Some Factors Affecting Maximum Allowable Loadings on Sucker Rods

By BRUCE RAMAGE
Bethlehem Steel Co.

INTRODUCTION

Any man responsible for oil production should obtain a maximum amount of oil with a minimum amount of expensive down time. In pumping wells, the fact that maximum allowable loading of sucker rods is intimately connected with this responsibility makes it a subject of importance to us all.

This paper will not attempt to outline any specific method of arriving at a set of maximum allowable loadings for various grades of rods under various pumping conditions, rather it will discuss a few of the many factors which have an influence on maximum loadings. Because of these factors, the subject is a complex and sometimes controversial one. We hope that this discussion will awaken a realization of how much additional research remains to be done, both in the laboratory and in the field, to obtain quantitative values for these factors. It is encouraging to know that efforts in this direction are being continued, both by sucker rod manufacturers and by the oil industry, under the auspices of such groups as the API and NACE.

DEFINITION

It might be well to start by attempting to define maximum allowable loading of sucker rods. Basically, it is a loading which, if not exceeded, will result in failure-free service of the sucker rod string. But, for how long? Actually, the maximum allowable load is an endurance limit, but laboratory tests have proved that, in corrosive media, there is no endurance limit for steel. So, instead of an endurance limit, we have a maximum life expectancy which is extremely variable under different loads and/or corrosion.

Since loads and corrosive conditions will vary from well to well and from lease to lease, we find that the maximum life expectancy and, by association, the maximum allowable loading of a string of sucker rods is dependent primarily on individual well characteristics. A realistic interpretation would be a stress level which may be used without failure during a specific practical time interval, based on normal depreciation, life of well, etc. In the design and application of a sucker rod string, however, there must bé some datum level from which to start. Such figures are available from all sucker rod manufacturers and from some of the oil companies themselves.

As a matter of interest, some of these values are shown in Fig. 1. In most cases these values were

	CARBON (C-1036)			INTERMEDIATE ALLOYS			N. MO. (A4621)			HIGH TENSILE		
	Non-Cor.	Brine	H_2S Brine	Non-Cor.	Brine	H_2S Brine	Non-Cor.	Brine	H_2S Brine	Non-Cor.	Brine	H_2S Brine
Mfr. A	27000			27000			29000			45000		
Mfr. B	28000						30000			30000		
Mfr. C	30000			30000			30000			40000		
Mfr. D	28000						30000	24000	17000	40000	30000	20000
Mfr. E*	22000			30000			33000			43000		
Mfr. F	35000	22000	16500				35000	33500	22500			
Mfr. G	29000			35000			35000			40000		
Mfr. H	30000	21600					32500	32500				
Opr. A	27000	19800	15000	27000	24000	18000	29250	26000	19500	45000	40000	27000
Opr. B	30000			30000			30000			40000		
Opr. C	28000			33000						40000		
Opr. D	30000						30000					
Opr. E	20000			28000			33000			40000		
Opr. F		22000	16500		22000	16500		33000	23000			
AVERAGE	28000	21350	16000	30000	23000	17250	31400	29800	20500	40300	35000	23500

* Figures based on 20% load range.
If load range is 30 to 40%, use 75% of figures shown.
If load range is 90 to 100%, use 50% of figures shown.
For deep pumping with low ratio fluid load to rod load, use 100% of figures shown.
For fast high range loading, use 55% of figures shown.

No recommendations for corrosive service.

