MEASUREMENT AND ANALYSIS OF SOIL PRESSURE DISTRIBUTION UNDER TRACTOR AND IMPLEMENT TRAFFIC IN AN ARTIFICIAL FIELD

Thesis for the Degree of M. S.

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Glen Edwin Vanden Berg

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MEASUREMENT AND ANALYSIS OF SOIL PRESSURE DISTRIBUTION UNDER TRACTOR AND IMPLEMENT TRAFFIC IN AN ARTIFICIAL FIELD

by

Glen Edwin Vanden Berg

AN ABSTRACT

Submitted to the Michigan State University of Agriculture and Applied Science in Partial Fulfillment of the Requirements for the Degree of

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THESIS

AN ABSTRACT

Twelve strain gage pressure cells (transducers) were built to make soil pressure readings under traffic in Maumee sandy loam soil. The traffic was provided by a plowing demonstration which was part of Powerama staged by the General Motors Corporation in Chicago, Illinois, from August 31 to September 25, 1955.

The cells were placed at various depths in the soil perpendicular to the direction of travel, and pressures were recorded with a six channel, direct-inking recording oscillograph. The necessary measurements to locate the cells with respect to the tires of passing tractors and implements were made and recorded on the oscillograph charts. Contact areas, weights, pull of implements, and other necessary information were measured to enable calculation of loads carried on each tire or implement.

The data from the charts was put in tabular form using only the maximum pressure readings for each cell during each pass. It was assumed that the maximum pressure occurred under the center of the tires. On the basis of this assumption, the maximum pressure readings for the same tire were plotted on a graph representing pressure versus depth. A smooth curve was drawn through the points and called "center of tire." The readings of cells adjacent to the cell indicating a maximum reading were averaged and plotted on the same graph as

mentioned above. The smooth curve drawn through these points represented the pressures 0.4 of a foot from the center of the tire since that was the spacing of the cells. This was continued until zero pressures were encountered with average readings from each pair of cells determining a curve representing pressures at the same distance from the center of the tire as were the cells. This was done for each tire where pressures had been measured over a large enough span in depth to permit drawing good curves from the contact surface to the depth of soil at Powerama.

Values from the averaging curves were then used to determine isobars under the tires. The resulting family of isobars gave a good visual picture of the distribution of pressure under the tires for the given soil conditions at Powerama. A formula developed by Froehlich and applied to soils by Soehne was used to calculate theoretical pressures under the center of the tires. These pressures were compared with measured pressures.

The following indications for the conditions at Powerama seemed true: greater pressures were transmitted through loose soils than through dense soils; the lugs on the rear tractor tires carried the majority of the rear tire load even in freshly plowed soil; the plow bottoms applied a small negative pressure to the soil; the peak pressure under a tire always occurred ahead of the wheel's axle; applying a load

in small scattered areas did not cause as much pressure in the soil as applying the same load in one area.

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A sincere thank-you is extended to the author's wife, Phyllis, who typed and helped edit the thesis and whose loyal support was given throughout the work. The author wishes to thank all the others who contributed in any way to this work, especially those connected with the plowing demonstration of the General Motors' Powerama.

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INTRODUCTION

With the development of a strain gage cell (transducer) for measuring pressures in soil (2)[1], techniques and methods for using the cell were needed. Particularly in field applications, the procedure for using the cell and analyzing data collected with the cell was not established. A rare opportunity to develop these procedures as well as partially investigate the distribution of pressures in soils was presented when the General Motors Corporation staged its 26-day Powerama in Chicago, Illinois from August 31 to September 25, 1955. The Powerama consisted of a technological circus, and exhibits and demonstrations of every application for which General Motors produces diesel engines.

One of the many exhibits was the plowing demonstration put on by the Detroit Diesel Engine Division of General Motors and the Oliver Corporation. They imported 14 train-car loads of Naumee sandy loam soil which was placed at Powerama in an area approximately 286 feet long and 60 feet wide to a depth of about 15 inches over the central 40 feet of width. This soil was plowed, moisture added if lost during plowing, and recompacted to original bulk density on

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1. Numbers in parenthesis refer to references listed in literature cited.

the average of approximately 11 times a day for the 26 days of Powerama.

