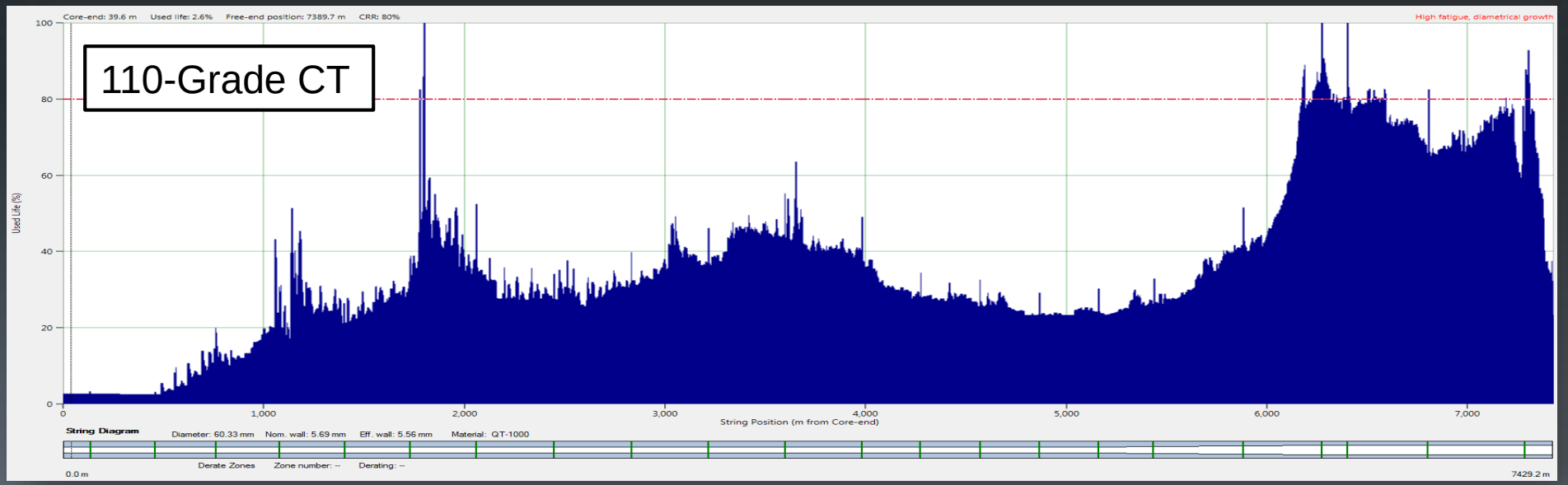


Diameter Growth

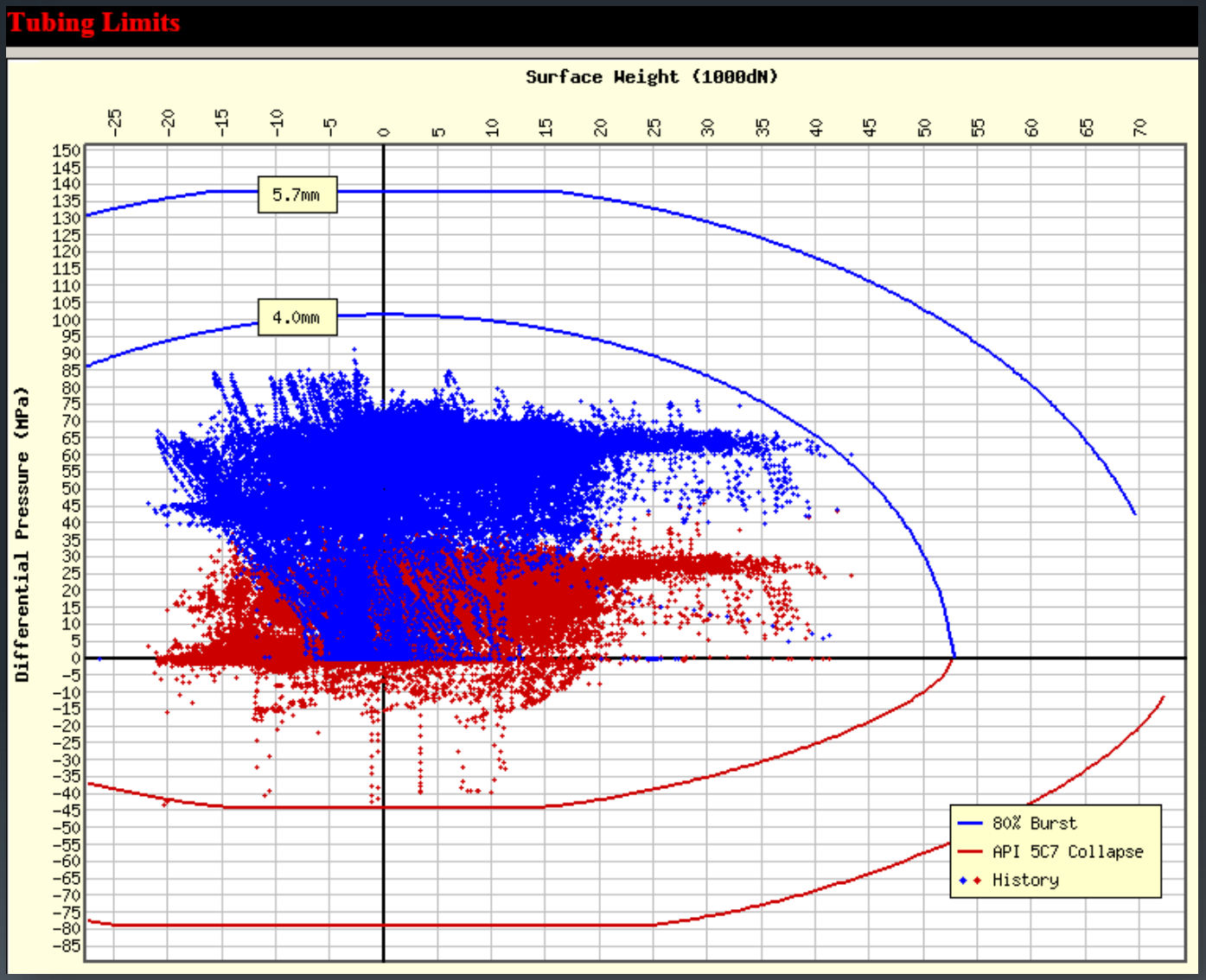


Equivalent 100/110-Grade Fatigue



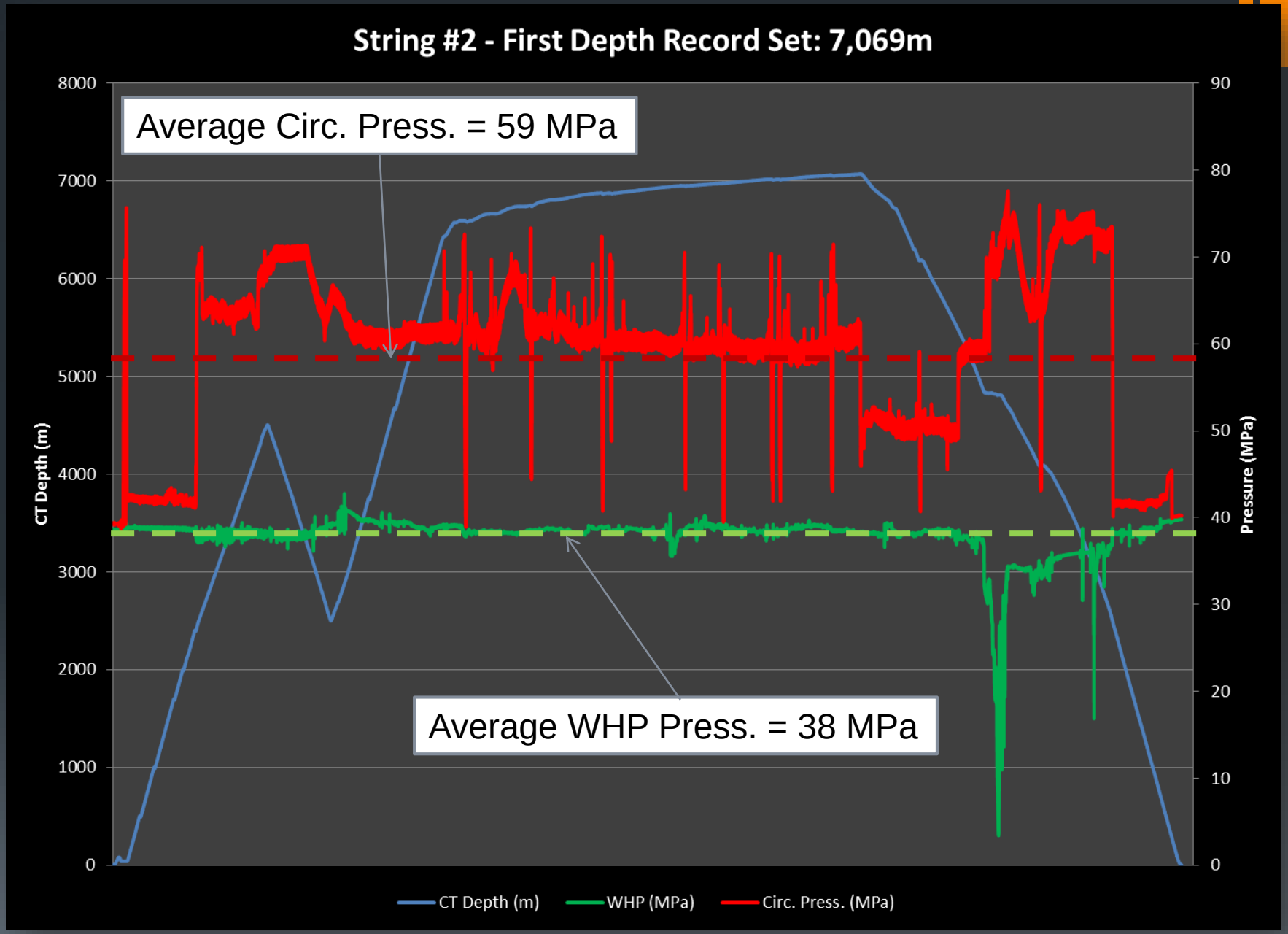


Coiled Tubing Limits



Average Lifetime Moving Pressure = 64 MPa

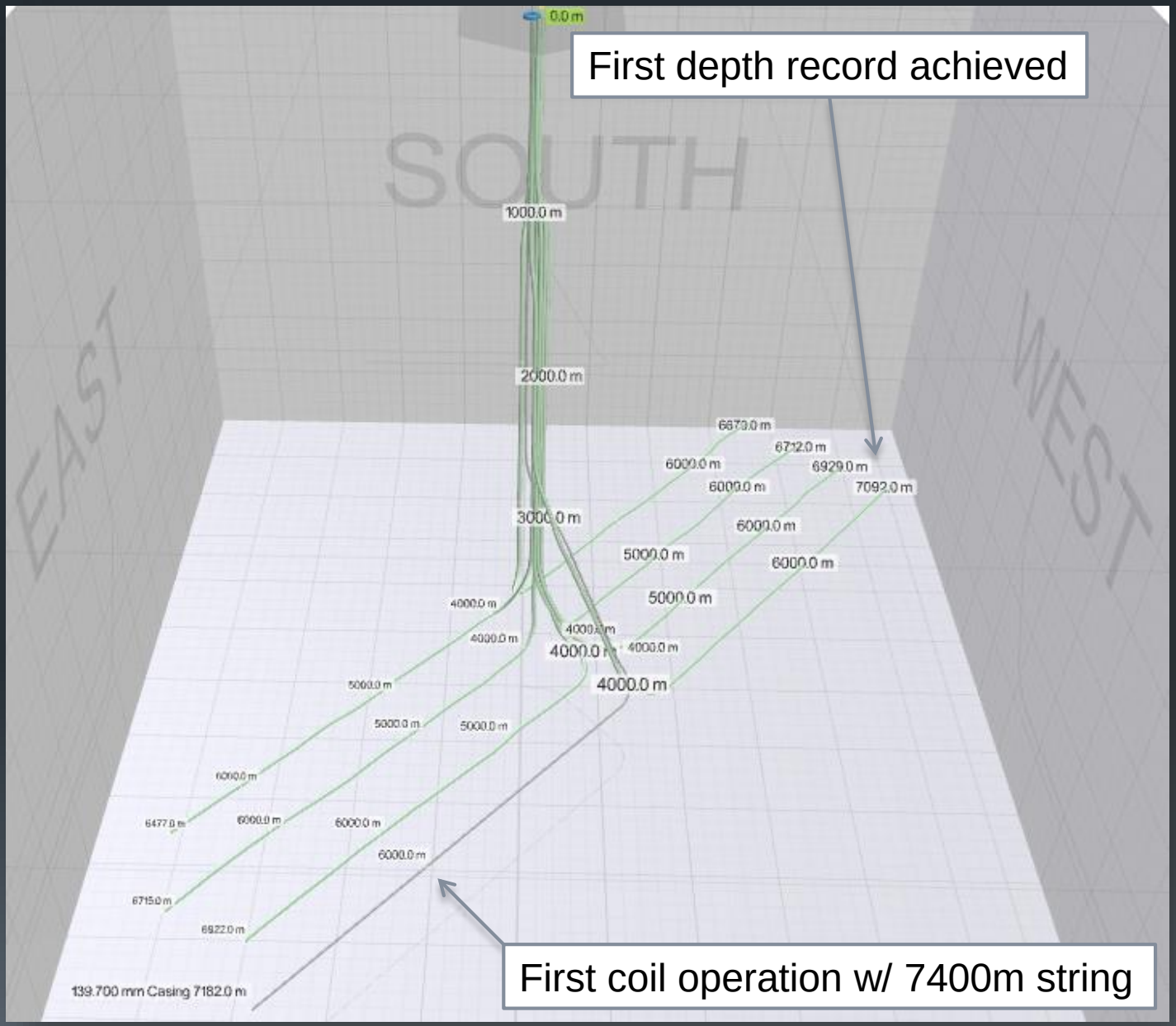
CT String #2 – October, 2015



Project Coiled Tubing History

String No.	Date First Used	Running Meters	Fatigue	Status
1	July, 2015	162,322	56%	Retired
2	Oct, 2015	135,000	39%	Retired
3	Feb, 2016	131,300	36%	Retired
4	March, 2016	131,400	36%	Retired
5	July, 2016	129,000	47%	Retired
6	Feb, 2017	74,488	30%	In Use

