Correcting Sucker Rod Troubles As Seen By A Manufacturer

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When a bridge falls down or any structural steel building or fabrication fails under load, criticism is strictly confined to the person or persons responsible for the design of the structure and never to the mill that rolled the steel. This is true and justified because steel as it is turned out today by our big steel mills is of very closely controlled quality. As a result steel has become one of our most exact engineering materials whose mechanical properties are reproducible within very close limits. The American Iron and Steel Institute is largely responsible for the specifications and control which give us this high quality and the mills themselves for the rigorous manner in which they adhere to these standards.

When a string of sucker rods fail, conversely, the comment most frequently heard is that "they must have been rolled from a bad heat of steel;" this in face of the fact that sucker rod steel is rolled under far more restrictive requirements than ordinary structural steel. Following is a typical specification clause taken from an order, placed on a mill for sucker rod steel.

"150 tons (Product of one heat) 3/4" Round x 26' 2" long AI&SI C-1036 open hearth kilned steel, hot rolled carbon bars, restrictive requirement B, "special surface (free of surface imperfections, including cracks, slivers, seams, rolled-in scale, etc.), fine grain, commercially straight (may have a maximum deviation from a straight line of not more than 1/4" in any five feet."

In addition to the specification as shown above, our first operation after receiving the steel is to inspect it and further straighten it to within 1/32" maximum deviation from a straight line in any five feet. Further, as the rods progress through the various manufacturing operations, each operator, in addition to the regular corps of inspectors, is trained to keep an eagle's eye open for defects of any nature. In fact, I have seen inspectors and operators find defects which were difficult to see even under a strong light without the aid of a microscope.

As far as heat treatment at the sucker rod manufacturer's plant is concerned, there was a time when only the forged end of the rod was normalized, leaving the body in the "as rolled" condition. This resulted in a transition zone between the heat treated end and the body where the heat ran out, in a condition that was highly susceptible to corrosion. Subsequent failure at this point, characterized by a band of pits called "ring worm corrosion," caused many rod breaks. Moreover, the optimum qualities of the body could not be developed due to lack of heat treatment. Today, all manufacturers heat treat the whole rod in a full length heat treating furnace, thus eliminating the coarse grained transition zone with its attendant failures, and in addition taking advantage of the chemistry of the steel to develop optimum mechanical and corrosion resistant properties. All manufacturers control the heat of their furnaces with accurate indicating and recording instruments, thereby maintaining positive pen and ink records of temperatures during the complete cycle. The correct heat cycles are determined, not by the mechanical and chemical reports on the steel given to the manufacturer by the steel mill, but by complete tests by the manufacturer himself on each separate heat when it is received from the mill.

Thus all the loving care that can be given a heat of steel that ends up as sucker rods in someone's well, is given by the mill and by the manufacturer, and the operator gets the highest quality steel in his rods that modern industry can produce. The charge that any particular heat of steel is a "bad heat" by a long string of disastrous coincidences could be technically plausible, but practically, as in the case of the bridge that fell down, would be entirely unjustified. Except in very rare cases, all sucker rod failures stem from poor handling practice in transportation, in running or in pulling, from poor operating practice, from poor string design, or in very rare instances, from very recognizable manufacturing defects. Because of this we hear a great deal, these days, about the "care and use of sucker rods." A lot of it sounds rather difficult and costly and some of it sounds downright silly and unnecessary. A review of the fundamentals involved, so that a thorough understanding of the reasons and necessity for the seemingly extreme care will be very helpful and enlightening.

Ninety-nine percent of our sucker rod failures are caused by so-called "fatigue" breaks. This term "fatigue" is an unfortunate one, because metal does not become tired as the word implies, nor does it crystallize or change its crystalline structure on repeated stress. This latter idea is a very popular misconception. This type of failure is nothing more nor less than ordinary plastic tensile failure, due to repeated stresses, which starts at some small local spot on the surface and progresses rather slowly at first across the rod at right angles to the direction of stress, and is almost invariably attended with bending and corrosion. The question then becomes: "What caused that spot on the surface which failed initially to become stressed beyond its tensile strength?" The answer always is, high repeated load cycles augmented by bending, accompanied by a small pit, scratch or imperfection at right angles to the direction of stress which prevents that particular part of the cross section from carrying its proportional part of the load.

