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THE EFFECT OF TEMPERATURE AND MECHANICAL
PROPERTIES ON FARM FENCE PERFORMANCE

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY

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1958

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ABSTRACT

The objectives of this investigation were: (1) to test the mechanical properties of wire from woven wire fence with special consideration for the tension curve, (2) to determine an accurate and suitable method for measuring the load in the individual wires of a fence, (3) to determine magnitudes of load changes due to temperature variation.

A review of literature was made. It was found that the load in fence may be increased by as much as 50 per cent due to temperature variation. Much of this load increase was due to the barbed wires which have no tension curves. It was also found that tension curves are not nearly elastic as they are thought to be.

The investigation on the mechanical properties was conducted in the Materials Testing Laboratory of the Applied Mechanics Department. Tension curves were the main object of interest. The specimens used in the tests were 16 inches in length and included two tension curves. The strain gage used to measure the elongation in the wire was a mechanical one with a 10 inch gage length. The strain gage was fastened to the specimen to include the two tension curves. Load was applied with a Baldwin-Emery SR-4 Testing Machine.

A means of measuring the load in the individual wires was needed and a load transducer composed of a metal link with two SR-4 A-18 gages bonded to it, was developed to meet this need. A switching mechanism was developed to

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handle the ten transducers at one time. This switching mechanism consisted of two low resistance intercom switch boxes used in conjunction with two toggle switches. A reference transducer was used as a means of accounting for zero shift of the transducers, due to unhooking and rehooking of the leads to the strainmeter.

Field tests were conducted on a 20 rod length of fence. The end arrangements were single span with a 8.25 feet compression member and two nine gauge wires as the tension member. The end posts were set 3.5 feet deep in concrete. Stretching was done with a winch of a Dodge Power Wagon.

Four tests were conducted, the first three on 1047-6-11 type fence, and the last one on 939-6-11 type fence. The greatest extreme in temperature was encountered on the fourth test when the high was 59 degrees F and the low was 5 degrees F. This temperature drop to 5 degrees F produced a load increase of 342 pounds over the lowest measured load of December 31.

The results of the field tests showed there was a general downward trend in the load over a period of time and this was due to horizontal movement of the end post and temperature variation. The temperature variation produced a saw-tooth effect in the load.

The laboratory investigation of the mechanical properties of the wire showed that, as the load increased the

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efficiency or the ability of the wire to return to its original shape, decreased. The wire specimens showed "yielding" at loads much lower than the yield loads of the material in the wire, which is due to the combined state of stress in the tension curves. Recommended tightening loads are high and use up much of the elastic potential of the wire. These high recommended tightening loads also require strong end post arrangements to insure freedom from failure.

THE EFFECT OF TEMPERATURE AND MECHANICAL
PROPERTIES ON FARM FENCE PERFORMANCE

by

Jack D. Wilson

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Figure

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INTRODUCTION

Farm fence being a passive, inactive part of the farm operation is probably the most neglected item on the American farm today. The farmer fails to realize the importance and value of fence. If the value could be measured in dollars and cents, farmers would realize the importance of good fence. An average farm of 160 acres might have 1040 rods of fence. Using a conservative value of \$2.50 per rod as replacement cost the total value of the fence would be \$2,600.00.

Most of the cause for the widespread disrepair of farm fence can be attributed to faulty construction, including the following:

1. Improper selection of materials,
2. Stretching the fence too tightly or too loosely,
3. Improper construction of end and corner post arrangements.

Since according to Giese and Henderson (4), fence failure is almost always a result of corner post failure, "overdesigning" of the corner post has been adopted as a means of assuring a lasting corner post arrangement and corresponding longer lasting fence. Practices which can be classified as overdesign are; using a large amount of concrete to set the posts and anchoring the corner posts

with cables. Generally, these are time consuming methods of constructing a fence.

Woven wire fence is designed with tension curves in the horizontal line wires. These curves spaced every six inches are designed to act like springs, keeping the fence taut and absorbing two possible changes in load conditions:

1. Internal loads due to temperature change,
2. External loads, such as transverse loads applied by livestock running into or leaning against the fence.

Tests have proven that tension curves, their elastic range being small, do not act like springs, and show little ability to spring back to their original shape after a load increase and decrease has taken place.

Fence manufacturers and fence builders use a general rule "that fence is under the proper tightening load when one-half the tension curves are removed." This is impractical as the amount of load to pull out one-half the tension curve varies due to temperature and size of the tension curve.

Tests have proved that loads on woven wire fence will decrease and increase with corresponding increases and decreases in temperature. They were conducted however by measuring the total load increase in the fence so the action on the individual wires when subjected to these temperature variations, is unknown.

OBJECTIVES

1. To determine an accurate and suitable method for measuring the load in the individual wires of a fence.
2. To determine magnitudes of load changes due to temperature variation.
3. To test the properties of the wire in the fence with special consideration for the tension curves.

REVIEW OF LITERATURE

The review of literature was made in six parts:

1. Properties of tension curves
2. Effect of temperature on woven wire fence
3. Bonded wire strain gages and their applications
4. Recommended tightening loads
5. Linear expansion
6. Horizontal movement of end posts

Properties of Tension Curves

Carlson (1) observed that tension curve efficiency or the ability of the tension curve to spring back to its original shape after a load is applied and subsequently released, increases as the wire size decreases. The load necessary to reduce the tension curve by one-half on a nine gauge wire is much greater than that to reduce the tension curve by one-half on a smaller 12.5 gauge wire.

Tests conducted by Giese and Henderson (4) and also by Carlson (1) indicate the more the tension curve is pulled out, the less efficient it becomes.

Giese and Henderson (4) also observed, that higher tension curves require less load to produce half reduction in height than shallower curves.

According to Schueler (13) the size and shape of the tension curves varies considerably, even in the same roll of fence. Figure 12 shows tension curves taken from the same roll of a commercial fence. (See Figure 12, page 31.)

In their summary Giese and Henderson (4) gave a general statement concerning tension curves. They wrote;

The tension curve in woven wire fencing is beneficial in helping to maintain a taut condition but is not entirely effective because the elastic range is small. The manufacturers recommendation to half remove the tension curve is not sufficiently specific, is not equally applicable to summer and winter stretching and is likely to give variable results because of differences in shape and size of tension curves.

Effect of Temperature on Woven Wire Fence

Giese and Strong (5) in their tests concluded, "that the total load on a fence end varies with the stretch and may be increased 50 per cent or more with varying temperature conditions." A great deal of this load increase is due to the barbed wire or wires above the woven wire. They obtained the following results on a double span end fence. On December 17 at a temperature of 61 degrees F, the load was approximately 1800 pounds while on January 2 the temperature was -4 degrees F and the load increased to 2600 pounds.

Giese and Henderson (4) using a coefficient of thermal expansion for steel (annealed) of 6.1×10^{-6} per degree F made the following computations. The decrease in a 400 foot length of fence with a drop in temperature of 80 degrees

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F to -20 degrees F is 3.12 inches. Assuming fixed ends for the wire, a nine gauge wire with no tension curves stretched to 380 pounds at 80 degrees F, would experience a load increase to 530 pounds for the temperature drop to -20 degrees F, a permanent stretching of the wire and subsequently a drop in load to 260 pounds when the temperature again reached 80 degrees F. The barbed wire under the recommended load of 250 pounds, and under the same temperature conditions would increase to 330 pounds, dropping to approximately 185 pounds. The number nine wire with the tension curves, under a 380 pound load would increase to 395 pounds dropping to 285 pounds. Apparently the tension curve absorbed the load increase but did not keep the wire taut for an increase in temperature and subsequent decrease back to the original temperature.

Bonded Wire Strain Gages and Their Applications

The SR-4 strain gage is a bonded wire strain gage. It consists of a grid or pattern of very small diameter wire cemented between two pieces of thin paper which acts as a base. The wire grid has the property of linear variation of electrical resistance with strain.

In order to measure strain in some specimen, one or more of these strain gages are bonded to the surface of the specimen. Next the gage is connected to an electrical

instrument which will measure small changes in resistance, such as a Wheatstone Bridge. If proper procedures of bonding and operation are used the expected accuracy of the gages will be as low as three per cent.

The duco type SR-4 gage is one where the wire is supported by a thin paper base impregnated with nitrocellulose. The duco gage is best adapted to temperatures of less than 150 degrees F. It is also more adaptable to bonding on small curved surfaces since the base is pliable.

Recommended Tightening Loads

Reynolds (12) gave 250 pounds as the load necessary to pull out one-half the tension curve in a 12.5 gauge wire. Giese and Henderson (4) found values of 421 pounds for nine gauge and 374 pounds for 11 gauge wire as the loads necessary to reduce the height of the tension curve by one-half. As was mentioned earlier, 250 pounds is the recommended stretching load for barbwire. Using these values for 1047-6-11 woven wire topped with one strand of barbed wire, the total recommended stretching load would be 4076 pounds. This presents a design problem for fence end corner constructions.

Linear Expansion

With a few exceptions the dimensions of all substances vary directly as the temperature of the substance varies. If a specimen is wire, the change in length is important.

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It has been found experimentally that the increase in length ΔL is proportional to the original length L_0 and very nearly proportional to the change in temperature ΔT . That is $\Delta L = \alpha L_0 \Delta T$ where α is a proportionality constant, different for different materials and is called the coefficient of linear expansion.

Horizontal Movement of End Posts

Giese and Henderson (4) conducted tests concerning the horizontal movement of single and double span end post arrangements with various levels of load. They concluded, 50 per cent of the horizontal movement of both ends came during loading or within 24 hours of loading. They also observed, "horizontal movement of the end post is the largest factor contributing to the reduction in fence loads prior to complete failure." The load on both ends tested, dropped approximately 20 per cent during the first 24 hours and approximately 40 per cent during the first month.

The end posts were in holes bored to size and no concrete was used in the end post arrangements.

PRELIMINARY INVESTIGATIONS

There were two considerations in the preliminary investigation. First a laboratory investigation was undertaken, to gain some knowledge about the mechanical properties of the wire in woven wire fence. The tension curve was given prime consideration in this investigation. Although numerous tests have been carried out on tension curves, in each case the height of the tension curve was used as a measure of the properties making it very difficult to correlate these results with the linear properties in which we are interested. The second part of the preliminary investigation was concerned with developing a method of measuring the load in the individual wires of a fence.

Mechanical Properties of the Wire

The objectives of the laboratory testing of the mechanical properties of various brands of wire were:

1. To try to relate some of the recommended practices of erecting farm fence with known physical properties of the wire,
2. To be able to analyze more thoroughly the experimental data from the field testing.

Procedure and considerations made on tension curve recovery tests. Three brands of wire were tested for the

recovery properties of the tension curves. The testing procedure was conducted in the following manner. The specimen in each case was a 16 inch length of line wire including two tension curves. A mechanical Timius Olsen Strain Gage of 10 inch gage length was fastened to the specimen to include the two tension curves. The load was applied by means of a Baldwin-Emery SR-4 Testing Machine.

The load was applied in increments of 50 pounds and at the end of each increment the load was backed off to "zero" load. During the return to zero load from each position, elongation readings were taken at convenient intervals. From the zero load position, a higher load was applied and the process was repeated again.

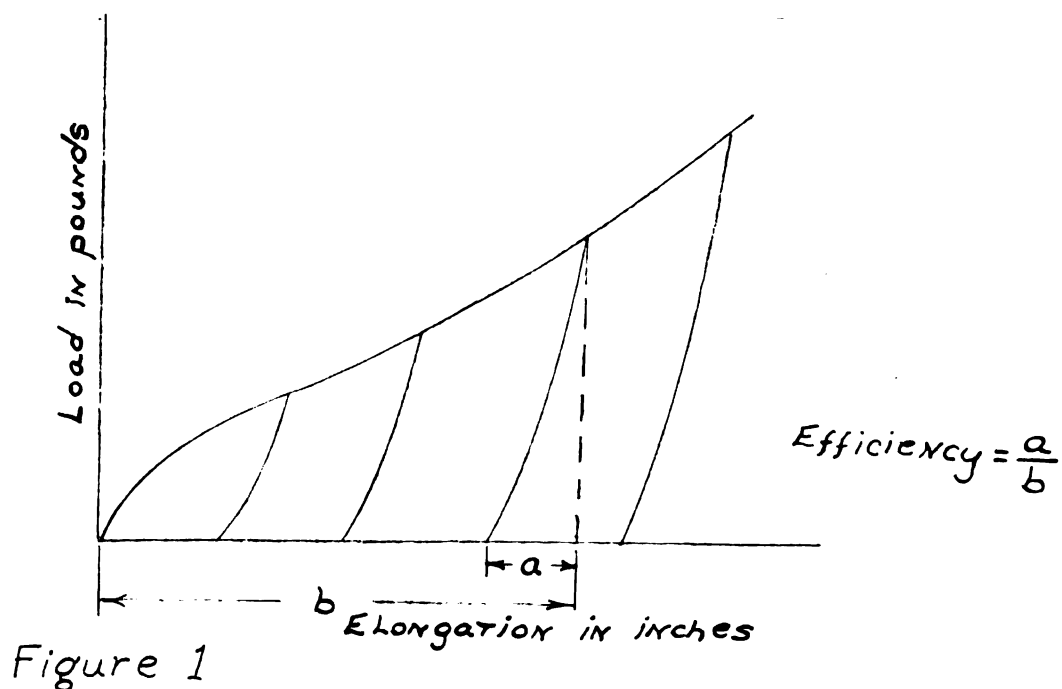
Two considerations were made in analyzing the recovery curve data. The first consideration was the elongation in the wire and it was assumed that permanent elongation due to loading could be attributed to the straightening out of the tension curves and therefore plastic deformation in the straight portion of the wire was negligible.

