TESTING AND ANALYZING THE ADAPTABILITY OF CERTAIN IMPLEMENTS TO ONCE-OVER TILLAGE

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Mirza Javad Shustary

1955

TESTING AND ANALYZING THE ADAPTABILITY OF CERTAIN IMPLEMENTS TO ONCE-OVER TILLAGE

By

Mirza Javad Shustary

AN ABSTRACT

Submitted to Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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Approved H. F. McColly

Mirza Javad Shustary

ABSTRACT

Tillage refers to the different mechanical manipulations of the soil that are used to provide the necessary soil conditions favorable to the growth of crops. It is one of the oldest of arts associated with farming. The evolution of tillage implements and machinery has been one of the most striking features in the growth of the art of farming. Even though phenomenal advances have been made in the perfection of tillage tools, tillage operations remain the most costly of all the various items that are concerned in crop production. Thirty per cent of the total power consumption in agriculture in the United States is expended in tillage.

There has been a tendency among the farmers to over-till their lands. Midwestern farmers have been in the habit of working their land several times after plowing. It was believed that twice with a tandem disk and twice with a spring tooth harrow constituted an average amount of tillage for crops such as corn, oats, beans, and sugar beets. With too much tillage, machinery is worn out, fuel and labor are wasted and expected yields are never reached. Soils are being excessively packed. The result is slow, shallow root penetration, slow water intake, and poor aeration. The packing is the result of organic matter depletion and too much tillage (6).

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The truth of these statements has been shown by nine years of experimental work conducted by the Soil Science and Agricultural Engineering Departments at Michigan State University. One of the objectives of the experiments was to determine the minimum tillage necessary after breaking the soil with a moldboard plow. Minimum tillage methods have led to the concept of once-over tillage. The author accepts the advantages of once-over tillage, and has attempted to adapt certain tillage implements to this method of seedbed preparation.

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INTRODUCTION

The concept of once-over tillage denotes a minimum tillage method, whereby a tillage implement is used in tandem with a plow and the entire tillage work is performed in one operation by going over the field once only. This method was conceived at Michigan State University in 1946 with the joint efforts of the Soil Science and the Agricultural Engineering departments, and since then considerable field work has been carried on to test the advantages of this method and to prove its practicability.

The one handicap in this method of tillage has been the need to pull a heavy and cumbersome implement behind the plow, which slowed operation and which caused unnecessary tearing of vegetation and soil around the ends of the field and also impeded maneuverability. This phase of once-over tillage interested the author and he attempted to experiment on various liftable implements that could be mounted on both "the mounted" type and "the trail" type plows, and which would lift off the ground when the plow lifted. This system would eliminate cumbersome pulling, as the implement would now be one unit with the plow. It would also facilitate maneuverability and simplify turning at the ends of the field as the implement would lift off the ground with the plow.

With this goal in mind, several implements were modified and field tested. The results of those tests and the practicability of the tested implements are recorded in this paper.

REVIEW OF LITERATURE

Requirements of Seedbed Preparation

Tillage operations account for two-thirds of the power and labor required to produce field crops (14). On many farms more than one-half of the tillage time is spent on seedbed preparation. Therefore, tillage operations which will prepare satisfactory seedbeds with less power and labor expenditures are of distinct advantage to the farmer. The conventional method of preparing a seedbed is, generally, plowing with a moldboard plow, then pulverizing the soil with a tandem disk harrow and spring tooth harrow. This method usually allows the soil to dry out too long after plowing before the pulverizing operation is performed, so that the soil becomes too cloddy. In thus fitting a seedbed, the farmer travels the newly plowed soil many times, often until the tractor wheels have excessively packed a large part of the surface soil.

In order to realize exactly how much tillage is necessary, the objects of tillage should be considered. These objects are:

1) To turn under and mix stubble, manure, and other organic matter, thus adding humus-forming material to the soil in such a manner that it will not interfere with

further tillage and planting operations;

2) To destroy and prevent the growth of weeds.

3) To loosen the soil so that it may take in and retain the maximum amount of rainfall and allow ready penetration of roots and air.

4) To loosen soil so seeds may be properly planted and covered.

5) To leave the surface of the soil as smooth as necessary for a satisfactory seedbed for the type of crop being planted.

6) To give a soil surface of such character as will prefent erosion by wind or water in those areas where erosion is a problem.

It is recognized that not all of these objects of tillage are obtained at one time, and that they are not all desirable at any one location. Baver (1) lists the basic requirements of a seedbed to be:

1) Permit the rapid infiltration and satisfactory retention of usable rainfall.

2) Afford an adequate air capacity and a ready exchange of soil air with the atmosphere.

3) Offer little resistance to root penetration.

4) Resist erosion.

5) Facilitate the placement of surface residues.

6) Provide stable traction.

If these are the characteristics of good tilth, the question arises as to possible means of achieving the desired tilth in the seedbed. This question necessitates a concept of the seedbed profile, together with the means of obtaining and maintaining such a profile through tillage operations.

The Seedbed Profile

In the old type of seedbed, the few surface inches were reduced to a powdery condition as a result of overworking with tillage implements. Rollers, drags and other pulverizing types of tools were used to perfect this fine condition. Below this thin layer of finely divided soil there was a little disturbance of the plowed layer. The whole layer remained somewhat coarse and full of large air pockets. Removal of these air pockets was attempted by reaching them from the surface. Consequently, the structure of the immediate surface was destroyed in trying to establish better contacts between the surface soil and subsoil. This dusty surface is the antithesis of good tilth. The finely divided soil runs together easily under the impact of raindrops which rapidly reduces the rate at which water and air can enter the seedbed.

The ideal profile should be the old one inverted. That is, the lower part of the seedbed should contain the finest granules and possess the firmest degree of settling. The coarseness of the granules, in most cases, should increase as one approaches the surface. The immediate surface should consist of distinctly coarse granules to absorb the shock of the impact of raindrops and thereby preserve an open structure. It is true that the granules should not be so coarse in the vicinity of the seed that sufficient moisture cannot be had for the purpose of germination. On the other hand, the granules should not be so fine that inadequate aeration will prove to be the limiting factor. But what are the limits of coarseness or fineness? This question cannot be answered satisfactorily in light of existing data. Yoder (22) found that the emergence of cotton plants from seedbeds with different degrees of granulation was most rapid when about half the granules were 1/8 to 1/4 inch in diameter and the other half were smaller. A mixture of granules of varying sizes showed the best effects on stand.

Tillage Tests at MSU

Power and Draft Requirements

There are many types of tillage machinery and the machine selected for any particular operation will depend upon field characteristics, vegetation, weather conditions, topography and other factors. Some machines or methods have been found to be satisfactory under one set of conditions but quite unsatisfactory in some other locations (9).

TABLE I

POWER AND DRAFT REQUIREMENTS OF THE VARIOUS TILLAGE IMPLEMENTS

Machine	Power and Draft Requirements
Plow, moldboard	5-12 lbs/sq. in. furrow section
Vertical disk tiller	150-350 lbs/ft width
Chisel plow	75-200 lbs/ft width
Tandem disk harrow	80-160 lbs/ft width
Smoothing harrow	30-60 lbs/ft width
Spring-tooth harrow	75-150 lbs/ft width
Field cultivator	90-160 lbs/ft width
Cultipacker	30-75 lbs/ft width
Rotary hoe	30-60 lbs/ft width
Auger tiller	5-10 H.P./ft width
Rotary tiller	5-15 H.P./ft width
Revolving packing-type tiller (Clodbuster)	60-85 lbs/ft width

A horsepower hour is the unit of power consumption at the rate of one horsepower for one hour (Table II). Thus, a tractor supplying 14 horsepower to operate a machine which performs an operation on one acre in one hour yields 14 horsepower hours. If a smaller tractor develops seven

TABLE II

POWER REQUIREMENTS OF VARIOUS TILLAGE IMPLEMENTS FOR SEEDBED PREPARATION

Machines	Primary	Tandem Disking	Harrowing	Firming	Total
Moldboard plow	14.0	9.0*	5.6*		28.6
Plow with sub-bases	14.0	4.5	5.6*		24.1
Plow and packer	15.5**				15.50
Plow and mulcher	17.0**				17.0
Plow and revolving tiller***	17.0**				17.0
Disk tiller	8.5	9.0		1.5	19.0
Auger-type tiller	30.0			1.5	31.5
Rotary tiller	75.0			1.5	76.5

*Two operations: normal - conventional
**Once-over tillage: fitting machines in tandem with plow
***Preliminary trials with the clodbuster

horsepower but requires two hours to perform the operation on one acre, horsepower hours necessary is still 14.

To compute the horsepower necessary to pull a machine, the following formula is useful:

$$H.P. = \frac{\text{lbs pull} \times MPH^{*}}{375}$$

*MPH = miles per hour

TABLE III

TIME REQUIRED FOR WEED CONTROL WITH VARIOUS TILLAGE IMPLEMENTS

Machines	Time - hours per acre
Moldboard plow	3.56
Plow with sub-bases	4.37
Plow and packer	3.08
Plow and mulcher	3.27
Disk tiller	5.00
Auger-type tiller	4.59
Rotary tiller	5.54

The power and labor requirements for seedbed preparation are naturally low for the once-over operations and also for those methods employing seedbed fitting immediately after plowing. The lowest requirements are for the plow with a packer in tandem, but for most all around conditions a little soil stirring with the packing is desirable in order to close up the furrow slice laps to control weed growth. For this reason the revolving packing-type tiller following behind the moldboard plow is a good system.

