LONG AND SLOW VS. SHORT AND FAST; IS THERE A PREFERENCE FOR SUCKER ROD LIFT OPTIMIZATION?

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ABSTRACT

There has been the concept that a long stroke and slow pumping speeds are the best way to design sucker rod lifted wells. Typically, longer sucker rod fatigue life is used as one of the reasons to rationalize this practice. Additionally, slow versus fast pumping speeds are relative numbers. This paper will discuss the various operation concepts, the background on pumping equipment capabilities, maximum design considerations, prior efficiency considerations, and provide rod string design comparisons showing rod loading and power comparisons resulting in new considerations for optimizing sucker rod lifted wells.

BACKGROUND

The design of a rod string for reciprocating downhole sucker rod lift artificial lift method is a complicated endeavor. One is faced with a variety of parameters to choose from that included the sucker rod grade, rod diameter(s), possible use of sinker bars, full sized or slim hole couplings, rod guides, along with the type and diameter of pump, the possible stroke lengths and pumping speeds to use and the type of surface pumping system. The system design is also compounded by possible downhole separation requirements and confined by the size of the production casing and tubing.

API RP 11L[1] provided industry guidance on the various calculations that should be done to determine system loading and then proper selection of sizes and strengths. This manual-graphical method was modified with the development of wave equation analysis and the availability of personal computers.[2-5]

Gipson and Swaim[6] provided industry training and generally accepted guidance on trying to address all the parameters and the variety of equipment that needs to be considered for a complete sucker rod lift system design. They also provided numerous rules of thumb such as on the recommended range of pump displacement to well capacity for optimum design and speed versus stroke length effects. Hein[7] provided further discussion of optimization recommendations and problem solving considerations for sucker rod lift systems.

Gault[8] considered the cost of operating sucker rod lift systems by comparing the design resultant polished rod horse power (HPpr) from these computer based rod string programs and then determining annual system power costs assuming 74.6% motor efficiency, 80% efficiency for the conventional type pumping unit, and a electrical power cost of $0.07/kW-hr. This work also compared the various design effects using 75, 76, 85, and 86 rod string numbers to produce 500 bfpd from 6000 feet pumping depth along with the effect of stroke length, pumping speed, pump diameter, and pumping unit geometry. Some results from this study showed:

- Heavier rod strings use more energy.
- But, there is a minimum stroke length that must be used with any selected design.
- Typically, there was a sharp reduction in energy costs (HPpr) when the stroke length was greater than 120 inches.
- Larger-bore pumps, when used with the optimum minimum stroke length, provide lower energy use due to a slower required pumping speed. These slower speeds generate less dynamic and frictional horsepower losses.
- Special geometry pumping units permit the use of longer stroke lengths without needing to increase the gear reducer size. However, for conventional units, increased stroke lengths typically require larger sized gear reducer/units.

These results may have lead the industry to assume longer, slower strokes are the "best" operating parameters for all sucker rod lift designs. However, not detailed are the associated trade-offs that also should be considered to determine if a design utilizes the available pumping equipment to fully optimize a well and/or a field.

ROD STRING SPEED LIMITATIONS

When determining the best selection of sucker rod lift operating parameters, one should consider what is meant by "long and slow" versus "short and fast." These are relative terms and should not be taken to extremes, especially since a design is typically bounded by the availability of pumping units and the size of the unit gear reducer. Thus, one should consider:

- How fast is fast? (conversely, how slow is slow?)
- Are there design limitations for pumping speeds?
- What are the things that effect optimum speed?
- What are the trade-offs that should be considered if long stroke lengths are used?

Gipson and Swaim summarized a variety of factors to consider for sucker rod string design and speed effects or limitations. The first design consideration is the Acceleration Factor (C). This speed maximum is related to the stroke length (S) and pumping speed (N) design/operating parameters by:

$$C = (S * N^2)/70{,}500$$

But the acceleration factor is limited by the free fall speed of the rods. This consideration dates back to 1962 when W. H. Ritterbusch in "Petroleum Production Handbook" said:

> **"Always choose a speed below that maximum practical limit permitted by free-rod fall so that the polished-rod clamp and hangar bar will not separate on the downstroke."**

This is the assumed to be the first recommendation for maximum permissible speed to be limited to 70% of the free fall limit.