The second consideration was that each curve, of the two curves included in the ten inch gage length, contributed one-half of the total permanent elongation due to loading. This assumption was based on the fact that tension curves in series require the same load to reduce the height of all the curves by a specified amount as the load required to reduce the height of one curve by the same amount.

With the first consideration in mind a relationship between the experimental results and a one foot length of line wire can be made. There are two tension curves in every one foot length of line wire therefore since it was assumed in the ten inch gage length that the deformation was due only to the flattening out of the two tension curves, then results of the testing will apply in each case to a one foot length of wire.

Efficiency of recovery for the various brands of wire was based on the ratio of the length which the specimen recovered upon reaching a no load condition, to the total increase in length of the specimen for that particular load increment. Efficiency would be measured in this manner since the important factor in actual field conditions is the ability of fence with tension curves, to return to zero elongation at a specific load.

Figure 1 shows how the efficiency was measured from the recovery curves.



Results of tension curve recovery tests. Since this testing was conducted in a cyclic manner of loading and unloading there is a tendency for the yield point of the metal to be raised. This is due to a strain hardening effect in the material at the tension curve, which serves to improve the yield strength.

Assuming a modulus of elasticity of 25×10^6 psi which was the value given by one of the companies for their wire, a tensile yield strength of 60,000 psi could be safely chosen since the wire is a cold drawn product. Using this as a criteria, the yield point for a 12.5 gauge wire would be 479 pounds, 650 pounds for an 11 gauge wire and 1060 pounds for a nine gauge wire. As the results showed there was permanent set in the wire at loads much lower than the yield point loads but the critical portion of the wire is not the straight portion but is rather the curved tension curves. These tension curves are subjected to a combined state of stress and it can be safely assumed that this is the reason for yielding of the specimen at loads below the tensile yield load of the material.

In one respect tension curves act as stress raisers and in this respect fail to add to the favorable properties of the wire but nevertheless they do have a definite value in the favorable performance of the fence.

Figures 2,3,4,5,6, and 7 show typical recovery curves for three brands of wire. The slope of the recovery curve is nearly constant for a particular size and brand of wire.