Initial 8-Well Pad Summary

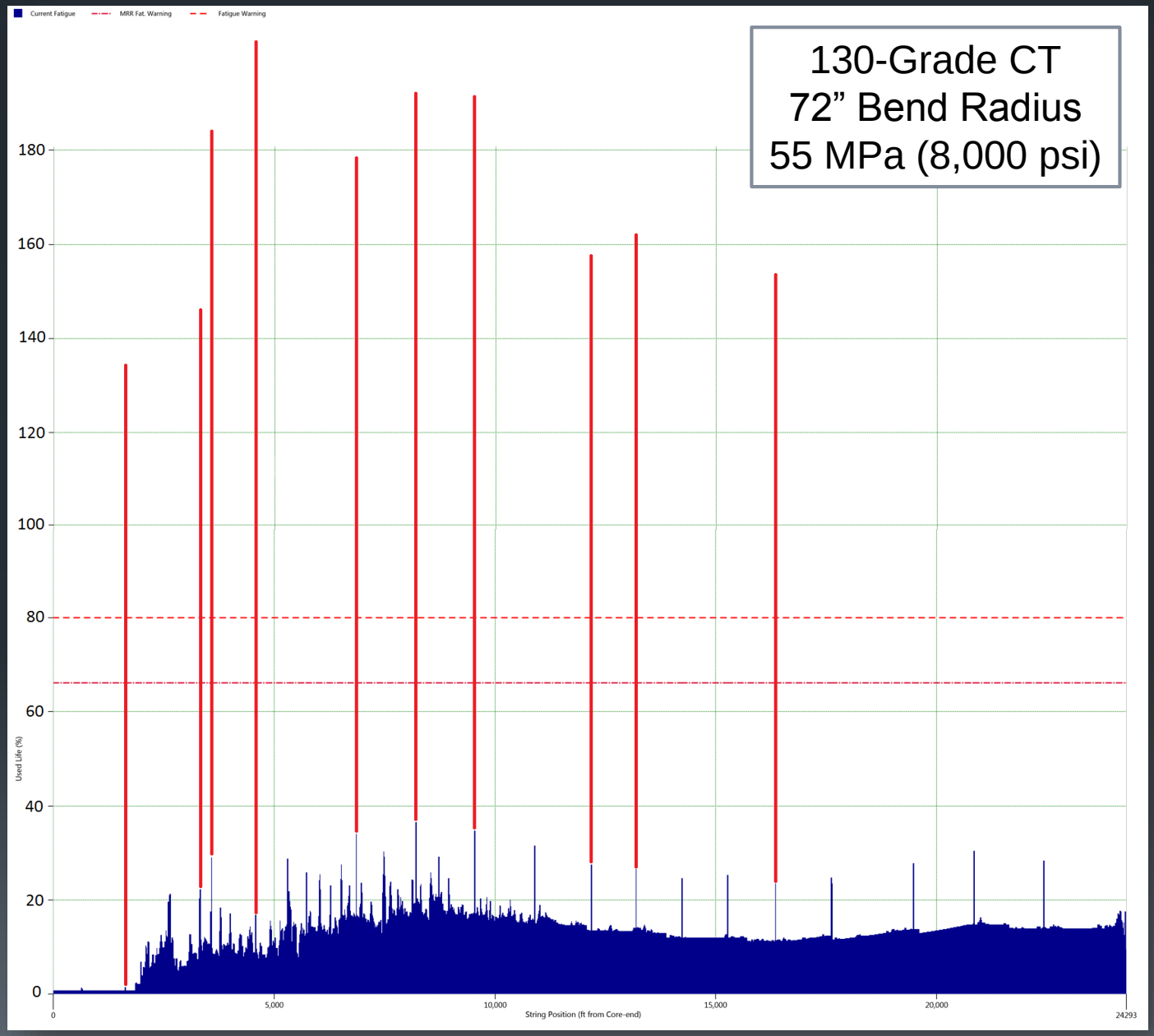


CT String #4 - Fatigue Bend Testing

Weld No.	Nom Wall (in)	Acc. Fatigue	Loc. from Tail End (m)	Cycles to Failure	Cerberus Prediction	Bend Fatigue Addition	Total Fatigue
1	0.156	17.5%	6	Not Tested			
2	0.156	28.3%	569	26	81	32.1%	60.4%
3	0.156	30.3%	1,052	43	81	53.1%	83.4%
4	0.175	27.8%	1,468	67	105	63.8%	91.6%
5	0.203	24.7%	2,036	139	138	100.7%	125.4%
6	0.224	23.4%	2,418	212	162	130.9%	154.3%
7	0.224	25.3%	2,753	Not Tested			
8	0.224	24.5%	3,064	Not Tested			
9	0.224	26.5%	3,382	221	162	136.4%	162.9%
10	0.224	27.5%	3,689	210	162	129.6%	157.1%
11	0.224	31.5%	4,082				
12	0.224	34.7%	4,494	252	162	155.6%	190.3%
13	0.224	36.5%	4,900	253	162	156.2%	192.7%
14	0.224	34.0%	5,311	233	162	143.8%	177.8%
15	0.224	25.8%	5,685	Not Tested			
16	0.224	28.7%	5,788	Not Tested			
17	0.236	16.7%	6,007	327	174	187.9%	204.6%
18	0.236	29.0%	6,312	274	174	157.5%	186.5%
19	0.236	20.9%	6,600	218	174	125.3%	146.2%
20	0.236	1.4%	6,906	231	174	132.8%	134.2%
21	0.236	1.3%	7,207	Not Tested			

- Manufacturer performed fatigue bend testing on String # 4 post-retirement
- Extracted and tested 14 bias welds out of 21
- Bend radius = 72”, Circ. Press. 55 MPa (8000 psi)
- Pitting corrosion found on samples 2, 3, and 4

CT String #4 - Fatigue Bend Testing

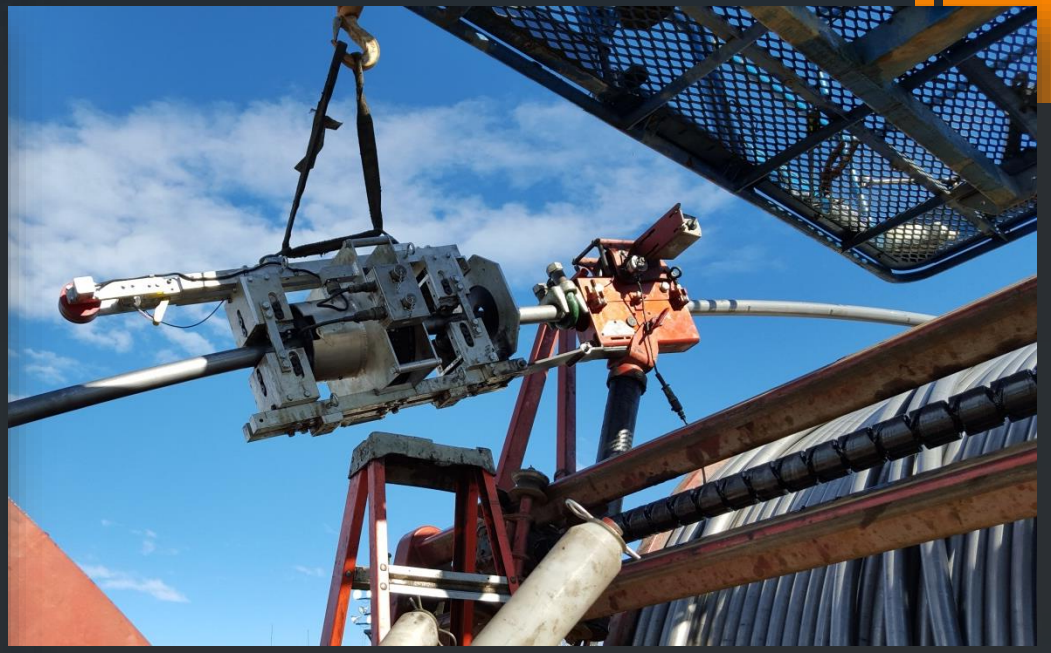


CT String #5 – Fatigue Bend Testing

Weld No.	Nom Wall (in)	Acc. Fatigue	Test Radius (in)	Loc. From Tail End (m)	Proposed Fatigue
5	0.175	24.0%	72	453	96.4%
6	0.203	22.2%	72	1,017	125.1%
7	0.224	19.4%	72	1,398	141.0%
8	0.224	20.8%	72	1,792	228.2%
9	0.224	25.3%	72	2,190	158.6%
10	0.224	28.0%	72	2,587	182.9%
11	0.224	33.4%	72	2,989	174.8%
12	0.224	36.2%	72	3,388	191.8%
13	0.224	27.3%	72	3,785	248.3%
16	0.224	24.9%	48	4,966	158.2%
17	0.224	18.6%	48	5,350	147.5%
18	0.224	5.6%	48	5,743	123.4%
19	0.224	1.2%	48	6,132	112.3%