In 1965, Bethlehem Steel published "Pumping Unit Selection Charts." These included a notation that:

"**Normally at speeds which exceed 0.7 of the free fall velocity, the polished rod begins to leave the carrier."**

Lufkin later supported the 0.7 of the free fall speed for Conventional Unit geometries in their pumping unit catalogs. They also included recommendations that the maximum speed should be further reduced by 10% for an Air Balanced Unit and 20% for a Mark II unit.

This would result in a C = 0.417 if a straight well was produced and only fresh water was pumped. But seldom is the well straight and typically fluids other than fresh water are pumped. Thus, Gipson & Swaim recommended for design:

$$\mathbf{0.225 \le C \le 0.3 \text{ (Shallow wells)}}$$

The 0.225 C factor lower limit is to assure optimized equipment (not too large). While the upper limit of 0.3 is to stay below the free fall speed for non-straight wells and non-fresh water fluids. However for deeper wells (>5,000 feet), the non-dimensional speed parameter of N/No' should be used. They recommended that the maximum speed parameter should be less than 0.35.

Finally, they stated:

"**In real world operating situation, the free fall speed of the rods and the gear box capacity determine maximum pumping speed."**

PUMPING UNIT SPEED LIMITATIONS

Table I provides a summary of speeds assuming 70% of the free fall speed of the rods and an acceleration factor, C, of 0.3 for various, common surface stroke lengths. Also shown is the resulting polished rod velocity for the C=0.3 pumping speed.

Speed effects and limitations are also due to the pumping unit gear reducer size and unit type/size. API Spec 11E[9] for "Pumping Units" covers the requirements for the gear reducers (or gear box) and the requirements for the structural unit. This standard originally based the gear reducer performance on AGMA Standard 422.02. Originally, it assumed all gear reducers would be based on 20 strokes per minute (SPM), regardless of the size of the reducer or pumping unit. In 1981, API revised the reducer rating slowing down the maximum operating design speed for larger reducers starting at the 456 size. Table II provides the new API requirements for maximum design/operational speed for larger sized reducers. Other changes in the standard continues to be made, especially since in 1998, the AGMA modified their standard and issued it as 422.03.[10]

Lufkin, a major supplier of gear reducers and pumping units world-wide, also provide double reduction gear reducers similar to pumping unit reducers for other applications, such as pumps, fans, etc. Table III shows the maximum speeds for assumed prime mover speeds of approximately 1150 rpm for the various sized gear reducers. These maximum, recommended speeds typically increase as the size of the reducer increases. It should be noted that for very large sized reducers (greater than 912,000 in-lb), the prime mover speed is assumed to be 870 rpm.

The difference in the capabilities of the gear reducer from the manufacturer is assumed to be due to the mechanical device the reducer is attached to. Thus, while the maximum capable speed for the reducer is much greater than that recommended from API, when the pumping unit is coupled to the reducer, the maximum speed is decreased.

Table IV, V, and VI shows the recommended maximum speed for various sized pumping units assuming Conventional, Mark II, and Air Balance unit types, respectively. Note that the maximum operational speed decreases as reducer size and coupled pumping unit structure size increases. Additionally, the speed for a given unit size decreases as the stroke length increases.

It should also be noted that these data were obtained from Lufkin in the early 1990s. While they probably are still valid, Lufkin, or other pumping unit manufacturers, should be consulted to determine if the maximum speed stated is still valid, especially since larger pumping unit sizes are now available (Conventional 1280 and 1824 units are now manufactured).

Rationalizing the speed effects on design and operation of sucker rod lift systems, we should now consider:

"In real world operation situations, the free fall speed of the rods and the Pumping Unit Stroke Length determine the maximum pumping speed."

FATIGUE CONSIDERATIONS

There are a variety of other factors that should be considered to design and optimize sucker rod lift systems. The first is load or stress and the resulting fatigue effect on rods.

API RP 11BR, "Recommended Practice for Care and Handling of Sucker Rods[11]" provides the Modified Goodman Diagram (MGD) to be used to determine maximum and minimum allowable loads for steel rod strings. This diagram was developed from the original R. Moore fatigue testing of small, polished, bent beam samples. Originally, the samples were fatigued at various loads, assuming full cycle tension and compression, until 1,000,000 cycles were reached. If the sample had not failed at this life, then the life at load was extrapolated to 10,000,000 cycles. This testing to a lower test life and then extending the life along the same trend to the next log cycle life is still typically done. The MGD was developed from consensus experience, testing, and actual performance from the industry representatives on this API task group. The MGD recommended loads was significantly reduced, using a straight line approximation.