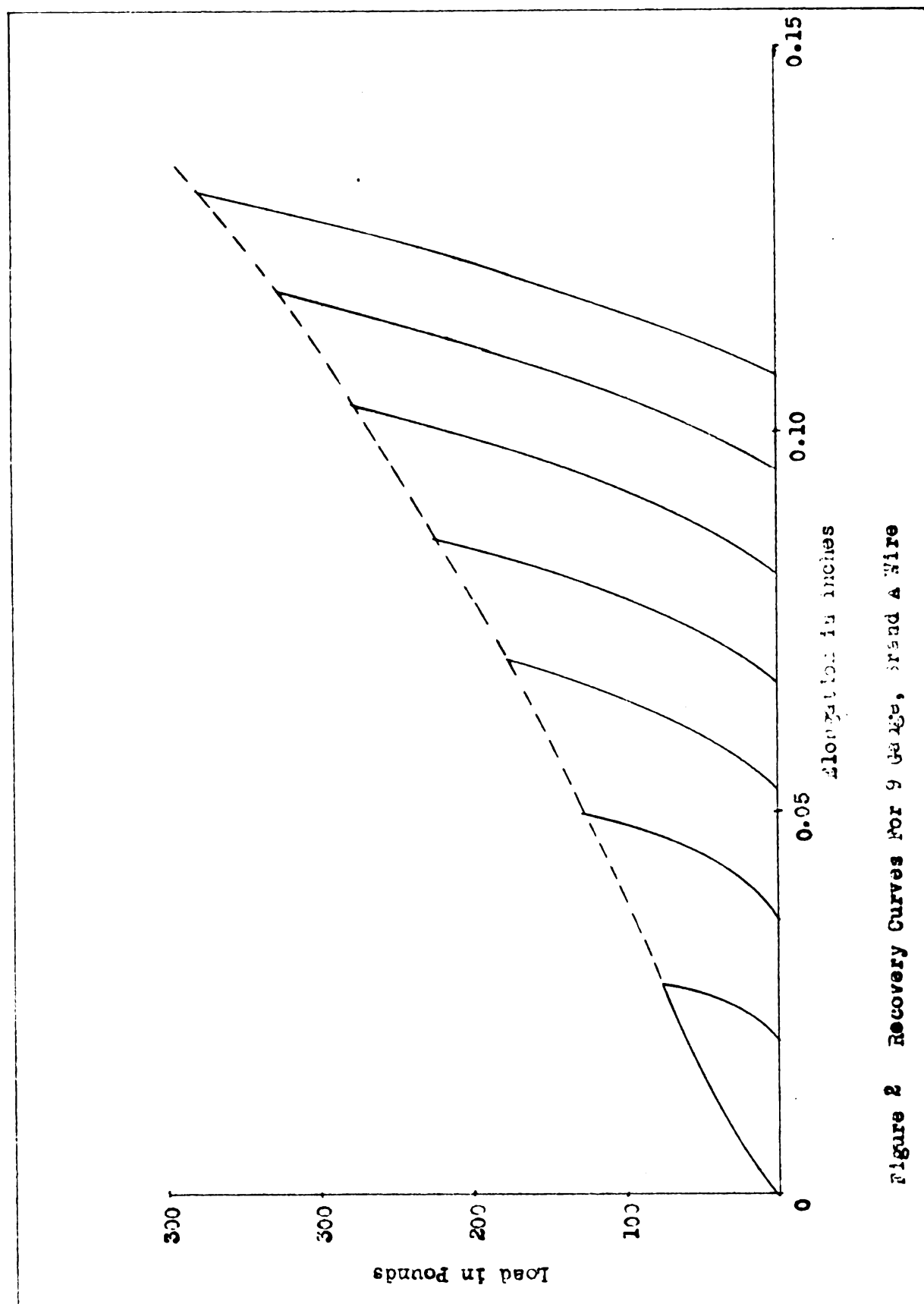


Figure 2 Recovery Curves for 9 Gauge, Brand A Wire

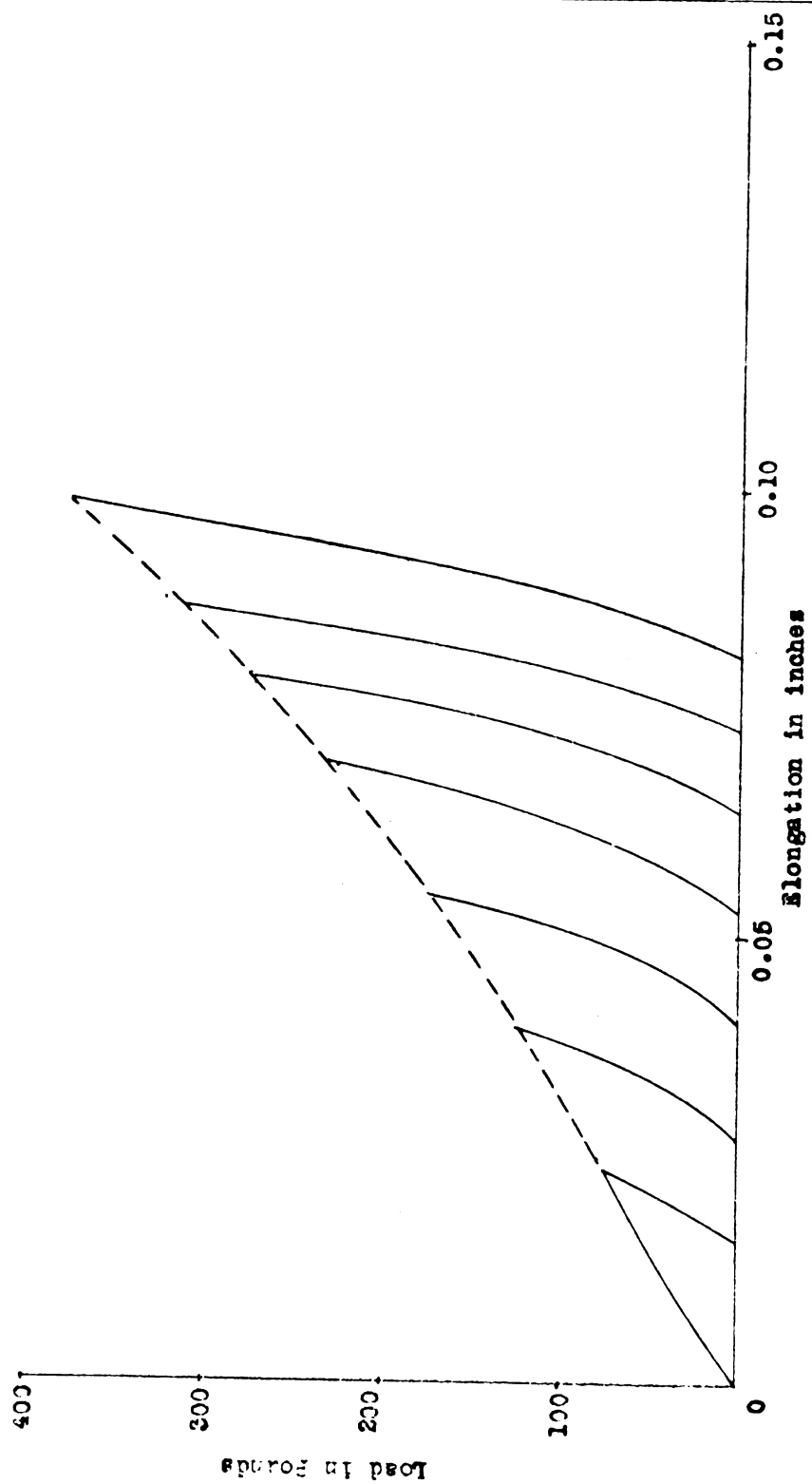


Figure 3 Recovery Curves For 9 Gauge, Brand B Wire

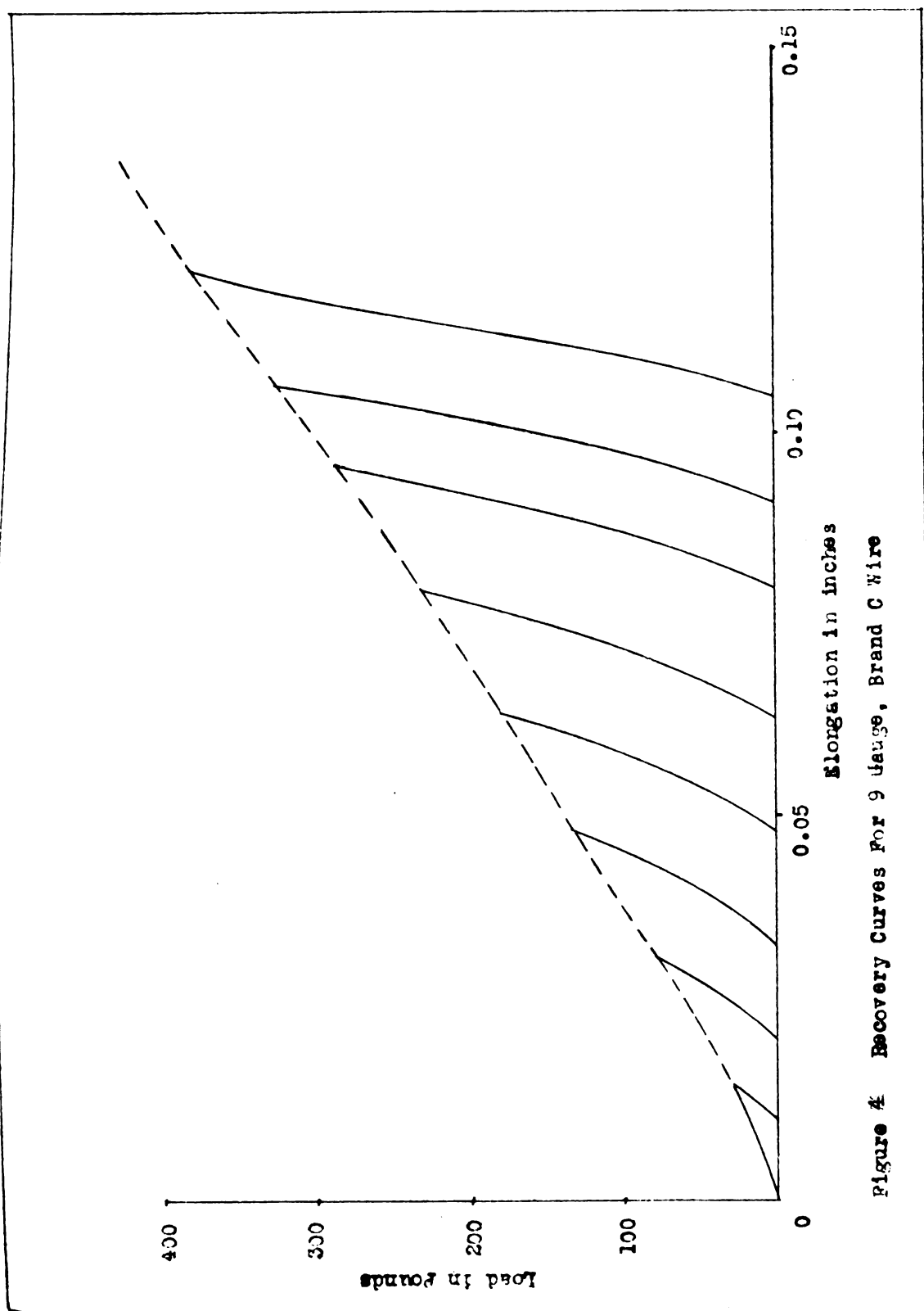


Figure 4 Recovery Curves for 9 Gauge, Brand C Wire

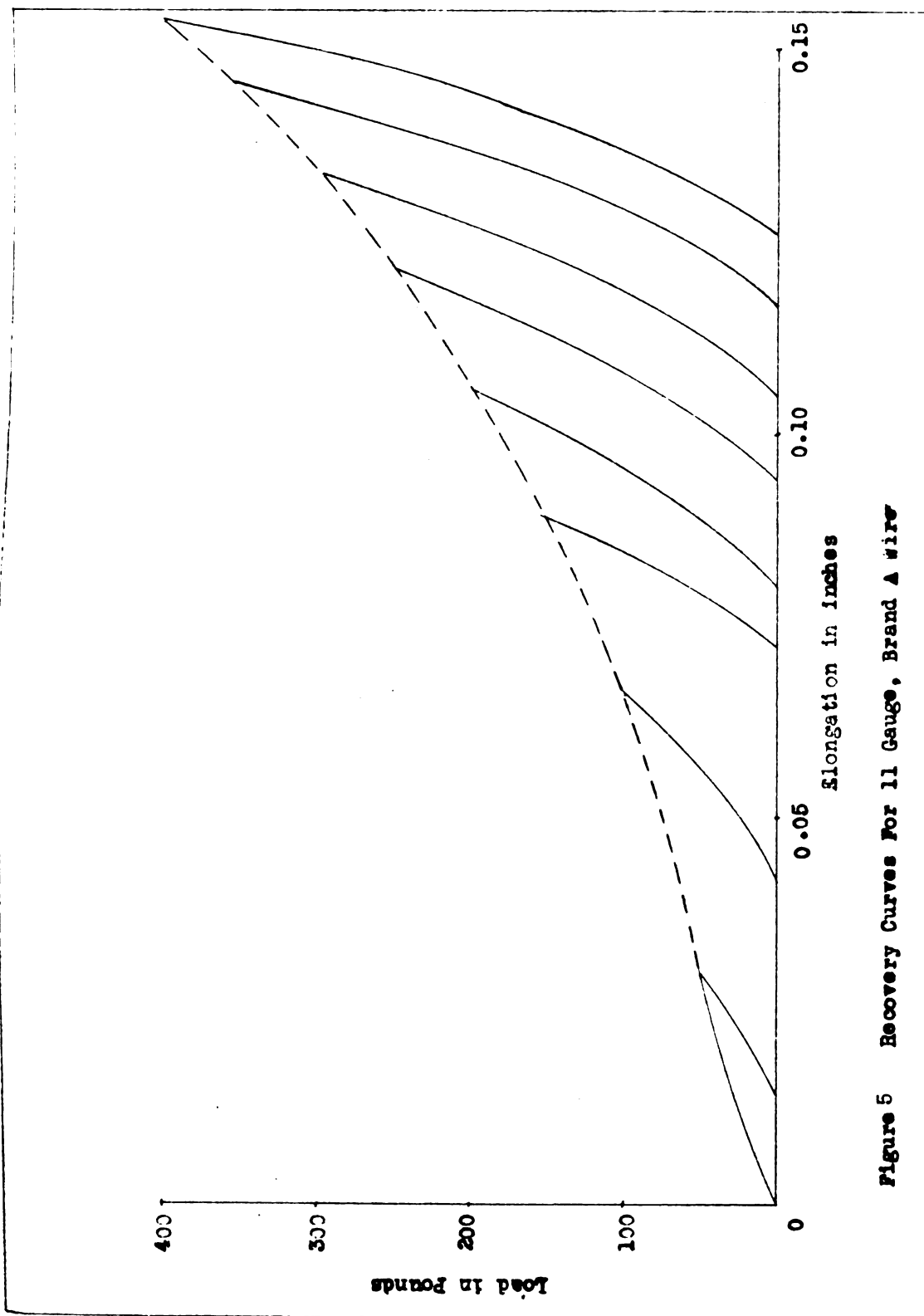


Figure 5 Recovery Curves For 11 Gauge, Brand A wire

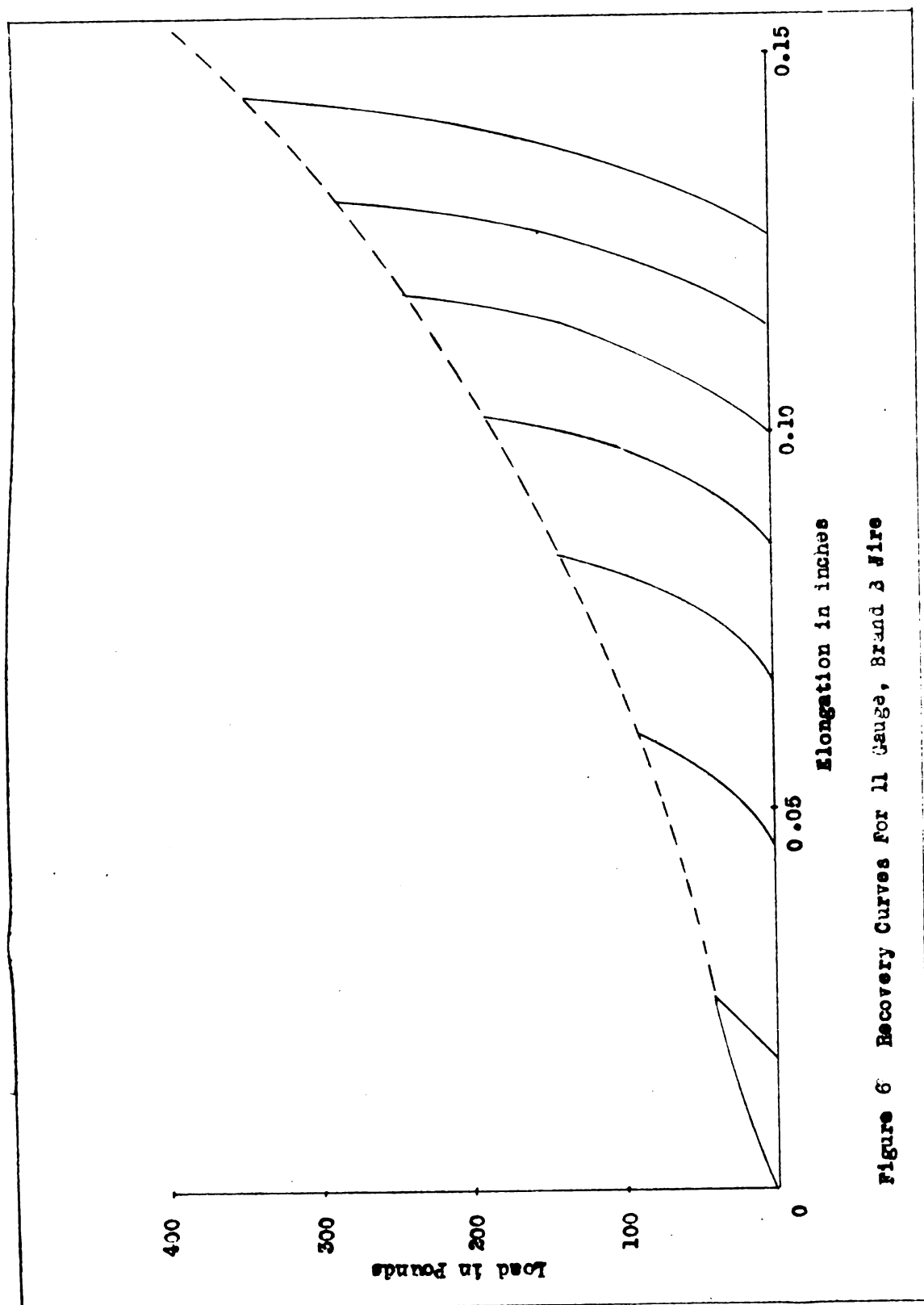


Figure 6 Recovery Curves for 11 Gauge, Brand 3 Fire

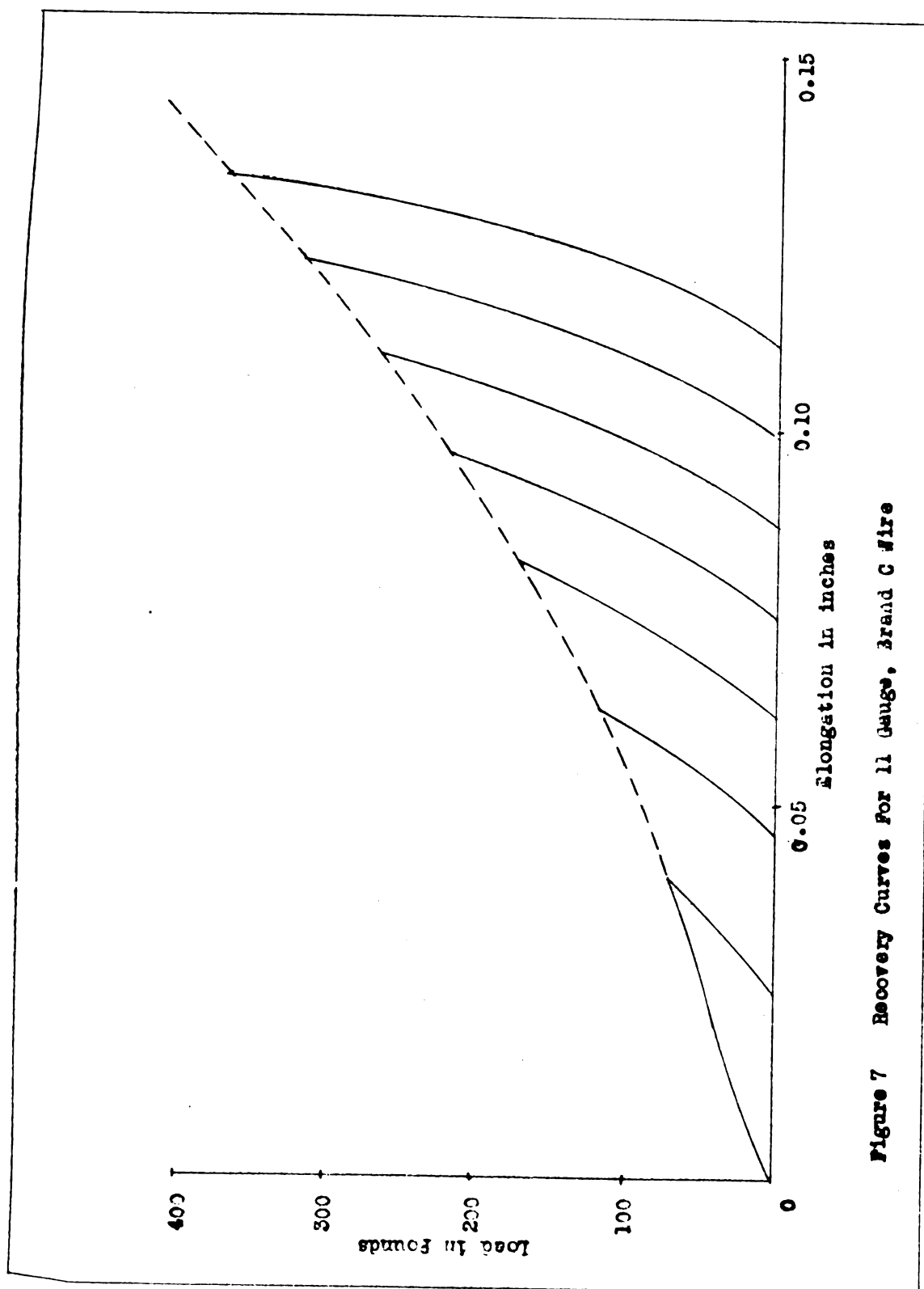


Figure 7 Recovery Curves for 11 Gauge, Brand C Wire

The efficiency of the tension curves decreases as the load increases in every case. This is a logical phenomena and gives a hint to the importance of initial stretching loads in fence. In general the efficiency of the various brands of wire was low at all loads. Efficiency ranged from a high of 37 per cent at 100 pounds to a low of 12.5 per cent at 340 pounds. No attempt was made to rate the efficiency of the brands of wire.

