Over Travel ~ Under Travel
Fo/Skr & N/No’
Limits

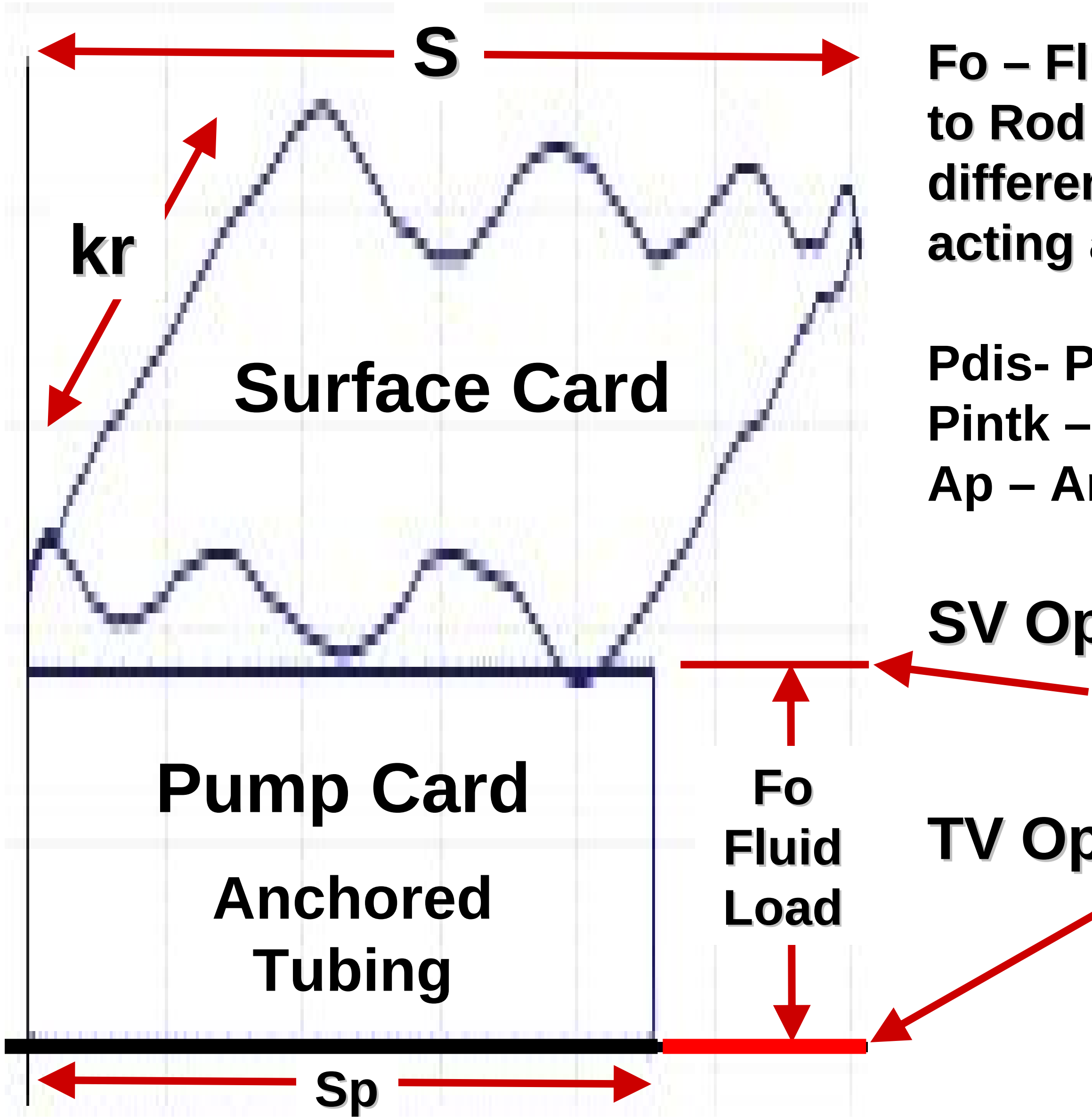
Introduction

1. API RP 11L - Figures
2. Discuss Properties of Dynamometer Surface and Pump Card
3. Define Fo/Skr & N/No'
4. Discuss How Increased SPM increases Overtravel
5. Does Fo/Skr & N/No' Limits Impact Rod Failures
6. Discuss ALEOC Failure Frequency Plot

Rod String Design Background

- Originally static loads; Mills formula (1939)
- Dynamics considered by Midwest Research Institute in 1954 via support Sucker Rod Pumping Research, Inc.
- Industry accepted results and adopted the technique into API RP 11L
- Advent of Wave Equation applied to rod string design allowed for other equipment, configurations, and pumping applications
- Personal computer availability and use has made it easy to run designs but detailed understanding of design relationships appears to have been lost.

Normal Pump Card Fluid Load, Fo



Fo – Fluid Load the Pump Applies to Rod String and caused by the differential pressure (Pdis-Pintk) acting across the pump plunger.

Pdis- Pump Discharge Pressure
Pintk – Pump Intake Pressure
Ap – Area of the Plunger

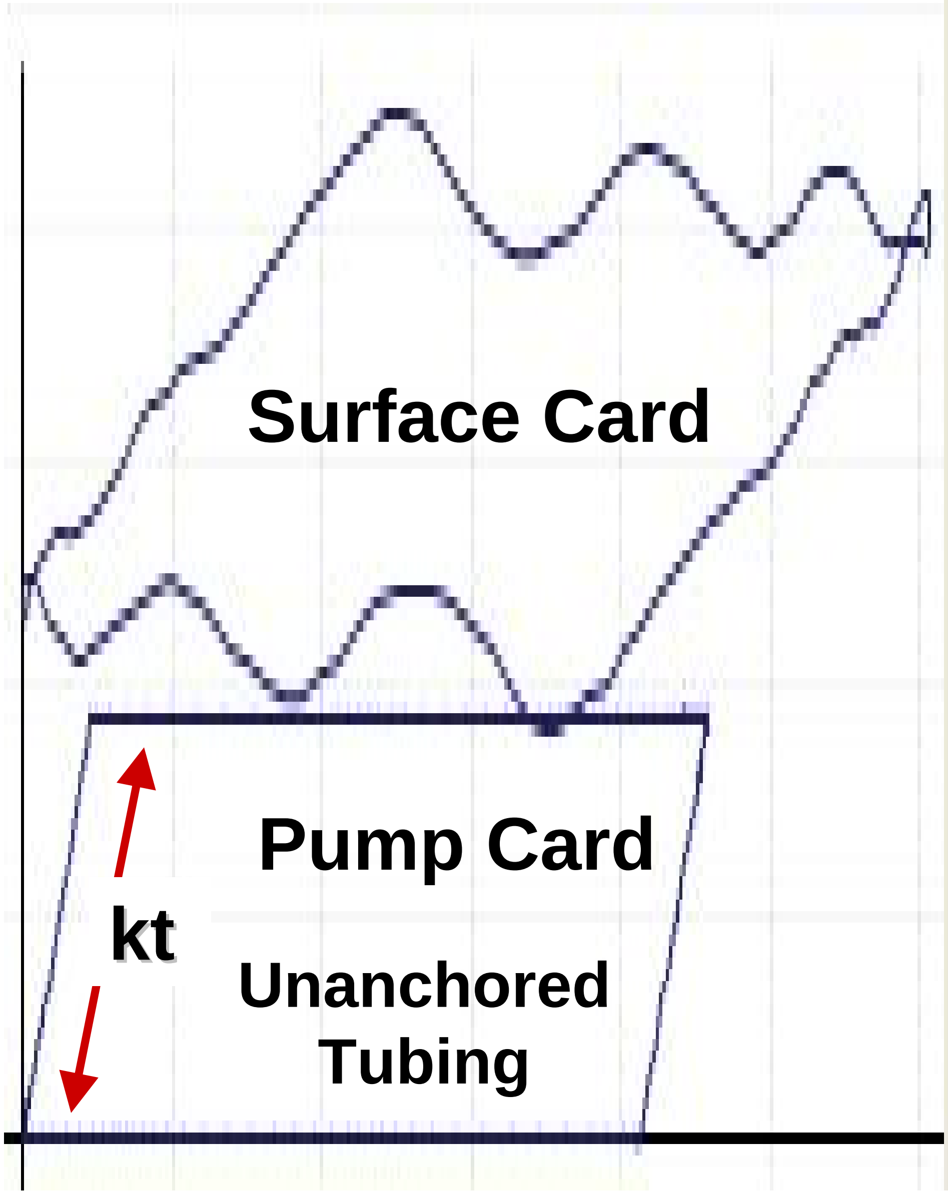
SV Open Upstroke:

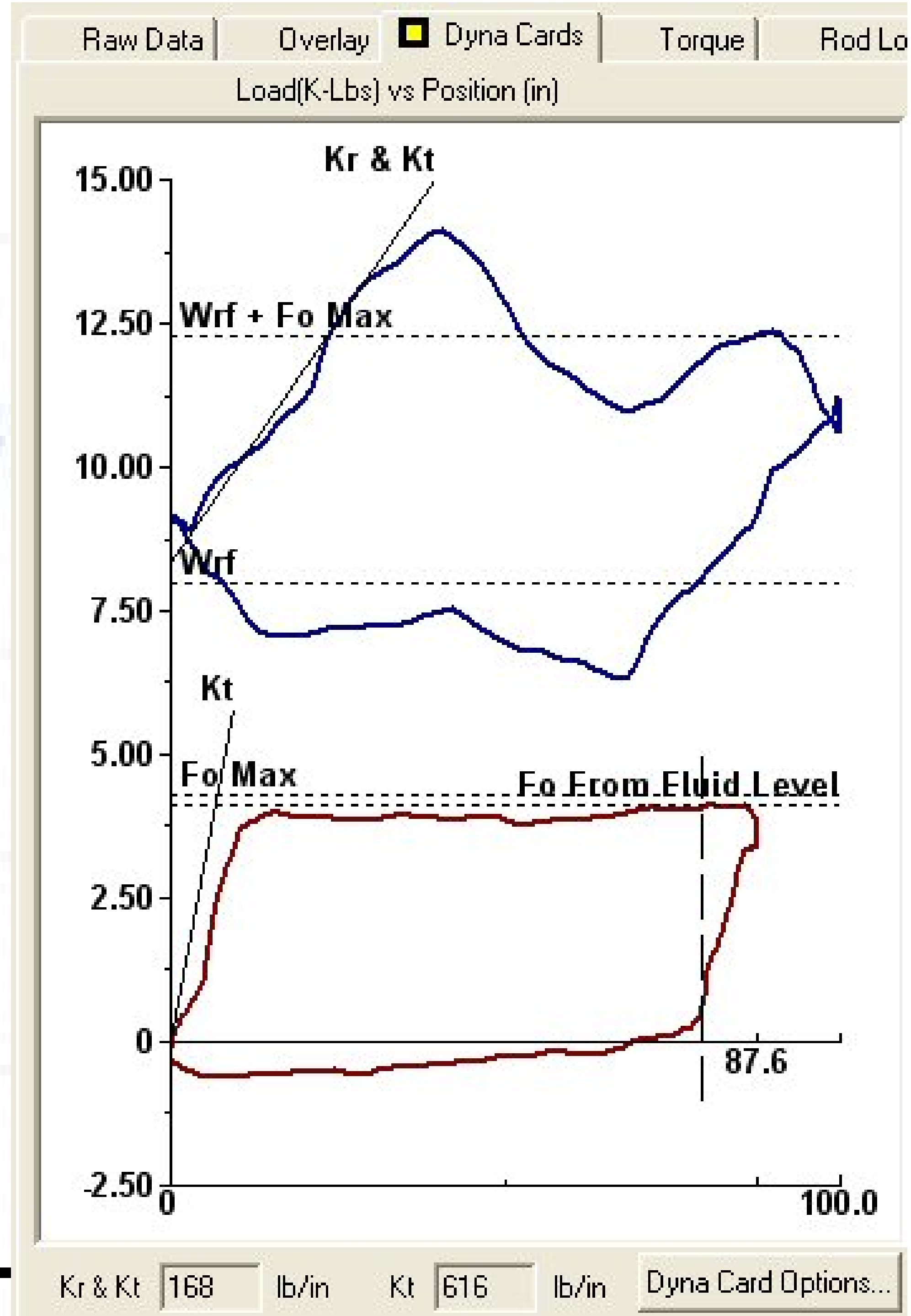
Fo = (Pdis - Pintk)*Ap

TV Open Downstroke:

