NEW HIGH LOADS SUCKER RODS FIELD EXPERIENCE

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ABSTRACT
This paper describes the premium connection (PC) sucker rods field experience in various applications and shows the results collected up to this point. When this paper was written, 11 wells were working with the sucker rods under different loads ratings.

INTRODUCTION
Sucker rods connection-related failures represent one of the main limitations of beam pumping applications today. More demanding field operative conditions are pushing connections to their limits, consequently becoming the weakest link of the system.
API Sucker Rods Specifications (11B) haven't changed much since the 70's. Poor stress distribution, along with the tendency to loosen from API connection design, is the main cause of stress concentration points, which will eventually lead to failure.
After several attempts to come out with a solution for this problem, a new premium connection (PC) was developed. The lab first showed that it is capable of working above the sucker rod body capacity and field tests are now showing its reality.
Through this revolutionary development, current conventional pumping application limits are expanded and thereby adding a new solution to the artificial lift systems users.

DEVELOPMENT
1- Limitations of API connection design.
Although API 11B sucker rod thread design has worked in the field for decades and it's manufacturing is quite simple, it has some limitations that should be mentioned:
- Loosening tendency of the connection due to a gap between threads. This gap allows movement between coupling and pin threads when rods suffer compression and/or shocks.
- Finite Elements Analysis (FEA) verifies permanent deformations in thread during well and make-up operations. These deformations make the appearance of cracks and propagation easier, and they produce difficulties in displacement repetition for make-up.
- Non uniform stress distribution in thread profile generates stress concentration areas and therefore makes cracks propagation easier (also verified with FEA).
- High reliance with the make-up operation due to the fact that an over-torque (increase in the stress level) as well as a loosen connection (stress concentration during well operation) are harmful for the connection and produces failures in sucker rod pins and couplings.

In addition to the aforementioned limitations, internal corrosion as well as thread deformations cause failures in the connection. However, the difference is that these cannot be solved with the thread design since they depend on the material handling and storage.
All of these analyses, in combination with the field experience, show that the conventional connection resistance is inferior to the rod body resistance. Therefore, the connection is the weakest point in a sucker rod string.

In order to solve this, high strength (HS) sucker rods were first developed. With them, all the material capacity is increased since a connection with higher capacity is produced. After this, sucker rods with reinforced connections were developed (7/8" rod body with 1" pin and 3/4" rod body with 7/8" pin) but they faced the physical limitation that most used tubing are 2 3/8" or 2 7/8" and in this pipes the 7/8" or the 1" connection cannot be increased due to the limited space. Therefore, the weak point in the sucker rod string was always located in the connection.

2- Premium Connection Characteristics.
After a large development process that included Finite Elements Analysis and lab tests, a connection capable of working

under high loads and that improved sucker rods fatigue life was achieved. This connection has the following main characteristics:

- Tapered trapezium profile thread
- Diametrical interference with flank-to-flank contact
- Low make-up pin stress

With these characteristics, the gap between pin and coupling conventional threads was eliminated. Consequently, the loosening tendency was improved, the permanent deformations in threads were reduced, and an improvement in stress distribution was achieved for the make-up operation as well as for the pumping (fatigue) operation. In general, a significant reduction of critical stressed areas was achieved.

3- Laboratory test.

Once the thread design was developed, it had to be tested for fatigue life resistance at different stress levels and comparing results gather with API sucker rods. An optimum behavior of the connection was verified working up to 300% of Goodman. (See annex I)

4- Manufacturing

Not described in this paper.

5- Field Experience.

Previous to the massive field tests, a pilot well was tested with 7/8" sucker rods intercrop in a High Strength (HS) string. Because of this, we have divided field experience into two categories.

1st Stage: only 7/8" taper

This stage consisted in testing a 7/8" Grade D taper with PC in a well actually working with HS sucker rods and that had many 7/8" failures in its background.
Analyzing the failure history of the well, half of them took place in the rod body and were associated with corrosion. The other half were associated with operative limitations of the connection (see annex III). Because of these two reasons, in September 2005 it was decided to install Grade D sucker Rods (with better behavior in corrosive environments) with premium connection (higher operative capacity than conventional ones) in the well.
The string design consisted in 93 1" HS rods, 94 7/8" Grade D with PC rods, 77 3/4" HS rods and 20 1½"Grade II sinker bars (see annex V). All installed sucker rods were new (no used/inspected sucker rods were installed) and the well operative condition was not modified in comparison with the one it had previously to this installation. (See table 1)

Although this operative condition has changed within working time, Grade D with PC sucker rods has worked under similar stress levels as high strength rods without failures. They worked over 137% of Goodman for 0.8 Service Factor (SF) calculated for Grade D rods. Actually, the well production flow has been reduced and these rods are stressed up to 106% while HS rods are working up to 59% (0.8 SF for all cases).
These wells haven't had any intervention since September 2005 when PC rods were installed but it has been stopped several times due to different kind of problems in the field but never linked to well PE-01. In total, it has been stopped for more than 6 months.