There was no conclusive evidence of a relationship between wire size and efficiency of the tension curves. Naturally for the same load the smaller size wire elongated more than did the larger wire.

Results of reload curve tests. After reaching the zero load position in the recovery curve tests the load was run up again to the next higher increment of load (usually 50 pounds). These reload curves did not coincide with the recovery curves even though the rate of loading and unloading was constant. In general the reload curve showed a smaller elongation than did the unloading or recovery curve for the same load. This property can be classified as mechanical hysteresis in the wire. Figures 8, 9, 10, and 11 show the reload and recovery curves for the three brands of wire tested.

The different paths of the recovery and reload curves also could be attributed to the fact that although the elongation readings taken at load intervals were subjected

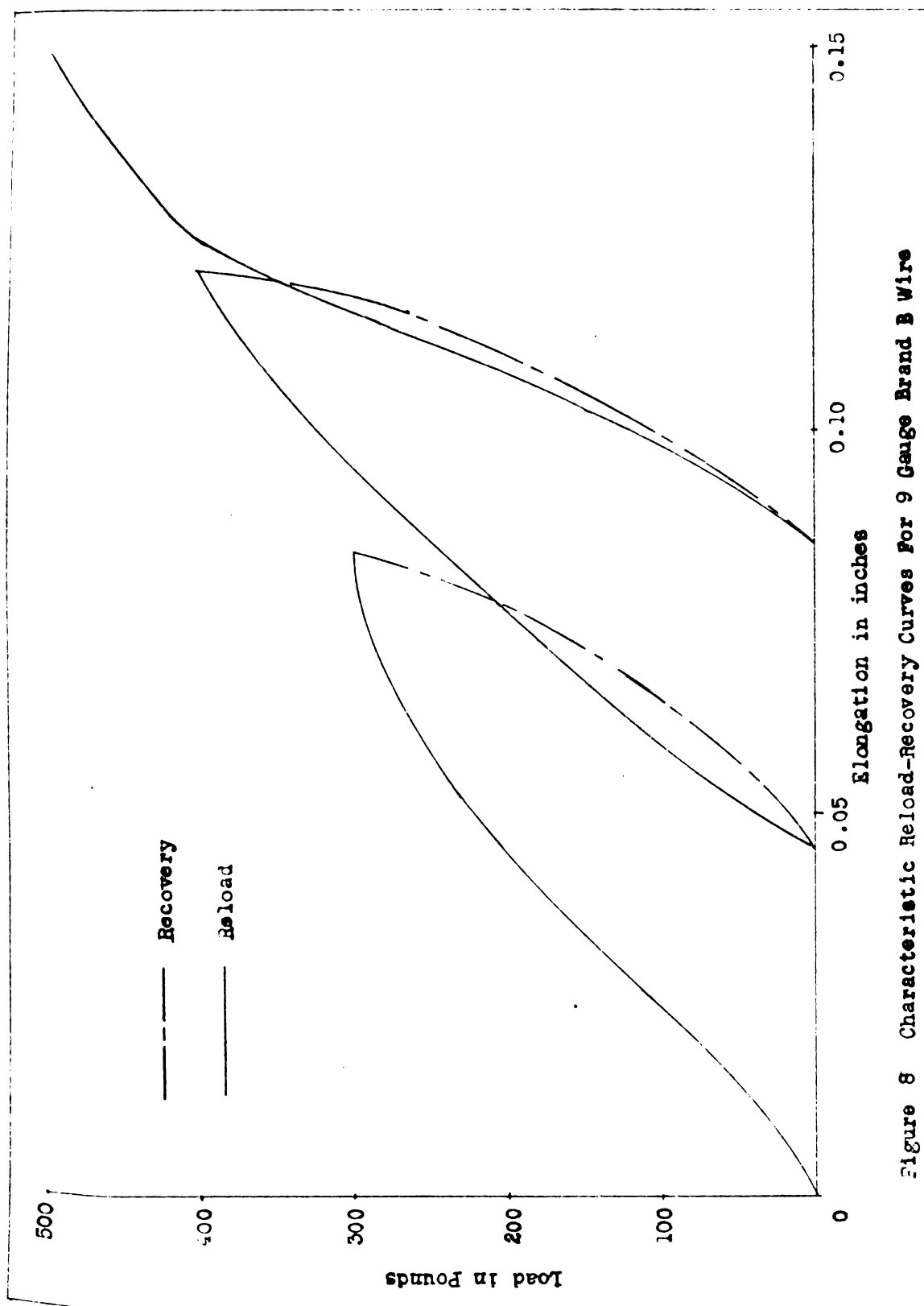


Figure 8 Characteristic Reload-Recovery Curves For 9 Gauge Brand B Wire

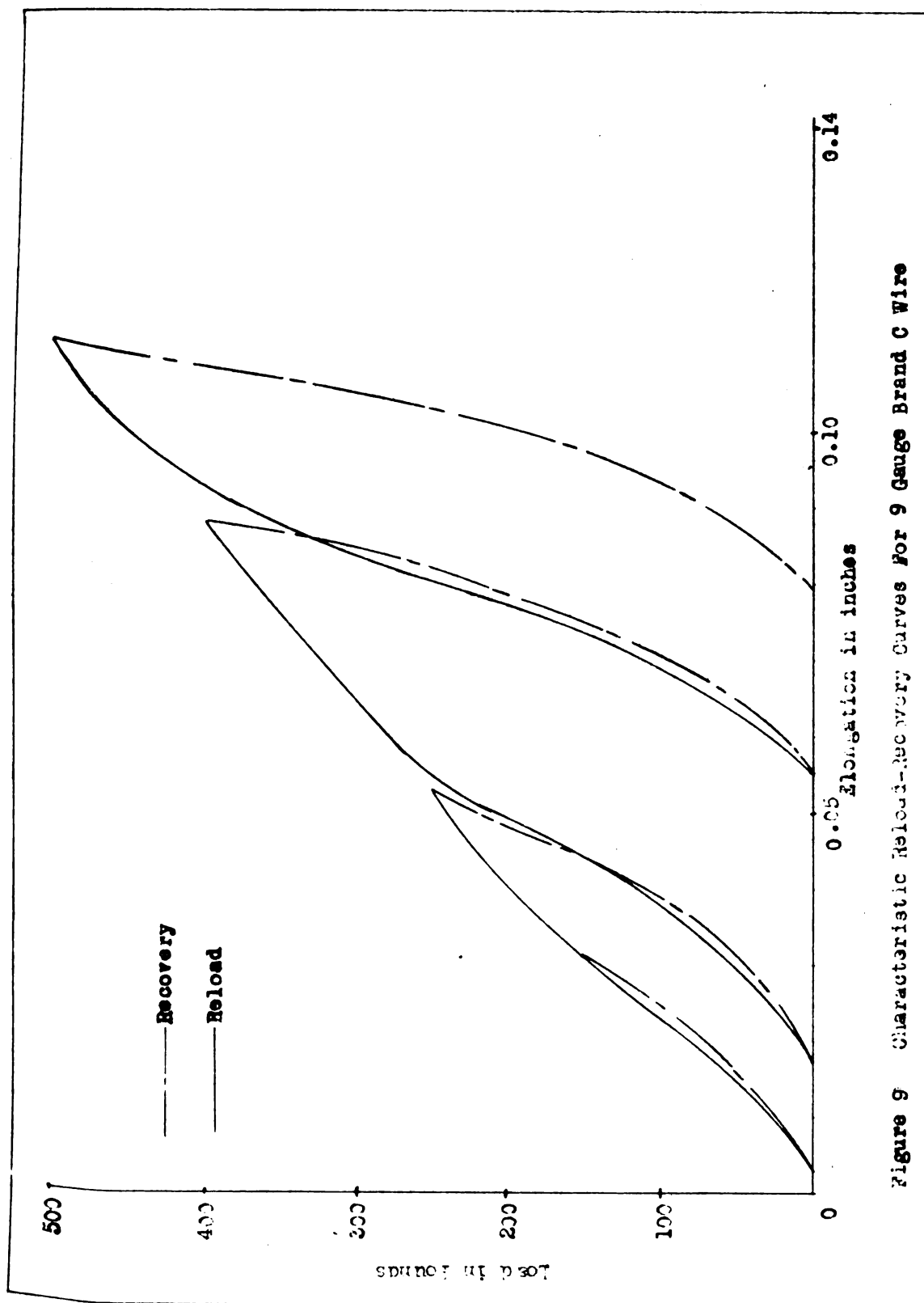


Figure 9 Characteristic Reload-Recovery Curves for 9 Gauge Brand C Wire

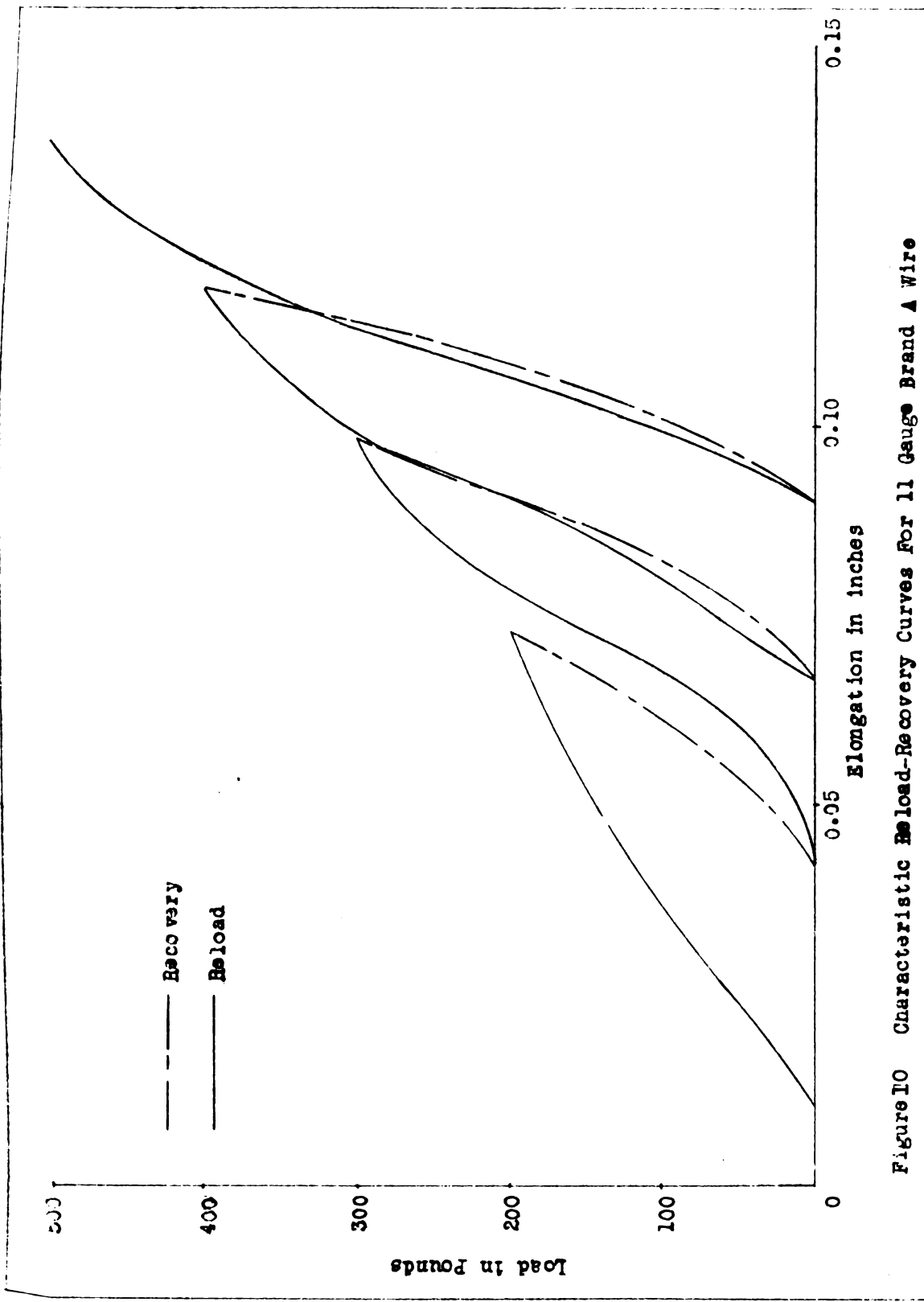


Figure 10 Characteristic Reload-Recovery Curves For 11 Gauge Brand A Wire

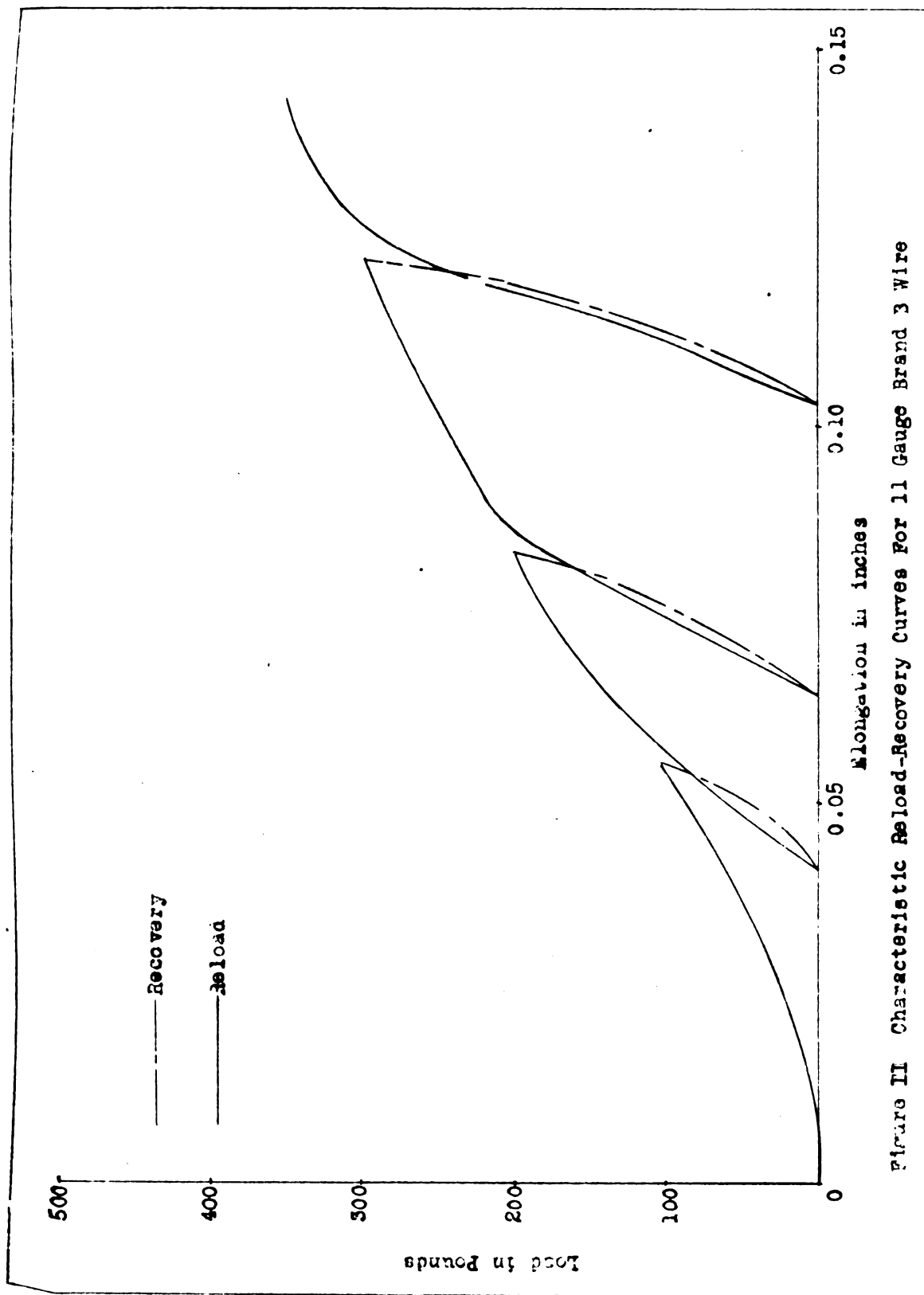


Figure II Characteristic Reload-Recovery Curves For 11 Gauge Brand 3 Wire

to a constant load rate, there was some time dependent elastic deformation which if taken into account, would cause the two curves to coincide. For instance, if the load were held constant at a certain level during the recovery tests, and was allowed to remain at that level for a period of time T_1 , then the elongation would decrease due to the time dependent, elastic after-effect. If during the reload period the load rate was stopped at the same load as the one during the recovery tests, then there would be a residual elongation during a period T_2 . Therefore, the combined effect of the time dependent elongation and contraction in the reload and recovery tests respectively would be for the two points at the same load to move closer together at that load and possibly even coincide.

A hypothetical correlation between recovery properties of wire and recommended tightening loads. A 421 pound load has been suggested as a proper tightening load on nine gauge wire. Recovery curves were not run from this load on any of the three brands of wire tested so a conservative load of 325 pounds on Brand A wire will be used as the criteria of this analysis.

An initial tightening load of 325 pounds would cause an elongation of .118 inches per foot or 6.49 feet in a 40 rod length of nine gauge wire. This increase in length can be attributed to the flattening out of the tension curves. Assuming that the load could be returned to zero in the

fence there would be a permanent elongation of 5.225 feet in the wire. Of course in actual field conditions this decrease to zero load would not occur as long as the wire was secure in place, but it does point up the fact that a great deal of the elastic range of the wire is used up in the initial stretching of the fence.

Brand B nine gauge wire under the same conditions of loading as described in the preceding paragraph would experience an initial elongation of 4.785 feet and a permanent elongation of 4.0158 feet upon return to zero load.

Type C nine gauge wire would experience an initial elongation of 5.885 feet and a permanent elongation of 5.005 feet upon return to zero load.

There is little difference between the final results for the three different brands of wire.

A 325 pound load in nine gauge wire would produce a stress of 18,400 psi which when related to 11 gauge wire would mean a load of 200 pounds in the 11 gauge wire.

For Brand A 11 gauge wire, an initial load of 200 pounds would produce an elongation of 5.83 feet in a 40 rod stretch. There would be a permanent elongation of 4.4 feet in the wire upon return to zero load.

In Brand B 11 gauge wire, an initial load of 200 pounds would produce an elongation of 5.775 feet while there would be a permanent elongation of 4.685 feet upon return to zero load.

Brand C 11 gauge wire would experience an initial elongation of 5.225 feet for a 200 pound load and a permanent elongation of 4.015 feet upon return to zero load.

The previous analytical relationships between arbitrary loading and known recovery curve data, produces an interesting point.

Suppose a 1047-6-11 standard fence, with top and bottom wires of nine gauge and the eight filler wires of 11 gauge is subjected to a 2250 pound load. This is the load resulting from combining 325 pound loads in the two nine gauge wires and 200 pound loads in the 11 gauge wires. The movement of the line wires relative to one another in the fence is fixed by the stay wires, therefore, all the line wires in the fence would theoretically stretch the same amount when the 2250 pound load is placed on the fence. The results of the laboratory testing and corresponding analytical evaluation has shown that if the load was distributed as was assumed previously, the nine gauge wires would elongate .66 feet more than would the 11 gauge wires. This would be impossible due to the relative fixed condition imposed by the stay wires. Therefore, the stress in the 11 gauge wires would be greater than that in the nine gauge wires and for all practical purposes the 11 gauge wires would be carrying more than their share of the total load.

A hypothetical correlation between transverse loads and known properties of the wire. As was mentioned earlier