Average Yields By Different Tillage Methods

Tests on the comparison of tillage implements and their effect on crop yields have been conducted since 1947 as a cooperative project between the Soil Science and Agricultural Engineering Departments. Points investigated were:

1) Time required to prepare seedbeds

2) Power required by different methods of tillage

3) Weed growth control required

4) General evaluation of quality of tillage, including deep tillage

5) Crop yield results

6) Adaptation of tillage methods to farm conditions.

Tables IV and V give the five-year average results (1947-1951) of crop yields by the different methods.

TABLE IV

AVERAGE CROP YIELDS ON BROOKSTON CLAY LOAM

Tillage Methods	Average Yields, 1947-1951 (Bu.)			
	Oats	Corn	Beets	Navy Beans
Plow, disk and harrow	76.6	55.1	12.0	23.3
Plow with sub-bases, disk and harrow	74.9	54.3	11.9	22.1
Plow, with plow packer (once-over)	77.5	56.9	12.1	23.4
Plow, with mulcher (once-over)	70.1	54.3	12.4	22.2
Disk tiller, disk and harrow	74.8	51.1	11.9	19.8
Auger-tiller, packer	65.7	43.6		14.9
Rotary tiller, packer	68.6	44.8	11.3	14.3

TABLE V

AVERAGE CROP YIELDS ON HILLSDALE SANDY LOAM

Tillage Methods	Average Yields, 1947-1951 (Bu.)		
	Oats	Corn	Navy Beans
Conventional*	66.6	45.8	16.0
Plow, with sub-bases	64.3	45.0	16.1
Plow, with packer	65.7	48.5	16.4
Plow, with mulcher	63.4	46.9	16.0
Vertical disk tiller	63.0	43.2	14.4
Rotary tiller			

*Moldboard plowing plus two tandem diskings and two harrowings.

Comparative Results

The results led to the following conclusions:

1) In all cases, yields were highest where the tillage methods employed moldboard plows.

2) The "once-over" soil preparation methods were entirely satisfactory for all crops on all types of soil. Yields were fully as high as those obtained where conventional tillage was employed, whereas power and labor requirements were the lowest.

3) Preliminary trials indicate that any device which smoothes the soil sufficiently to make accurate planting possible, accomplishes all the tillage that is necessary for oats, sugar beets, and corn. The soil is usually moist at the time of plowing and as a result of the firm contact established between seed and soil, germination is rapid.

From the data presented it is evident that yields were on the average as high after the "once-over" tillage methods were employed as they were after the conventional diskings and harrowings. The horsepower data show that just slightly over one-half as much labor was required where the packer method of "once-over" tillage was used as where the method employed the old conventional tillage after plowing. In short, the highest yields were obtained when the least power and labor were expended in seedbed preparation. In terms of money saved, once-over tillage can result in a saving of over one dollar per acre, with as high as three dollars per acre possible.

RESEARCH WORK

Objectives

The objectives of this investigation were to adapt certain tillage implements for once-over tillage such that the implement could be mounted on the plow and be lifted with it, with due consideration to the weight of the implement, the stresses its loading causes in the plow bottom, and the effectiveness of the implement as a tillage tool.

Methods of Procedure

1) A review of past research work done on minimum tillage methods and once-over tillage. This study gave information on the various types of implements that have been used by the Soil Science and Agricultural Engineering Departments of Michigan State University, and paved the way for experiments to adapt certain of these implements to be liftable with the plow, as well as to test some new tillers.

2) A study of the available equipment and a choice of those best adapted for lifting.

3) Field tests of the adapted implements.

4) Stress analysis - to determine the stress caused in the plow due to the weight of the lifted implement.

5) Force analysis of the soil reactions on the implements.

6) Suggestions made for further research.

Experimental Investigation

Choice of Implements

Several implements that had been tried by the Soil Science and the Agricultural Engineering Departments and some others were considered on the basis of:

a) weight and draft load

b) ease of mounting and dismounting on the plow

c) type of action on soil

d) appearance of soil surface the implement leaves.

Consequently, the following implements were picked for adaptation to mounting on the plow and liftability, and were field tested:

1) Courey's* short-toothed tiller

2) Courey's long-toothed tiller

3) The cultipacker unit

4) The plow-packer unit

Choice of a Hitch

Two types of hitches were tried and tested:

1) The 'Z' hitch

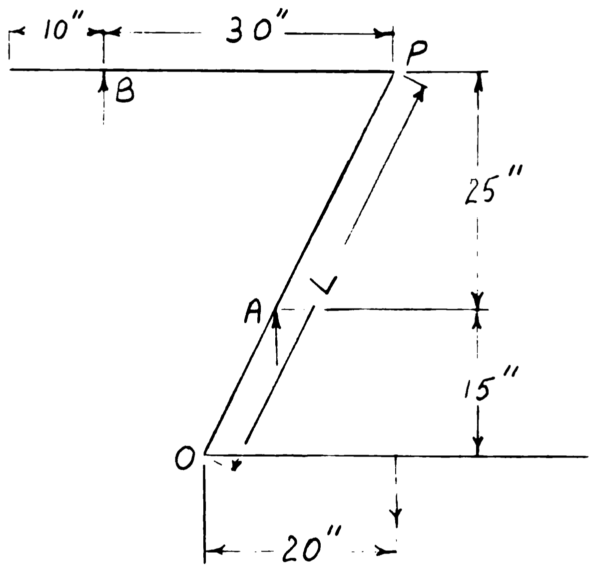
2) The 'L' hitch.

---

*Named after the inventor of the implement - N. J. Courey of Saline, Michigan.

The 'Z' hitch. A detail sketch of the Z hitch is given in Figure 1. This type of a hitch proved most practical and best adapted for maneuverability and lifting. The clamp is designed to fit any size of plow beam and can be attached to various parts of the beam by means of a system of staggered holes (Fig. 1).

Design of the hitch: bending load in lifting, based on lifting a plow-packer weighing 350 lbs.



Checking for load at B:

$$\Sigma M_A: \quad 350 \times 15 = F_B \times 25$$

$$F_B = \frac{350 \times 15}{25} = 210 \text{ lbs.}$$

A bending stress is caused in the implement shaft, as well as in the diagonal shaft. The two shafts will be considered separately.

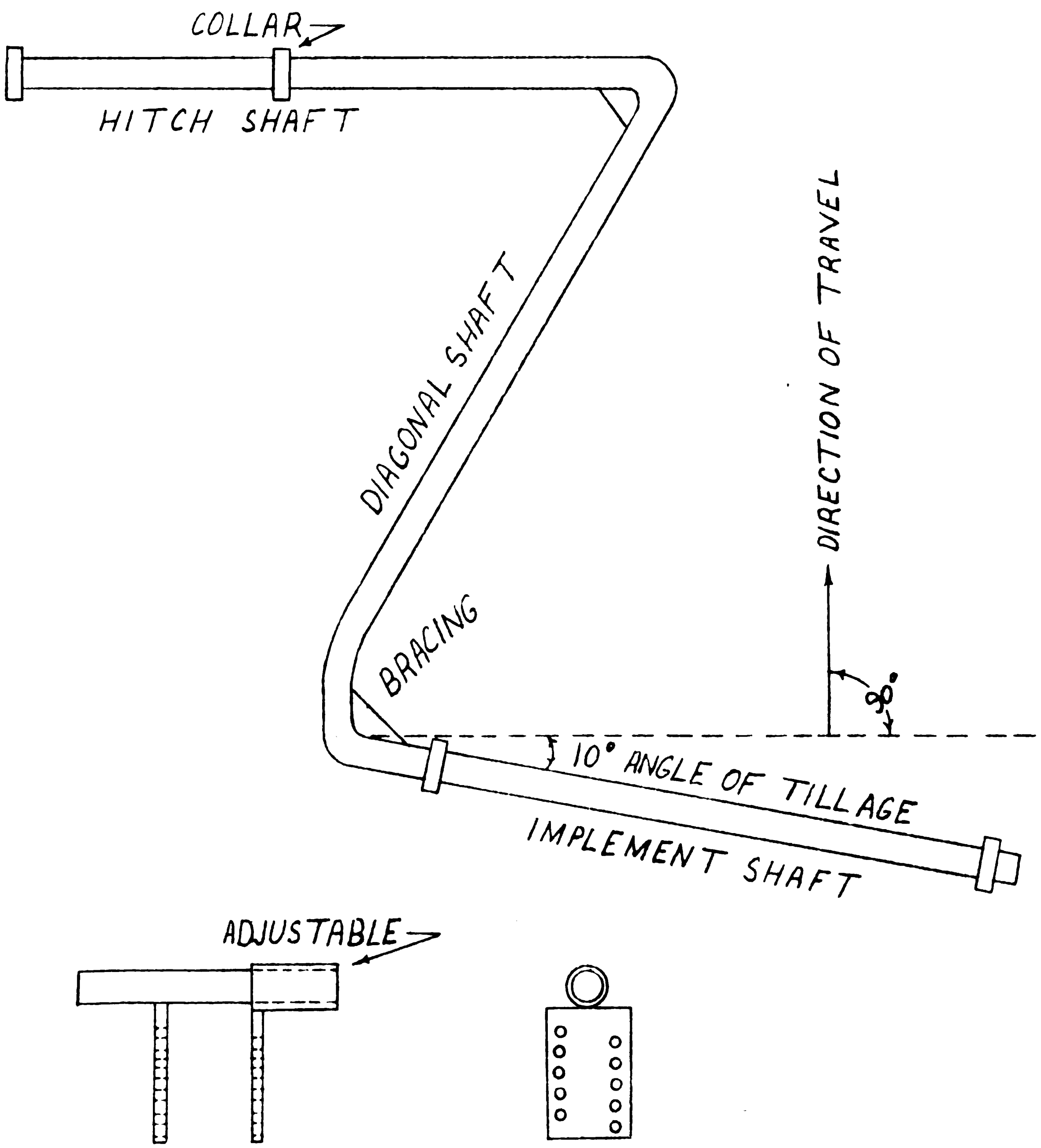


FIG. 1 . THE Z HITCH AND CLAMP
SCALE : 1 :10

The implement shaft:

Bending moment M_o = 350 x 20 = 7000 in. lbs.

