

THE EFFECT OF DIAMETER AND DEPTH OF SET  
UPON THE OVERTURNING RESISTANCE OF WOOD FENCE POSTS

by

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## INTRODUCTION

It is an accepted fact among agricultural authorities that fences are a major problem in the present-day farming schemes. In the colonial days farmers in some localities built their fences with stone because it was convenient to pile the stones from the fields on the boundaries. Split rail fences were a common sight, and the use of a hedge fence was a general practice. Land was relatively plentiful and cheap, and it did not matter so much if rail fences and hedgerows did occupy considerable of it. Too, the cost of manufactured fence materials was almost prohibitive, making the use of native materials necessary.

Since pioneer days, however, farming conditions have undergone many radical changes. At the same time, the materials used for fence construction have been subjected to an evolution, an evolution which has adapted itself to the changing farming practices as best it could. The present-day farmer does not have at his disposal an almost unlimited supply of native material with which to build fences, and he must incur an investment of money to secure these materials. To him, the question of adequately fencing his farm is a major economic problem.

A solution to this problem is a challenge to the Agri-

cultural Engineer; a challenge which is being felt more and more keenly. The Pressure Treated Fence Post Institute in cooperation with the Agricultural Engineering Department of Iowa State College sponsored a fellowship for the purpose of obtaining definite research data connected with the fence problem.

The purpose of this investigation was to study some of the problems presented by the line fence post.

## HISTORICAL

### The Project

Since the fall of 1939 the Pressure Treated Fence Post Institute has sponsored a fellowship in cooperation with the Agricultural Engineering Department of Iowa State College.

G. L. Hazen, the first research fellow, made both laboratory and field tests, using various fence end arrangements. M. D. Strong, the second research fellow, continued the work with the fence end arrangements, expanding to include corner constructions as well. The purpose of these tests was to analyze the structures from an engineering standpoint so that recommendations for fence end and corner constructions, based upon test data, combined with conventional practice, could be made. In addition, Strong made some preliminary studies of the line fence post.

### Review of Literature

As early as 1916 the problem of fencing had attained national prominence. Humphrey (7), in a government bulletin, makes the following statement:

"The enormous proportions which the farm-fence problem has assumed to the farmers of the United States can best be

shown by the use of figures given in the reports of the last census, combined with data obtained in the studies of this office. In 1909 there were 6,361,502 farms in the United States, averaging 138.1 acres each. It has been found that the average of 140 acre farm requires six rods of fence to the acre, or a total of 828.6 rods to the farm. This would mean that there were, in round numbers, 5,271,000,000 rods, or 16,472,000 miles, of fence in the United States in 1910. This amount of fence would encircle the earth about 659 times. To replace this with only a medium grade of woven-wire fence, a type which has been very commonly used by American farmers in the past, would cost, at the rate of sixty-five cents per rod for wire, posts, miscellaneous materials, and labor, \$3,428,241,362, which is 8.3 per cent of the total value of all farm property, 12 per cent of the value of all farm land, 54.1 per cent of the value of farm buildings, 69.5 per cent of the value of domestic animals, poultry, and bees on farms, and more than double the value of all implements and machinery on farms, according to the values estimated for these items by the last census. It must be borne in mind, however, that the figures represent the first cost of fences, while the census figures represent the present value of buildings and machinery. Therefore, the ratio will not be quite as great."

Again, in 1929, the problems of fencing were given prominence in an article by Lyman (9) presented to a meeting of Agricultural Engineers:

"It seems that fencing has seldom been regarded as a subject or problem of sufficient importance to warrant any considerable study on the part of agricultural research agencies, be they engineering or economic in character. When fence has been thought of, it has been to wonder how we might get along with less or do away with it entirely. It has taken its place in the minds of the farmer, the teacher and the research man similar to that occupied in the mind of a grocer by sugar and flour; a staple, necessary commodity, but nothing to get enthused over.

"Yet fence is almost as basic as the soil itself in most of our systems of farming and over the major part of our productive agricultural area. To the structures man fence is of great importance, for without fence there is but little need for the income-producing portion of farm structures. The magnitude of the fence problem at present is spotlighted by the fact that from 25 to 50 per cent of existing fences, averaging around 30 per cent the country over, are entirely inadequate to turn livestock."

Little data are available concerning the behavior of fence posts set in soil. However, some information is available concerning the load carrying characteristics of transmission line poles, and this information has served as a guide in preparing a program for an investigation. Large companies have seen the importance of having definite design

data for setting transmission poles, and as a result a number of analyses have been presented by different investigators.

Seiler (11) makes the following statement:

"For any pole of a certain strength and set in a given soil, there is a depth of embedment such that its strength will be just developed. If the depth is less than that, money is uselessly spent for a post whose strength can not be utilized. If the depth is too great, there is a waste of labor in excavating the hole for the pole. Considering the many uncertainties in the action of the soil, conditions which may cause wide variations in the capacity of a given soil, and other factors, it would be ridiculous to assume that any great accuracy could be secured in the attempt to determine a precise depth of set. However, even an approach to the correct or ideal depth would, without doubt, result in important economies to large consumers of poles."

With the increasing practice of contour farming, the problem of contour fencing is becoming more and more important. This is brought out by an editorial (3) which appeared in the Agricultural Engineering Journal in 1935.

"It was logical, and might well be prophetic, that an entire session of the Structures Division, during the 29th annual meeting of the American Society of Agricultural Engineers, was devoted to farm fencing. Taking the country as a whole, it seems sure that no other part of the farm plant is so far

gone into disrepair and disorganization. It seems equally obvious, in general, that few structural improvements are so quickly self-liquidating.

"While there are piece-meal contributions to sundry detailed phases of farm fencing, there is no orderly literature covering the subject in a way both comprehensive and soundly technical. No one can, with any assurance, define what is an optimum fence for a stated situation. Fencing evidently is a vernacular art not well organized empirically, much less engineered on a foundation of basic studies. As such an art it has been more efficient than could be expected--another testimonial to the judgment and resourcefulness of the American farmer.

"Several developments now dictate a dignified program of fence engineering. One consists of technical advances by fence manufacturers during the years that fences(as farm plant) retrogressed. These are mainly metallurgical improvements (sic) to achieve longer fence life. In this phase of fencing industry is doing its part, and it is logically about as far as the province of industry goes. Determination of optimum height, spacing, wire size, etc., in relation to service requirements would seem to be a job for agricultural engineers and animal husbandmen.

"While it has not progressed as might be wished by our profession's participants therein, the ASTM program of fence-testing creates an occasion and should afford data for

accelerated activity in fence engineering. Terracing and other phases of soil conservation, and indeed all land-use progress, create new need for fencing, or need for new fencing.

"Though its work was brought to an untimely end by economic troubles, the Farm Fence Institute lived long enough to demonstrate the need for fence engineering as a form of farm management, and that farmers were not really so indifferent to fencing as fence sales curves might seem to indicate. Whether that Institute or something akin to it should be given another chance in a more normal economic atmosphere, is not for us to suggest. We do believe that the engineering work, both research and extension, toward which it pointed should be promptly organized and systematically pursued."

The fact that there are possible means for setting line posts other than the conventional method of digging a hole larger than the post to be set and then tamping the loose soil around the post was demonstrated on the Tri-county Project (2) along the Union Pacific Railroad right-of-way in Nebraska. The following is an account of the experiment:

"The usual method of setting and tamping posts in dug holes was discarded in setting 17,000 creosoted posts along the Union Pacific Railroad right-of-way in Nebraska recently, when it was found that 3-inch diameter round posts could be sharpened and driven 2.5 feet deep in the average soils of

that region in about two minutes by one man equipped with a 37 lb. driver. The driver was designed for this particular purpose, and specifications covering the installation of the posts were based on tests made last year under the supervision of engineers from the railroad and the Central Nebraska Public Power and Irrigation District, in which these posts are located. The posts were not damaged by the driving and were more firmly fixed in the ground by this method than by the usual method of digging and tamping in place. Five 2-man drivers were used, and the posts were set rapidly and satisfactorily.

"The posts were lodgepole pine, pointed at the treating plant with an electric motor-driven sharpener, and then given an empty-cell treatment with a final retention of 6 lbs. of Grade One creosote per cubic foot of wood. The specifications contained the following provisions:

"Line Posts. - Shall be 3-inch diameter, minimum allowed 2 1/2 inch; length 6 feet, 6 inches; the small diameter end to be pointed before treatment for driving, taper point to be 6 to 8 inches in length.

"Corner Posts - Shall be 5 1/2 inch diameter, minimum allowed 5 inch; length 8 feet.

"Corner Brace Posts and Intermediate Brace Posts - Shall be 5 1/2 inch diameter, minimum allowed 5 inch; length 6 feet, 6 inches.

"All corner and brace posts and intermediate brace posts

shall be formed for braces before treatment and shall be notched 1 inch deep for braces; top of horizontal braces shall be 7 inches below top of posts; braces shall be 4 1/2 inch diameter, minimum allowed 4 inch.

"All line posts must be driven. Corner posts and brace posts may be furnished without pointing and may be set by hand, or they may be pointed before treatment with a taper 8 to 10 inches long and driven. Corner posts and brace posts pointed for driving must not be set by hand...."

Giese (4) makes the following statement regarding line posts:

"Wood posts should be set six inches deeper in the ground than required for steel posts under ordinary soil conditions. Steel posts, if not used exclusively, may be alternated with the wood posts to advantage. Used in this manner, the steel posts are usually placed on the opposite side of the fence from the wood posts. The steel posts reduce the labor required for setting the posts and, because of the grounding effect on the fence, reduce the danger of lightning damage to livestock.

"Fences supported by wood posts only should be grounded at 8 or 9 rod intervals by the use of short lengths of steel posts tightly attached to the fence and set deeply enough to reach permanent moisture."

In a bulletin published for use by farmers, Kelley (8) gives the following information:

"The size of wood posts varies considerably with the strength and durability of the species used. Line posts of Osage-orange are sometimes as small as 2 1/2 inches in diameter. With other wood line posts are commonly 4, 5, or 6 inches, and corner posts and gateposts 8 to 12 inches in diameter. The least dimension for split posts is usually not less than 5 inches. Large posts usually last longer than smaller posts of the same wood.

"Posts usually are set 2 1/2 feet in the ground and extend about 6 inches above the top wire. The over-all length, of course, depends on the height of the fence but is generally 7, 7 1/2 or 8 feet for line posts, while gateposts and brace posts are of sufficient length to meet the service required."

In general, due to the development of preserving methods, the tendency has been to reduce the size of the commercial wood post. However, definite design data for these posts are still lacking.

## EXPERIMENTAL

### Laboratory Tests

#### Introduction

One of the major reasons for the lack of adequate fences on the farms of America today is the necessary labor involved in the proper construction of these fences. An important attempt to reduce the labor of setting line posts has been made with the introduction of the steel post. Since there are thousands of steel posts in use this may be considered an indication of their success. The fact that a treated wood post of equal or greater strength may be purchased more cheaply than a steel post has led to investigations of possible methods for reducing the labor involved in setting the wood post.

Because the season was entirely unsuitable for field work, an effort was made to conduct some laboratory tests which might serve as a guide to field tests. Too, it was felt that certain variables which occur in field operations could be eliminated in the laboratory tests.

Objects of tests

The objects of the laboratory tests were as follows:

- (1) To check the equipment which had been built for securing data in field tests.
- (2) To compare steel and wood posts.
- (3) To study the failure of model end constructions.
- (4) To compare various points on wood posts.

Equipment used

Deflectometer. Two items of interest in testing a post for stability are deflection and load increment. Loads are relatively easily secured by use of dynamometer readings or by known dead weight applications on the pull line, but measuring deflection at a number of points simultaneously presents a problem. It is felt that five points are necessary to give a true picture of what happens as a post is pulled over, since some bending will occur. The first of these points is located at the ground surface, and the remaining four points are spaced at one foot intervals above the ground surface. The top and bottom points will show deflections of the post being tested, and the intermediate points will show any bending which might occur.

Another important item to be considered in taking data is the time involved. Since it is necessary to complete as many tests as possible in the shortest time possible, a

method for recording data quickly is almost essential. In an effort to solve the problem of recording data quickly a device known as a deflectometer, shown in Figure 1, has been designed and constructed.

The framework of the deflectometer is constructed of 1" x 1" x 1/8" angle iron fabricated with 3/16" machine bolts to permit changes to be made easily.

The recording board is made of four-ply plywood treated with dark oak stain, and is mounted on two round pin hinges to permit movement in a vertical direction and also to allow the board to swing horizontally. This board is held in place during a test by a small latch on the frame. The vertical movement is utilized to make vertical interruptions in the horizontal progress of each recording pencil, and is obtained by a manually operated lever arrangement. These vertical interruptions represent load increments. The horizontal movement of the board permits changing of pencil leads and data sheets.

All data sheets are carefully hand punched to register on two round pins fastened to the recording board, and are also clamped under a bar to prevent any possible movement during a test.

Carefully filed notches in the frame exactly one inch apart hold the pencil bars in place. Since the bars are rectangular, they can slide horizontally but cannot twist or move vertically. The pencil bars are made of 1/4" x 1/8"

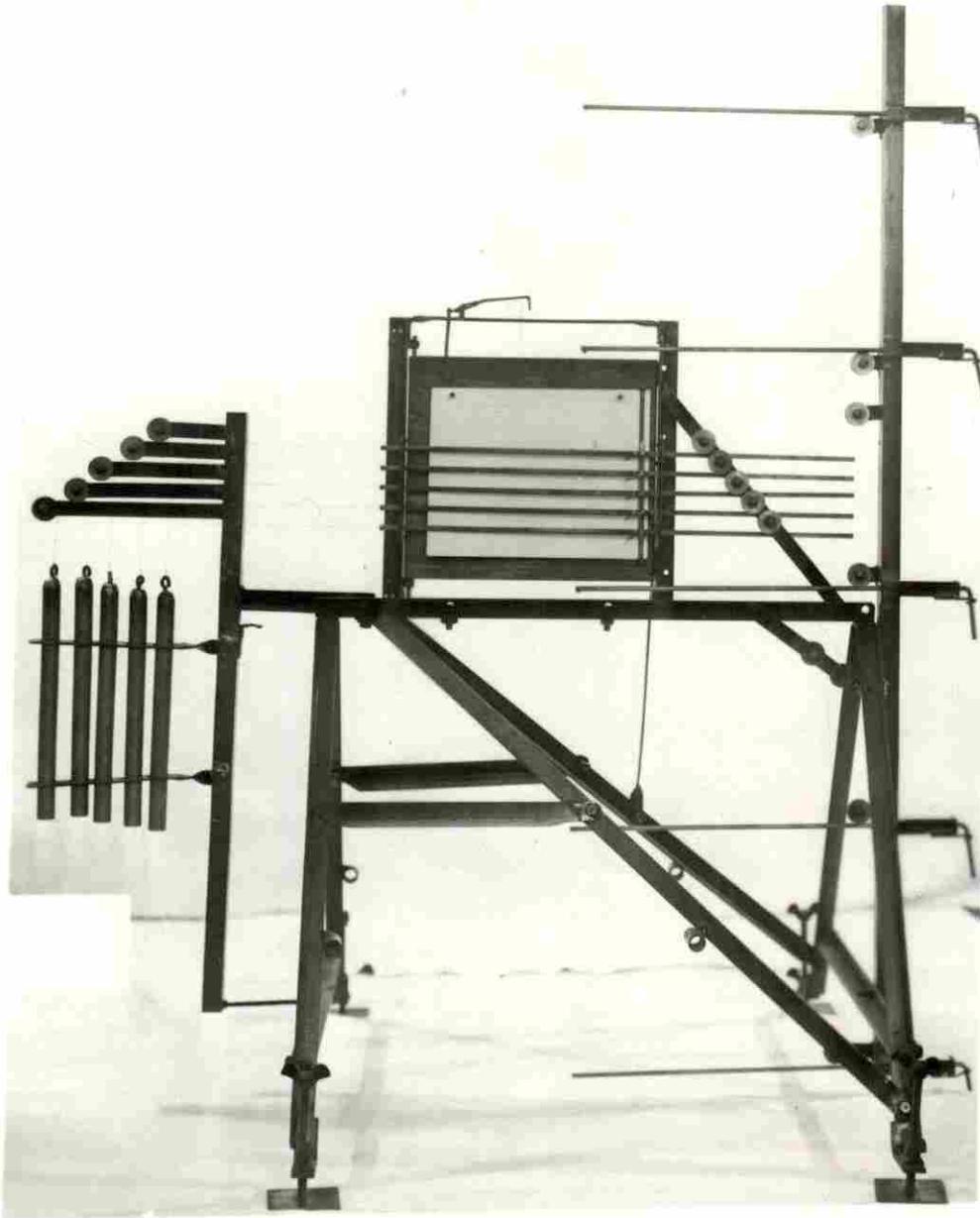


Fig. 1. Deflectometer.

cold rolled steel, and the lead holders were obtained by removing the points from five autopoint pencils, and soldering these points into holes drilled in the bars. Autopoint pencil points are made in such a way that the lead must be forced through the point due to a clamping action at the extreme end of the point. While this was an undesirable feature, an examination of other types of mechanical pencils showed that the leads were not held firmly enough by the points. The clamping action was eliminated by drilling through the points with a very small drill, and enough material was removed from each point to allow a lead to fit quite snugly, but still move freely. By means of special plungers and small rubber bands the leads are forced against the recording board. A small brass binding post on the end of each pencil bar permits individual setting of each pencil to any position on the recording page.

Five small diameter piano wires, because of their extreme flexibility and high tensile strength, transmit the deflections of the points on the post being tested from the follow rods to the pencil bars. These wires are mounted on small brass pulleys to produce changes of direction, and each wire has a two-pound weight fastened on one end, the other end being attached to a 1/4" cold rolled follow rod. The weights were made by cutting equal lengths from a 1" cold rolled steel rod, and they not only keep equal tension on each wire, but they also provide the necessary force for

pulling the pencil across the recording sheet and keeping the follow rod against a nail driven into the post.

The follow rods are spaced 12 inches apart and each one is supported at two points. The end of each follow rod, which rests against a nail driven in the post, is bent in a vertical direction to permit vertical movement of the post without influencing the recording of the horizontal deflection. There is no fastening between the post being tested and the deflectometer. This is an important feature because in case a post should break during a test, the deflectometer will not be damaged. The follow rods and pencil bars are of such length to permit the maximum recording of 10 inches of deflection for any one of the five points. The data sheets are placed on the recording board upside down; the reason for this being that the pencil which records the deflection of the point 4 feet above the ground is located at the bottom of the recording board. Therefore, when the sheets are removed from the board and turned right side up, the deflection of the highest point on the post appears at the top of the sheet and reads from left to right. The remaining four deflections occupy relative positions below this top one. A special bolt attached to each leg of the deflectometer and resting against a small steel plate on the ground provides adjustment of the instrument for small irregularities in the ground surface.

Thus, the deflectometer simultaneously records, by actual measurement, the deflections of five separate points on a post. In addition, the deflectometer records load increments which cause corresponding deflections. Too, the distances between the lines of deflections are recorded on the sheet to the scale of 1 inch equals 12 inches; therefore, a line drawn through corresponding load increments will represent, to scale, the true position of the post as it was tested. By a continuation of the line thus obtained, the point, or series of points, below the surface of ground about which a post rotates as it is overturned, can be quite accurately determined.

Dynamometer. In general, a test load may be placed on a structural member in two ways. First, a load may be developed by a combination of levers, jacks, or some mechanical combination; and second, a load may be produced by actually applying weight to the member. In the first case, some method or instrument must be had which will accurately measure the load, while in the second case the load will be equal to the weight applied. After considering the possibilities of both methods, it was decided that the simplest and most effective method would be to develop a dead weight dynamometer.