The use of newer technology and fatigue considerations from when the original bending fatigue testing was done in the 1920s was addressed by Hein and Hermanson.[12] They provided a discussion on the development of the MGD, along with recommendations that the techniques used do not reflect current industry steel making practices, quality control capabilities nor fatigue testing understanding. Further, they recommended a non-linear approach using the Gerber Parabola that would allow increased loading versus current MGD recommendations.

When all of these factors are considered, rather than the API 11BR fatigue expectations of only 10,000,000 cycles, it was postulated that the fatigue life to first failure should be 50,000,000 cycles for current day steel rods strings. Assuming 24 hour/day operations, at 10 spm, this should provide approximately 9.8 years of running until the first failure for new sucker rods. This is an expected failure frequency (FF) of 0.102. This resulting life should be considered a conservative minimum, especially since most wells are not pumped continuously 24 hr/day. However, this FF is considerably better than the industry expectations of approximately 0.3 to 0.4 based on an industry consortium operating in the West Texas area.[13]

SPEED AND STROKE CONSIDERATIONS

The final design considerations are related to the original formulas from API found in RP11L. These formulas show that the well pump displacement (PD) is dependant on the stroke length (surface (S) and more importantly downhole pump (Sp), the pumping speed (N), and the diameter of the selected plunger (D). The formula for PD that can be used directly without the need for pump constants described in this standard is:

$$\mathbf{PD = 0.1166 * S * N * D^2}$$

Gipson and Swaim recommended for sucker rod lift, the PD should be determined within an acceptable range and it should be related to the well's production capability (WC). Thus the range of PD is:

$$\mathbf{WC/0.85 \leq PD \leq WC/0.65}$$

Thus, the pump displacement is designed to be greater than the well capacity, but some what limited so that it is not too much greater and 50% over the expected production rate from the well. This is to allow for changes in operating time from when the downhole pump is new and requires time clocking so that the well is not over-pumped. Additionally sufficient design capacity is available to increase pumping duration as the equipment wears and downhole slippage increases.

There are other design formulas that should be considered to determine optimum design/ speed and stroke considerations. The RP also provides the following formulas for Peak Polished Rod Load (PPRL), Minimum Polished Rod Load (MPRL) and Peak Torque (PT). These respective formulas follow:

$$\mathbf{PPRL = Wrf + [(F1/Skr) * Skr]}$$

$$\mathbf{MPRL = Wrf - [(F2/Skr) * Skr]}$$

$$\mathbf{PT = (2T/S2kr) * Skr * S/2 * Ta}$$

The RP should be consulted for detailed discussion on the determination of these pumping parameters and the significance of the terms. But, one thing that should be obvious is that the loads and peak torque are primarily influenced by the stroke length (S). Note that the term for pumping speed (N) does not have major influence on these parameters.

DESIGN COMPARISONS

While the work done by Gault is similar to this paper, the production rate of 500 bfpd may be considered toward the upper capabilities of sucker rod lift. Thus, this paper considers lower production rates (approximately 100 to 200 bfpd).

A modified API computer program (Beam Pump) was used to develop comparisons of design parameters for various surface stroke lengths and pumping speeds. This program was used since it was shown to be most accurate for steel rods strings without sinker bars.[14] The well design assumptions were:

- Vertical well 5000 feet deep
- Tubing anchor catcher was placed at approximated 4940 ft.
- Pump diameter was 1.5 in.

- Specific Gravity (G) of the mixed produced fluids was 1.0
- 65 rod string
- Class D sucker rods
- No sinker bars

Table VII shows the results of varying the stroke length (S) from 74, 86, 100, and 168 -inches while the pumping speeds (N) were varied to obtain similar theoretical pump displacements of 113, 120 and 200 bfpd. Table VIII shows the results assuming a PD of approximately 150 bfpd for the assumed well using S of 74, 86, 100, 120, 144, and 168 –inches.

The design parameters reported include:

- Fo/SKr; non-dimensional load parameter,
- N/No'; non-dimensional speed parameter,
- Sp; resulting downhole stroke length (inches);
- PD; resulting pump displacement (bfpd)
- Standing Valve (SV) load = Wrf (lbs),
- Traveling Valve (TV) load (lbs),
- PPRL (lbs),
- MPRL (lbs),
- PT at the polished rod (m-inch-lbs,
- HP at the polished rod, and
- Load range (lbs)

It can be observed in Table VII, for a given S, as the N increases:

- PD increases,
- Sp increases
- PPRL increases,
- MPRL decreases,
- PT increases, and
- HPpr increases.