This is illustrated in figure one. The load it should carry is then transferred to the adjacent metal, again causing overload and tensile failure there. In this manner the failure progresses across the section at right angles to the direction of stress until the remaining metal is all overloaded and fails simultaneously as a simple tensile break, thus leaving a ragged tear 180 degrees from the start of the break. Surface imperfections such as the one which started the failure described above are called "stress-raisers" and can be microscopically small, particularly when the rod is subjected to bending. Bending, of course, stretches the metal on the outside or convex surface of the rod thus causing high local stresses at that point, which together with even a small pit or scratch, can very easily initiate the action described above.

Such is the nature of "fatigue failure" which is simply ordinary plastic tensile failure at a small isolated point starting at the surface and progressing under repeated loads. From this we can understand why corrosion pits or scratches caused by mishandling can be so serious, even tho they appear to be inconsequential in nature, and why they should be avoided.

It should be pointed out that "fatigue failures" are not peculiar to sucker rods but do occasionally occur in most any mechanical part subjected to repeated stress. However, in most such cases, the part in question can be so designed by adding additional metal, that stress can be held to a level sufficiently low to prevent spots on the surface, even attended by imperfections, from exceeding their tensile strength. In the case of sucker rods, the space in the tubing is so small that the addition of more metal such as by using larger rods, becomes uneconomical and impracticable.

There is another phenomenon in this connection which is worthy of note. It is the so called "fatigue endurance life" of metal. We prepare a specimen in the laboratory, being careful to polish out all imperfections, and subject it to repeated reverse bending at various stress levels. It is found that metals and alloys possess a certain stress level, usually about one half of its ultimate strength in the case of steel, below which it will not fail even if subjected to an infinitely large number of cycles of stress under non-corrosive conditions. If subjected to a higher stress, it will fail after a finite number of cycles. This is illustrated in figure two. This critical stress level is called the "endurance limit" of the particular steel in question. However, if the test is run in a corrosive environment we will not find a similar critical stress level which will result in non-failure. The fatigue endurance life must then be given at a specified number of reversals and, furthermore, should also include the time element as corrosion will proceed towards failure, with time, even at zero stress.

An A.P.I. committee drew up Code 30 several years ago which prescribed definite procedures for determining fatigue endurance life of sucker rod steels in the laboratory under controlled conditions. This was an attempt to correlate laboratory tests with field performance of various steels and thus evaluate them for different field conditions. No correlation was found because pits, scratches and imperfections were meticulously removed from the specimens, while the actual hot rolled rods used in the field must necessarily have a few even though great care is taken in manufacture, transportation and use. Hence code 30 was abandoned. This was not done, however, before most of the manufacturers made use of these laboratory results upon which to base recommended loads for field operation under varying degrees of load and corrosive environment. These load recommendations have been carried in sucker rod literature in many cases to the present day. This is most unfortunate, for the actual load carrying capacity of any grade of rod in any particular type of environment can only be determined accurately by field tets and experience under that particular set of conditions; thus such recommended loads should be used with great caution.