Fo = 0

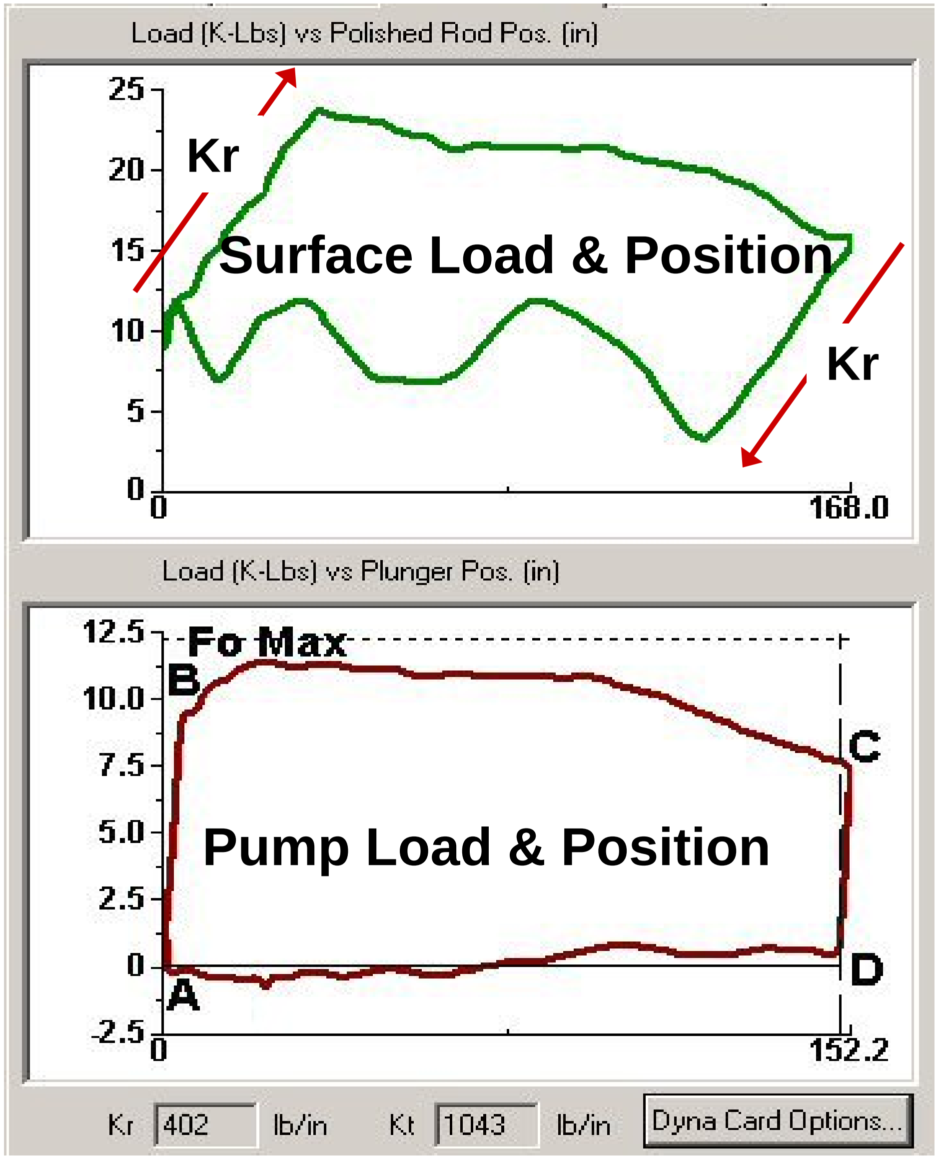
Kr & Kt

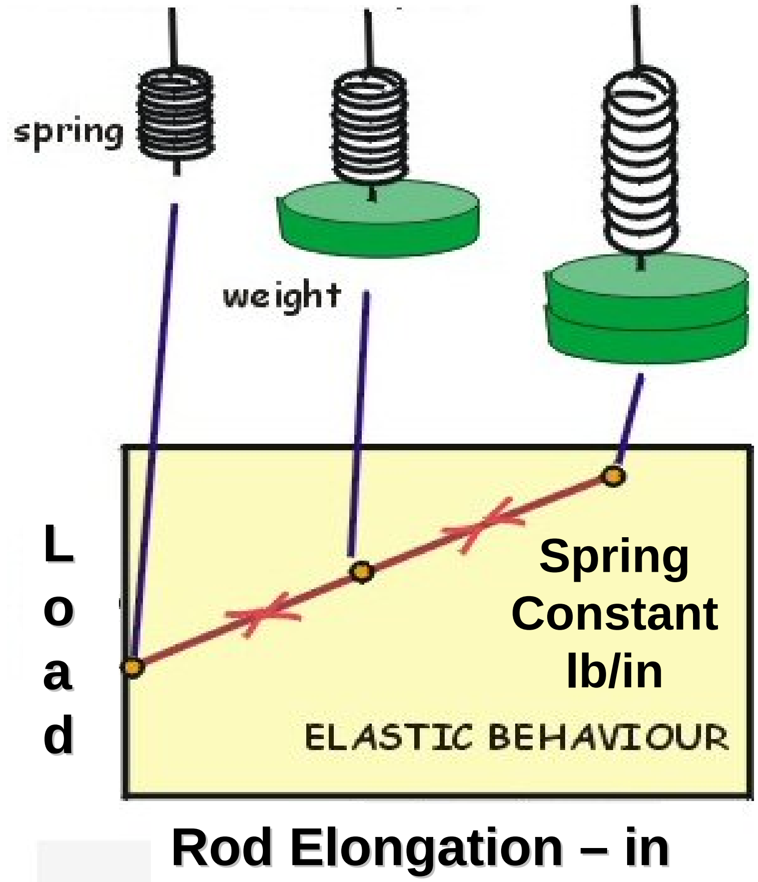

Surface Card
Pump Card
kt
Unanchored
Tubing


Raw Data
Overlay
Dyna Cards
Torque
Rod Lo
Load(K-Lbs) vs Position (in)
Kr & Kt
15.00
12.50
10.00
7.50
5.00
2.50
0
-2.50
Wrf + Fo Max
Wrf
Kt
Fo Max
Fo From Fluid Level
87.6
0
100.0
Kr & Kt
168
lb/in
Kt
616
lb/in
Dyna Card Options...

Rod Stretch = S x Fo/SKr

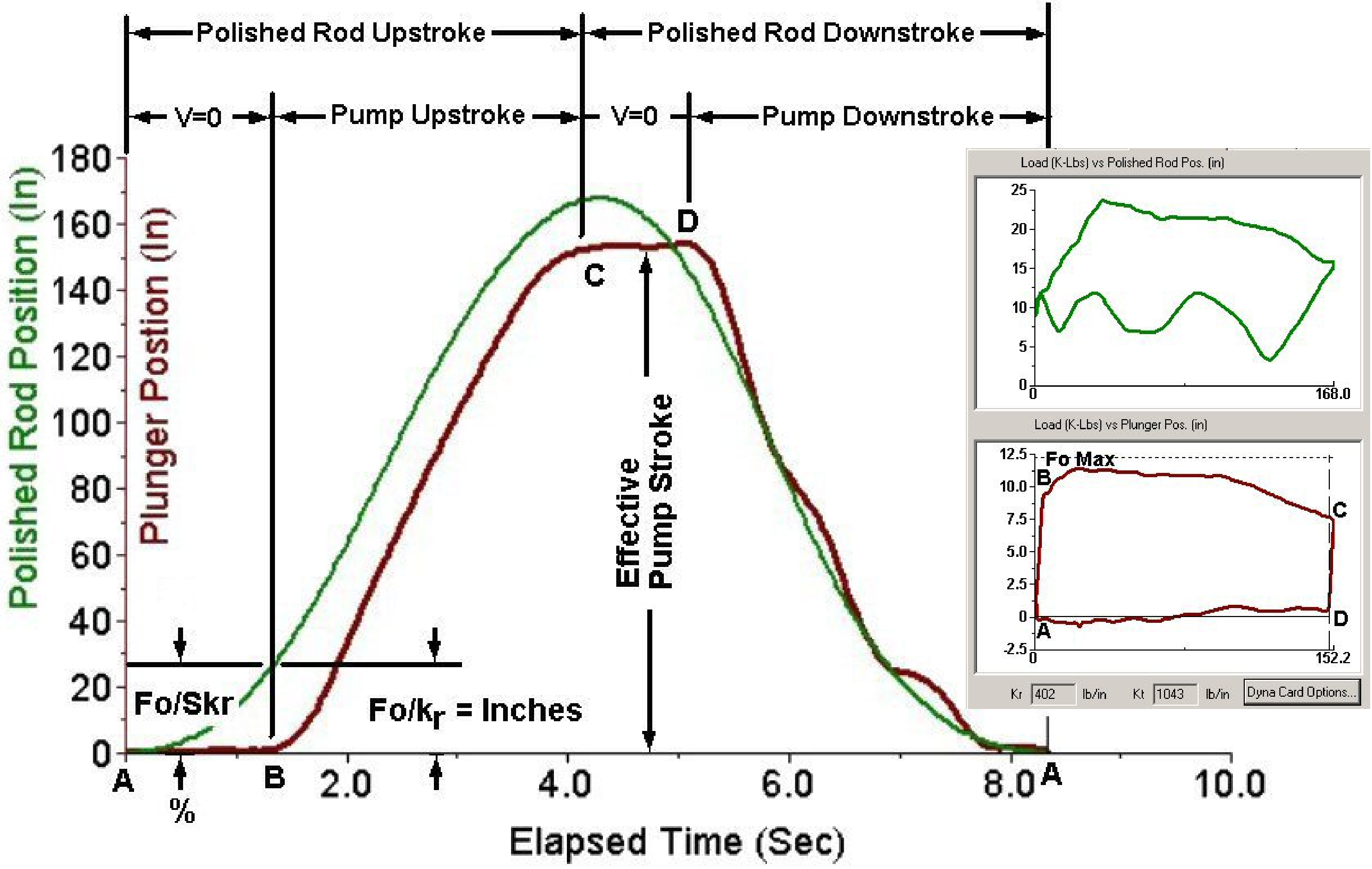
Rods Elastically Stretch to Pick Up Fluid Load



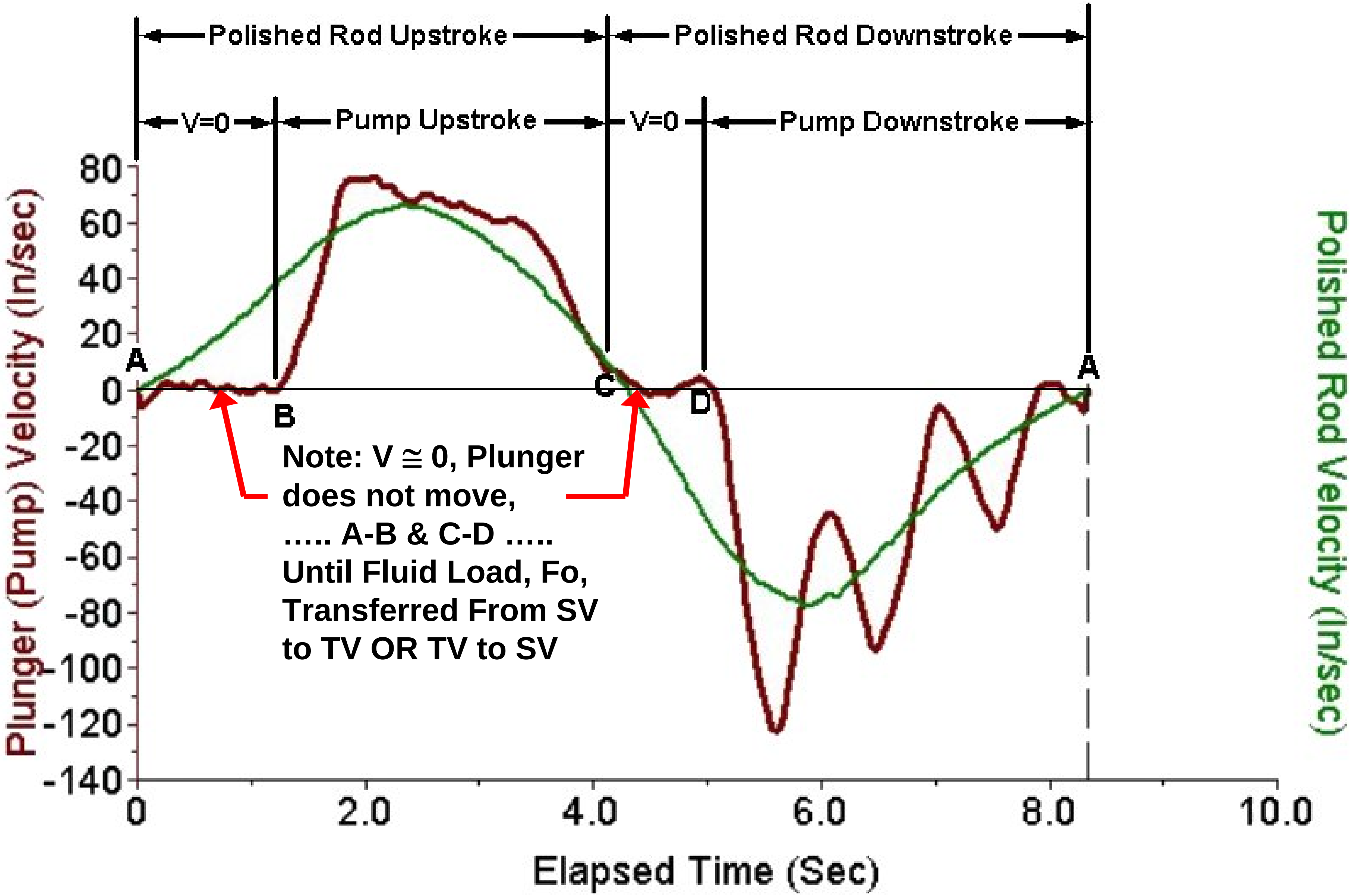


Rods Elastically Stretch to Pick Up Fo from A-B & Un-stretch to Release Fo from C-D