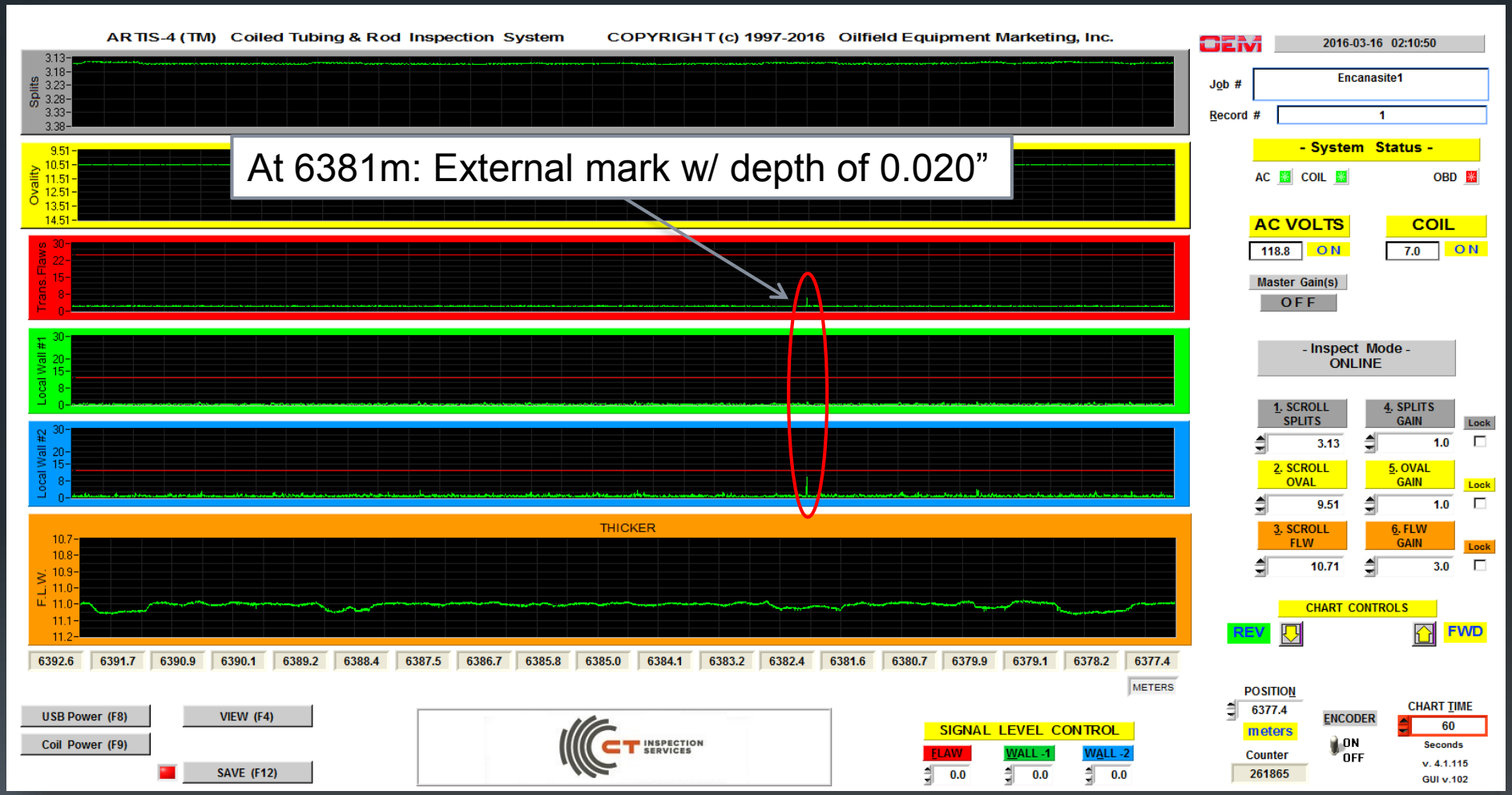
- Manufacturer's conclusions:
  - Model is extremely conservative with the larger bend radius
  - Model is suitably conservative with the smaller bend radius

