Ask Echometer Online Seminar – May 27, 2020

Examples of Forces NOT Accounted for by the Wave Equation

TOTAL ASSET MONITOR (TAM)

http://www.echometer.com/Software/Total-Asset-Monitor

"EXAMPLES OF FORCES NOT ACCONTED BY THE WAVE EQUAYION", Rowlan, Haskins, Taylor, Skinner, SWPSC 2018

"DOG LEG SERVERITY (DLS) AND SIDE LOAD (SL) RECOMMENDATIONS TO DRILLING", Hein & Rowlan, SWPSC 2019

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Introduction

- **Use field measured dynamometer data to show examples of different types of forces NOT accounted for by the wave equation.**

- **Forces are:**
  1. **Mechanical Friction**
  2. **Piston Force on polished rod due to tubing back pressure**
  3. **True Vertical Rod Weight.**

- **Mechanical friction due to**
  1. **Over-tight Stuffing Box**
  2. **Down hole sticking due to Severe Dog Leg in wellbore profile**
  3. **Friction from Paraffin along a section of the rod string.**

- **Not Planning to Discuss Mechanical Friction Resulting from Drag between moving rods/couplings and tubing due to deviation**

$$\frac{\partial^2 u}{\partial t^2}(x,t) = a^2\frac{\partial^2 u}{\partial x^2}(x,t) - c\frac{\partial u}{\partial t}(x,t).$$

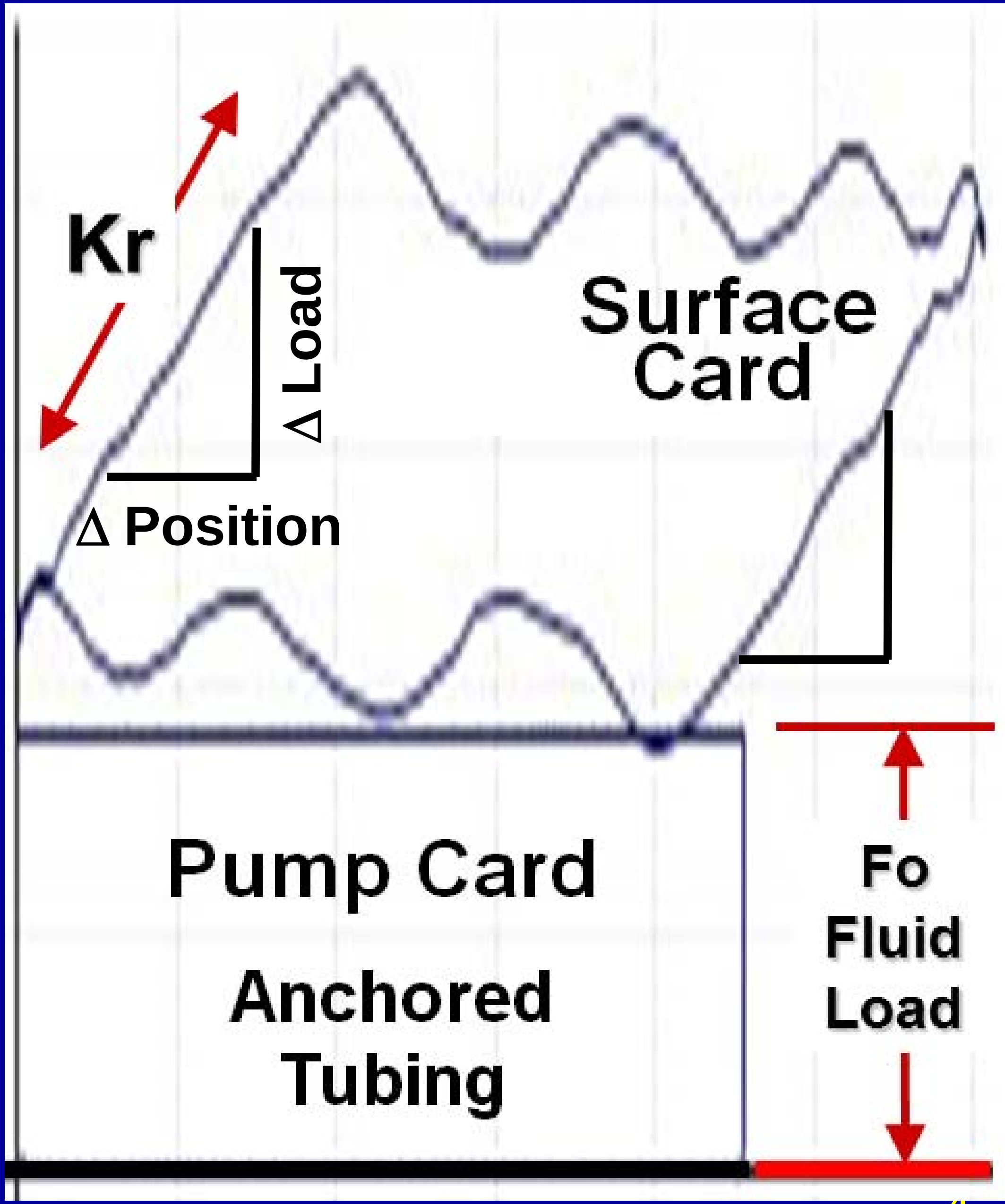
Condensed Version of Vertical Wave Equation
Victoria Pons, Ph.D.

Downhole Mechanical Friction

- Downhole Mechanical Friction impacts the rod loading measured at the surface.
- Mechanical Friction acting on the rods is not modeled by the wave equation, resulting in the excess frictional loads and horsepower being displayed in any plot of the rod loads versus position below the surface.
- If the plunger velocity unexpectedly becomes zero during the up or down stroke, sticking down hole may be the reason.
- Coefficient of Rod Stretch, Kr, and the measured surface dynamometer card can be used to identify the depth to severe mechanical friction that is causing the downhole sticking.

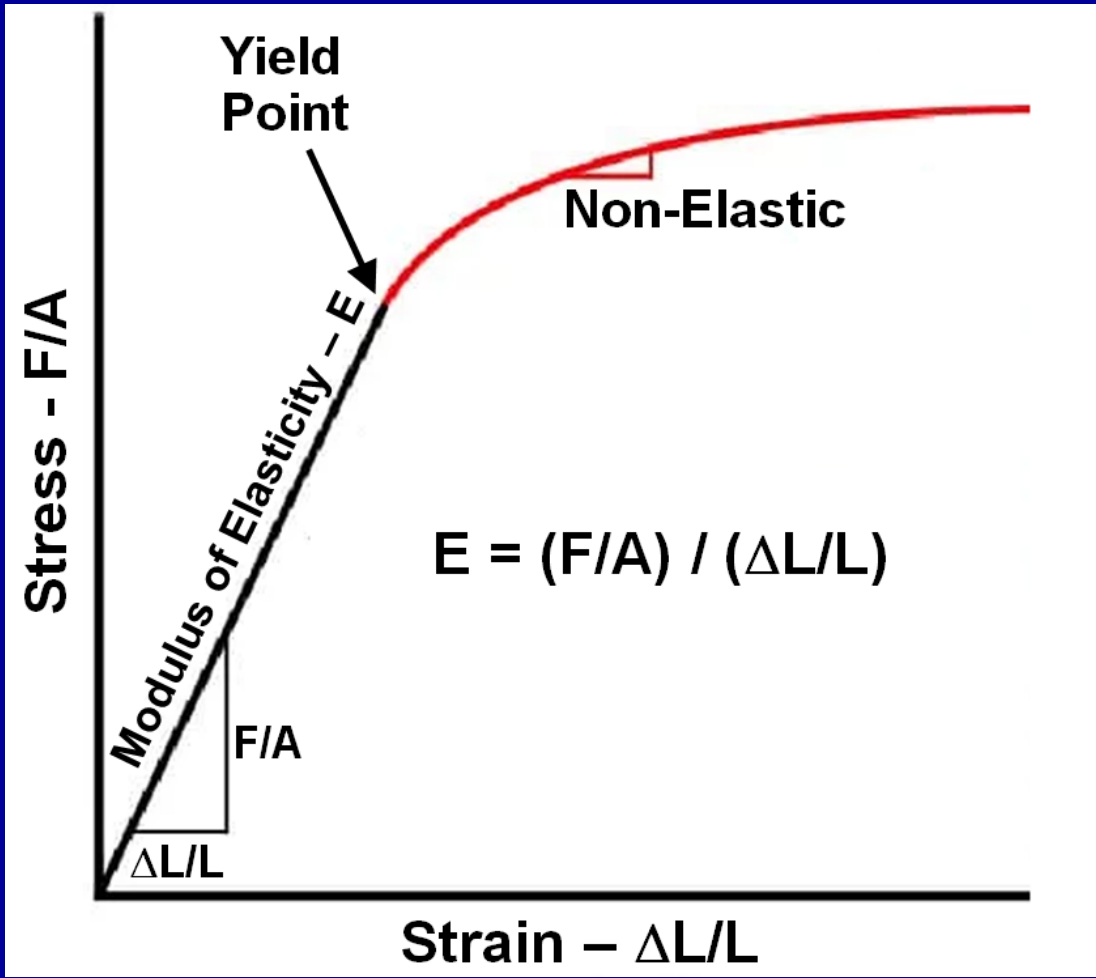
Normal Rod Stretch

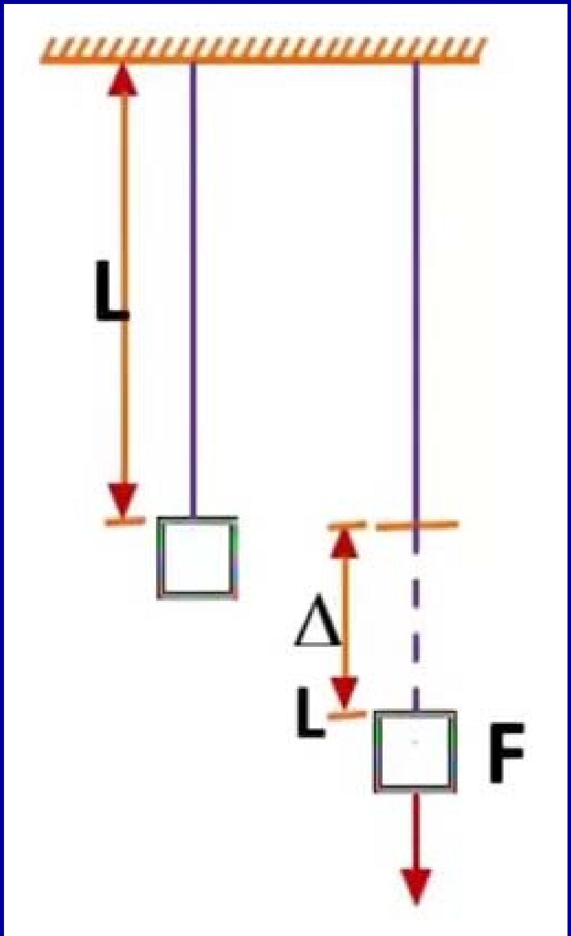
- Coefficient of Rod Stretch, Kr, is defined as the required load in pounds applied to a constant area, A, rod of length L to stretch the entire rod string length equal to 1 inch.
- Kr (Lbs/Inch) is the slope of the surface dynamometer card load versus position, when the entire rod string stretches to pickup or release the fluid load, Fo, applied to the rods.
- Polished rod moves up, X, inches at the surface to exert the spring force, $F = Kr \times X$.



During Pumping Rod Strings Elastically Stretch and Unstretch

When a Force, F, is applied to a Sucker Rod String, then the Rod String elastically **stretch**, ΔL, based on the length, L, area, A, and Modulus of Elasticity, E, of the rods





$$\Delta L = FL/(AE)$$

Wave Equation Models Entire Rod String from Surface to Pump

- For a constant diameter rod string the Spring constant Kr is defined as

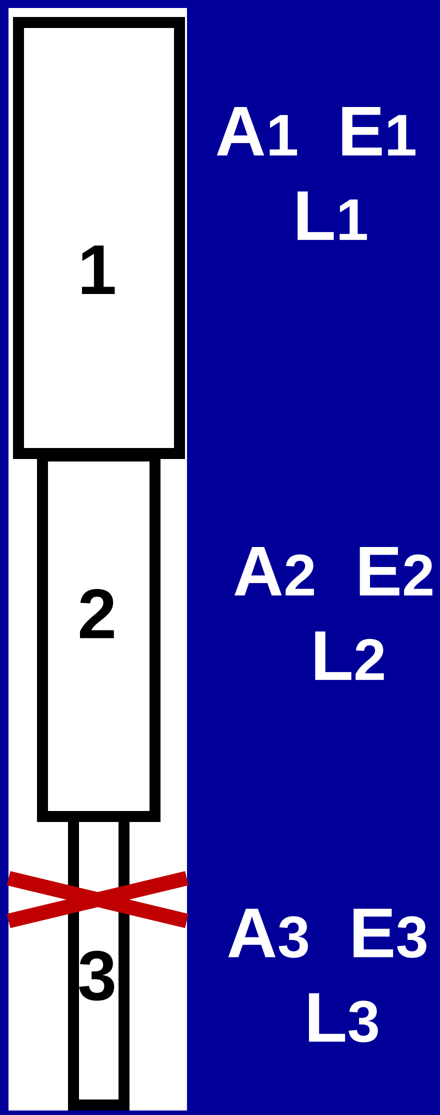
  Kr = AE/L

- For a tapered sucker rod string **Kr =**

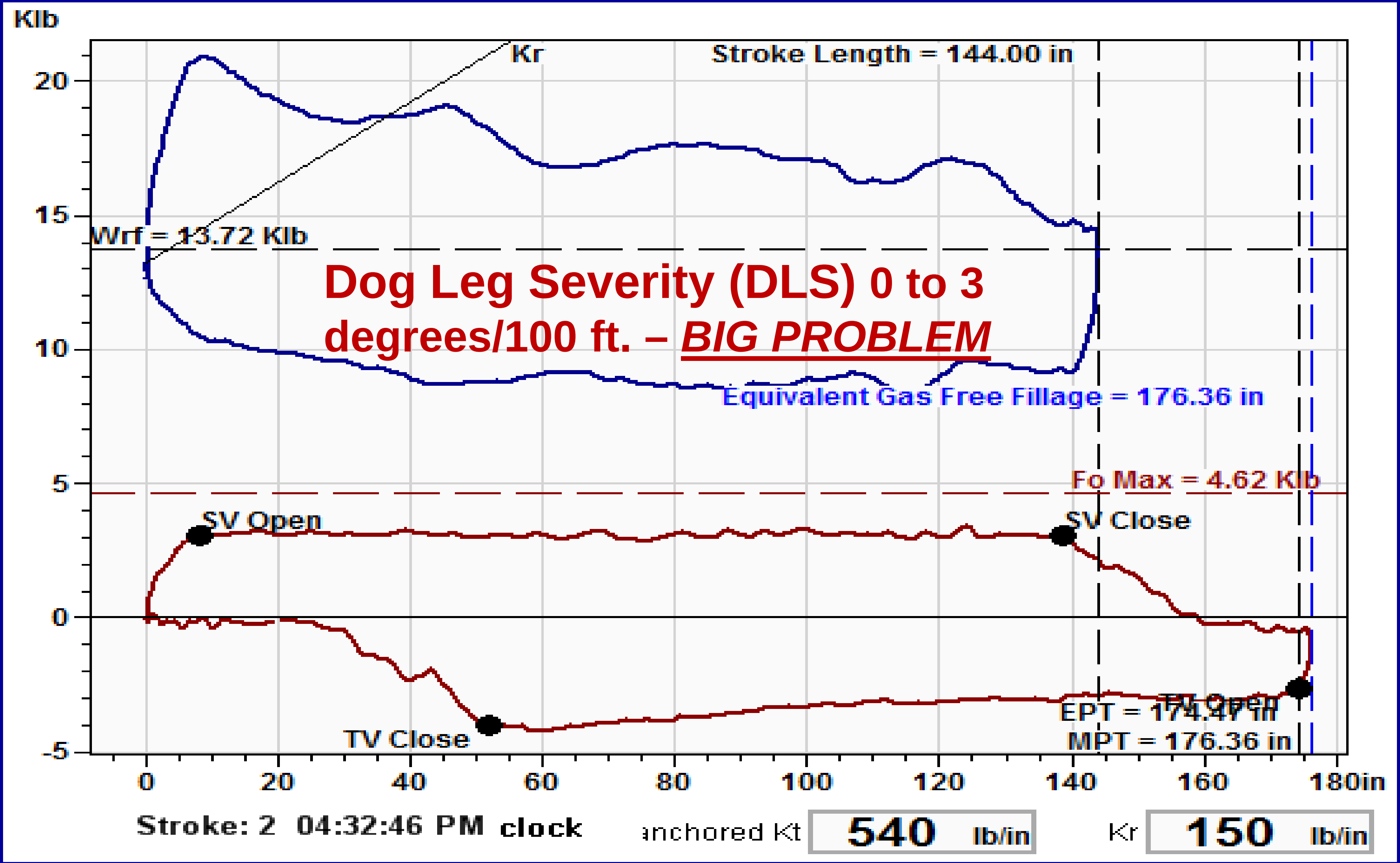
  $1 / (L_1/A_1/E_1 + L_2/A_2/E_2 + L_3/A_3/E_3 + \ldots)$

- If Mechanical Downhole sticking at a point occurs (like at a dog leg), then the rod string from the downhole sticking point to the surface stretches. A stiffer shorter section of the sucker rod string is stretching, the rod string Kr increases.

- If sticking occurs at the red X a shorter **L_3** length would need to be used to determine **Kr**

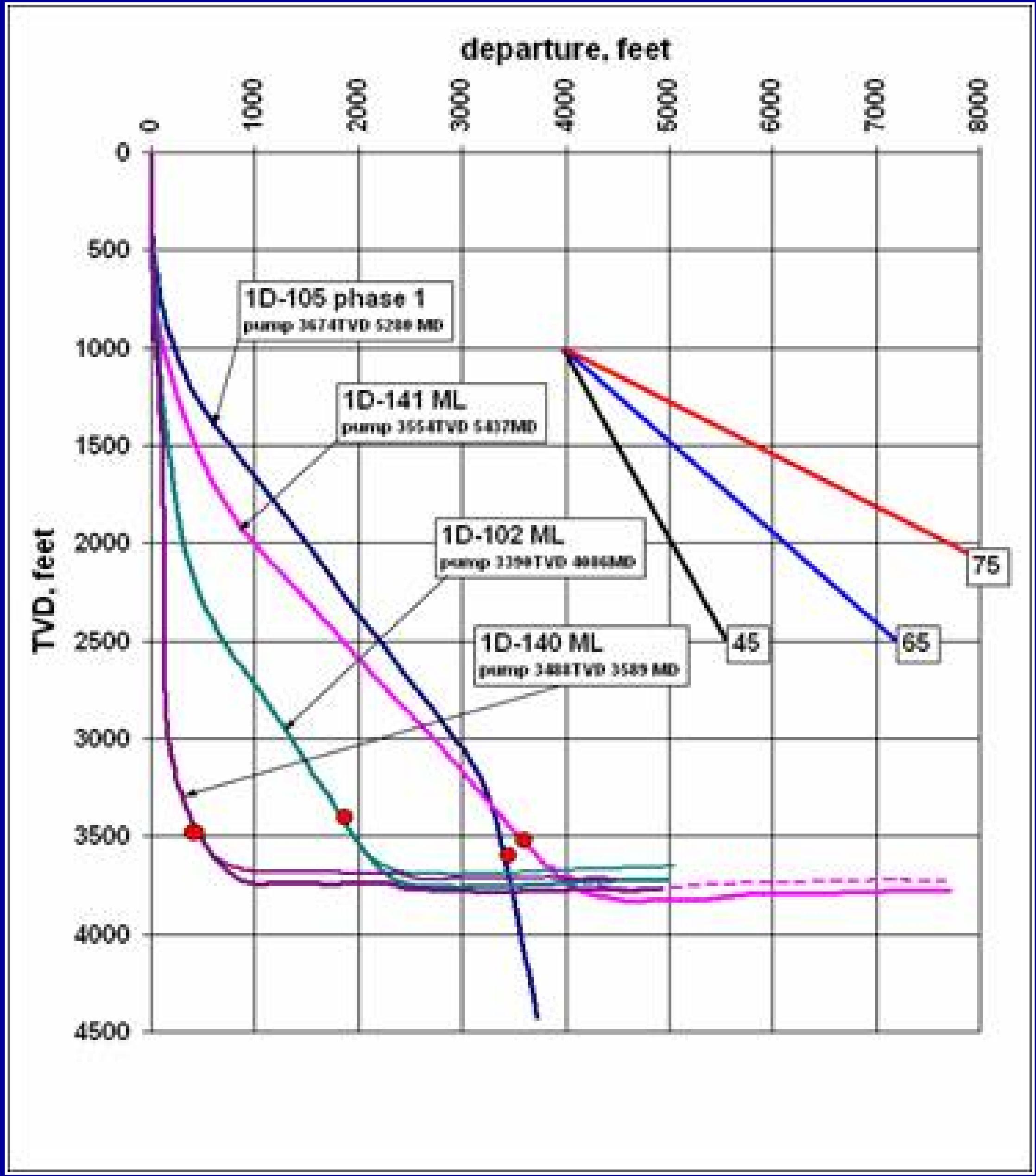


What does this Pump Card Show?



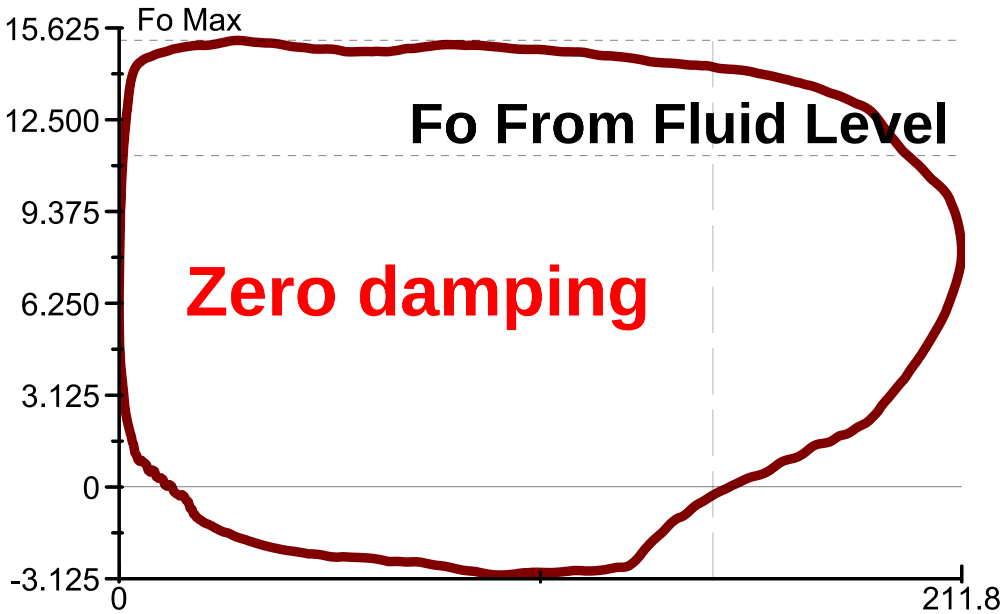
Are changes to drilling plans needed?