Compare Polished Rod Position to Pump Plunger Position - Anchored Tubing

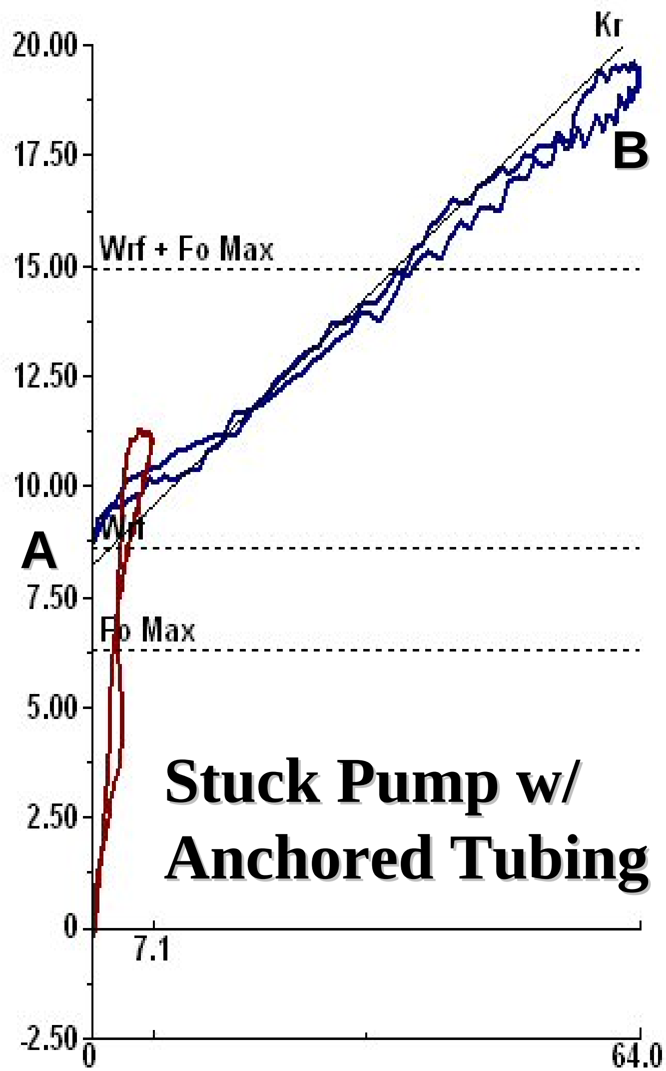


Compare Polished Rod Velocity to Pump Plunger Velocity (Anchored Tubing)



From A to B Rods Stretch to Pickup Load

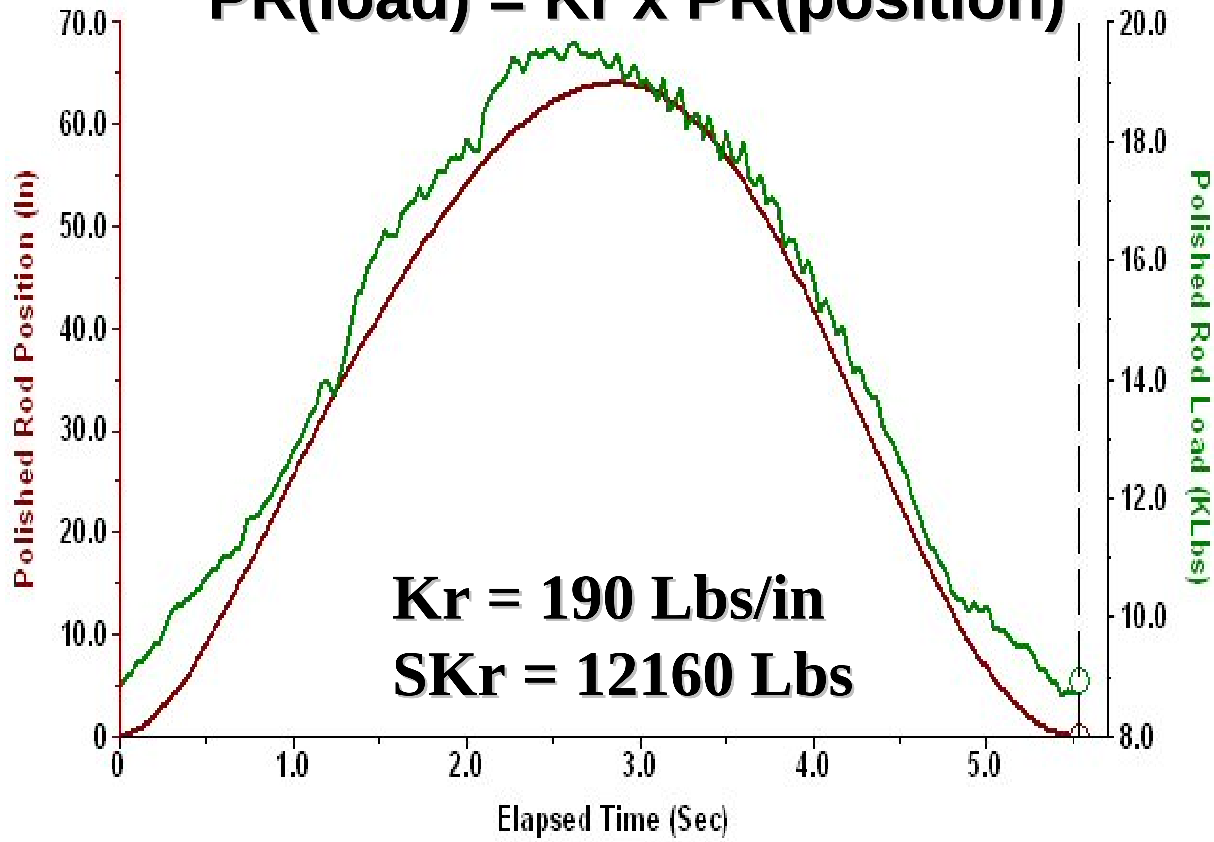
Kr: Change in Load Proportional to Change in Position