(Fig. 20)  
The dynamometer consists of a frame supporting a pulley wheel mounted on double ball bearings, a weight basket, a

rope attachment between the dynamometer and the post to be tested, and a number of weights. This dynamometer is designed to safely withstand a 1000-pound load on the weight basket, and it is so constructed that the resultant of the vertical and horizontal forces, produced in the rope by the weights, is transmitted through the single front leg, and onto a bearing plate which rests on the ground. A piece of sharpened 1" x 1" x 1/8" angle iron about six inches long welded to the bearing plate prevents any forward slipping of the device.

Black iron pipe was used in the construction of the frame, the front leg being 1-inch diameter and the two rear legs are 1/2-inch diameter pipe. A brass pulley wheel, mounted on double ball bearings, serves to transmit the vertical load from the weights to a horizontal force on the post being tested.

A weight basket was constructed of angle iron in such a manner that rectangular weights could be placed on it in layers. Each layer contains a maximum of eight weights.

Lead, because of the ease with which it can be cast, and because of its density, was utilized in making the weights. One thousand pounds of lead were purchased in 100-pound ingots, and this was cast into 10 and 20-pound rectangular weights. The lead was melted in a trough constructed by welding two plates on the ends of a piece of

8-inch steel pipe which had been cut in half in a longitudinal direction. This trough was set directly over a forge fire and was of sufficient capacity to hold 200 pounds of molten lead.

Casting the weights presented no serious problems. Figure 2 shows the melting trough, ladle, and weight form. Angle iron, 2-1/2" x 2-1/2" x 3/16", was used in making the sides of the form, and a piece of 3/16" flat steel plate was used for the bottom. The sides were welded together, and the bottom was held in place by two large clamps when the molten lead was poured. No special effort was made to tape the form, and no difficulties were encountered in removing the weights from the form. By filling the form full, a 20-pound weight was cast, and by filling form half-full, a 10-pound weight was formed. All weights were checked on a scale immediately after casting to be sure they were slightly overweight. By drilling 1-inch holes in the weight, any excess weight was removed, giving the exact weight desired. A picture of the form, preparatory to casting, weight, and some completed weights is shown in Figure 3.

Post driver. One piece of equipment which did not need to be built is the post driver. This driver was built by Strong (13), but was used to drive only two posts. The idea involved in the design of this driver was to suspend a weight a certain distance above the post being driven and allow the weight to drop, thus driving the post into the ground. This

type of arrangement necessitated a trip which would cause the weight to fall the same distance each time it was tripped, regardless of how deep the post might have been driven by previous blows from the weight. Preliminary tests were made with weights and sledge hammers to determine how heavy the weight should be made. It was decided that a 70-pound weight dropped 18 inches was comparable to an average 6 or 8-pound sledge blow.

The weight consists of a 6-inch pipe about 12 inches long with a square plate welded on the bottom and filled with lead to give a total weight of <sup>86</sup>nearly 80 pounds. This weight is guided by two sleeves fitting over two of the four vertical pipes which serve as a framework for the driver. The weight was raised by a drum and crank arrangement, and tripped by means of a lever arrangement, which was attached to the post being driven.

This driver was used to drive two posts, and the following troubles were encountered:

- (1) The weight did not drop smoothly; neither did it lift smoothly.
- (2) The trip did not work satisfactorily because too much force was required to operate it.
- (3) The drum was too large and the crank too small. It was difficult for one man to lift the weight.
- (4) The trip did not raise or lower freely.
- (5) The wire rope used to raise the weight had a

tendency to jump off the pulley at the top of the driver, ten feet above the ground line.

Upon redesigning the driver the following changes and additions were made:

- (1) The pulley at the top of the driver was fitted with a cage, preventing any possibility of the pull line coming off.
- (2) The original trip was discarded. The new trip consists of a hook, welded firmly to the weight; a ball bearing, mounted on a shaft between two short pieces of strap iron; and a lever arrangement fastened to the hook to push the bearing off the hook. The two pieces of strap iron holding the bearing are suspended freely on the end of a 1/4" rope which serves as a pull line. In lifting the weight, the bearing is placed in a small recess in the hook. To trip the weight, a lever arrangement with a mechanical advantage of about 8:1 pushes against the strap irons holding the bearing, causing the bearing to roll out of its seat. Once the bearing is moved, it leaves the hook, allowing the weight to drop. A force of less than two pounds will trip the weight. A small head chain, because of its flexibility, serves as the connection between the post and the trip lever. By stapling

the end of the chain to the post, the weight is caused to fall exactly the same distance each time it is tripped.

- (3) A 1/4" manila rope is used in place of the original steel cable.
- (4) A 2-1/2" drum with a 10" crank was attached. The weight is easily lifted with one hand in less than four revolutions.
- (5) A ratchet was mounted on the drum to permit the weight to be held at any height.
- (6) The sleeves guiding the weight were reamed 1/8" larger. The weight moves extremely freely, and it is unnecessary to grease the guides.

Soil, box, and platform. Even though results obtained in laboratory tests are sometimes not accepted to be as reliable as field tests, this type of testing is very often valuable in determining procedures for field operations and also provides a method for controlling certain variables more closely than they might be controlled in field testing. Until such time when the weather would permit field tests, it was felt much could be learned from laboratory testing. The laboratory testing was conducted in a soil box surrounded by a platform designed to support the testing equipment.

The box was constructed of 2" x 8" lumber, and was three feet long, two feet wide, and three feet deep. One end of the box was constructed so that the end boards could be

slipped in or out between cleats which were nailed to the sides of the box. This was to facilitate in loading and unloading soil from the box.

Surrounding the box was a platform constructed of 2-inch lumber, the top being the same height as the top of the box. The platform was constructed 11 feet long and five feet wide, giving ample room for the deflectometer, driver, and dynamometer to be set on it.

When selecting the soil for the box, the following things were kept in mind:

- (1) That the soil should be friable enough to prevent excess clodding when air-dried.
- (2) That the soil should pack or tamp firmly when moistened.
- (3) That the soil should be uniform with reference to particle size--no gravel or excessive colloidal content.

After considerable searching, a soil used in making a fill on one of the Engineering Experiment Station plots north of the Iowa State College campus was selected. A small sample of this soil was brought into the laboratory and allowed to air-dry. Observation indicated that it had a tendency to be quite loose and friable. Since the soil sample showed it would not clod upon drying, the next step was to determine the behavior of the sample when moistened. A

portion of the sample was put into a pan and enough moisture added to cause the soil to hang together when placed in the hand and squeezed. This portion of the sample was then weighed, dried on an electric hotplate, and reweighed to determine the moisture content. Several trials were made in this manner to see how accurately the same percentage of moisture could be obtained by visual inspection. The results indicated that a moisture content of 12 per cent, based on dry weight, seemed to give the best working qualities to the soil.

Figure 6 shows a particle size accumulation curve for this soil determined from the method outlined by Hogentogler (6). This method consists of a mechanical sieving of the soil combined with a hydrometer analysis. The equipment used in the hydrometer analysis was developed recently by Doctor G. J. Bouyoucos, and the theory upon which the analysis is made is based upon the speed of settling of particles which are suspended in water. Other properties which were determined for the soil used in the laboratory tests are:

Hygroscopic moisture content	2.25%
Plastic limit	15.53%
Liquid limit	23.20%
Plastic index	7.67

Using the properties of the soil as determined by the laboratory tests, and referring to the textural-classification chart as given by Hogentogler (6), the soil may be classified as sandy loam. Hogentogler (6) makes this statement about a

sandy loam soil:

"A sandy loam is a soil containing much sand but having enough silt and clay to make it somewhat coherent. The individual sand grains can readily be seen and felt. Squeezed when dry, it will form a cast which will readily fall apart; if squeezed when moist, a cast can be formed which will bear careful handling without breaking."

Penetrometer. In order to have a control over the degree of compactness of the soil used in the laboratory box, an instrument known as a Rototiller Soil Penetrometer was used. This penetrometer was designed by Stone and Williams (12) and was used by McKibben and Hull (10) in a study of wheel loads and rolling resistance.

The penetrometer consists of a 1 1/4-inch metal tube, 55 inches long, with a ten inch square metal base welded on one end. The base has a hole drilled in it so there is an unobstructed opening from one end of the tube to the other. By placing the tube on the soil to be tested, dropping a conical point down the tube into the soil, and reading the depth of embedment of the point, a relative degree of compactness can be determined for the soil. The conical point ranges in size from a small blunt point at the lower end to 1-1/8 inches in diameter at the other end. It is 22 inches long, weighs three pounds and three ounces, and has graduations at one inch intervals to facilitate in reading depths of embedment.

A picture of the laboratory equipment prior to filling the box with soil is shown in Figure 4.

Specimens used

Wood posts. Five pressure treated wood posts 3-1/4 inches in diameter were used in the laboratory tests. Conical points were put on these posts by placing one end of a post in the chuck of a machine lathe and supporting the post about 16 inches from the other end with a center rest. The points had the following lengths: twelve, eight, six, four, and two inches, the length being measured on the length of the post and not on the slant height of the cone. These five points<sup>s</sup> are shown in Figure 5.

Steel posts. Since there are a large number of both wood and steel posts in use, it was felt a comparison should be made between steel and wood posts. Four different designs of steel posts were selected as representative of the steel posts available at this time. These posts are shown in Figure 7. It should be noted that in every case there is a plate of some design attached to the post. Further, it is interesting to note that in every case the top of the plate is very near a point 18 inches from the bottom of the post.

Model end constructions. A general practice in fence construction is to place the load, due to tension in the fence wire, on the end post of an end arrangement. Thus, in

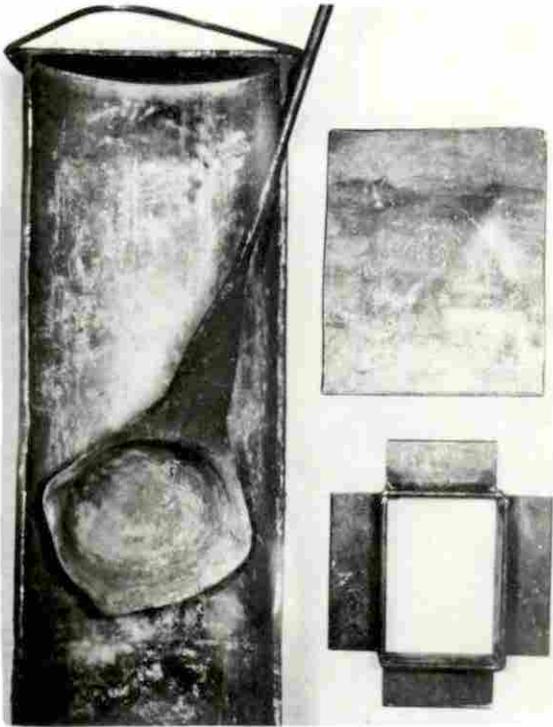


Fig. 2. Ladle, Trough, and Form

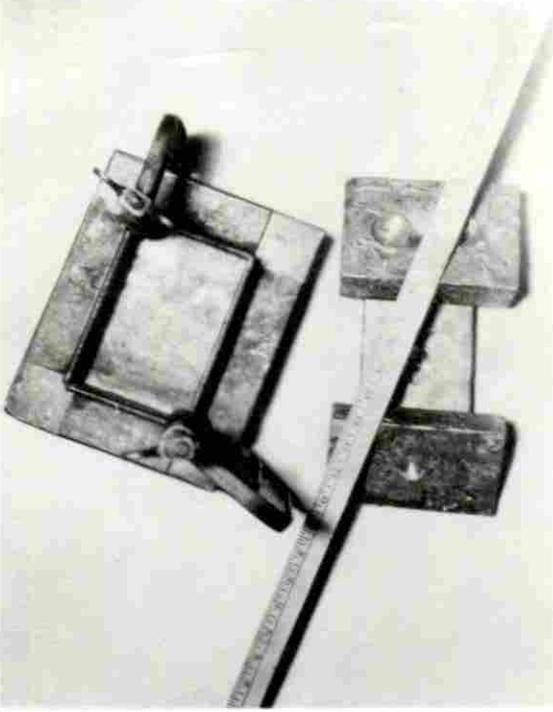


Fig. 3. Weights and Form

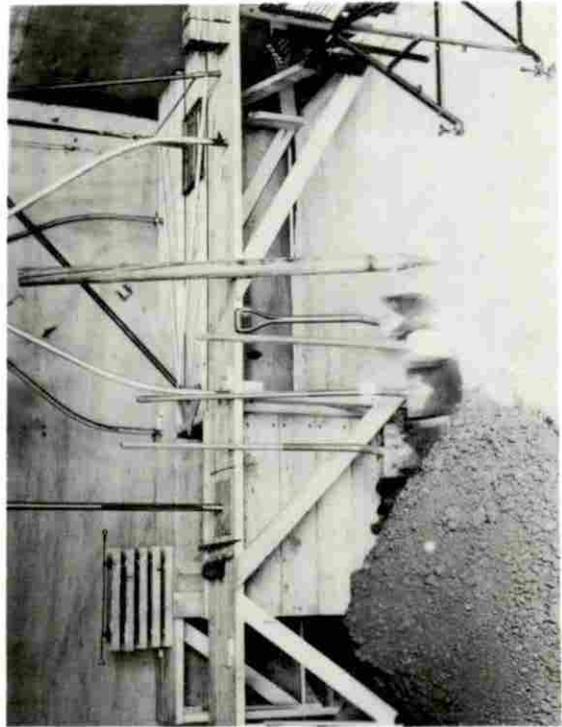


Fig. 4. Laboratory Equipment

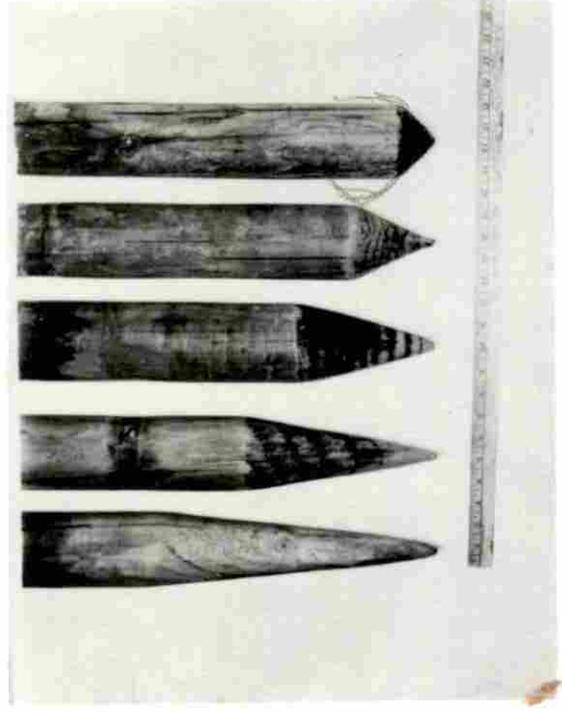


Fig. 5. Wood Post Points

general, the main portion of the load must be distributed to the soil through compression members. Theoretically, if the load were placed on the front post of an arrangement instead of on the end post, the arrangement might conceivably withstand more load since the tendency for it to buckle when in compression would be eliminated. Since end arrangements are statically indeterminate, perhaps the best way to analyze their behavior is by testing.

Three models were constructed to be used in the laboratory box. The models were made of steel rod and bead chain. All joints not hinged were welded together, and provisions were made to load any of the three vertical posts. The models were made to the scale one inch equals eight inches, making them 24 inches long and 11-1/4 inches high when assembled. These models are shown in Figures 8, 9 and 10.

#### Methods of procedure

Method of moistening soil. After considerable manipulation of the soil used in the laboratory box, it was found the best way to add moisture to the soil was to punch several holes in the soil when it was compacted in the box. These holes were made with a 1/4-inch diameter length of pipe, and were made vertically. Water was poured into these holes and allowed to remain overnight. The holes were made different depths to distribute the moisture as evenly as possible, and it was found the moisture content could be controlled very

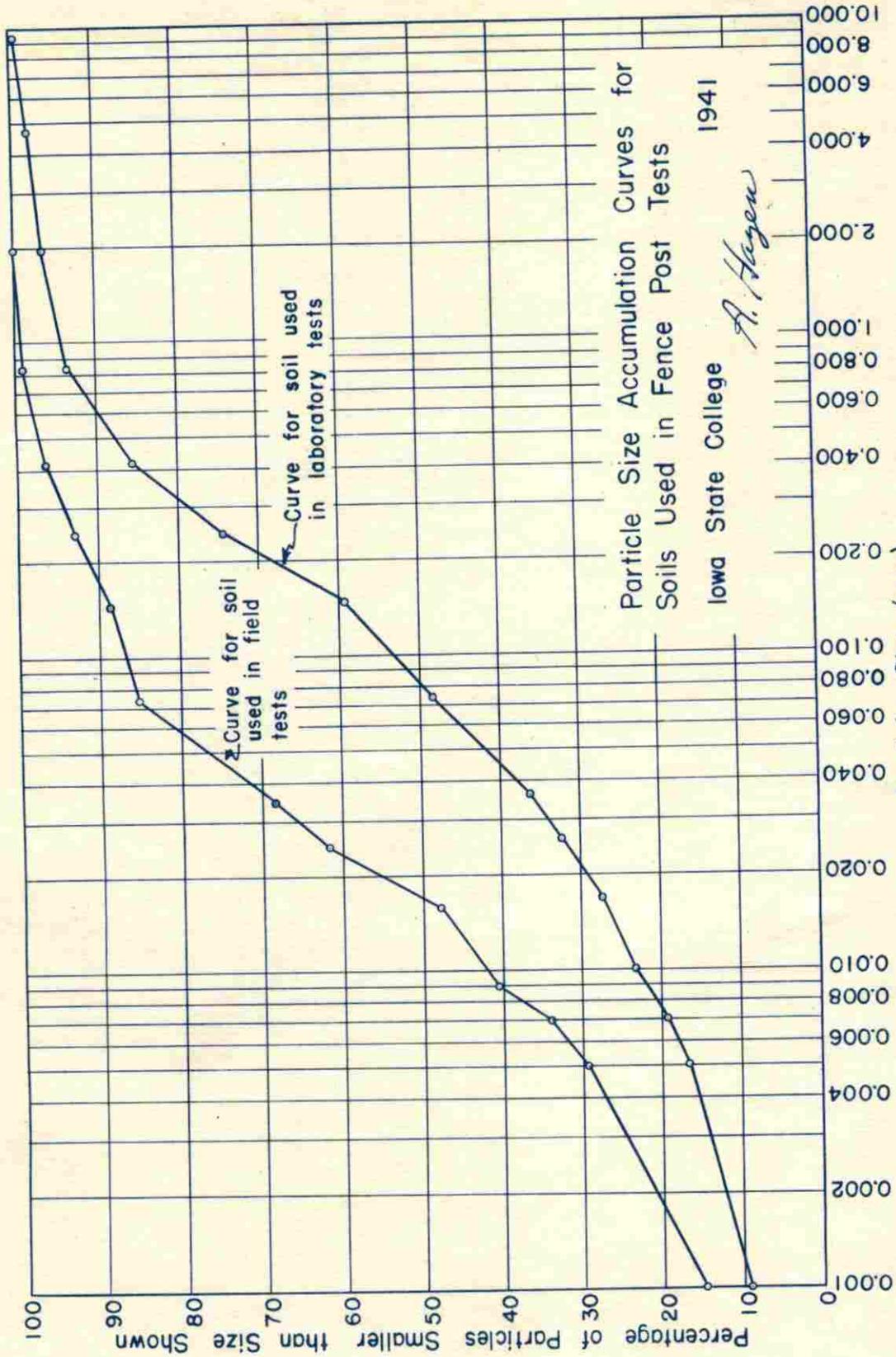


Fig. 6. - Particle Size Accumulation Curves

closely by this method. The amount of water to be added was determined by visual inspection and moisture determinations. Attempts to add moisture to the soil when in a pile on the floor resulted in small balls of wet soil and large quantities of dryer soil. The soil was left in the box and covered with damp burlap when not in use, and under these conditions it was not necessary to add moisture more than twice weekly, even when the soil was used daily.