- Easier to drill vertical wells:
  - Keep dog legs down
  - Prevent escapes
  - Hit target
- Now most wells are or will be horizontals and many drilled from pads to reduce costs and environmental impact
- But should there be changes even if vertical wells drilled

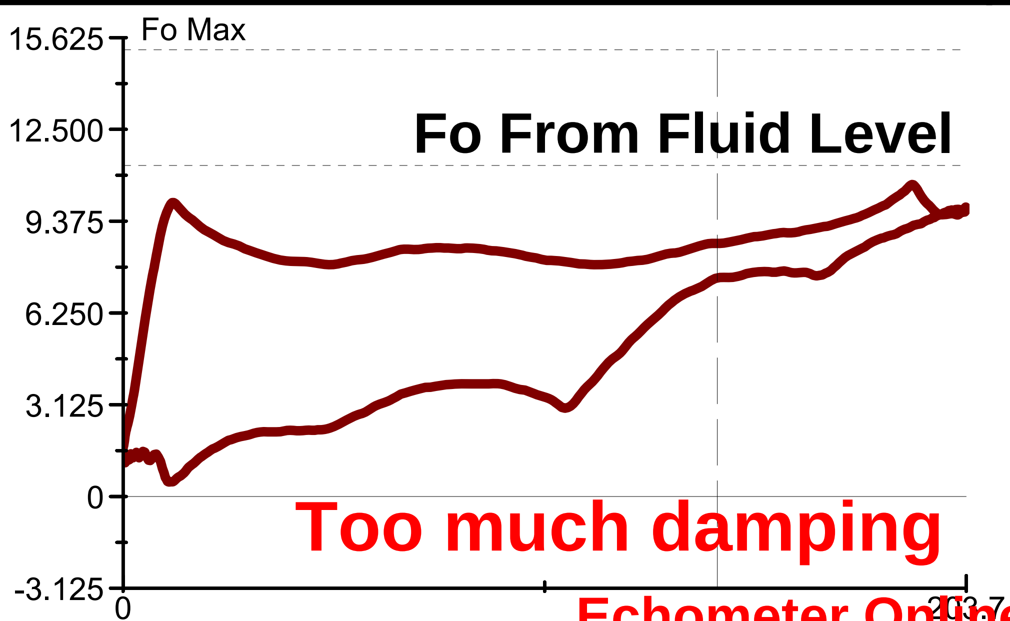


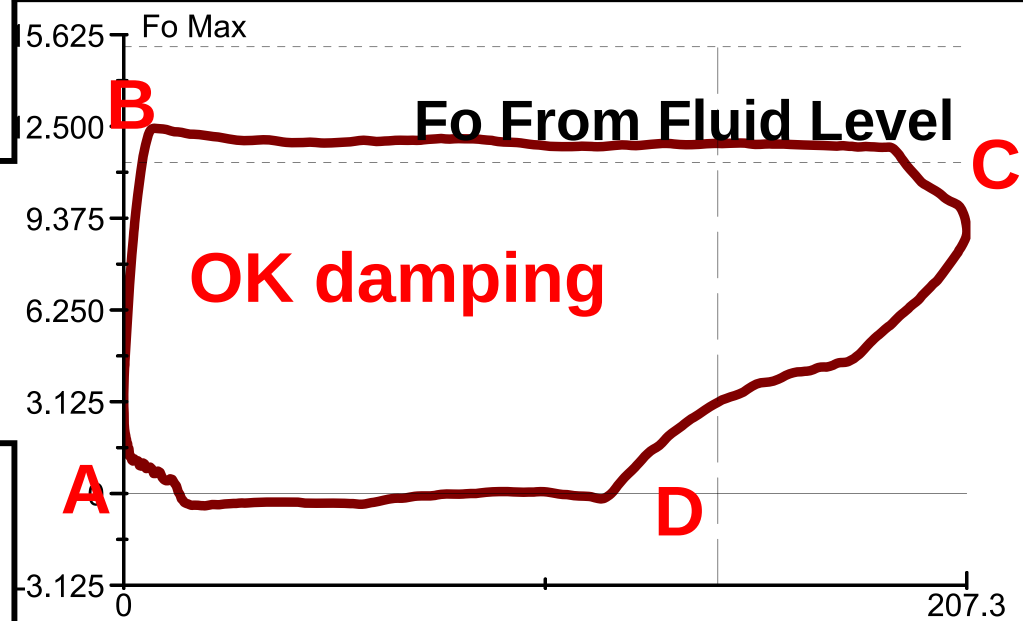
Wave Eq. Accounts for Fluid Damping Acting on Sucker Rods

Zero damping surface and pump card have same HP



Concave in and the damping coefficient are too high

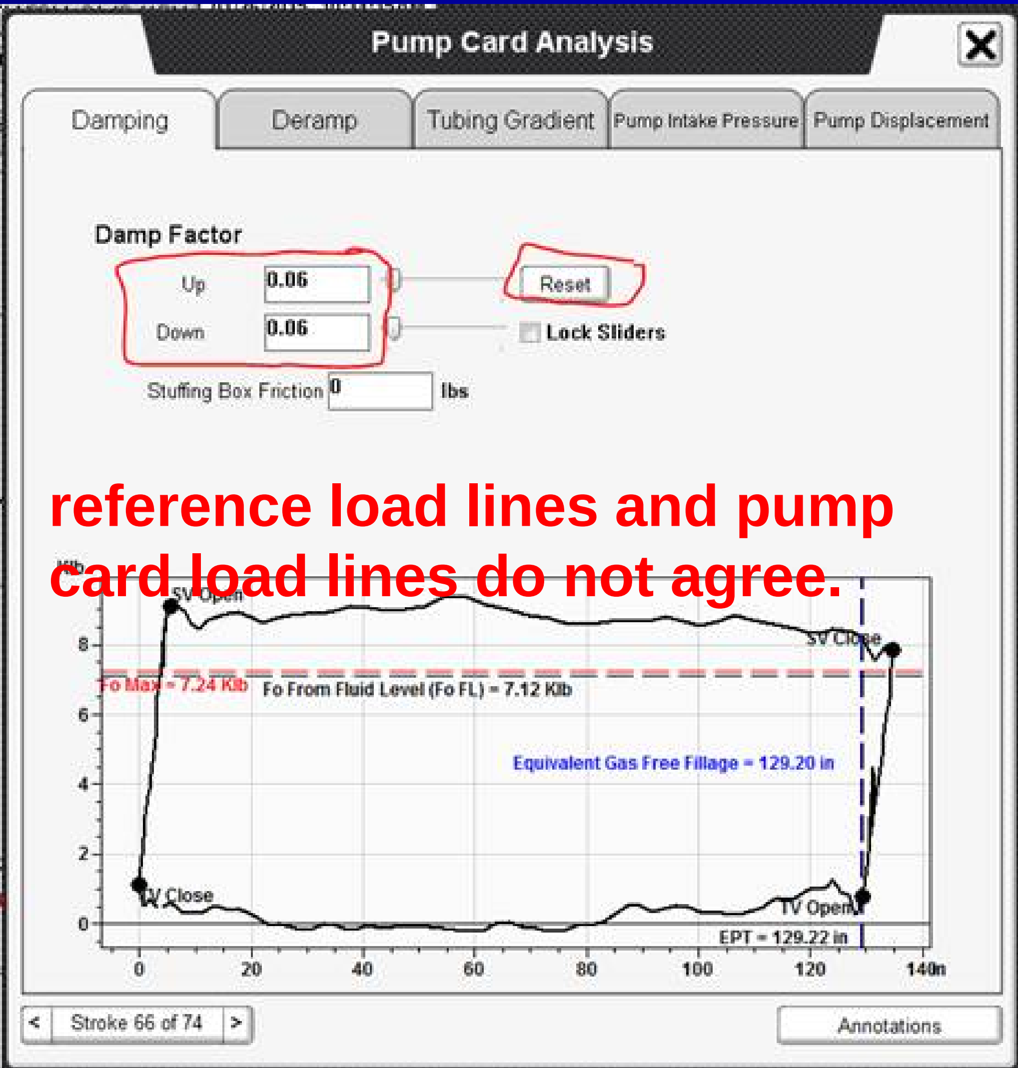


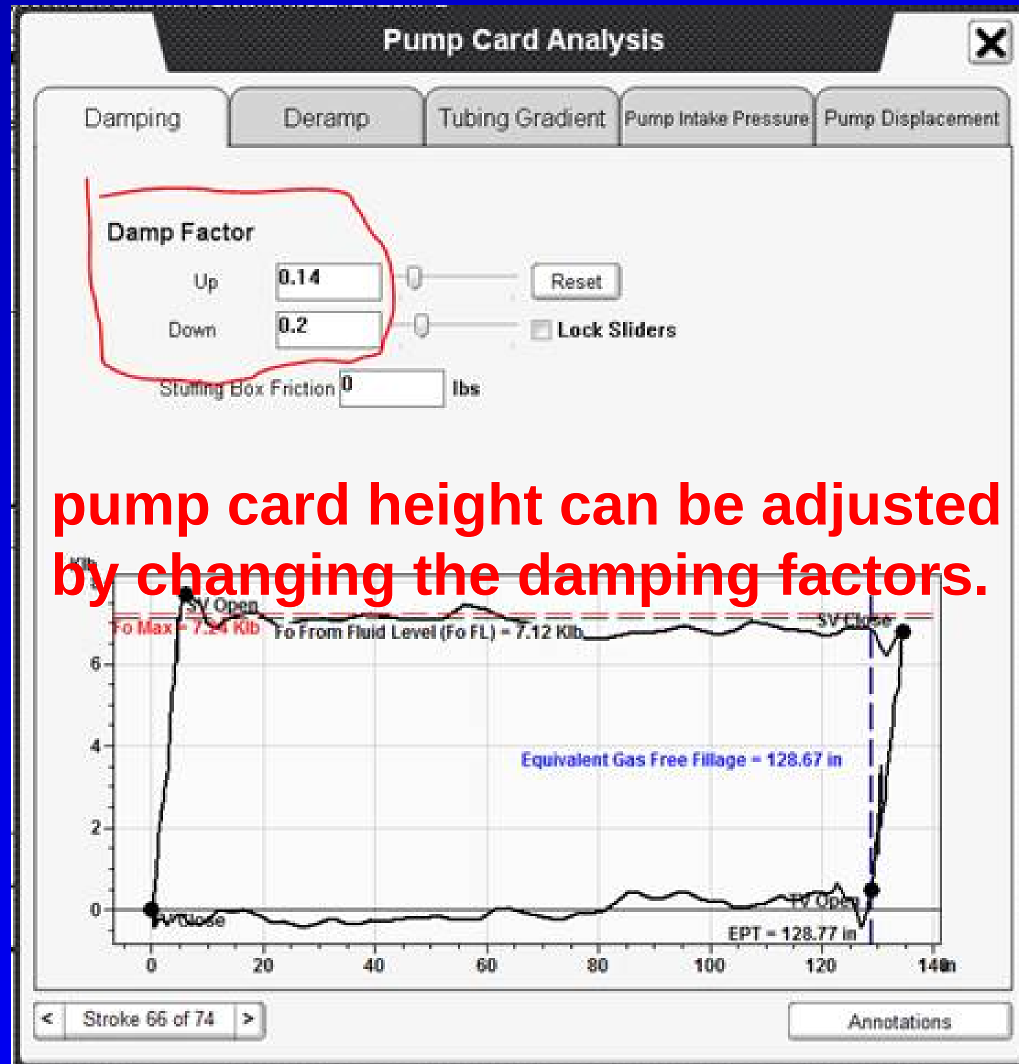


When the pump load lines B - C and D - A are nearly flat then the proper amount of damping has been added

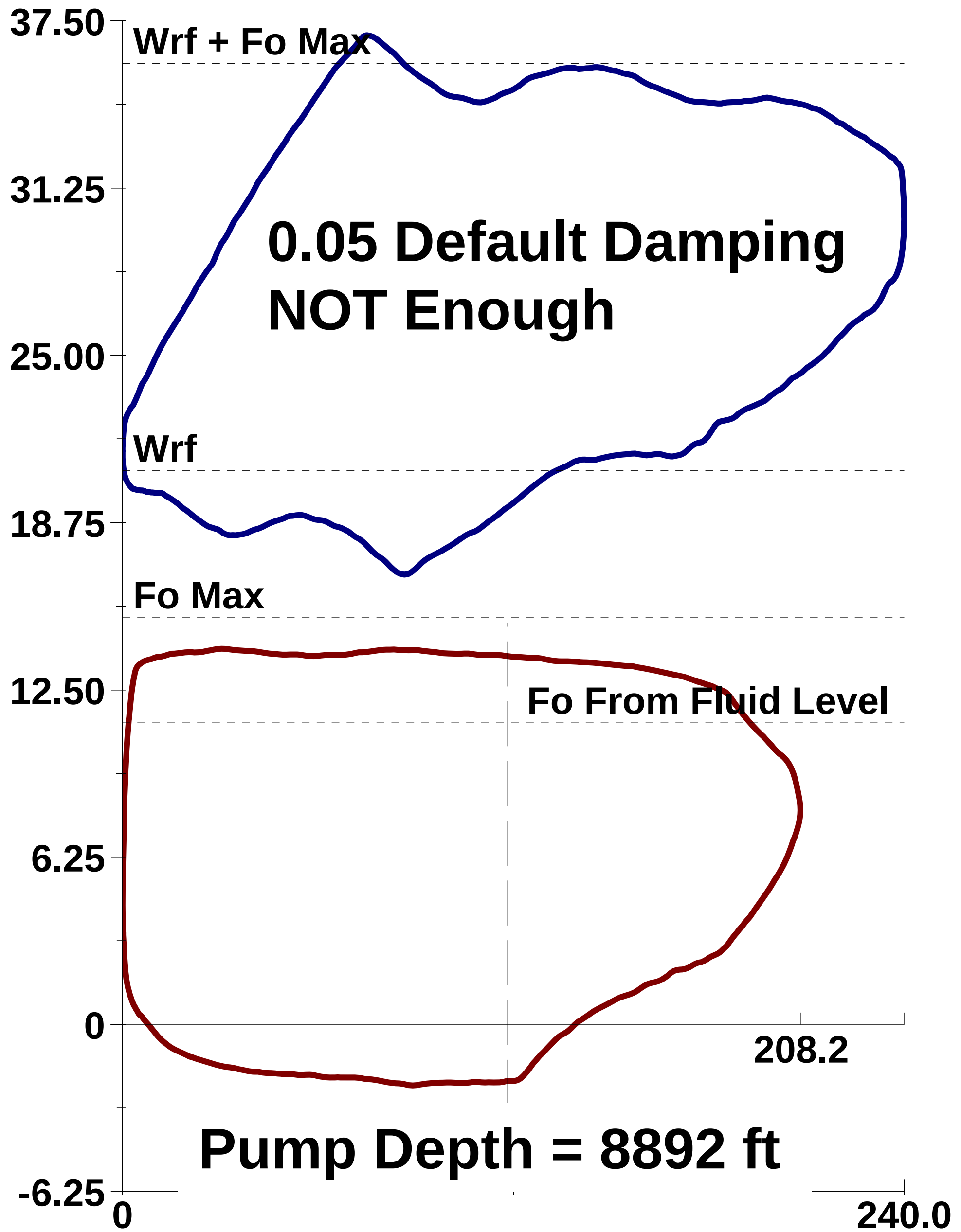
Damping – WPRT or PRT

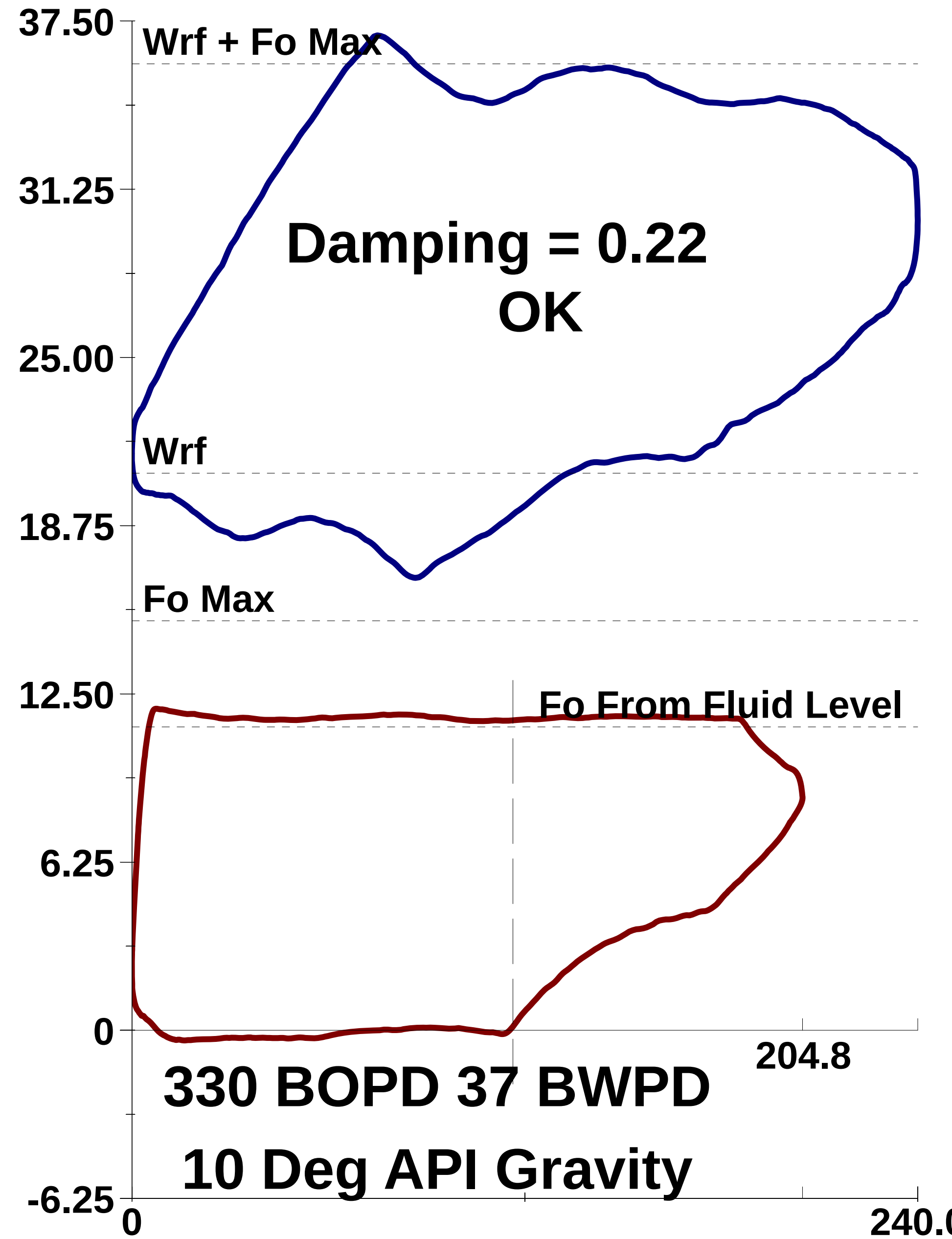
Verify pump card loads on the up stroke and down stroke are flat and match fairly close to Fo from the Fluid Level and Zero Load Lines. If not, *then surface loads may be in error*. If the pump card bows outward on the up and down stroke then the damping factors may be too low.



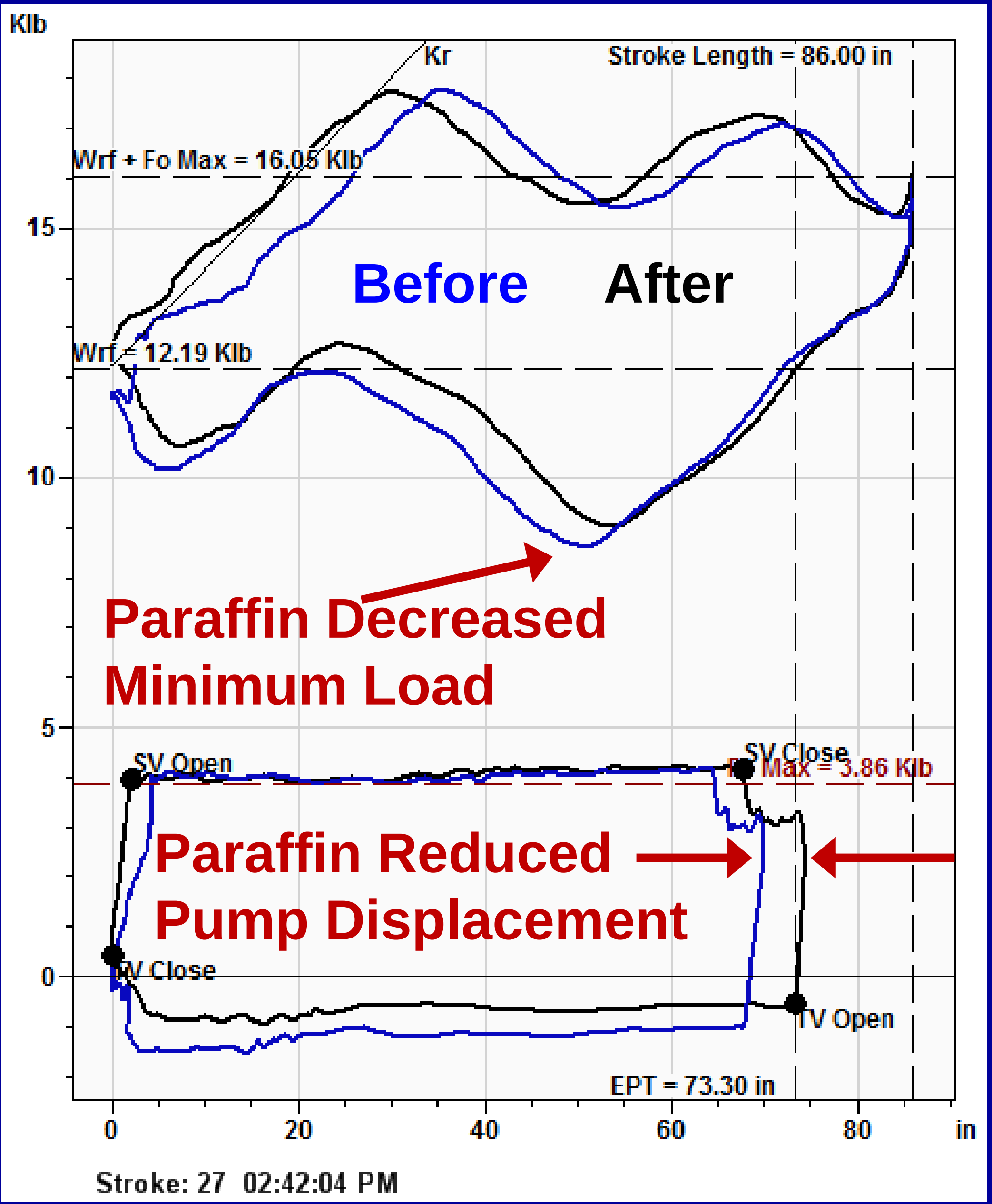


Damping Coefficients for Viscous Crude





"Effective" Treatment Improves Rod Loading & Increases Downhole Stroke



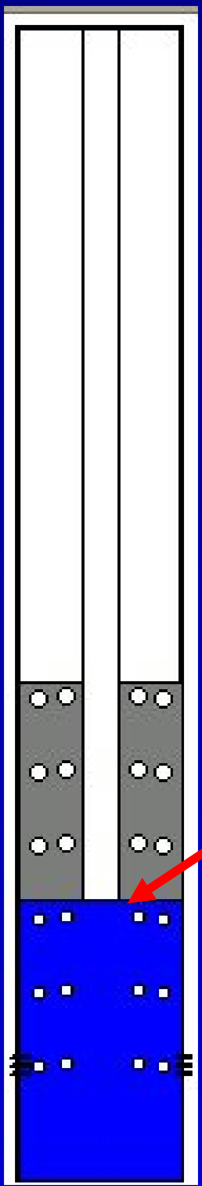
Mechanical Friction Sources:

1. Paraffin
2. Scale
3. Over Tight Stuffing Box
4. Misalignment
5. Dog-Leg Severity
6. Deviated Well
7. Pump Friction
8. Crimped Tubing
9. Other

Mechanical Friction Results:

- Decreased Loads on Down Stroke
- Increased Loads on Upstroke
- Reduced Downhole Stroke
- Raised Fluid Level
- Increased HP + Reduced Efficiency