2nd Stage: massive complete string field tests

After a successful field test stage, it was decided to increase test quantity. 10 more wells were installed, 3 of them in Progressive Cavity Pumping (PCP).
Also, different stress level applications were tested in different fields in order to learn about the rods working capacities in the field. Each test had a different objective.
Test in PE-01 well was not stopped.

Conventional Pumping Wells (CP)

At the moment this paper was written, 7 wells were working with a complete PC sucker rod string in three different oil companies with different characteristics. (See table 2)

In order to determine sucker rod stress level, we used the API 11BR specs recommended method: Modified Goodman Diagram for Grade D rods (see annex II). Doing this, the installed sucker rods stress level could be compared to the one a conventional rod would have.

In general, it can be seen that PC sucker rods work at stress levels above the API conventional Grade D working allowable range (Goodman % values above 100%). (See table 3)

Of the almost 2000 sucker rods been tested at this stage, none of them had failed. Nevertheless, two of these wells (PE-03 & PE-04) had the sucker rods pulled out due to a tubing leakage in the first one and an anchor change in the latter.
As noted in dynacards, several 3/4” and 7/8” sucker rods are working under compression (negative loads) although most wells have sinker bars.

Progressive Cavity Pumping Wells (PCP)

Also, when this paper was written, 3 other wells were working in torque applications (PCP).
Although the torque capacity of the sucker rods does not increase with the new connection (due to the fact that the torque capacity is limited by the rod body), it has increased the connection reliability to reduce failures caused by overtorque or unscrew (caused by *backspin* effect). Because of this, it was decided to test 3 wells at high torques and RPM.

The 343 1” PC sucker rods working in PCP have an average of 3 months in the wells with no failures. In average, they have worked for 50 million cycles with torques of 714 lbs*ft and at 300 RPM. (See table 4)
Two of the test wells had the rods pulled out due to leakage problems in the tubing, caused by wear with couplings (fiberglass tubing was used). After changing for a steel tubing string, wells continued operation.

OBSERVATIONS

- Due to the fact that PC connection make-up is controlled with circumferential displacement like conventional rods, all PC sucker rods were installed with tools normally available in rigs. The only difference to be mentioned is that 7/8” PC rods have a reinforced wrench square with EL (Electra) or PL (Plus) rods size. These rods are regularly used in the oil industry.
- As threads have diametric interference, dope must be applied before making them up in order to avoid galling (see annex IV). In any reassembly operation galling was detected and none of the rods had to be changed.
- Diametric interference also makes the connection to have *stand off* (space between faces in the *hand-tight* position). Although we can expect to have a reduction of the *stand off* value after the first assembly, threads kept reliable and constant values during reassembly. (See annex IV)
- Although total service rig time for the sucker rod installation was increased, it was related only to two main causes. The first cause relates to a correct cleaning operation and dope application supervised by specialized personnel (50% of the installation time). The second cause relates to more frequent displacement measurement and rig crew capacity.

  In the future, we estimate that the installation of PC sucker rods shouldn’t require more time than the one required to install conventional rods due to the fact that the only step to be added is the faces contact achievement with the power tong (step 4 in annex IV), but this has to be done only for the power tong calibration and the displacement verification (few rods per string).
- Power tong pressures needed for the PC make-up are estimated to be 10% higher than the ones required for making-up high strength sucker rods of the same diameter. (See table 5)
- In all stage 2 tests, all the sucker rod string connections were premium but the polished rod and the sinker bar ones. (See annex V)

CONCLUSIONS

- Critical stress area reductions cause the premium connection to have higher resistance to fatigue than the API thread design. This was verified in lab tests and later in the field.