Method of tamping soil. The soil was placed in the box in layers eight inches deep. Each layer was tamped with a small concrete tamper weighing 14 pounds, and the degree of compactness was maintained by a reading of four inches with the penetrometer. The operator had little difficulty in maintaining a constant degree of compactness after a slight amount of experience.

Method of setting and pulling posts. The 3-1/4 inch wood posts were driven in the laboratory box with the post driver. Data were taken in order to determine the relative merits of each different point. The steel posts were driven, but no data were recorded since they drove very easily. Each of the steel posts was tested with and without the plate attached to determine the value of the plate. All wood posts were set at a depth of 24 inches and the force for overturning was applied at a point four feet three inches above the ground line. Loads were recorded in 10-pound increments, and the time interval each load increment occupied was held as nearly

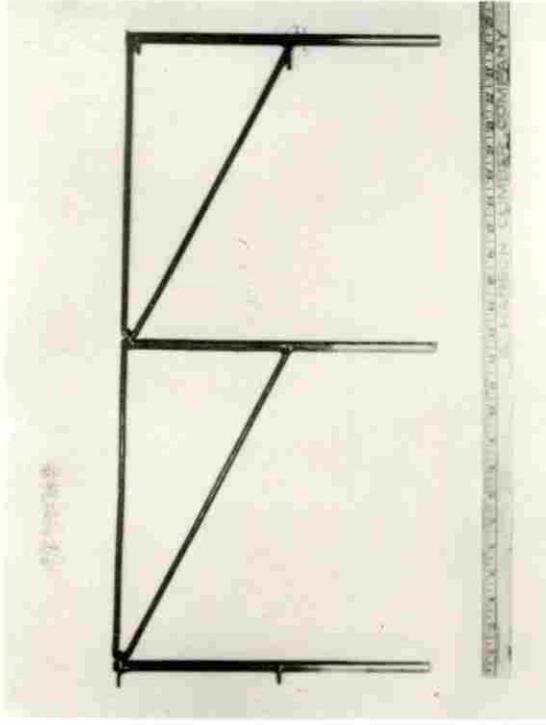


Fig. 8. Model End No. 1

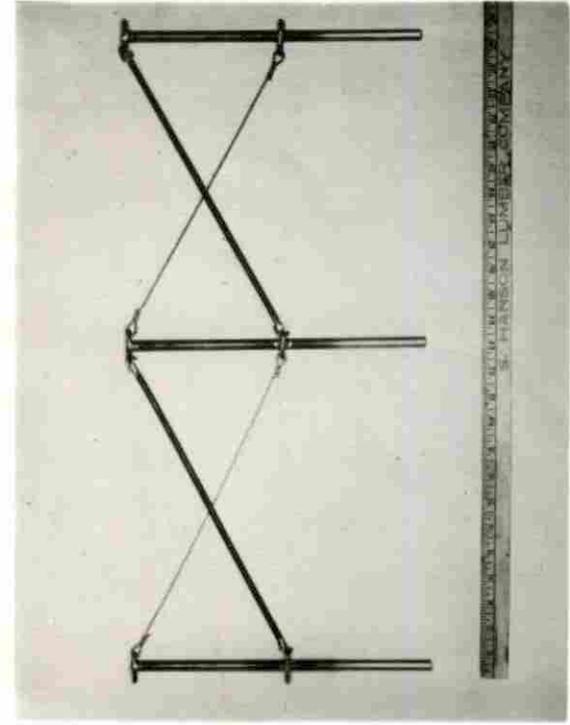


Fig. 10. Model End No. 3

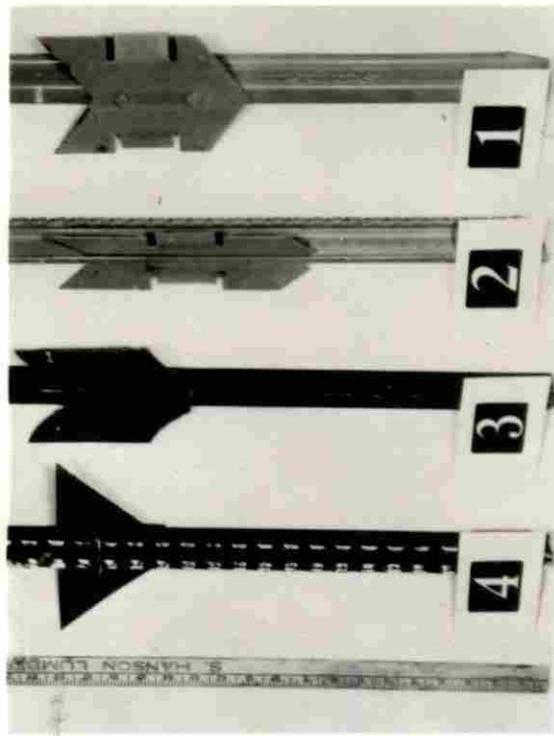


Fig. 7. Steel Posts

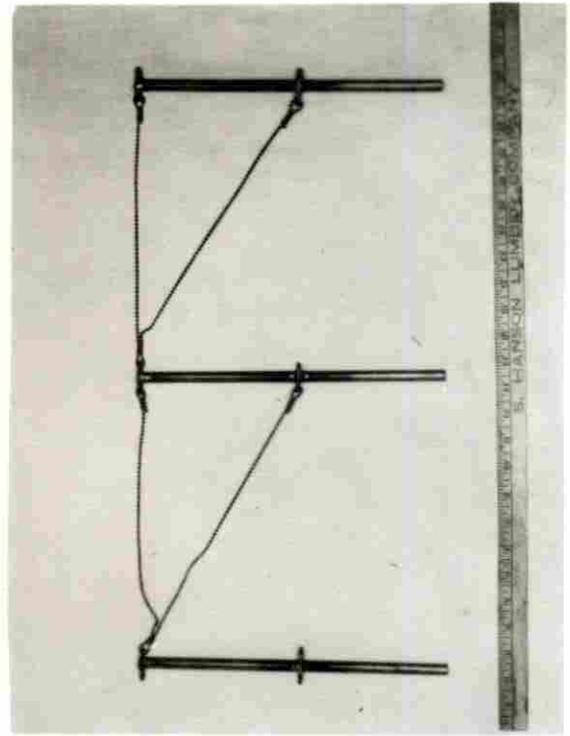


Fig. 9. Model End No. 2

constant as possible. This time interval was about eight seconds. Each time a post was tested the soil was taken from the box and retamped for the next test. Figures 11 and 12 show typical laboratory tests of a wood and a steel post respectively.

Method of setting and pulling model end arrangements.

Tests were conducted with the model end arrangements by pressing the vertical posts into the soil and applying equal loads at the ground line and at a point six inches above the ground line. The loads were applied by means of a special boom built on the platform. A rope was passed through a pulley and the two ends passed over two pulleys in the boom and attached to the two points on the post of the end arrangement. The weight basket from the dynamometer was attached to the free pulley and lead weights placed in the basket to produce the load. Any weight in the basket was thus divided equally between the top and the bottom of the post. A model end arrangement just before testing is shown in Figure 13. Sufficient loads were applied to each arrangement to cause complete rupture of the soil.

Results of laboratory tests.

Wood posts. Data taken from 30 tests using five different posts, each 3-1/4 inches in diameter, and having conical points of twelve, eight, six, four and two inches in length gave these results:

- (1) The number of 10-inch blows from the 85-pound weight of the driver necessary to set a 3-1/4 inch post 24 inches deep varied as follows:

<u>Length point</u>	<u>Number of blows</u>
12"	20
8"	24
6"	36
4"	34
2"	36

- (2) The loads necessary to produce ten inches deflection at a point four feet above the surface of the ground varied as follows for 24 inches depth of set:

<u>Conical point</u>	<u>Load</u>
12"	103#
8"	120#
6"	145#
4"	115#
2"	130#

- (3) The point, or series of points, beneath the ground surface about which the posts rotated were recorded as follows for 24 inches depth of set:

<u>Conical point</u>	<u>Distance</u>
12"	10" to 11"
8"	12" to 13"
6"	13" to 14-1/2"

4"                      13" to 14-1/2"  
 2"                      13-1/4" to 14"

Steel posts. As was stated before, the steel posts were tested both with and without the plates attached to determine the weight per unit length of post, and also to determine the length of post represented by the weight of each plate. The results were as follows:

Post & plate no.	Wt. post (ounces)	Wt. plate (ounces)	Length post (inches)	Post wt./inch (ounces)	Length post in plate (inches)
1	122	110	72	1.53	7.84
2	145	131	72	1.82	7.69
3	149	133	72	1.85	8.64
4	152	139	72	1.93	6.73

Note: Post numbers refer to Figure 7.

The results of the tests conducted with the steel posts are as follows:

Post no.	Depth set (inches) With plate	Depth set (inches) No plate	Weight necessary for 10" deflection (pounds)
1	18	18	60
		24	40
			90
2	18	18	50
		24	40
			80
3	18	18	60
		24	40
			70
4	18	18	60
		24	70
			70

Note: Post numbers refer to Figure 7.

Model end arrangements. Three model end arrangements were tested to see whether loading the front or center post

of a two span arrangement would produce different load characteristics than would be obtained by loading the end posts. The results of these tests are as follows:

<u>Arrangement No.</u>	<u>Rupture load</u>
1 (Figure 8)	70# to 100#
2 (Figure 9)	70# to 100#
3 (Figure 10)	130# to 140#

### Conclusions

Conclusions based upon data and observations compiled during the laboratory tests are presented below:

- (1) While there is apparently little difference in the number of blows necessary to drive a post with a two, four or six inch point, it has been observed in driving the posts with the two and four inch points that holes larger than the diameter of the post were formed. This was not true for any other point tested.
- (2) There is little difference between the points of rotation below the surface of the ground of the posts with two, four or six inch points. In any one test the points move from the upper limit to the lower limit.
- (3) The most stable wood post after driving and before loading is the post with the 12-inch point, and the

- least stable is the post with the two inch point.
- (4) Steel posts display excellent driving qualities.
  - (5) The longer post without a bearing plate can be set more easily than a post with the bearing plate.
  - (6) The bearing plates tested will increase the stability of the post, but not so much as when the post is lengthened by the amount of material in the bearing plate and set deeper.
  - (7) In loading the end arrangement, Model No. 1 (Figure 8), with the load applied to the end post, the arrangement failed suddenly due to buckling at the center post.
  - (8) Little difference in the rupture load could be detected between loading Model No. 1 at the center and front posts and loading the end post. The arrangement failed as a unit and was gradually pulled out of the ground when loading the front and center posts.
  - (9) The vertical loads necessary to produce rupture with this arrangement varied from 70# to 100# and this variation occurred in such an erratic manner as to discourage any definite conclusions as to comparative rupture loads.
  - (10) These tests indicate no advantage in loading the front or center posts of Model No. 1 because

failure occurred gradually, while in loading the end post the failure occurred suddenly.

- (11) Model No. 2 (Figure 9) was constructed to indicate the compression and tension members in Model No. 1. Upon testing, it was found that the horizontal and diagonal members in the front span and the diagonal member in the rear span were tension members. The horizontal member in the rear span was a compressive member.
- (12) Model No. 3 (Figure 10) required loads between 130# and 140# to produce rupture when the loads were applied to the center post. If the soil conditions were nearly the same in all tests, this arrangement displays the best load resisting qualities of any of those tested. Model No. 3 failed gradually and as a unit.
- (13) Any tests conducted in the laboratory should be repeated under field conditions.

#### Summary

Laboratory tests are very valuable in determining field procedures and for testing equipment when weather conditions will not permit field tests. The equipment used in these tests consisted of a deflectometer, post driver, dynamometer, penetrometer, soil, box and a platform. Tests were conducted using wood posts, steel posts, and model end arrangements.

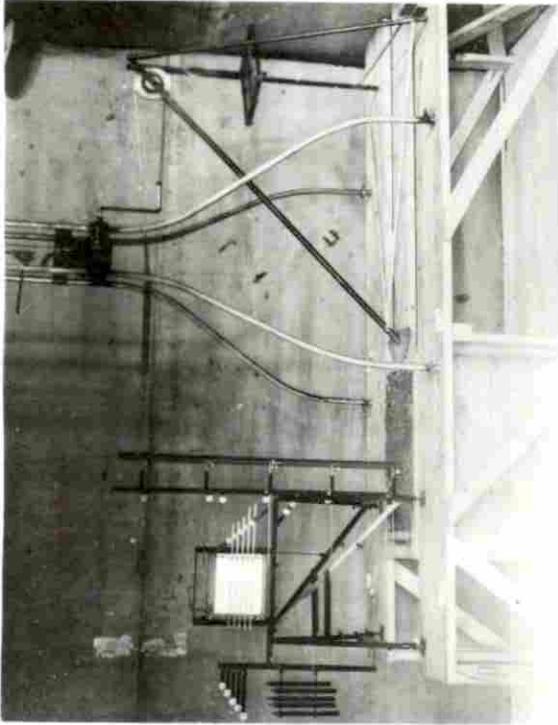


Fig. 12. Laboratory Steel Post Test

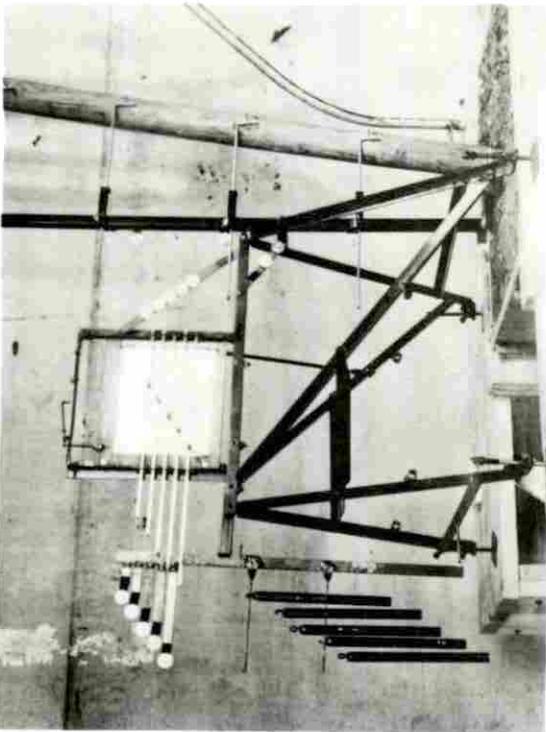


Fig. 11. Laboratory Wood Post Test

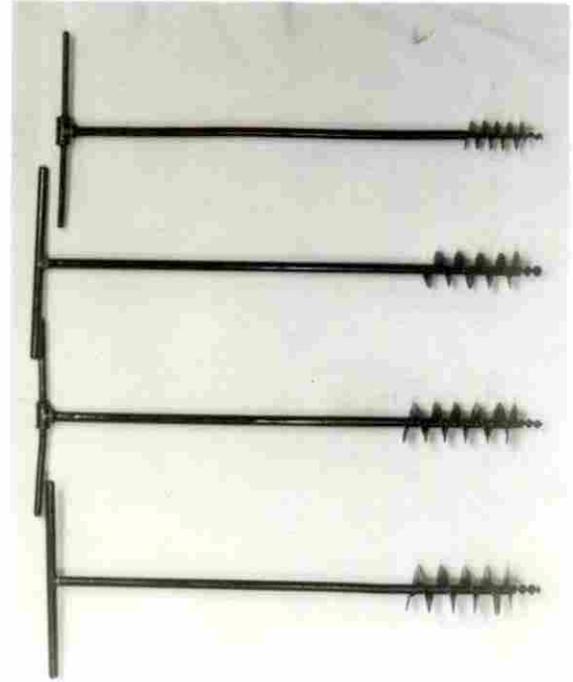


Fig. 14. Post Hole Augers

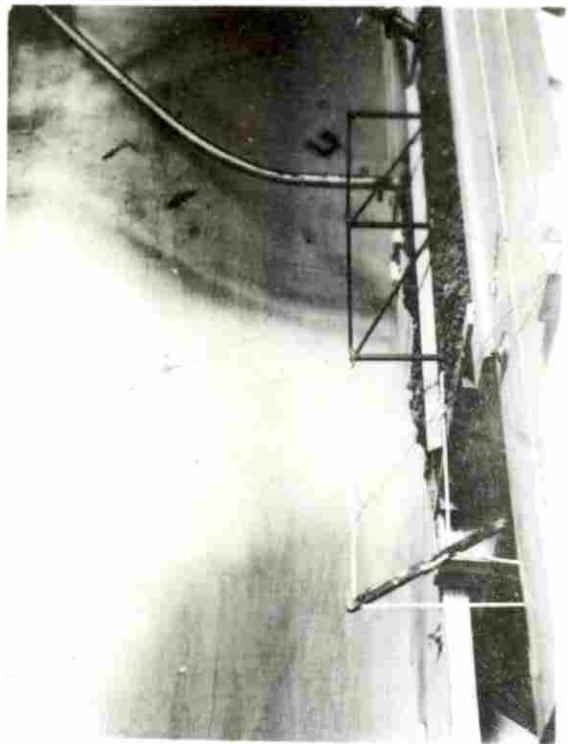


Fig. 13. Typical Model End Test

All data taken in these tests have been regarded as helpful in planning field tests but have not been regarded as a sufficient basis for definite conclusions applying to field conditions.

## Field Tests

### Introduction

One method of analysis for certain types of problems is to secure data from experimental tests upon which to base theories and conclusions. This method of analysis seems most appropriate in the determination of the effect of diameter and depth of set upon the overturning resistance of wood posts. The reason for this is because from an engineering standpoint, soil is not as structurally determinate as other engineering materials such as wood, steel, or concrete. The true importance of soil as a structural material has until recently been overlooked, and as yet, due to the many variations encountered in soils, the exact results which will occur under given soil conditions are difficult to predict. For this reason, field tests have been made in an effort to determine some of the specific relations between a wood post and the soil in which it is set.

### Objects of tests

Field tests were conducted to obtain data upon which to

base conclusions relative to the effect of diameter and depth of set upon the overturning resistance of wood fence posts, to investigate the possibilities of driving line fence posts, and to compare the driving qualities of different types of points on wood posts. Posts not driven were carefully set in undisturbed soil by digging accurate size holes.

#### Equipment and specimens used

Augers. One of the main factors in erecting a line fence is the labor involved in setting the posts. In an attempt to reduce this labor many ideas have been carried out, and at the present time one may buy a variety of post hole diggers and augers. A recent survey, however, showed that no augers or diggers could be purchased which would make holes in the ground between two and four inches in diameter. In this study the range in diameter of the posts used is between two and one-half and four inches.

In general, fence posts are set in the ground in one of three ways. An excess of soil may be removed in preparing the holes and a portion or all of the soil replaced around the posts with a <sup>u</sup>temping bar; posts may be driven in the soil; or a hole may be made in the soil to an exact size such that the post will fit snugly when placed in it. Since one of the main factors which might be expected to influence the stability of a post is the density or compactness of the soil in which it is set, and since it would be difficult to

maintain a constant density in the soil around a post if the soil were disturbed, the method of setting posts by digging a hole larger than the post was discarded in these tests. Driving the test posts was considered, but again, it would be difficult to maintain the same soil density and also the effect of the shape or size of a point on the stability of the post is not known. Therefore, it was decided that the best method for setting the test posts to obtain data relative to the effect of diameter and depth of set upon the overturning resistance of the posts would be to make the holes the same diameters as the posts to be tested in them.