Unaccounted Wellbore Friction



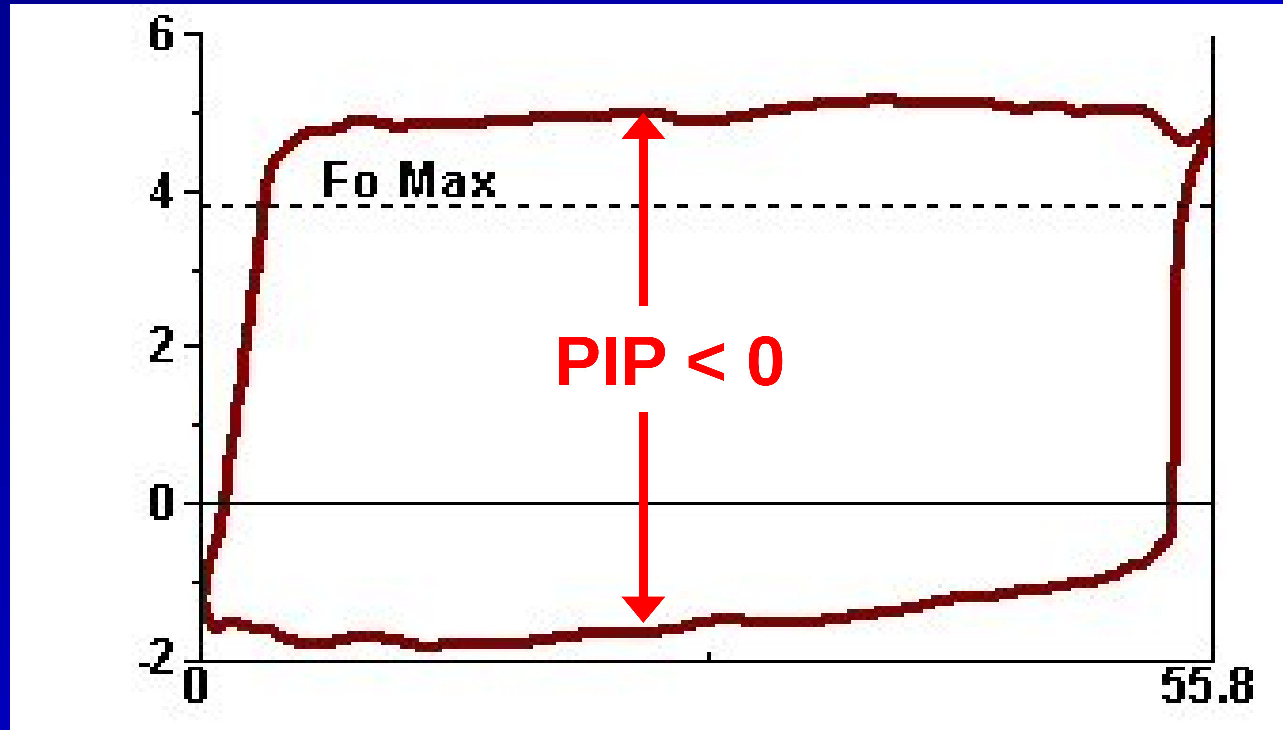
Fo(fl) = 3505

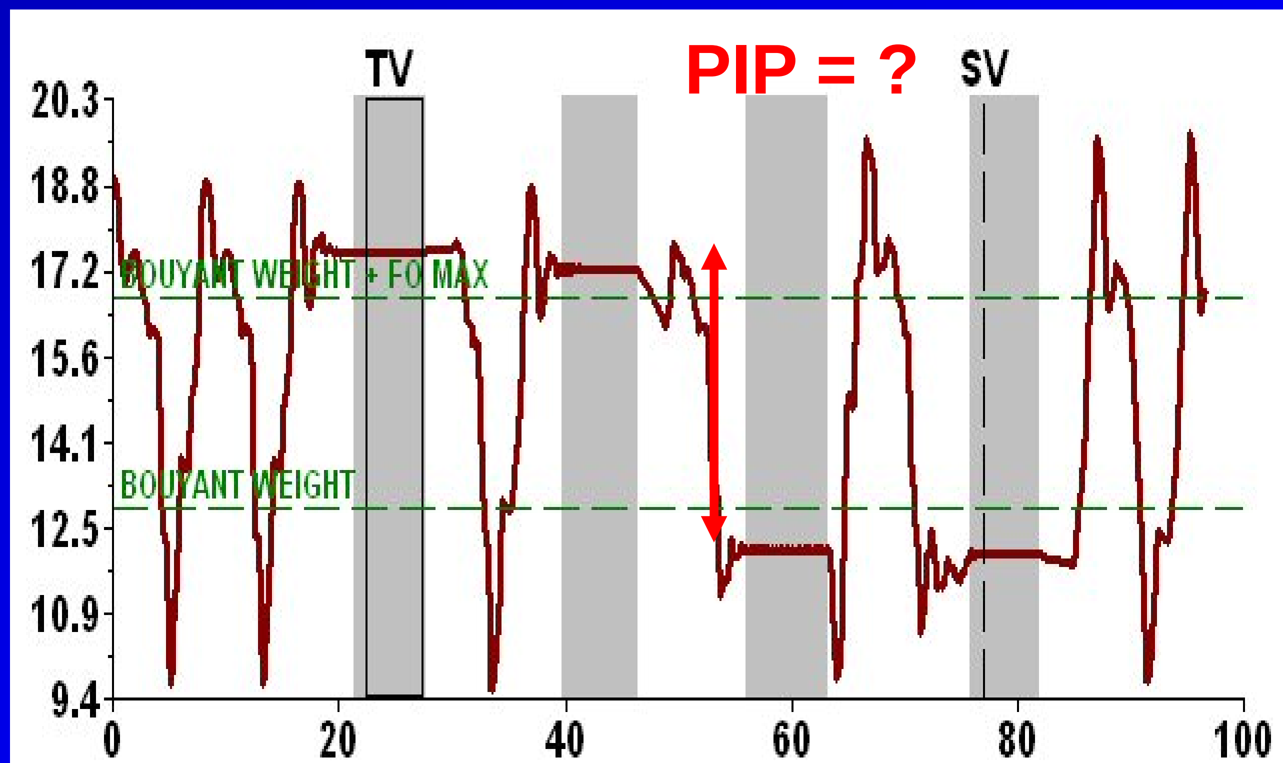
Fo(pc) = 3502

Fo(vc) = 5518

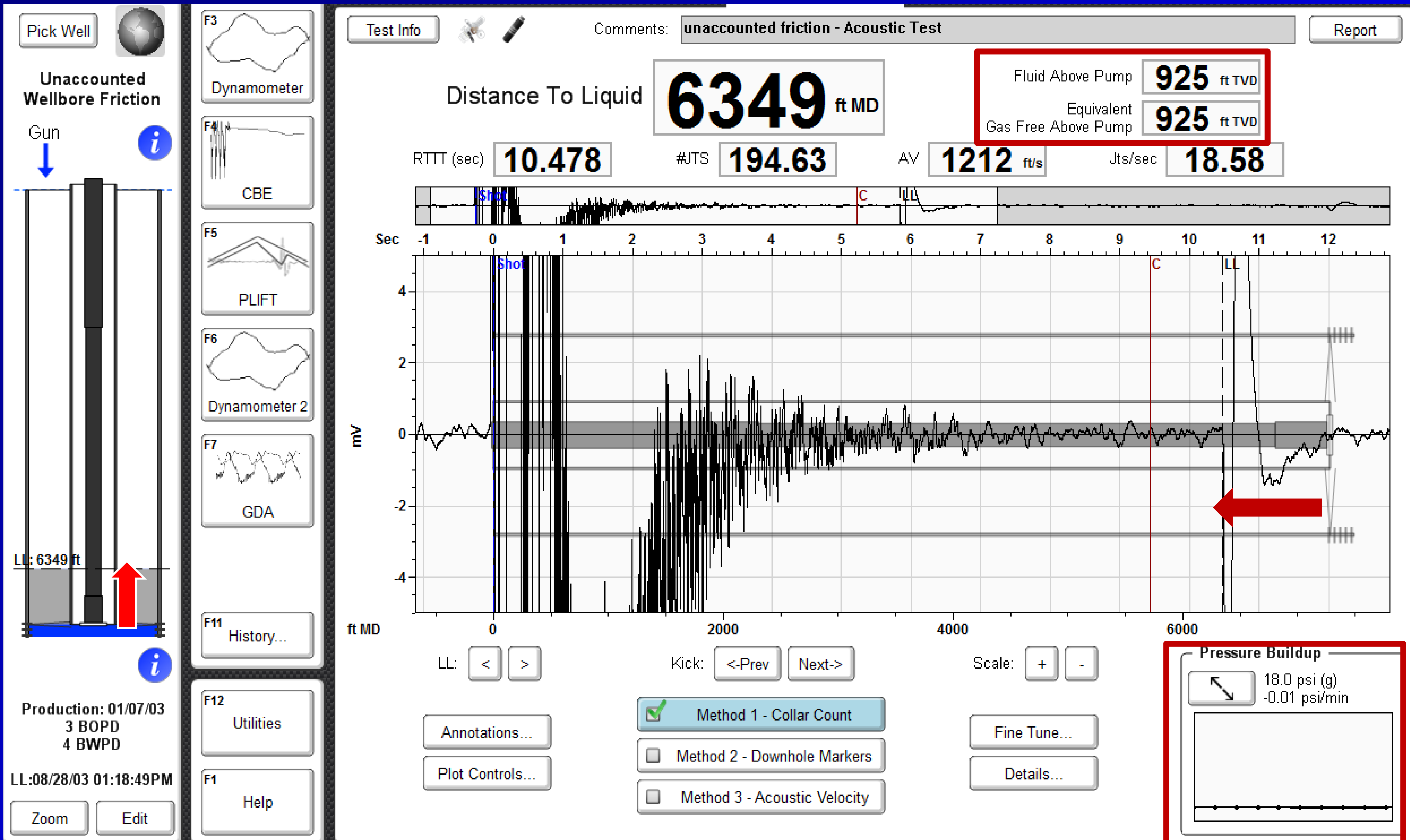
% Liq = 27

PIP = 268

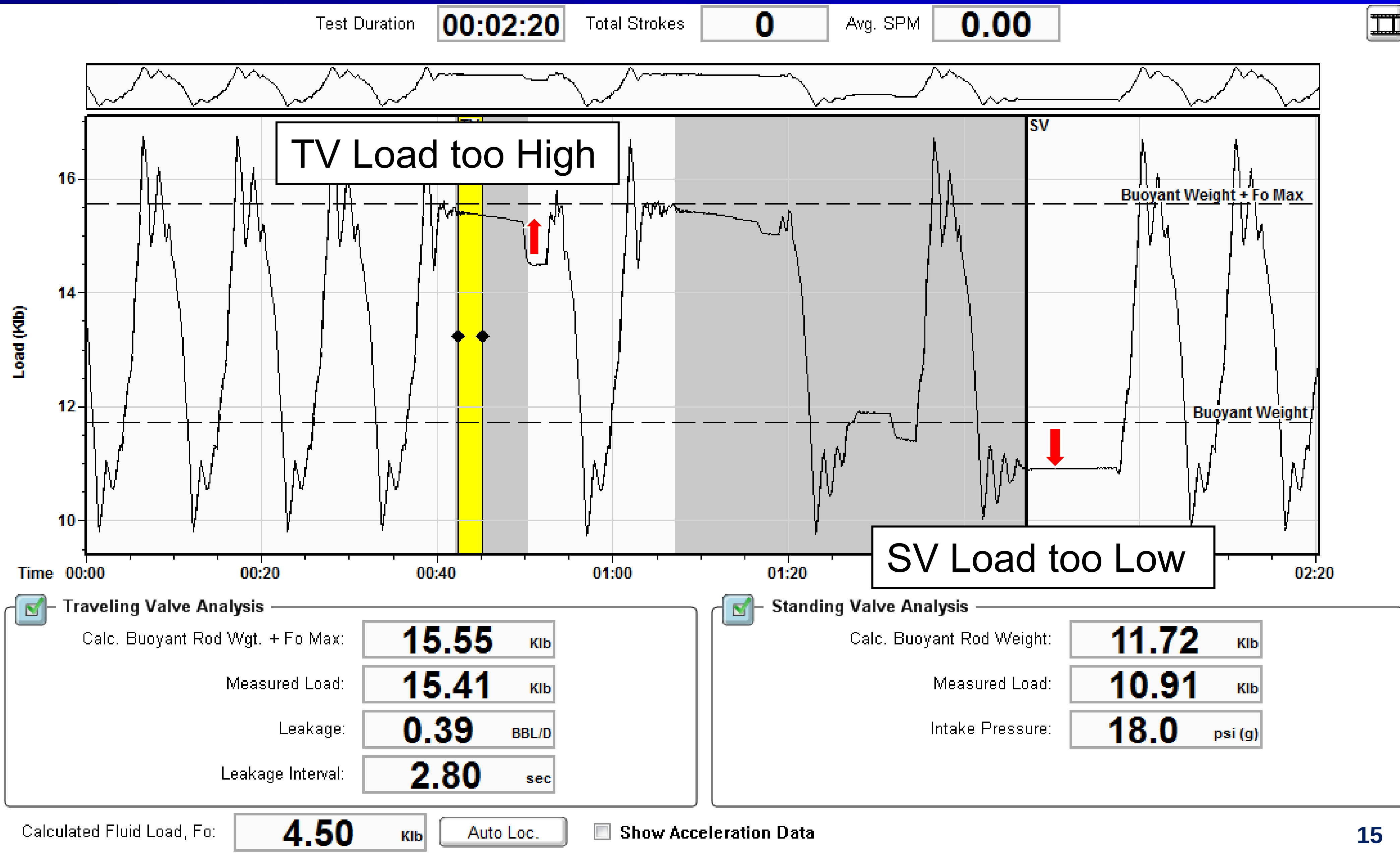




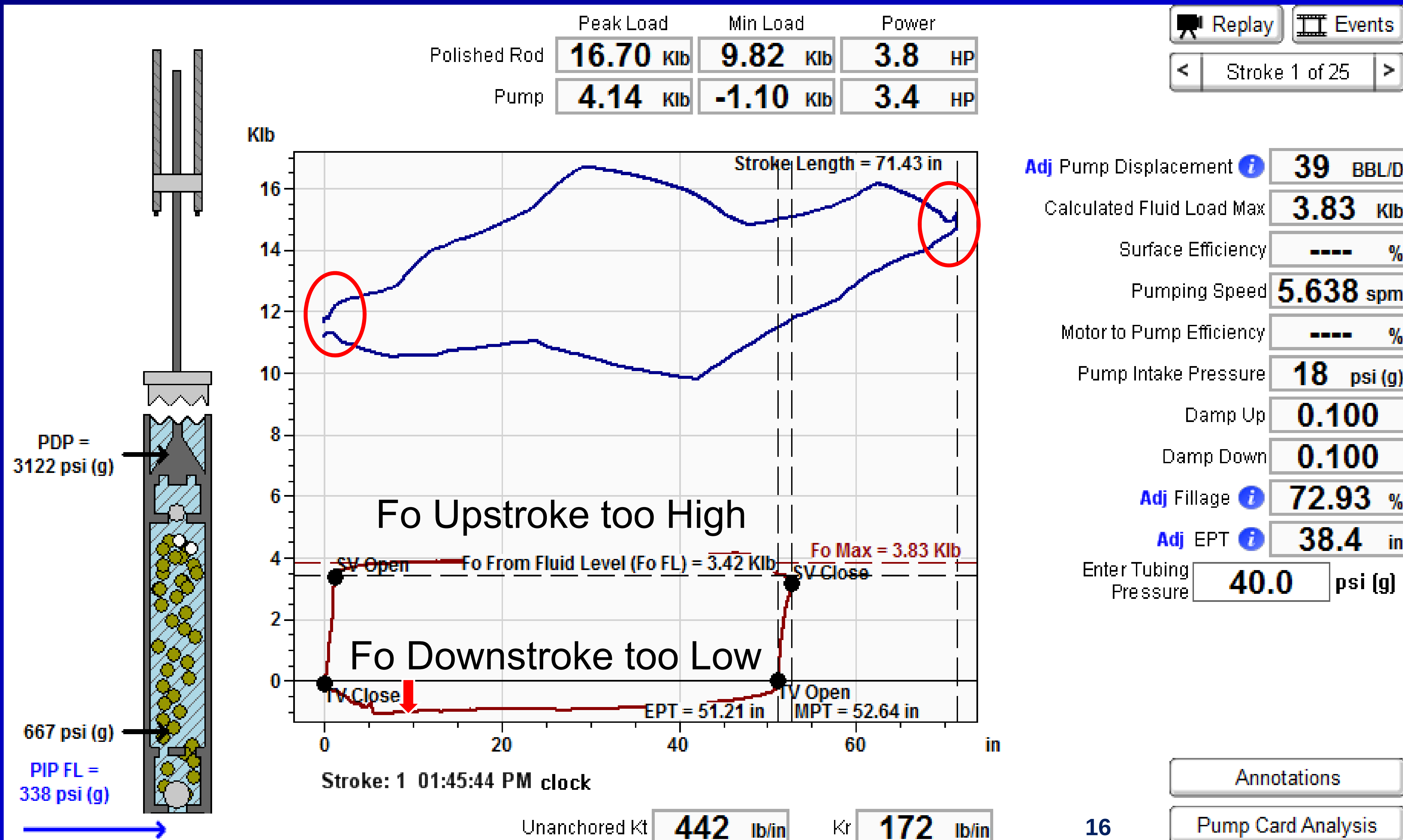
Unaccounted Friction: Reduced Downhole Stroke & Raised Fluid Level



Unaccounted Well Bore Friction: Friction Affects Valve Load Test



Excess Well Bore Friction: Friction Affects Dyno Cards

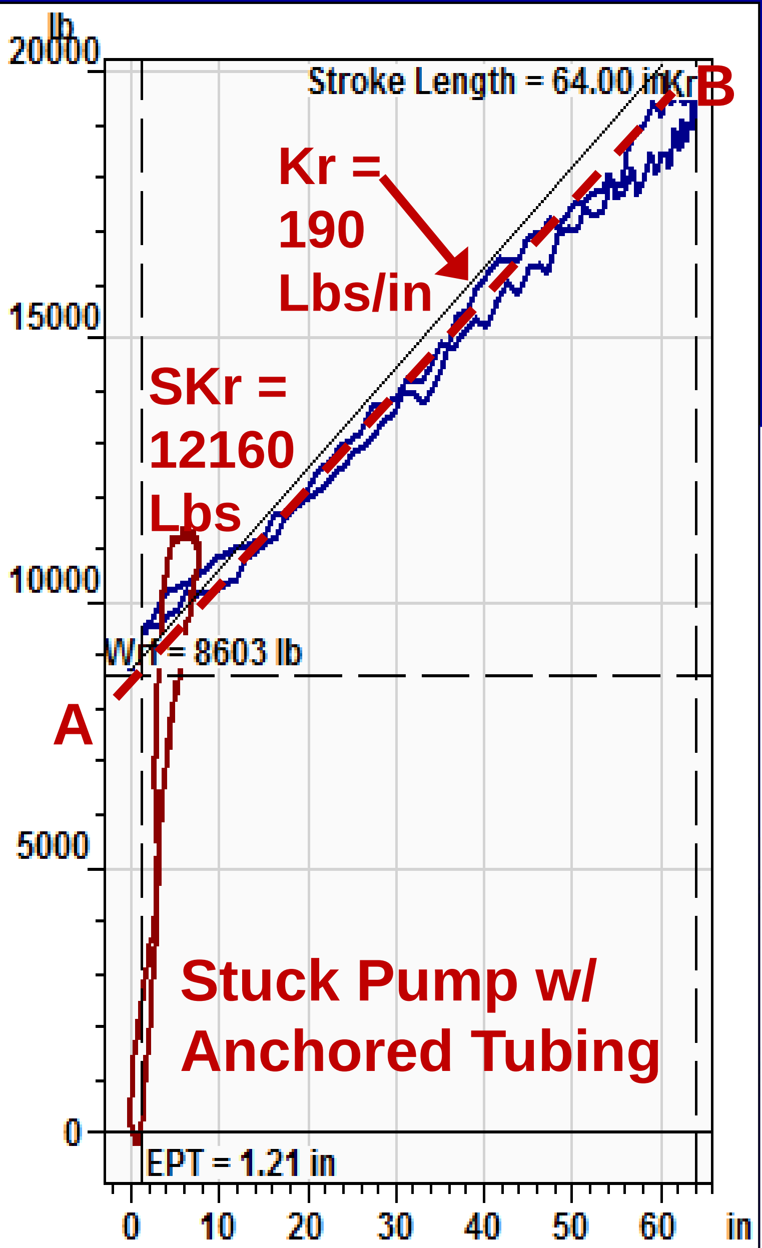


Unaccounted Friction Indicators

1) Fluid Level is higher than normal
2) Surface card shows a vertical change in load at the top and bottom of the stroke (Extra friction opposite to the direction of movement is broken by changing the direction of motion of the rod string)
3) Pump card should set between the ZERO load line & Fo Max, pump loads outside this range indicate of unaccounted friction.
4) SV valve check is low and TV check is too high (Friction is resisting the lifting the rods on the upstroke and friction is holding rod load on the downstroke)
5) TV load immediately drops as brake released (When the direction of motion changes or the rods go from stopped to moving the friction force that was being applied opposite to the prior motion of the rods is broken).
6) Unaccounted friction impacts shape of pump card: increases load range when extra friction is not removed by wave equation calculating the pump card.
7) Low system efficiency

From A to B Rods Stretch 64” to Pickup SKr

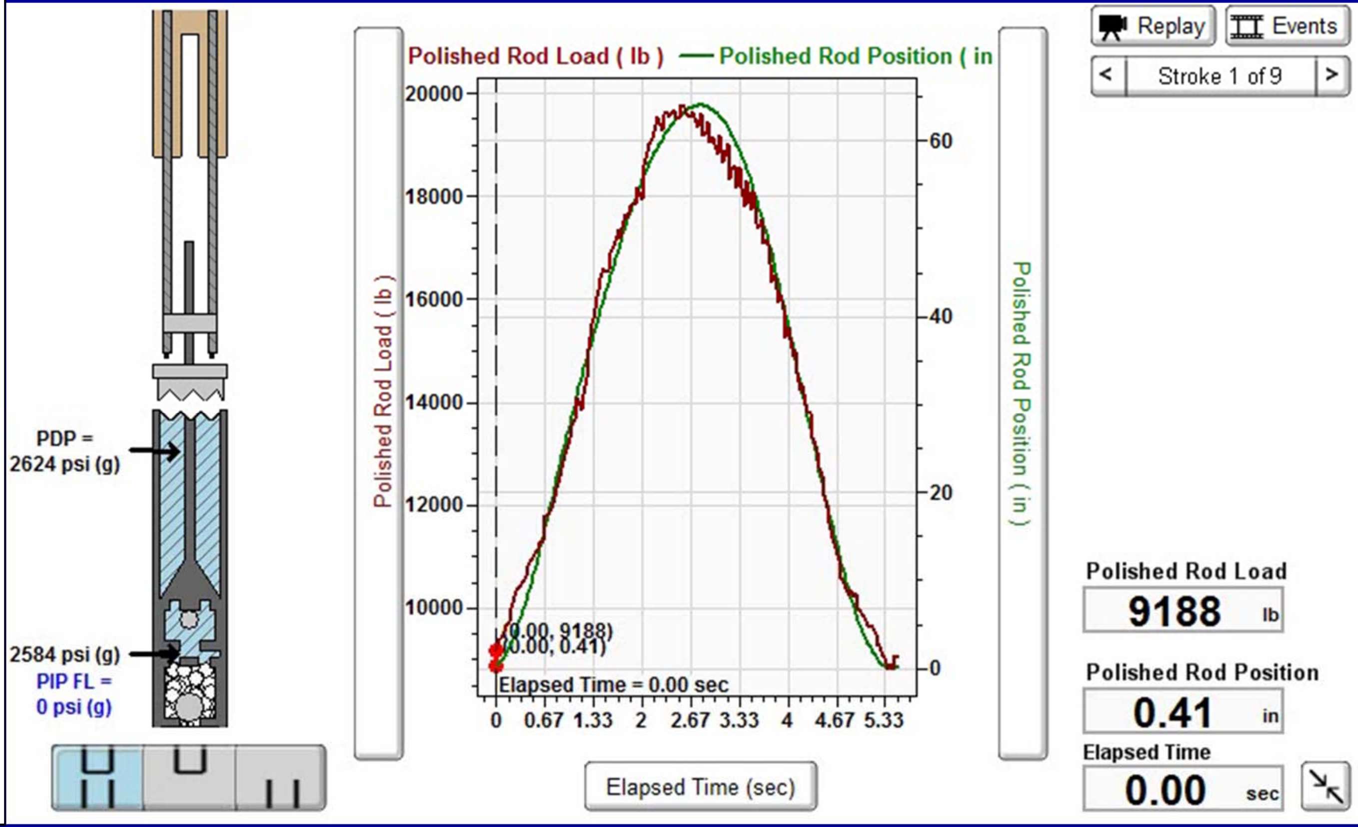
Kr: Rod String Spring Constant f(Rod Length & Area & Type)



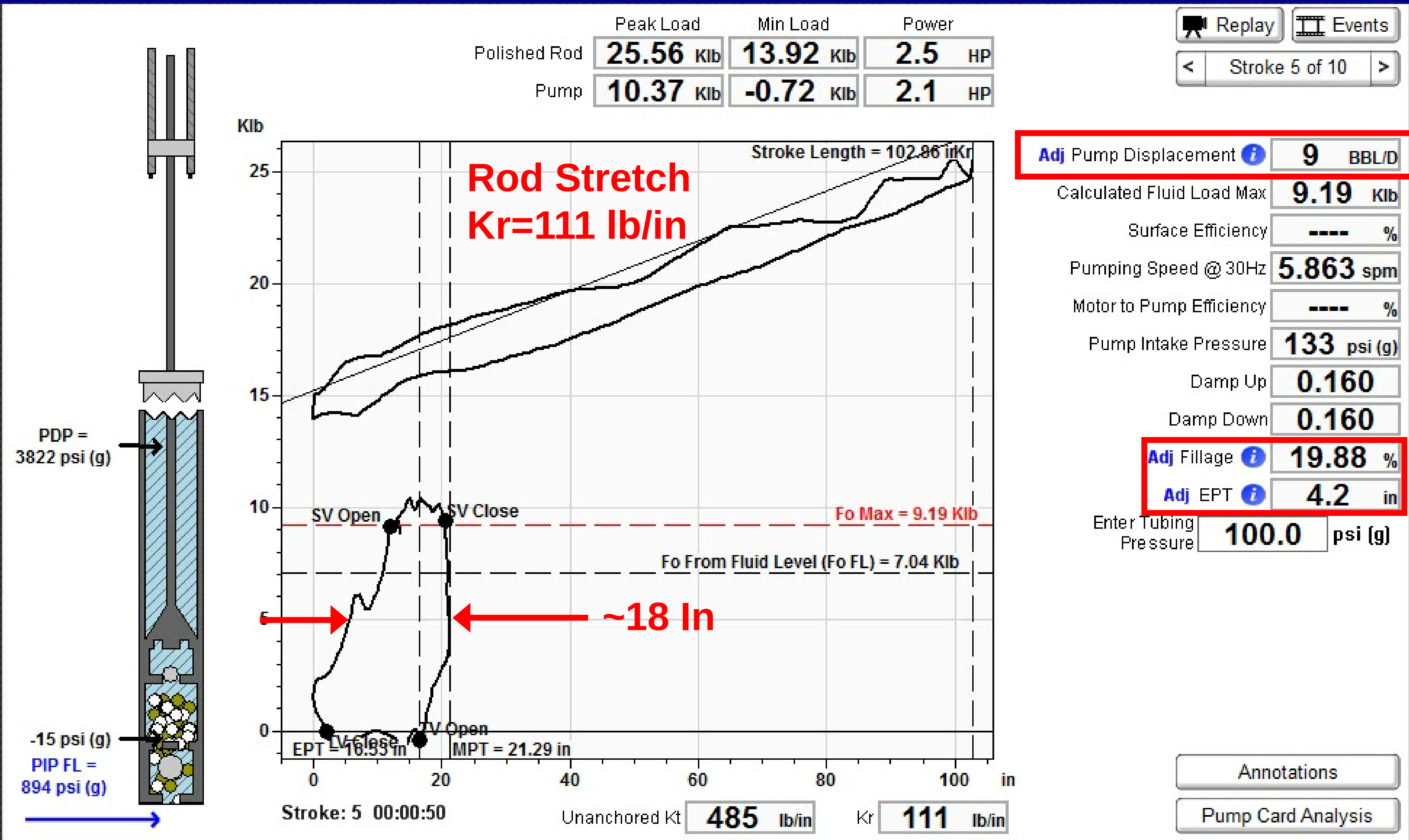
Illustrate Spring Constant - Kr:

A Stuck Pump causes the Change in Polished Rod Load to be proportional to Change in Polished Rod Position

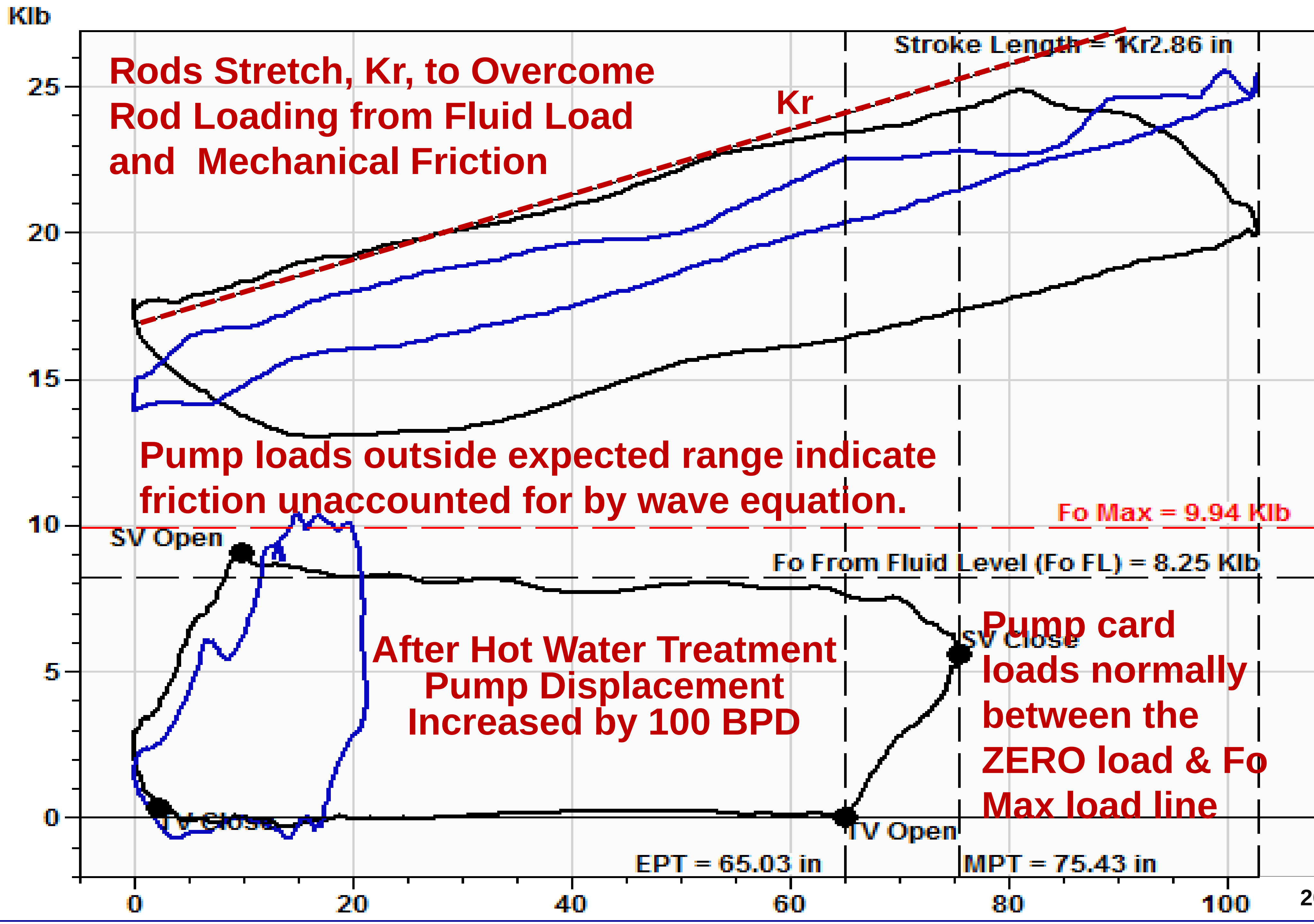
PR(load) = Kr x PR(position) + 9000



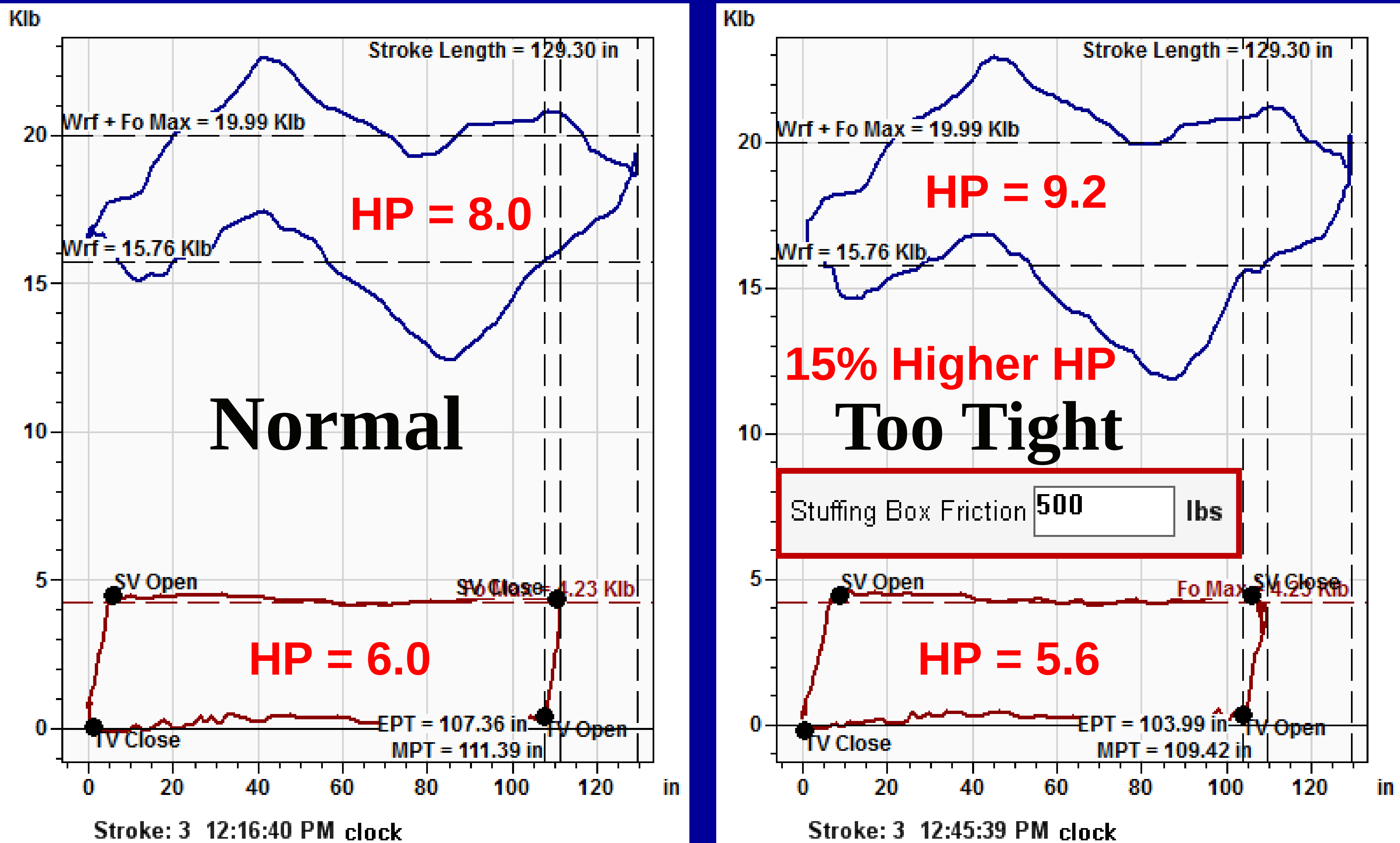
Mechanical Friction From Paraffin:
82% of Surface Stroke lost to Rod Stretch