in the introduction, transverse loading imposes a critical test on the fence, particularly the end and corner post arrangement.

The wire in the following analysis will be nine gauge Brand A wire. At some time T_1 , there is a load of 225 pounds on the wire. The wire is then subjected to momentary transverse loading at some time T_2 , and there is a corresponding increase in the load to 325 pounds. If the load dropped off again to the original 225 pounds then the wire would have suffered an elongation of .027 inches per foot or for a 40 rod length of fence, 1.485 feet. This resultant elongation would mean a definite sagging, permanent in nature for the wire. The results in a fence subjected to this same loading would be analogous to the results for a single wire as shown above.

Instrumentation Methodology

There were three possible methods of measuring loads in individual wires. They were;

1. Mechanical strain gages mounted on the line wires,
2. SR-4 gages bonded directly to the line wires,
3. A load transducer, composed of SR-4 gages mounted on a metal link which would be fastened in the line wires.

The use of mechanical gages as a means of measuring loads in wire was deemed undesirable for several reasons;

1. Cost would be prohibitive since ten gages would

be necessary at one time to measure the total load,

2. They are relatively bulky and subject to being bumped, in the field.

Bonding SR-4 strain gages directly on the wire has both advantages and disadvantages. The advantages are;

1. Speed of bonding when using a thermoplastic cement,
2. Flexibility.

The disadvantages are:

1. In using a strain gage small enough to fit on a wire there is a chance that this gage may be bonded to a spot on the wire where there is a discontinuity in the material and thus erroneous strains would be measured;
2. The heat necessary for the application of the gages with a thermoplastic cement, may have an injurious effect on the gages.

The load transducer seemed to have good possibilities for measuring loads.

Advantages are:

1. The transducers can be checked for proper functioning prior to installation in the line wire;
2. They can be used more than one time if properly cared for.

Disadvantages are:

1. They would be measuring loads in the transducer and not in the wire directly.

Procedure for testing SR-4 gages bonded directly on wire. Two A-18 SR-4 gages were bonded to the wire with DeKhotinsky cement. A thermoplastic cement such as DeKhotinsky was the only feasible method of bonding the gages to the wire directly, since under field conditions it would be impractical to use the slow drying duco cement. The gages were mounted opposite each other on the wire to eliminate bending strains which would otherwise be picked up.

Results.--The E value computed from the experimental results for Brand C nine gauge wire ranged from a high of 31.6×10^6 psi to a low of 25.5×10^6 ps. The average value of E, from six tests on the same specimen was 29.91×10^6 psi.

The load computed from experimental results and the known load from the testing machine agreed quite well although the computed load was lower in each case.

On the Brand B wire, tests were not conclusive. The E value was approximately 45×10^6 psi which is an unreasonably high value.

Mounting the gages directly on the wire was discontinued for various reasons, other than the ones already given as disadvantages;

1. DeKhotinsky cement tends to polymerize when left in warm air,
2. Under field conditions there would be a problem of trying to check the gages to insure no damage

had been done during bonding,

3. In bonding and molding the gage to the contour of the wire there is a good chance for injury to the gage and subsequent unreliable performance.

Procedure in developing load transducers. The idea of using tension links as load transducers in the line wires was first conceived by Lee (9). The load transducer is fastened into the line wire. The load in the tension link and the load in the wire would be the same. Knowing E for the link, A (area for the link) and ϵ (the measured strain in the link), the value of P (load) can be computed using a modified version of Hookes law ($P = \epsilon AE$). The link itself was constructed as a metal strap with looped ends to facilitate fastening the wire to it. A-12 SR-4 gages were bonded to both sides of the metal link and the gages were hooked in series in the same leg of the bridge, thus eliminating bending. Figure 13 shows a tension link.

Results.--First tests were run with a link (no. 1), .1875" by .1875" in cross section. Although the test proved successful, there was some question as to the sensitivity of the tension link since the area of the link was quite large compared to the area of the wire.

For this reason, tension link no. 2 with a cross section of .125" by .125" was adopted as the one to be used in field tests. This was the smallest dimensions which



Figure 12 Variation in size of tension curves from same roll of fence

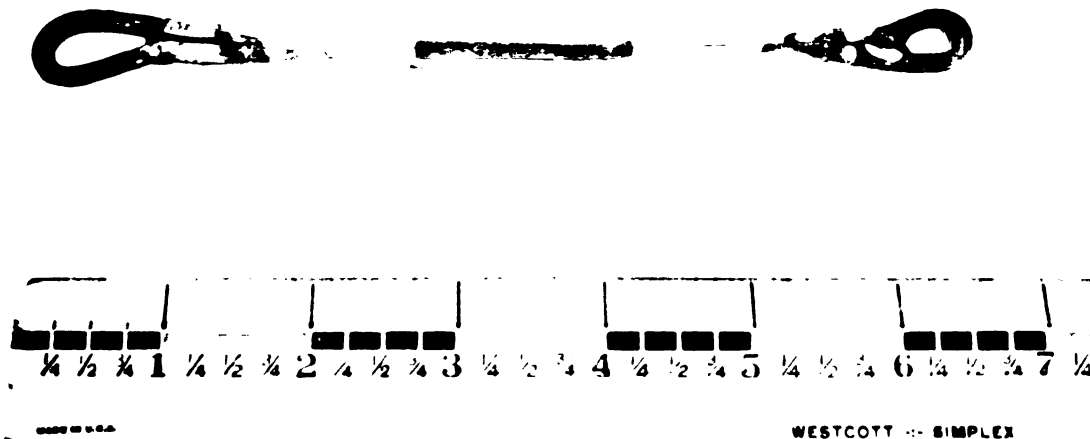


Figure 13 Load transducer (tension link)

could be used with the SR-4 A-12 gages which have a minimum trim width of .125". Tests were run on the original tension link no. 2 and Figure 14 shows the relationship between the actual load applied by the testing machine and load computed using the modified Hookes law.

Fourteen tension links were constructed in the same manner as described for link no. 2. The links were checked by the prescribed methods to insure proper functioning and E values were computed for each link as a further check.