As has been stated, an effort to purchase a tool or group of tools for digging these holes proved fruitless; making it necessary to construct soil augers which would give the results desired. The method used in the construction of these augers, shown in Figure 14<sup>b</sup>, was to cut discs from 1/8-inch sheet metal the desired diameter of the hole to be dug. One inch holes were drilled in the centers of the discs and a cut was made on one radius of each disc. These discs for each auger were then opened and welded together at the cuts to form a right hand spiral. This spiral was then welded on one end of a piece of 1/2-inch black iron pipe three feet long. A short piece of 1/2-inch pipe welded to the other end serves as lever arms for turning the auger in the soil. A portion of a one inch wood drill bit welded to the end of the pipe on which the spiral was welded serves

as a guide and point for the spiral.

Upon trial it was found that for each auger the pitch of the first disc, the "biting" part of the auger, should be much less than the pitch of the remaining discs. The reason for this is so the soil will actually be loosened and lifted when the auger is twisted into it. The pitch given the first disc was about 1/2-inch and for the remaining discs, between one and one-half and two inches depending upon the diameter of the discs. A spiral approximately eight inches in length is a practical limit due to the friction involved in pulling the auger from a hole.

The spiral is filled with soil by twisting and pressing downward slightly. In some soils pressure is not necessary after the first four inches of depth is reached. The auger must be pulled and cleaned as soon as the spiral is full of soil, otherwise the hole will be "scrubbed" oversize and difficulty encountered when attempts are made to remove the auger from the hole. Thus, in digging a hole 30 inches deep, four or five removals of the auger would be necessary, and the entire operation would require from five to ten minutes under ordinary conditions. Augers were constructed to dig holes two and one-half, three, three and one-half, and four inches in diameter.

Testing equipment. In addition to the augers, the equipment used for testing the posts during the field tests was the same as was used for the laboratory tests, with the

exception of course, of the soil box, and platform. Briefly, the equipment used in the field tests consisted of the following: augers, post driver, deflectometer, dynamometer, and penetrometer.

Specimens used. The wood posts used in the field tests were prepared by Strong (13) and were turned to a constant diameter in a wood lathe. The diameters chosen for these tests were two and one-half, three, three and one-half, and four inches, and the lengths of the posts varied from six feet six inches to eight feet. The test posts were made from treated, heartwood pine. In addition, for the driving tests, the five posts used in the laboratory tests (Figure 5) were used in the field. Referring to Figure 7, the steel posts numbered 1 and 3 were used in the field tests.

#### Test plot

Since soils differ so widely, considerable attention must be given to the type of soil and the conditions of the soil in which tests are conducted. The plot used for the field tests is located on the Iowa State College grounds just north of the Agricultural Engineering building. This plot is the same one used for previous testing by Hazen (5) and Strong (13) in their investigations of end and corner constructions.

The test plot consists of a clay loam layer of soil to a depth of about 29 inches. Below this a thin layer of yellow

clay was found, and at a depth of 34 to 36 inches a gravelly, sandy, clay was encountered. Since the major portion of the testing was conducted in the layer of clay loam, a laboratory analysis of this soil was made. The sample for this analysis was taken at a depth of six inches, and the particle size accumulation curve is shown in Figure 6. Other properties of the soil determined in this analysis are as follows:

Hygroscopic moisture content	7.80%
Liquid limit	52.75%
Plastic limit	31.87%
Plastic index	20.88

Using the properties of the soil as determined by the laboratory tests, and referring to the textural-classification chart as given by Hogentogler (6), the soil may be classified as clay loam. Hogentogler (6) makes this statement about this type of soil.

"A clay loam is a fine-textured soil which breaks into clods or lumps which are hard when dry. When the moist soil is pinched between the thumb and finger it will form a thin ribbon which will break readily, barely sustaining its own weight. The moist soil is plastic and will form a cast which will bear much handling. When kneaded in the hand it does not crumble readily but tends to work into a heavy, compact mass."

The test plot was cleared of all vegetation and stakes

were set in rows five feet apart, with the stakes five feet apart in each row. Enough ground was cleared to allow the setting of 120 stakes in this manner. Later, stakes were set between those already set, making a total of 240 stakes on the plot. Each stake represented a spot for testing a post. The test plot and a number of wood and steel posts ready for testing are shown in Figure 15.

#### Method of procedure

Setting posts. All holes for the test posts were prepared with the augers described above. Care was exercised to prepare each hole in the same manner, and the holes were not allowed to dry out before being used.

Driving posts. Due to limited time, only 15 driving tests were made. The posts were driven with the post driver as shown in Figures 16, 17 and 18. Figures 16 and 17 show a three and one-quarter inch post being driven, and Figure 18 shows the method for determining the depth which the post has been driven. The platform shown in these pictures is to facilitate fastening the trip arrangement when the driving is first begun. The steel posts were set with this driver, but no driving data were recorded for them.

Testing posts. The method used in testing the posts was much the same as that outlined for the laboratory tests. Little difficulty was encountered in placing the deflectometer in position, since the ground was very nearly level. As in



Fig. 15. Field Test Plot

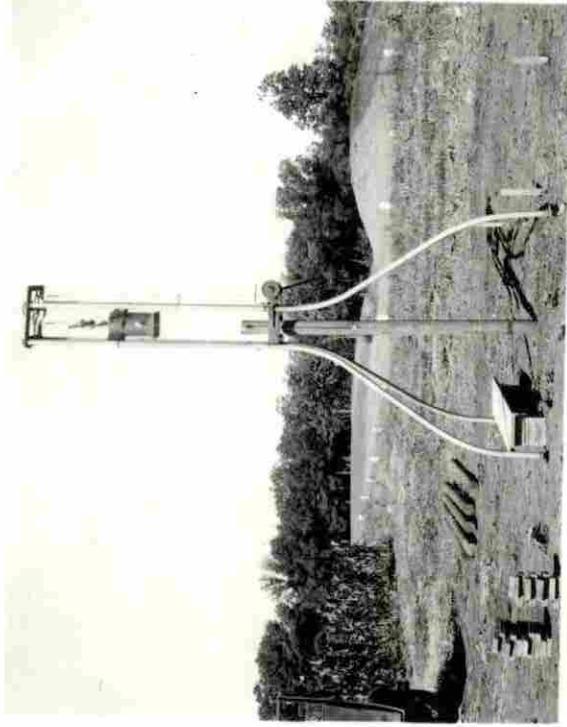


Fig. 16. Driving Wood Post

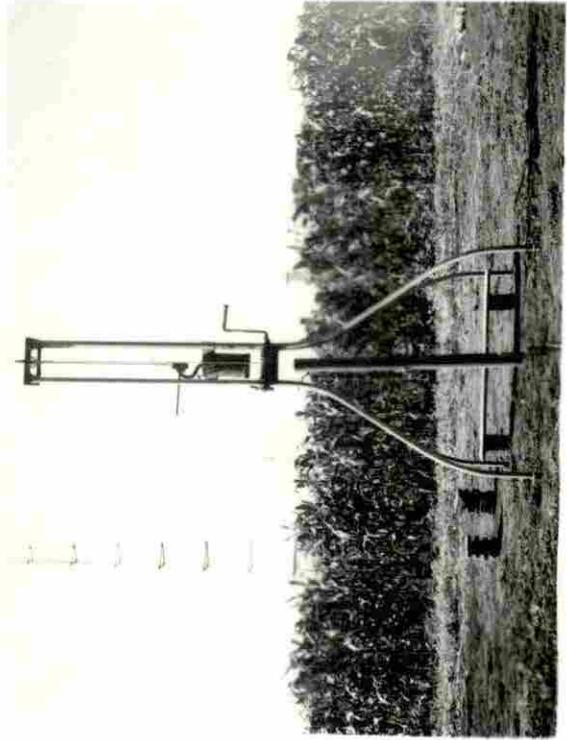


Fig. 17. Driving Wood Post

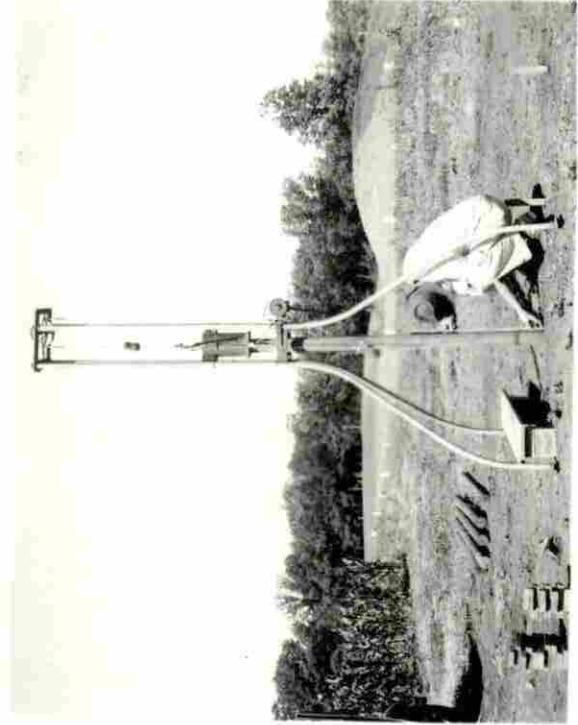


Fig. 18. Checking Depth Driven

the laboratory tests, the increment of time between increments of loads is a factor which must be considered. In these tests a period of eight to ten seconds was allowed between load increments. At the beginning of a test this is more than sufficient time for the post to come to a stationary position. As the load increases, however, ten seconds is not long enough for the post to come to a complete rest. All loads were placed on the posts at a distance of 50 inches above the surface of the ground.

A data sheet used on the deflectometer is shown in Figures 19 and 20. Figure 19 shows the sheet just after it is removed from the deflectometer and Figure 20 shows the relative positions of the post as determined by deflection and load increments. While the deflections recorded are actual size, it should be noted that the spacing between the lines of deflection on the sheet represents, to scale, the spacing of the points on the post at which the deflections were recorded. The points of rotation of the post below the surface of the ground are shown in Figure 20, and this distance is determined by measuring on the sheet.

Soil moisture determinations were recorded daily, and the samples for these determinations were obtained at a depth of 16 inches below the surface of the ground. The determinations were made in the soils laboratory of the Engineering Experiment Station. During the testing period, the soil

moisture varied from 26.7% to 34%. This variation was not entirely constant from one limit to the other due to intermittent rainfall.

### Schedule of tests

Posts set in accurately bored holes. Several preliminary tests were made before a schedule was established. At first, only four posts were used. These posts were two and one-half three, three and one-half, and four inches in diameter. One series consisted of setting one of these posts four times at each of the depths desired. Thus, if a post was to be tested at four different depths, a series of tests for one day would include sixteen separate tests. About twenty tests were found practical for two men to complete in a day. The schedule outlined above had the disadvantage of not comparing different diameter posts in the same series. For this reason, a second schedule was tried and adopted. Enough posts of the same diameter were obtained to have one post for each depth of set. These posts were all set at one time, and then the testing was done. This schedule contained eighteen tests and was easily performed in one day. Ten series of this type were made for the wood posts set in accurately bored holes. Figures <sup>23</sup> 21 and <sup>24</sup> 22 show a four inch wood post before and after testing.

Driven posts. Only fifteen driving tests were made,

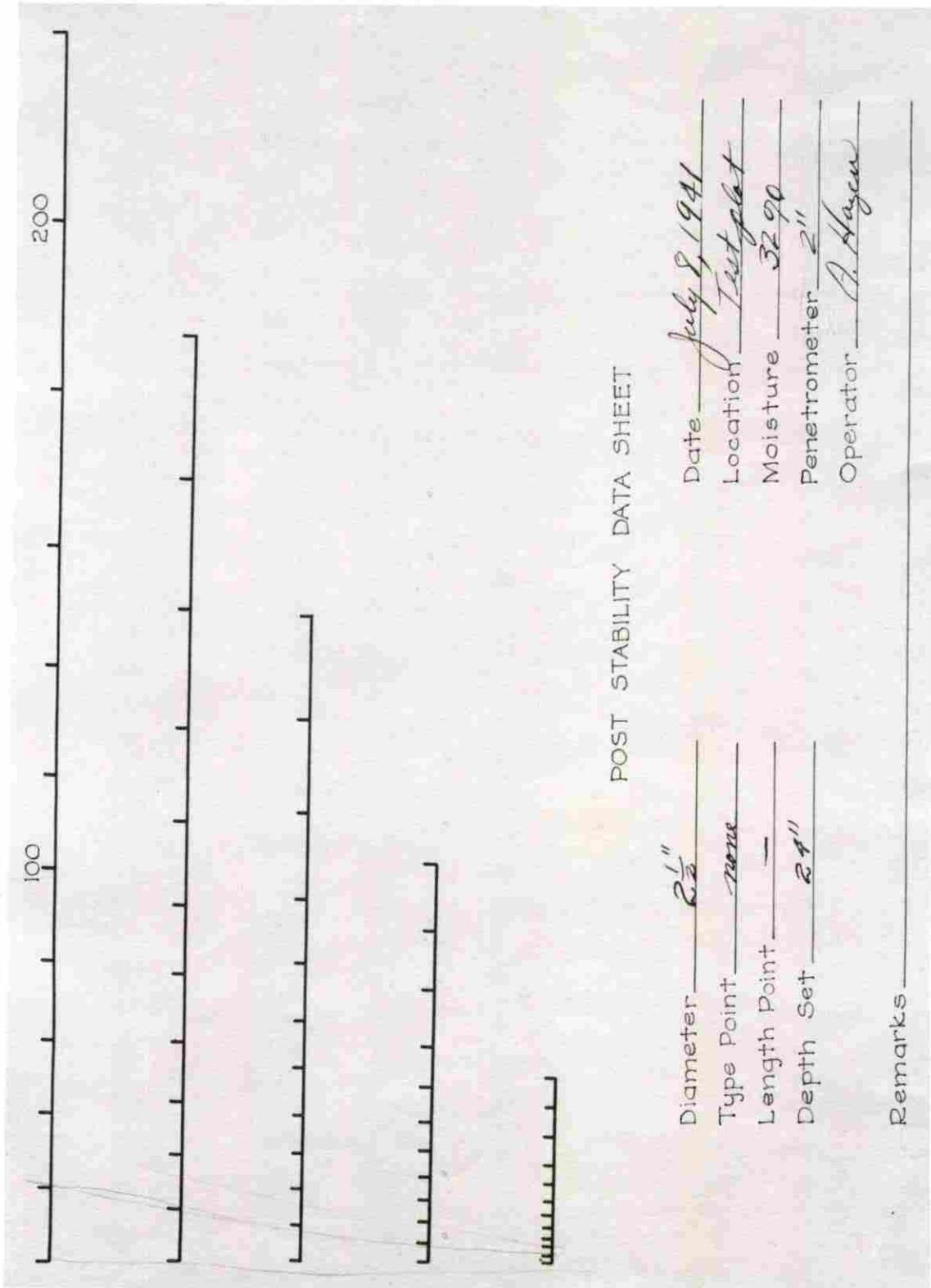


Fig. 19. Typical Data Sheet



due to lack of time. These tests were made using the five pointed posts, and no definite schedule was adopted. The five posts were driven consecutively and were then tested, and these tests were made on three different days.

Steel posts. The main interest of the testing program was in the accurately bored holes and wood posts. However, as a comparison, eight tests were made using the two steel posts numbered 1 and 3 in Figure 7. These two posts were tested with and without bearing plates, and no definite schedule was followed. Typical positions of a steel post before and after testing are shown in Figures 23 and 24.

#### Results of field tests

Results of tests using posts set in accurately bored holes. The data taken from 180 tests conducted with the two and one-half, three, three and one-half, and four inch posts are presented in the form of graphs in Figures 25 to 36, inclusive.

Figures 25, 26, 27 and 28 present curves showing the effect of depth of set upon the overturning resistance of the four different diameter posts tested. Each point on the curves represents an average of ten tests, and each figure represents the tests made with one diameter post. In each of these curves the diameter and depth of set are constants, while load increments and deflections are variable.

In the next group of curves, shown in Figures 29, 30, 31



Fig. 22. Wood Post after Field Test

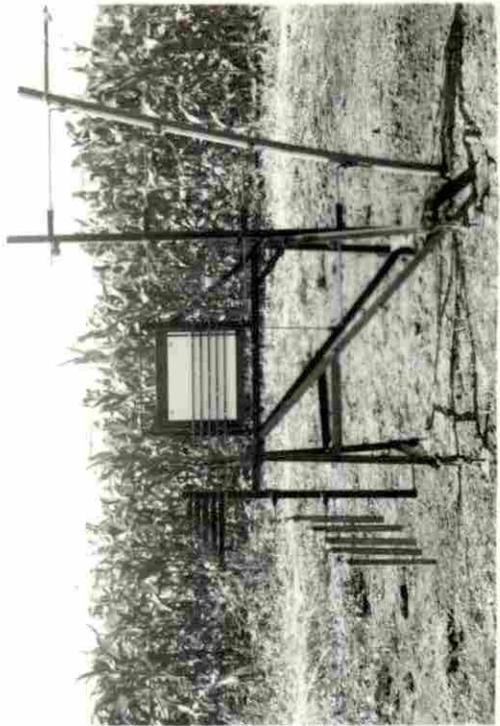


Fig. 24. Steel Post after Field Test

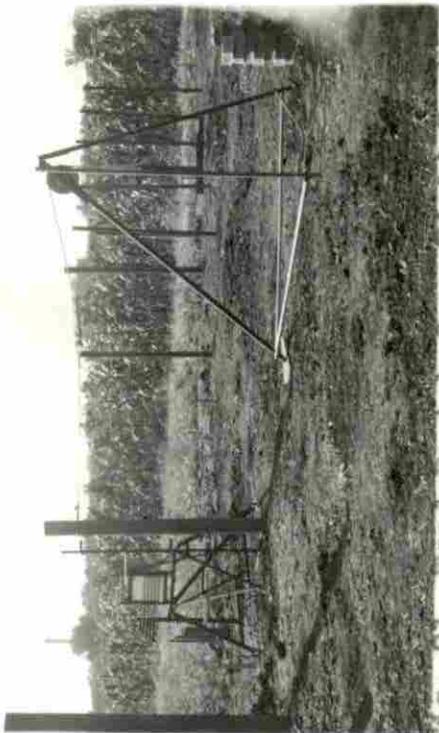


Fig. 21. Wood Post before Field Test

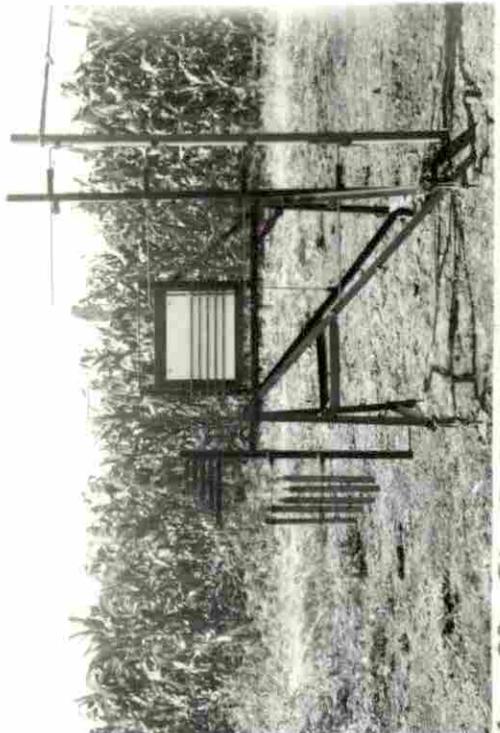


Fig. 23. Steel Post before Field Test

and 32, the effect of diameter upon the overturning resistance of wood posts of the four different diameter posts tested is shown. In these figures the diameter and depth of set are constant, while the load increments and deflections are variable. Again, each point represents the average of ten tests.