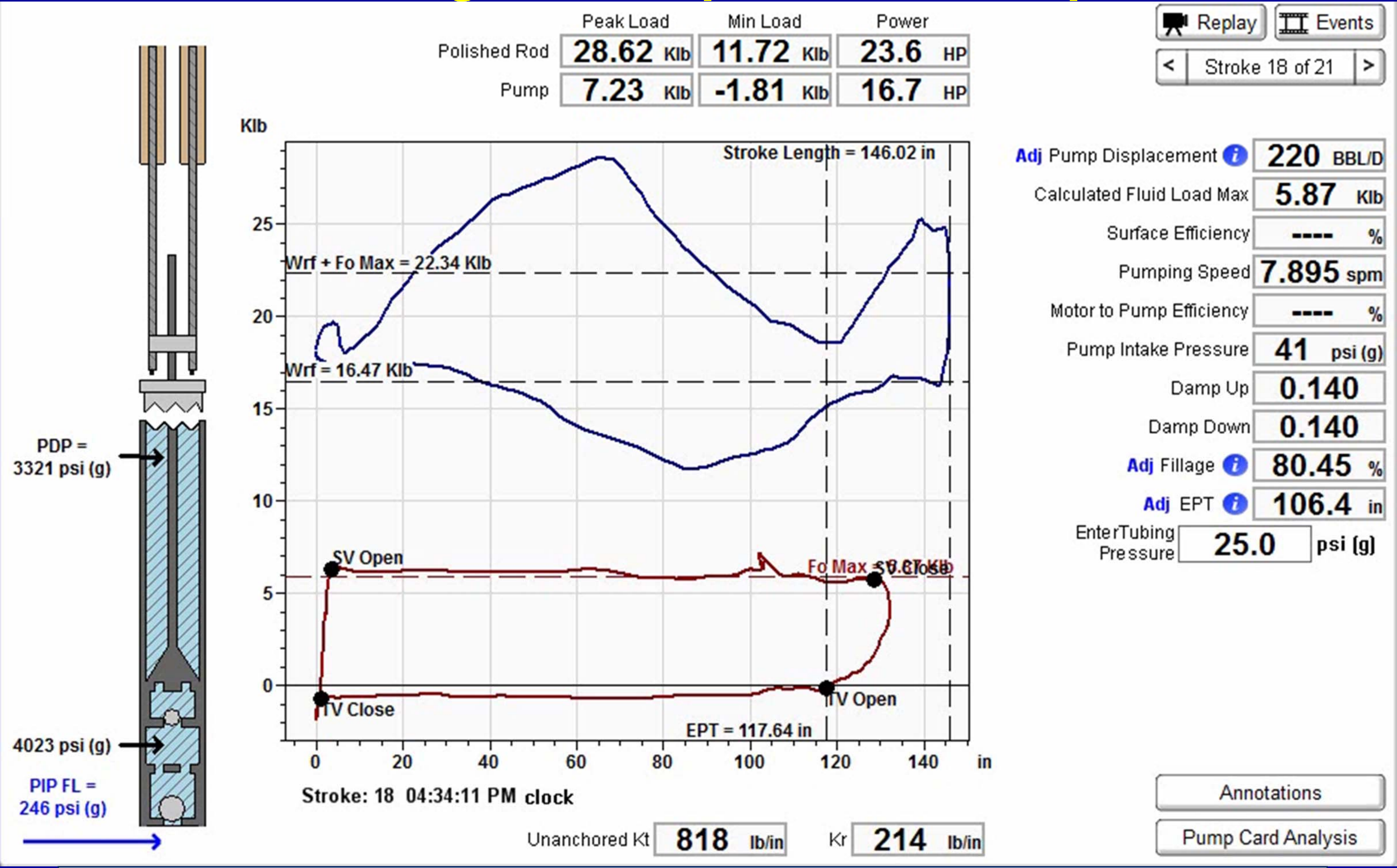
Excess Wellbore Mechanical Friction



Mechanical Friction – Tight Stuffing Box

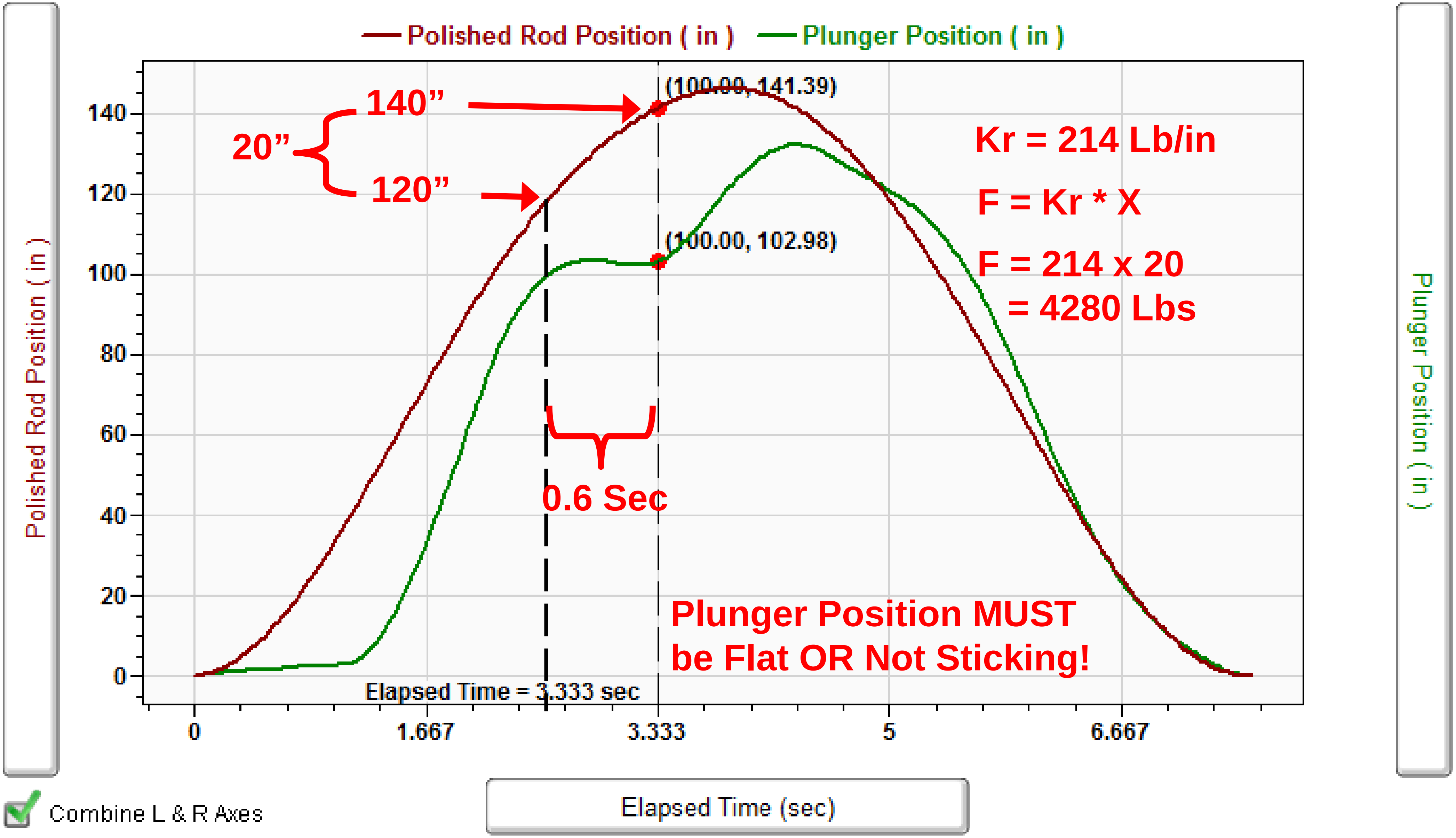


What Depth Uphole Does Mechanical Friction Cause Plunger to Stop at 100” on Upstroke

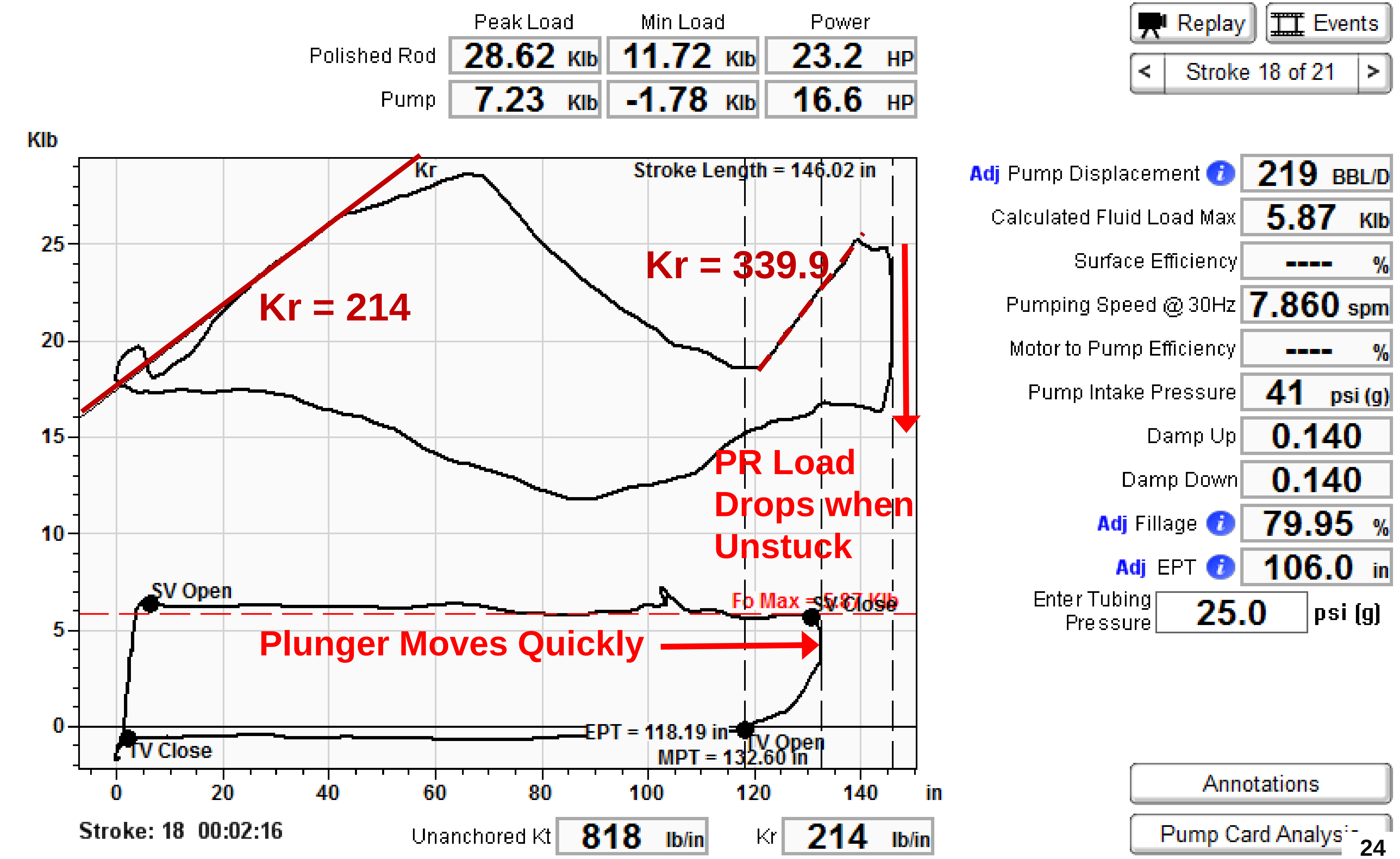


Echometer Online_Mechanical Friction: Stick_Release_Upstroke

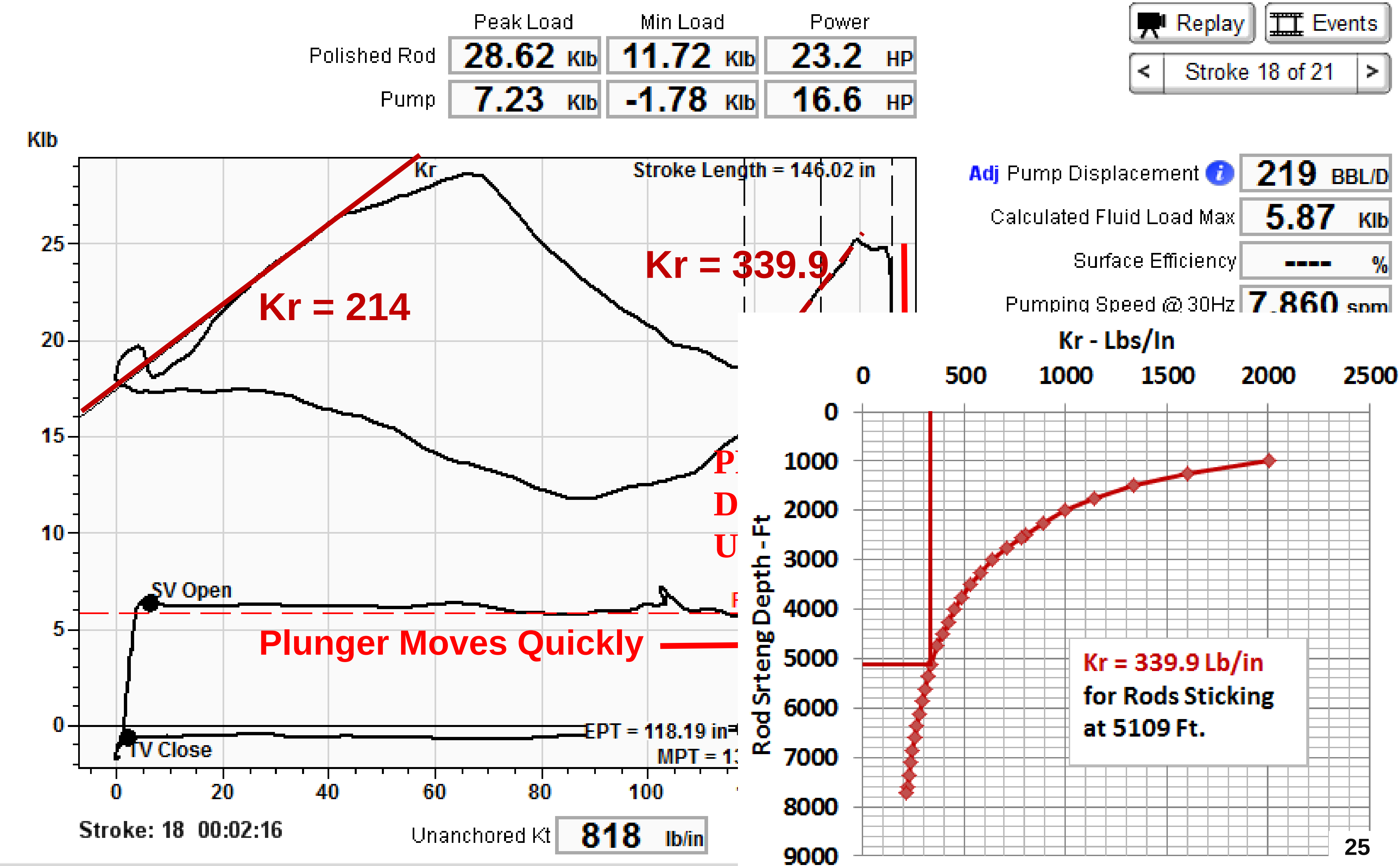
Polished Rod Moves up 20” to Apply 4280 Lbs Spring Force



When Kr of Rods from Surface to Depth Equals Slope of Surface Load vs Position



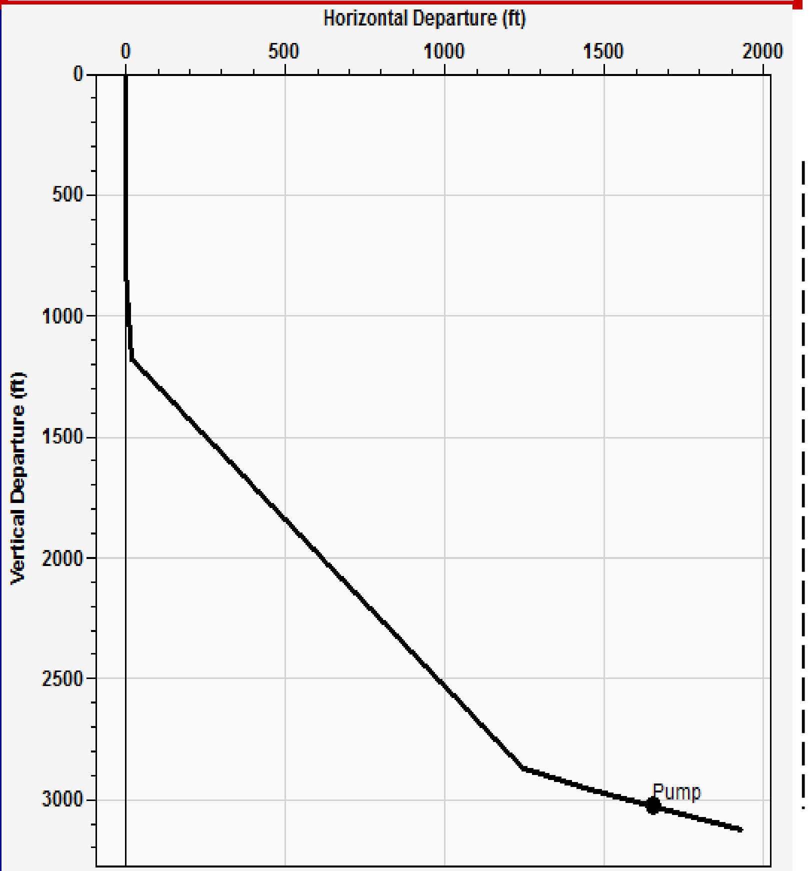
When Kr of Rods from Surface to Depth Equals Slope of Surface Load vs Position

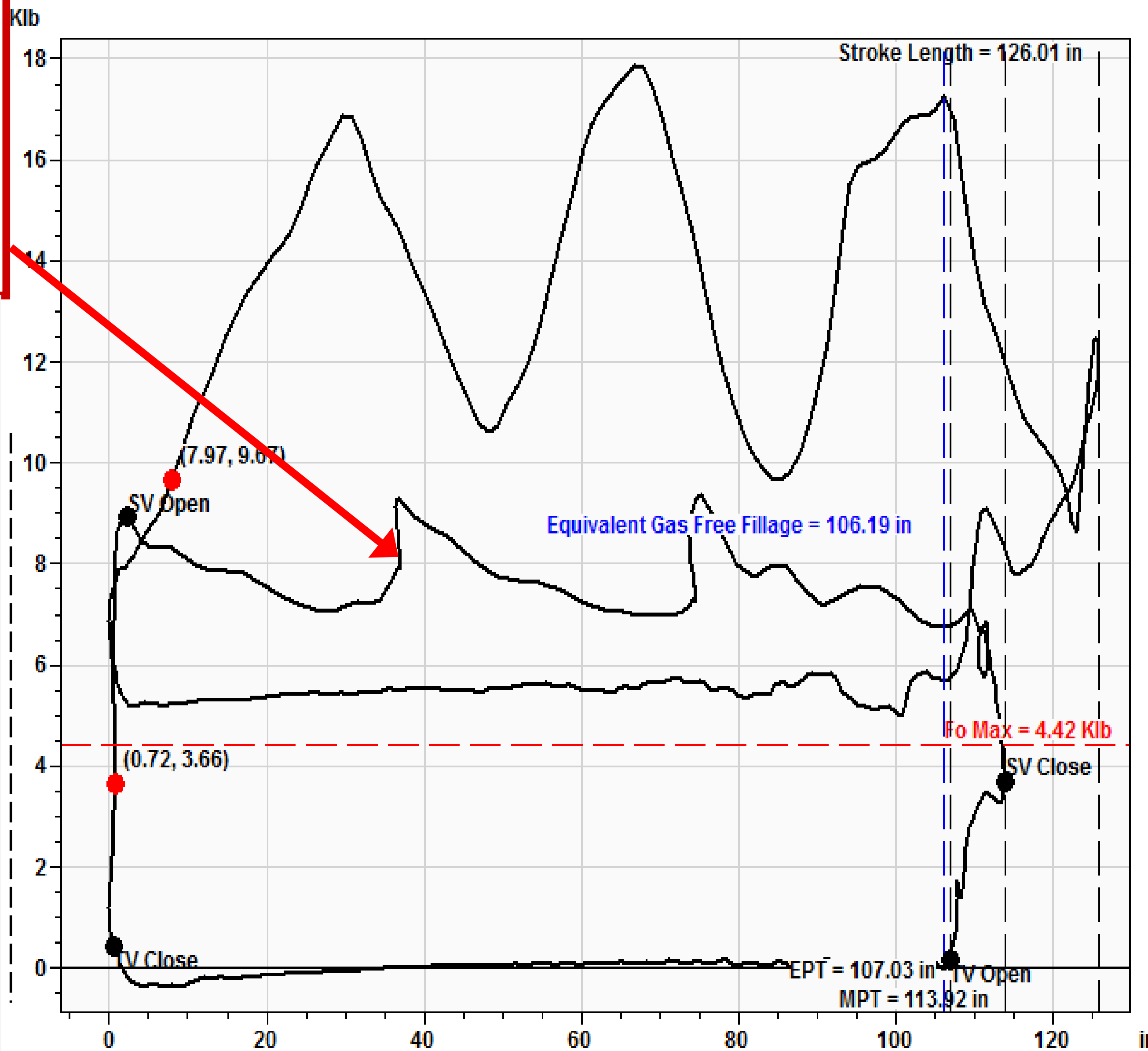


Increasing Pump Load on Upstroke Indicates Plunger Stops Due to Downhole Sticking

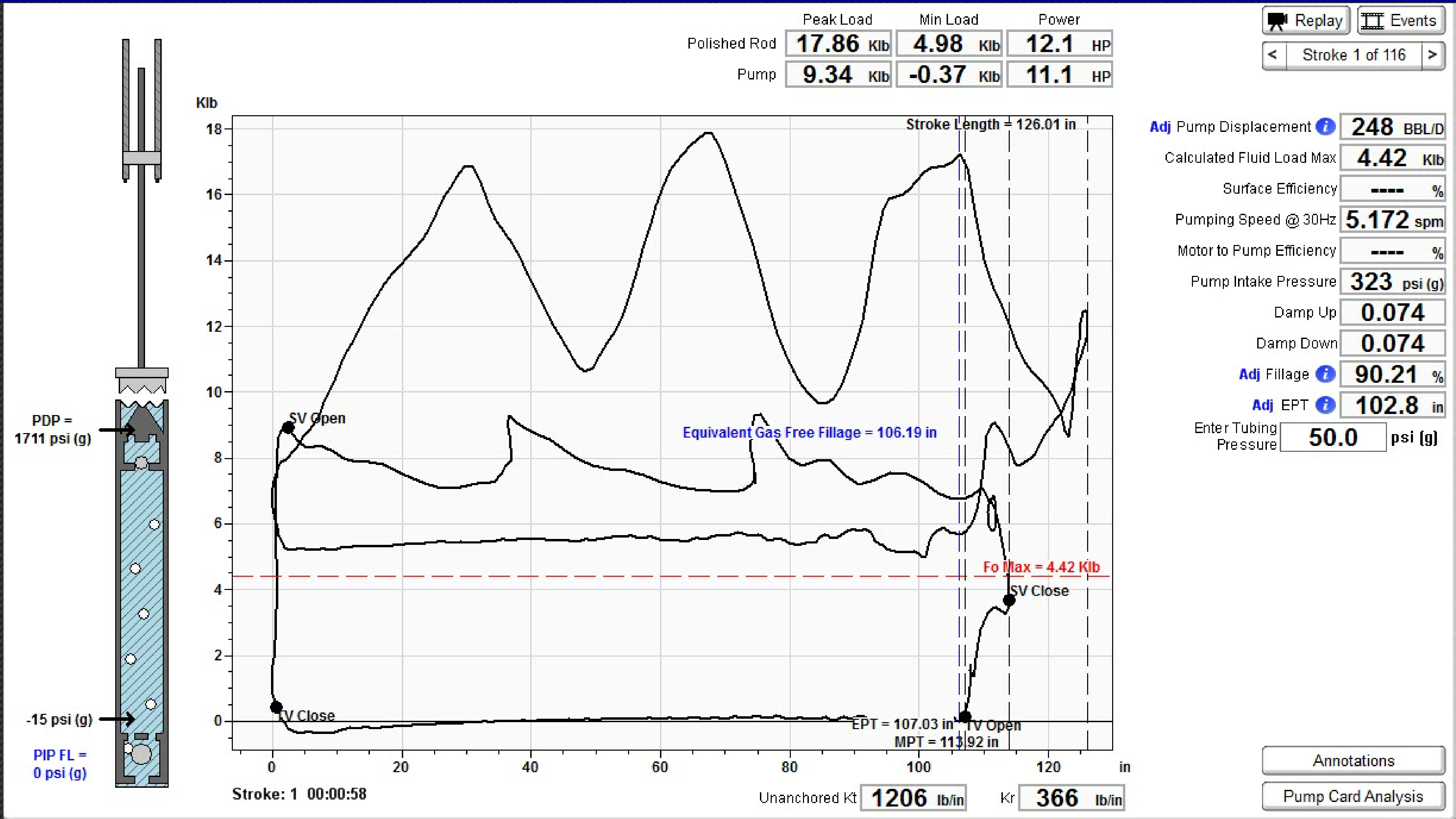
Sticking:

Pump Stops,
Rods Stretch, then
Plunger Moves

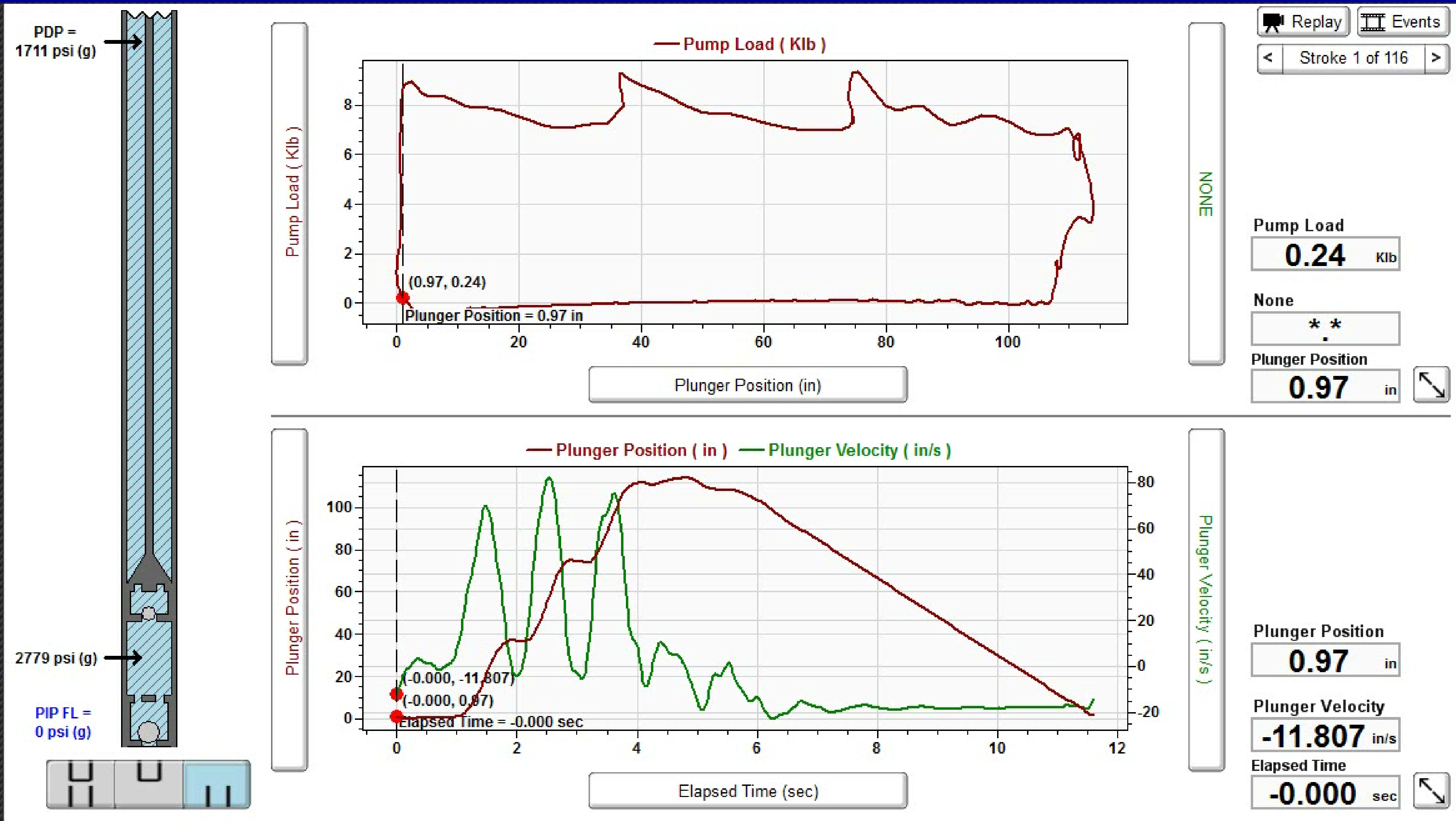




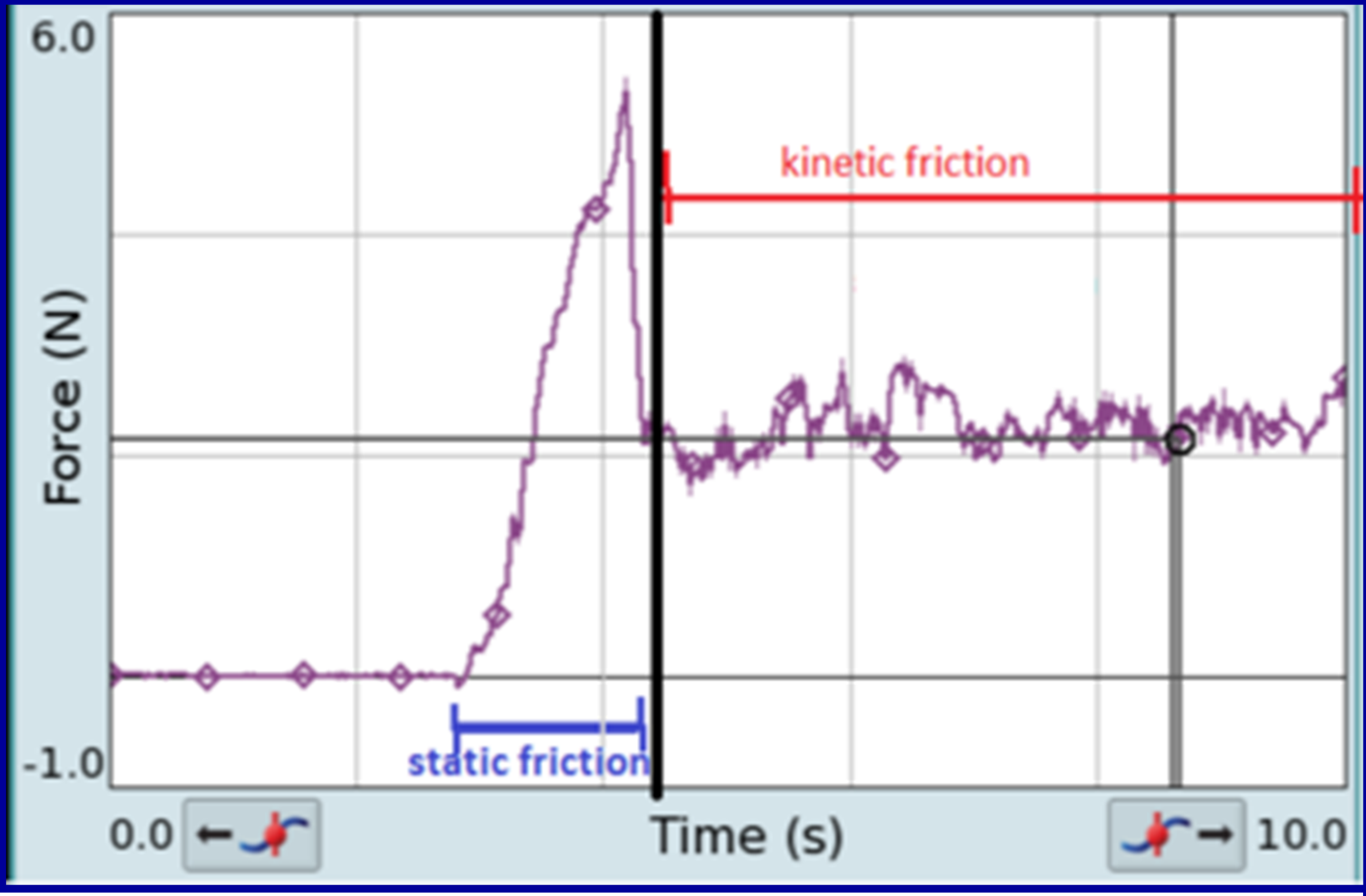
Plunger Stops During Up and Down Stroke Due to Downhole Sticking



Plunger Position Flat When Stops During Up and Down Stroke Due to Downhole Sticking

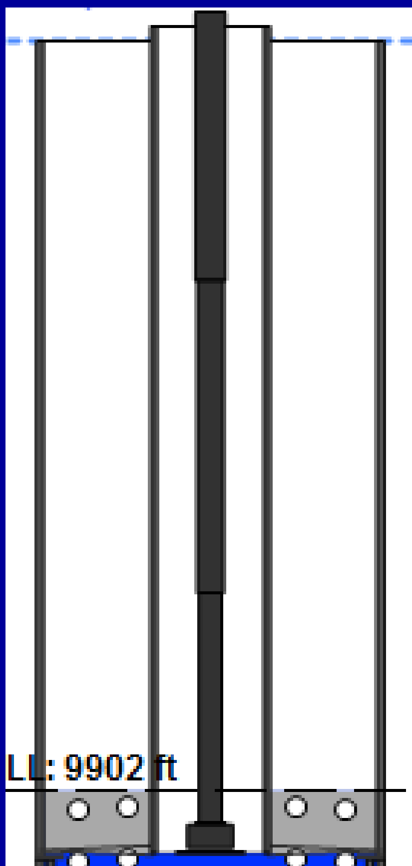


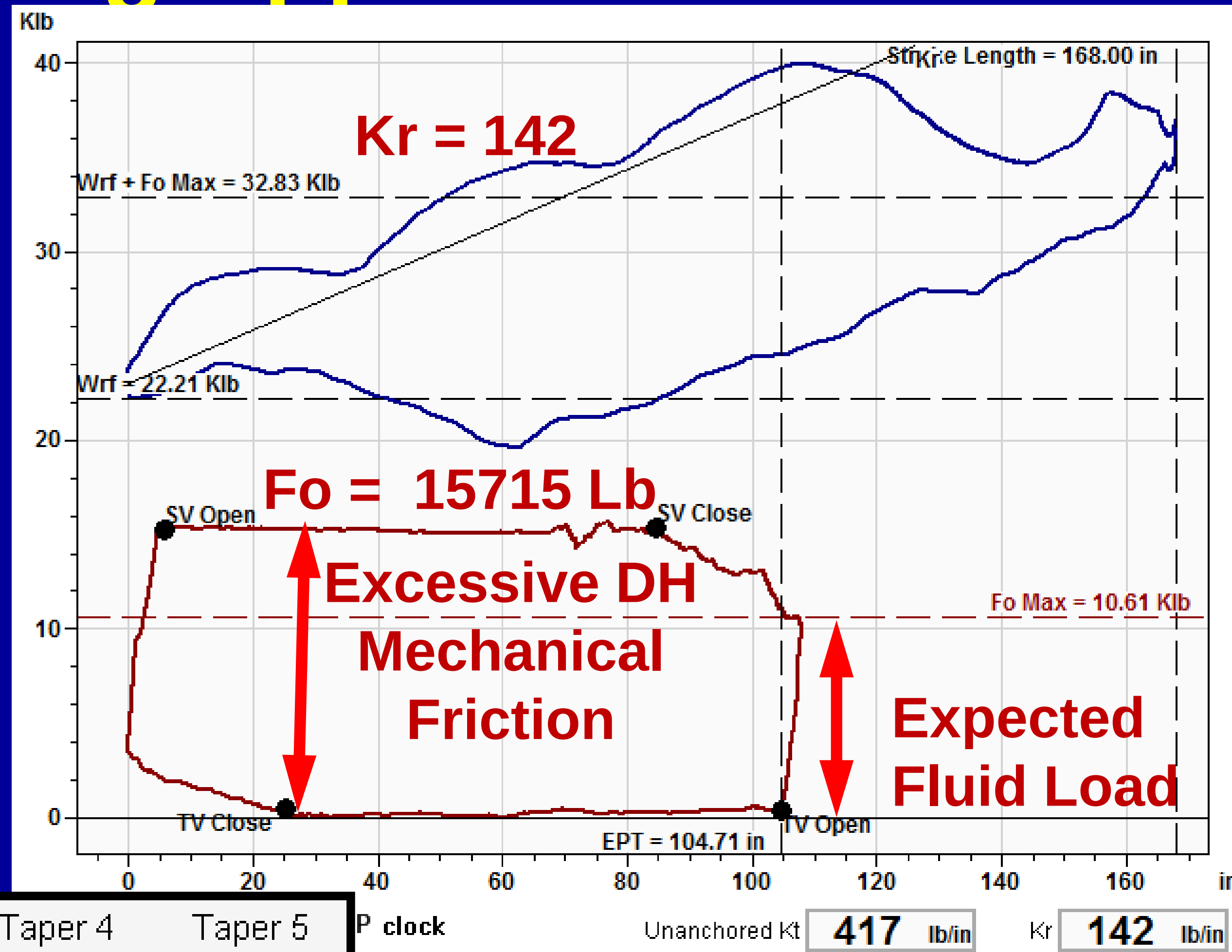
Static vs Kinetic Friction



- Coulomb's Law of Friction: Kinetic friction is independent of the sliding velocity. (Is deviated wellbore model ignoring static friction and only looking at Coulomb/Kinetic friction?)
- Static friction is friction between two or more solid objects that are not moving relative to each other. For example, static friction can prevent an object from sliding. The coefficient of static friction, typically denoted as μs, is usually higher than the coefficient of kinetic friction
- Read https://en.wikipedia.org/wiki/Friction

What Depth is Excessive DH Mechanical Friction Being Applied to Rods



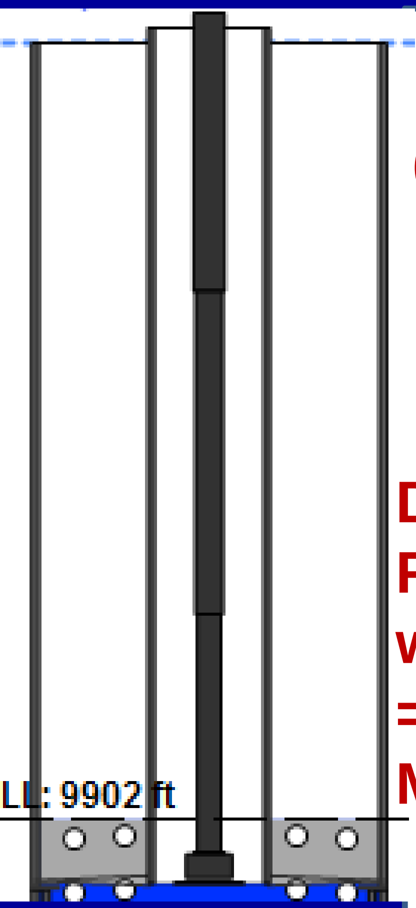


	Top Taper	Taper 2	Taper 3	Taper 4	Taper 5
Rod Type	EL	EL	EL	SB	SB
Length	3162.00	4125.00	3025.00	32.50	300.00
Diameter	1.000	0.875	0.750	1.000	1.500
Weight	9145.1	9124.4	4910.9	94.0	1958.9

Unaccounted Friction Ratio
UFR = 1.48

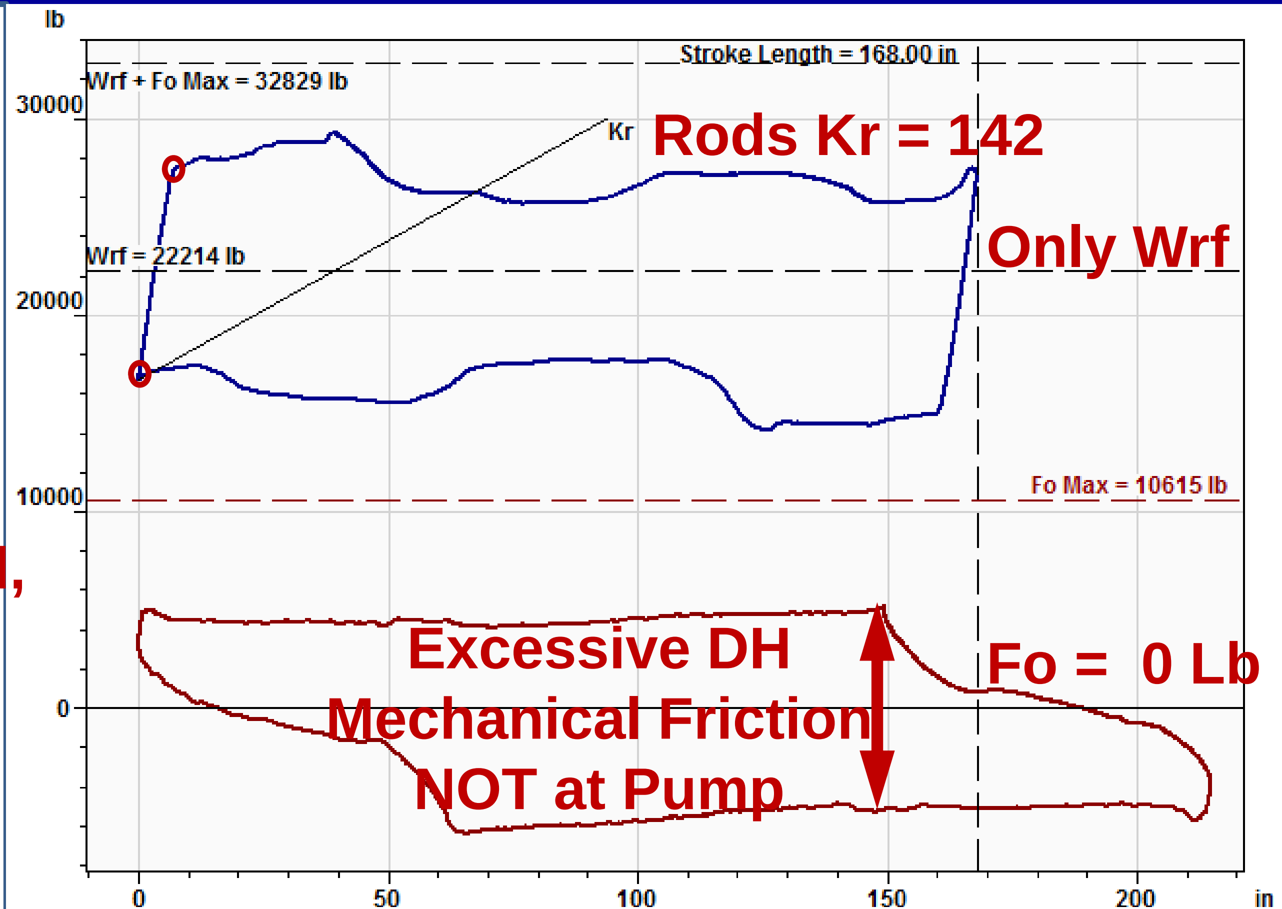
Echometer Online_Mechanical Friction: StickFriction_wRodPart

Excessive DH Mechanical Friction ***BUT*** NO Production to the Surface



Measured Kr = (27430-16670) / (7.28-0) = 1478 Lb/In

DH Mechanical Friction Applied, where Rods Kr = 1478 Lb/in Kr Measured



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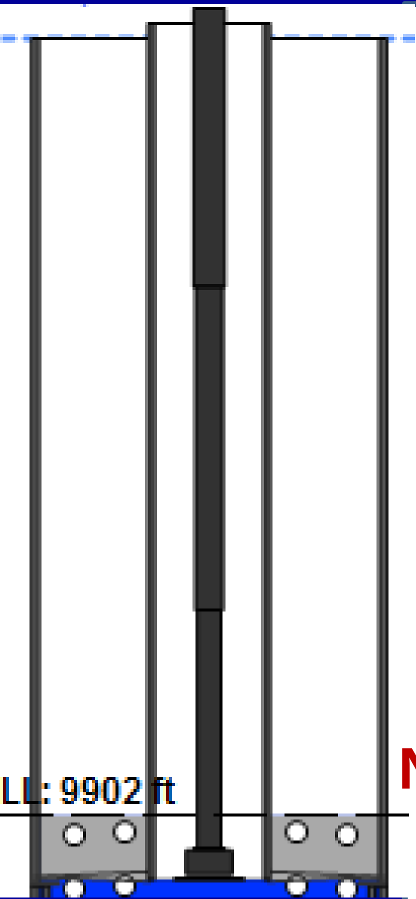
Rod Type	EL	EL	EL	SB	SB
Length	3162.00	4125.00	3025.00	32.50	300.00
Diameter	1.000	0.875	0.750	1.000	1.500
Weight	9145.1	9124.4	4910.9	94.0	1958.9

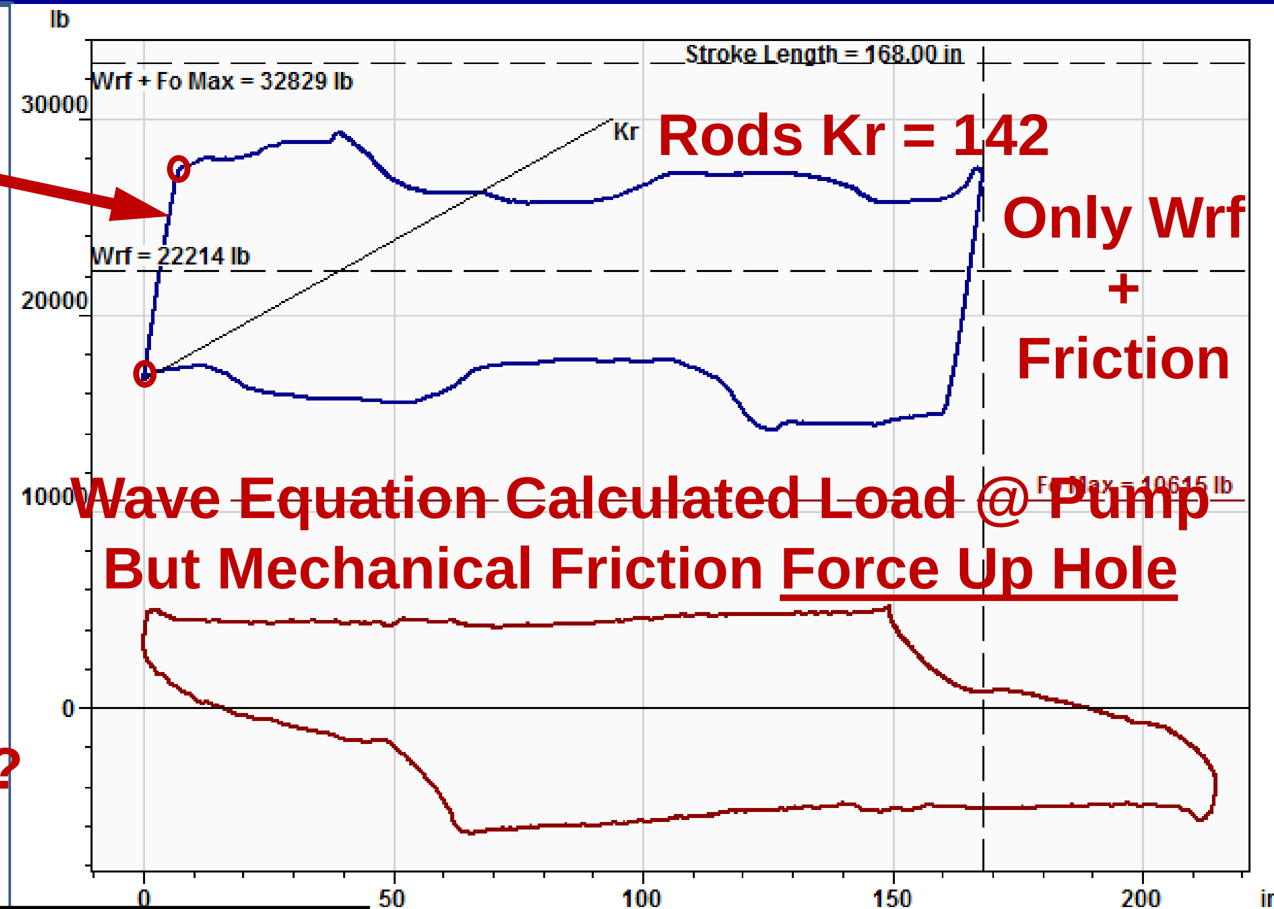
TV Stuck OPEN
No Pump Load

Point? Where DH Mechanical Friction Applied: ***Rods Kr = Kr Measured***



Measured Kr = 1478 Lb/In

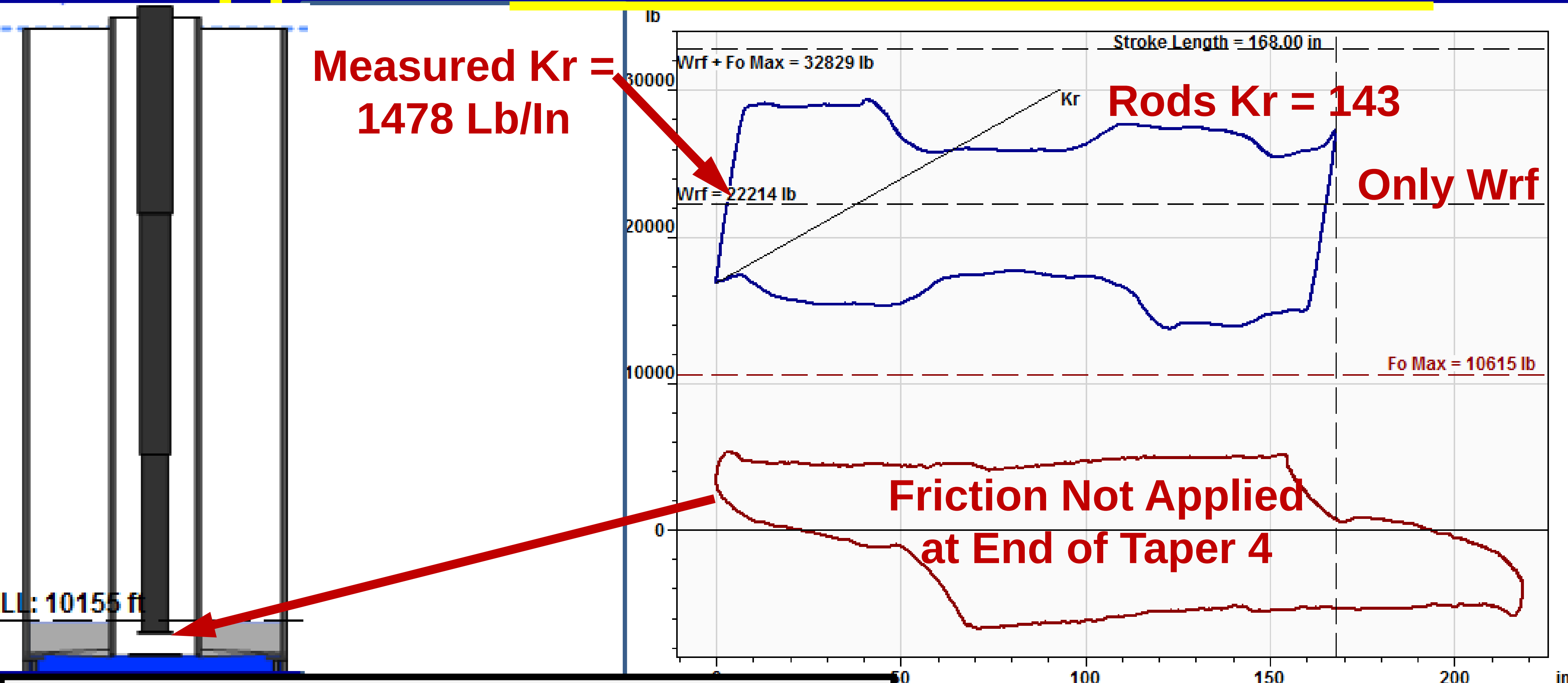
No Production
No Pump Load?