  The PC has demonstrated to be more efficient for high loads than the sucker rod body, expanding the total sucker rod working capacity. We see that: Premium connection resistance > Rod body resistance
- Performance of PC allows the utilization of Grade D sucker rods in high load wells where high strength sucker rods were needed (with special steel allows and thermal treatments and more susceptible to fail under corrosive environments).
- The PC appeared to have an excellent repetition in circumferential displacements (it is not sensible to variations in the power tong pressure).
- Rig service time (installation/extraction) didn’t show significant variations in comparison to the original time necessary to run conventional sucker rods. Little increases are needed for the power tong pressure calibration and for the dope application to sucker rods’ threads.

ANNEXES

I- Premium Connection Axial Fatigue Lab Tests

II- API 11 BR stress level determination

API 11BR Specs. recommend the use of the modified Goodman stress diagram for determining the allowable range of stress and allowable sucker rod stress for sucker rod strings.

The stress value has to be calculated with the following formulas:

$$S_{adm} = (\frac{UTS}{4} + 0.5625 \times S_{\min}) \times SF$$

$$\%Goodman = \frac{(S_{máx} - S_{mín})}{(S_{adm} - S_{mín})} \times 100$$

S_{adm}: Max. Admissible Working Stress (psi)
UTS: Ultimate Tensile Strength (Grade D=115 ksi)
S_{min}: Minimum Stress (psi)
$S_{máx}$: Maximum Stress (psi)
SF: Service Factor

Similar curves (lines) exist for all steel grades depending on its characteristics and on the manufacturer.

III- Well PE-01 (1st stage) sucker rod failures background

This well had a large background of failures in 7/8" sucker rods in previous two years. Half of them took place in the connection and the other half in the rod body and were associated to corrosion problems.

Doing the mirror comparison of interventions associated costs; an important reduction is seen after installation of PC sucker rods due to the fact that the well did not fail any more.

IV- Make-up operation

1. Threads cleaning: conventional connection cleaning is done assuring that all solid particles must be removed from the threads. Rod and coupling faces shouldn't have grease.
2. Dope application: tubing conventional dope is used in sucker rod threads in order to avoid galling.
3. Hand-tight position: due to the fact that the connection has *stand off*, it is not possible to get the rod and coupling faces in contact using manual tongs.

4. Faces contact: the power tong must be calibrated to make contact between the rod and the coupling faces without displacing them. This operation must be checked with a 0.05 mm gauge and is only done for the power tong calibration.
   Average power tong pressures for this step were 625 psi for 1", 427 psi for 7/8" and 563 psi for 3/4" sucker rods.

5. Circumferential displacement control: once the faces contact is assured, a vertical line is drawn between them and displacement is done and controlled like with conventional rods. A special displacement card is required since values are different from all other connections.
   Average power tong pressures for this step were 1100 psi for 1", 857 psi for 7/8" and 775 psi for 3/4" rods.

Reassembly

In all 4 reassembly operations that took place in the test wells the expected reduction in the *stand off* was observed as well as a reduction in the power tong pressure needed for the connection make-up.

V- String design description

General accessories used in the PC sucker rod strings are described in table 8.

Table 1

Well PE-01* main characteristics	
Pump depth	7155 ft (2181 m)
Pump bore size	2”
Tubing	2 7/8”
Production	478 bpd (76 m^3/d)
Pumping Unit	M 912-365-168
SPM	7.81
Oil Density	~10 °API

* PE stands for Experimental Well in Spanish.

Table 2

Well			PE-02	PE-03	PE-04	PE-05	PE-06	PE-07	PE-08
Country			Arg.	Arg.	Arg.	Arg.	Arg.	Arg.	USA
Installation date			5-Oct-08	14-Oct-08	2-Nov-08	24-Dec-08	8-Jan-09	21-Nov-08	25-Nov-08
Estimated cycles [th]			574	861	779	330	71	661	NA
Working days			101	92	73	21	6	54	50
SPM			3.95	6.5	7.41	7	8.25	8.5	NA
Pump depth [m]			1996	2050	2279	2240	2050	2644	2043
Production flow [m3/d]			120	65	47	100	52	70	62
WO time [hr]			12	9.5	10	15	11	15.5	14.5
Average time for SR [SR/hr]			22	33	60	20	24	30	NA
String Design	1" sucker rods		117	106	99	116	78	95	100
	7/8" sucker rods		119	155	111	100	89	112	114
	3/4" sucker rods		0	0	70	65	93	126	0
	Sinker Bars*	Quantity	26	8	20	13	9	14	54
		Diameter	1”	1 5/8”	1”	1 5/8”	1 5/8”	1 1/2"	1”
Pump			2.75"	2"	2.25"	2 1/4"	2 1/4"	2"	2"
Submergence [m]			NA	NA	NA	NA	NA	450	NA
Test objective			Failures reduction	Failures reduction	Production increase	Failures reduction	Failures reduction	Production increase	Replace High Strength SR

* Sinker Bars have API connection.