Fig. 1

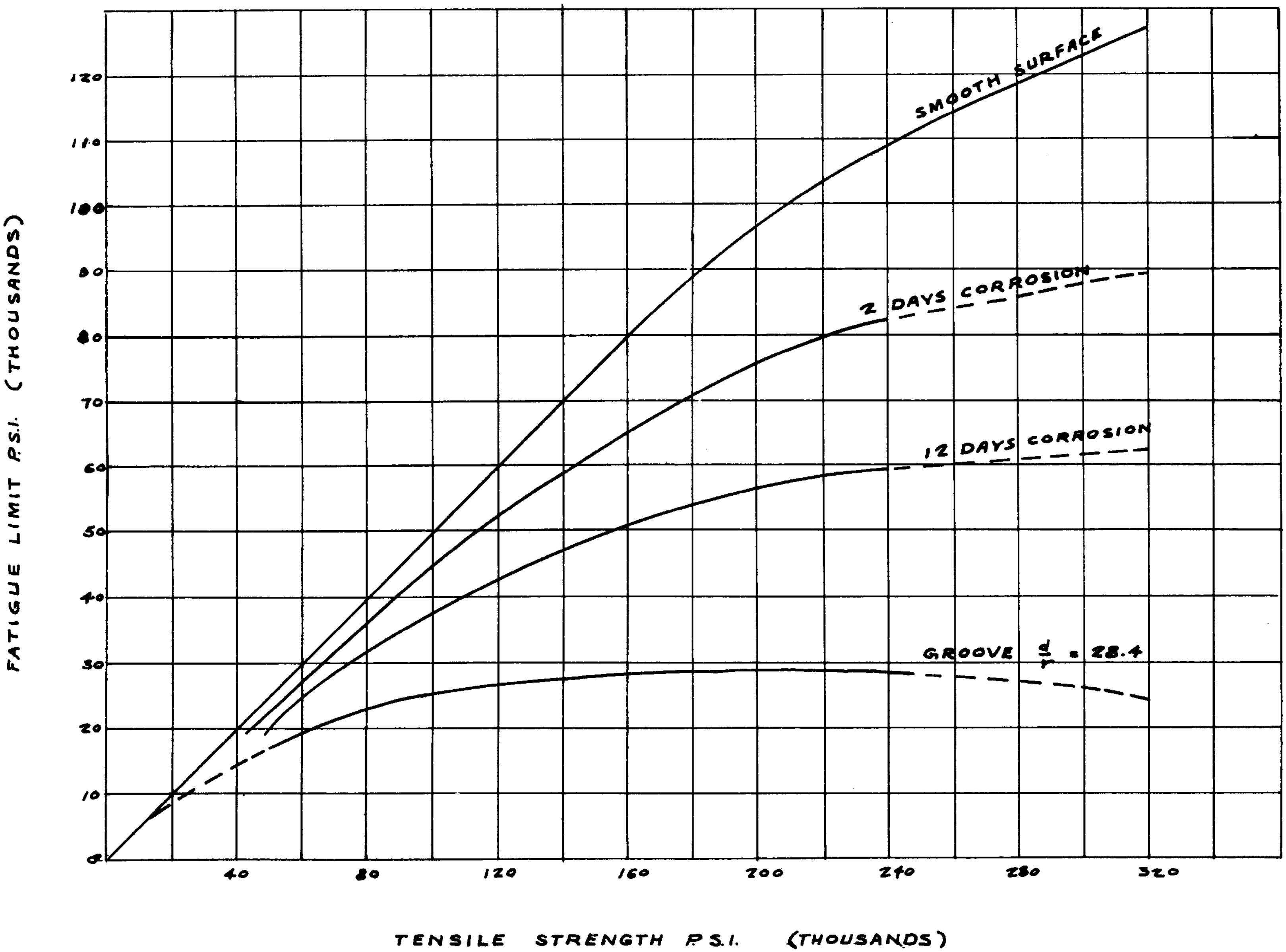

SMOOTH SURFACE
2 DAYS CORROSION
12 DAYS CORROSION
GROOVE $\frac{d}{r}$ = 28.4
120
110
100
90
80
70
60
50
40
30
20
10
0
40
80
120
160
200
240
280
320
FATIGUE LIMIT P.S.I. (THOUSANDS)
TENSILE STRENGTH P.S.I. (THOUSANDS)

FIG. 2

derived through experience, i.e., actual service records supplemented with dynamometer studies. Several are based on certain percentage of yield strength and several represent a composite figure averaged from all other available data. Some figures are now considered obsolete and several manufacturers are in the process of trying to develop new and more realistic values.

We will not discuss the relative merits of methods used in obtaining these load figures, because we suspect the lack of sufficient basic scientific data has, in all cases, fostered the inclusion of a considerable amount of what we will call "flying by the seat of one's pants".

Study Of Values

The study of the values in Fig. 1, however, reveals a certain conformity in spite of a few rather wide variations. For each grade of rod under each fluid condition, there is very little basic variation. It is also apparent that there are still very few people brave enough to predict the effects of corrosion. In fact, as revised figures become available, there will probably be fewer recommendations for loadings under corrosive conditions. But, at the present time, the figures do represent the most realistic datum level from which to start. These values are based on average pumping conditions and must be reduced, or in some cases increased, as experience dictates.