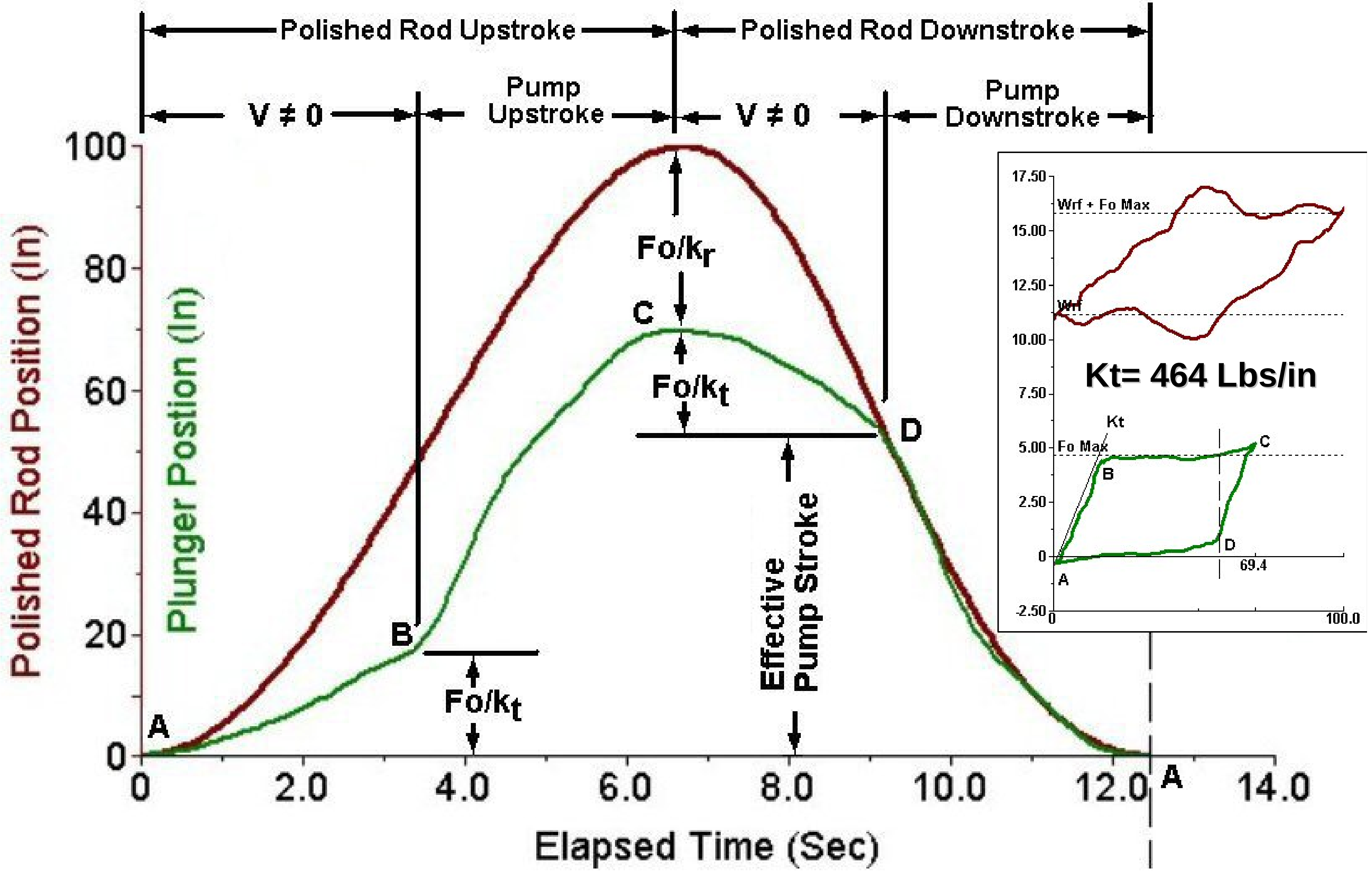
<u>Illustrate Spring Constant - Kr:</u>

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

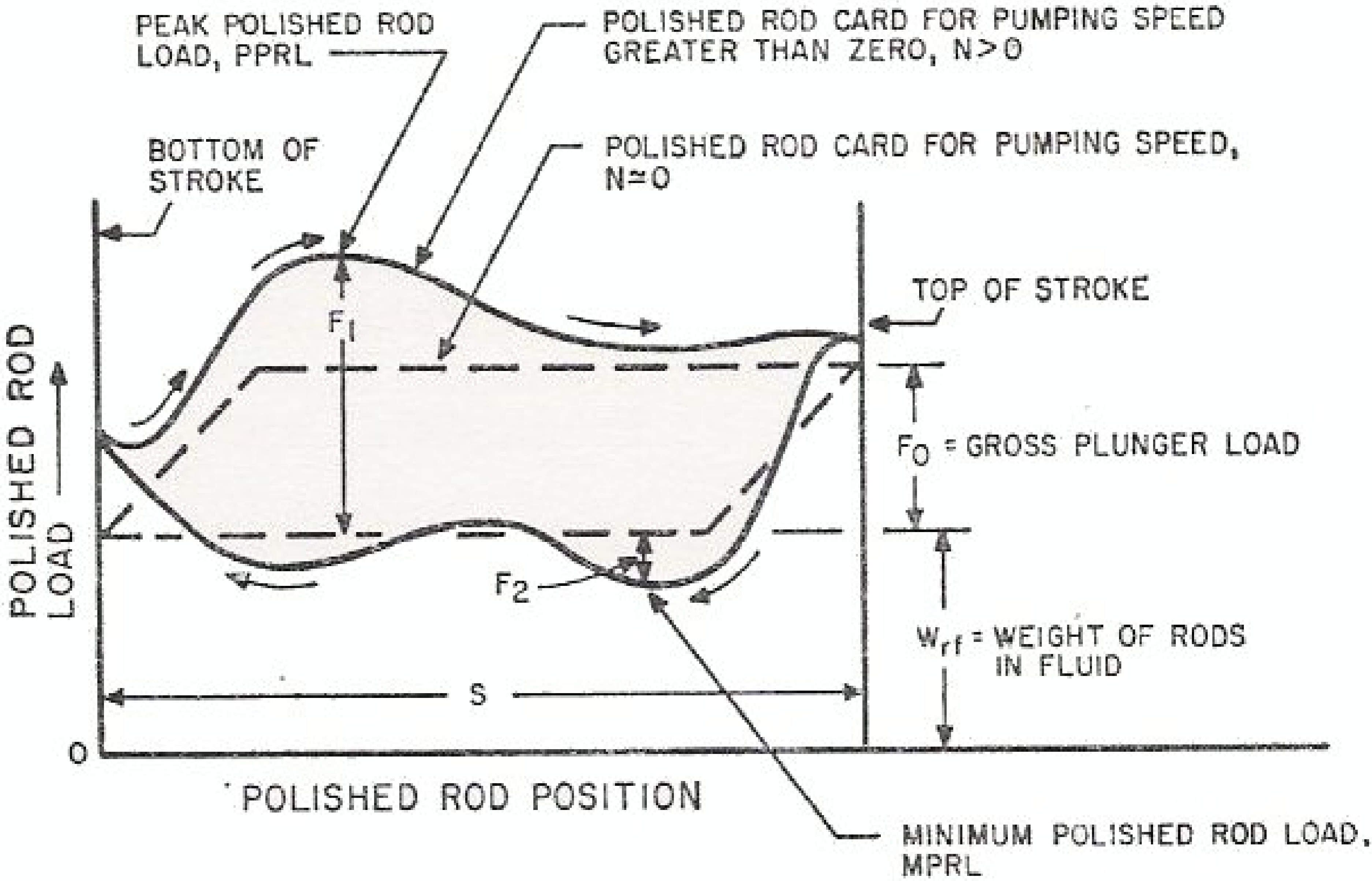
PR(load) = Kr x PR(position)

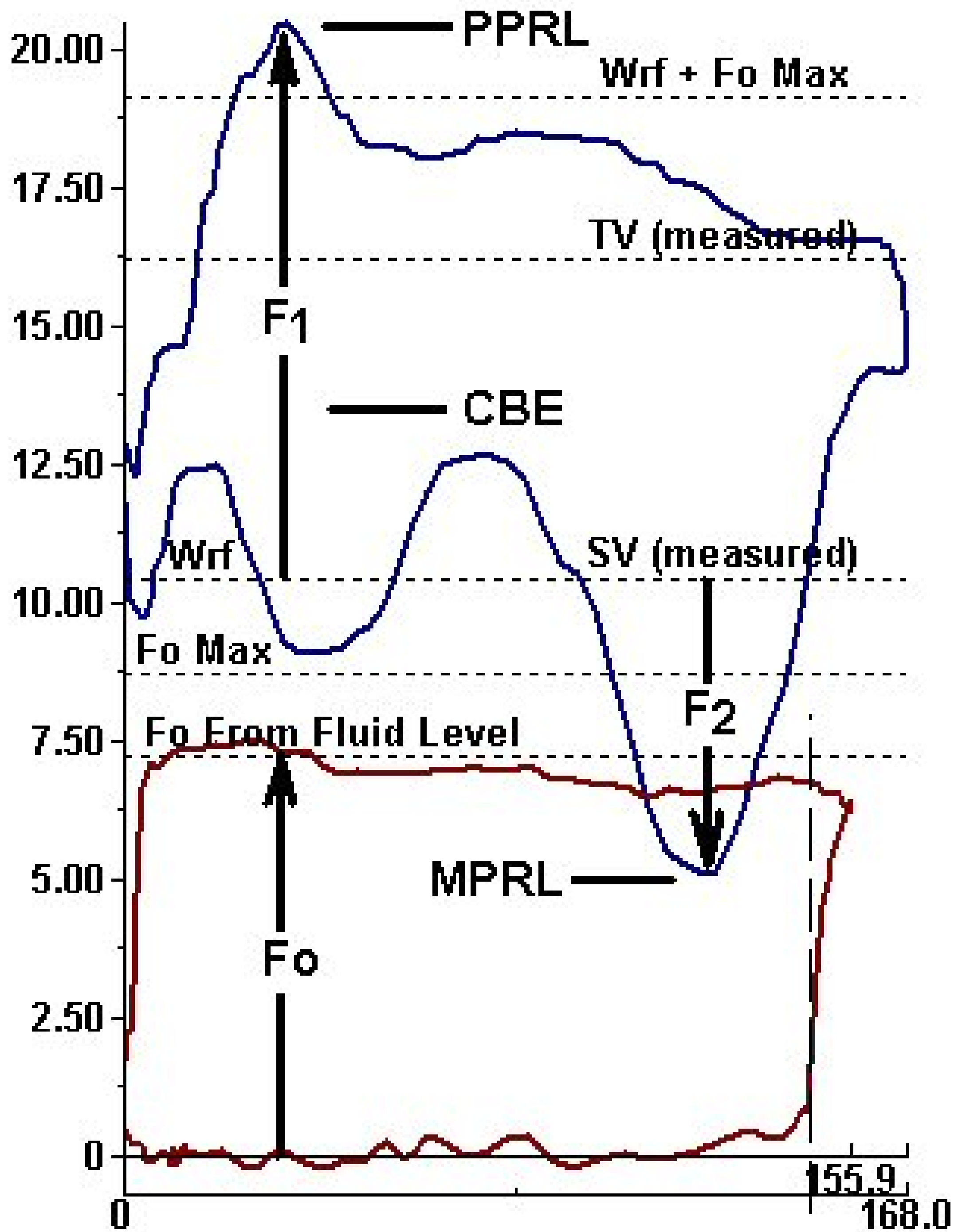


Compare Polished Rod to Pump Plunger Position (Un-anchored Tubing)



API RP 11L Figure





TV Weight of Rods in Fluid, Wrf, plus the Fluid Load, Fo, plunger is applying to the rods.

Wra weight of the rod string suspended in air.

Wrf = Wra - Buoyancy

Fo fluid load the pump applies to the rod string.

F1 dynamic force required at the surface to apply a static force Fo at the pump..

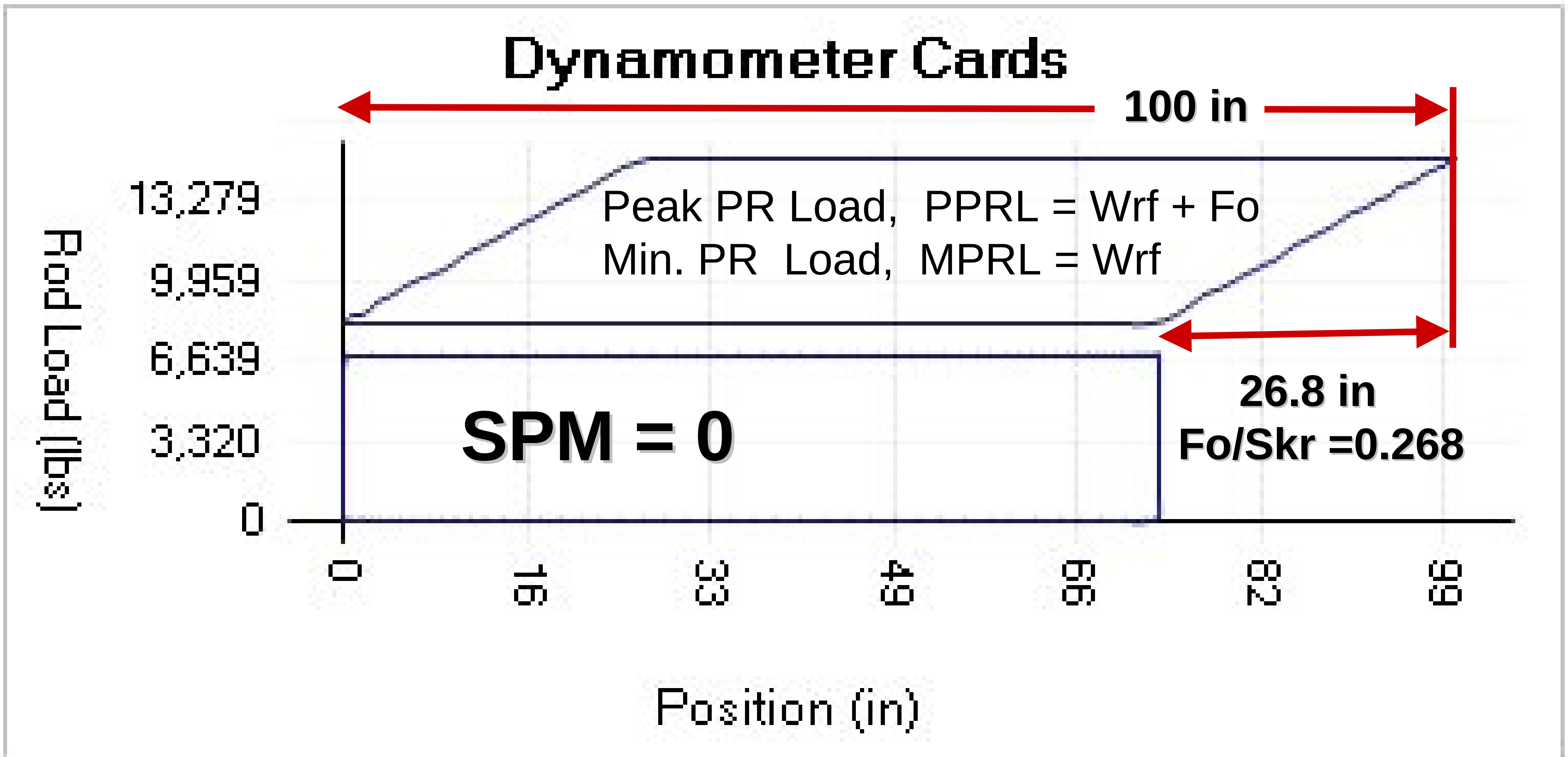
F2 dynamic surface force due to transferring the Fo carried by the traveling valve to the standing valve.