	Top Taper	Taper 2	Taper 3	Taper 4	Taper 5
Rod Type	EL	EL	EL	SB	SB
Length	3162.00	4125.00	3025.00	32.50	300.00
Diameter	1.000	0.875	0.750	1.000	1.500
Weight	9145.1	9124.4	4910.9	94.0	1958.9

Rod Length = 10644 Ft
Rods Kr = 142 Lb/in

Point? Where DH Mechanical Friction Applied: *Rods Kr = Kr Measured*



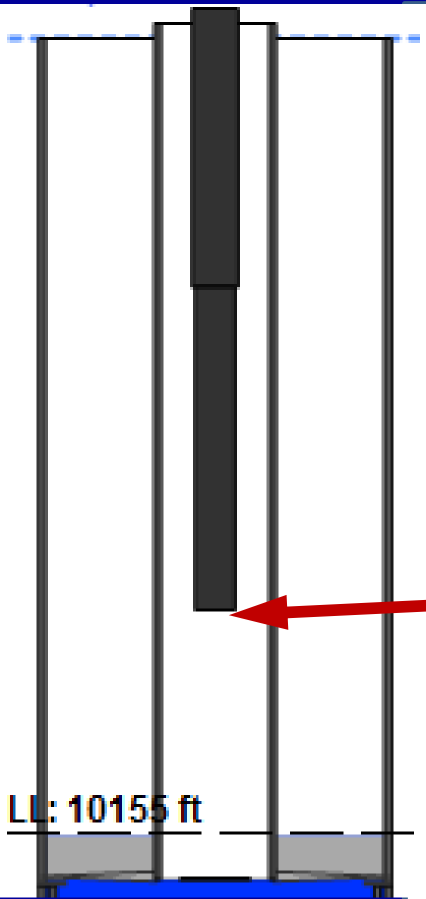
	Top Taper	Taper 2	Taper 3	Taper 4	Taper 5
Rod Type	EL	EL	EL	SB	NONE
Length	3162.00	4125.00	3025.00	32.50	
Diameter	1.000	0.875	0.750	1.000	
Weight	9145.1	9124.4	4910.9	94.0	

Set Taper 5 = 0

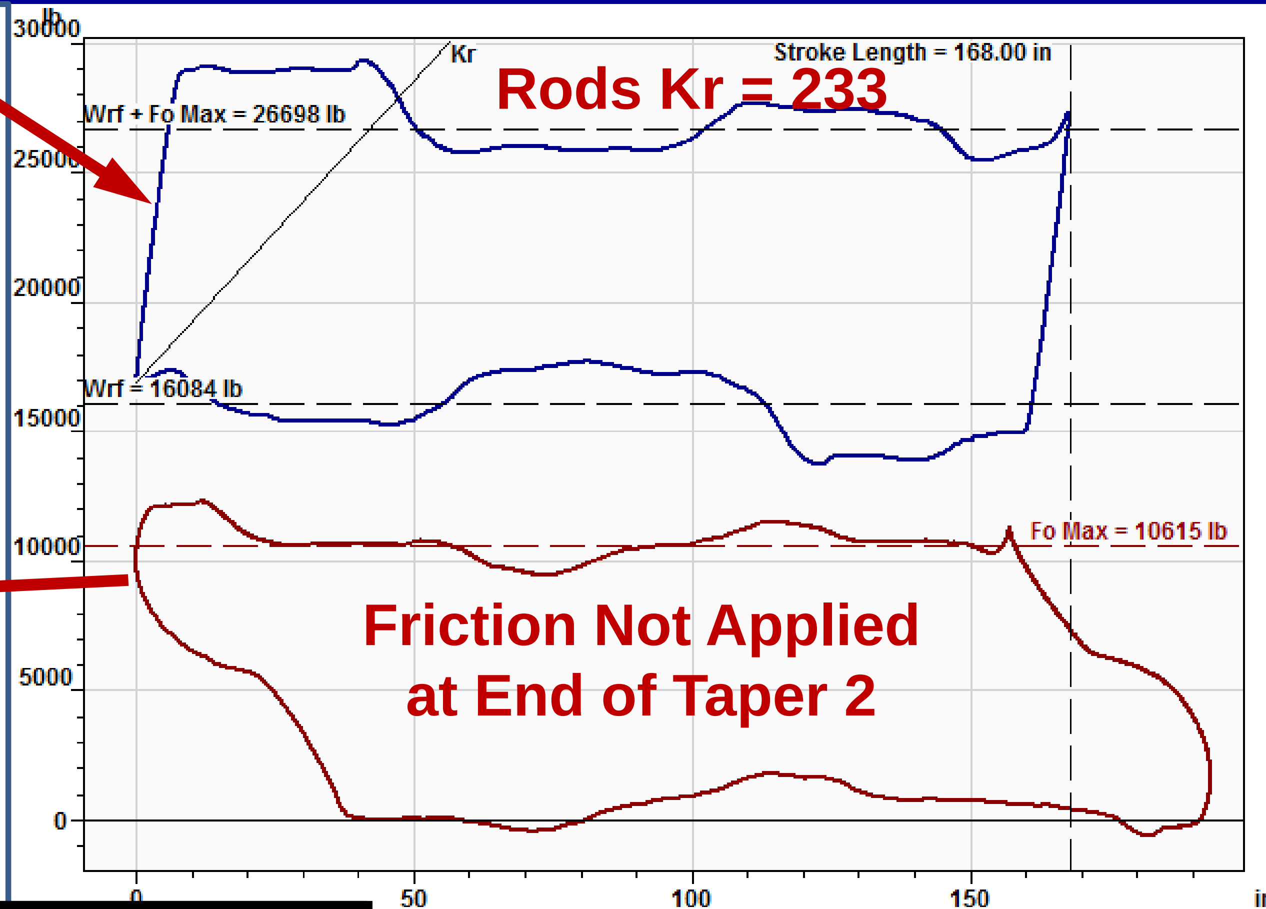
Rod Length = 10344 Ft

Rods Kr = 143 Lb/in

Point? Where DH Mechanical Friction Applied: *Rods Kr = Kr Measured*



Measured Kr = 1478 Lb/In



Rods Kr = 233

Friction Not Applied at End of Taper 2

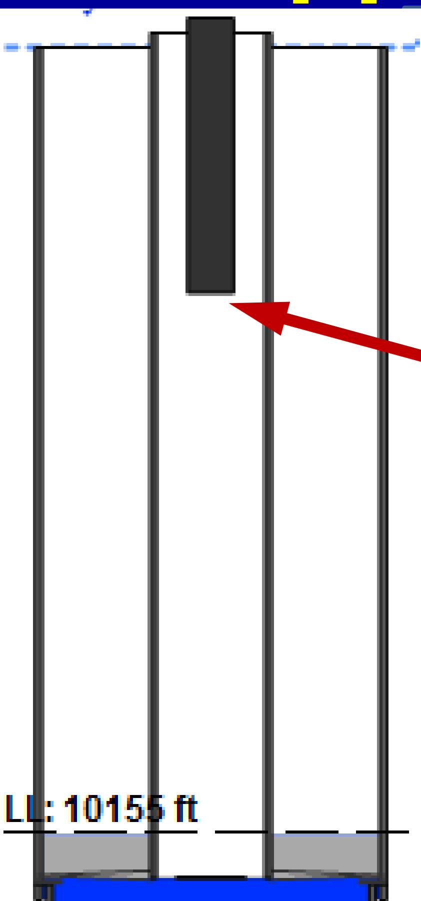
	Top Taper	Taper 2	Taper 3	Taper 4	Taper 5
Rod Type	EL	EL	NONE	NONE	NONE
Length	3162.00	4125.00			
Diameter	1.000	0.875			
Weight	9145.1	9124.4			

Taper 3&4 = 0

Rod Length = 7287 Ft

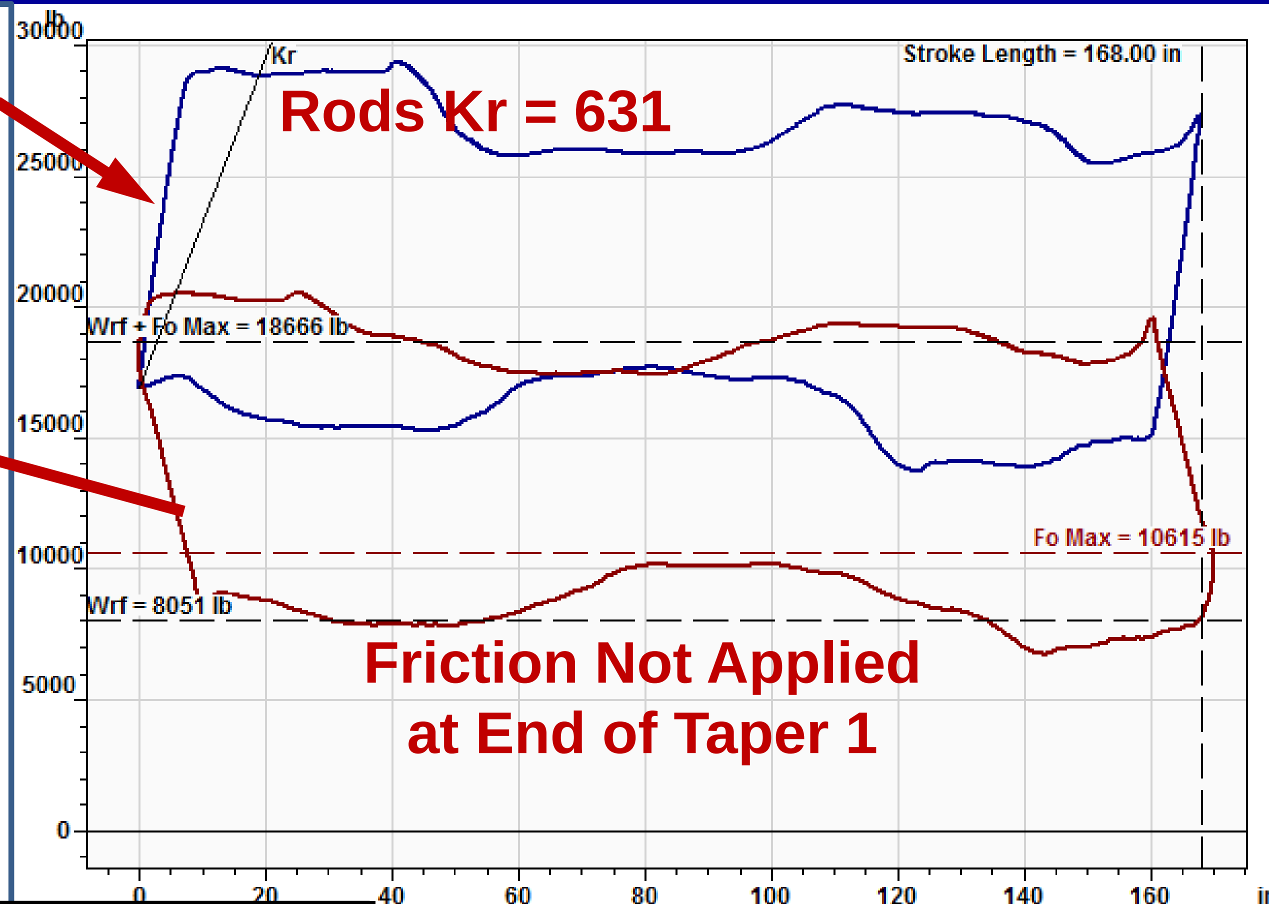
Rods Kr = 233 Lb/in

Point? Where DH Mechanical Friction Applied: *Rods Kr = Kr Measured*



Measured Kr = 1478 Lb/In

3162*631 /1478= 1350 ft



Rods Kr = 631

Friction Not Applied at End of Taper 1

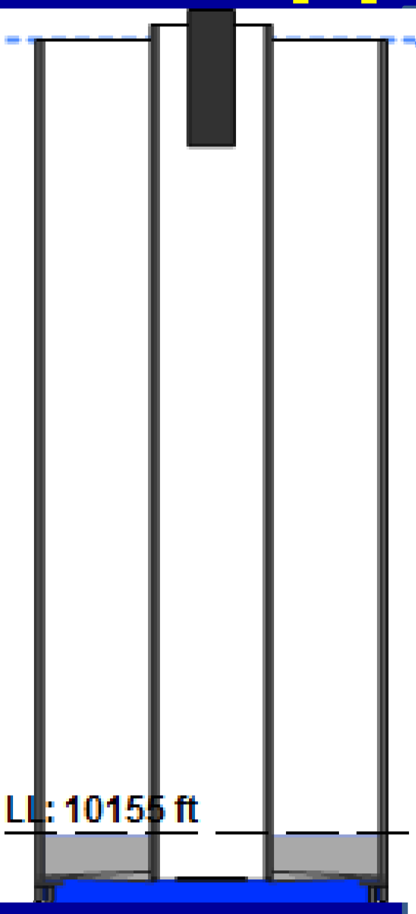
	Top Taper	Taper 2	Taper 3	Taper 4	Taper 5
Rod Type	EL	NONE	NONE	NONE	NONE
Length	3162.00				
Diameter	1.000				
Weight	9145.1				

Taper 2 = 0

Rod Length = 3162 Ft

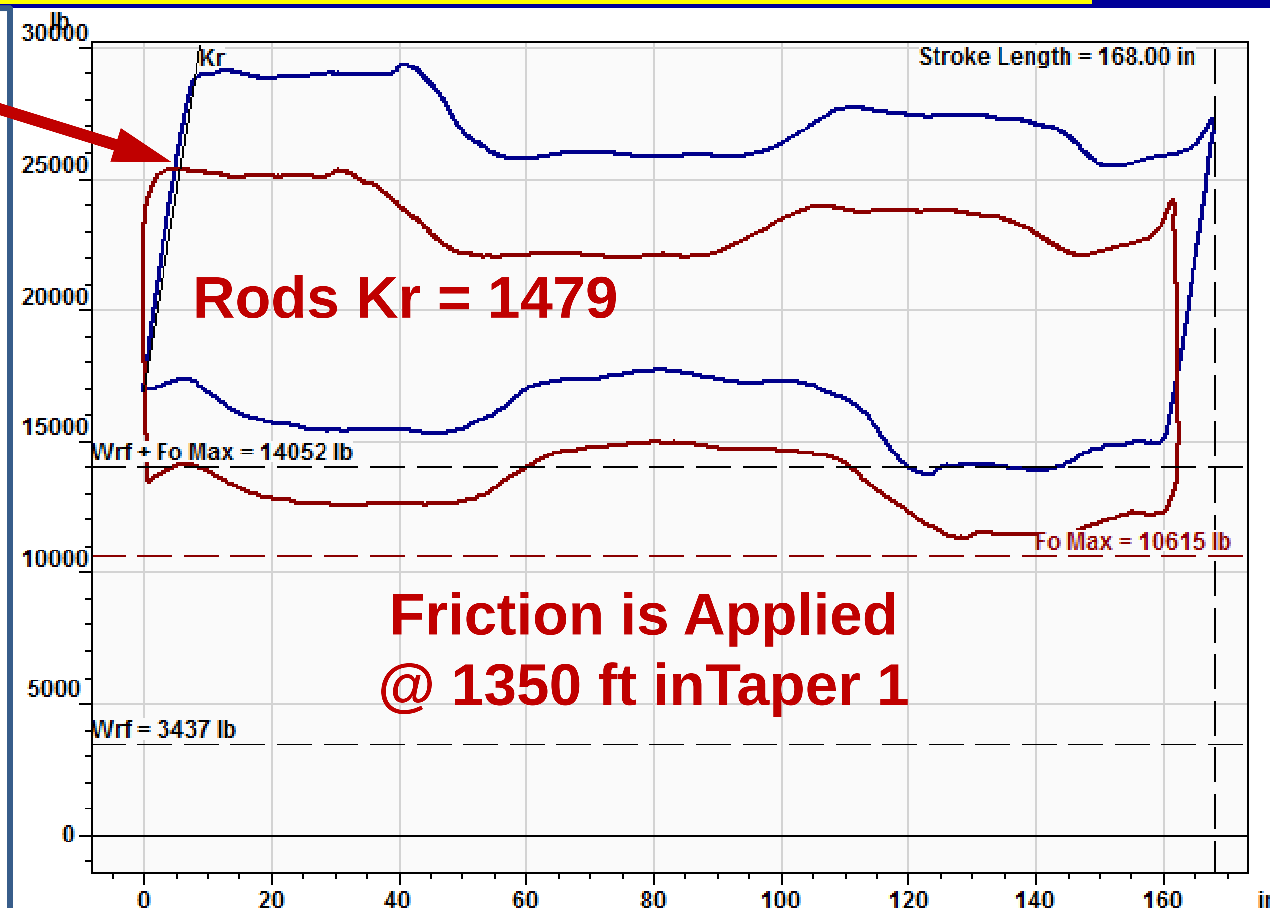
Rods Kr = 631 Lb/in

Point Where DH Mechanical Friction Applied: *Rods Kr = Kr Measured*



Measured Kr = 1478 Lb/In

Severe Dog Leg at 1350 ft is location where DN Mechanical Friction is Applied



	Top Taper	Taper 2	Taper 3	Taper 4	Taper 5
Rod Type	EL	NONE	NONE	NONE	NONE
Length	1350.00				
Diameter	1.000				
Weight	3904.5				

Partial Taper 1

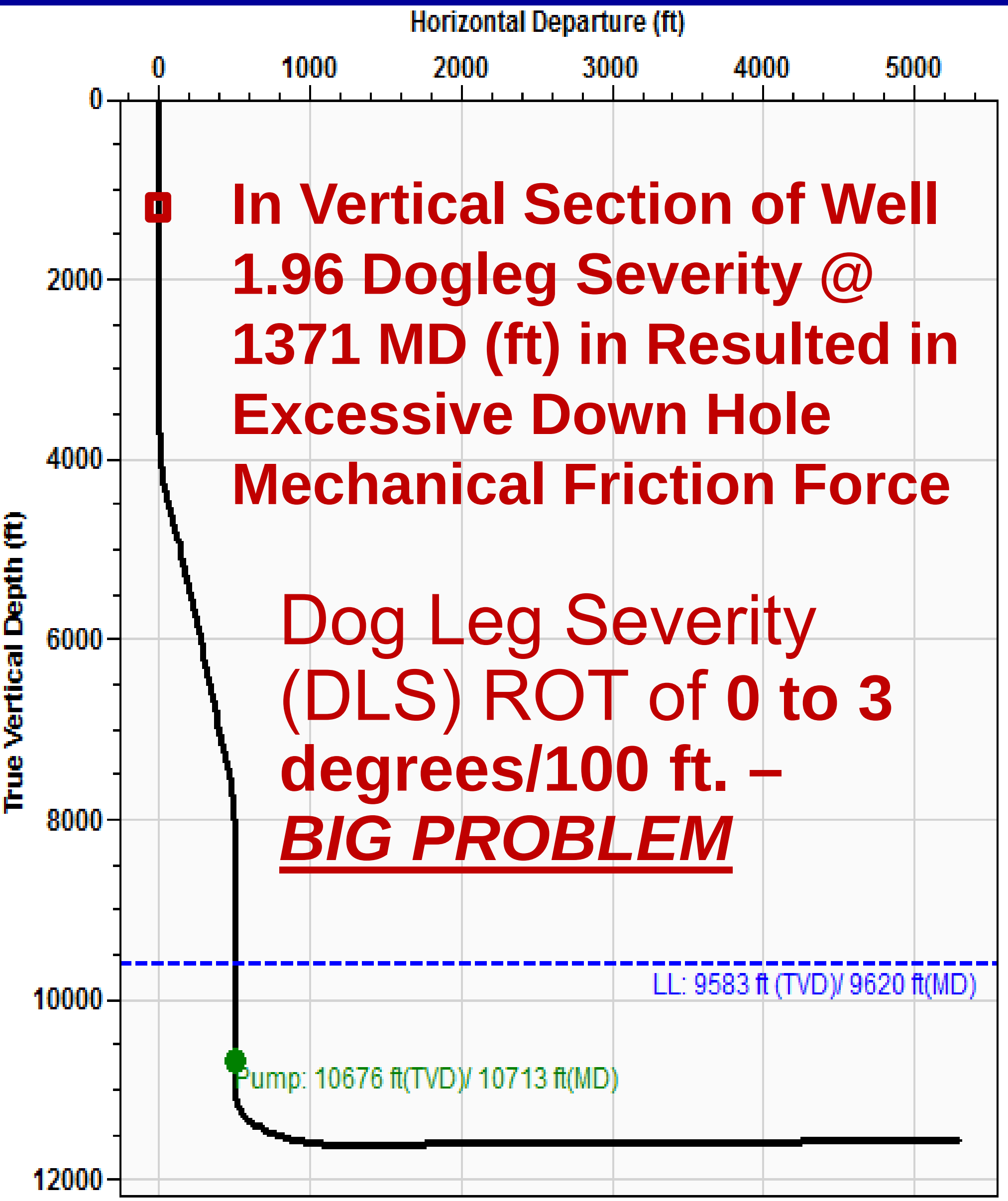
Rod Length = 1350 Ft

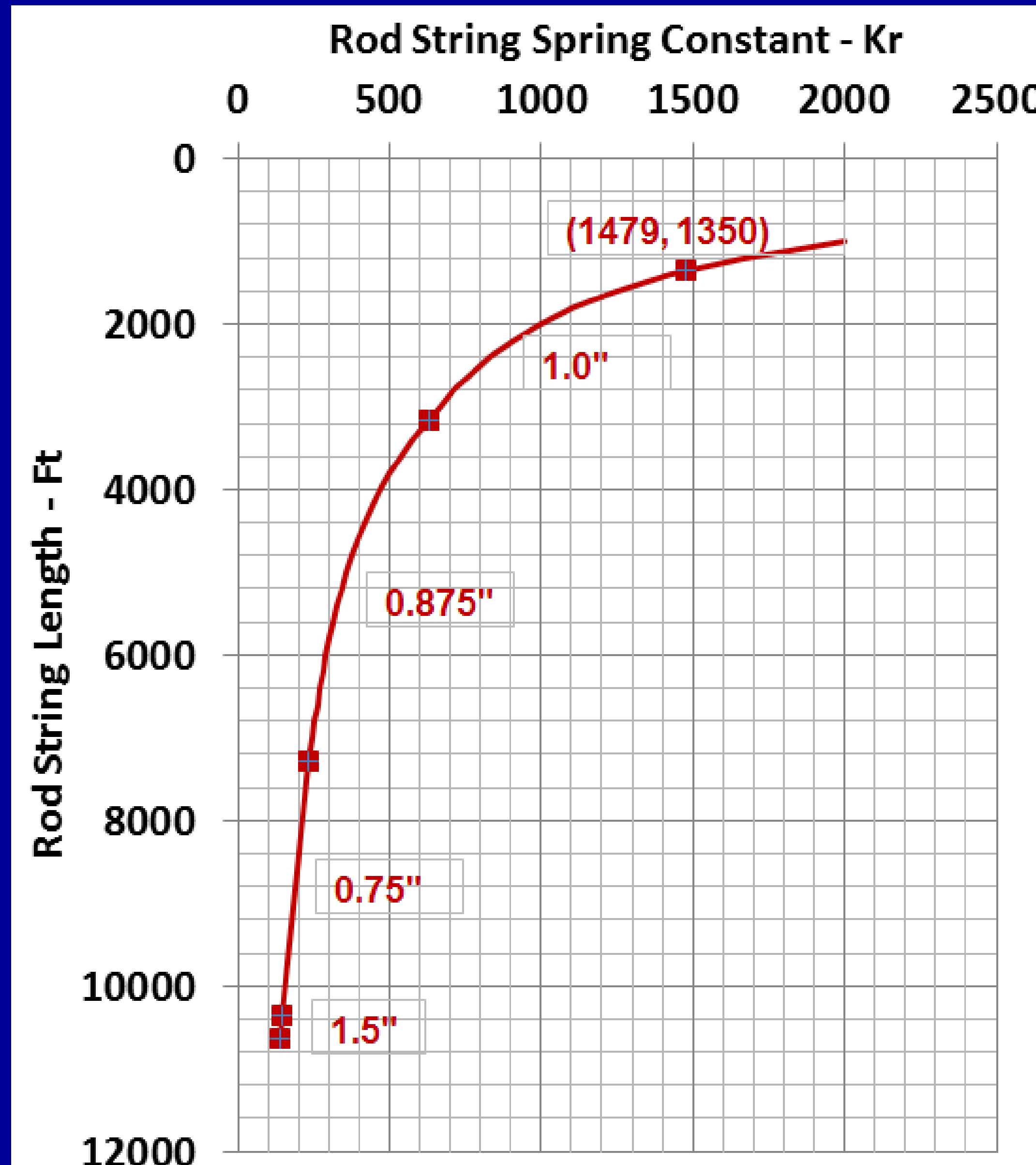
Rods Kr = 1479 Lb/in

1.96 Dogleg Severity @ 1371 MD (ft)

	Survey De	Inclinatioi	Azimuth	True Verti	Vertical S	Coordinates		Closure		DLS	Build Rate	Walk Rate
No.	MD (ft.)	Incl (°)	Azm (°)	TVD (ft.)	VS (ft.)	N-S (ft.)	E-W (ft.)	Dist. (ft.)	Ang. (°)	°/100'	°/100'	°/100'
Tie In (0)	0	0	0	0	0	0	0	0	0	0	0	0
1	140	0.7	218.2	139.9965	-0.66929	-0.67207 S	-0.52886 W	0.855201	218.2	0.5	0.5	155.8571
2	233	0.6	231.3	232.9905	-1.55375	-1.42296 S	-1.2602 W	1.900764	221.5287	0.191927	-0.10753	14.08602
3	326	0.3	127.8	325.9886	-1.84073	-1.87664 S	-1.44784 W	2.370239	217.6503	0.785783	-0.32258	-111.29
4	419	0.3	68.2	418.9875	-1.44704	-1.93545 S	-1.0294 W	2.192176	208.0069	0.320627	0	-64.086
5	513	0.3	46.1	512.9862	-0.99183	-1.67342 S	-0.62358 W	1.785834	200.4374	0.122339	0	-23.5106
6	608	0.4	53.1	607.9844	-0.47388	-1.30186 S	-0.17919 W	1.314137	187.8372	0.114291	0.105263	7.368421
7	703	0.1	99.5	702.9835	-0.09358	-1.11644 S	0.167756 E	1.128973	171.4547	0.356701	-0.31579	48.84211
8	798	0.4	21	797.9826	0.169717	-0.82054 S	0.368361 E	0.899428	155.8234	0.41315	0.315789	-82.6316
9	894	0.4	201.4	893.9818	0.167789	-0.81969 S	0.36618 E	0.897765	155.9283	0.833128	0	187.9167
10	990	0.6	165.2	989.9783	-0.00982	-1.61766 S	0.372308 E	1.659952	167.0389	0.379397	0.208333	-37.7083
11	1086	0.4	132.5	1085.975	0.191693	-2.33002 S	0.74777 E	2.447073	162.2071	0.354891	-0.20833	-34.0625
12	1180	0.1	128	1179.973	0.529989	-2.70121 S	1.183607 E	2.950974	156.3536	0.110248	-0.10638	-4.78723
13	1277	0.5	99.7	1276.971	1.078359	-2.93086 S	1.800905 E	3.439942	148.4308	0.283938	0.206186	-29.1753
14	1371	2.3	79.2	1370.939	3.340495	-2.6465 S	4.058167 E	4.844864	123.1101	1.957458	1.914894	-21.8085
15	1466	2.1	80.2	1465.869	6.98227	-1.99304 S	7.64584 E	7.901334	104.6102	0.214361	-0.21053	1.052632
16	1561	1.8	79.9	1560.814	10.20929	-1.43513 S	10.82991 E	10.92459	97.5486	0.315971	-0.31579	-0.31579
17	1656	1.7	83.6	1655.769	13.09792	-1.01641 S	13.69917 E	13.73682	94.24327	0.158778	-0.10526	3.894737
18	1710	1.6	77.9	1709.747	14.64682	-0.76909 S	15.2323 E	15.2517	92.89046	0.355682	-0.18519	-10.5556
19	1803	1.8	85.7	1802.706	17.38752	-0.38742 S	17.95831 E	17.96249	91.23586	0.328401	0.215054	8.387097
20	1899	1.8	83.3	1898.659	20.3744	-0.09846 S	20.9592 E	20.95943	90.26917	0.078521	0	-2.5
21	1995	1.1	82.1	1994.628	22.78954	0.204097 N	23.36938 E	23.37027	89.49962	0.729812	-0.72917	-1.25
22	2091	0.1	289.3	2090.622	23.63638	0.358444 N	24.20307 E	24.20673	89.15152	1.239396	-1.04167	215.8333