Considerations and results in instrumentation of load transducers. There were two problems remaining which had to be solved before tension links could be used in a field test. These were;

1. A multiple switching unit was needed to handle the ten tension links at one time,
2. A means of keeping track of the "zero" of the tension links from one set of readings to another was necessary.

Two low resistance, intercom switch boxes were used in conjunction with two toggle switches, as the multiple switching system. This system had a capacity of handling 15 tension links at one time. Figure 15 is the schematic of the wiring while Figures 16 and 17 show the actual switching unit being used in the field. This system was tested before actual use in the field, to insure that strain readings would not vary appreciably due to switching.

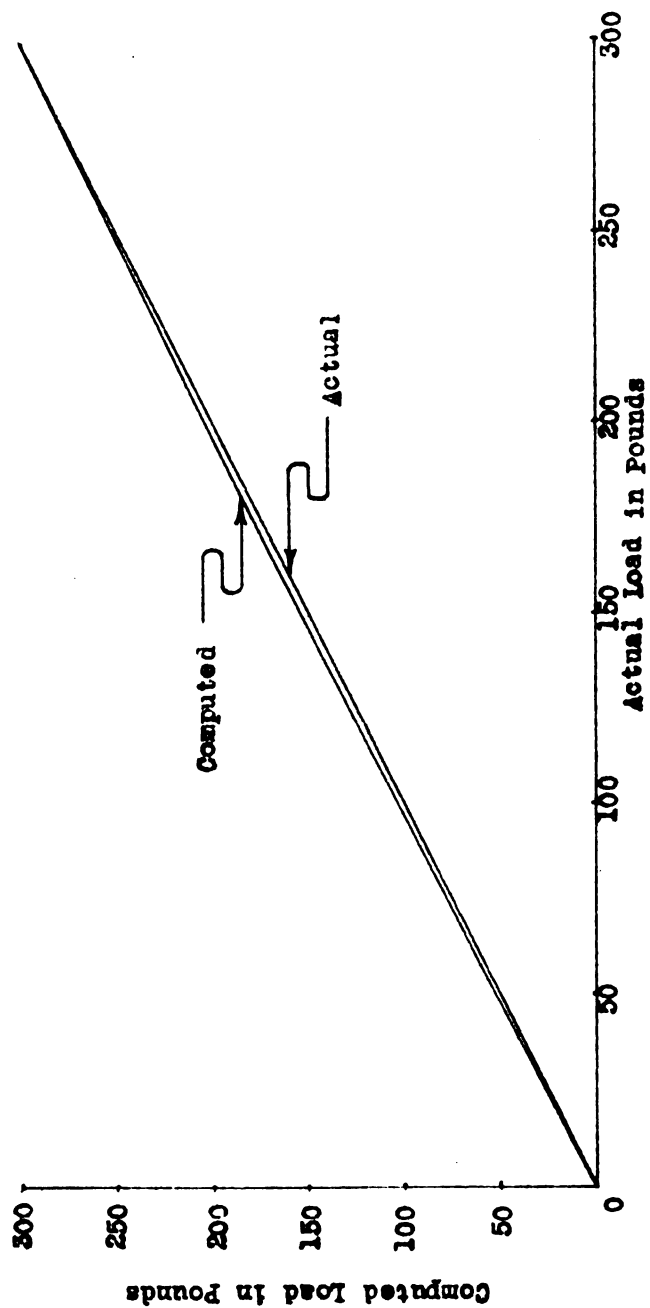


Figure 14 Comparison of Actual and Computed Loads on no. 2 Tension Link

Nos. Denote Tension Links

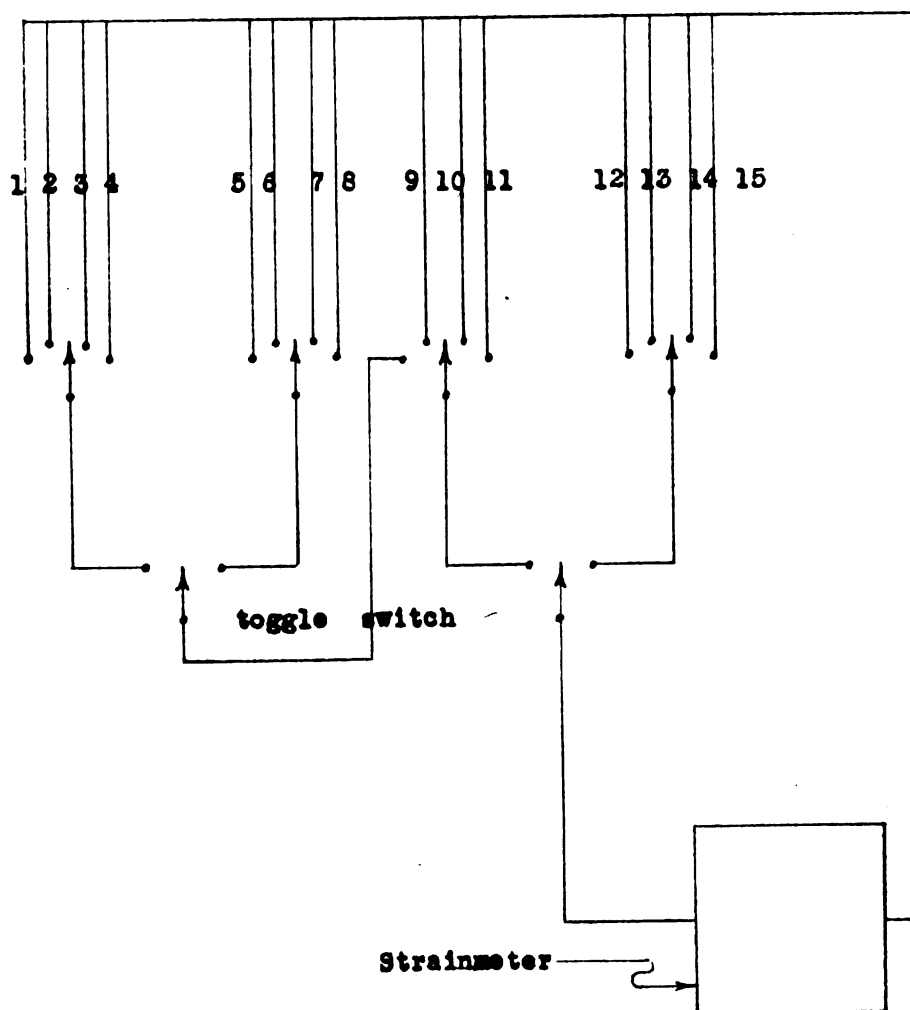


Figure 15 Wiring Diagram of Strainmeter and Switching Unit

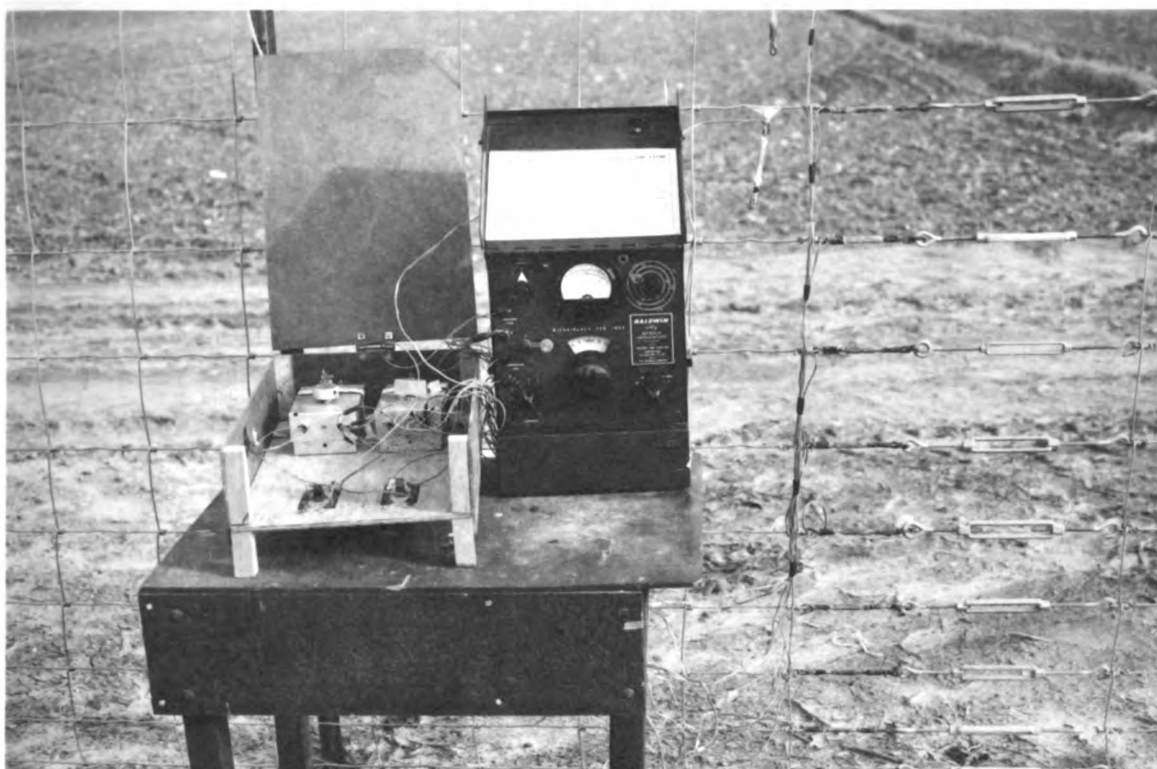


Figure 16 Switching unit with strainmeter



Figure 17 Switching unit in use

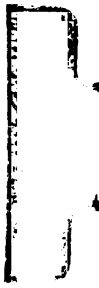
Since readings would be taken at intervals of one-half or more days apart it was impossible to leave the strainmeter hooked up out in the field. Consequently, since unhooking and rehooking the lead wires to the strainmeter causes a shift in the zero of the system, a method was needed to account for this shift in zero and adjust the values of the strain readings accordingly.

A reference link was used to account for the zero each time. This reference link was identical to the tension link and was hooked into the switching unit also, but instead of being fastened in a line wire was taped to the fence and therefore was unstrained, due to load, each time a series of readings was taken on the fence, a reading was taken on the reference link. Since there was no strain in the reference link due to load, any change in strain from the previous series of readings was due to the change in hooking and unhooking of the lead wire. One lead of all the gages was a common lead and the other was hooked in the switching unit, and the lead to all the links through the switching unit was in effect a common lead, thus the assumption was made that the change in strain in the reference link was the same as that in the tension links due to unhooking and rehooking of the lead wires.

For example, if the initial reading for the reference gage was 11,000 and at some later time after unhooking and rehooking of the lead wires was 11,050 then 50 would be

subtracted from all the readings of the tension links to compensate for zero shift.

To account for any possible zero drift of the strain-meter itself, a reference setup was used. This reference setup is described in Perry and Lissner (10, pp. 170-174). In this case, two A-12 SR-4 gages bonded on a piece of cold rolled steel, comprised the reference setup.



FIELD TESTING

Apparatus

The initial requirement in the field testing phase was to construct two end post arrangements which would closely approximate fixed end conditions. The end arrangement was single span with a 8.25 feet horizontal compression member and a diagonal tension member of two strands of nine gauge wire. The end posts were set 3.5 feet deep in concrete, the concrete being 18 inches in diameter. The line posts were steel and were driven by means of a mechanical driver. Line posts were spaced at one rod intervals. The testing area was level thus eliminating many problems of construction of the fence itself. Initially a forty rod length was deemed desirable but after the first test, the length was shortened to 20 rods.

Two angle irons were bolted to the ends of the fence to facilitate fastening of the stretching mechanism and to give an even pull on the fence. Stretching of the fence for the first test was accomplished using two block and tackle type stretchers in conjunction with a dummy pull Post arrangement but this proved unsatisfactory as to the amount of load that could be applied, so subsequent stretching was done with a winch of a Dodge Power Wagon. A chain was fastened to the top and bottom of the angle

irons to get an even distribution of the pull of the winch, on the fence. A hydraulic dynamometer was connected between the chain and the winch cable to measure the initial stretching load. This method of stretching proved successful but is not recommended for use by farmers since lack of an instrument such as the dynamometer for measuring the load might cause too great a load to be applied with possible serious results.

The tension links were fastened into the fence before stretching was begun. Turnbuckles were used to facilitate an even increment of length being added to the fence when the tension links were added, since it was difficult to use exactly the same amount of wire in tying the tension links into the fence.

Test No. 1

The first test was conducted on a forty rod length of fence. Two block and tackle type stretchers were used. The pull was made from two dummy pull post arrangements, one at the halfway point (20 rods) and the other at the end of the fence. The fence used was Brand A 1047-6-11. No effort was made to record the initial load although this would be desirable, as it was later learned. During the cutting and stapling of the wires to the corner posts, the second and third wires from the bottom slipped before they could be secured and this had a bearing on the final results as will be clarified later.