Pressure readings were made under all traffic in this artificial field. In this thesis the methods and techniques used at Powerama and the analysis of the data collected there will be presented. Wherever possible, the results of the analysis will be compared with Soehne's (1) theoretical observations on pressure distribution in soil.

REVIEW OF LITERATURE

Although much work has been done dealing with various aspects of the soil such as McKibben (3), Nichols (4)(5), and Baver (6) have reported, very little is available on distribution of pressure in the soil. The primary reason for this has been the lack of a physical means of measuring soil pressures.

Soehne (1) took emperical formulae that had been developed by Boussinesq and modified by Froehlich to calculate theoretical pressure distribution in the soil. The formulae of Boussinesq were developed for use in an isotropic homogeneous body which obeys Hooke's law. Froehlich modified the formulae for use with a plastic body similar to the soil.

Some of the theoretical observations by Soehne are:

1. The more pliable a soil the more concentrated will be the compressive stresses towards the center. This is primarily due to the lateral giving way or flowing of the soil from under the load. Thus we would expect greater pressures transmitted through a pliable soil than through a dense soil.

2. In a dense soil the pressure bulbs or isobars tend to be circular whereas in a more pliable soil the isobars will be slender and reach farther down.

3. Pressure at a point in soil is determined both by the magnitude of the unit pressure applied and the

area over which the unit pressure is applied. Thus if the same unit pressure is applied over one area twice as large as another, there will be more pressure under the larger area at a given depth than under the smaller area.

4. The difference in pressure under a lug of a tire and the slots between lugs would be slight in a pliable soil.

5. Under a circular load surface in a dense soil, the pressure under the center of the load at a certain depth is given by the formula

$$\sigma_z = P_m (1 - \cos^3 \alpha)$$

where:

σ_z = pressure at a point in the soil

P_m = average pressure applied to the surface of the soil

α = the half aperture angle of a circular cone with its apex at a point under the center of the load and where the base of the cone is the circular load itself, as illustrated in Fig. 1.

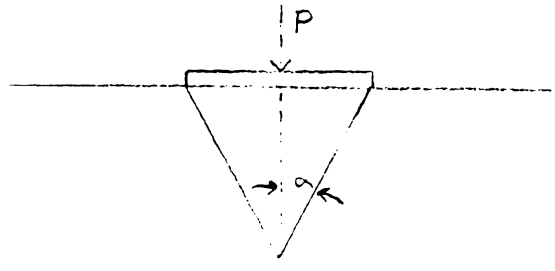


Fig. 1. Half Aperture Angle Under a Circular Load

DESCRIPTION OF EQUIPMENT

Twelve strain gage pressure cells of the type designed by the Agricultural Engineering Branch, Agricultural Research Service, U.S. Department of Agriculture, and the Agricultural Engineering Department of Michigan State University (Fig. 2) were built to make the pressure measurements. Each cell had two SR-4 strain gages (type A-18) cemented to the underside of the 0.025 of an inch thick stainless steel top. The strain gages used were 1/8 of an inch in length, 120 ohms in resistance and had a gage factor of 1.73. Two more gages of the same lot were cemented to the sides of the brass body of the cell to complete the wheatstone bridge.

This arrangement provided perfect temperature compensation. Thirty feet of four wire rubber covered shielded cable was connected to each cell. Breakaway connectors (Cinch-Jones series 400) were placed in the cables approximately 25 feet from each cell to protect the recording instrument in case the cells were caught by the plow.