All steels have an air endurance limit which is normally found to be about half the ultimate strength of the steel. This figure reflects a loading in air under which a steel will withstand an indefinite number of stress reversals without failure. Air endurance limits are normally obtained on highly polished laboratory specimens in what is known as a rotating beam test. These test specimens must be carefully ground and highly polished in order to remove all traces of scratches or other surface irregularities. Any such scratches or surface irregularities will result in a reduced air endurance value.

Thus, it follows that the surface condition of the sucker rods is important. If it is not as free of irregularities, scale pits, etc., as is economically possible, service life will be affected and maximum allowable loading will be reduced. The effect of notches in all kinds of steel has long been acknowledged to be a major factor in fatigue fractures. The magnitude of the effect produced is dependent upon the size, depth and shape of the notch, and also on the notch sensitivity of the steel. In general, notch sensitivity increases with tensile strength. Corrosion seems to produce a distinctly destructive type of notch.

SURFACE CONDITION OF RODS

Fig. 2[2] illustrates the comparison between fatigue limit and tensile strength in polished specimens of steel and samples which have been roughened by corrosion and those which have been severely notched. In discussing the effect of notches, it should be remembered that the endurance strength of the metal is not altered by the notch, although the endurance strength of the piece as a whole is tremendously altered. The notch increases the local stress beyond the endurance strength, although the nominal calculated stress for the cross section at the base of the notch is far below it.[3]

Photoelastic studies have shown that a sharp bottomed notch, such as a corrosion pit, can increase the stresses at the base of a notch to several times the stress level to which the overall section is subjected. For example, a threaded section with a thread root radius of 0.017 inches has been found to result in a stress concentration factor of between 4 and 5.[4] This means that a similar pit or notch in an A4620 nickel molybdenum sucker rod, with an ultimate strength of 90,000 psi, operating at a stress of 30,000 psi, would have a stress concentration at the base of the notch, or pit, of from 120,000 psi to 150,000 psi, or from 30,000 to 60,000 psi beyond the ultimate strength of the steel. Under such conditions a fatigue fracture is inevitable. It is obvious that for any degree of satisfactory service in this example, the maximum loading would have to be kept from 1/4 to 1/5 of the ultimate, or from 22,500 to 18,000 psi.

Fortunately, new sucker rods should be quite free of any surface irregularities. Practically all rod manufacturers now shot blast their rods after heat treatment. This effectively removes all mill and heat treatment scale, thus leaving a clean surface which makes it much easier for inspectors to detect any irregularities which may have developed in the surface during rolling and subsequent manufacture. Proper handling of the rods in the field will prevent any mechanically formed notches from being introduced before the rods are run into the well. This is a factor which can be controlled.

Corrosion Factor

After the rods are run in the well, the corrosion factor appears. There is no such thing as a completely non-corrosive oil well, even though the rate of corrosion in many is low enough for them to be classified as such. The rate of corrosion controls the rate of pit propagation. When pits are formed, the notch effect becomes a critical factor, and, once again, maximum allowable loadings will be affected. Now, instead of plain fatigue being the factor in rod failures, we have what is referred to as corrosion fatigue.

How much shall we reduce the maximum allowable loadings to compensate for the corrosion factor? As we shall see, there is no pat answer to this question. A considerable amount of laboratory work was done some years ago, under simulated corrosive conditions most commonly found in oil wells, in an effort to obtain a so-called corrosion fatigue value which could be used as a recommended maximum allowable loading. As a result of these tests, certain values were published by various manufacturers as corrosion fatigue endurance limits for the common grades of sucker rod steels under salt water and hydrogen sulphide brine conditions.