Table 3

Well Name		PE-02	PE-03	PE-04	PE-05	PE-06	PE-07	PE-08
Stress Level (0.8 SF)	1" SR	107%	150%	150%	176%		170%	157% *
	7/8" SR	111%	145%	147%	174%		175%	162% *
	3/4" SR	NA	NA	138%	178%		180%	NA
	SB	94% *	48% *	77% *	NA		38% *	67% *

* Due to the fact that not all test wells have had dynamometer cards, some values have been estimated with simulation software.

Table 4

Well Name		PE-09	PE-10	PE-11
Country		Arg.	Arg.	Arg.
Installation date		3-Oct-08	4-Oct-08	27-Nov-08
Estimated cycles		57960000	41040000	
Working days		115	114	60
RPM		350	250	380
Pump depth	[m]	846	1013	754
Production flow	[m3/d]		128	
SR quantity		111	133	99
SR diameter		1”	1”	1”
Pump		NTZ-400-150-ST78	NTZ-400-150-ST62	NTZ-400-150-ST78
Submergence	[m]	260	180	
Observations		Fiberglass tbg. leakage (Oct-08). Reinstall sucker rods.	Fiberglass tbg. leakage (Nov-08). Reinstall sucker rods.	
Working torque	[lbs*ft]	783	603	755
Objectives		Production increase	PCP behavior test	PCP behavior test

Table 5

Premium connection diameter	First assembly needed pressure [psi]		
	Average	Maximum	Minimum
1”	1026	1400	900
7/8”	872	1000	700
3/4”	775	850	700

Table 6

Sucker rod Diam.	Thread	Max. Load (Ton)	Max. Load (Lbs)	Smax (Ksi)	Min. Load (Ton)	Min. Load (Lbs)	Smin (Ksi)	% Goodman	Test cycles (Miles)	
3/4"	API	15	33069	75	5	11023	25.0	279.8	2960	Pin failure
		15	33069	75	5	11023	25.0		4870	Pin failure
	Premium	15	33069	75	5	11023	25.0	279.8	10000	
		16	35274	80	5	11023	25.0	308.0		
		17	37479	85	5	11023	25.0	336.0		
		18	38581	87	5	11023	25.0	350.0	1250	Rod body failure
7/8"	API	22	48502	81	5	11023	18.3	300.7	1400	Pin failure
		22	48502	81	5	11023	18.3	300.7	1271	Coupling failure
	Premium	16	35274	59	5	11023	18.3	194.6	10000	
		16.5	36376	60	5	11023	18.3	203.4		
		17	37479	62	5	11023	18.3	212.3		
		17.5	38581	64	5	11023	18.3	221.2		
		18	39683	66	5	11023	18.3	230.0		
		22	48502	81	5	11023	18.3	300.7		
		23	50706	84	5	11023	18.3	318.7		
		24	52911	88	5	11023	18.3	336.0		
1"	Premium	23	50706	65	5	11023	14.0	223.5	10000	
		25	55116	71	5	11023	14.0	247.8		
		27	59525	76	5	11023	14.0	262.3		
		28.5	62832	81	5	11023	14.0	280.5		

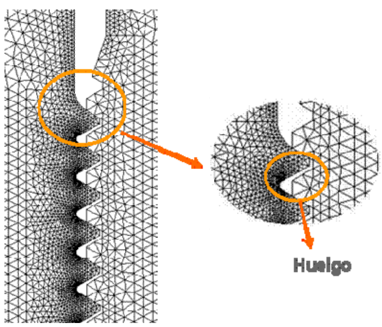
Note: In order to focus tests to the connection, reinforced rod bodies were used (7/8" rod body to test the 3/4" connection and 1 1/8" rod bodies for all other connection diameters). Tested material was Grade D with high strength couplings.