Bending stress $S_y = \frac{M_o c}{I} = \frac{M}{I/c} = \frac{M}{\frac{\pi d^3}{32}}$

c = radius of shaft I = moment of inertia

I/c = section modulus d = diameter of shaft

$S_y = \frac{7000}{0.526} = 13{,}300$ psi.

The shaft being of SAE 1010 material has an allowable bending stress S_a = 24,000 psi. (9).

Factor of safety F.S. $= \frac{24{,}000}{13{,}300} = 1.8$

To strengthen the joint O, a bracing was welded on at the point. Joint P was also braced.

The diagonal shaft:

$L = \frac{15}{\sin 60^\circ} = 17.3''$

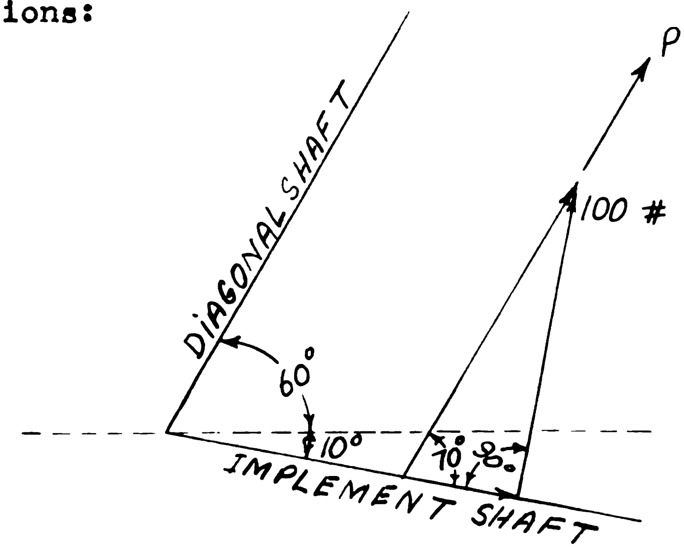
Bending moment M_o = 350 x 17.3 = 6050 in. lbs.

Bending stress $S_y = \frac{6050}{0.526} = 11{,}500$ psi.

$F.S. = \frac{24{,}000}{11{,}500} = 2.1$

The hitch thus designed would, therefore, be safe for experimental purposes.

Draft considerations:



Pulling force $P = \frac{100}{\sin 70°} = 107$ lbs.

Tensile stress $S_T = \frac{P}{A} = \frac{107}{2.4} = 44.6$ psi.

A = cross-sectional area of the shaft $= \frac{\pi d^2}{4}$

This tensile stress is negligible.

The advantages of the 'Z' hitch are:

1) Ease of mounting and dismounting

2) Strength - capable of supporting heavy loads

3) Ease of pulling - being fixed at the joints, once the hitch is set in place, it remains fixed and will not be thrown out of position

4) Elimination of side support - due to its 'Z' design, when lifted the diagonal shaft rests on the hind moldboard, while the beam shaft is attached to the plow beam. This enables the hitch to bear the implement without side support.

The implement shaft is set at an angle of 10° from the horizontal (Fig. 1). This inclination is called The Angle of Tillage. The one disadvantage of this hitch is its inelasticity of angle of tillage. Once set for a certain angle of tillage, it is fixed. Any alteration in this angle will have to be by means of furnace or torch heating and reshaping of the joints.

<u>The 'L' hitch</u>. The basis of design of this hitch is very similar to that of the 'Z' hitch, and therefore will not be discussed. Figure 2 shows a detail sketch of this hitch. This type of a hitch has most of the advantages of the 'Z' type, plus being adjustable as regards the Angle of Tillage. The direction lever allows adjustments within a range of 35°. It consists of a metal bar that connects the Pull shaft to the Hitch bar (Fig. 2).

The direction lever - adjusting the angle of tillage:

The direction lever support on the pull shaft was welded in such a way that the triangle formed by the pull shaft, hitch bar and the lever would be a 30°, 60°, 90° triangle, with dimensions as shown in Figure 3 when the angle of tillage is zero.

By a system of holes a, b, c, d, on the lever and the hitch bar, spaced as shown in Figure 3, various angles of tillage could be obtained from -15° to 20°, giving a range of 35°. When the Pull shaft is tilted at a certain angle,

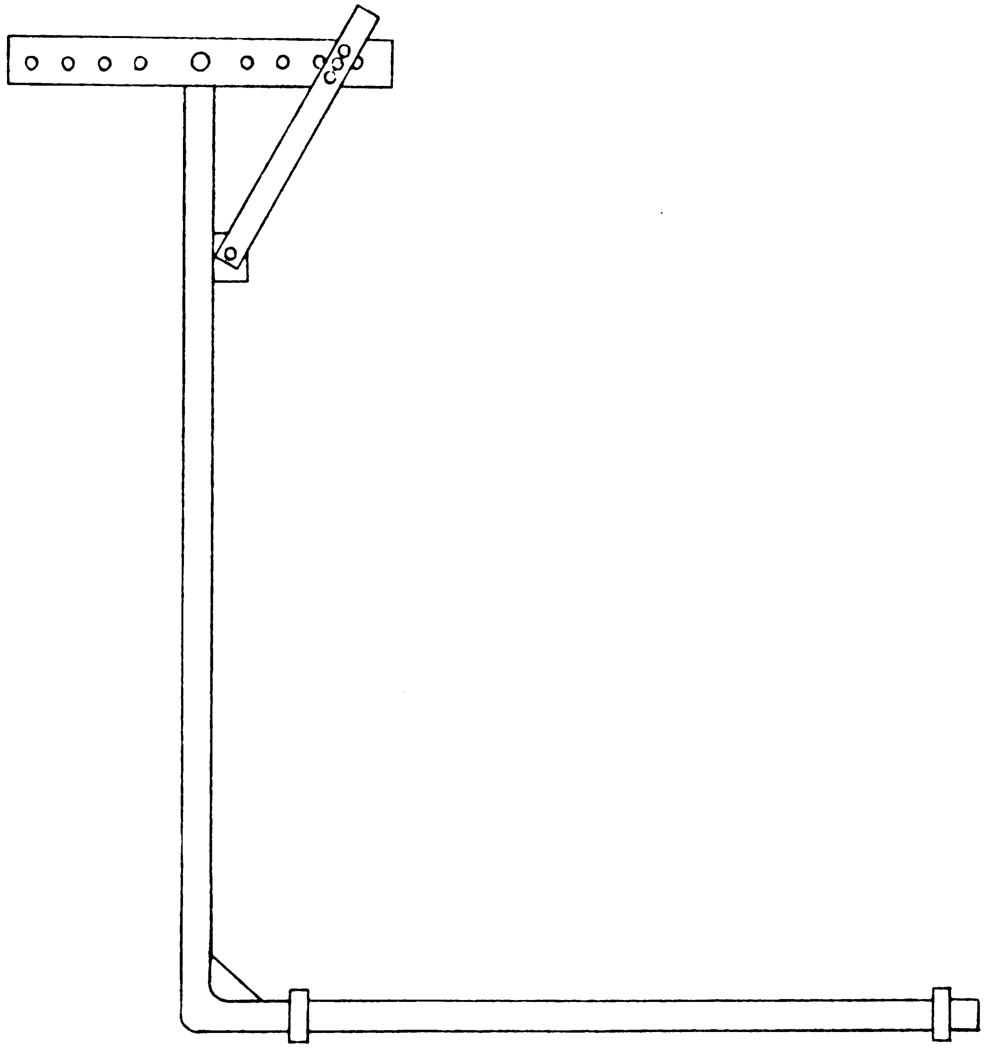


FIG. 2 THE L HITCH WITH HITCH BAR AND DIRECTION LEVER
SCALE 1:10

the same angle is produced on the implement shaft due to the fixed connection between the two shafts.

With reference to Figure 3 the various settings are given in the following table.

TABLE VI

THE VARIOUS SETTINGS OF ANGLE OF TILLAGE FOR THE 'L' HITCH

Settings*	Angle of Tillage**
O on O	0
A on O	-10
A on D	-15
B on O	11
B on C	20
O on C	6
O on D	-5

*The central hole on both the hitch bar and the lever are designated as 'O'.
**Angle toward the furrow is designated by a (-) sign.

The disadvantages of the 'L' hitch are:

1) Slightly longer time (than the 'Z' hitch) needed to mount and dismount on the plow

2) Need for a side support.

The hitch bar consists of two iron bars (1/2" x 3") with symmetrical holes in them, spaced to fit on the plow beam. The two bars clamp to the beam by means of a system of bolts and nuts holding the two pieces together (Fig. 11).

Field tests showed both hitches to be practical and well adapted to lifting and maneuverability. These hitches were designed to be versatile. Thus, each has an implement shaft such that an implement unit can be mounted on the shaft, removed and replaced by another unit. Both hitches were used with various implements.

The 'Z' hitch was used with:

1) Courey's short-toothed tiller

2) Courey's long-toothed tiller

3) The cultipacker unit.

The 'L' hitch was used with:

1) The cultipacker unit

2) The plow-packer unit.