It can also be observed that for a similar PD, as the S increases:

- N decreases,
- PPRL does not change much until the longest stroke length,
- MPRL increases,
- PT increases, and
- HPpr, SV, and TV are approximately the same.

When designs in Table VIII are run for a constant production rate of 150 bfpd, as S increases:

- N decreases,
- SP increases,
- PPRL is approximately the same until 120 inch stroke, then PPRL decreases,
- MPRL increases,
- Load range decreases,
- PT increases, and
- HPpr is about the same

Some of these results may be surprising, especially the same polished rod horsepower for longer stroke lengths or slower speeds. This is different that Gault since he made additional assumptions on efficiency that changed for the motor and type of unit. However, if one thinks about the amount of work that has to be done, it is approximately the same to lift the total production of 150 bfpd to the surface. Thus, the system work should be the same.

The PPRL staying about the same is a combination of fluid load effects balancing out the dynamic & frictional effects on the up stroke. However, if one considers lifting 150 bfpd, the actual applied fluid load is greater when a longer S is used. This is because more fluid is actually lifted per stroke cycle. The MPRL increasing with longer S is another remnant due to dynamic effects. The computer program changes the MPRL to account for increased speed requirements with shorter stroke lengths. However, if sinker bars are used, then physically, the dynamics will be reduced for faster pumping speeds. This has been shown many times where the MPRL is increased when sinker bars are used. The one main parameter that is significantly increased with increased S is the PT. These results are similar to the results previously published by Gault.

While the loads and horsepower at the polished rods can be explained, the increased PT implies more work is being done. This requires higher capacity gear reducers and a larger, more expensive pumping unit. For this example, a 160 pumping unit could be used for the 74 inch stroke and 9.8 SPM, but a 228 pumping unit would be required just from changing to 86 or 100 inch stroke. If the stroke length is increased to 120, 144 or 168 inches, then a 320 pumping unit would be required.

During optimization of the well or field, the smallest size acceptably loaded equipment should be used when ever possible. This may require changing units around a location. It may also show that the pumping units are much larger than will be required. While the same polished rod horsepower will be required, increasing stroke increases applied work and the resulting increase in gear reducer will may require even larger sized prime mover to enable starting up the unit if the counter weights are down.

CONCLUSIONS AND RECOMMENDATIONS

1. Long & Slow has been sold as way to reduce fatigue failures due to fewer cycles and increased electrical power savings.
2. Short & fast vs. long & slow are relative terms.
3. Fatigue theory shows load range most important to fatigue life.
4. 1920's fatigue life of 10,000,000 cycles not represents current rod manufacturing and well optimization. 50,000,000 cycles should be obtainable. (FF ~0.10)
5. Typically for same production, same work required to lift to surface, so PPRL and HPpr approximately the same until very long stroke lengths.
6. As S increases MPRL increases due to dynamic effects which reduces load range.
7. While longer/slower may reduce load range, PTpr and required PT for unit increased.
8. Slowing down long S design may be problematic since efficiency reduces for smaller sheaves.
9. Jack shaft may be used to provide additional speed reduction, but further reduces power transmission efficiency and increases costs.
10. Sinker bars will provide same dynamic effect of increasing MPRL and reducing load range for shorter/faster operation.
11. Optimization of pumping equipment might say 'shorter/faster' w/ sinker bars is more operational effective.

REFERENCES

1. API RP 11L"Design Calculations for Sucker Rod Pumping Systems," Fourth Edition, API, Washington D.C. (June 1988 and errata October 1, 1988).
2. Gibbs, S.G.: "Predicting the Behavior of Sucker Rod Pumping Systems," SPE 588, *JPT,* (1963) 769.
3. Gibbs, S. G.: "A General Method for Predicting Rod Pumping System Performance," SPE paper 6850, presented at the 1977 52nd ATCE, Denver, (October 9-12).
4. Gibbs, S .G.: "A Review of Methods for Design and analysis of Rod Pumping Installations," SPE 9980, *JPT*, (1982), 2931.
5. Clegg, J. D.: "Rod Pump Design Using Personal Computers," paper 021, SWPSC, Lubbock (1986).
6. Gipson, F. W. and Swaim, H .W.: "The Beam Pumping Design Chain", paper presented at the SWPSC, Lubbock, April 23-25, 1988.
7. Hein, Jr., N. W.: "Beam-Pumping Operation: Problem Solving and Technology Advancements," *JPT,* SPE Distinguished Author Series, (1996) 330-336.
8. Gault, R. H.: "Designing a Sucker-Rod Pumping System for Maximum Efficiency," *SPE Production Engineering,* (Nov. 1987), 284.
9. API Spec 11E, "Specification for Pumping Units," 17th Edition, API, Washington, D.C. (November