1.96 Dogleg Severity @ 1371 MD (ft)

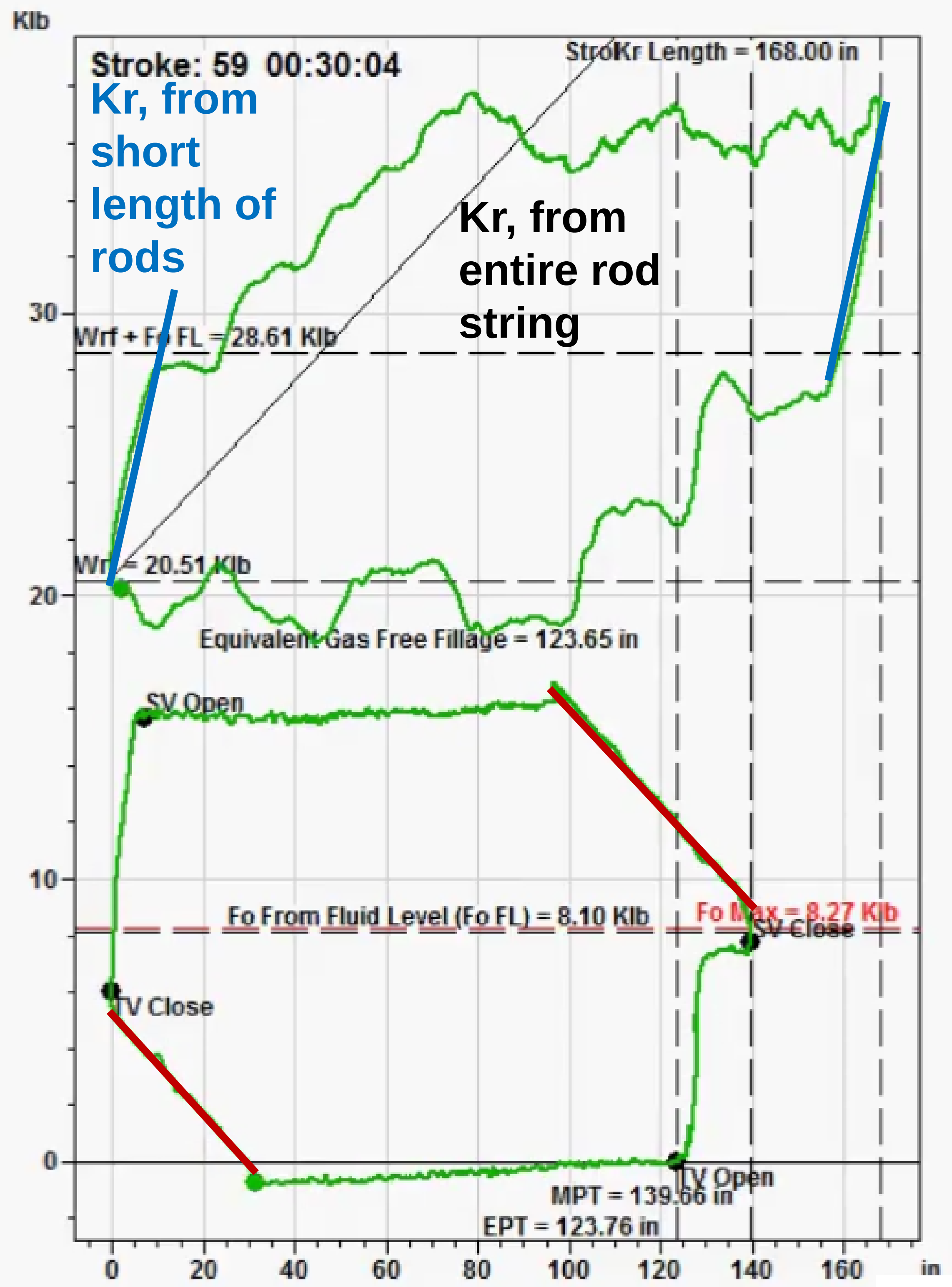




When the pump card slopes "backwards" (red lines) then that slope is the indication of the a mechanical friction force acting on the sucker rods, but not at the pump. The "backwards" slope is result of the wave equation calculating what the up hole mechanical friction force should look like if it were applied at the pump.

If the sucker rod used in the wave equation to calculate the pump card are removed from the bottom of the rod string, then the "backwards" slope of the pump card will become a vertical load at the length of rods where the mechanical friction force is applied.

As the rod string length is shortened , the Kr line will become steeper and match the slope of the surface dynamometer card when the length of rods equals the depth to the point where the sticking force is applied.



Deviation survey shows Doglegs greater than 3 degrees at 2600-2750 ft

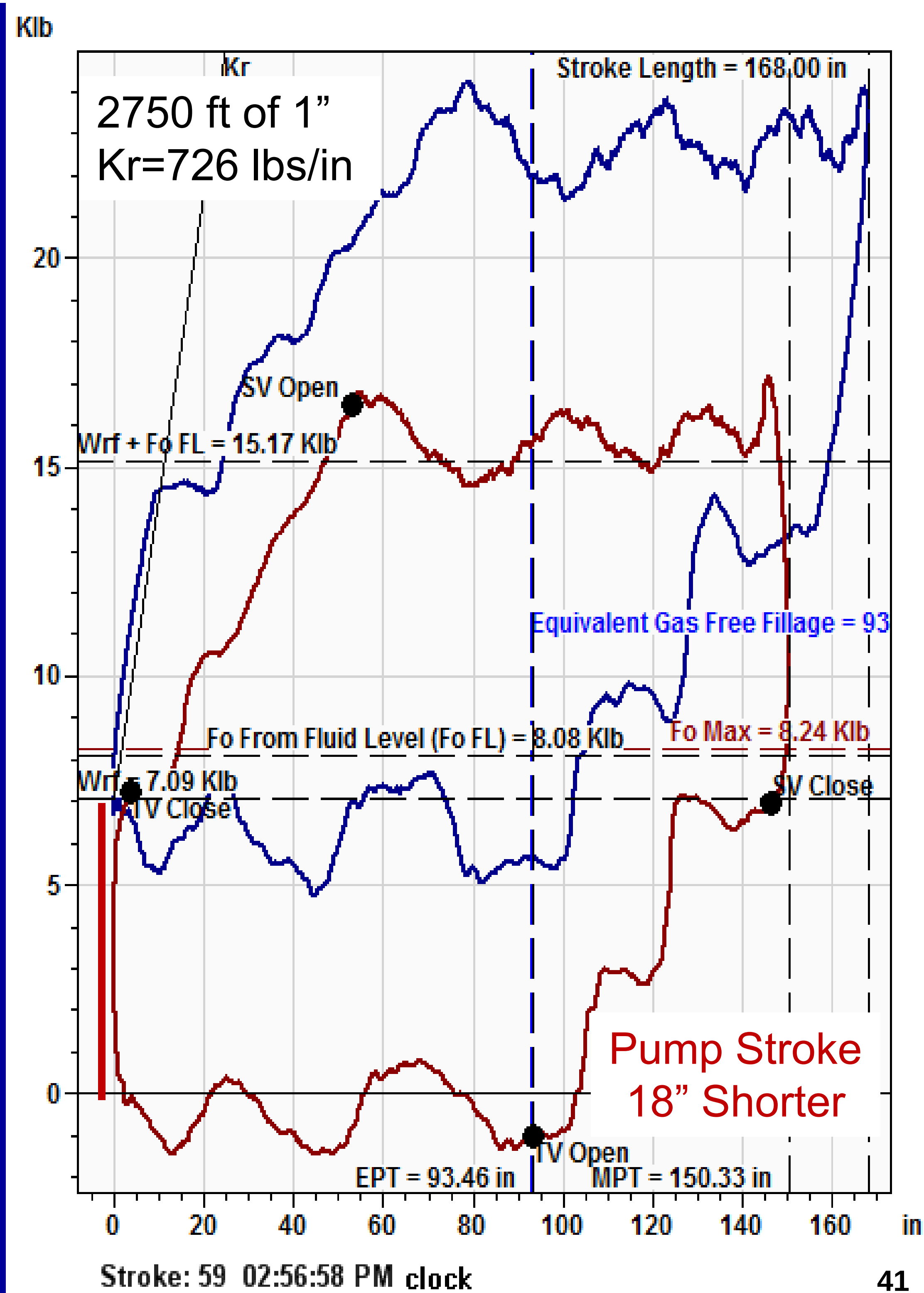
No.	Tool Type	Survey Depth	Incl (°)	Azi (°)	CL (ft)	TVD (ft)	DLS (°/100')	Bld Rate (°/100')	Wlk Rate (°/100')	BRN (°/100')
18	MWD	1700	5.63	125.11	100	1698.78	0.82	0.69	4.8	0.33
19	MWD	1800	6.46	128.89	100	1798.22	0.92	0.83	3.8	0.36
20	MWD	1900	7.5	130.67	100	1897.48	1.06	1.04	1.8	0.39
21	MWD	2000	8.62	134.61	100	1996.49	1.25	1.12	3.9	0.43
22	MWD	2100	9.72	138.89	100	2095.21	1.29	1.10	4.3	0.46
23	MWD	2200	11.13	142.25	100	2193.56	1.53	1.41	3.4	0.50
24	MWD	2300	12.43	145.18	100	2291.45	1.43	1.30	2.9	0.54
25	MWD	2400	14.37	149.15	100	2388.73	2.15	1.94	4.0	0.60
26	MWD	2420	14.75	149.05	20	2408.09	1.90	1.90	-0.5	0.61
27	MWD	2572	14.95	149.18	152	2555.01	0.13	0.13	0.1	0.58
28	MWD	2605	13.72	149.53	33	2586.98	3.74	-3.73	1.1	0.53
29	MWD	2699	11.61	149.7	94	2678.69	2.25	-2.24	0.2	0.43
30	MWD	2731	11.61	149.44	32	2710.03	0.16	0.00	-0.8	0.43
31	MWD	2762	11.78	149.88	31	2740.39	0.62	0.55	1.4	0.43
32	MWD	2856	8.79	146.89	94	2832.87	3.23	-3.18	-3.2	0.31
33	MWD	2951	5.99	143.68	95	2927.07	2.98	-2.95	-3.4	0.20
34	MWD	3045	4.31	137.14	94	3020.69	1.89	-1.79	-7.0	0.14
35	MWD	3139	4.66	146.72	94	3114.40	0.88	0.37	10.2	0.15
36	MWD	3234	3.69	154.19	95	3209.15	1.17	-1.02	7.9	0.11
37	MWD	3328	1.85	150.49	94	3303.04	1.97	-1.96	-3.9	0.06
38	MWD	3422	0.53	236.72	94	3397.02	2.01	-1.40	91.7	0.02
39	MWD	3517	1.14	278.64	95	3492.01	0.87	0.64	44.1	0.03
40	MWD	3611	1.58	273.98	94	3585.98	0.48	0.47	-5.0	0.04

Kr line has become steeper and matches the slope of the surface dynamometer card when the 2750 ft length of rods equals the depth to the point where the sticking force is applied.

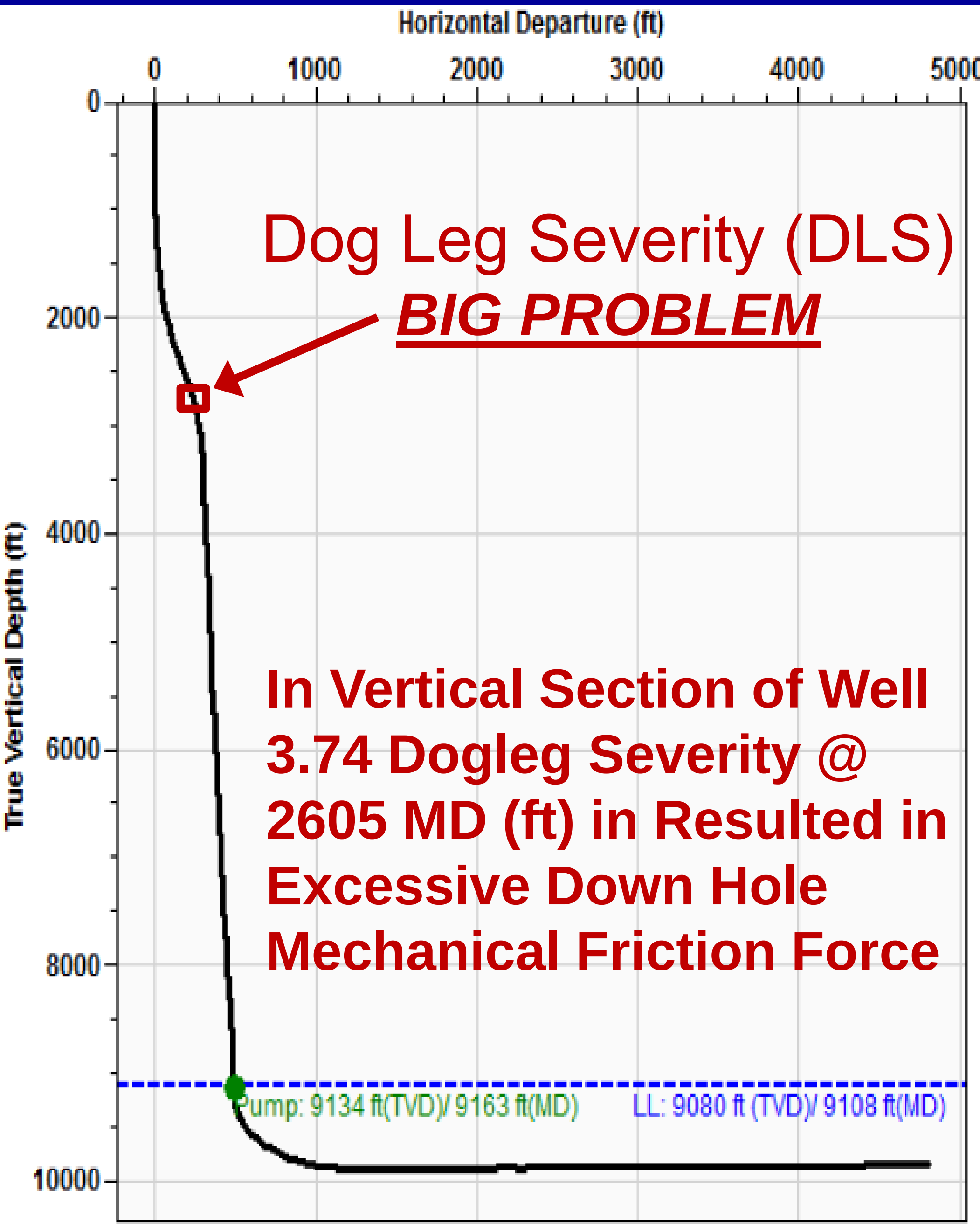
Sticking mechanical force appears to be approximately equal to 7000 lbs. The 1”rod string stretches 7000/744= 9 inches to over come the 7000 lbs force applied at 2750 ft.

Depth to the location where the mechanical sticking force is applied is 2600-2750 ft. This mechanical sticking force causes the surface loads to be approximately 7000 lbs higher.

Pump stroke is shorter. The pump card to the right at 2750 ft has a max stroke of 150 inches and the surface stroke is 168.



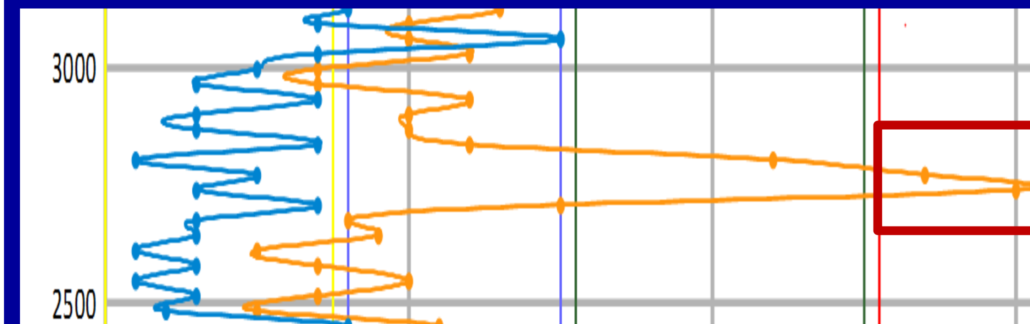
3.74 Dogleg Severity @ 2605 MD (ft)



Dog Leg Severity (DLS)
BIG PROBLEM

In Vertical Section of Well 3.74 Dogleg Severity @ 2605 MD (ft) in Resulted in Excessive Down Hole Mechanical Friction Force

Well Head Tubing Inspection Report "Depth Graph" shows greater than 50% wall loss at a depths of 2700 ft.



Need to remove all but top 2750 ft of 1" Rods.

Tapers

	Top Taper	Taper 2	Taper 3	Taper 4
Rod Type	S-88	S-88	S-88	SB
Length	3610.00	3200.00	1975.00	350.00
Diameter	1.000	0.875	0.750	1.500
Weight	10368.5	7074.4	3204.0	2284.6

Observations – Mechanical Friction

- Rods **stretch** to pickup Fluid Load
- Rods **also stretch** to overcome downhole mechanical friction
- When rod, Kr, spring force exceeds the down hole mechanical friction force, then rods and plunger can move
- "Effective" Treatment of paraffin friction "should" show change in rod Loading, pump stroke, and/or horsepower
- Dogleg severity and stuffing box friction are mechanical friction forces that are applied at a point in the well
- Wave Equation will calculate EXTREMELY unusual pump card shapes, when mechanical friction forces not applied at the pump occur somewhere else along the rod string
- Dogleg severity **limits** should be enforced when the well is drilled
- ***Severe Doglegs in the upper section of the well should be avoided***, because of resulting extreme mechanical friction forces being applied to the rod string

Dog Leg Severity (DLS) had been used as recommendations to drill oil and gas wells

- Dog Leg Severity (DLS) Recommended Limits:
  - **Provide "trouble free" operating conditions**
  - **Historically based on vertical, shallow (<5000 ft.) deep wells**
  - **With the current drilling and operating practices of deviated and/or horizontal wells, these recommendations may no longer be applicable**
  - **Deviation measurement interval (degrees/100 ft.) may no longer be representative of downhole problems using existing rod string design software**
  - Paper provides <u>*new recommendations for drilling wells*</u> for better, longer term, less problematic operation of operating Sucker Rod Lifted (SRL) vertical, deviated and horizontal wells

"DOG LEG SERVERITY (DLS) AND SIDE LOAD (SL) RECOMMENDATIONS TO DRILLING", Hein & Rowlan, SWPSC 2019

Dogleg severity friction is mechanical friction forces that are applied at a point in the well

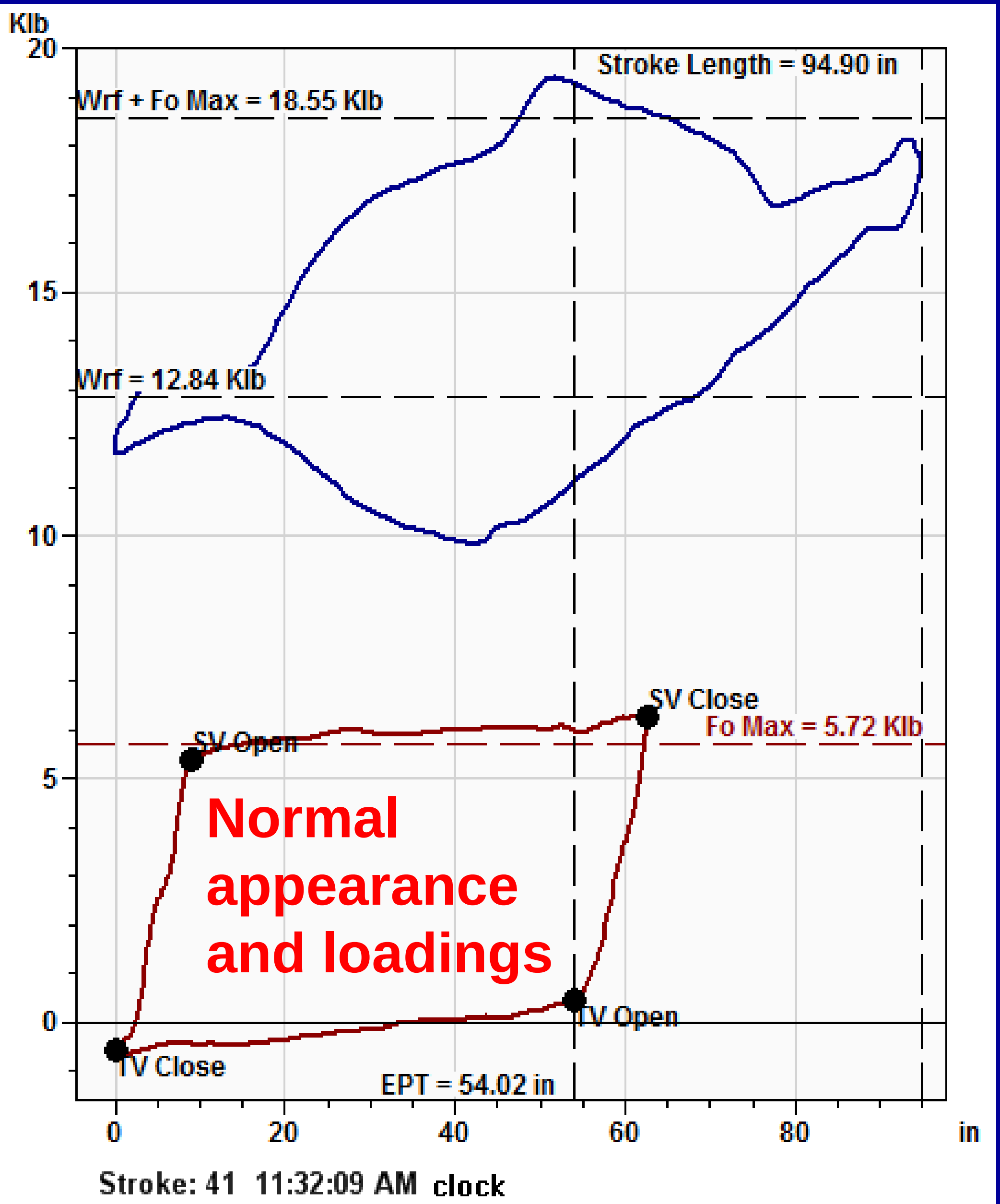
- **For vertical wells previous Rule of Thumb if Dog Leg Severity (DLS):**
  - **Deviation 0 to 3 degrees/100 ft. – *<u>no problem</u> !@#$%^&***
  - **Deviation 3 to 5 degrees/100 ft. – increased wear & friction**
  - **Deviation >5 degrees/100 ft. – will have problems (doesn't mean can't pump, just extra precautions may be required or may have increased operating costs, failures, decreased run time/life, etc.)**
- **Now, with improved deviation measuring equipment**
  - **Degrees per 100 ft. are not be sufficient to provide accurate impact of a dogleg**
  - **Best to run tubing gyro surveys at 1 foot intervals then process to the rod string design program interval limit**