In 1945, the API tentatively adopted Code 30 for corrosion fatigue testing of sucker rod materials which had been formulated by the Topical Committee on Materials of the Central Committee on Drilling & Production Practices. Its purpose was "to provide uniformity in the method of obtaining data on the behavior of sucker rod steels under repeated stress in specific corrosive solutions".[5] Subsequent tests performed, according to Code 30, showed that some of the figures published from earlier tests did not conform and it was found to be almost impossible to duplicate results from one test to another. In 1948, API Code 30 was withdrawn and in 1950 the Committee on Materials was disbanded with the following comment:

"It became evident that the corrosion fatigue testing of sucker rods has been misunderstood by many. It was never intended to furnish stress values that may be safely imposed upon sucker rods in service. The tests furnish only relative information indicating that one material is better than another. The endurance limit of steel varies with every corrosive environment and the so-called corrosion fatigue strengths that have been published have often been misused. Some think emphasis should be placed on field tests of sucker rods instead of laboratory tests. It is becoming more generally recognized that improvements in corrosion resistance of sucker rod material afford only a partial solution to subsurface corrosion, and that down-the-hole treatments offer greater potentialities which may eliminate the need for special sucker rod alloys except for high mechanical strength in deep pumping wells".[6]

Further study was referred to the Standardization Committee on Sucker Rods who in turn enlisted the aid of the NACE. Studies have continued to date in both groups with action confined mainly to controlled field testing. However, the value of continued laboratory testing, coupled with follow-up field testing, has been emphasized by the work initiated by Dr. F. M. Radd and now being conducted by R. L. McGlasson, Continental Oil Company research department.

So far testing, both laboratory and field, by both groups, seems to be aimed primarily toward improvement of sucker rod steels and toward the most economic choice of grades of steel, with little emphasis being placed on maximum allowable loadings.

We know the corrosion factor has a serious effect on maximum allowable loadings, and as the rate of corrosion increases, the maximum loading must be decreased. However, we can see that in spite of all the years of testing, it still has no quantitative value.

Chemical Inhibitors

Developments over the past 15 years in chemical inhibitors have, in many cases, simplified the problem to some extent. Establishment of a maximum loading figure is influenced by whether or not inhibition is economical and effective and, if so, what percent retardation of corrosion is obtained. In any case, we must agree that the decision has to be made on the basis of each individual well and can be reached only through experience.

Sucker rods are currently available in four basic classes of steel; carbon (C1036), intermediate alloys (low nickel and chromium), nickel molybdenum (A4621) and the so-called high tensile steels. Can the maximum allowable loading be increased by going to a higher alloy steel or to a higher strength steel? In non-corrosive service, there is no doubt that the higher strength of the steel will permit higher maximum loading. Under corrosive conditions, the picture is not so clear.

It has been generally conceded that nickel addition to steel improves its resistance to corrosion and therefore should permit higher loadings. In some cases, this is true. The proved superior service of 9% nickel sucker rods and those of Monel in untreated sour wells would indicate higher permissible loadings, but their high initial cost usually makes their use uneconomical.

In sweet corrosive wells (high carbon dioxide content), both inhibited and uninhibited, the intermediate alloy rods have generally proved to be superior, under comparable loadings, to carbon steels and the higher alloy steels alike.

In untreated sour wells, alternate string testing, which allows comparison of various grades of rods under comparable loadings and operating conditions, has shown that intermediate alloys and A4621 steels (1.75% nickel) operate equally as well as 3-1/2% nickel steels, and all three were better than the C1036 carbon steel rods. Without inhibition, however, none of them performs satisfactorily under any appreciable degree of loading.

In sour wells treated with corrosion inhibitors, alternate string testing has shown a definite indication of comparable service from both carbon and alloy steels. Consequently, it would appear that the effect of the carbon versus alloy factor on maximum loadings in corrosive service has been fairly effectively nullified by the use of chemical inhibitors.