The Field Tests

All the field tests on the various implements were carried out on Brookston Clay Loam and Hillsdale Loam soils.

Courey's short-toothed tiller. The implement consists of angle-iron spikes welded to a pipe. The unit slides on and off the implement shaft of the hitch. Figure 4 shows the tiller mounted on the 'Z' hitch.

Field tests on this tiller proved it to be an effective implement. Its light weight makes lifting easy. The teeth

Fig. 4. Courey's short-toothed tiller mounted on the 'Z' hitch.

do a good job of tillage. It leaves the soil surface sufficiently smooth, while leaving the surface granules comparatively coarse. The soil-stirring action of the teeth aerates the soil well while causing good coverage of trash. The tiller teeth mix the soil and the vegetative cover satisfactorily. Its light weight and draft make manipulation easy. It is economical in operation due to low power requirements for pull.

Advantages:

1) Good job of stirring, mixing, aerating and trash cover.

2) Economical in operation.

3) Ease of mounting and dismounting on the implement shaft of the hitch.

Its limitation is that it is an effective tillage tool only on heavier soils which do not need firming (clayey soils). On sandy soils, its type of action is not essential, and due to its light weight it does not help in firming.

The following table gives the specifications for the tiller as well as those for the long-toothed implement.

TABLE VII

SPECIFICATIONS OF COUREY'S SHORT AND LONG-TOOTHED TILLERS

Specification	Short-toothed Tiller	Long-toothed Tiller
Weight	20 lbs.	25 lbs.
Draft	60 lbs.	80 lbs.
Overall width	32 in.	30 in.
Number of teeth	6	4
Width of each tooth	1 1/2 in.	1 1/2 in.
Spacing between teeth	4 1/2 in.	7 in.
Diameter of pipe (on which blades are welded)	2 in.	2 in
Length of tooth (from pipe to point)	6 in.	8 in.
Soil penetration	5 in.	7 in.
Diameter of rotation	14 3/8 in.	18 3/8 in.

Fig. 5. Courey's long-toothed tiller mounted on the 'Z' hitch.

Courey's long-toothed tiller. This tiller does a successful job of tillage and showed itself an effective tool for once-over tillage. It stirs the soil thoroughly and covers trash well. Due to its longer teeth it performs better for aerating and mixing. Its advantages and limitations are the same as for the short-toothed tiller.

The cultipacker unit. This implement consists of a gang of cultipacker wheels as shown in Figures 8 and 9. Ten cultipacker notched wheels are mounted on the implement shaft of the hitch and held in place by means of collars. Field tests showed the implement to be an effective tillage tool.

Fig. 6. Courey's long-toothed tiller shown in the elevated position when lifted with the plow.

Fig. 7. Courey's long-toothed tiller shown in operation in the field.

TABLE VIII

SPECIFICATIONS OF THE CULTIPACKER UNIT

	Specifications
Weight	300 lbs.
Draft	95 lbs.
Overall width	38 in.
Number of wheels	10
Width of each wheel	3.8 in.
Diameter of axle hole	2 in.
Soil penetration	2 1/2 in.
Diameter of wheel	15 1/2 in.

Figure 8 shows the cultipacker unit when on the ground. This implement is best adapted to sandy soils that need firming. It leaves a smooth surface, covering trash well. Its limitation is that it does not do sufficient stirring and as such is not suitable for clay soils.

Fig. 8. The cultipacker unit used with the 'L' hitch shown when on the ground.

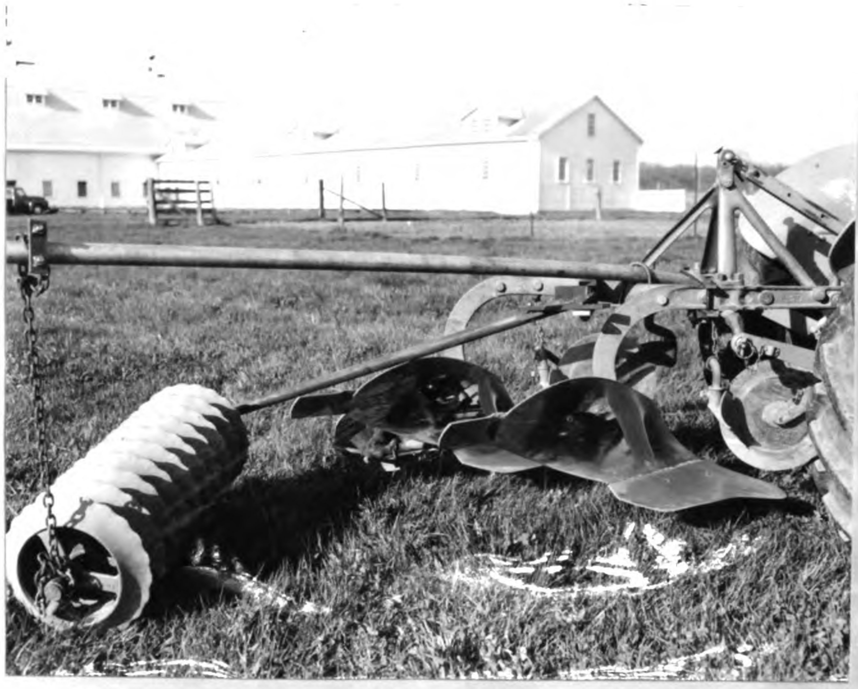


Fig. 9. The cultipacker unit about to be lifted. The boom is for side support.

Fig. 10. The cultipacker unit lifted off the ground. Note the outer end of unit is supported by chain clamped to boom.

Fig. 11. A view of the hitch bar and direction lever of the 'L' hitch, and the boom support on the plow beam.

Fig. 12. The cultipacker unit in field operation.

Fig. 13. Brookston clay loam field after once-over tillage with the cultipacker unit.

Fig. 14. A Hillsdale loam field after once-over tillage with the cultipacker unit.

The plow-packer unit. Several tests have been conducted by the Soil Science and the Agricultural Engineering Departments to show the practicability of this implement for once-over tillage. The author was mostly interested with the weight problem involved in lifting this unit.

Analysis of the maximum weight that can be lifted behind a plow is as follows:

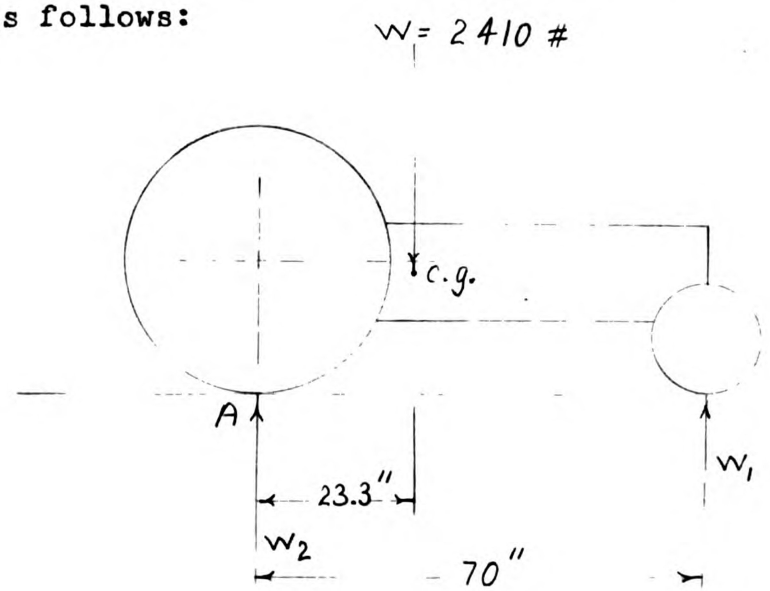


Fig. 15. The plow-packer unit used with the 'L' hitch in tandem with a trail-type plow. Note the boom and hydraulic cylinder used for lifting.

Basing computations on a mounted plow:

Tractor data: (Ferguson, model 35)

Wheel base: 70"; tread: 48 "

Shipping weight: 2410 lbs.

Center of gravity: approximately one-third the distance between axles, in front of the rear axle. (1/3 x 70 = 23.3")

With reference to the diagram on page 33:

Moments at A: $2410 \times 23.3 = W_1 \times 70$

$W_1 = 804$ lbs.; $W_2 = 2410 - 804 = 1606$ lbs.

Using a Dearborn 2-bottom 14" plow: weight = 420 lbs.