Each cell was individually calibrated in a water pressure chamber using a Young strain indicator to record strain. A mercury manometer was used to record pressures in the water chamber. Each cell was calibrated in increments of ten up to 60 inches of mercury. This was repeated three times for each cell and an average computed. A calibration curve

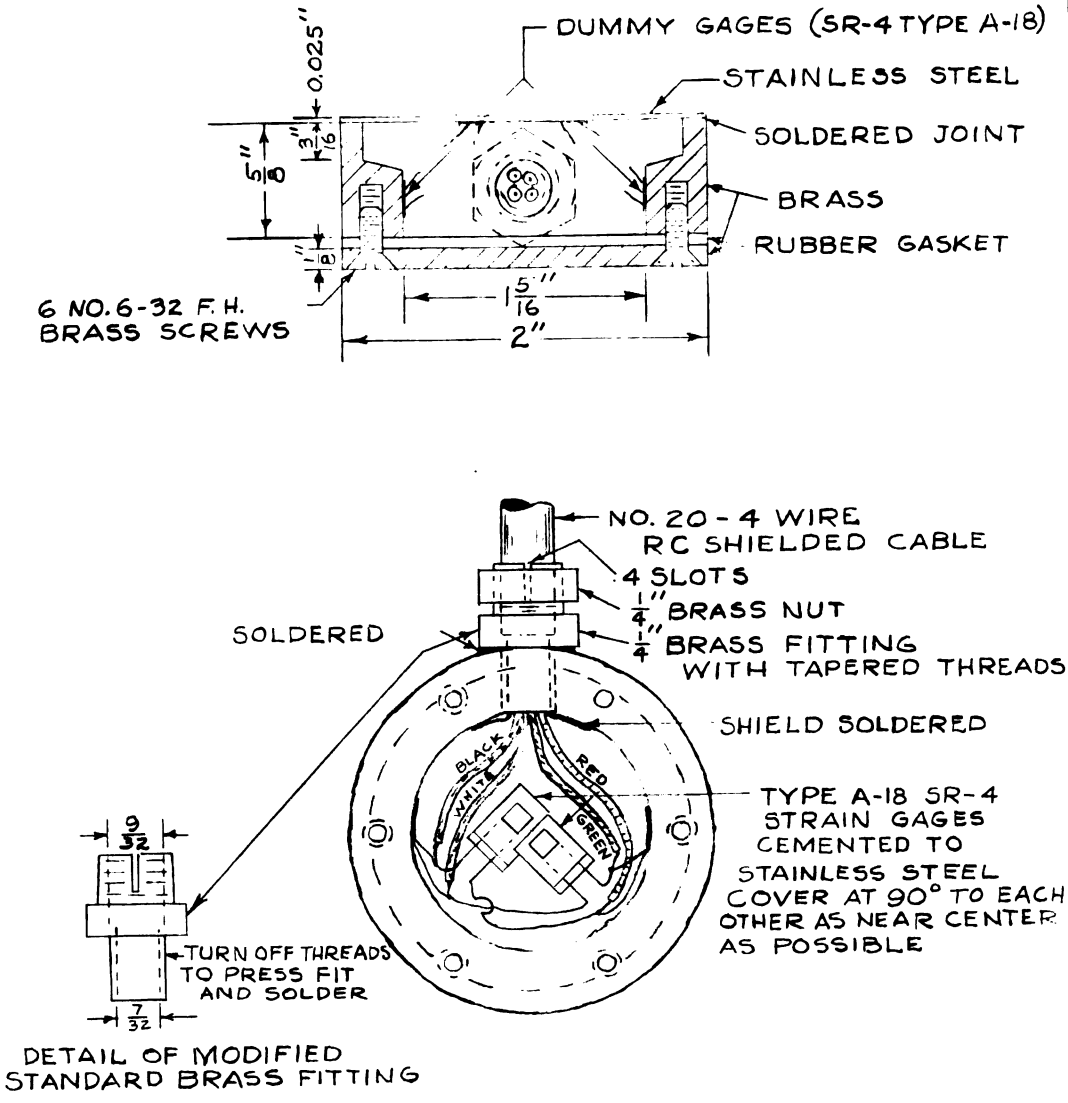


FIG. 2
TYPE A SOIL PRESSURE CELL

SCALE-ACTUAL SIZE

AUGUST 1955
AWC & DEV

was plotted for each cell with strain in the metal (μ in./in. x 10) on the ordinate and pressure (psi) on the abscissa. These calibrations were linear for each cell within a range of 0 to 30 psi. Two of the cells were later calibrated up to 60 psi and found to be linear to approximately 50 psi.