Example Well

1. 5000 ft pump depth, 100 in surface stroke (s), 50 psi tubing and pump intake pressure
2. 2 inch diameter plunger with anchored tubing
   a) Fluid Load 6802 lbs
3. Tubing Fluid Gradient 0.433 psi/ft
4. 76 API Designation rod string
   a) 41.2% - 7/8” and 58.8% - 3/4” rods
   b) Weight Rods in Fluid – 8,288 Lbs
   c) Kr = 254 lb/in & SKr = 25400 lb
   d) Fo/SKr =0.268 with 26.8 in of Stroke lost to Stretch

Example Well

Dynamometer Cards at Pumping Speed of approximately 0



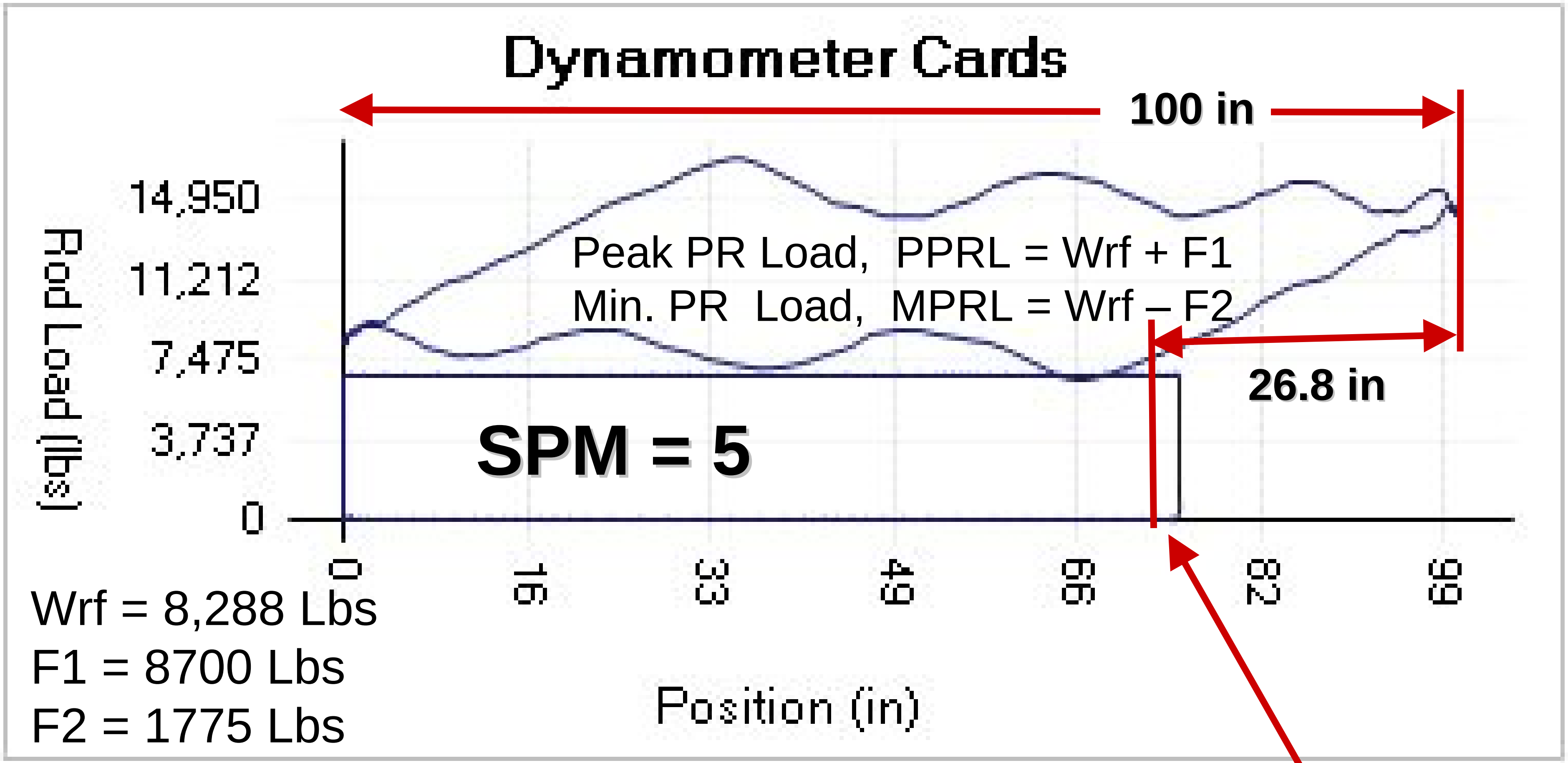
PPRL 15,089 lbs | MPRL 8,288 lbs | Fo 6,802 lbs

Pump Stroke 73.2 in | Static Stretch 26.8 in | Overtravel 0.0 in

Fo/Skr 0.268 | Kr 254 lb/in | Kt 894 lb/in

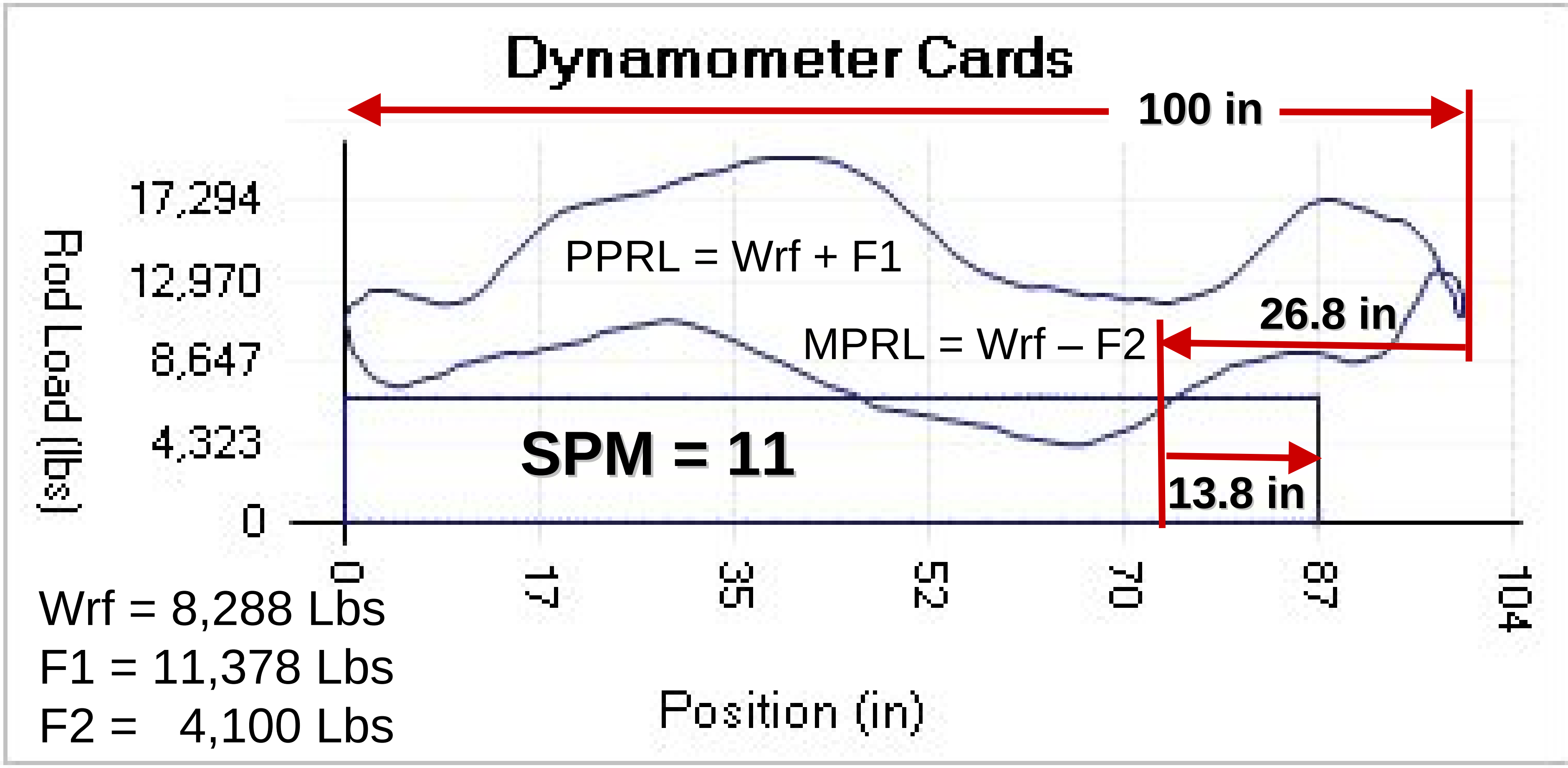
Example Well

Dynamometer Cards at Pumping Speed of approximately 5 SPM



PPRL 16,988 lbs	MPRL 6,513 lbs	Fo 6,802 lbs
Pump Stroke 75.0 in	Static Stretch 26.8 in	Overtravel 1.7 in
Fo/Skr 0.268	Kr 254 lb/in	Kt 894 lb/in

Rod String 76 Design loaded to 100% of the Allowable Modified Goodman Stress



PPRL 19,666 lbs	MPRL 4,188 lbs	Fo 6,802 lbs
Pump Stroke 87.1 in	Static Stretch 26.8 in	Overtravel 13.8 in
Fo/Skr 0.268	Kr 254 lb/in	Kt 894 lb/in