1994/Reaffirmed January 2000).
10. AGMA 422.03, "Practice for Helical and Herringbone Speed Reducers for Oilfield Pumping Units," Alexandria, Virginia (1998).
11. ANSI/API RP 11BR, "Care and Handling of Sucker Rods," Eighth Edition, API, Washington, D.C. (October 1989 including supplement 1, July 1991).
12. Hein, Jr., N.W. and Hermanson, D.E.: "A New Look at Sucker Rod Fatigue Life," paper SPE 26358 presented at the 1993 6th Annual Technical Conference, Houston, October.
13. Rahman, M.M. and Heinze, L.R.: "Development of ALEOC Beam Pumping Failure Data Base," paper 017, SWPSC, Lubbock (2000).
14. Hein, Jr., N. W. and Stevens, R.: "A Current Comparison of Rod String Design Programs, SWPSC, 2004.

Table 1
Acceleration Factor Pumping Speed Considerations for Common Stroke Lengths using 70% of the Free Fall Speed of the Rods Versus a C Factor of 0.3 and the Resulting Polished Rod (PR) Velocity

S (in.)	**SPM @70%**	**SPM @C=0.3**	**Velocity PR (fpm)**
16	**42.9**	**36.4**	**97**
24	**35**	**29.7**	**119**
30	**31.3**	**26.6**	**133**
36	**28.6**	**24.2**	**145**
42	**26.5**	**22.7**	**157**
48	**24.7**	**21**	**168**
54	**23.3**	**19.8**	**178**
64	**21.4**	**18.2**	**194**
74	**19.9**	**16.9**	**208**
86	**18.5**	**15.7**	**225**
100	**17.1**	**14.5**	**242**
120	**15.7**	**13.3**	**266**
144	**14.3**	**12.1**	**291**
168	**13.2**	**11.2**	**315**
192	**12.4**	**10.5**	**336**
216	**11.7**	**9.9**	**356**
240	**11.1**	**9.4**	**376**
300	**9.9**	**8.4**	**420**

Table 2
Maximum Speed Design Limitations for Larger Sized API Gear Reducers from API Spec 11E

Reducer Peak Torque Rating (in-lbs)	**SPM**
456,000	**16**
640,000	**16**
912,000	**15**
1,280,000	**14**
1,824,000	**13**
2,560,000	**11**

Table 3
Lufkin Hi-Q Herringbone Gear Speed Reducers – Double Reduction Units Maximum Recommended Speeds for Various Sized Gear Reducers
(Assumes operating ~1150 rpm prime mover w/30 to 1 gear ratio)

API Gear Reducer Size	**Maximum Recommended Speed (RPM)**
D40	**25.1**
D57	**40.4**
D80	**55.8**
D114	**87.3**
D160	**115**
D228	**160**
D320	**252**
D456	**353**
D640	**432**
D912*	**441**
D1280*	**590**
D1824*	**853**
D2560*	**1456**

***assumes prime mover speed of 870 rpm**

Table 4
Recommendations from Lufkin for Maximum Speeds for Available Conventional Pumping Unit Sizes
(Note: Larger sized units are now available. Lufkin should be consulted for maximum speed recommendations)

Pumping Unit Size	**Max. SPM**	**Pumping Unit Size**	**Max. SPM**
C912-365 (305)-168	**13.2**	**C160-173-64**	**21.4**
C640-365 (305)-168	**13.2**	**C80-119-64**	**21.4**
C4556-305-168	**13.2**	**C114-173-54**	**23.3**
C912-427-144	**14.3**	**C57-76-54**	**23.3**
C320-256-144	**14.3**	**C80-133-48**	**24.7**
C640-305-120	**15.7**	**C40-76-48**	**24.7**
C228-213-120	**15.7**	**C57-89-42**	**26.5**
C456-256-100	**17.1**	**C40-89-42**	**26.5**
C160-173-100	**17.1**	**C40-89-36**	**28.6**
C320-246-86	**18.5**	**C25-56-36**	**28.6**
C114-119-86	**18.5**	**C25-67-30**	**31.3**
C320-246-74	**19.9**	**C25-53-30**	**31.3**
C114-143-74	**19.9**		