Table 7

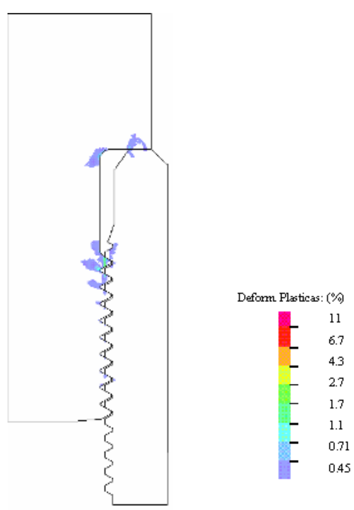
PE-01 background failures (1st stage)						
Year	Month	Failure	Ø	SR #	Grade	Observations
2004	1	coupling	7/8"	96	-	1" x 7/8" subcoupling failure
2004	7	Rod body	7/8"	3	-	
2004	12	pin	7/8"	18	HS	Inferior pin failure
2005	2	pin	7/8"	59	HS	Couplings changed for wear and corrosion
2005	3	Rod body	7/8"	15	HS	Failure at 2" from the pin.
2005	9	Rod body	7/8"	1	D	Failure at 2" from the pin.

Table 8

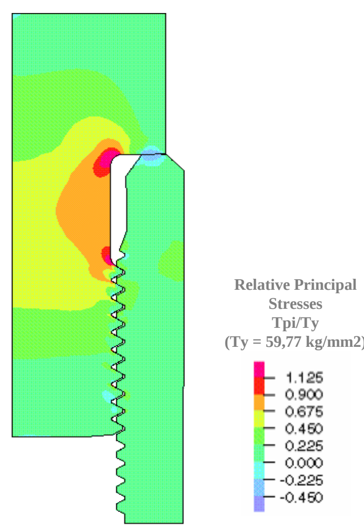
1st Stage	2nd Stage	
	Conventional Pumping Wells	PCP Wells
Conventional API Polished Rod 1” API polished rod Coupling 1” HS Sucker Rods 1” API x 7/8” PC 2’ Cross Over 7/8” PC Sucker Rods 7/8” PC x 7/8” API 2’ Cross Over 7/8” x 3/4” API Subcoupling 3/4” HS Sucker Rods 1½” Sinker Bars Conventional Pump	Conventional API Polished Rod 1” API polished rod x 1” PC Coupling 1” PC Sucker Rods 1” PC x 7/8” PC 2’ Cross Over 7/8” PC Sucker Rods 7/8” PC x 3/4” PC 2’ Cross Over 3/4” PC Sucker Rods 3/4” PC x 3/4” API 2’ Cross Over Sinker Bars Conventional Pump	Conventional API Polished Rod 1” API polished rod x 1” PC Coupling 1” PC Sucker Rods 1” PC x 1” API 2’ Cross Over 1” API Coupling Progressive Cavity Pump



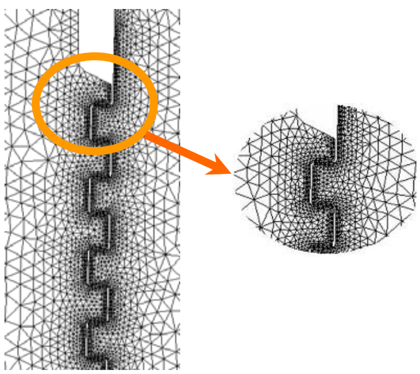
Gap Between Sucker Rod Pin And Coupling That Exists In API Design Connections



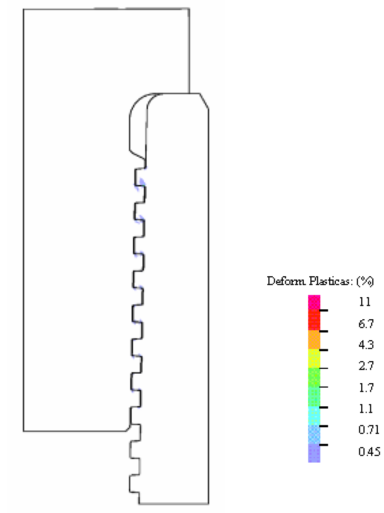
Permanent deformations at 100% of Goodman



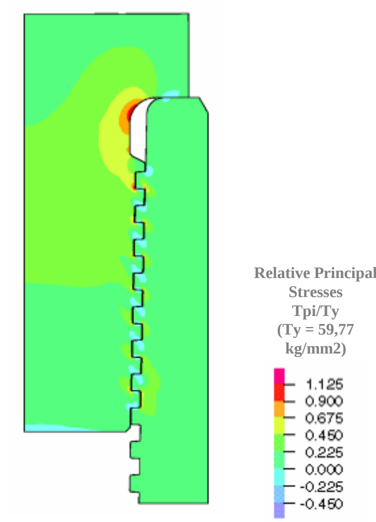
Relative Principal Stress distribution at 100% of Goodman