Figures 33, 34, 35 and 36 contain curves showing the effect of diameter upon the overturning resistance of the four different diameter wood posts tested. These curves present the same relation as shown in Figures 28, 29, 30 and 31 in a different manner. Each curve represents a constant load for a given depth of set. Load increments of forty pounds were chosen to show the effect of increased loads upon the deflection of the post being tested. It should be noted that in these figures the load and depth of set are constants, while deflections and diameters are variable. Each point on these curves also represents the average value of ten tests.

The points of rotation below the surface of the ground about which each post rotated during the tests are presented in Table I. These points were determined from the data sheets in the manner shown in Figure 20. On many of the sheets one value for a point of rotation was not obtainable, and in that case the maximum depth of rotation was recorded. Each value listed represents an average of ten tests.

Table I. Points of Rotation for Wood Posts.

Post Diam. (in.)	:	Depth Set (in.)	:	Point of Rotation (in.)
4	:	16	:	8.45
	:	20	:	11.45
	:	24	:	13.05
	:	28	:	14.70
	:	32	:	15.40
	:	36	:	17.80
3	:	16	:	8.85
	:	20	:	10.65
	:	24	:	12.80
	:	28	:	12.45
3 1/2	:	16	:	8.80
	:	20	:	11.15
	:	24	:	13.20
	:	28	:	16.35
	:	32	:	14.85
2 1/2	:	16	:	8.05
	:	20	:	9.28
	:	24	:	10.25

Results of tests using steel posts. During the field tests conducted with the wood posts eight tests were made using the two steel posts numbered 1 and 3 (Figure 7). Figures 37 and 38 present a series of curves obtained from the data taken in these tests. Figure 37 shows the curves giving the relation between load and deflection for steel post No. 1, while Figure 38 shows the same relation for steel post No. 3. These curves are presented to give a comparison between wood and steel posts, and also to show the effect of the bearing plate found on steel post No. 3.

The points of rotation as determined from the data sheets in the manner shown in Figure 20 for the two steel posts are given below:

<u>Steel post</u>	<u>Depth set (inches)</u>	<u>Point of rotation (inches)</u>
No. 1 with plate	18	5.00
without plate	18	7.00
No. 3 with plate	18	6.80
without plate	18	10.00
without plate	24	6.00

Results of tests using driven wood posts. Figure 37<sup>9</sup> shows the effect of the various cone points on the stability of the three and one-quarter inch posts. Each point on the curve is the average of three tests.

The various points below the surface of the ground about which the three and one-quarter inch pointed posts

rotated when tested are given below. All pointed posts were tested at a depth of 24 inches.

<u>Cone Point (inches)</u>	<u>Point of rotation (inches)</u>
2	12.5
4	12.0
6	15.0
8	11.5
12	10.7

Table II contains the data taken while driving the three and one-quarter inch pointed posts with the post driver. The weight was dropped a distance of 20 inches in each test. The variations in these data reflect the necessity of a larger number of tests.

#### Discussion of results

The results obtained from the tests made with the wood posts set in accurately dug holes were quite variable. In an effort to overcome these variations ten tests were conducted for each different diameter post and at each depth of set. The values of these tests were then average for a final working value.

From the curves presented in Figures 25, 26, 27, and 28 data were taken to obtain an expression showing the effect of depth of set upon the stability of the wood posts tested. The method used in selecting the data was as follows: From

Table II Post Driving Data

2" Cone Point					
Test 1		Test 2		Test 3	
Blows	Depth Set	Blows	Depth Set	Blows	Depth Set
0	0.00	0	0.00	0	0.00
5		5	3.50	5	3.50
10	5.25	10	6.00	10	5.75
15		15	8.00	15	8.00
20	11.25	20	10.50	20	10.50
25		25	12.50	25	13.75
30	17.00	30	15.00	30	17.75
35		35	17.00	35	21.00
40	22.50	40	19.00	40	23.25
42	24.00	45	21.00	41	24.00
		50	23.00		
		52	24.00		

4" Cone Point					
Test 1		Test 2		Test 3	
Blows	Depth Set	Blows	Depth Set	Blows	Depth Set
0	0.00	0	0.00	0	0.00
5		5	5.00	5	4.25
10	8.00	10	7.00	10	6.75
15		15	9.00	15	9.25
20	13.75	20	11.00	20	12.00
25		25	13.00	25	15.50
30	19.50	30	15.25	30	19.00
35		35	17.25	35	22.25
39	24.00	40	19.50	37	24.00
		45	22.00		
		50	24.00		

6" Cone Point					
Test 1		Test 2		Test 3	
Blows	Depth Set	Blows	Depth Set	Blows	Depth Set
0	0.00	0	0.00	0	0.00
5		5	5.75	5	5.50
10	11.25	10	7.75	10	7.70
15		15	10.00	15	9.75
20	20.50	20	12.50	20	12.00
25	24.25	25	14.75	25	14.50
		30	17.00	30	17.25
		35	19.00	35	19.00
		40	20.50	40	21.00
		45	22.00	45	22.75
		50	23.50	48	24.00
		51	24.00		

Table II. Continued.

8" Cone Point			
Test 1		Test 2	
Blows	Depth Set	Blows	Depth Set
0	0.00	0	0.00
5		5	8.00
10	10.50	10	10.50
15		15	12.50
20	15.00	20	15.00
25		25	17.50
30	19.25	30	19.25
35		35	20.75
40	23.00	40	22.50
43	24.00		

12" Cone Point			
Test 1		Test 2	
Blows	Depth Set	Blows	Depth Set
0	0.00	0	0.00
5	9.50	5	8.25
10	12.75	10	11.25
15	15.00	15	13.50
20	16.75	20	15.25
25	18.25	25	17.00
30	20.00	30	19.00
35	21.75	35	20.75
40	23.50	40	22.25
42	24.00	45	23.75
		46	24.00

each of the Figures, except Figure 28, the loads for 16 and 28 inch depths of set were recorded for 2, 4, and 6 inch deflection. In Figure 28 loads for 16 and 24 inch depths of set were used. If two values of depth of set and the corresponding loads for a given deflection are substituted in the general formula below, the values of the exponent "n" can be determined for different depths of set.

$$P = Kd^n$$

In this formula P represents the load, d represents the depth of set, and K is a constant reflecting the soil variations.

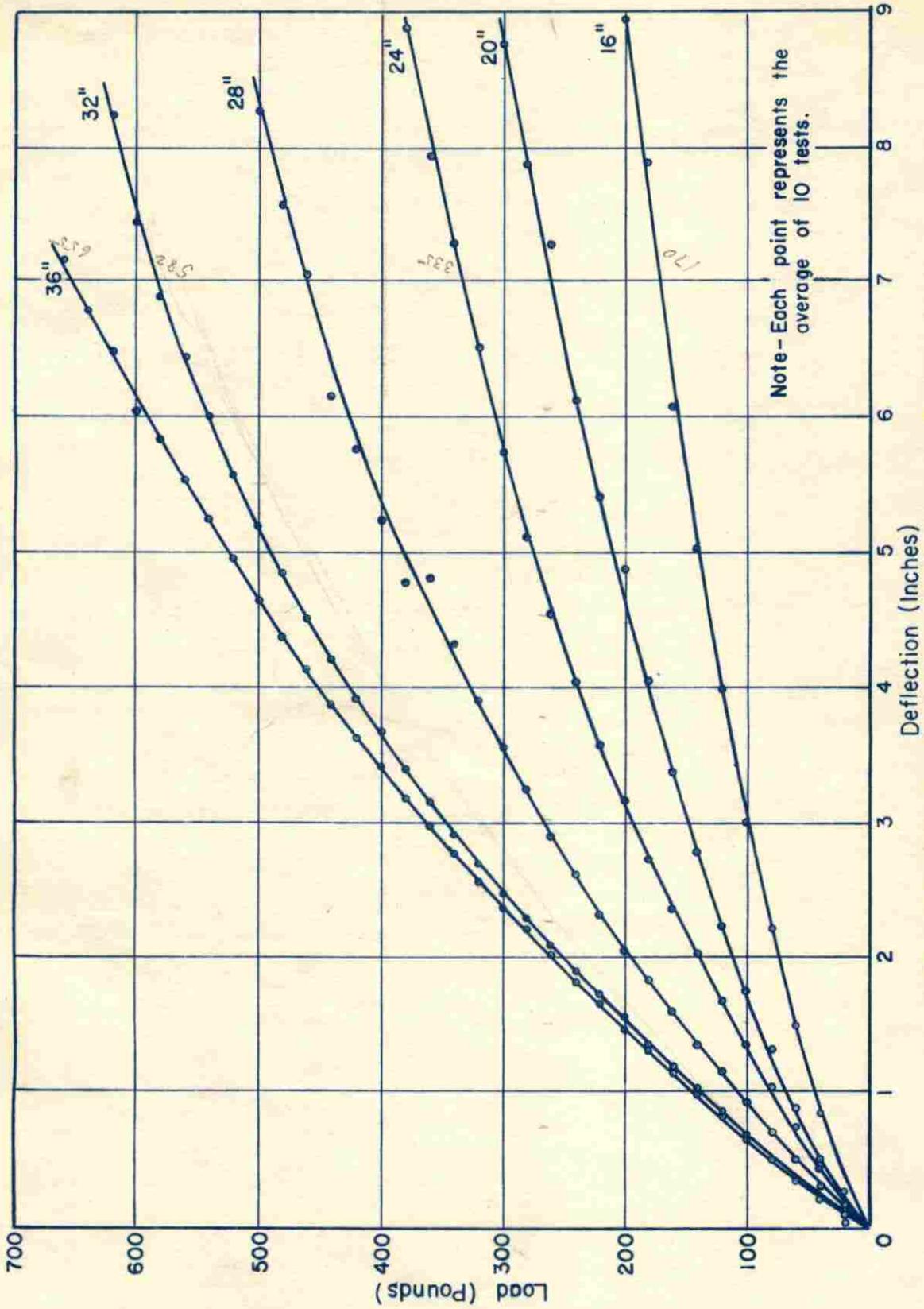
Figures 29, 30, 31, and 32 were used in determining the effect of different diameters upon the overturning resistance of the wood posts. The method used in determining this effect was as follows: From each of the Figures, except Figure 29, the loads for the two and one-half and four inch posts at deflections of two, four and six inches were recorded. From Figure 29 the loads for the three and four inch posts were used. Using the general formula below, and knowing two loads for corresponding diameters at a constant deflection, the values of the exponent "n" can be determined for the different diameters.

$$P = KD^n$$

In this formula P represents the load, D represents the post diameter, and K is a constant reflecting the soil variations.

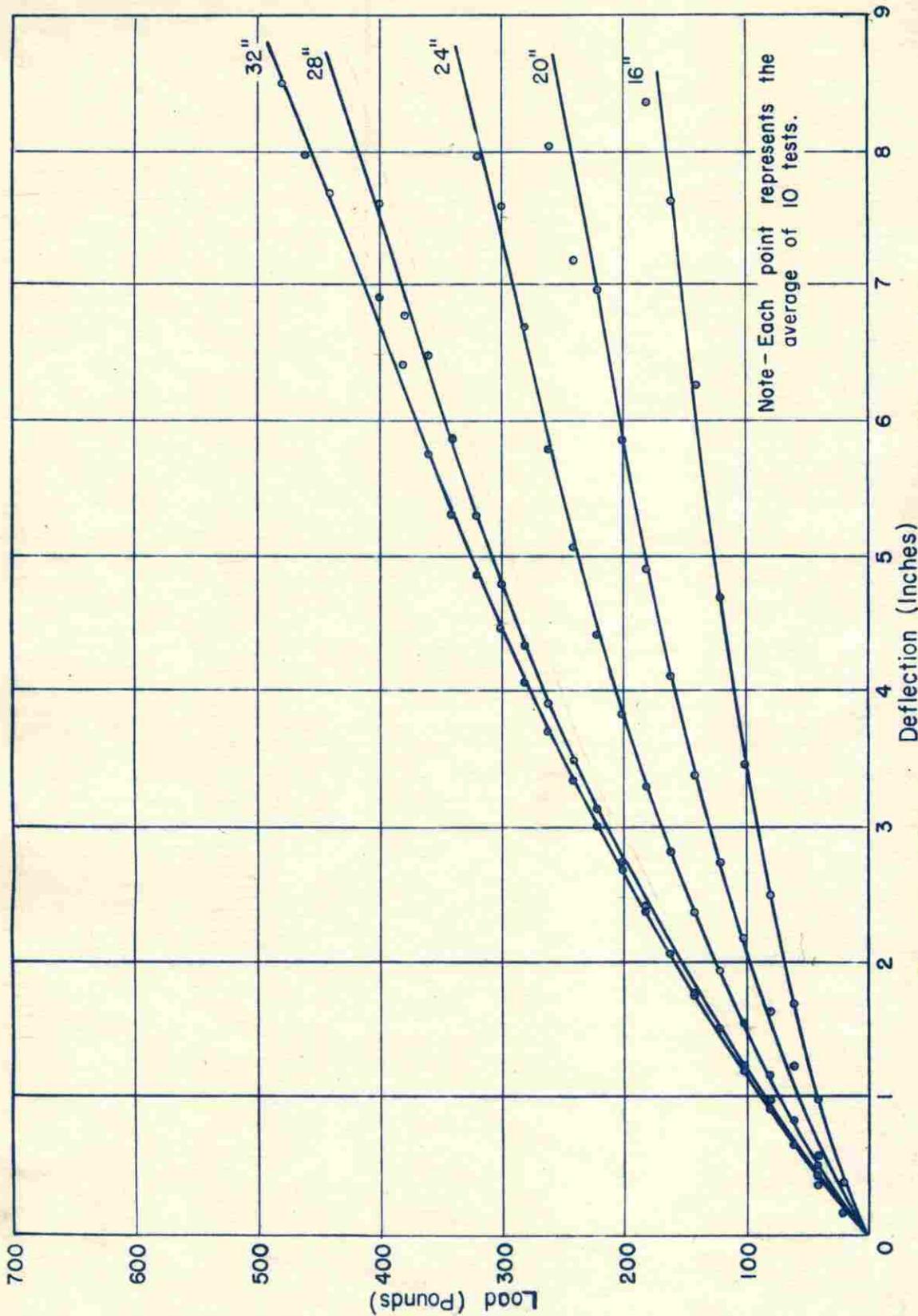
#### Summary and conclusions

The field tests were conducted to obtain data which



Note - Each point represents the average of 10 tests.

Fig. 25.-Effect of Depth of Set upon Overturning Resistance of Wood Post - 4" Diameter



Note - Each point represents the average of 10 tests.

Fig. 26. - Effect of Depth of Set upon Overturning Resistance of Wood Post -  $3\frac{1}{2}$ " Diameter

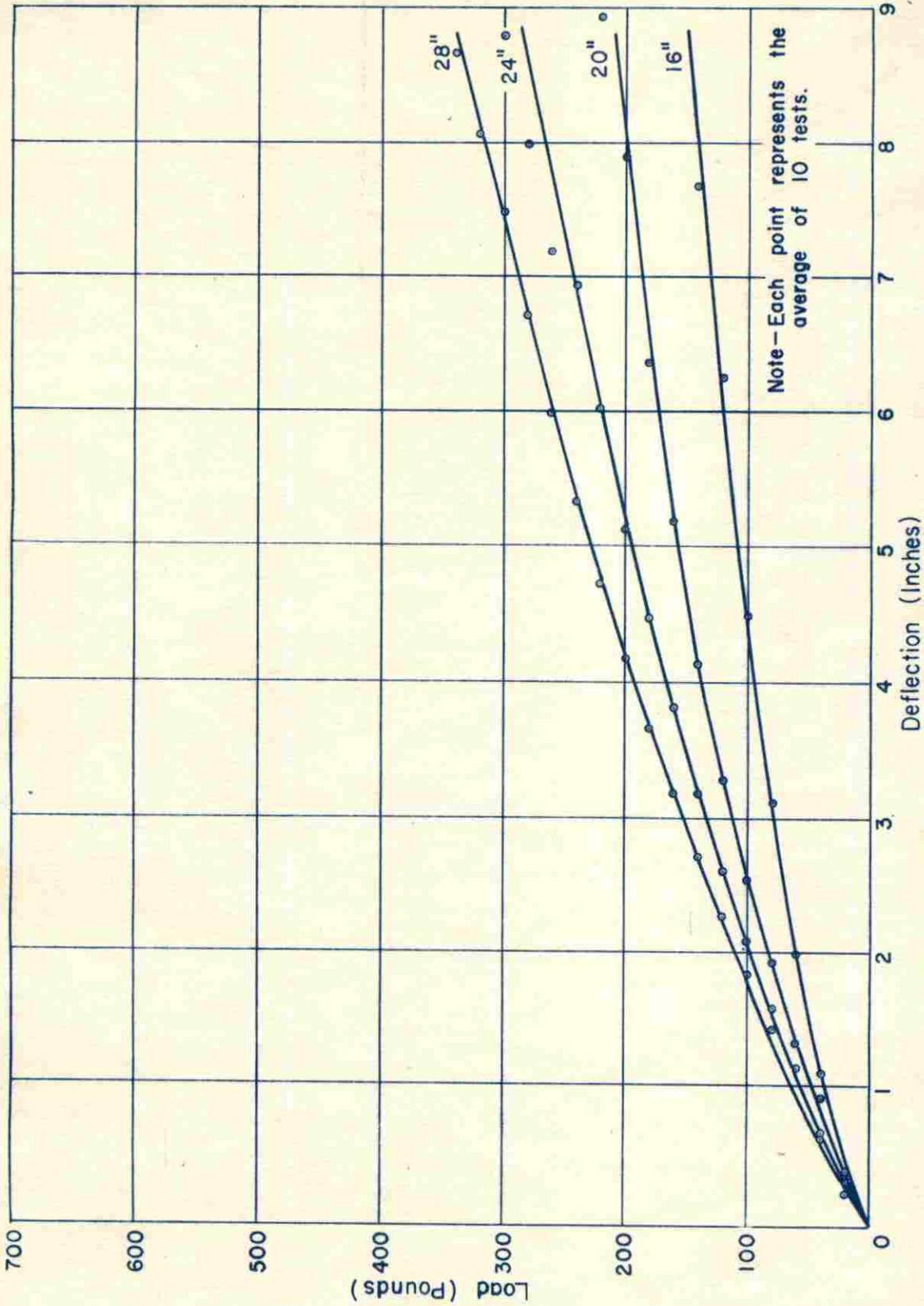


Fig. 27. - Effect of Depth of Set upon Overturning Resistance of Wood Post - 3" Diameter