A six channel direct-inking recording oscillograph * was used to make all pressure measurements at Powerama.

Fig. 3. Offner Dynograph Recording Assembly

* The oscillograph was a six channel Dynograph Recording Assembly loaned to this project by Offner Electronics, Inc., Chicago, Illinois.

The instrument was calibrated according to the formula:

$$S = \frac{10^6 \cdot R}{N \cdot GF \cdot (R + R_c)}$$

S = indicated strain μ in./in.

R = resistance of active gage

R_c = resistance of calibration resistor

N = number of active gages

GF = gage factor

With the strain gages used in the cells, the formula reduced to:

$$S = \frac{10^6 \cdot 120}{2 \cdot 1.73 \cdot (300{,}000 + 120)} = 115\ \mu\text{in./in.}$$

The instrument was calibrated so that each line of the chart represented five μ in./in. strain in the metal. With this calibration, each line represented approximately 0.35 psi; however, this varied slightly for each cell.

PROCEDURE

The plowing demonstration was conducted as follows: An Oliver Super 99 GM tractor was used to pull a 6 bottom 16 inch plow which plowed an 8 foot strip with each pass. The center 40 feet of the artificial field were plowed in five passes which took less than five minutes. After the soil had been plowed, another Oliver Super 99 GM tractor pulled a 500-gallon capacity high pressure sprayer which replaced any moisture lost during plowing. The same tractor then recompacted the soil to its original bulk density by first pulling a 38-inch diameter sheeps-foot tamper and then a pneumatic tired roller.

To make the pressure readings, six of the cells were buried at the same depth, spaced 0.4 of a foot apart on center, and in a line perpendicular to the direction of travel of the traffic. The cells were placed five times during the 26 days of Powerama, always below depth of plowing. Three of the locations were with the cells resting on the pavement and the remaining two were suspended in the soil. These placements were distributed periodically throughout the demonstration, the times being approximately the beginning, middle and end. During the intervals when readings were not being made, the cells were removed from the soil. Large clods were carefully avoided when covering the cells and the soil was packed as tightly as possible by tamping with feet.

Except for one location, a cycle of the plowing demonstration was completed before readings were taken.

To obtain pressure measurements at less than plowing depth, the cells at three of the previously mentioned locations were placed so that one dead furrow during the plowing operation was over the center of the cells. On the next

Fig. 4. Replacing Moisture Lost from the Soil

pass this permitted the front and rear wheels of the tractor running in the furrow to pass over the cells with as little as one inch of soil between tires and cells. To obtain pressure measurements at maximum soil depths, the cells were placed on the remaining two locations so their center line

fell under tractor's wheels not in the furrow. By this arrangement it was possible to make pressure readings under