Table 5

Recommendations from Lufkin for Maximum Speeds for Available Mark- II Pumping Unit Sizes

Pumping Unit Size	Max. SPM	Pumping Unit Size	Max. SPM
M1824-427-216	9.3	M320-305-100	13.7
M912-365-216	9.3	M228-173-100	13.7
M1280-427-192	9.9	M228-246-86	14.8
M456-305-192	9.9	M114-143-86	14.8
M912-427-168	10.6	M228-200-74	15.9
M456-305-168	10.6	M114-173-74	15.9
M912-365-144	11.4	M114-173-64	17.1
M320-256-144	11.4	M114-143-64	17.1
M456-365-120	12.5		
M228-213-120	12.5		

Table 6

Recommendations from Lufkin for Maximum Speeds for Available Air Balanced Pumping Unit Sizes

Pumping Unit Size	Max. SPM	Pumping Unit Size	Max. SPM
A2560-470-240	10.0	A912-427-144	12.9
A912-470-240	10.0	A456-305-144	12.9
A1824-427-216	10.5	A640-365-120	14.1
A912-427-216	10.5	A320-256-120	14.1
A1824-427-192	11.1	A320-305-100	15.4
A912-427-192	11.1	A228-173-100	15.4
A1280-305-168	11.9	A160-200-74	17.9
A640-305-168	11.9	A114-173-64	19.3

Table 7

Summary Design Parameters Showing Results of Different S and N to Obtain Similar Pump Displacements (PD) (assuming 5000 ft. well, 1.5 inch pump, 65 D rod string, no sinker bars, G=1.0, and tubing anchor at ~4940 ft.)

S	N	Fo/SKr	N/No'	Sp	PD	SV	TV	PPRL	MPRL	PTpr	HPpr
74	7.7	0.2868	0.1414	56.0	113.1	5852	9677	10,992	4,714	135.4	4.5
	9.8	0.2868	0.1800	58.4	150.1	5852	9677	11,336	4,190	147.7	6.0
	12.3	0.2868	0.2315	60.8	200.9	5852	9677	11,850	3,605	165.2	8.7
86	6.4	0.2467	0.1176	67.0	113.2	5852	9677	11,002	4,914	138.1	4.5
	8.3	0.2467	0.1525	69.2	150.6	5852	9677	11,358	4,446	174.7	6.1
	10.6	0.2467	0.1947	72.1	200.5	5852	9677	11,801	3,792	196.4	8.5
100	5.3	0.2122	0.0973	81.3	113.0	5852	9677	11,001	5,055	182.0	4.4
	7.0	0.2122	0.1286	82.6	151.7	5852	9677	11,389	4,660	201.6	6.1
	9.0	0.2122	0.1653	84.7	200.0	5852	9677	11,825	4,049	228.6	8.4
168	2.9	0.1263	0.0532	148.0	112.8	5852	9677	10,662	5,407	268.0	4.5
	3.9	0.1263	0.0707	148.9	150.4	5852	9677	11,064	5,169	286.7	6.0
	5.1	0.1263	0.0938	149.8	200.9	5852	9677	11,567	4,821	317.4	8.4

Table 8
Summary Design Parameters Showing Results of Different S and N for Approximately 150 bfpd Pump Displacement (assuming 5000 ft. well, 1.5 inch pump, 65 D rod string, no sinker bars, G=1.0, and tubing anchor at ~4940 ft.)

S	N	Fo/Skr	N/No'	Sp	PD	PPRL	MPRL	Load Range	PTpr	HPpr
74	9.8	0.2868	0.1800	58.4	150.1	11,336	4,190	7,146	147.7	6.0
86	8.3	0.2467	0.1525	69.2	150.6	11,358	4,446	6,912	174.7	6.1
100	7.0	0.2122	0.1286	82.6	151.7	11,389	4,660	6,729	201.6	6.1
120	5.6	0.1768	0.1030	101.9	149.9	11,304	4,897	6,407	229.1	6.0
144	4.6	0.1473	0.0839	125.2	150.1	11,180	5,052	6,128	257.5	6.0
168	3.9	0.1263	0.0707	148.9	150.4	11,064	5,169	5,895	286.7	6.0