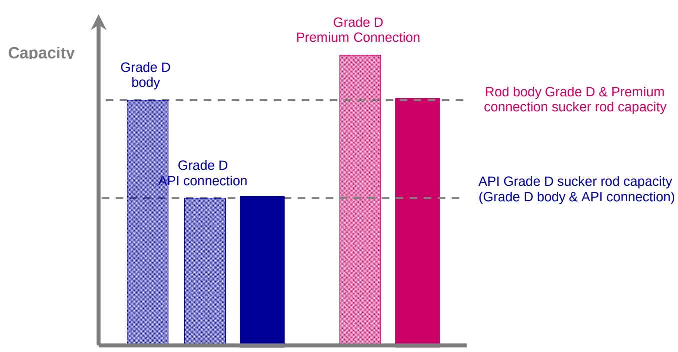
There is no gap between sucker rod pin and coupling threads



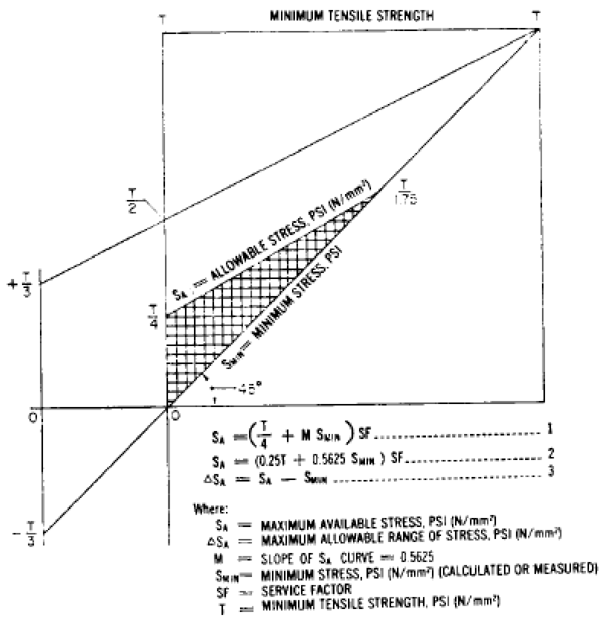
Permanent deformations at 100% of Goodman



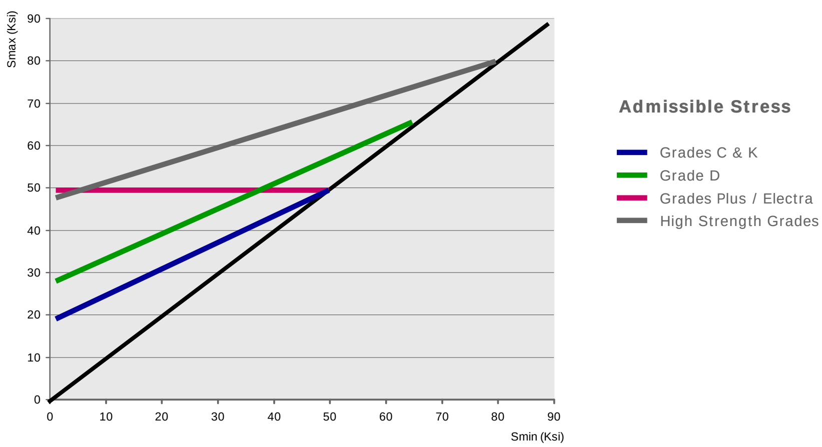
Relative Principal Stress distribution at 100% of Goodman



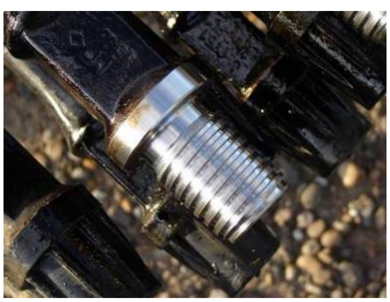
Working capacity comparison for Grade D rod body and connection



Modified Goodman Diagram for allowable stress and
range of stress for Grade D sucker Rods



Modified Goodman Diagram for allowable stress and range of stress for Sucker Rods



Cleaning operation


Dope application

Hand tight position

Faces contact verification