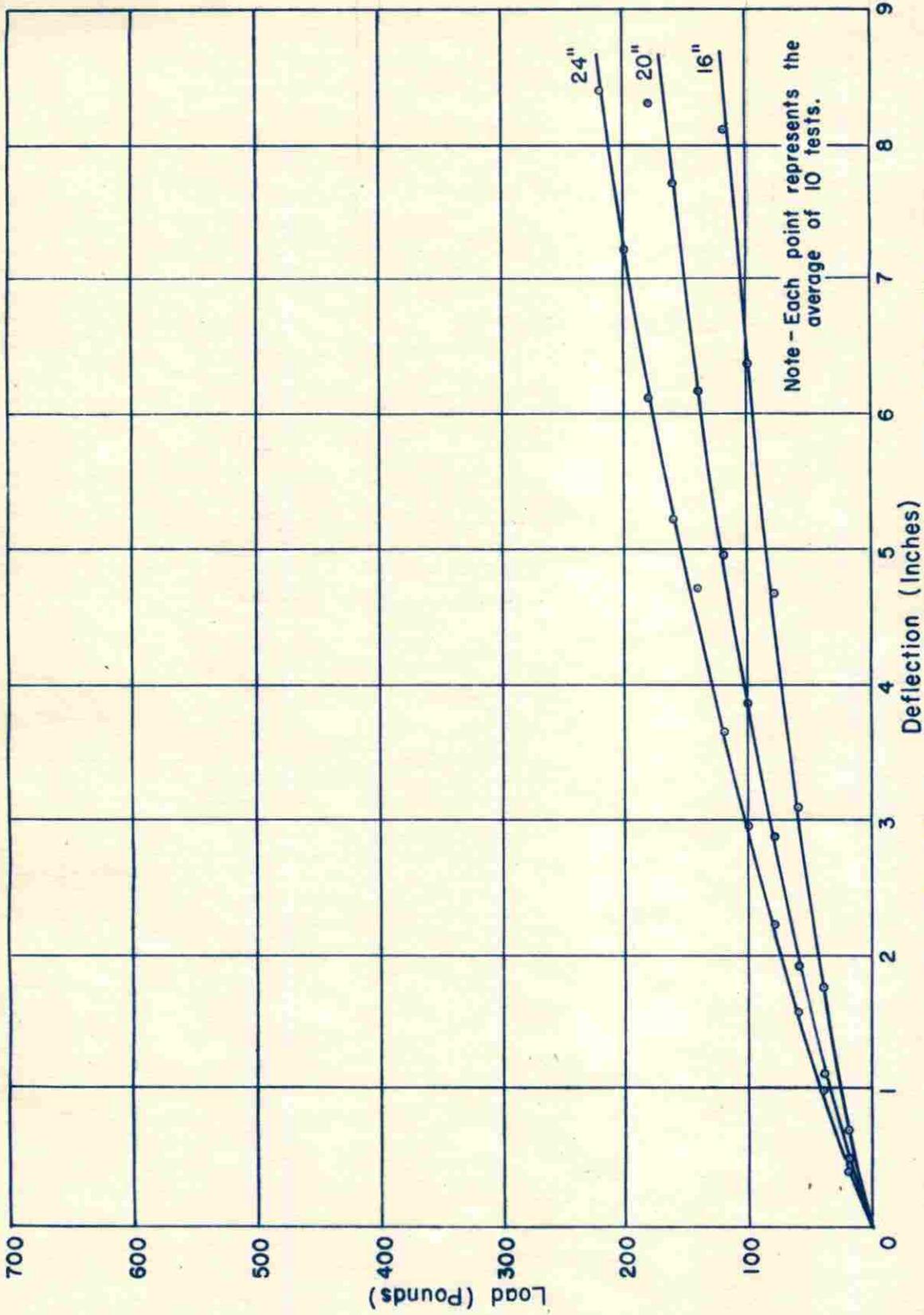


Fig. 28.-Effect of Depth of Set upon Overturning Resistance of Wood Post - 2 1/2 Diameter

Note - Each point represents the average of 10 tests.

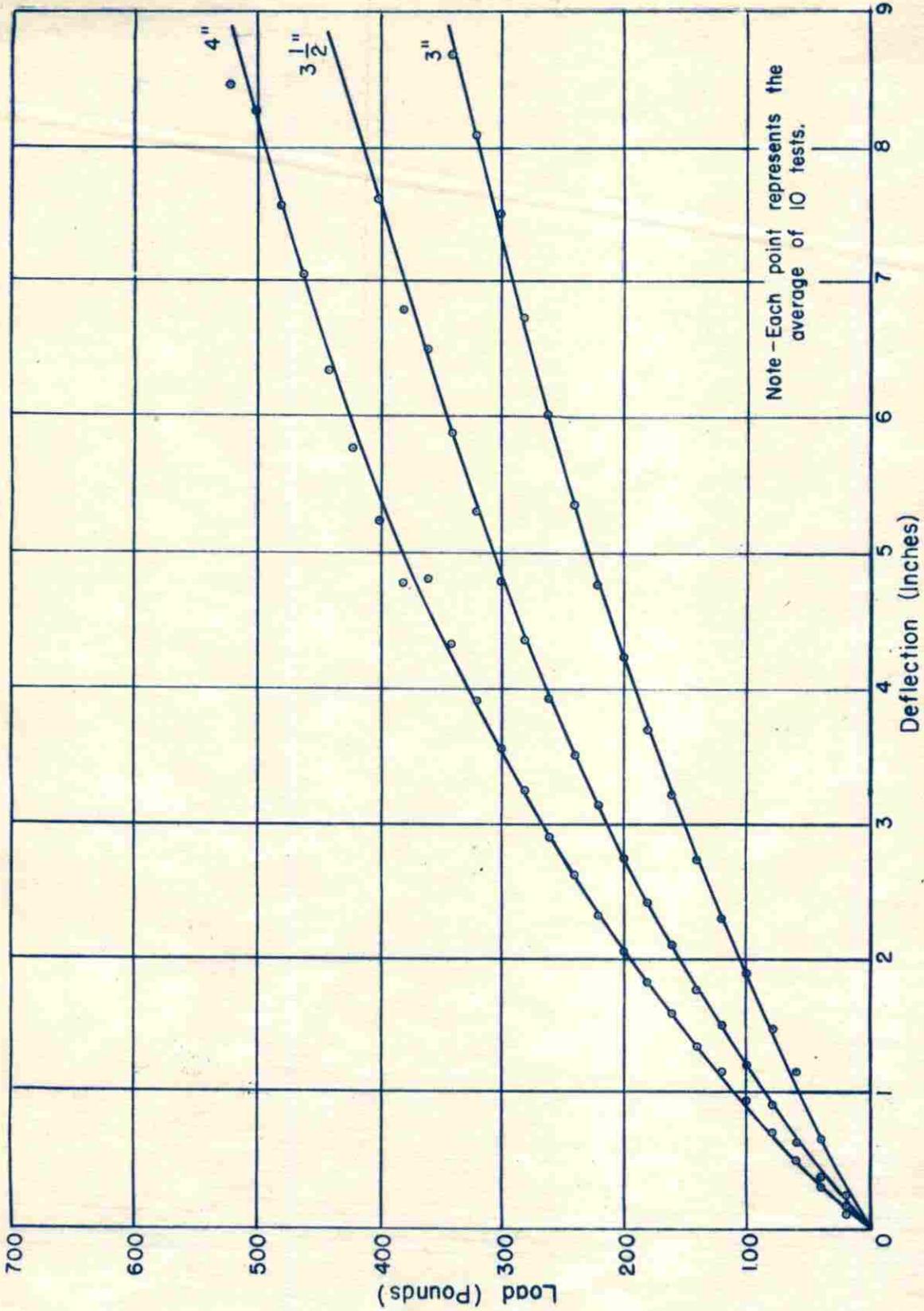
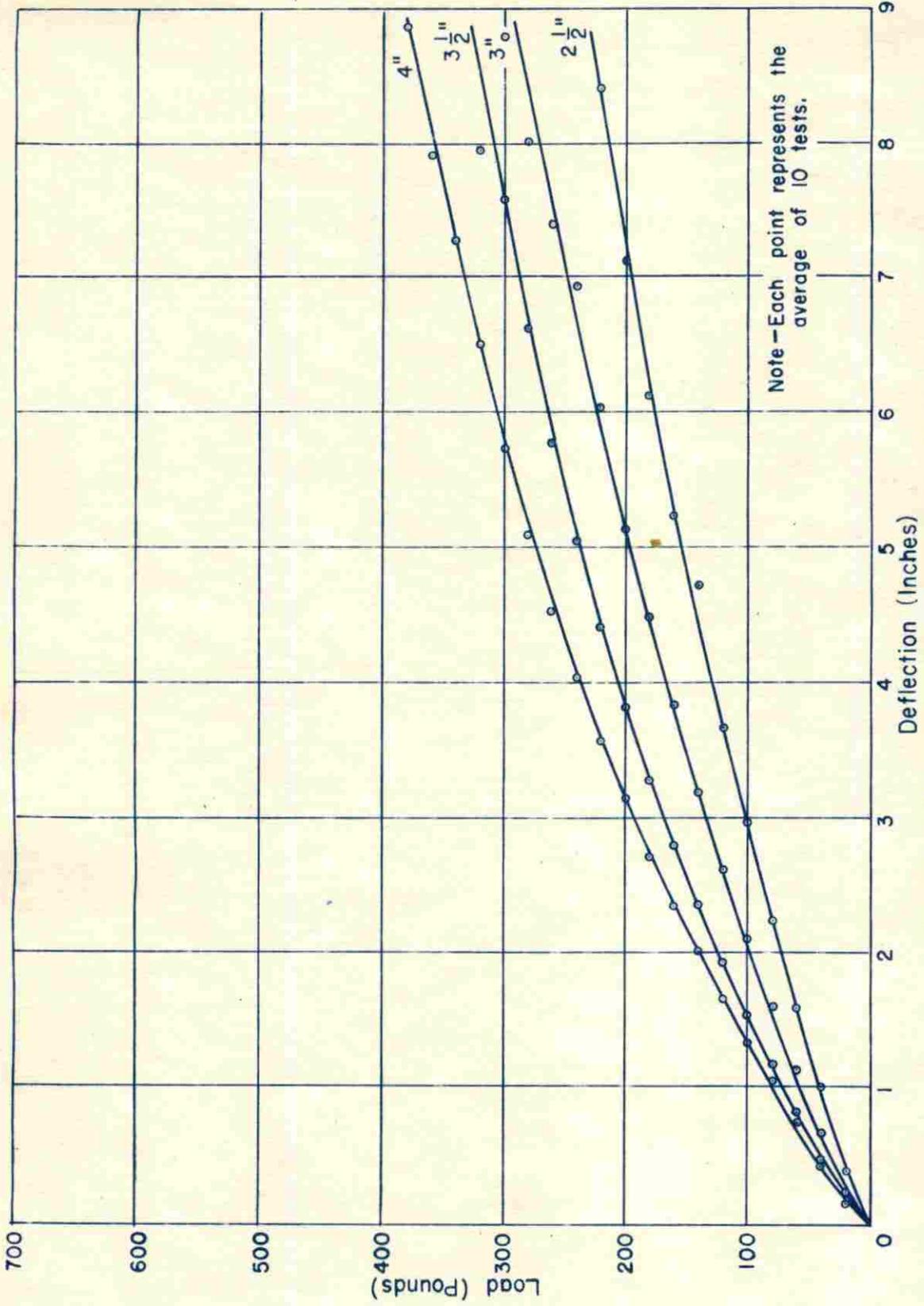
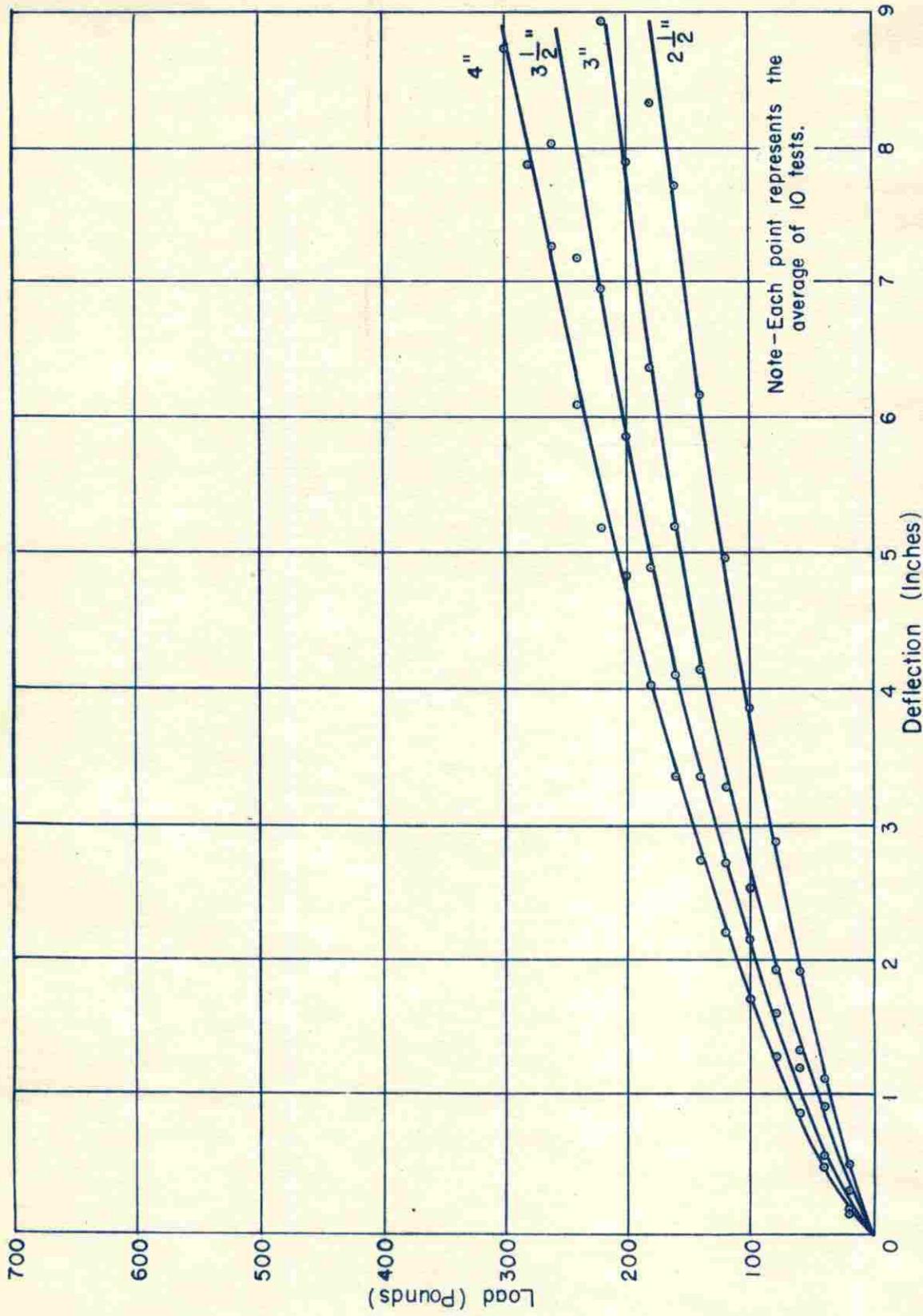


Fig. 29.-Effect of Diameter upon Overturning Resistance of Wood Posts-28" Depth of Set



Note - Each point represents the average of 10 tests.

Fig. 30.-Effect of Diameter upon Overturning Resistance of Wood Posts-24" Depth of Set



Note - Each point represents the average of 10 tests.

Fig. 31.-Effect of Diameter upon Overturning Resistance of Wood Posts - 20" Depth of Set

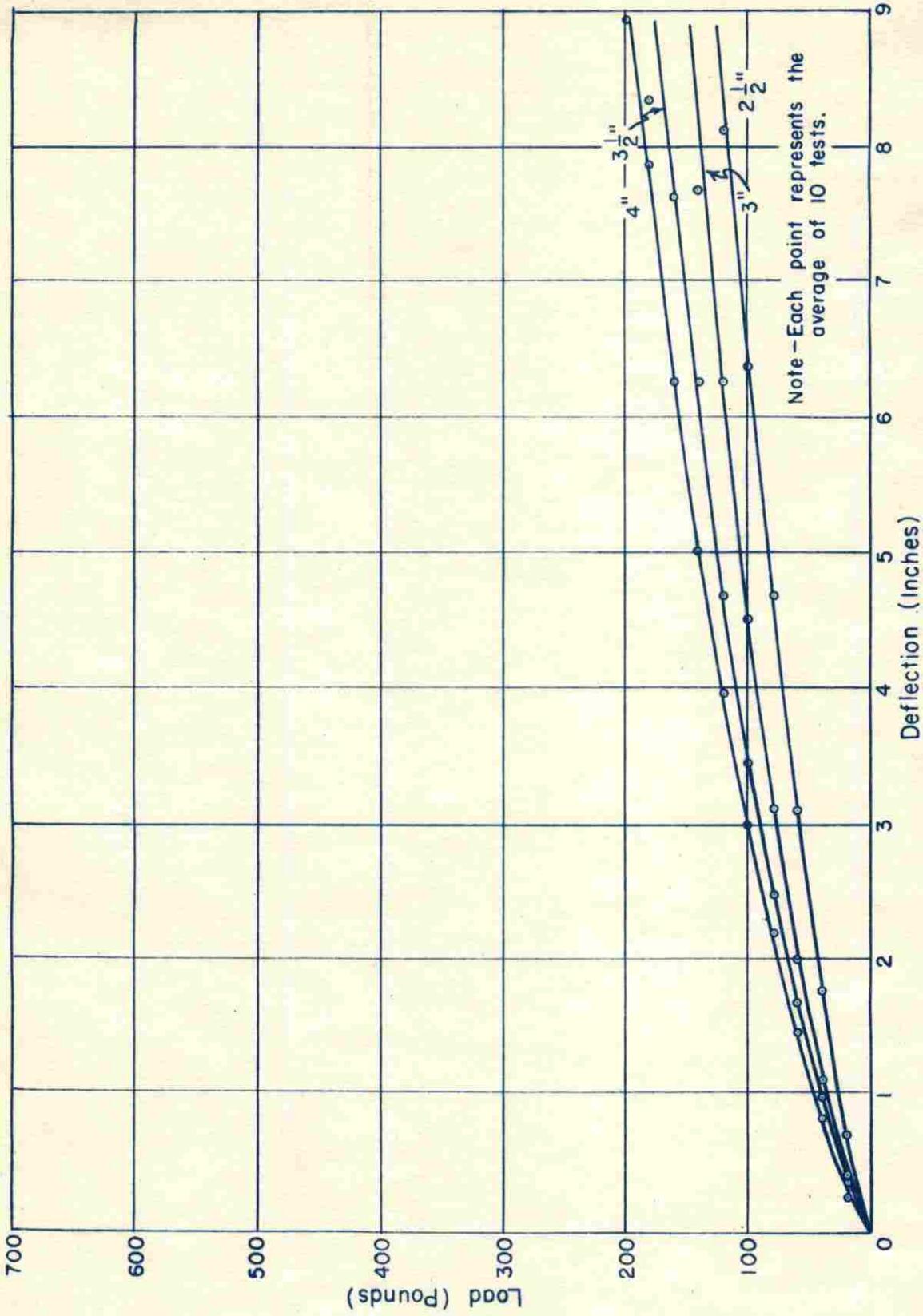


Fig. 32. - Effect of Diameter upon Overturning Resistance of Wood Posts - 16" Depth of Set