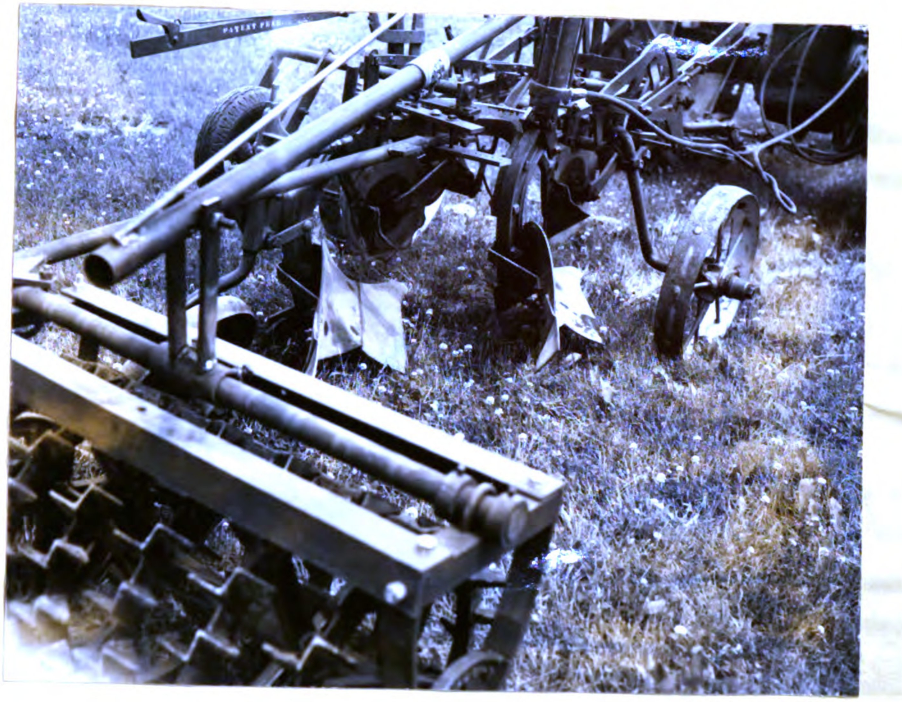
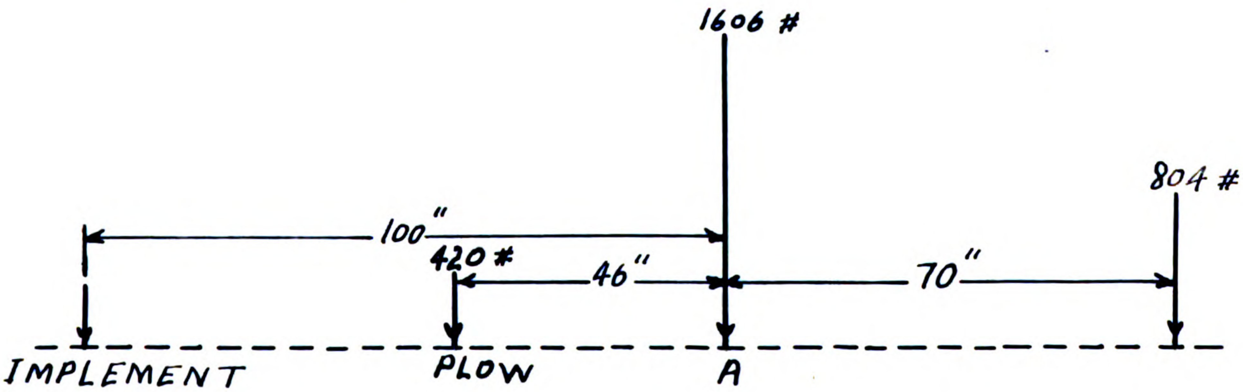


Fig. 16. Plow-packer used with 'L' hitch, showing connections.



$$\Sigma M_A: \quad 804 \times 70 = (420 \times 46) + 100 X$$

$$56{,}300 - 19{,}320 = 100 X$$

$$X = 369.8 \text{ lbs.} \cong 370 \text{ lbs.}$$

The plow-packer weighs 350 lbs. Thus, as far as the tractor stability is concerned, it would be safe to lift the packer behind the plow.

Fig. 17. View showing the plow tipping when the packer was attempted to be lifted.

Basing computations on a trail-type plow:

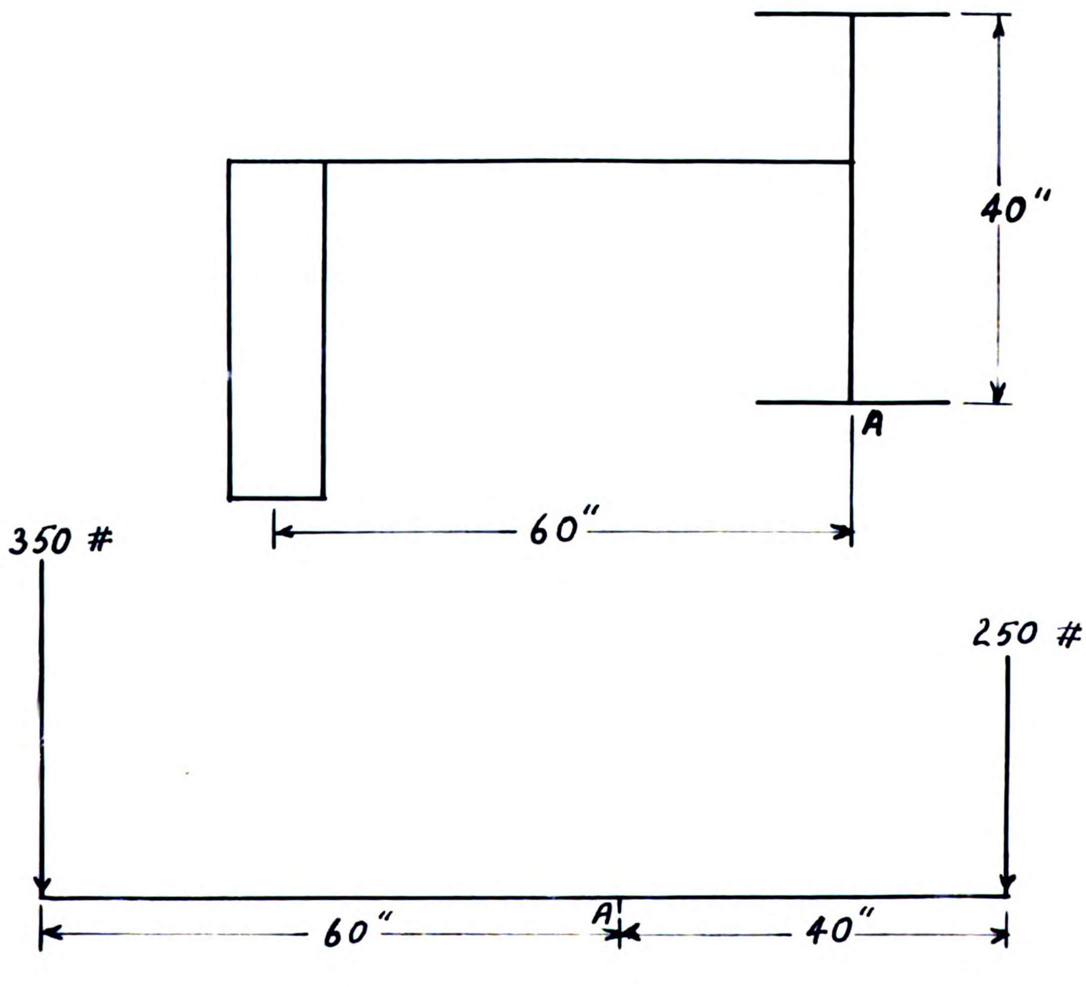
Lifting tests were carried out on the plow-packer with the 'L' hitch in tandem with a trail-type McCormick two-bottom plow. To lift the packer a one-way hydraulic cylinder was mounted on the plow-beam.

As expected, an overturning moment was caused tipping the plow. Taking the plow to weigh 500 lbs, and the packer to weigh 350 lbs, the analysis is the following in reference to the diagram on page 37:

$$\Sigma M_A : \quad 350 \times 60 = (40 \times 250) + M_x$$

$$M_x = 21{,}000 - 10{,}000 = 11{,}000 \text{ in. lb.}$$

Fig. 18. Another view showing the tipping of the plow.



An overturning moment of 11,000 in. lbs. is caused. Hence, the tipping of the plow. For a trail-type plow, therefore, with a load acting 60 inches behind the wheels of the plow, the weight of the implement should not exceed the value computed below.

$$60 \times F_x = 40 \times 250$$

$$F_x = \frac{10,000}{60} = 166 \text{ lbs.}$$

Allowing a safety margin of 46 pounds, the load should not exceed 120 pounds.

Stress Analysis

In order to check for stresses caused in the rear plow-bottom due to the weight of the implement resting on it, a stress analysis test was conducted. The Brush equipment was used, together with electric resistance wire SR-4 strain gages, type A-1.

Attachment of the gage to the test structure. The surface was made free of any coating, such as paint or mill scale, and then made smooth by using a medium-fine-grain emery cloth. The surface was cleaned thoroughly with a solvent (carbon tetrachloride). The test surface and the underside of the gage were coated with a suitable cement (Duco cement) and the gage was applied to the test surface. A uniform pressure was applied over the top of the gage to assure uniform contact and to eliminate all excess cement

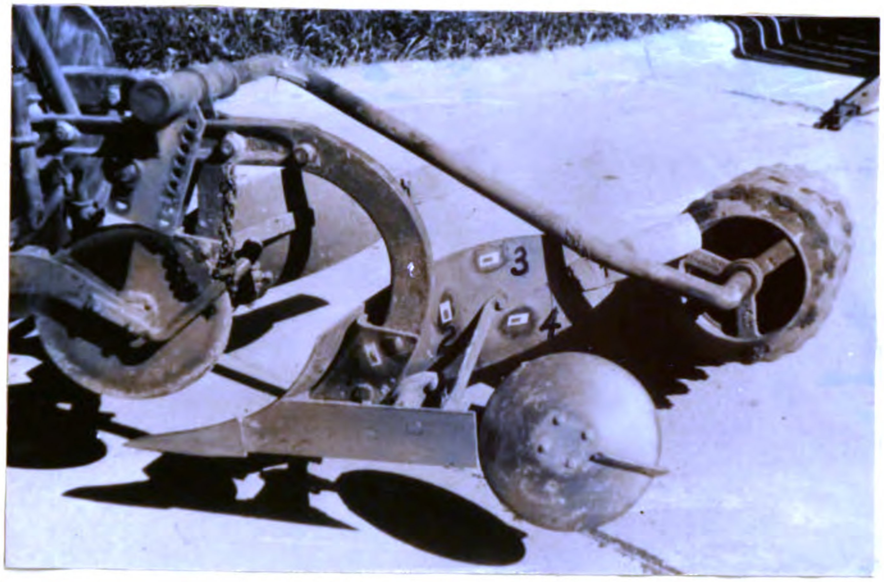


Fig. 19. Positions of the gages on the rear plow-bottom.

between the gage and the surface. This pressure was maintained until the cement was thoroughly dry (about 24 hours).