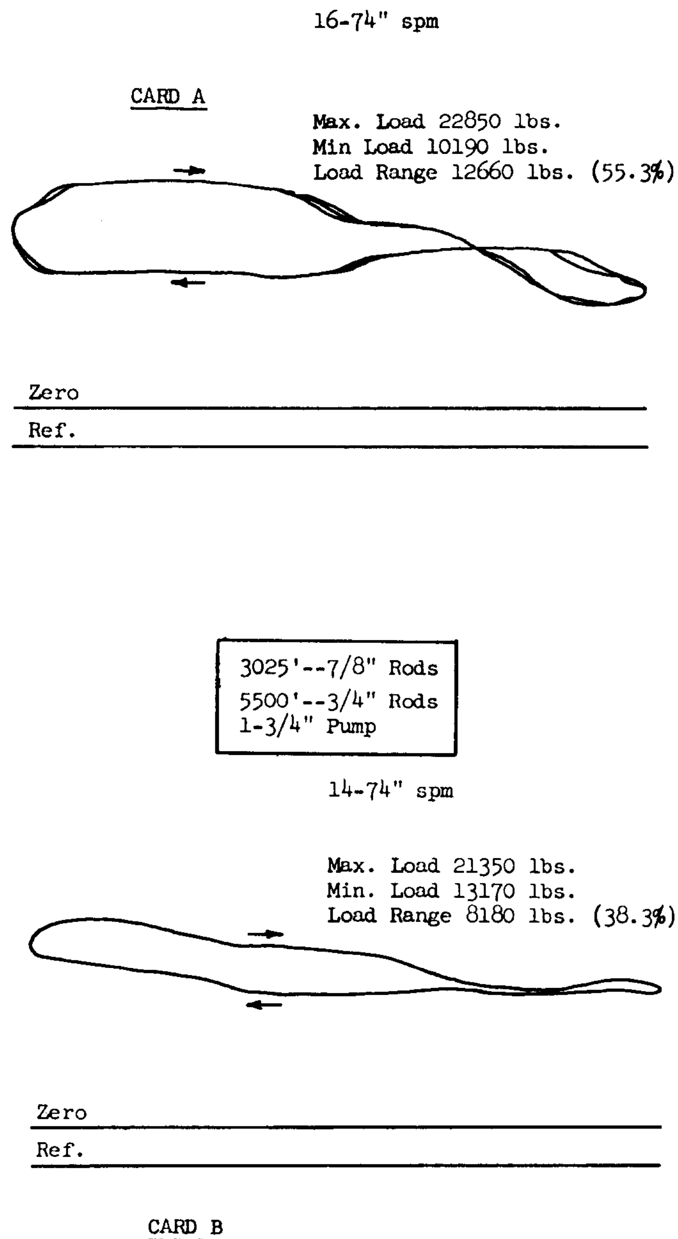


Fig. 3

The use of high tensile rods in corrosive service, in order to obtain higher allowable loadings, is open to question. There are not enough controlled field test reports available as yet to support theory on this subject. One 27-1/2 month alternate string test in an untreated sour well in western Kansas, between low alloy high tensile rods and carbon steel rods at 31,670 psi maximum stress, resulted in no high tensile failures as against 11 carbon rod failures. In general, however, one should be cautious about the application of high tensile rods in corrosive service. As already mentioned, it is an established metallurgical fact that, as the tensile strength of steel increases, so does its notch sensitivity. Consequently, any corrosion pits in a high tensile steel will form much more serious stress raisers than they would in a steel of lower strength.

It is hoped that a few more years of effort on alternate string testing will produce enough data to allow some correlation of service versus maximum loadings.

RANGE OF LOAD

Another important factor influencing maximum allowable loading is range of load, or the difference between maximum and minimum loads. This is usually expressed as a percent of the maximum load. (See paper presented by Mr. A. A. Hardy of W. C. Norris Mfrs., Inc.)

The effect of range of load has been outlined by Goodman.[7] To put it simply, his laboratory tests showed that, as maximum stress increases, range of stress must be decreased in order for steel to undergo the same number of stress reversals without failure. In actual sucker rod service, this same theory should apply, and it does - to the extent that it is not influenced by other factors.

Unfortunately, it is difficult to present concrete examples to prove this point. Any steps taken to reduce range of load in a well will usually result automatically in a reduction of maximum load and, very often, an improvement in other factors detrimental to sucker rod service life. However, one fairly good example of the effects of reduced load range is shown in Fig. 3. A reduction in pumping speed of only 2 spm reduced the load range by 35% while reducing maximum stress only 4% - from 38,000 psi to 36,500 psi. This well experienced 16 failures in new rods in 4 months while operating at 16 strokes per minute. After installation of another new rod string, the well was slowed to 14 spm and has operated for 5 months to date with no failures.

As previously mentioned, reduction of range of load sometimes improves other operating conditions. Fig. 4 illustrates this point on a well pumping from 8950 feet with a 7/8 inch and 3/4 inch tapered string of intermediate alloy rods. Dynamometer Card A reflects initial pumping speed of 12.5 spm. Rods operated satisfactorily for 7 months and then experienced 4 body failures in the next 5-1/2 months. Slowing the pumping speed to 7 spm resulted in Card B. This represents a reduction of load range of 15% and a reduction of peak load of 2.5%. The same rod string, while still considered to be overloaded, has operated at 7 spm for 4-1/2 months to date with only one body failure. In this case, however, the attempt to reduce load range also eliminated a fluid pound which probably contributed equally as much in improving the sucker rod service.