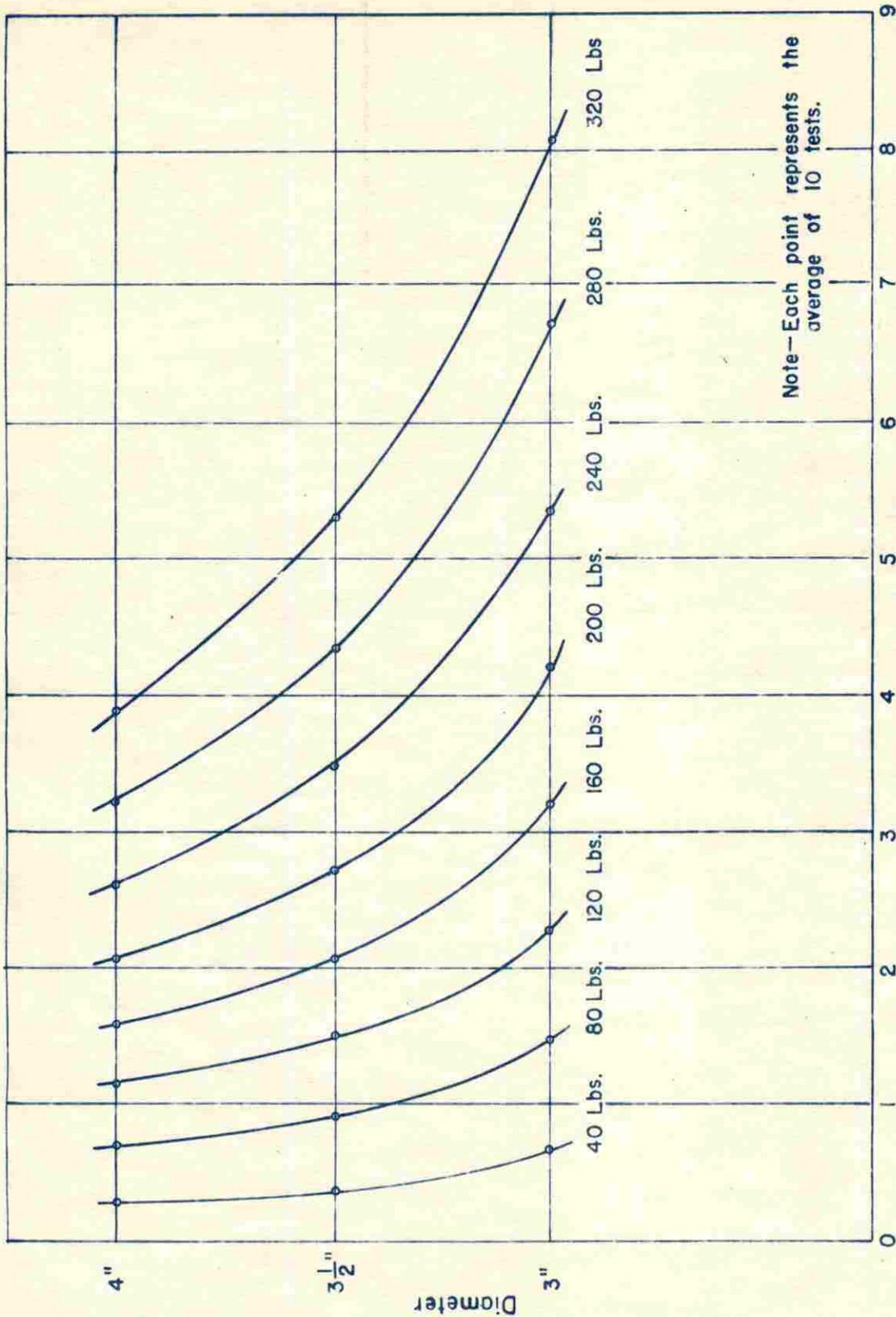


Fig. 33.—Effect of Diameter upon Overturning Resistance of Wood Posts—28" Depth of Set

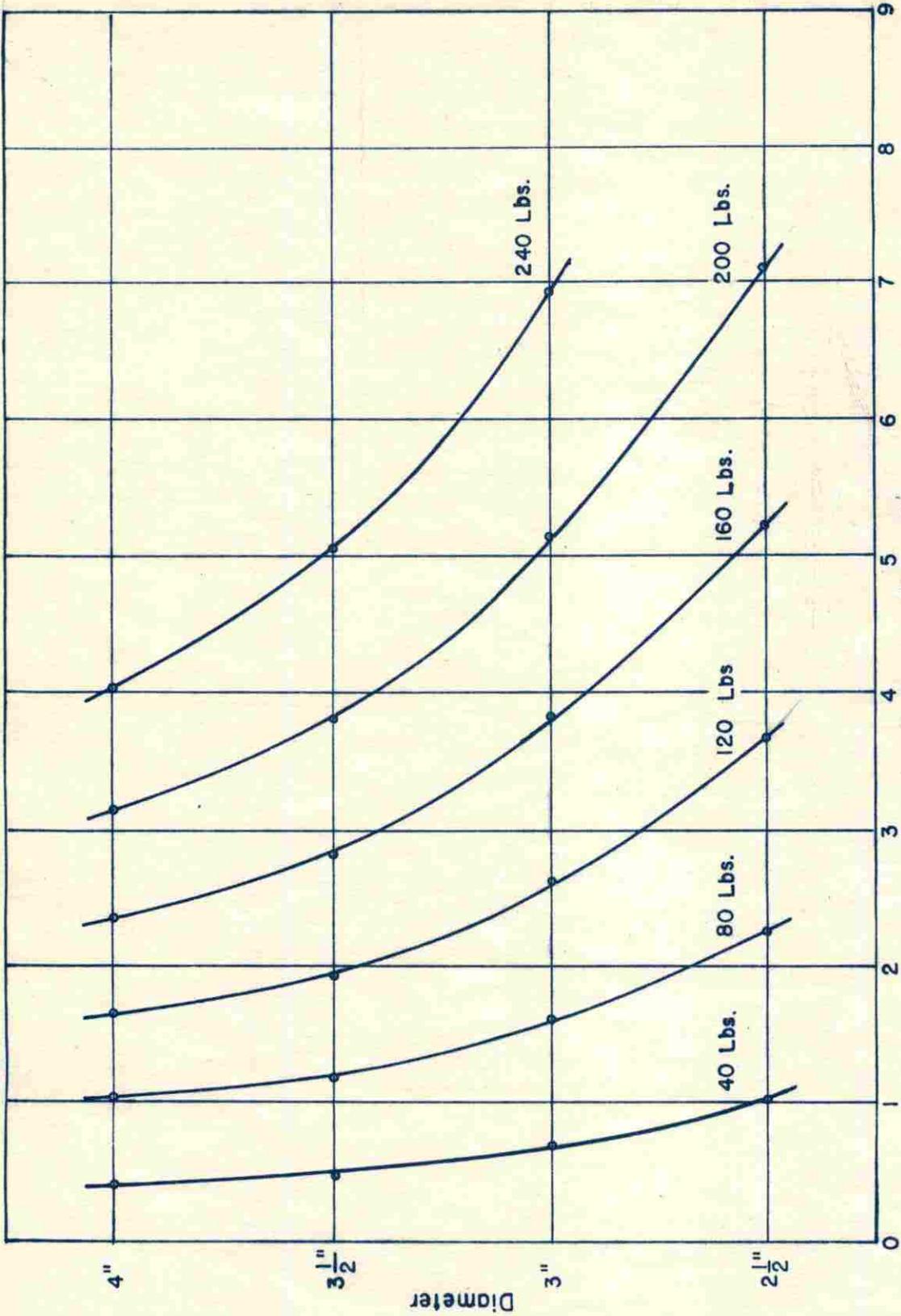


Fig. 34 - Effect of Diameter upon Overturning Resistance of Wood Post - 24" Depth of Set

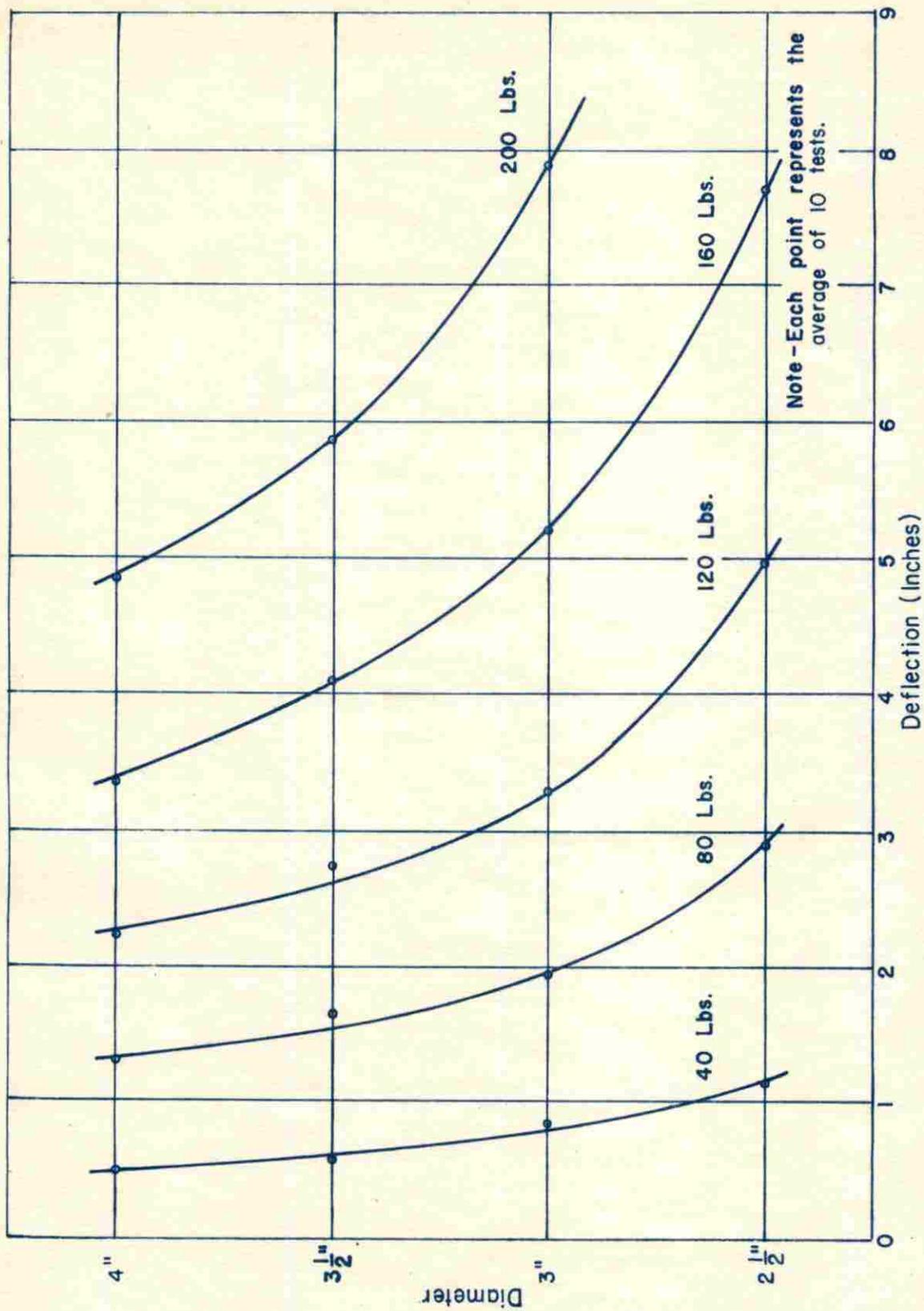


Fig. 35 - Effect of Diameter upon Overturning Resistance of Wood Posts - 20" Depth of Set

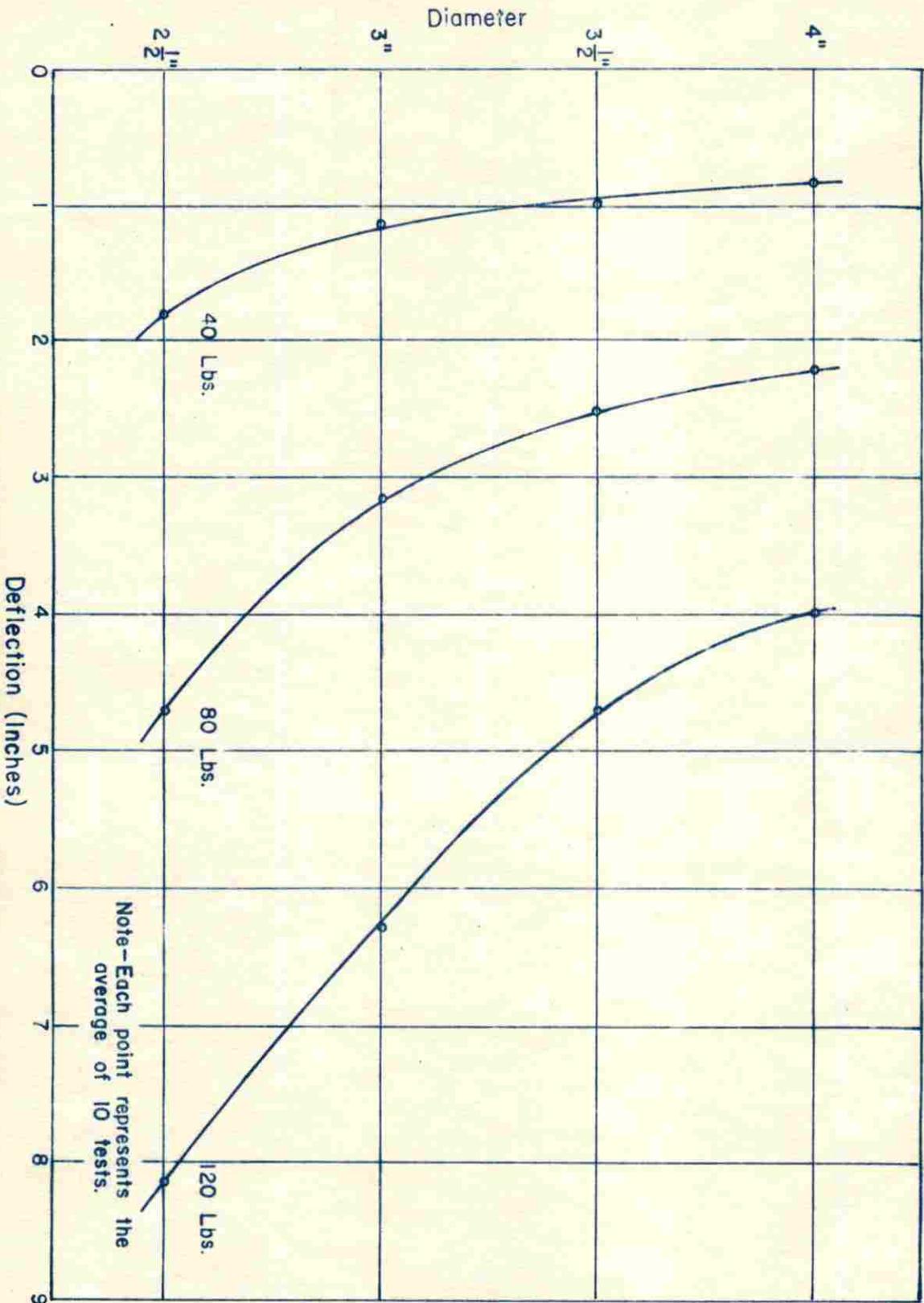


Fig. 36—Effect of Diameter upon Overturning Resistance of Wood Posts—16" Depth of Set