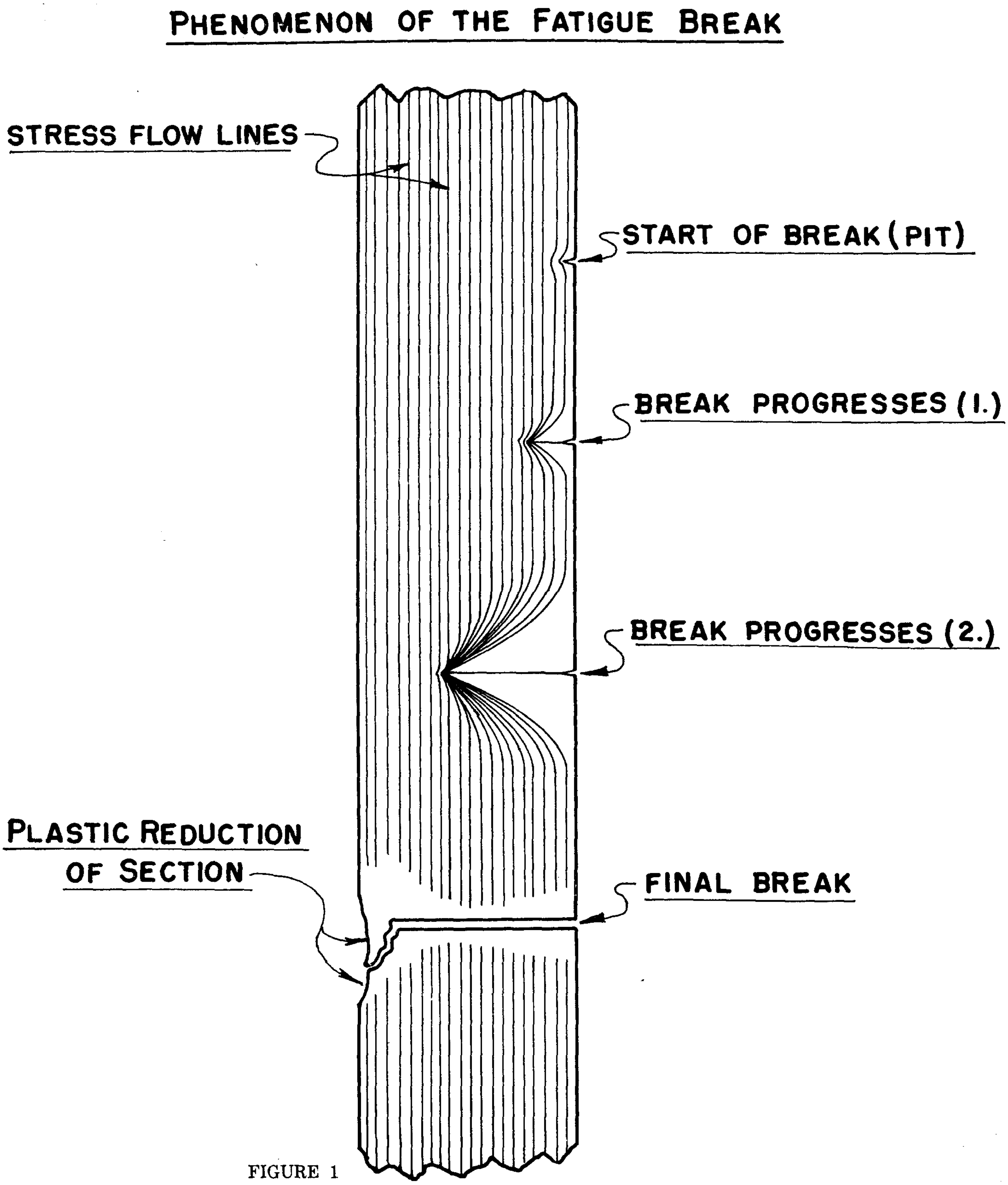