Dynamometer Studies

Dynamometer studies are essential in any effort to determine a correct maximum allowable loading for a well, simply because there is no other way to accurately measure the peak loads. However, attention to peak loads and a dynamometer card interpretation, without consideration of all other factors, can be very misleading, as illustrated in Fig. 5, which shows cards taken on two similar wells in the same field. Well A was pumping at 18-74 inch spm from 5260 feet with 3/4 inch rods and a 1-3/4 inch pump. Maximum stress was 35,000 psi with a load range of 79.3%. Well B was pumping at 18-1/2 - 74 inch spm from the same

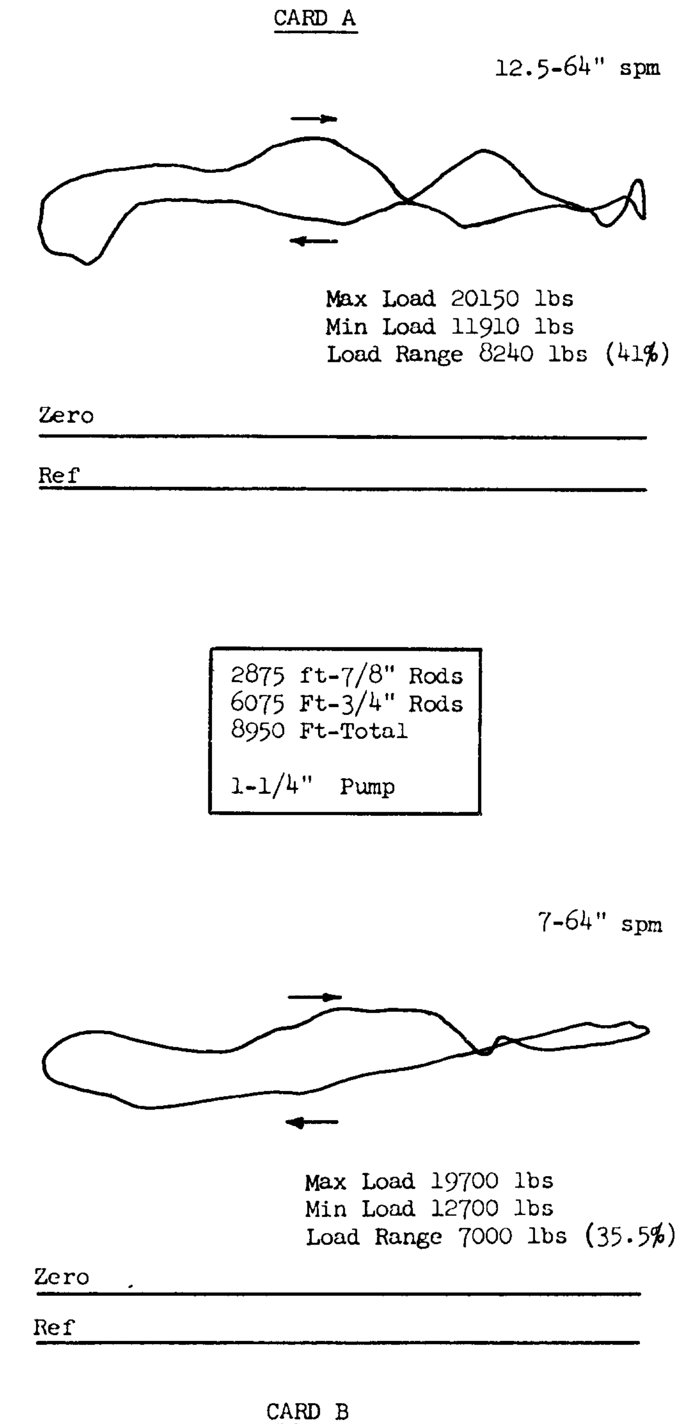
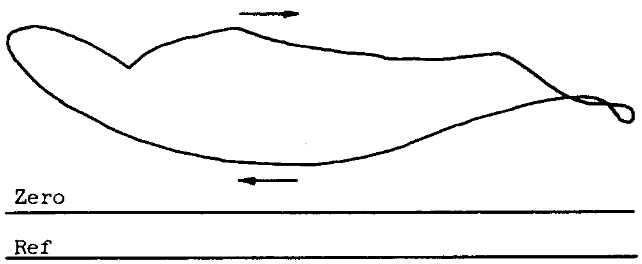