Results. The fence was erected on September 30 at a temperature of 70 degrees F. Early the next morning at a temperature of 49 degrees F, there was a 231.96 pound increase in load. The second and third wires from the bottom showed a decrease in load and this might be due to many variables; such as the original slipping of the wires through the staples and contraction and expansion of the tension member. It is felt that these inconsistent actions of the second and third wires are not important in the over-all picture of temperature versus load since the total results do show a consistent relationship between temperature and load.

When the temperature rose to 62 degrees F on the afternoon of the same day the fence showed a total loss in load of 163.25 pounds.

Test No. 2

Test No. 2 was conducted on a twenty rod length of Brand C 1047-6-11 fence. The dynamometer showed a load of 2700 pounds before the fence was fastened to the end post. After fastening the fence to the end posts, during which some load was visibly lost, the tension links showed a total load of 2080 pounds. The temperature at erection was 52 degrees F.

Results. A temperature decrease of 18 degrees F produced a 72 pound increase in load the first day. Ten days

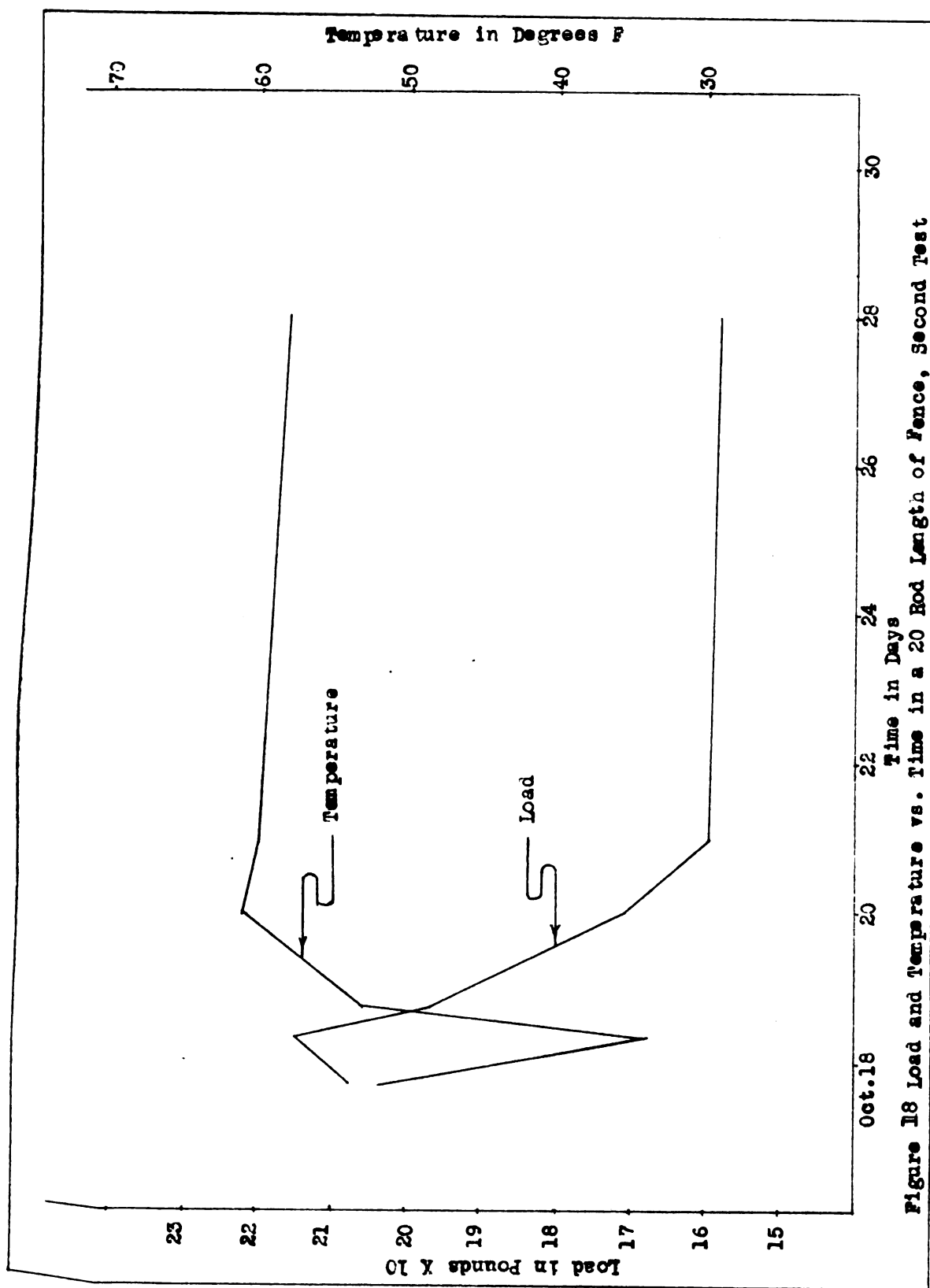
later at a temperature of 58 degrees F there was a total load of 1583.135 pounds in the fence. Thus the total decrease in load in the fence for the ten day period was 496 pounds. This total decrease in load was due to a combination of yielding and stretching of the wire and a small horizontal movement of the end posts through the soil.

The following hypothetical analysis is approximate in the assumptions made but gives a characteristic descriptive picture of what happens in the fence. Since the total load initially is 2080 pounds, there would be a load of 208 pounds in each wire assuming an equal distribution of the load throughout the fence. This would mean that the fence elongated 5.4166 feet during the initial stretching if the 11 gauge filler wires are used as the criteria of analysis.

Figure 18 shows the load versus time and the temperature versus time curve of the fence.

Test No. 3

Test No. 3 was conducted using 1047-6-11 Brand C fence. The fence was erected on November 6 at a temperature of 45 degrees F. The initial load from the dynamometer was 2800 Pounds while the initial load from the tension links after the fence had been fastened to the end posts, was 2549.158 Pounds. Again there was a drop in load which occurred during cutting and fastening of the line wires to the end Posts.



Results. A drop in temperature to 40 degrees F showed a load drop of 59.5 pounds. The largest load increase measured was from November 12 at a temperature of 54 degrees F to November 26 at a temperature of 32 degrees F. This load increase was 124.42 pounds. After being up for 38 days and at the same approximate temperature (43 degrees F) as when it was erected, the fence showed a total load drop of 766.78 pounds. The slackening off of the load produced a definite observed slack in the fence.

Figure 19 shows the load versus time and temperature versus time curve of the fence for the 38 day period.

Test No. 4

The fourth test was conducted on a 939-6-11 Brand C fence. The initial load according to the dynamometer was 1550 pounds. The bottom tension link gave inconsistent results from the beginning of this test. On the next to the last readings taken, the reason for this inconsistency with this particular tension link was discovered to be an error in the switching procedure used and not due to a malfunctioning of the link itself. It was impossible to take into account the error; thus the results give the load in eight wires and not the total load of the nine wires. The test was begun on December 20 at a temperature of 59 degrees F.

Results. This particular test included the greatest extremes in temperature. On January 3 the temperature

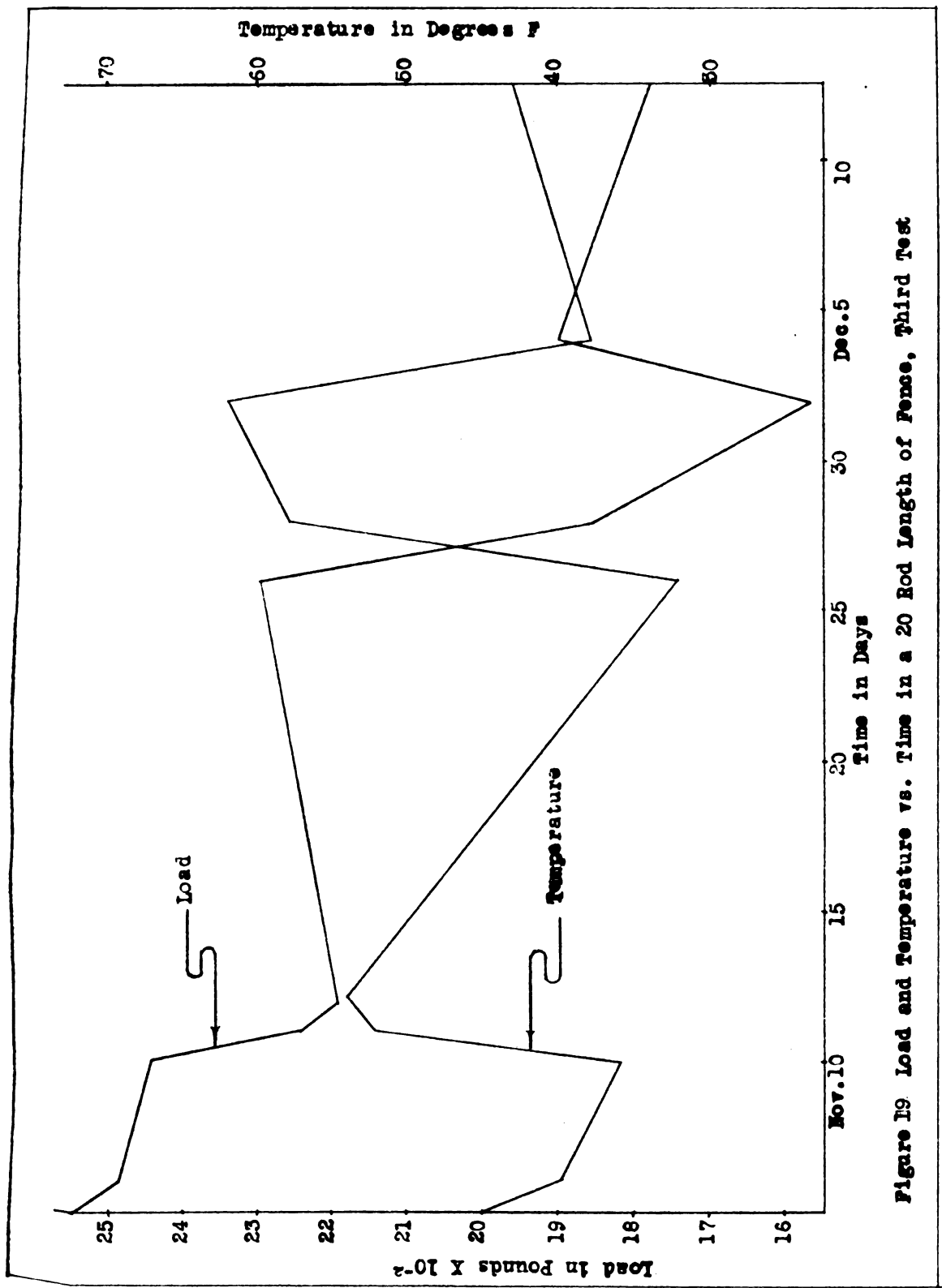


Figure 19 Load and Temperature vs. Time in a 20 Rod Length of Fence, Third Test

11

reached a low of 5 degrees F and the total load for that time was 1395 pounds which is an increase of 93 pounds over the initial load and an increase of 342.18 pounds over the lowest measured load on December 21. Figure 20 shows the load versus time and temperature versus time curves for the fourth test.

General Results of Field Tests

Two general observations were made in analyzing the data from the field testing. First, there was a general decline in the total load in the fence over a period of time. Second, although the general tendency of the load was to decrease, there was a saw-tooth fluctuation of the load due to temperature, which followed the general downward trend of the load.

The general downward trend of the load with time cannot be called solely a time dependent relationship. The downward trend is a function of temperature variation, horizontal movement of the end posts, initial load, and properties of the soil.