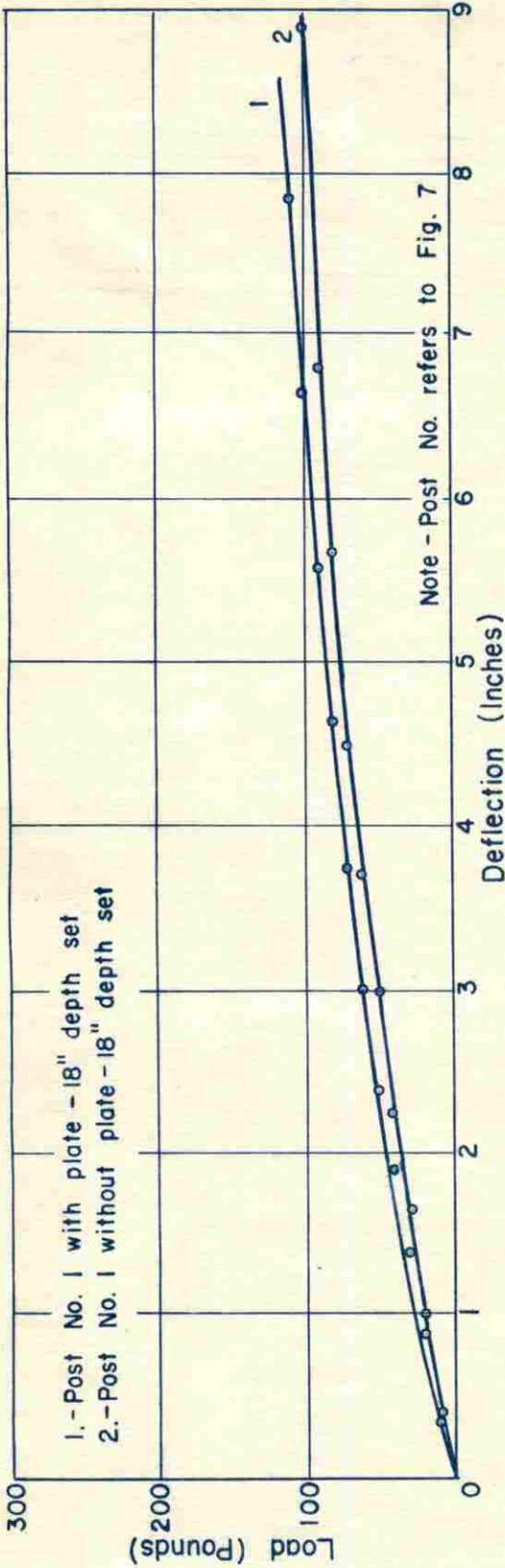


Fig. 37. - Relation between Load and Deflection for Steel Post

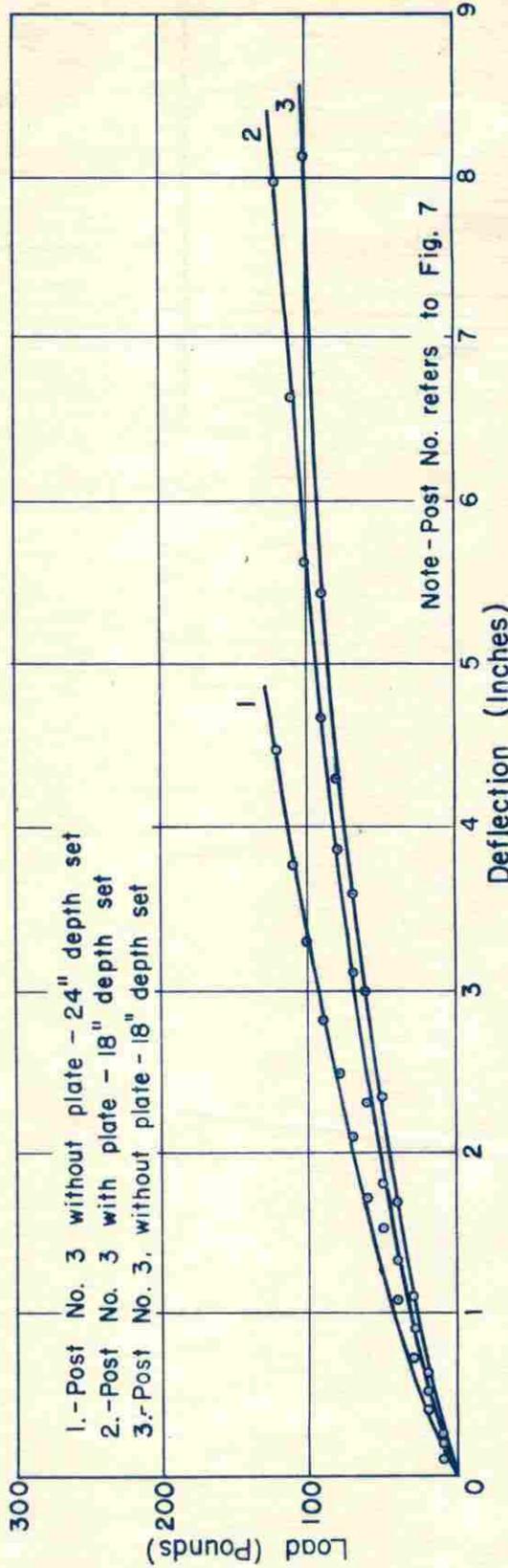


Fig. 38. - Relation between Load and Deflection for Steel Post

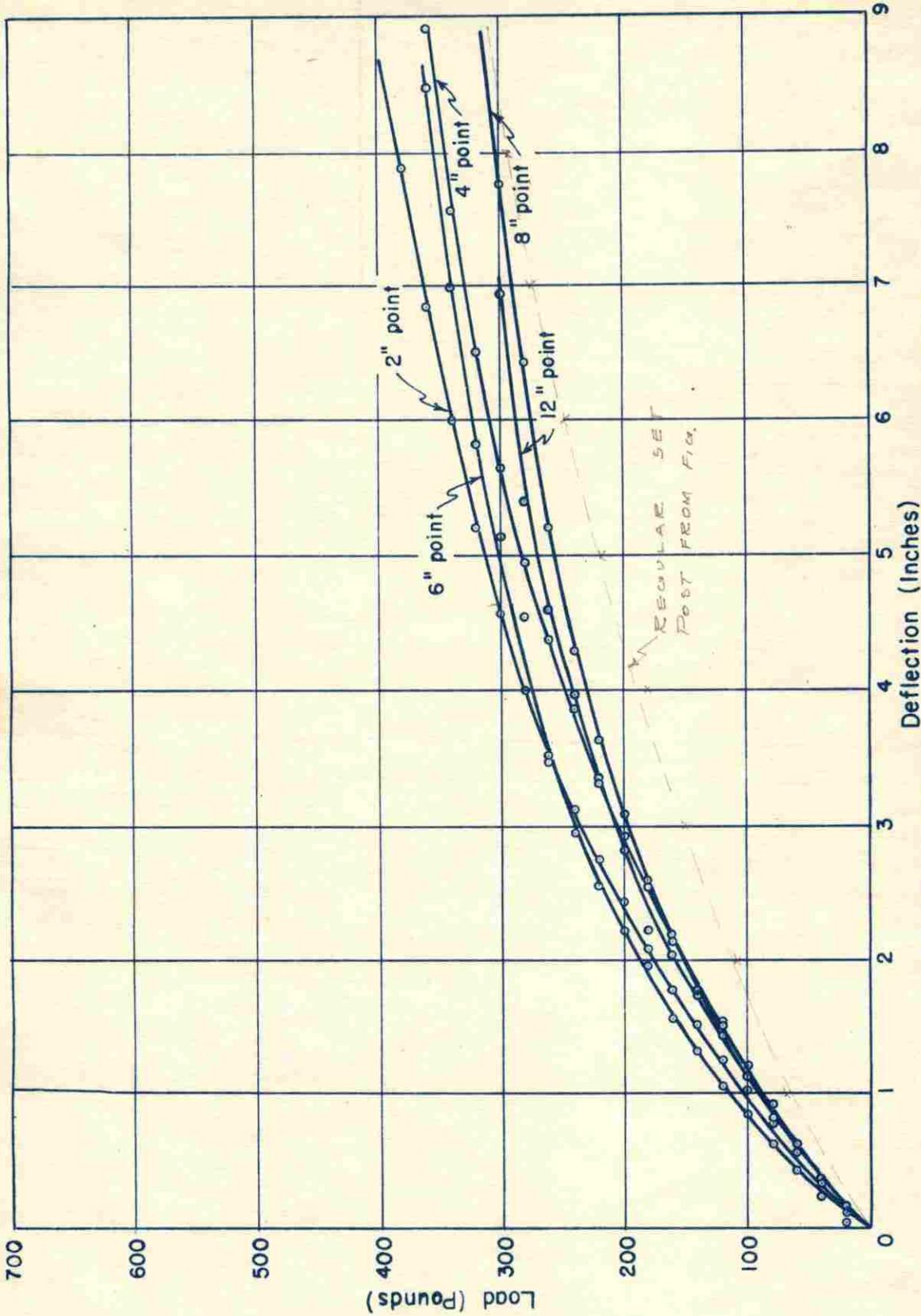


Fig. 39 - Effect of Length of Point on Stability of 3 1/4" Wood Post Driven 24"

would give definite information for determining the effect of diameter and depth of set upon the overturning resistance of wood fence posts. A method was developed for constructing augers which would dig accurate size holes for constant diameter posts, making it possible to test the posts in undisturbed soil. Some attention and tests were devoted to driving and testing steel and pointed posts, but extensive tests were not made. The conclusions drawn from the field tests are as follows:

- (1) The use of augers for setting accurate diameter posts was quite successful. Further developments should be made of these augers and their possibilities investigated.
- (2) In the type of soil used for the field tests the depth of set which develops the strength of a two and one-half inch post is between 24 and 28 inches.
- (3) The method used for loading the posts was quite successful, but would not be recommended for loads above 1000 pounds.
- (4) The depth of set at which the strength of the three inch posts was developed occurred between 28 and 32 inches.
- (5) The effect of the depth of set upon the stability of a constant diameter post may be expressed by

the formula below.

$$P = Kd^n$$

In this formula P represents the load applied to the post, K is a constant depending upon the soil variations, and d is the depth of set. Average values for the exponent n obtained from the data are given below:

<u>Diameter (in.)</u>	<u>n</u>
4	1.81
3 1/2	1.58
3	1.24
2 1/2	1.41

The above values for the exponent n give results very close to the points on the curves. Approximate results may be obtained by using the value 1.51 for n, which is an average of the above values, and applying this value to all different diameter posts within the range of those tested.

- (6) The effect of the diameter of a wood post upon the stability of the post for a constant depth of set may be expressed by the general equation below.

$$P = KD^n$$

In this equation P represents the load, K is a constant depending upon the soil variations, and D represents the diameter of the post. Using the curves in Figures 29, 30, 31 and 32 the value of n has been found to vary as follows:

<u>Depth set (inches)</u>	<u>n</u>
16	1.93
20	1.68
24	1.19
28	1.13

These values for the exponent  $n$  give results very close to those shown by the curves. Approximate values of load for a given deflection, diameter, and depth of set, may be obtained by using the value 1.48 for  $n$ , which is an average of the above values.

- (7) The points of rotation of a post below the surface of the ground move downward to a maximum value, and then move upward. This maximum value is very close to one-half the depth of set in every case.
- (8) Tests conducted with the steel posts in the clay loam soil indicate the strength of the steel posts may be developed at a depth of set of 18 inches. Deeper depths of set result in permanent bending of the posts.
- (9) The bearing plates on the steel posts tested helped prevent the post from twisting sideways as the load was increased.
- (10) From the standpoint of stability of the steel post, an additional depth of set equal to the length of post represented by the material in the bearing

plate would be more effective than the use of the bearing plate.

- (11) The steel posts without bearing plates were set more easily than those with plates.
- (12) The results from driving the three and one-quarter inch wood posts are very erratic, indicating that a large number of tests should be conducted before definite conclusions can be made.
- (13) These tests indicate the difficulties involved in attempts to obtain consistent results upon which to base definite conclusions.
- (14) Extensive tests with the wood posts should be conducted on other soil types and the results obtained correlated with the results of this investigation.

## DISCUSSION

The fact that attention has been given to the problem of pole stability in soil is reflected by two articles which give theoretical explanations for the behavior of both a pole and the soil in which it is embedded as the pole is subjected to a horizontal force near the top.

A summary of an article entitled "Effect of Depth of Embedment on Pole Stability" by J. F. Seiler (11) is presented as follows:

- (1) When an unguayed pole is subjected to horizontal forces, resistance to overturning is furnished by the ground in which it is set. The capacity of the soil to resist these forces gives the measure of stability of the pole under given loads.
- (2) For a pole of a certain strength and set in a given soil, there is a depth of embedment such that its strength will be just developed.
- (3) Pressures developed by a pole in the soil are considered as ordinates to a parabola whose position is such that the pressure area on one side of the pole bears the same relation to that on the other side as the butt reactions do to each other.
- (4) The neutral axis (or point of rotation) of the pole

occurs at a point approximately 0.68 d from the surface of the ground. (d refers to depth of set).

- (5) As a pole is overturned an area in front and behind the pole is affected. The resistance to overturning is expressed by the equation

$$R = Md^2 + Nd$$

M is a constant determined from the soil, and N is a constant reflecting the diameter of the pole.

- (6) The diameter of a pole has little or no effect upon the stability of the pole, but the stability varies as the square of the depth of embedment.

A second article written by R. W. Abbett (1) and entitled "Stability of Cantilever Poles in Sandy Soils" contains the following information:

- (1) When a cantilever pole in compacted sandy soil rotates due to a horizontal force near its upper end, the pole rotates about a center between two-thirds and three-fourths of the depth of embedment below the surface of the ground. The point of rotation moves up as the pole continues to overturn.
- (2) When the pole overturns a cone shaped mass of soil is pushed out of the ground behind the pole. The resistance to rotation comprises the forces of friction and cohesion acting on the surface of the cone.
- (3) The resisting moment may be expressed by the

equation

$$M = \frac{ecd^4(10k^2-15k+6)}{30k} \quad \text{or} \quad M = Cd^4$$

In the first equation,

e = deflection of the pole at the surface of the ground.

c = coefficient of resistance of the soil.

d = depth of embedment.

k = ratio of the distance from the surface of the ground to the point of rotation to the depth of embedment of the pole.

- (4) Two constants must be known to determine the stability of a pole. One is the safe or allowable rotation of the pole, e, and the other is the coefficient of resistance of the soil, c.

The results of this investigation are not in accord with either of the above theories. One explanation for this may be the fact that this investigation was limited to comparatively shallow depths of set, while the other theories are based on deeper depths of set. Too, this investigation is based on short poles suitable for line fence posts, while the proposed theories are based upon transmission line poles.

Special note should be given to the fact that neither of the above authors considers the diameter of a pole to be an important factor to be considered in the stability of the pole. While this may be true for depths of set greater than those used in this investigation, the results of this in-

vestigation certainly would not warrant such a conclusion. Too, it should be noted that Seiler (11) proposes that the stability of a pole varies as the square of the depth of embedment, while Abbett (1) contends the stability of a pole varies with the fourth power of the depth of set.

Perhaps the most logical conclusion to be drawn from these investigations is to recognize the need of further investigations of this type. These investigations show how variable soils may be, and also how difficult it is to propose definite mathematical formulae which will explain the behavior of these soils.

The problems connected with line fence construction are greater and more numerous than one might realize at first thought. In view of the past work done on this project, it might be well to present a program, consisting of a list of problems and suggested procedures, for future investigations. It is only logical to assume that more problems will present themselves as future investigations are undertaken.

The more important problems which have presented themselves thus far are as follows:

- (1) A study of the relative stability of fence posts.
- (2) A study of the possibilities of driving fence posts.
- (3) A study of the possibilities of boring post holes to an accurate size.
- (4) A study of the time and labor involved in setting fence posts by the various methods.

- (5) A comparison of the strength of different kinds and shapes of fence posts.
- (6) A study and development of fence fastenings for small diameter wood posts.
- (7) A determination of fence requirements, such as height, weight of wire, spacing of posts, etc., for different types of fences.

Each problem is discussed below:

A study of the relative stability of fence posts involves the following items:

- (1) Effect of depth of set of post.
- (2) Effect of diameter or shape of post.
- (3) Effect of soil type.
- (4) Effect of soil density.
- (5) Effect of soil moisture.

Tests have already been conducted relative to this problem. In these tests four different diameter wood posts, and two different types of steel posts were used. An effort was made to confine the tests to one soil type, and execute the tests quickly enough to minimize the effect of soil moisture variation. Approximately two hundred individual tests were made, and the data collected show the effect of diameter and depth of set for this soil type. The soil is of the clay loam type. The exact procedure for these tests has been outlined before, and similar tests should be conducted in other soil types. Perhaps the best method for determining the

effect of soil moisture and soil density would be a series of small scale tests in the laboratory where these variable factors could be accurately controlled. This would involve a soil box and different types of soil.

A study of the possibilities of driving fence posts has been started. However, much is yet to be done. This study would involve the following:

- (1) Shape of point.
- (2) Size of post.
- (3) Type of driver.
- (4) Practicability of driving posts in different soil types.

It is an accepted fact that steel posts may be successfully driven in most soils, but little attention has been given to driving small diameter wood posts. This investigation would include the selection and testing of many different types of points on different size posts. For example, five different length conical points have been tested on 3 1/4-inch diameter posts. These tests should be repeated using smaller size posts. Again, one point might perform differently in different soil types, and there again, duplicate tests would necessarily need to be made.

Before tests could be made regarding the stability of fence posts, some method had to be devised for setting the posts in the soil. It was desirable to test the posts in the natural, undisturbed soil, and this was accomplished by

constructing an auger for each diameter post to be tested. As a result of this, the idea of developing the auger for setting posts has been conceived. It has been found that the holes are quite easily dug with the auger, and no filling and tamping are necessary if the hole and post are of the same size. Further work and study should be conducted toward the development of these augers.

A study of the time and labor involved in setting fence posts by the various methods should be conducted to have comparative data. This could be easily done by actually erecting a line of fence posts, by each of the various methods, of such length as to give average, reliable data. This, of course, would include both steel and wood posts. It is possible these tests should be made on more than one type of soil and under different moisture conditions.

A study of the strength of different kinds and shapes of fence posts could be done by two methods. One, by testing the posts in a testing machine; and two, by testing the posts under field conditions. It has been observed in tests already made that the breaking strength of wood posts and the yield point of steel posts can be measured by setting the posts to such a depth that this strength must be developed before overturning will occur. The two methods should be investigated and correlated.

It is a common practice to fasten fence wire to wood posts with staples. The introduction of steel posts required

a different type of fastening. If a small diameter wood post is to be used, it is very probable the staple will prove an unsatisfactory fastening. This is a challenge for the development of a simple, effective fastening for this type of post.

A determination of fence requirements is an extensive study within itself. For example, does a field pasture fence need to be as heavy as a lot fence? Should the posts be set as deep in straight line fences as in contour fencing? Should the posts be as large in straight line fences as in contour fencing? These and others are questions which are unanswered. The answers to these questions depend upon a combination of the results of the investigations outlined above and common practice. Thus, it will be necessary to make a comprehensive study of existing fences so that a basis for recommendations can be obtained. This survey would include a study of spacing of posts, size of posts, type of wire, height of fence, and other such pertinent information.

## SUMMARY AND CONCLUSIONS

### Summary

The problems connected with fencing are not new. However, definite solutions to these problems based upon theoretical and practical procedures are lacking. Therefore, any attempt toward obtaining data which will help to solve the fencing problems will be not only justified, but also of considerable value.

Laboratory tests were conducted for the primary purpose of testing the equipment which had been built for field testing. These tests also proved valuable in preparing procedures for the field tests. Wood and steel posts were tested in the laboratory and the results obtained compared favorably with the field tests. In addition to the wood and steel posts, a laboratory study was made of three model end arrangements.

The equipment used for testing in both the laboratory and field tests designed and built for this investigation consisted of a deflectometer, dynamometer, four soil augers, and a post driver.

The deflectometer was designed to record load increments and deflections. The deflections of five separate points on the post being tested were recorded simultaneously. These points were spaced twelve inches apart on the post, be-

ginning at the ground surface and going upward to and including the point four feet above the ground surface.

The dynamometer was designed to apply loads in increments as small as ten pounds. Lead weights cast in ten and twenty pound sizes were used for these load increments.

The soil augers were constructed to dig accurate size holes for setting constant diameter posts. This permitted tests to be conducted with posts set in undisturbed soil.

The post driver was designed to drive posts in such a manner that comparative data might be recorded. The driver consists of a framework supporting a weight which may be dropped a given distance each time, regardless of the depth to which the post was driven by previous blows. The weight is lifted with a drum and crank arrangement.

Another piece of equipment used in these tests, but not constructed for these tests, was a Rototiller penetrometer. This instrument was used in obtaining consistent results in tamping the soil in the laboratory box.

Field tests were conducted using both wood and steel posts. The wood posts were set in accurately dug holes and were also driven. The main interest in the field tests was confined to the posts set in accurately dug holes. Inconsistent results necessitated a large number of tests to give average values upon which to base conclusions.

### Conclusions

The conclusions to be drawn from this investigation are

as follows:

1. In the laboratory tests Model No. 3 (Figure 10) required from 50 per cent to 100 per cent more load to produce failure than did the other model end arrangements tested. This would indicate a definite advantage in loading the center post of a double span end arrangement as compared with loading either the front or end post.

2. The use of augers for digging accurate diameter post holes was quite successful. Further designing should be done to develop these augers.

3. In the type of soil used in the field tests a depth of set of 28 inches was sufficient to develop the breaking strength of the two and one-half inch posts tested. A depth of set of 32 inches developed the strength of the three inch posts tested.

4. The points of rotation of a post below the surface of the ground move downward to a maximum value, and then move upward. This maximum value is very close to one-half the depth of set in every case.

5. A depth of set of 18 inches is sufficient to develop the strength of the steel posts used in the field tests.

6. The value of the bearing plate found on each of the steel posts tested is questionable from the standpoint of overturning resistance. If the weight of the plate were transformed into an additional length of the post, and the

post set an equivalent amount deeper, the stability of the post will be greater than if the plate were left on.

7. The effect of the depth of set upon the stability of a constant diameter post set in clay loam soil may be expressed by the equation

$$P = Kd^n$$

In this equation P represents the load applied to the post, K is a constant depending upon the soil variations, and d is the depth of set. Average values for n vary between the limits of 1.24 and 1.81, depending upon the diameter of the post used.

8. The effect of the diameter of a wood post set in clay loam soil upon the overturning resistance may be expressed by the equation

$$P = KD^n$$

In this equation P represents the load, K is a constant depending upon soil variations, and D represents the diameter of the post. Average values for n vary between the limits of 1.13 and 1.93, depending upon the depth of set. An average value for n of 1.48 gives approximate values for P.

LITERATURE CITED

1. Abbett, R. W. Stability of cantilever poles in sandy soils. Civil Engineering. 11:301. 1941.
2. Anon. 17,000 creosoted fence posts driven on tri-county project in Nebraska. Wood Preserving News. 17:118. 1939.
3. Anon. For fence engineering. Agr. Engr. 16:292. 1935.
4. Giese, Henry. Farm fence handbook. Republic Steel Corporation, Chicago. p. 51. 1938.
5. Hazen, G. L. Analysis and test of fence end construction. Unpublished Thesis. Library, Iowa State College, Ames, Iowa. 1939.
6. Hogentogler, C. A. Engineering properties of soil. First Edition. p. 37, 44. McGraw-Hill. New York and London. 1937.
7. Humphrey, H. N. Cost of fencing farms in the north central states. U. S. Dept. Agr. Bul. 321. p. 1-2. 1916.
8. Kelley, M. A. R. Farm fences. U. S. Dept. Agr. Farmers' Bul. 1832. p. 22-23. 1940.
9. Lyman, F. A. Economic and engineering problems in farm fencing. Agr. Engr. 11:329. 1930.
10. McKibben, Eugene G. and Hull, Dale O. Soil penetration tests as a means of predicting rolling resistance. Agr.

Engr. 21:231. 1940.

11. Seiler, J. F. Effect of depth of embedment on pole stability. Wood Preserving News. 10:152. 1932.
12. Stone, A. A. and Williams, Ira A. Measurement of soil hardness. Agr. Engr. 20:25-26. 1939.
13. Strong, M. D. Wood post end and corner constructions for wire fences. Unpublished Thesis. Library, Iowa State College, Ames, Iowa. 1940.

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