The Brush equipment was set up in the laboratory and the leads connected to the gages.

<u>Checking for maximum stress</u>. Figure 19 shows the positions in which the four gages were placed to check the strains caused at those points. The charts obtained for the different points are shown in Figure 21.

Recorder speed: 5 mm./sec.

Attenuation: 10 μ in./in. per line.

With reference to Figure 21, the unit strains obtained are:

1) Point 1, e = 28 μ in./in.

2) Point 2, e = 20 μ in./in. (shock)

3) Point 3, e = 30 μ in./in.

4) Point 4, $e = 70\ \mu$ in./in. (steady)

$e = 120\ \mu$ in./in. (shock-loading)

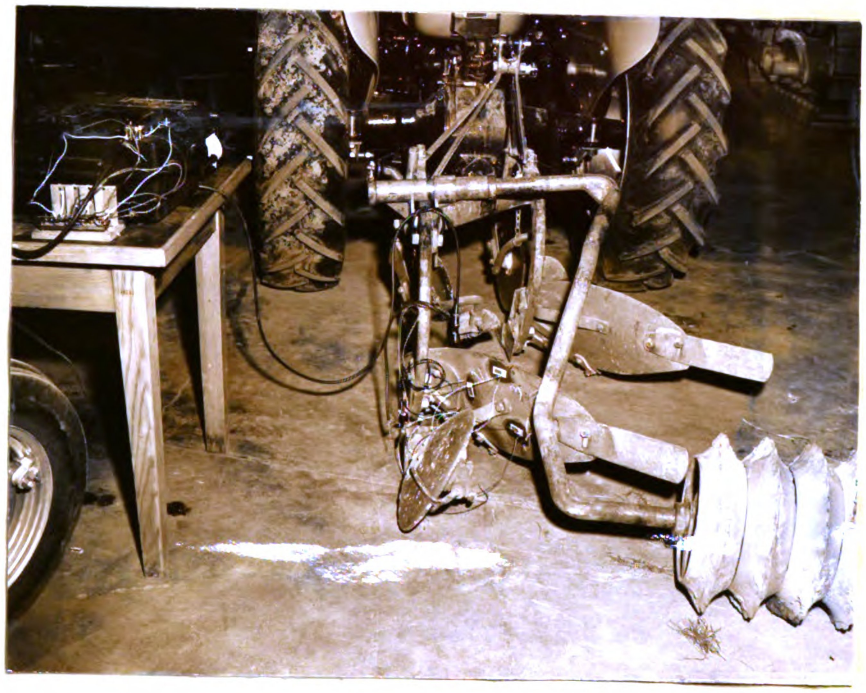


Fig. 20. Strain gages placed on the rear plow-bottom connected to the Brush equipment. Loading by the cultipacker unit mounted on the 'Z' hitch.

Material of the plow - S.A.E. 1010

Modulus of elasticity $E = 30 \times 10^6$ psi.

Elastic limit = 31,000 psi.

Unit stress $S = E\,e$.

Unit stresses at the various points are:

1) $S = 30 \times 10^6 \times 28 \times 10^{-6} = 840$ psi.

2) $S = 30 \times 10^6 \times 20 \times 10^{-6} = 600$ psi.

3) $S = 30 \times 10^6 \times 30 \times 10^{-6} = 900$ psi.

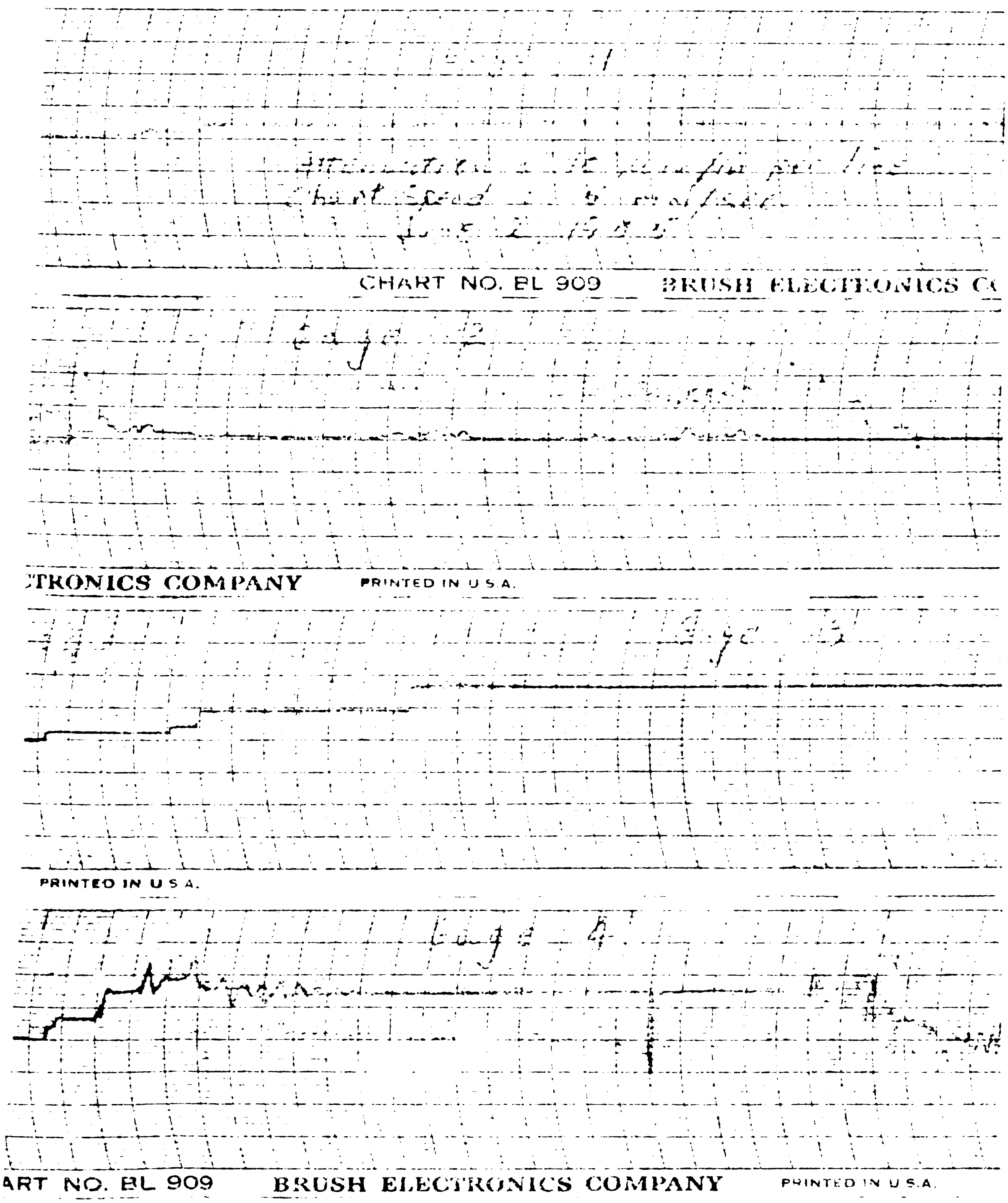


Fig. 21. Charts showing the strains indicated by the various gages.

4) $S = 30 \times 10^{6} \times 70 \times 10^{-6} = 2100$ psi. (steady-loading)

$S = 30 \times 10^{6} \times 120 \times 10^{-6} = 3600$ psi. (shock-loading)

Maximum stress is seen to occur at point (4).

Checking for safety factor:

$$\text{Safety Factor F.S.} = \frac{\text{Allowable Stress}}{\text{Actual Stress}}$$

$$= \frac{31{,}000}{3{,}600} = 8.6$$

Say a Safety Factor of 8:1.

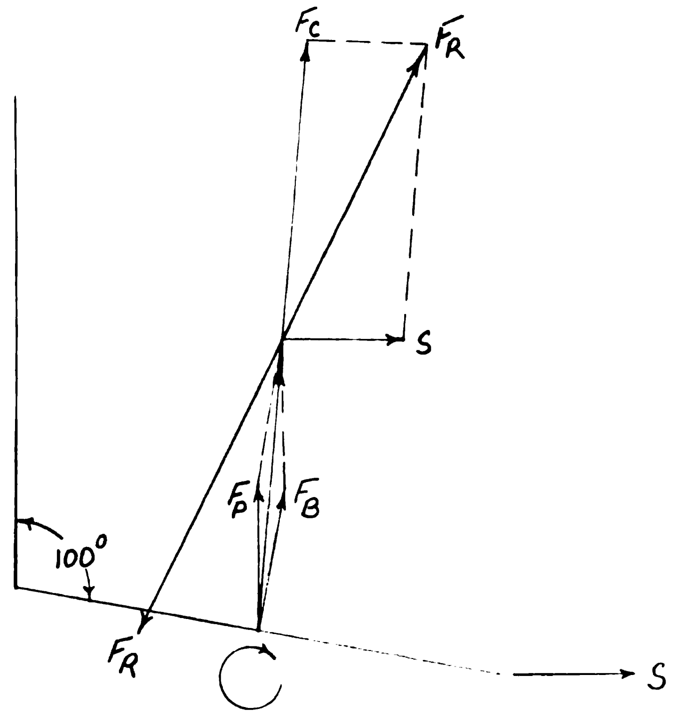
Shock loading takes place when the plow is being lifted. In field operation, the undulations in the field will cause the implement to rock, which results in shock-loading.