Generally, the temperature probably contributes to the load decrease in the following manner. The temperature fluctuates, causing the fence to contract and expand. These contractions and expansions produce corresponding load increases and decreases which are the saw-tooth effect of the data shown in Figures 17, 18, and 19. For instance, a temperature drop and corresponding load increase would cause

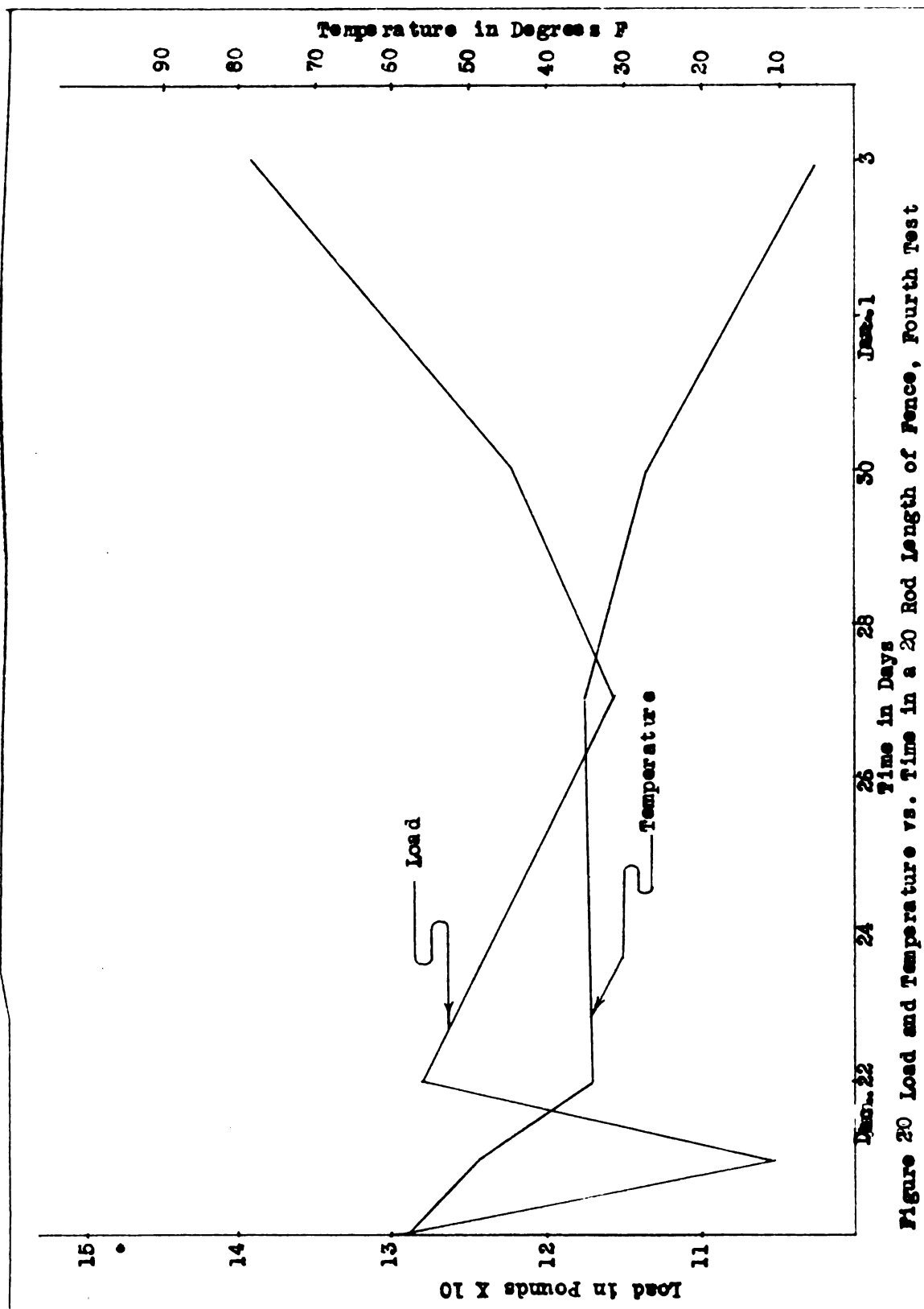


Figure 20 Load and Temperature vs. Time in a 20 Rod Length of Fence, Fourth Test

the fence to contract and be stretched. When the temperature rose again the load in the fence would slacken off but as the recovery curves of the laboratory tests showed, there would be an added permanent elongation in the fence due to the initial temperature drop and corresponding load increase. The added elongation would in effect reduce the load. Since this process is repeated again and again in the fence, the load would decrease with time.

The horizontal movement of the end posts is a major factor in load drop in the fence, as was observed by Giese and Henderson (4), but the amount of horizontal movement is a function of temperature variation, initial load, properties of the soil, and fence end construction. High initial loads would cause a greater horizontal movement of the end post initially and probably a larger drop in total load over a period of time. In other words, it would seem the higher the initial load the greater would be the percentage load drop in the fence. Temperature variation would also seem to effect the amount of horizontal movement as the fluctuating loads due to temperature changes would mean a cyclic type of load bearing between the end post and the soil. Thus there might be a crushing action and breaking down of the soil around the base of the end post as the temperature and load varies thus permitting the end post to move. In the tests run, the load drop due to horizontal movement of the end post could be safely assumed to be less than the

values given by Giese and Henderson (4) since the base of the post was set in concrete.

Properties of the soil would affect horizontal movement of the end posts but it was not taken into account for these tests.

Figures 17, 18, and 19 show the relationship between load and temperature. After the first couple of readings, during which the load drop is most likely due to movement of the end posts and possibly a more even distribution of the load throughout the fence, there was a "mirror" relationship between the temperature-time curve and the load-time curve. When the temperature rose, the total load decreased and as the temperature decreased the total load increased.

Since the total load at any time is a function of time and temperature, a linear regression curve was run through the data using time x temperature on one coordinate axis and load on the other axis. The linear regression curve was run only on Test No. 3. The equation of the regression curve is $y = 2524 - .550xz$ where y = load, x = time, and z = temperature. A linear curve seems illogical at first since at some high value of time x temperature the load would go to zero but the regression curve is defined only in the interval of the data taken and thus cannot be applied outside this interval. Figure 21 shows the regression curve.

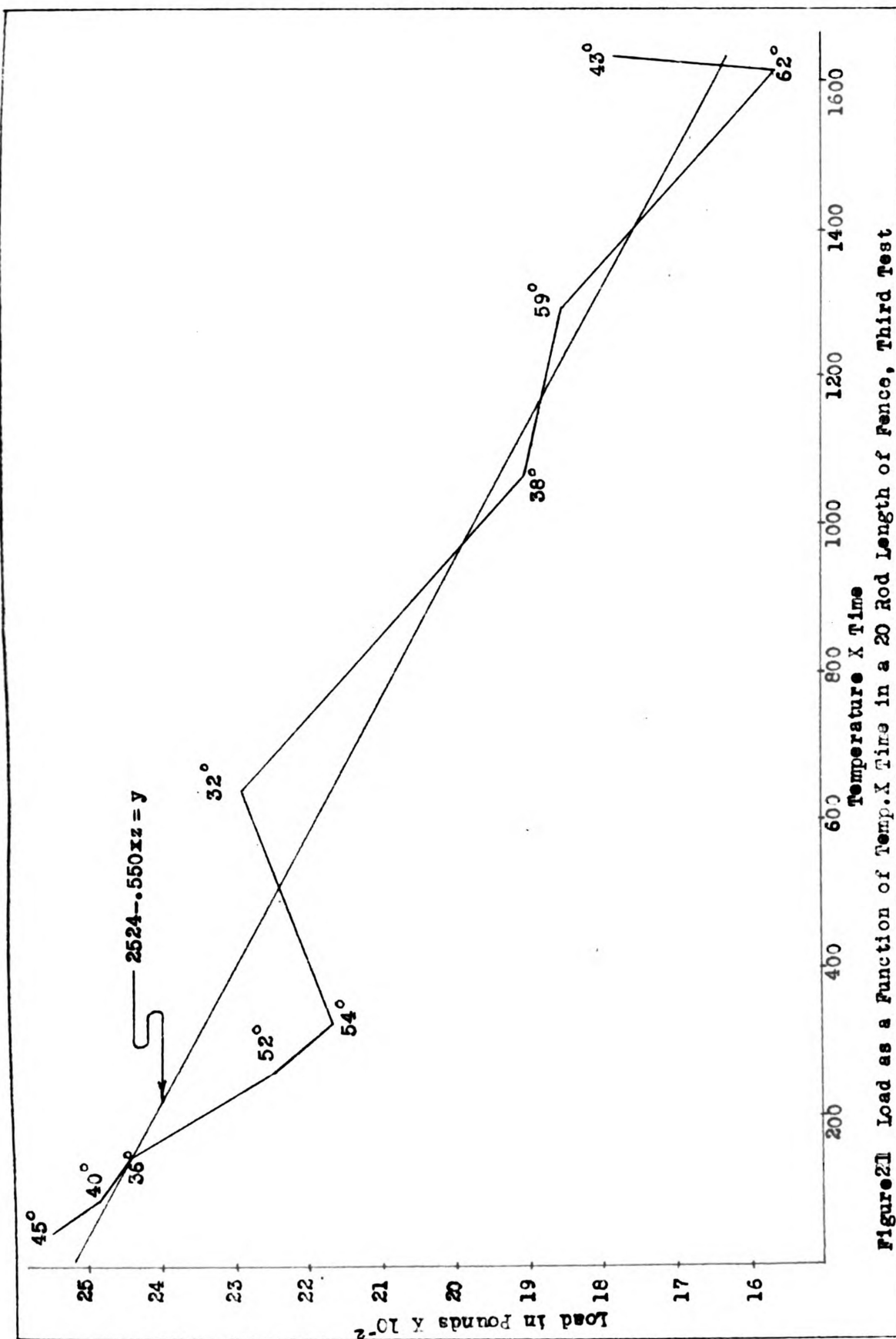


Figure 21 Load as a Function of Temp. $\times$ Time in a 20 Rod Length of Fence, Third Test

A three dimensional relationship (no. 1) of the form $y = ax^b z^c$ was found ($y = \frac{9355}{x^{.3298} z^{.10404}}$) and a three dimensional relationship (no. 2) of the form $y = a+bx+cz$ ($y = 3677 - 26.438x - 20.422z$) was fitted to the data. The standard error of estimation was 4.53 per cent for the linear curve used, while it was 6.34 per cent for the three dimensional relationship (no. 1) and 6.35 per cent for the three dimensional relationship (no. 2). Thus the linear curve fitted the data better.

Actually the three variables of load, time, and temperature would constitute a regression plane if they were plotted on three coordinate axes where load, temperature, and time represent the three axes.

A non-linear curve (no. 1) of the form $y = ax^b z^c$ was found ($y = \frac{9355}{x^{.3298} z^{.10404}}$) and a non-linear curve (no. 2) of the form $y = a + bx + cz$ ($y = 3677 - 26.438 x - 20.442 z$) was fitted to the data. The standard error of estimation was 4.53 per cent for the linear curve used, while it was 6.34 per cent for the non-linear regression curve (no. 1) and 6.35 per cent for the non-linear regression curve (no. 2), thus the first straight line fitted the data better.

Actually the three variables of load, time, and temperature do not constitute a regression line but a regression plane. The load (y), temperature (x), and time (z) represent three coordinate axes and thus for any one reading there is a value for each of the three variables. The three variables can be represented as a regression line on paper but we are actually looking at a side view of the three coordinate axes system, where the x and z axes coincide.

The only method for separating the variables time and temperature would be to run a test holding the temperature constant. The load drop would thus be a time function only.

CONCLUSIONS

1. The actual yield load for all brands of wire is lower than the theoretical yield loads and is due to a combined stress condition in the tension curve. The wire did not show a tendency to fail at the tension curve in any of the series of tests. Page 12

2. The efficiency of the tension curves decreases as the load increases and there is no relationship between wire size and tension curve efficiency. Page 19

3. Reload curves do not coincide with recovery curves which emphasizes even more the non-elastic behavior of tension curves. Page 19

4. Recommended tightening loads use up much of the elastic potential of the tension curves, thus the feasibility of using high stretching loads is questioned. Page 25

5. The smaller wires in a woven wire fence have a higher concentration of stress and thus carry more than their share of the load as compared to the top and bottom wires. Page 26

6. Strain gage, tension link transducers are adaptable to measuring loads in the individual wires. Pages 30-37

7. There is a general downward trend of the load due to temperature variation and movement of the end posts. The two cannot be separated except through controlled experiments. Page 45

RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

1. Develop a tractor mounted mechanism to erect the fence with a relatively small initial load.
2. Test the feasibility of mechanical driven steel posts (not line posts) as corner posts.
3. Measure the load at various positions along the fence to determine load distribution.

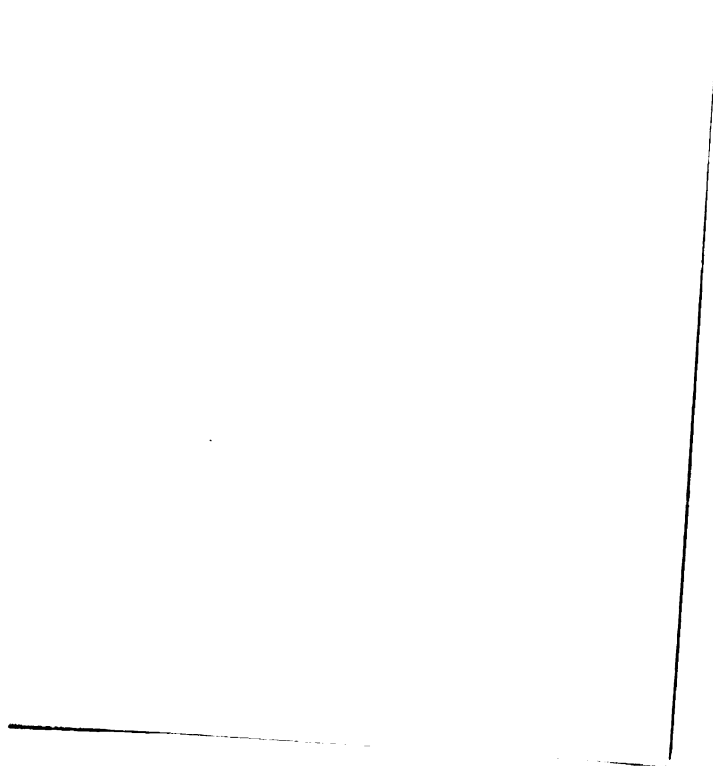
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