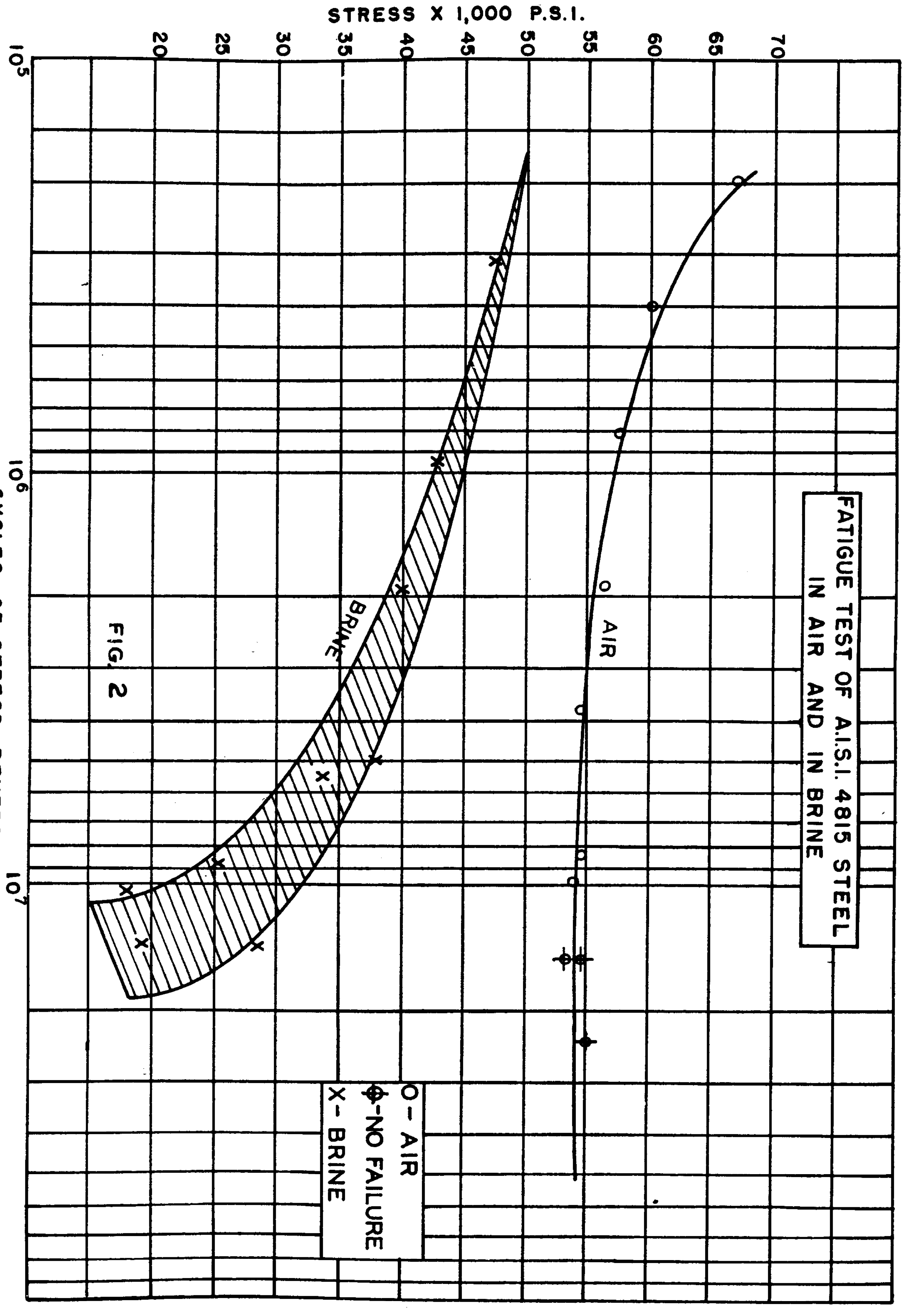