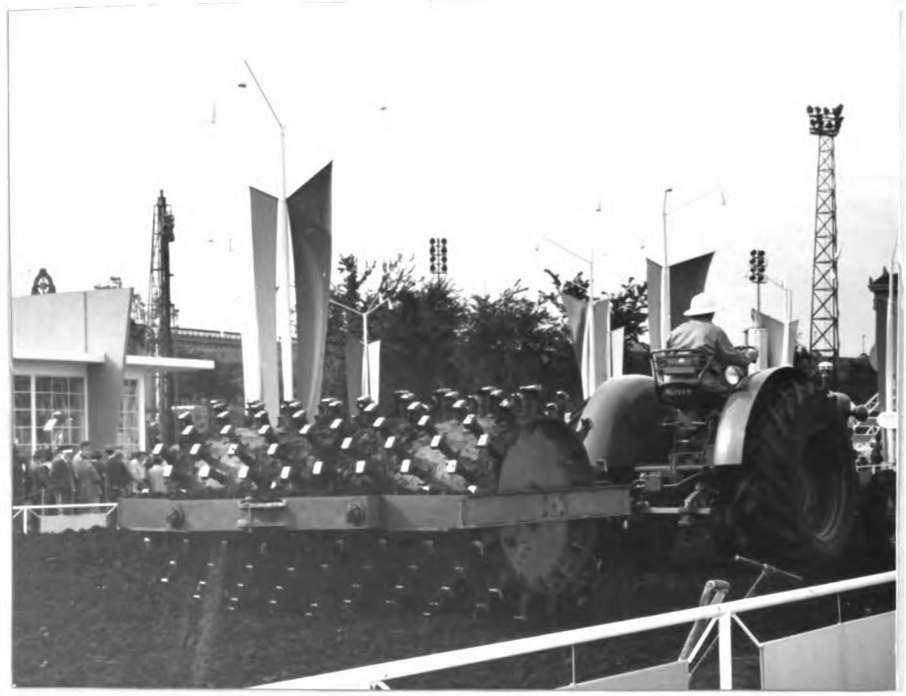


Fig. 5. Compacting the Soil with Sheepsfoot Tamper

the front and rear wheels of the tractor while plowing at shallow as well as deeper depths.

Pressures were also recorded under the wheels of the plow and plow bottoms. Pressures were recorded under the front and rear wheels of the auxiliary tractor while watering, tamping and rolling and under the sprayer wheels, tamping feet and roller wheels. During each location of the cells, several plowing demonstration cycles were followed by

recording pressures under all traffic that passed over the cells.

When the cells were placed for a series of recordings, the distance to the cells from the inside of the fence surrounding the demonstration area was measured with a steel tape. On each pass over the cells by traffic, a measurement was taken from the fence to some reference point of the passing implement. In the case of plowing, the furrow wall was the reference point and all wheels were located with

Fig. 6. Smoothing Surface with Pneumatic Tired Roller

respect to the wall. In watering, tamping and rolling, the

center of the outside tamper foot or roller wheel nearest the fence was used.

It was observed that the depth of soil above the cells changed during every demonstration cycle. Therefore the total depth of soil was measured after each demonstration cycle had been completed. The depth of soil, distance to reference point, wheel identification, direction of travel, and other necessary remarks were recorded directly on the

Fig. 7. Placing Cells to Make Pressure Readings

oscillograph chart.

A small hydraulic cell dynamometer was used to determine the average force required to pull each implement.

Necessary distances were measured to enable calculation of weight transfer during each operation. The Oliver Corporation provided the total weights of the tractors and implements as well as the weight on each wheel of the tractor. The contact area between the ground and the tires and tamper feet and ground were measured as accurately as possible.

Fig. 8. Recording Soil Pressures Under Tractor and Plow

RESULTS

To facilitate handling, the data recorded on the charts was put in tabular form (Fig. 9). Only the values indicated by the maximum deflections of the pens were recorded in the tables. The weight transfer from front to rear wheels of the tractors and individual loads on each wheel and implement were calculated for each operation. The average amount of water in the sprayer tank was used in calculating the total weight of the sprayer. In the analysis, each front wheel and each rear wheel of the tractor were assumed to have the same weight for each given operation.

Except for the rear tractor tires, all wheels were assumed to have an elliptically shaped contact area. Soehne (1) also made this assumption in his analysis. In dense soil such as was the condition of the soil while plowing, the lugs on the rear tire did not penetrate the soil enough to allow the slots between the lugs to touch the soil. Consequently, only the portion of the lugs of the rear tires in contact with the soil was considered as contact area. The contact area varied so much for the tamping and rolling operations that it was impractical to try to obtain these areas. In the analysis the average unit pressure applied by each tire or implement was calculated by dividing the load carried by the contact area. A summary of this information is presented

Plowing

(Tractor front Wheel)

TEST NUMBER	CELL NUMBER	CHART READING (div)	PRESSURE (psi)	CENTER OF TIRE (ft.)	POSITION OF CELLS (ft.)	DEPTH OF SOIL ABOVE CELLS (in.)
		SERIES 3 9/14/15				
II	1	0	0	14.88		10.0
	2	0	0			
	7	0	0		1.32 L	
	8	4	1.0		.92 L	
	9	11	2.9		.52 L	
	10	15	3.3		.12 L	
III	1	0	0	16.57	.93 R	3.0
	2	28	7.7		.03 R	
	7	84	20.6		.37 L	
	8	0	0		.77 L	
	9	0	0			
	10	0	0			

Fig. 9. Sample Data Page

in Table 1.