The stress analysis test shows that stress caused in the rear plow-bottom due to loading of the implement is within the safe limits and, therefore, no damage is done by raising and lowering the implement with the plow.

Force Analysis of the Soil Reactions

Soil Throw

The following diagram shows the forces determining the direction in which the soil is thrown.



F_R = Resultant force

F_P = Force in direction of pull

F_B = Force in direction of rotation of implement

F_C = Resultant of F_P and F_B.

S = Side force

Distribution of Pressure

The distribution of the vertical pressure on any horizontal plane in the soil beneath a concentrated load is represented by a bell-shaped surface (19). The maximum ordinate of this stress surface is at the vertical axis. Theoretically, the stress approaches zero at infinity; but for practical purposes it may be considered to reach the zero value at a relatively small finite distance. The maximum pressure ordinate is relatively high at shallow depth, and it decreases as the depth increases. In other words, the bell-shaped surface flattens out with increasing depth.

If the stress surface is plotted for each of a series of horizontal planes at various depths and if points of equal stress on the various planes are connected, a surface of revolution having a bulb shape is developed. Such a surface, which is often called the bulb of pressure, is illustrated in Figure 22. The pressure at each point on the pressure bulb is the same. Pressures at points inside the bulb are greater than that at a point on the bulb surface; and pressures at points outside the bulb are smaller than the pressure at points through which the bulb surface passes. Any number of bulbs of pressure may be drawn for any applied load, since a different one corresponds to each arbitrarily chosen value of pressure.

Friction Between Implement and Soil

When the implement is at rest, it is in equilibrium under its own weight W and the equal and opposite reaction N provided by the soil (Fig. 23a). When a horizontal force S is applied to the implement, it will be balanced by an equal and opposite force S in the plane of contact, and the implement will remain at rest if the force is relatively small. If the applied horizontal force is gradually

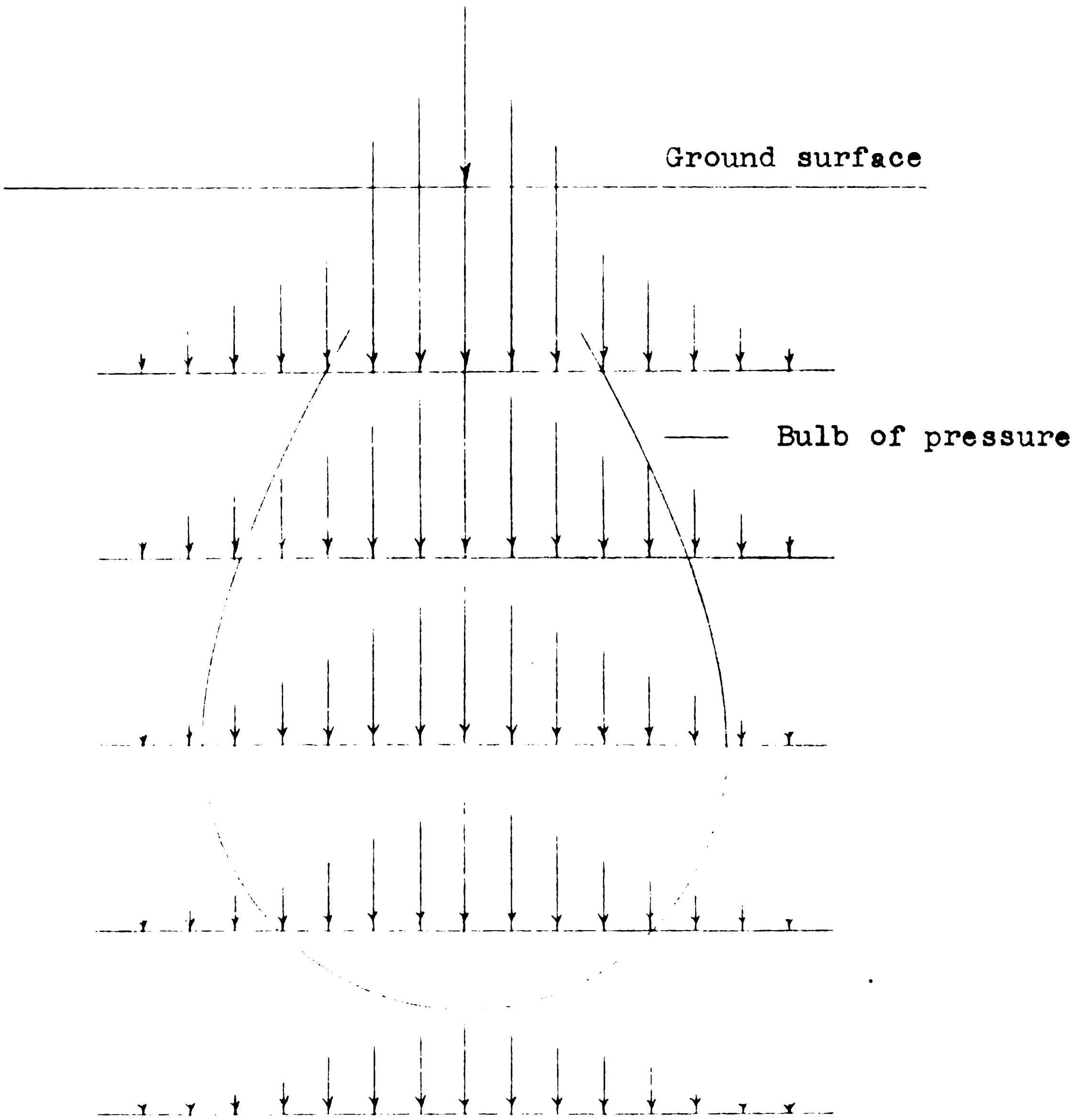


Fig. 22. Bulb of pressure or Iso-stress surface.

increased, the resisting force will likewise increase, always being equal in magnitude and opposite in direction to the applied force. There is a limit, however, to the amount of resistance which can be developed at the plane of contact; and, when the applied force equals or exceeds the maximum possible resistance, equilibrium will be destroyed and the implement will move along the soil. This movement is a shear failure. The applied horizontal force is a shearing force and the developed force is friction or shearing resistance. The maximum shearing resistance which a soil is capable of developing is called the shearing strength.

Friction Angle

The resultant R of the shearing force and the weight acts at an angle with the line of action of the force representing the weight. This angle, designated as α in Figure 23b, is called the obliquity of the resultant or simply the obliquity angle. When the shearing force is increased to a value just equal to the shearing strength, that is, when sliding or failure is impending, the obliquity angle reaches its maximum value and is designated α_m. The forces that are applied normal and tangential to the shear plane are related to each other in accordance with the following equations:

$$\tan \alpha = \frac{S_a}{W}$$

$$S_a = W \tan \alpha$$

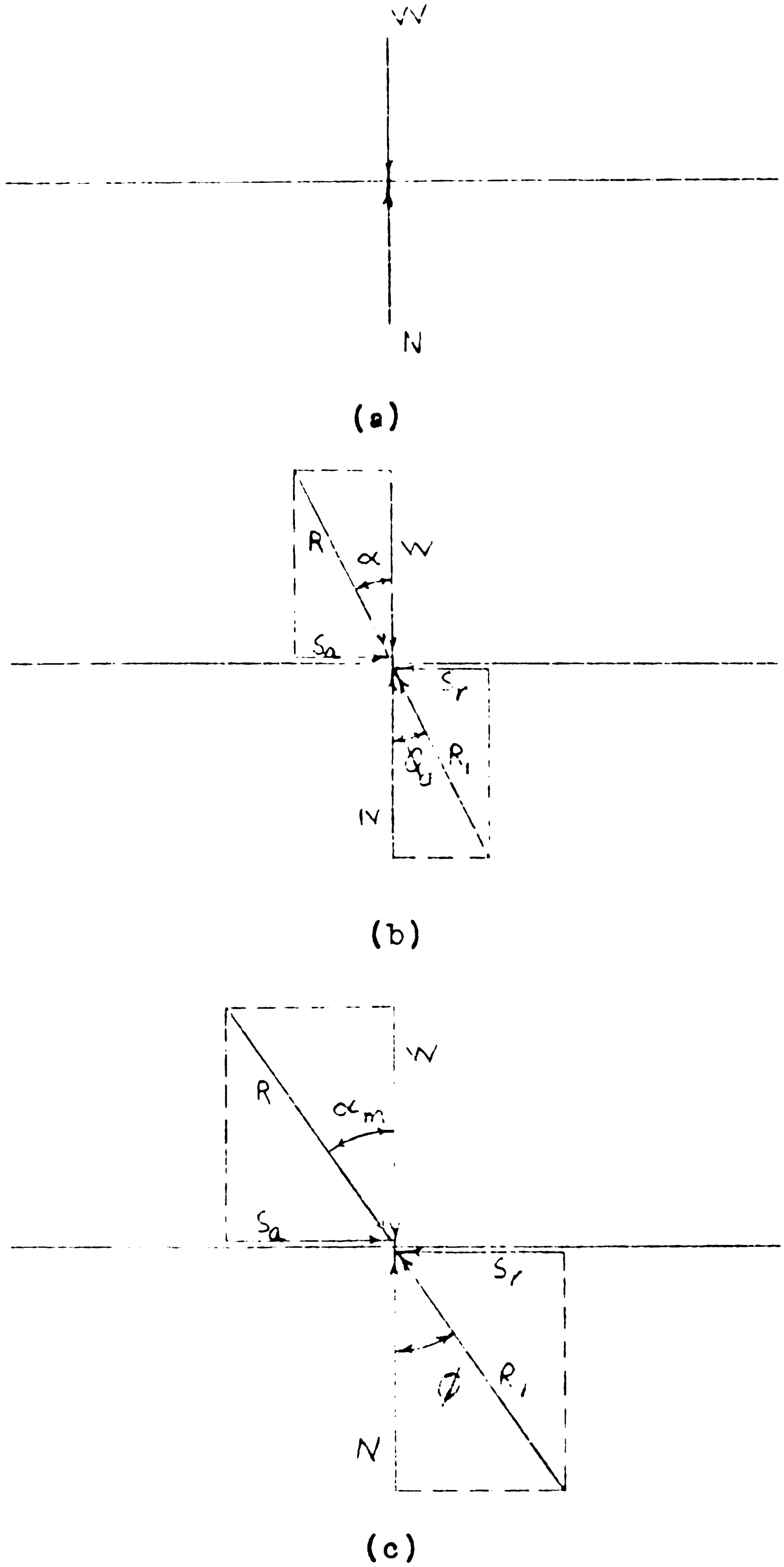


Fig. 23. Force diagram of the action of the implement and the reaction of the soil.