FIGURE 1


FATIGUE TEST OF A.I.S.I. 4815 STEEL
IN AIR AND IN BRINE
STRESS X 1,000 P.S.I.
20
25
30
35
40
45
50
55
60
65
70
10^5
10^6
10^7
CYCLES OF STRESS REVERSALS
AIR
BRINE
FIG. 2
O - AIR
⊕-NO FAILURE
X - BRINE

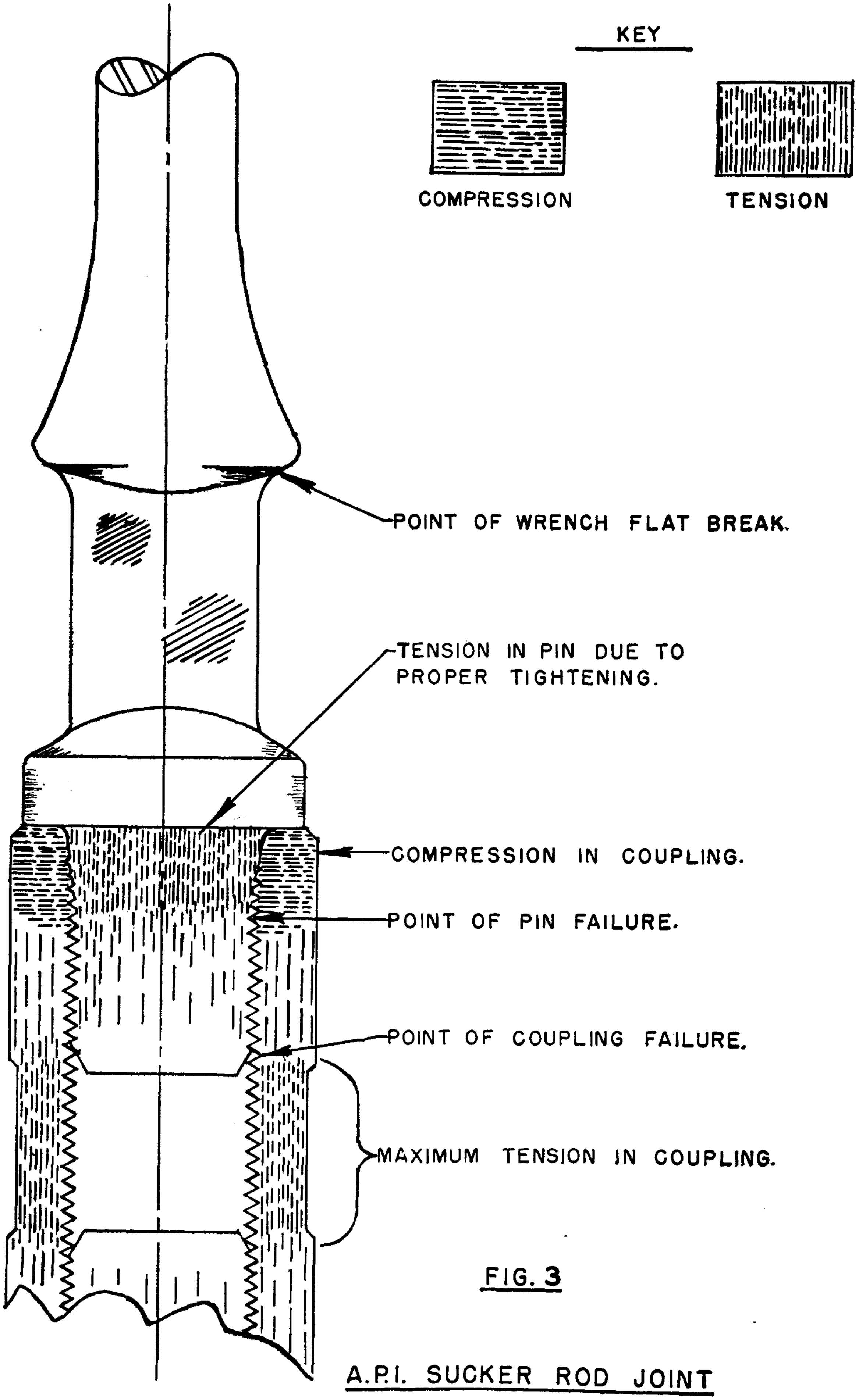


FIG. 3

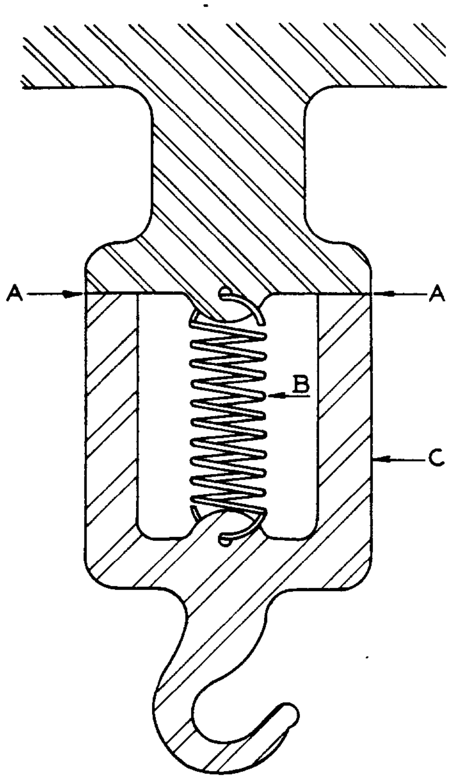
A.P.I. SUCKER ROD JOINT

In light of the above knowledge, let us review the four principal types of sucker rod failures; body breaks, wrench flat breaks, pin breaks and coupling breaks. See figure three.

The body of the rod is, structurally the weakest part of the string and therefore, all failures should occur here if the rods have been handled properly to avoid nicks, if the joints have been properly tightened, if the forger has avoided folds in the upset which we will cover later, if the string has been properly designed, loaded and operated, and if the rods meet A.P.I. specifications. Moreover, the eventual failure, if one occurs should occur just under the upset, two to three inches under the bead. This latter position is most vulnerable even in a perfect rod because the cross section of the rods string varies. Being not uniform and subjected to slight bending stresses even with the best design and operation, these bending stresses will be concentrated at points of local stiffness which occur at the rod joints. The rod thus acts as a continuously loaded beam with supports at the joints. Maximum bending moment and consequently maximum stress therefore occurs adjacent to these supports or joints, which falls just two or three inches from the bead. Therefore, if the break occurs at some other point in the rod body, it must have been caused by an imperfection, by a scratch, or by concentrated corrosion which acted as a stress raiser, thus raising the stress level at that point to a value sufficiently above normal to effect the break.

Wrench flat breaks, meaning those breaks which occur in the upset portion of the rod exclusive of the pin, can be dealt with very shortly. This portion of the rod is of appreciably greater metal cross-sectional area than the balance of the rod and should never fail. If it does fail, and failures do occasionally occur, the cause can be invariably traced to a fold in the forging or an improperly placed die stamp. Such failures are, of course, manufacturing defects and should be treated as such. Fortunately, they are very rare.

Pin breaks, too, are fatigue failures originating at stress raisers and initiated by bending. The stress raisers are the notches made by the threads and we can do very little to eliminate them. However, we can limit the range of stress reversals which will off-set the effect of these stress raisers very satisfactorily. The bending occurs when the shoulder face and the coupling face separates under load and we can do something about that by tightening the joint properly. All this is illustrated in figure four. Assume spring "B" to be exerting a pull of ten pounds in the assembly. There will then be a re-acting pressure of ten pounds at the contact faces "A." Now, if we hang a load of six pounds on the hook, pressure at "A" will be reduced to four pounds, hence the faces must still be in contact. If the faces are still in contact, there has been no change in the length of the spring, and no change in the length