String #6 - CT Real-Time Inspection

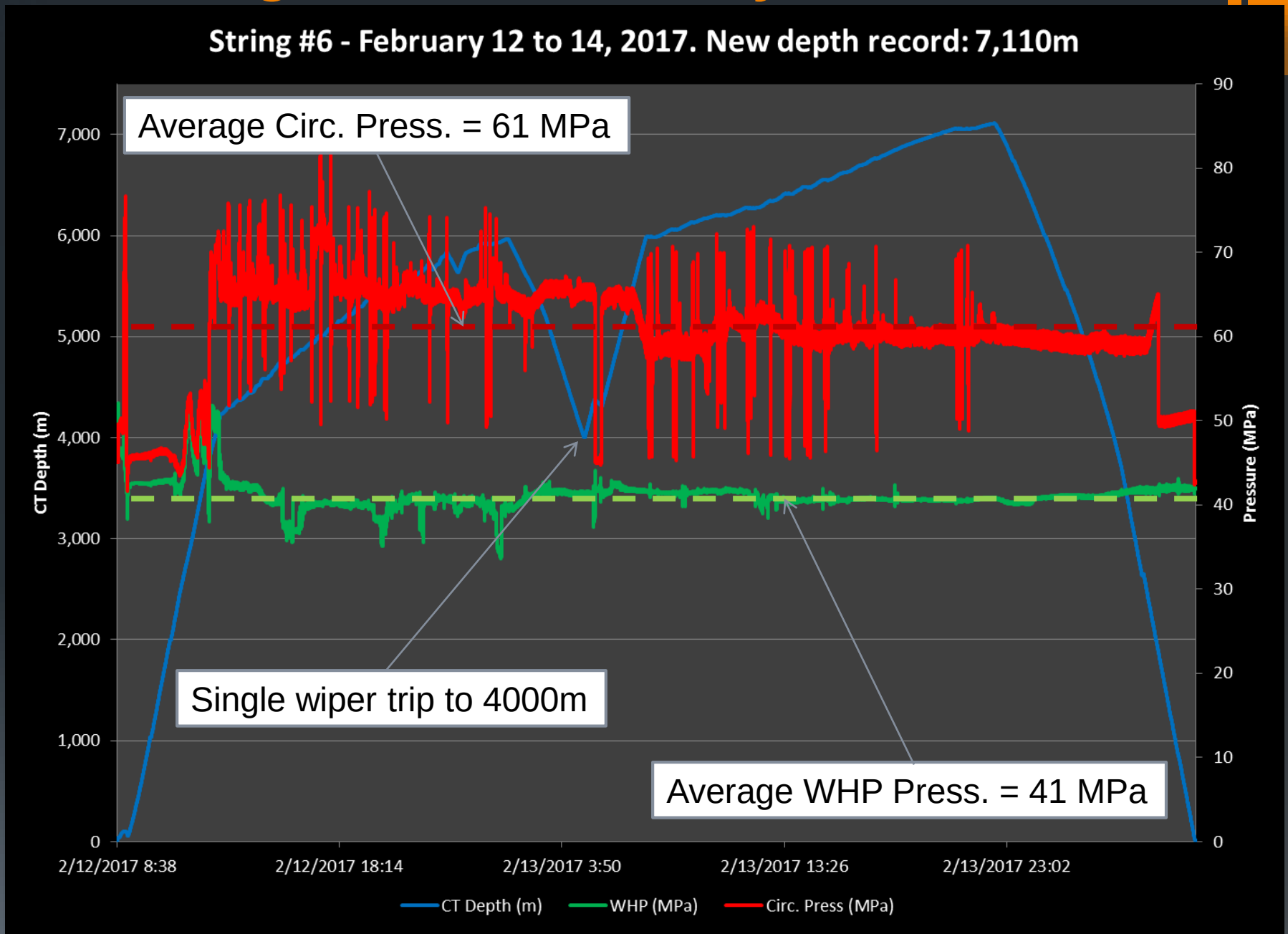


- Using electromagnetic induction (EMI) measures wall thickness, ovality, and anomalies.
- Required securement to counter arm.
- Inspected CT while pulling out of hole.
- Required minimal vibration and consistent pull out of hole speed.
- Performed a single inspection, require additional opportunities.