No - Undamped Natural Frequency

Synchronous Speed of Straight Uniform Sucker Rod String

$$No = 15\ v_s\ /\ L$$

No = 15 x 16300 / 5000 = 48.9

No – Undamped natural frequency , SPM

v_s – Velocity of Sound in Steel, ft/sec

v_s = 16,300 ft/sec

L – Length of Rod String, Ft

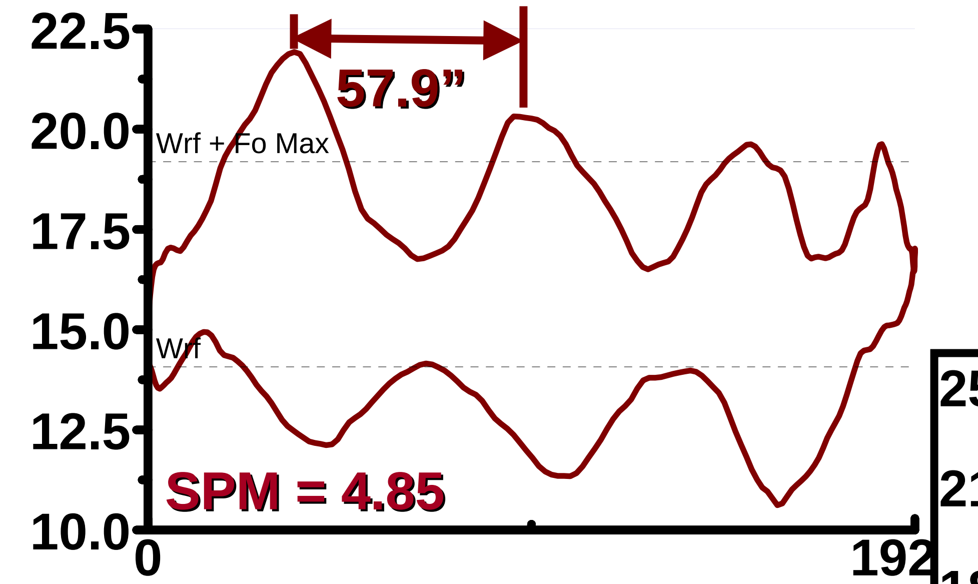
N – Current Pumping Speed, SPM

No' – Natural Frequency adjusted for Taper – Fc x No

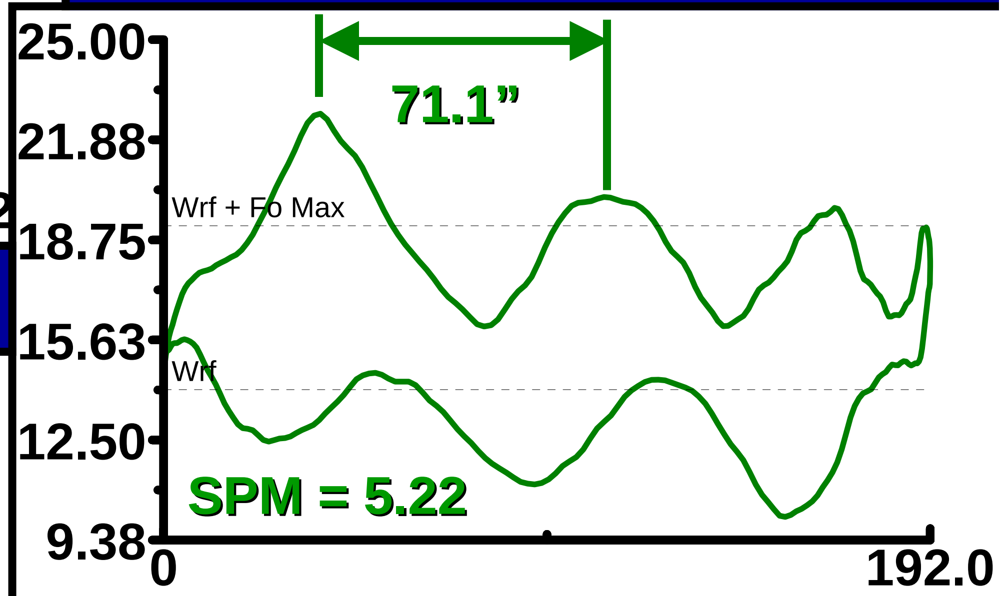
Fc = 1.093 No' = 1.093 x 48.9 = 53.4

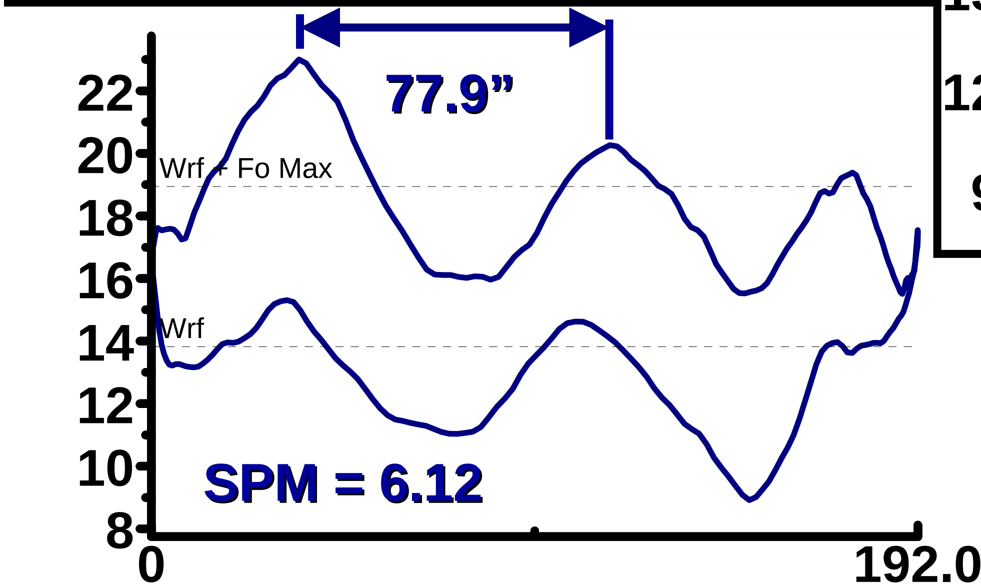
N/No' - Dimensionless Speed Ratio

Increase SPM from 4.85 to 6.12



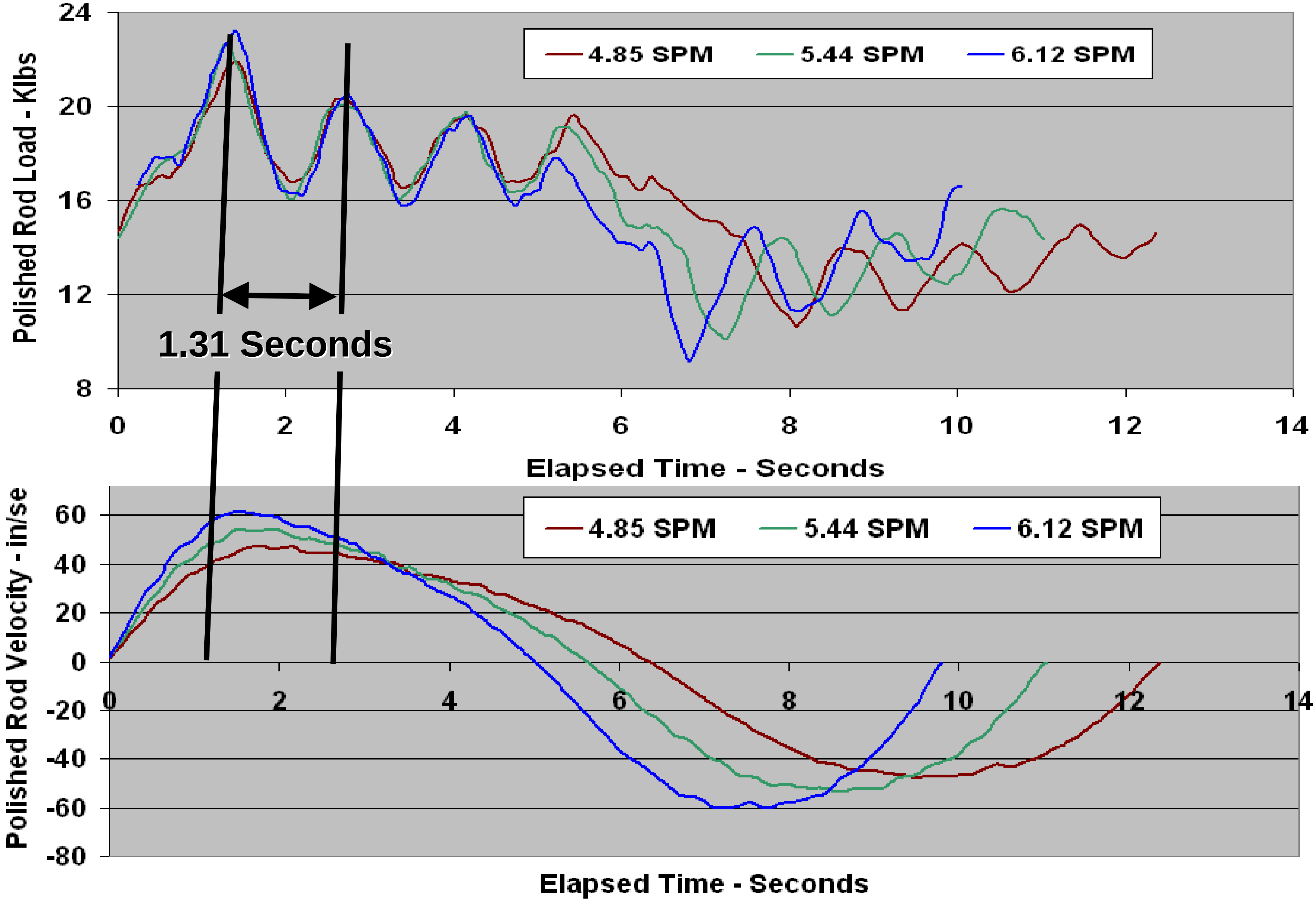
Natural Frequency adjusted for Taper = 45.88 SPM

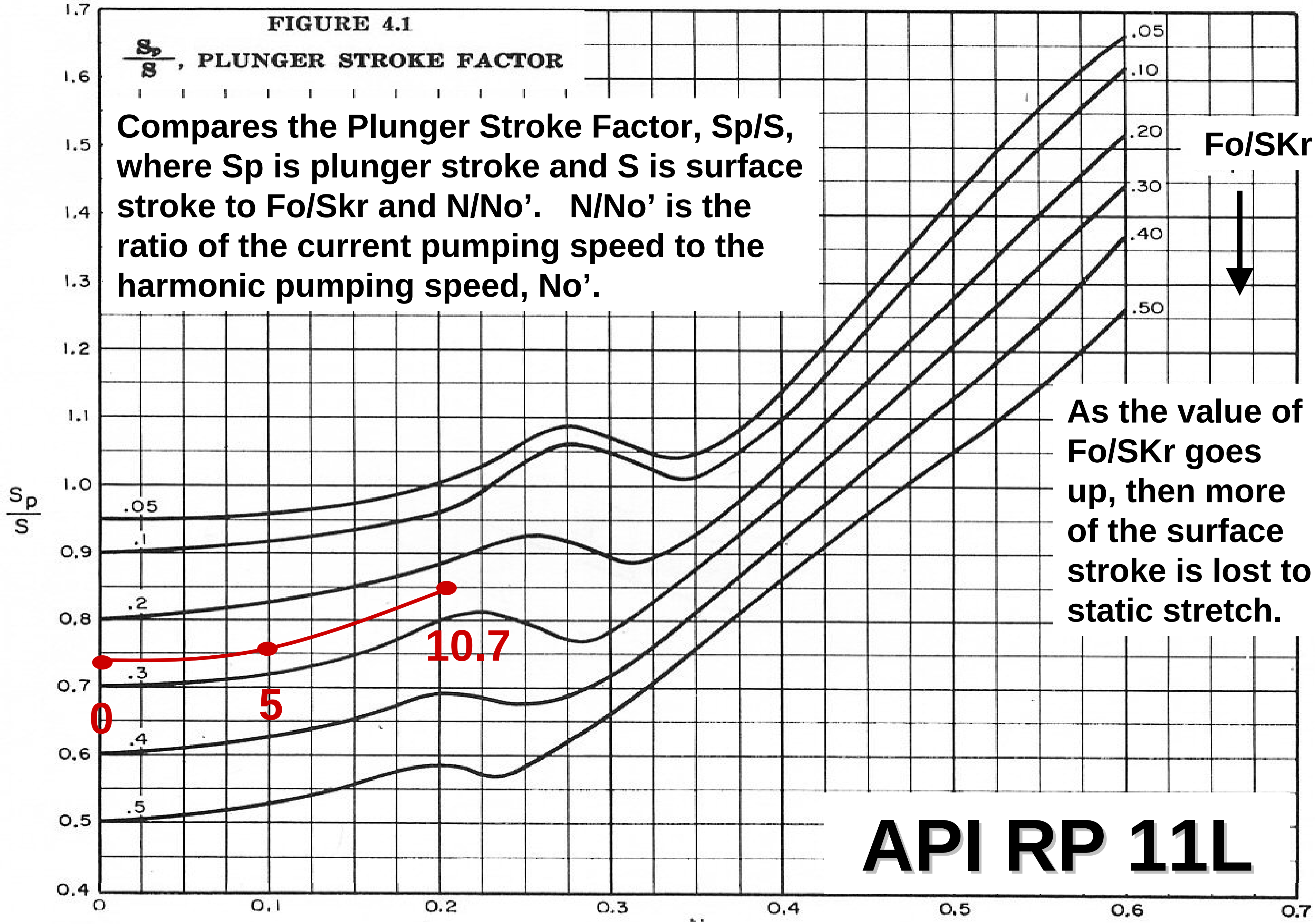




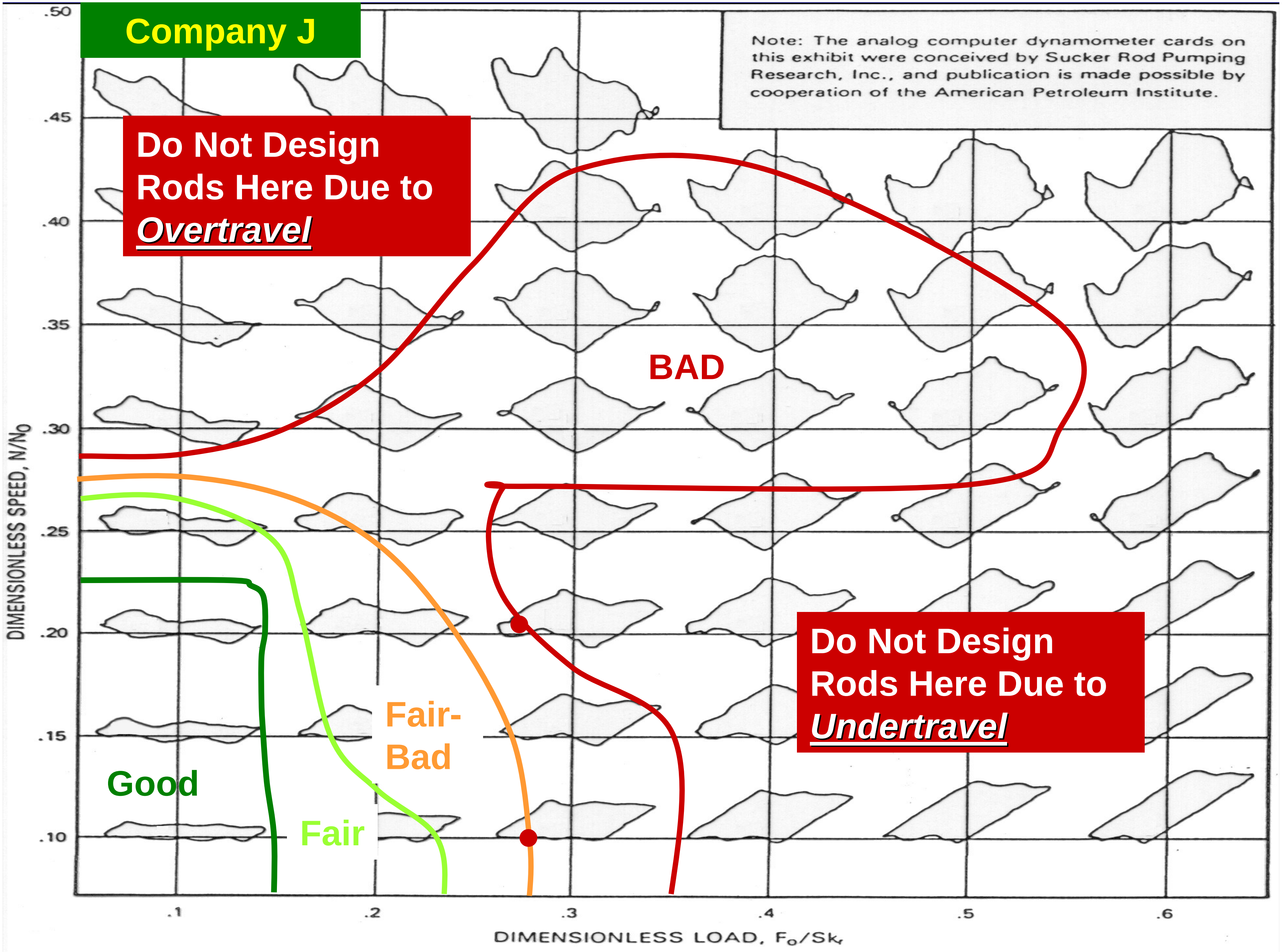
Elapsed Time Between Repeating Load Peaks = 1.31 Seconds