Fig. 4

18-74" spm
3/4" Rods
5260 ft
1-3/4" Pump

Max Load 15490 lbs
Min Load 3200 lbs
Load Range 12290 lbs

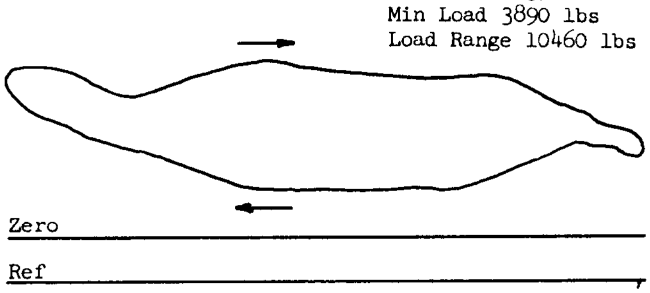


WELL A

Max Stress 35000 psi
Load Range 79.3%

18.5-74" spm
3/4" Rods
5282 ft
1-3/4" Pump

Max Load 14350 lbs
Min Load 3890 lbs
Load Range 10460 lbs



WELL B

Max Stress 32500 psi
Load Range 72.9%

Fig. 5

formation with 5282 feet of 3/4 inch rods and a 1-3/4 inch pump. Maximum stress here was 32,500 psi and load range was 72.9%. From a study of maximum loads and load ranges, if any troubles existed, one would expect them to be in Well A. Yet Well A had operated for 5 years with only one body failure and Well B had experienced five body failures in 4-1/2 years of service.

It would appear that here we have evidence contrary to all established theory. However, the answer lies in one important difference between the two wells which is not reflected in the dynamometer cards. Both wells produce large volumes of water and bottom hole pumps in both wells are set approximately 3,000 feet off bottom. Well A has a tail pipe set to bottom, but the tubing perforations are right under the pump. Well B also has a tail pipe set to bottom, but in this well the tubing perforations are at the bottom of the tail pipe. Scale falling off the inside of the casing in Well A falls harmlessly to bottom whereas in Well B it is drawn in through the tubing perforations at the bottom of the tail pipe and must pass through the bottom hole pump. Occasionally, the scale will cause the pump to hang up and when that occurs, the rod string is subjected to a terrifically high shock load, which in some cases is enough to cause an immediate failure.

We have used this last example to illustrate the importance of factors, other than those we have mentioned here, which can influence the life of sucker rods. The list of poor operating practices is too long to enumerate, but we want to emphasize that without good operating practices, all the reasoning and theory applied to the determination of a correct maximum allowable loading will be to no avail. And we also want to emphasize that no one factor can be considered alone, for they are all closely interrelated.

CONCLUSION

We have discussed a few of the factors which we know are influential in controlling maximum allowable loading and, while figures for maximum loading are available as shown in Fig. 1, we hope we have been able to convey the thought that these figures are not the final answer and cannot be used blindly and with an implicit faith that they will solve all problems. We have pointed out that much work remains to be done before quantitative values can be assigned to these various factors. In view of this, the answer to a safe maximum allowable loading on a sucker rod string lies in your own experience with your own individual wells.

REFERENCES

1 H. F. Moore. "Corrosion Fatigue of Metals", ASM Metals Handbook, 1939, Page 147.
2 D. J. McAdam, Jr. & R. W. Clyne, "Influence of Chemically and Mechanically Formed Notches on Fatigue of Metals", Bur. Stand. J. Research, Vol. 13, 1934, Pages 527 to 572.
3 Battelle Memorial Institute. "Prevention of Failure of Metals Under Repeated Stress", Page 5.
4 W. F. Franz. "A Three Dimensional Photoelastic Stress Analysis of a Threaded Drill Pipe Joint", Pet. Engr. Feb., 1951.
5 API Code 30, April, 1945, Page 3.
6 API Standardization Bulletin No. 110, 1950, Page 898-19.
7 ASTM Fatigue Research Committee, "Summary of Present Day Knowledge of Fatigue Phenomena in Metals", ASTM Proc., Vol. 30, 1930.