SPRING ANALOGUE

FIG. 4

of the spring means no change in stress or pull of the spring. Therefore as long as the load hung on the hook is less than the pull exerted by the spring, there will be no change in stress in the spring, nor will it be subjected to bending. When the load does exceed the spring's initial pull, the faces separate and not only is all the load carried directly by the spring, but having no support at the contact faces, it is also subjected to bending. The spring "B" is, of course, analogous to that part of the sucker rod pin which lies between its shoulder and the last full thread. The body "C" is analogous to the corresponding part of the coupling, and the initial load in spring "B" to the initial load set up in the pin by proper tightening of the joint. For those interested in delving further into this question, a rigorous mathematical analysis of these stresses is contained in a paper titled 'Sucker Rod Joint Failures" reproduced in the A.P.I. "Drilling and Production Practice" 1952. The above analogy, of course, as here given is simplified and incomplete, but it does serve to illustrate the high importance of tightening the joint so that a sufficient preload is induced in the pin to prevent the contact faces from separating under load. If this is not done, the pin, which is necessarily notched by the threads, will not only be subjected to a high range of stress but will also be subjected to bending. This will be invariably disastrous if any appreciable load is carried by the rod string. Following are the recommended torques to be applied to the various sizes of sucker rods. They are based on generating a load at the contact faces which will be higher than any load to which the string might be subjected.

5/8" rods: 213 ft-lb
3/4" rods: 340 ft-lb
7/8" rods: 512 ft-lb
1" rods: 770 ft-lb

In terms of weight or force at the end of a 3-foot arm, this would be:

5/8" rods: 71 lb
3/4" rods: 113 lb
7/8" rods: 171 lb
1" rods: 257 lb

From the figures above we can see that it takes quite a bit of push even at the end of a three foot cheater to tighten rods sufficiently. Where broken pins are giving trouble, it will pay big dividends to take a little care and follow this recommendation.

Coupling failures, too, are fatigue failures originating at stress raisers although they are not usually initiated by bending. The stress raisers, again, are the notches resulting from the necessary threads, if the break starts on the inside, as is most frequently the case. If the break starts on the outside it originates in cracks in the hardened outer skin resulting from hammer blows liberally dealt in pulling the rods. Coupling breaks starting from the inside are far more prevalent than the average person realizes and are a result of the notch, together with corrosion pitting from fluid that seeps into the joint. Such failures are fairly easy to distinguish as they will have the usual half moon stain that is characteristic of all fatigue breaks with the concave side facing toward the center of the coupling and in addition will also have several small radial rays or cleavage lines radiating from the center in the area where the break started. On the other hand, breaks which start from the outside of the coupling will have the half moon stain but it will be convex to the center and the surface of the break near the threads will be smooth and will not have the radial cleavage lines. Obviously, the remedy for breaks starting on the outside from a hardened case cracked by a hammer blow, is to put away the hammers and use cheaters in the pulling operation. This may be laborious and time consuming but it will certainly pay big dividends if the trouble stems from this cause. Correcting breaks originating from the inside is not so simple, for here we cannot limit the range of stress as we did in the case of the pin. Three possible methods to help the situation do present themselves, however. We can increase the metal area, the tubing permitting, thus decreasing the magnitude of the stress; we can use an inhibitor type grease inside the coupling to reduce the pitting or notch effect of corrosion, thus increasing the corrosion fatigue life of the metal; or we can round the roots of the threads in the coupling as we do on the pins, thus reducing the notch effect and consequent fatigue vulnerability. The second, that of using an inhibitor type grease, is the most practical and has been used with success. The other two suggestions are more difficult and would require a change in the A.P.I. specification.

With an understanding of the above

principles, rules for the care and use of sucker rods can be greatly simplified as follows:

1. Protect the surface from nicks and pits in transportation, storage, handling and operation by use of great care, paint and inhibitor.

2. Don't bend the rods permanently in handling or by flexing in service.

3. Don't over stress in service. Design strings carefully and remember the effect of corrosion. Don't allow the well to pound.

4. Tighten joints with proper torque, don't hammer couplings and use a corrosion inhibitor type grease inside them.

5. In analyzing breaks, don't assume that the heat of steel from which the rods were made was a "bad heat." That just doesn't happen in this day and age. Look for the real cause, in a rational and logical manner, applying the fundamental knowledge given above and thus correct the difficulty before further damage is done.