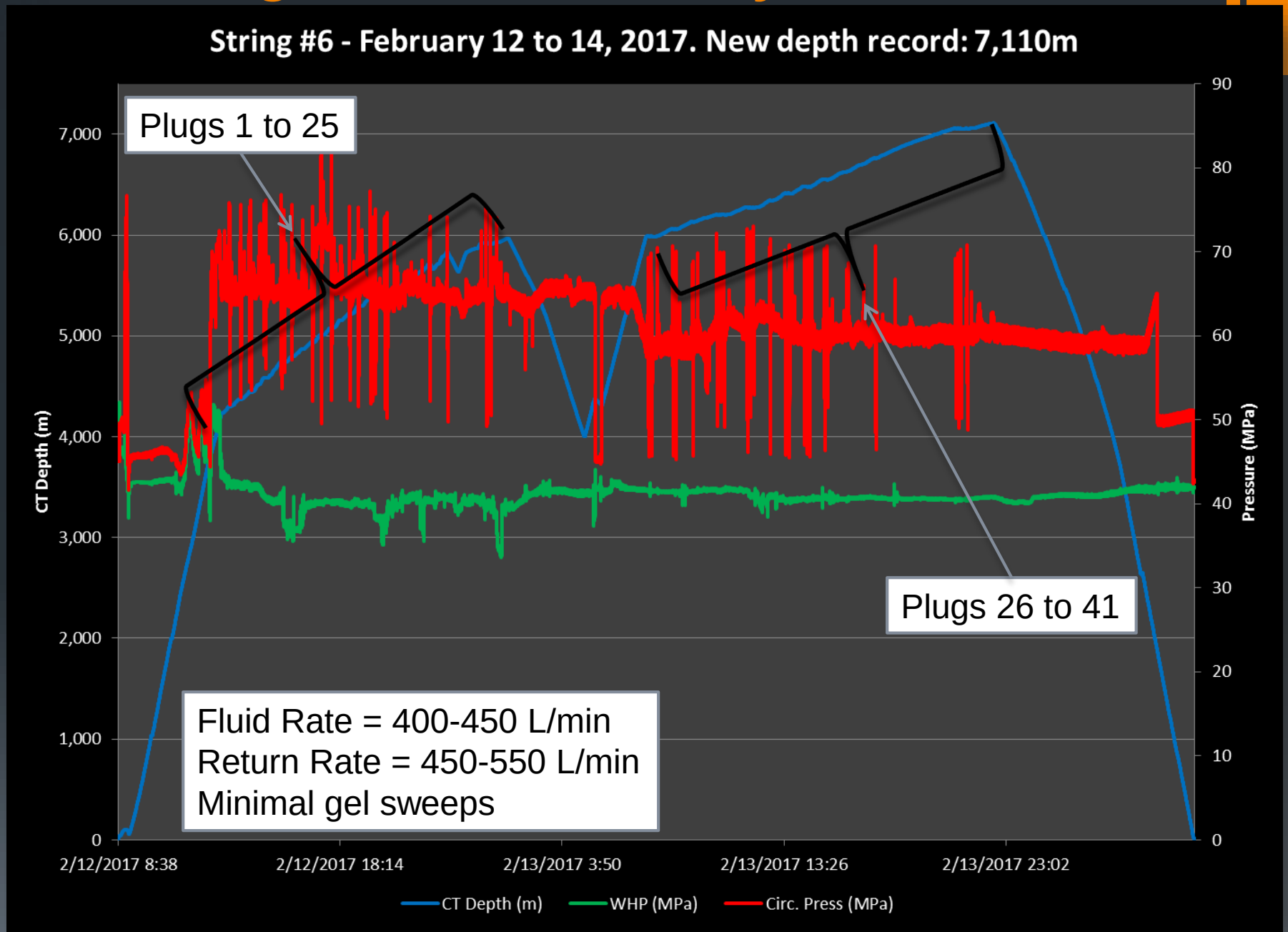
String #6 - CT Real-Time Inspection



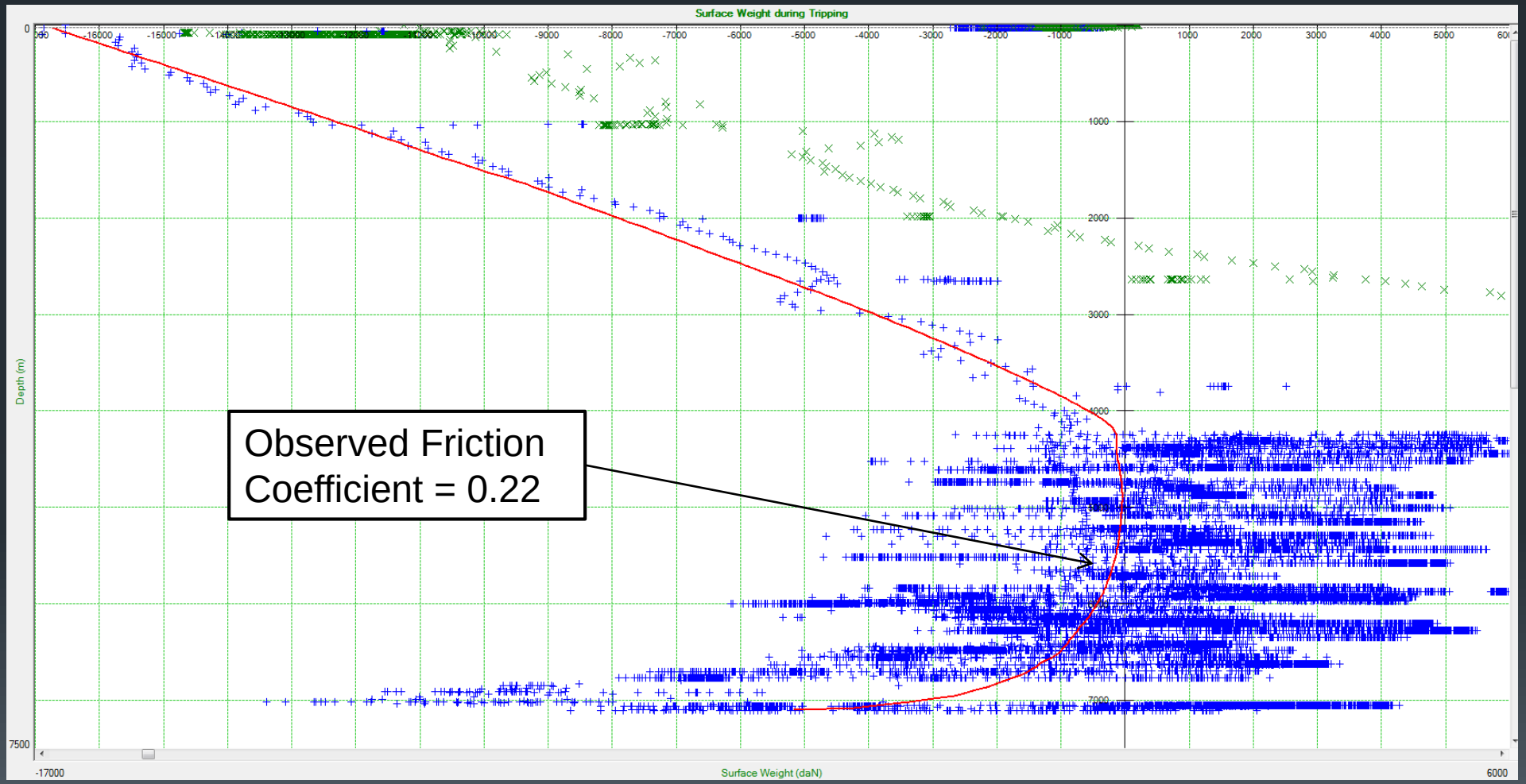
CT String #6 – February, 2017



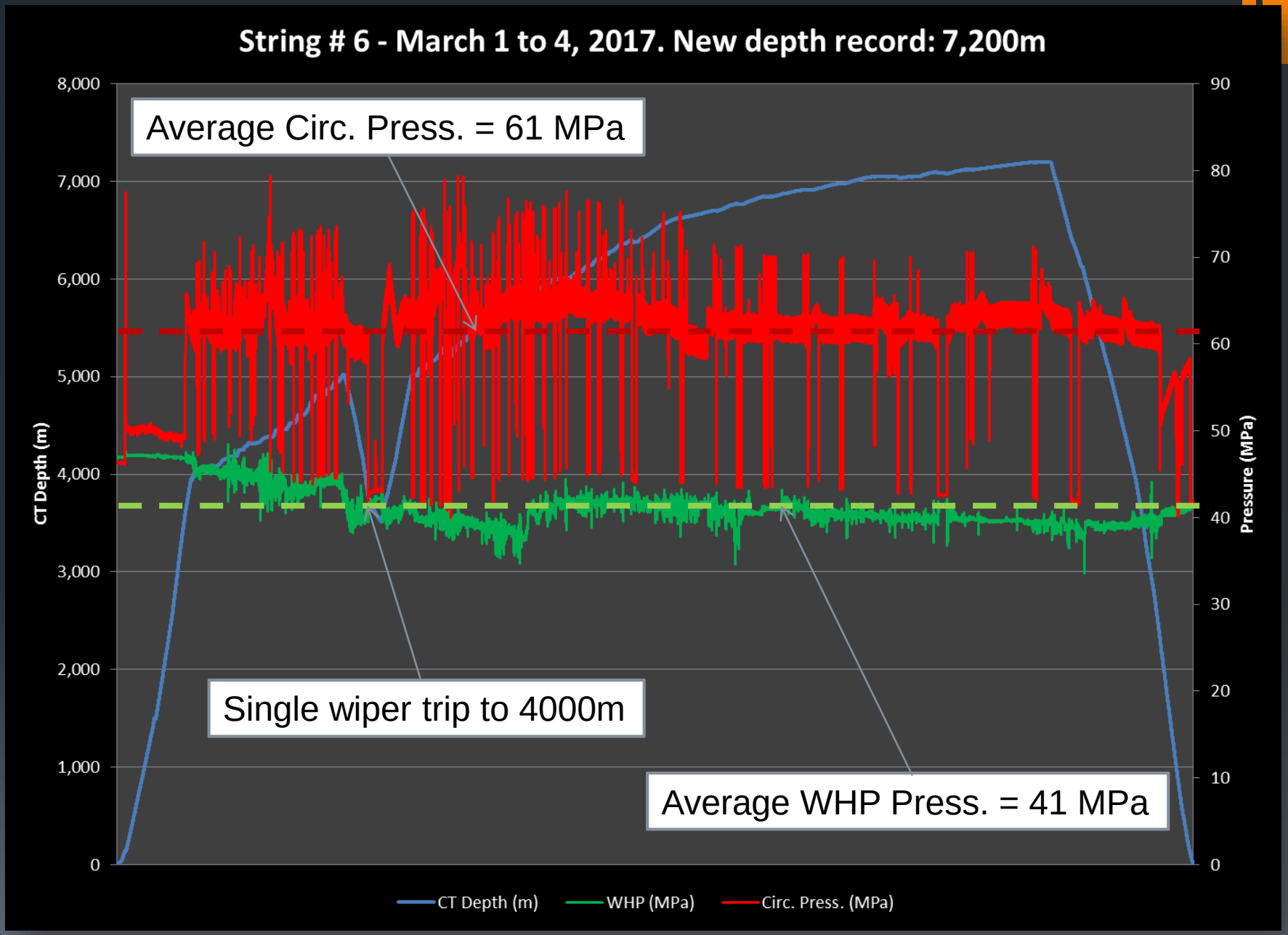
CT String #6 – February, 2017



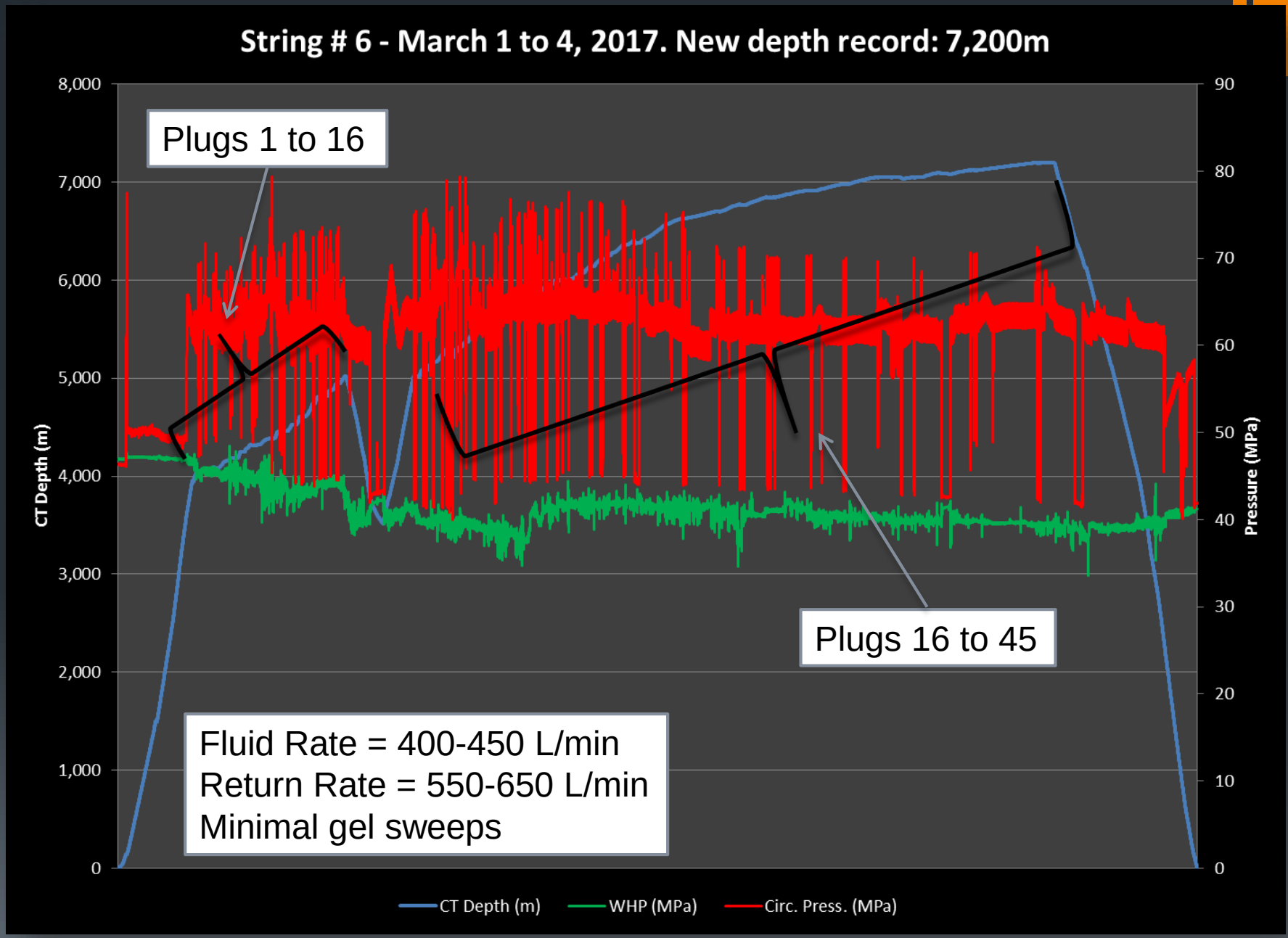
Friction Match – February, 2017



CT String #6 – March, 2017



CT String #6 – March, 2017



Conclusions

- 130-grade coiled tubing with an aggressive taper required to successfully mill out plugs.
- Maintaining a conservative retirement criteria despite fatigue bend testing providing confidence.
- Simulation software used overestimates diameter growth.
- 100-150 L/min return rate with minimal gel sweeps produced low friction coefficients and enabled wiper trip minimization.

Recommendations

- Additional work needs to be done on a fatigue model that closer reflects reality.
- An improved diameter growth model needs to be developed.
- Casing issues present a great opportunity for tool manufacturers to develop new technology.

Thank You

- Ben Layton, STEP
- Vladimir Ivaniuk, STEP
- John Cairns, STEP
- Kevin Elliott, Quality Tubing
- Garrett Sears, CTI
- Cody Koch, CTI
- Chris McClelland, CJ-CSM
- ICoTA Canada