In a similar manner, the reaction N to the weight of the implement, which also acts normal to the shear plane, may be combined with the shearing resistance to obtain a resultant R_1 which makes an angle ϕ_d with the normal. This angle ϕ_d is called the developed friction angle; and it is equal to the obliquity angle since the reaction is equal to the weight and the shearing resistance is equal to the applied shearing force. The angle ϕ_d depends on the magnitude of the applied shearing force, as long as this force is not sufficient to cause shear failure. The angle ϕ_d reaches its maximum value at failure and this maximum value is designated as ϕ, as shown in Figure 23c. This limiting angle ϕ is called the friction angle and constitutes a physical property of the soil.

If shear on an interior plane in a mass of soil is considered, the angle ϕ is a property of the soil, and the value of tan ϕ is called the Coefficient of friction of the soil. This Coefficient is here denoted by μ. The value of tan ϕ is equal to the shearing strength of the soil divided by the reaction normal to the shear plane. Also it is equal to the shearing stress at failure divided by the applied weight force normal to the shear plane.

Thus,

$$\tan \phi = \mu = \frac{S_r}{N} = \frac{S_a}{W} = \tan \alpha_m$$

For example, if the friction angle ϕ of a cohesionless soil is given as 20°, it means that the soil is capable of providing sufficient shearing resistance to maintain equilibrium as long as the applied shearing force produces an angle ϕ_d less than 20°. When the applied shearing force causes ϕ_d to become equal to or greater than 20°, shear failure will result.

Cohesive Soil

Some soils have a finite shearing strength even when they are not subjected to external forces normal to a shear plane. Furthermore, when soils of this kind are subjected to normal forces, the shearing strength is not increased. These are called cohesive soils; and their shearing strength, which is independent of normal pressure, is called cohesion or no-load shearing strength. Cohesion may be illustrated by considering two sheets of fly-paper with their sticky sides in contact. Considerable force is required to slide one sheet over the other, even though no normal pressure is applied. The shearing resistance in this case is due to cohesion between the sticky surfaces. In contrast to this, shearing resistance due to friction may be illustrated by considering two sheets of sandpaper with their sanded surfaces in contact. These may be very easily caused to slide over each other when no normal force is applied. When a normal force is applied, the resistance to sliding or the shearing strength increases in direct proportion to the normal force.

Total Shearing Strength of Soil

Most natural soils exhibit shearing resistance due to both cohesion and friction. These components of strength are found to exist in widely varying relationships, ranging from zero cohesion in the case of clean dry sand to practically zero friction in the case of fine-grained, highly plastic clay. The cohesion and friction components are added together to give the total shearing strength properties of soil. The shearing strength is expressed by an empirical formula proposed by Coulomb (19). This formula is:

$$S = C + N \tan \phi$$

S = Shearing strength, in pounds per square foot

C = Cohesion, in pounds per square foot

N = Pressure normal to shear plane, in pounds per square foot

ϕ = Friction angle of soil

$\tan \phi = \mu$ = Coefficient of friction.

The Coulomb formula is an equation for a straight line having an intercept on one coordinate axis. A typical graph of the equation is shown in Figure 24, in which unit pressures normal to a shear plane are plotted as abscissae and unit shearing stresses are plotted as ordinates. The intercept at zero pressure represents the cohesion of the soil, and

the angle which the graph makes with the horizontal is the friction angle ϕ .

A graph of this kind is called a shear diagram. If the diagram is extended to the left of the origin and the graph is prolonged to intersect the horizontal axis, the distance from this point of intersection to the origin may be thought of as an internal initial stress which is inherent in the material and is associated with the cohesion property. It is analogous to molecular attraction in solid materials. If the origin is transferred to this point of intersection, a new shear diagram representing total stresses, both initial and applied, is obtained; whereas the diagram as first drawn represents applied stresses only.

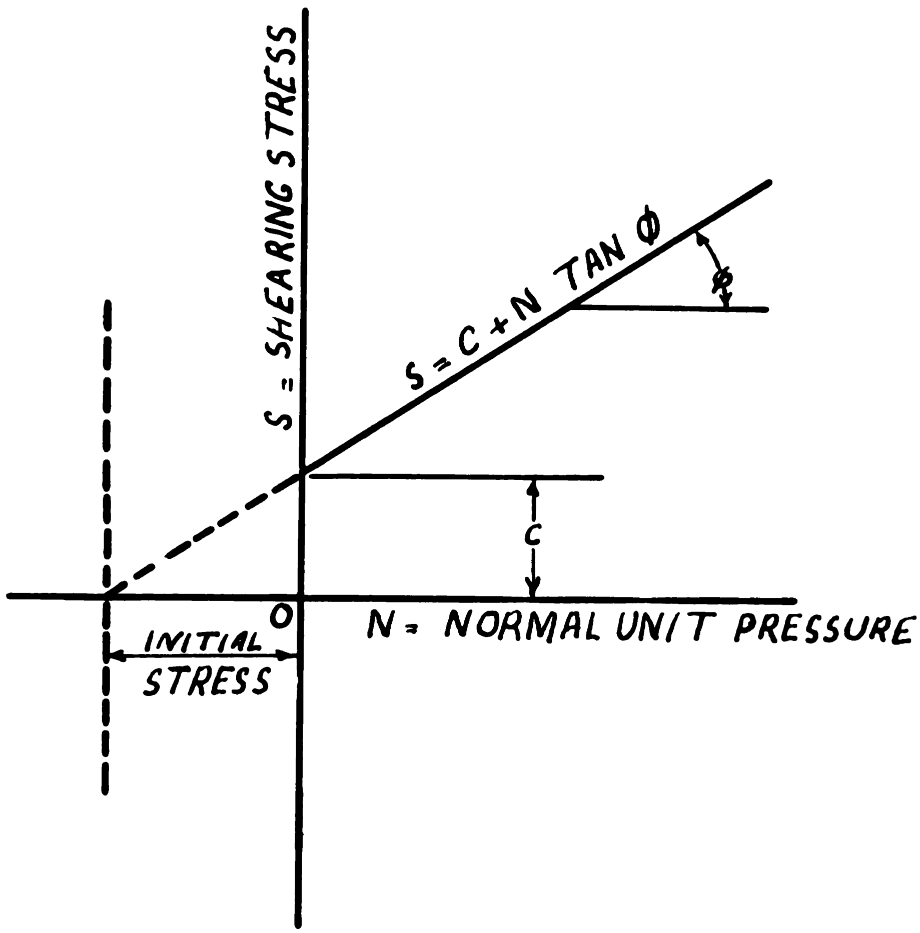


Fig. 24. Graph of Coulomb Formula for shearing strength of soil.

CONCLUSIONS

As a result of the tests on the various implements and a study of their applications, the following conclusions can be derived:

The once-over method of tillage is very practical and a time, labor and money-saving system. For the conditions and the crops to which it is applicable, it provides all the tillage that is necessary in preparing the seedbed. It avoids excessive packing of the soil and preserves the soil structure.

Liftable once-over implements are an efficient means of tillage as they are simpler to operate than the trail-type implements, and eliminate dragging and tearing of soil at the ends of the field.

Courey's long-toothed and short-toothed tillers are well adapted to clayey soils. The cultipacker unit is most effective on sandy soils which need packing.

The weight of the implement lifted causes stresses in the moldboard of the rear plow, the maximum stress being caused around a point designated by gage number four in Figure 19. By keeping the weight of the implement within safe limits, the stress caused in the moldboard will be negligible and lifting the implement will cause no damage to the moldboard.

SUGGESTIONS FOR FURTHER STUDY

The advantages of a once-over tillage method using liftable implements are manifold. It offers great possibilities as a time and labor-saving device, which does an effective job of seedbed preparation. Various aspects of this system offer a challenge to ingenuity of design and ability of analysis.

Research in design work for various shapes of a liftable tillage implement would hold great promise. This work should be done while considering the type of action of the implement on the soil, whether it would produce the ideal seedbed profile - the lower part of the seedbed should contain the finest granules and possess the firmest degree of settling, with the coarseness of the granules increaseing as the surface is approached.

Another interesting study would be a weight analysis of the different types of metals that could efficiently (and economically) be used in the design of such an implement. In lifting, weight of the implement is a definite problem; hence, the importance of this study.

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