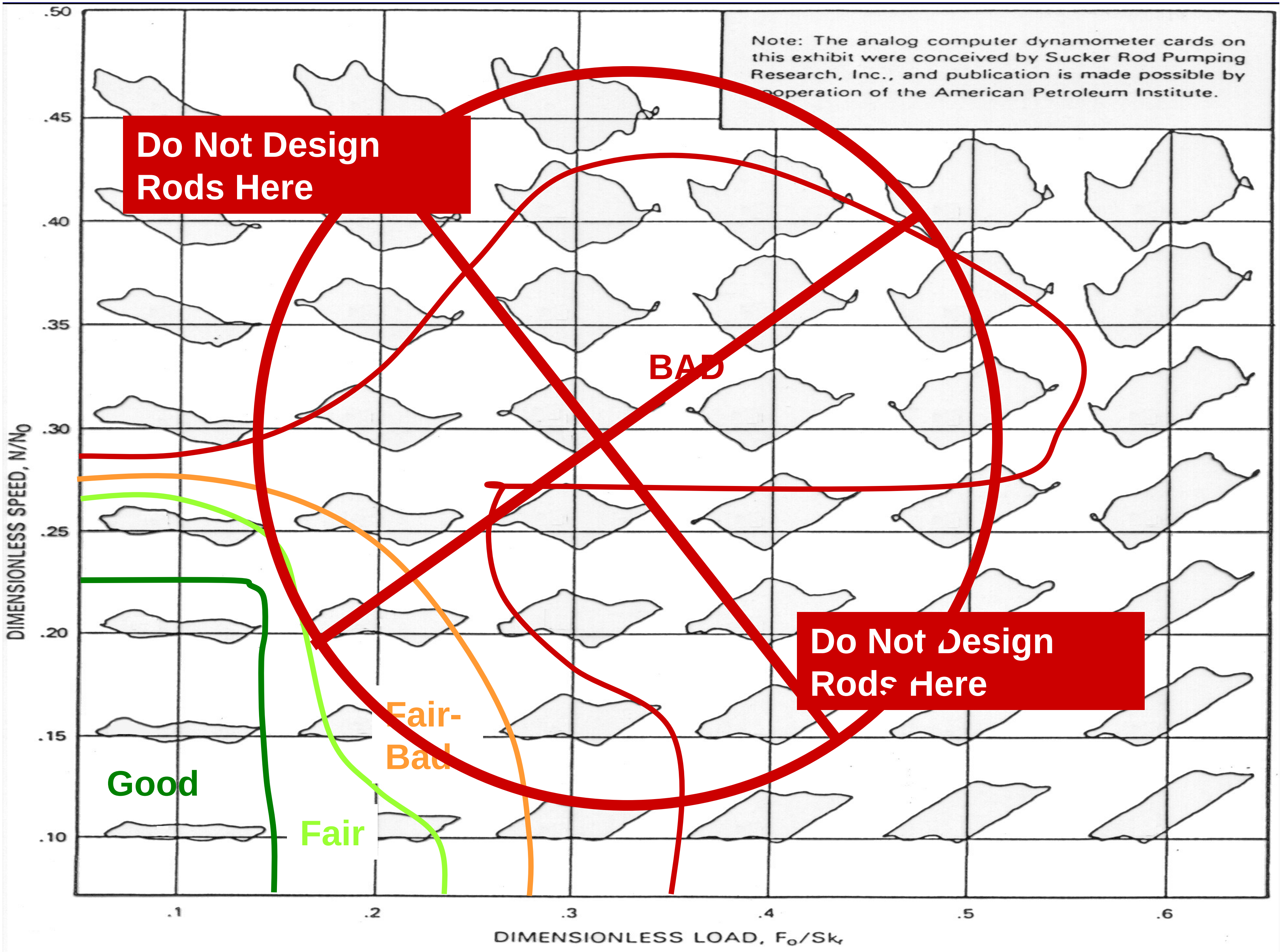
Equal Time From Load Peak to Peak





As N/No' increases, then more overtravel occurs


Company J
Note: The analog computer dynamometer cards on this exhibit were conceived by Sucker Rod Pumping Research, Inc., and publication is made possible by cooperation of the American Petroleum Institute.
Do Not Design Rods Here Due to Overtravel
BAD
Do Not Design Rods Here Due to Undertravel
Good
Fair
Fair-Bad
DIMENSIONLESS SPEED, N/No
DIMENSIONLESS LOAD, Fo/Skr
.50
.45
.40
.35
.30
.25
.20
.15
.10
.1
.2
.3
.4
.5
.6



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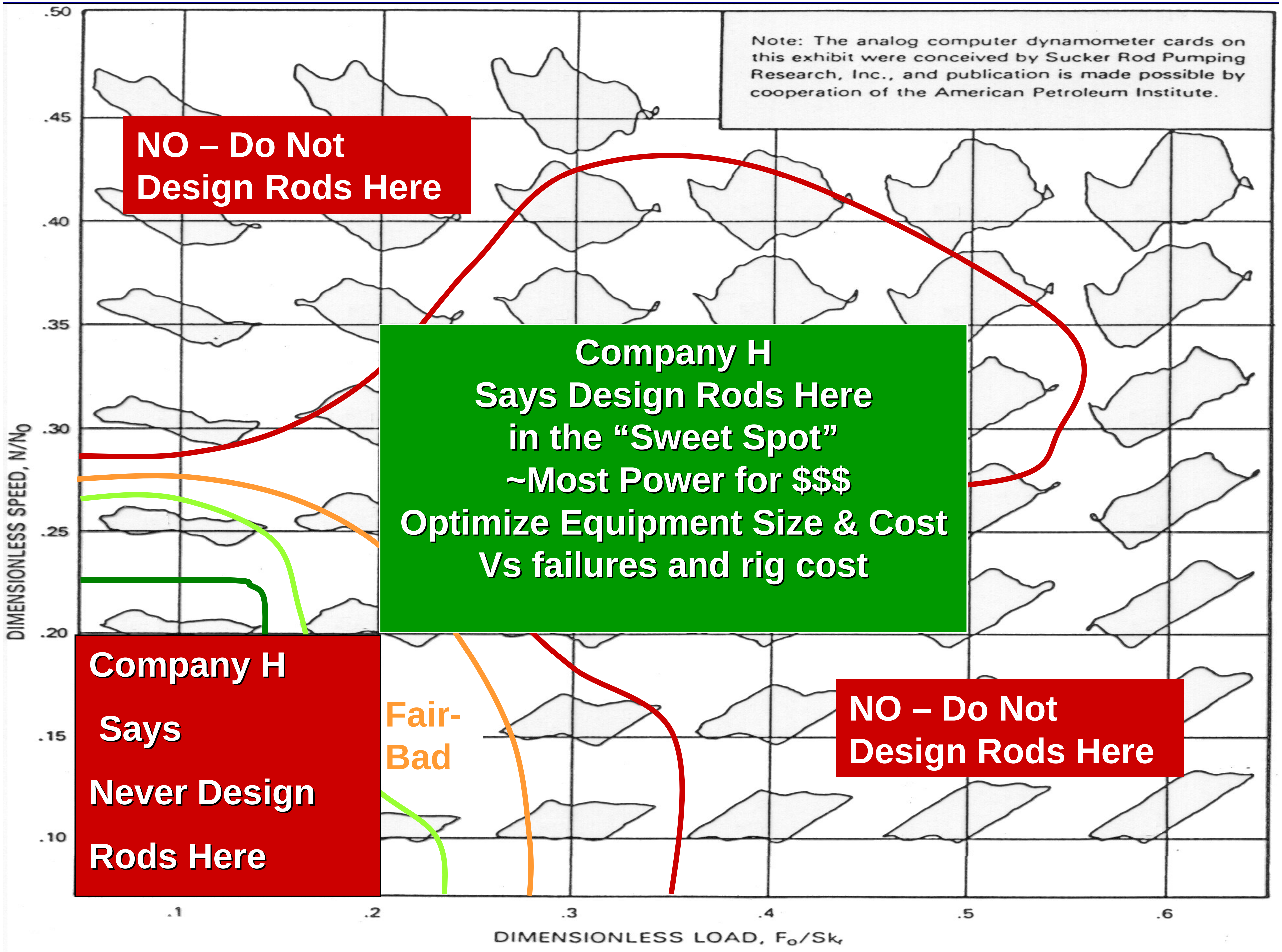
Do Not Design Rods Here
BAD
Do Not Design Rods Here
Fair-Bad
Good
Fair
DIMENSIONLESS SPEED, N/No
DIMENSIONLESS LOAD, Fo/Skr


Note: The analog computer dynamometer cards on this exhibit were conceived by Sucker Rod Pumping Research, Inc., and publication is made possible by cooperation of the American Petroleum Institute.
NO – Do Not Design Rods Here
Company H
Says Design Rods Here
in the "Sweet Spot"
~Most Power for $$$
Optimize Equipment Size & Cost
Vs failures and rig cost
Company H
Says
Never Design
Rods Here
Fair-
Bad
NO – Do Not Design Rods Here
DIMENSIONLESS SPEED, N/No
.50
.45
.40
.35
.30
.25
.20
.15
.10
.1
.2
.3
.4
.5
.6
DIMENSIONLESS LOAD, Fo/Skr

Fo/Skr & N/No' Rod Design Practice

1st company's rod design practice where:

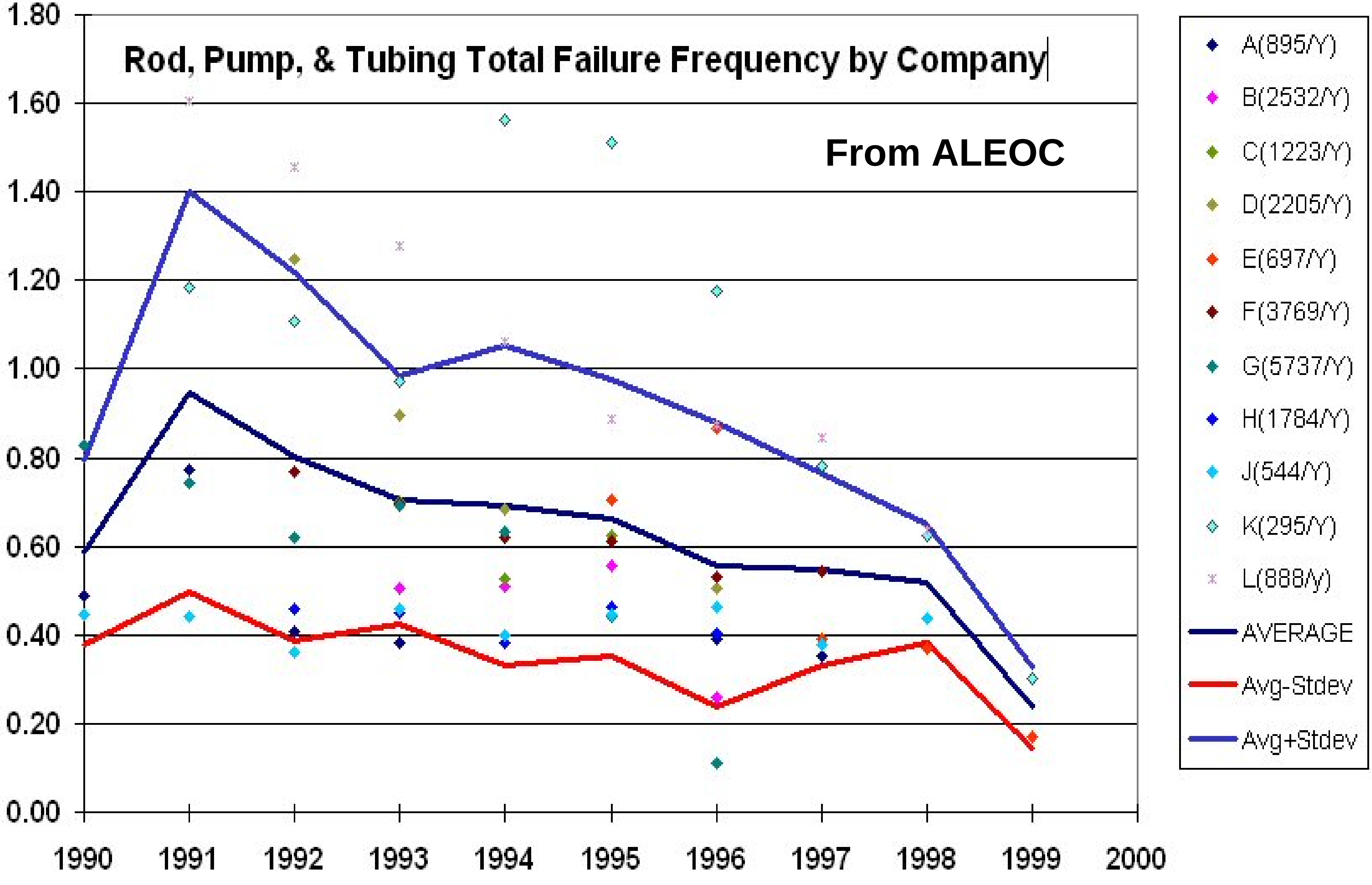
Fo/SKr<0.2 and N/No'<0.2 Maximum

2nd company designed rod strings where:

Fo/SKr>0.2 and N/No'>0.2 Minimum

Did design practice impact failure Rates?

Both had 0.4 Failure Frequency.



What did Companies have in Common?

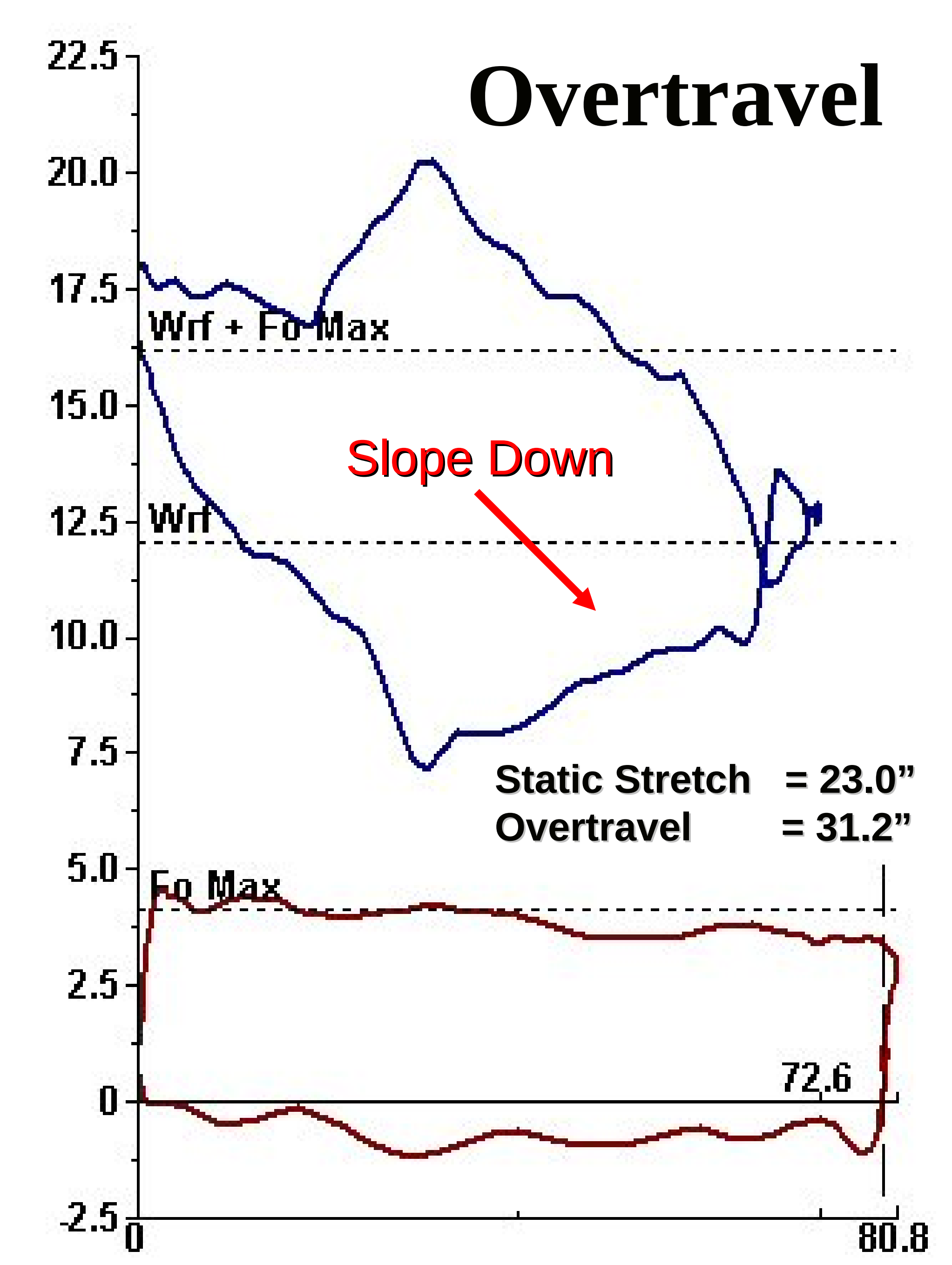
1. Active Program where Technicians:
   a) Acquired Data
   b) Analyzed Problems
   c) Followed-up Recommendations
2. Practiced a “Company” Methodology to Analyze, Optimize, and Trouble Shoot Wells
3. Tracked Cause and Condition of Failed Downhole Equipment in a Failure Data Base
4. Determined to investigate Root Cause of Failure and Correct the Problem.

What does the ALEOC Failure Data Show?

1. **Making an effort to analyze the well's operation and _*taking action*_ to fix problems discovered is the _*MOST important requirement*_**
2. **Everyone in the study group _*recognized their performance could be improved*_ and they took action to reduce failures**
3. **Their _*different actions*_ with-in their individual companies _*resulted in a reduction of failures*_ for all companies in the study group**
4. _**Expect a 0.4 Failure Frequency in Your Field**_

Is Overtravel Good or Bad?

1. ***Good*** **because Pump Displacement Increases with Increase in SPM**
2. ***Bad*** **because Failures "tend" to increase with increased SPM**
3. **Operating within a pumping speed 5-10 SPM range is common practice and failures rates should not increase when pumping within this speed range.**

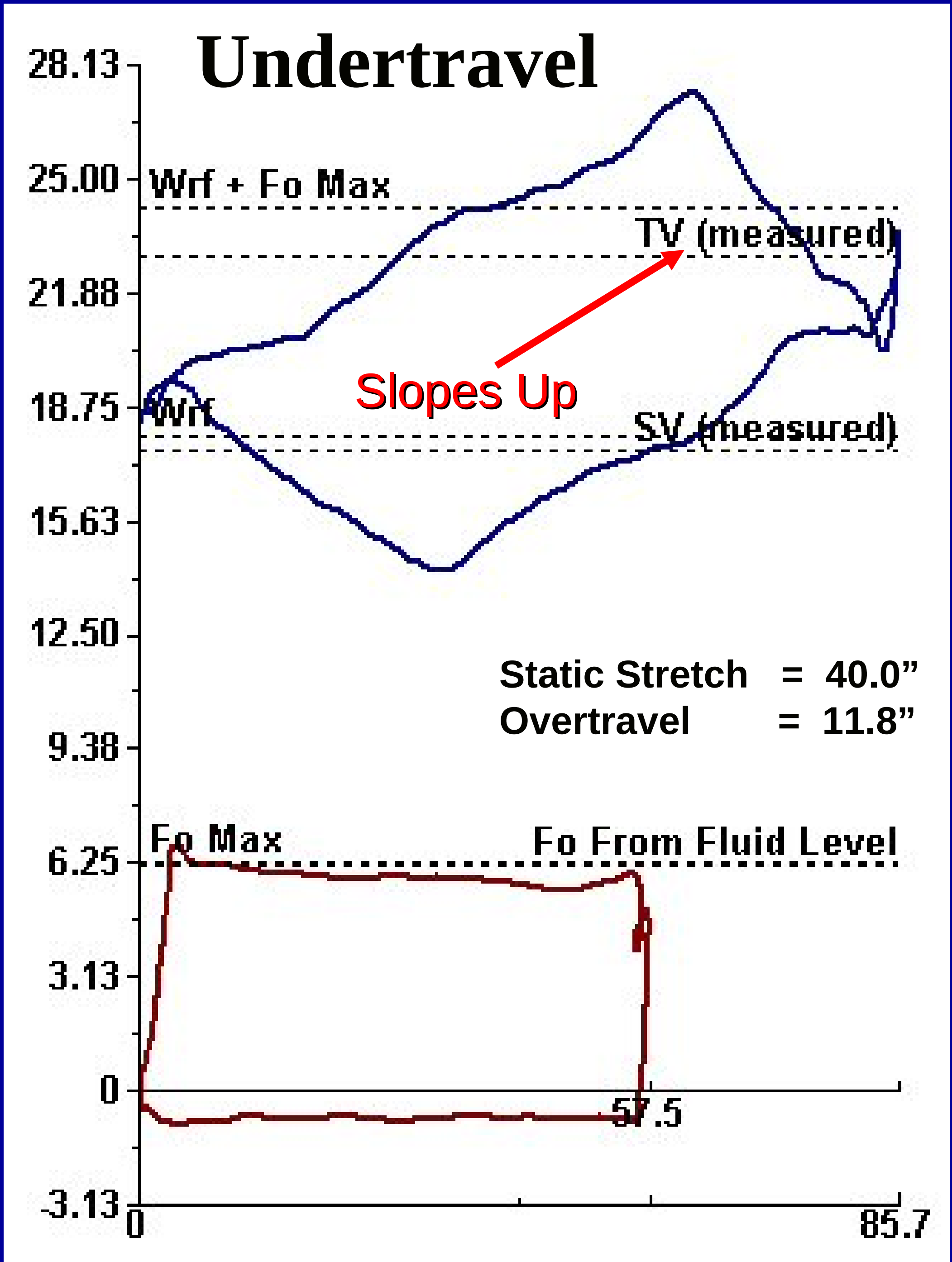


<u>Overtravel</u> Plunger stroke is longer than PR stroke. Surface card slopes downward from left to right.

Example: The 80.8” plunger stroke is ***more*** than the 72.6” polished rod stroke. The surface stroke is reduced by 23” of rod stretch required to lift the fluid load. The 13.74 SPM adds momentum to the rods increasing stroke by 31.2” inches.

Overtravel cards include: parted rods, flowing wells, unseated pumps, gas locks, worn pumps, fiberglass rod strings or pumping at a very fast SPM.

76 Rod String + 250’ Wt. Bars
1.25 “ Diameter Plunger
7054 Pump Depth



Undertravel Surface card slopes upward from left to right. The pump plunger moves ***less*** than the plunger stroke. Undertravel is due to rod stretch from fluid load, downhole friction or other reasons. Undertravel cards include: stuck pumps, ***plunger is too large for the rod string***, sand or scale problems, too tight stuffing box and/or paraffin.

Example

86 Rod String + 150 WT Bars
1.5 “ Diameter Plunger
9317 Pump Depth
6.69 SPM

Summary

- The following minimum rod string design results should be provided from the design program
  - PPRL
  - MPRL
  - SVL
  - TVL
  - PRHP
  - PT
- Excessive overtravel or undertravel should be avoided for optimum design and equipment life
- Properly analyzing failures, redesigning equipment , repairing and optimizing wells should be conducted if low operating costs, optimum production and maximum well and field value are important