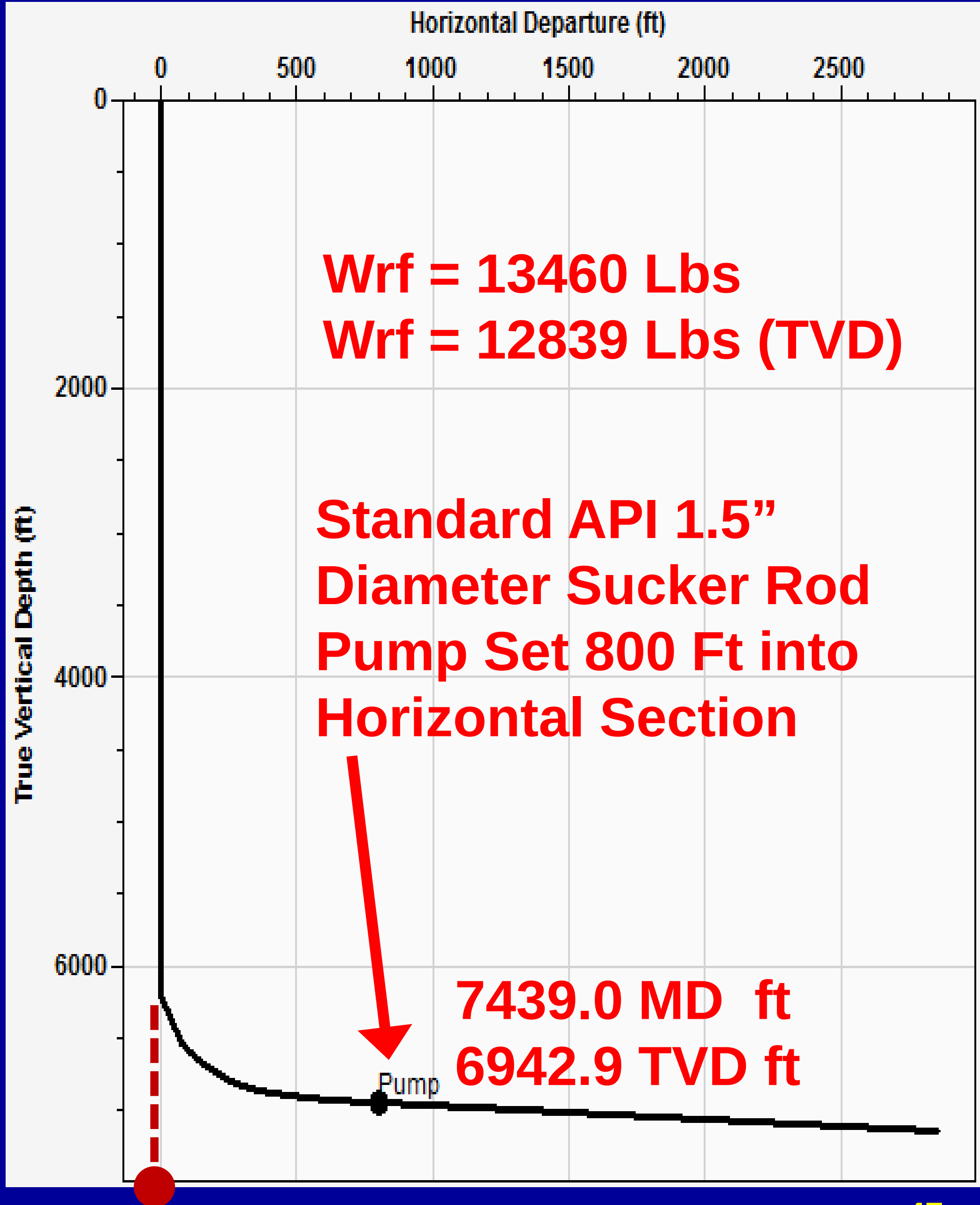
Recommended Dogleg Severity Limits to Control Drilling a Wellbore

Dogleg Severity (Deg)	Wellbore Location Above Kickoff
< 0.50	0 to 1,500 feet
< 1.00	1,500 feet to 25% of distance to Kickoff
< 1.25	25 to 50% of distance to Kickoff
< 1.50	50 to 75% of distance to Kickoff
< 2.50	75% to 50 feet above top of pump
< 1.00	50 feet above top pump to Kickoff

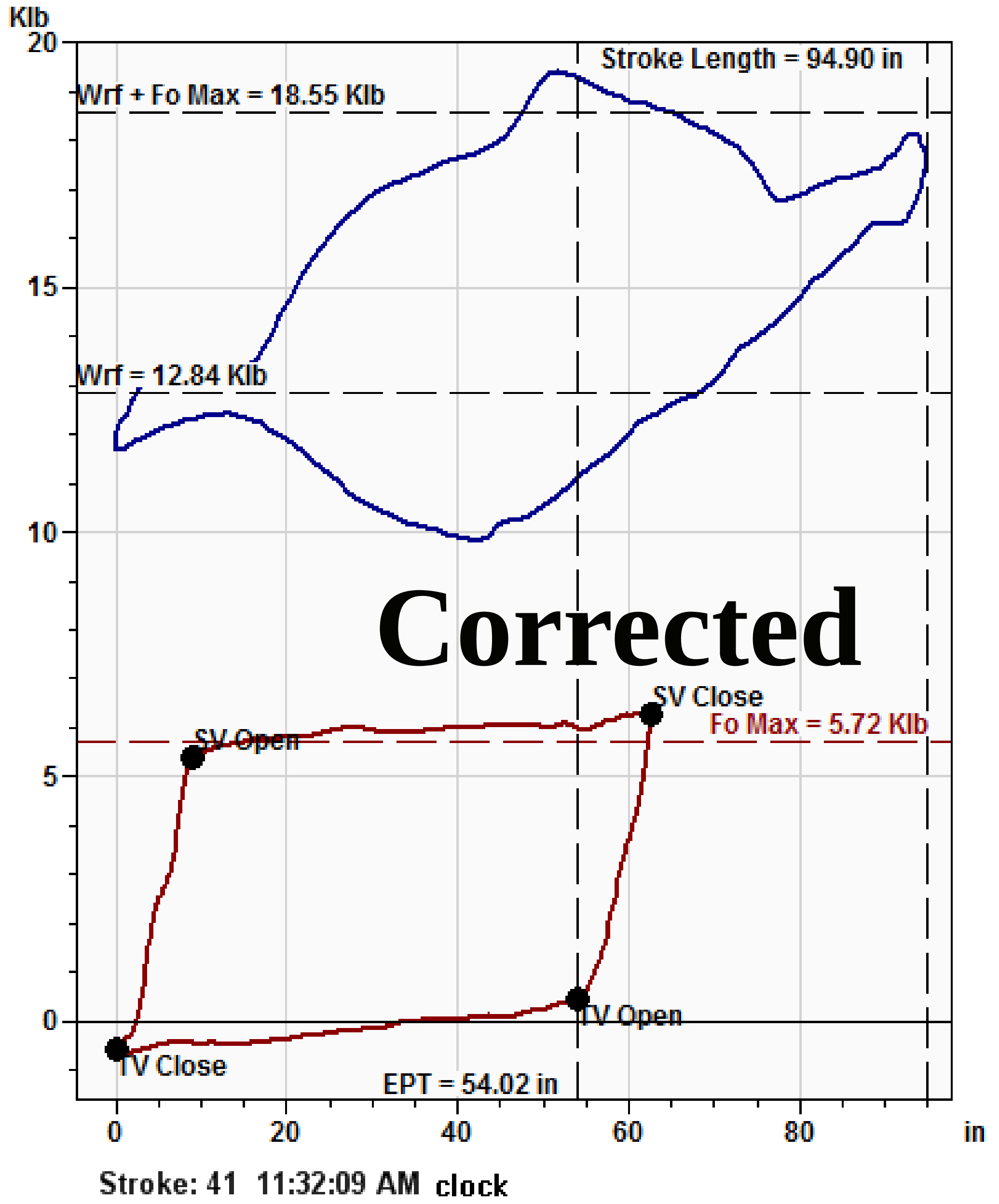
Use predictive rod design software to limit the degree of Dogleg Severity to calculated side loading acting on a 25 foot rod to be less than 200 lbs.

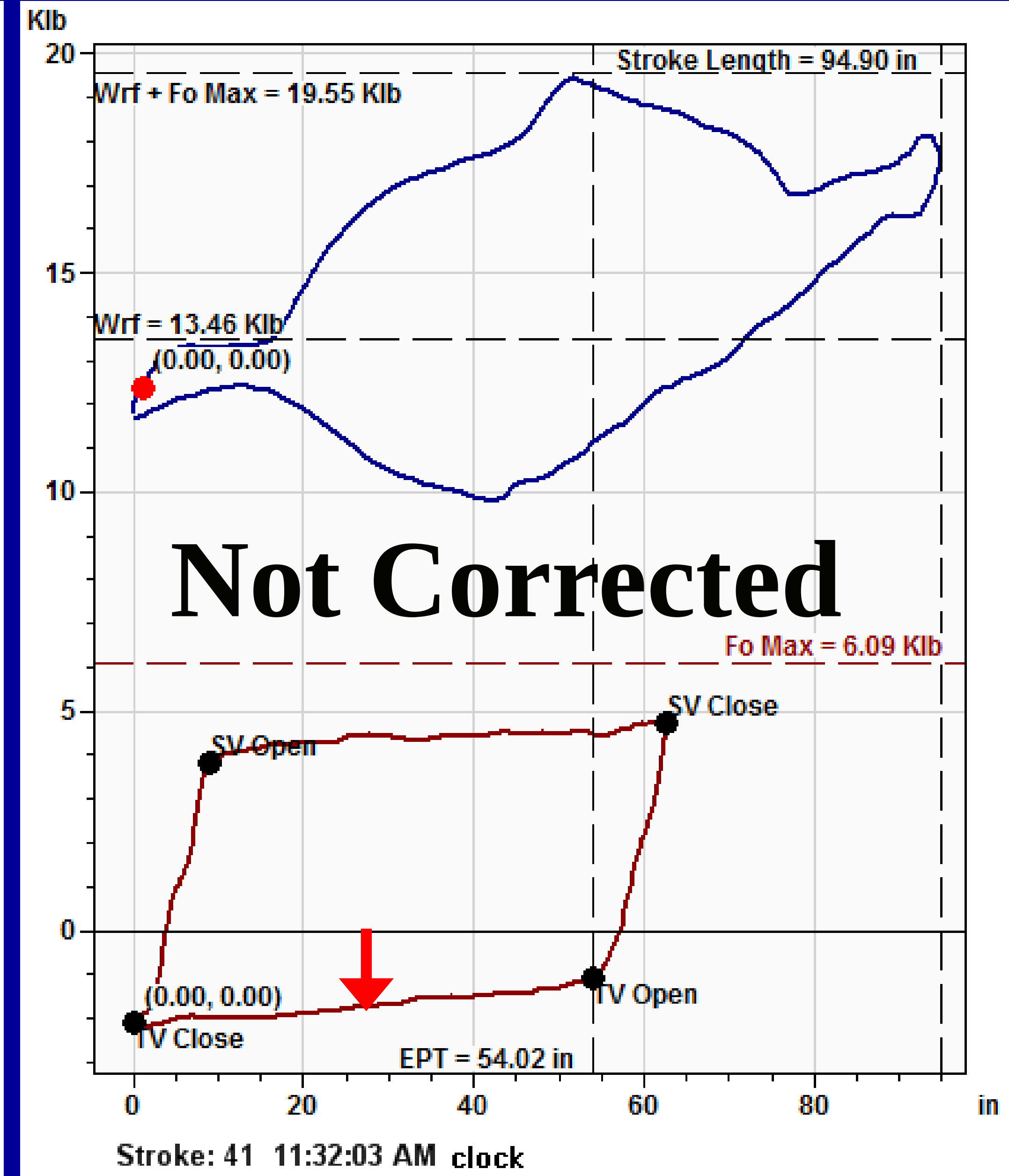
Use TVD Rod Weight in Fluid Because 621 Lbs of Wrf Resting on Tubing Side



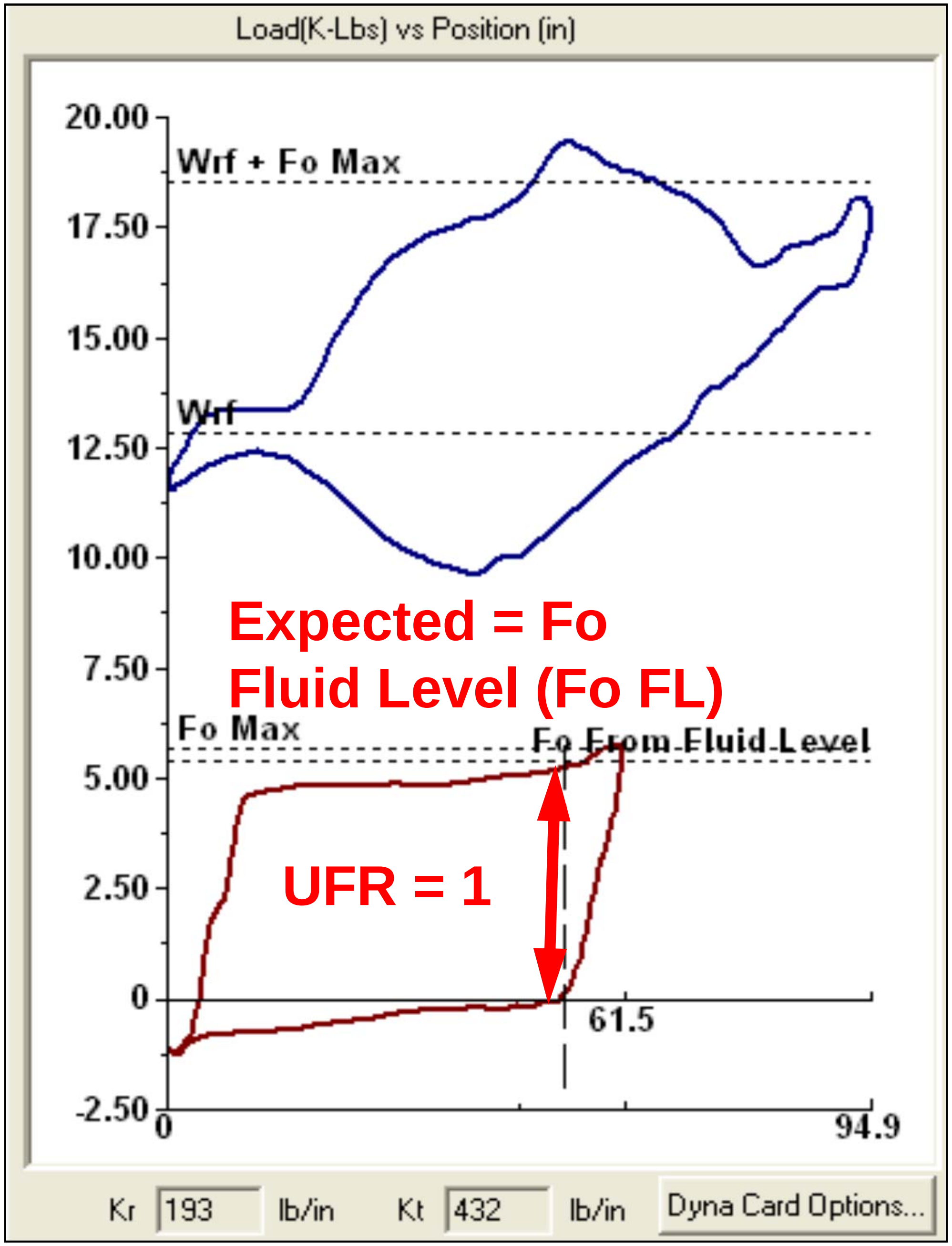


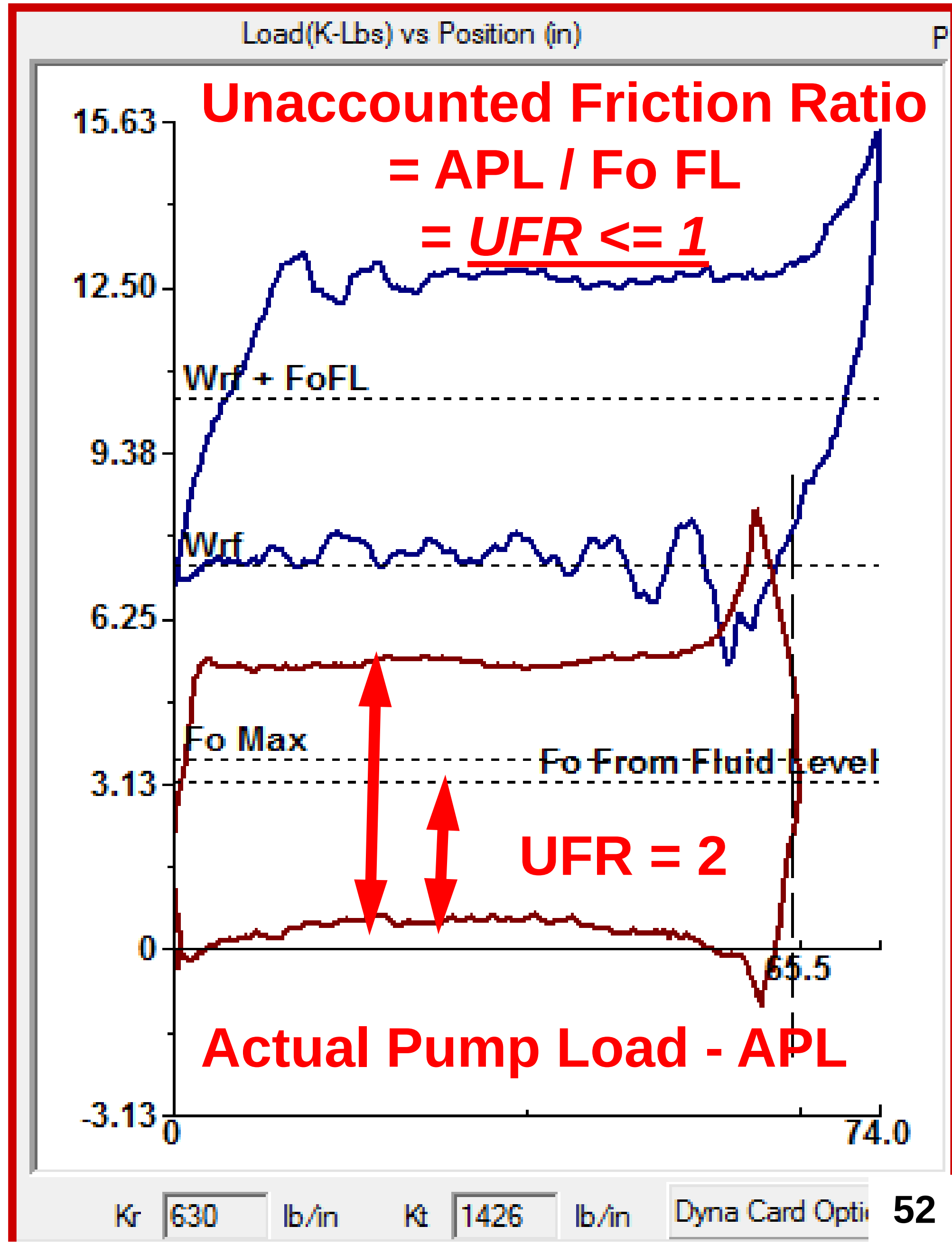
Pump Card NOT Positioned Correctly Without Correction for TVD Wrf and Piston Force





High Dog-Leg or Kick Off Bad for the Environment? Pad Drilling ~ Bad?





Polycore™ High Density Polyethylene Liner

Polycore™ is a High Density Polyethylene (HDPE) liner with added proprietary lubricant, manufactured with the most current material formulations & extrusion techniques. As a result, the extremely smooth & highly abrasion resistant liner achieves excellent flow characteristics and elimination of rod on tubing wear. Mechanical & handling damage are eliminated as compared to IPC coatings. Polycore is chemically inert to most corrosive agents. Polycore is mechanically bonded to the ID of tubing and is tolerant to surface imperfections of even used tubing, unlike adhesive based or thermoset liners & coatings.

Maximum Temperature 65°C (Oil) 75°C (Water)

Enertube™ Polyolefin Liner

Enertube™ is manufactured from a specially formulated blend of Polyolefins, and has similar mechanical properties to our field proven Polycore™ liner with a moderate increase in tensile strength and temperature resistance. This second generation liner is specifically designed to limit (not prevent) permeability of acid gas such CO_2 and H_2S. Enertube™ is a seamless mechanically bonded liner providing a smooth tubing surface.

Maximum Temperature 100°C

Ultratube™ PolyPhenylene Sulphide Liner

Ultratube™ is a patent pending liner manufactured from a proprietary blend of PolyPhenylene Sulphide thermoplastic resins; specially formulated for use in aggressive downhole oil and gas production environments. This third generation liner has a significant increase in temperature stability, tensile strength, abrasion, and chemical resistance. The innovative polymers in this liner offer the broadest range of resistance to solvents, steam, strong bases, fuel and acids. Ultratube™ is specifically designed to limit (not prevent) permeability of acid gas such CO_2 and H_2S.

Maximum Temperature 175°C

Extremetube™ Thermoplastic Liner for Extreme Conditions

Extremetube™ is a high performance liner for the most extreme operating conditions. This unique liner is made from VICTREX® PEEK™ Polymer and is the highest tensile strength and highest temperature liner available. Extremetube™ is an excellent alternative to corrosion resistant alloy (CRA) tubulars and offers protection against corrosion and wear problems under the most severe environmental conditions.

Maximum Temperature 260°C

Applications

TVD Rod Weight Observations

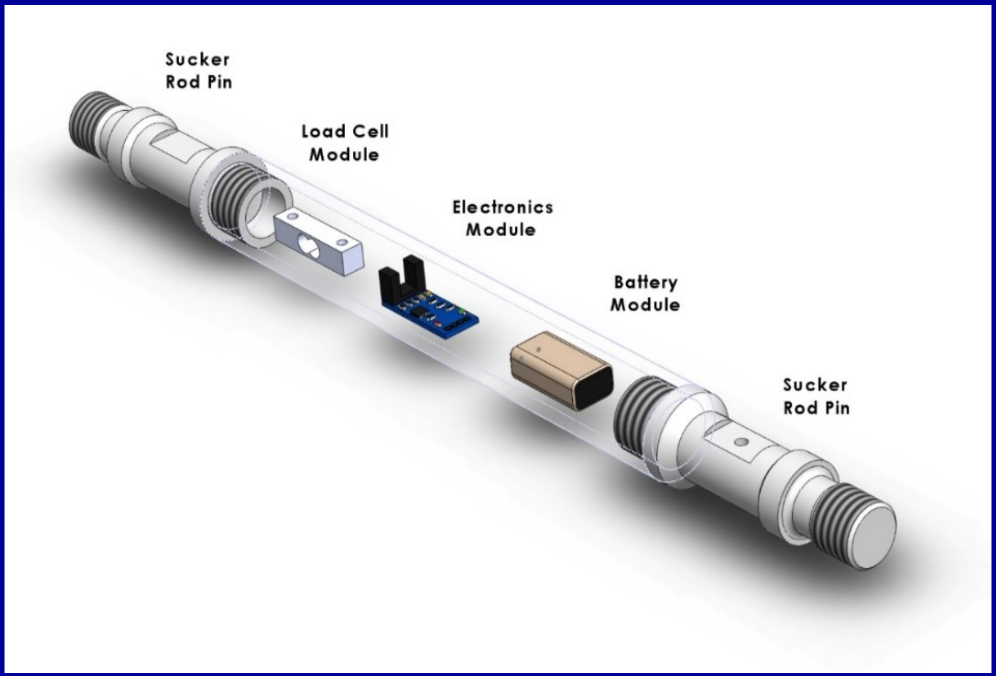
1. TVD Rod Weight Adjustment Positions the pump on zero load line reasonably well in horizontal wells
2. Mechanical Rod on Tubing Friction in horizontal wells low because rod load is typically low below kickoff
3. Setting the pump below the kickoff point increases downhole failures
4. Pump set in the curved section results is 3x more failures, set pump in horizontal section results in 2x more failures; than setting pump above kickoff

Conclusion

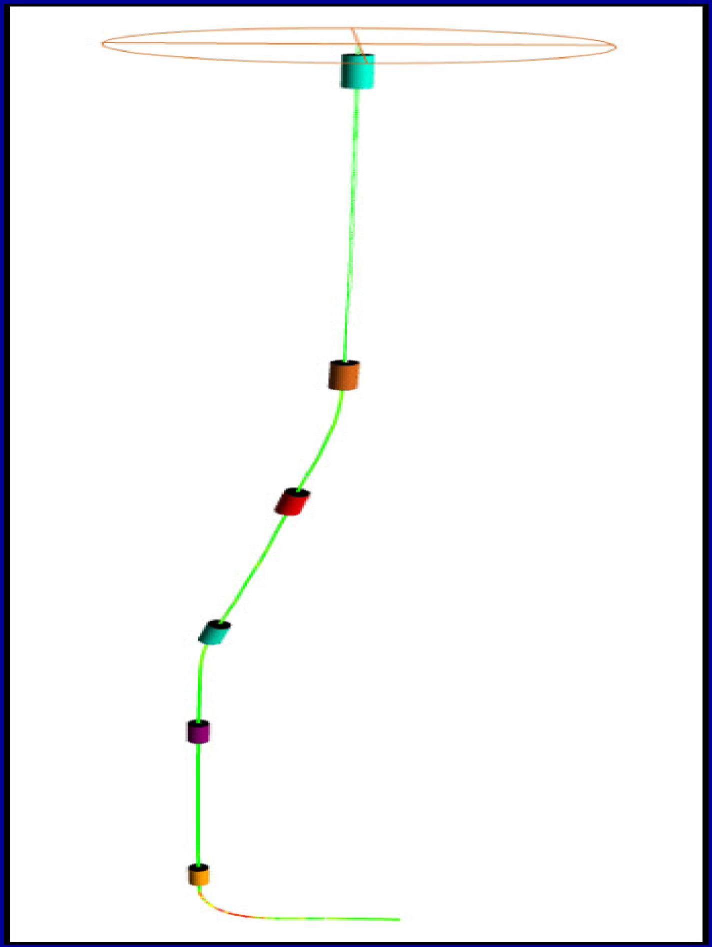
- Pump card is the "Trash Can" for Mechanical Loads NOT applied at the Pump.
- Forces discussed:
  1. Mechanical Friction
  2. Tubing Back-pressure Piston Force on polished rod
  3. True Vertical Rod Weight.
- Mechanical friction due to
  1. Over-tight Stuffing Box
  2. Down hole sticking due to Severe Dog Leg in wellbore profile
  3. Friction from Paraffin along a section of the rod strong.
- These external forces impact measured surface loads, down hole stroke length, horsepower and plunger velocity, plus calculated rod loading at the pump or other locations in the rod string.

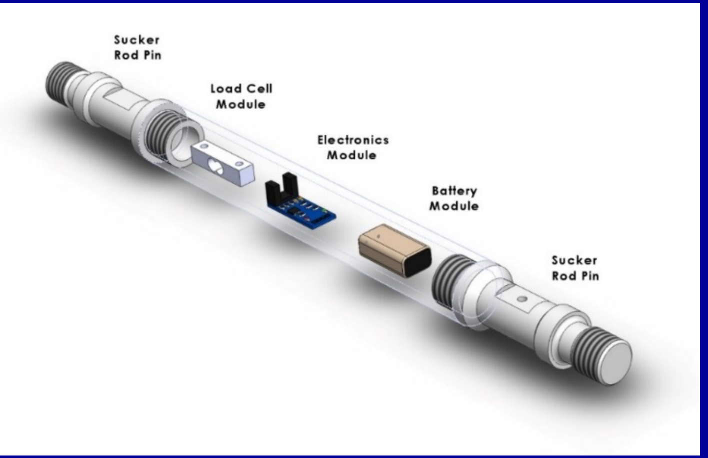
Horizontal Well
Downhole Dynamometer Project Update

- Directly measured load and position data is required to validate and improve the accuracy of the existing software for deviated wells
- A new generation of down-hole sensors are required to gather true measured forces and stresses
- This data will be used to improve design software for rod systems
- Participants in the project will have first access to data, results, and developed tools



Horizontal Well Downhole Dynamometer Project





Tools

- Placed along the rod string for collecting and storing data on-board
- Location of tools to be determined by deviation survey

Sensors:

- 3 axis accelerometer – position & relative gravity vector
- Multiple load cells – linear loading, plus bending and compression
- Pressure, temperature, vibration, etc.
- Synchronized clocks – for correlating data across multiple tools