Most of the items in the summary table are self-explanatory; however, additional information about some items seems necessary. The major and minor axes of the elliptical contact areas were measured as accurately as possible, but the contact areas may not have been exactly elliptically shaped. Also the contact areas were probably varying considerably throughout the tests. This was especially true when the soil was loose. Consequently the contact areas can only be considered as close estimates. It should be noted that the contact area of the rear tire while watering contains lug area plus the area of slots between lugs whereas the contact area for plowing consists only of lug area. For the sheeps-foot tamper and the straight wheeled roller, the total area of the implements in contact with the soil was used as contact area.

The pressures in the soil under the tires were average values ten inches below the centers of the tires. Where possible the values were taken from curves; otherwise a statistical average was computed. The average pressure under the tamper feet was determined by averaging all the cell readings recorded under the feet. The maximum pressure was determined by averaging the largest single pressure reading for each pass over the cells. Under the straight wheeled roller, the average of all readings was used.

To try to get some means of comparing the different

TABLE I

SUMMARY OF LOADS CARRIED, CONTACT AREAS AND PRESSURES MEASURED IN MAUMEE SANDY LOAM SOIL PLACED ON PAVING

Tire or Implement	Pressure In Tire (psi)	Load Carried (lb.)	Estimated Contact Area ($in.^2$) [a]	Average Pressure Applied (psi) [c]	Measured Pressure 10" Below Surface (psi)	Ratio [d]
Front Tire Plowing	36	985	33.0	29.8	3.5	282
Rear Tire Plowing	16	4505	84 [b]	53.6	12.5	360
Front Tire Watering	36	1350	100	13.5	5.8	233
Rear Tire Watering	16	4127	396	10.4	14.0	294
Front Tire Tamping	36	1265	-	-	5.4	233
Rear Tire Tamping	16	4212	-	-	12.9	327
Front Tire Rolling	36	1360	-	-	6.0	226
Rear Tire Rolling	16	4117	-	-	12.5	328
Sprayer Tire	31	2852	692	41.3	13.8	208
Tamping feet Maximum psi	-	8550	156	51.4	8.0	-
Tamping feet Average psi	-	8550	156	51.4	5.6	-
Roller packer	-	4365	226	19.3	1.7	-

a. Elliptical contact area assumed except under tamping feet.
b. Only lug area in contact with soil.
c. Load carried divided by estimated area
d. Load carried divided by measured pressure 10" below surface

tires and loads directly, a ratio of load on tire to measured pressure ten inches below the center of the tire was calculated. The ratio was obtained by dividing the load on each tire by the measured pressure. This ratio may not seem to be of much value since it is not a true dimensionless ratio. However, recalling that pressure in the soil at a point below the center of a load is determined both by the magnitude of the load and the area over which the load is distributed, it can be seen that the ratio may mean something. Two factors will determine the magnitude of the ratio – the contact area and the soil itself. For a given soil condition, dividing the load by the pressure measured results in a ratio number which reflects variation in contact area. The contact area in turn will be influenced by physical characteristics of the tire such as flexibility and size. Therefore, the ratio number will reflect physical characteristics of the tire and a lower number will indicate more pressure transmittal.

Considering the effect of the soil on the ratio, for a given tire a lower number indicates the soil transmits more pressure or the contact area changes so more pressure is transmitted or a combination of both. But certainly the contact area is dependent on the soil condition, as the contact area is increased in looser soils. However, since the same tire is considered, the change in contact area will be

influenced by the change in soil. Thus, whether the higher pressure results from contact area change as the soil changes or the soil change itself or a combination of both, a lower number means more pressure was transmitted because of soil change. Therefore whether a constant tire or a constant soil, a lower number indicates more pressure was transmitted through the soil. Consequently, the ratio number does have a significant meaning, even though it is not dimensionless.

The ratios indicate some interesting things. The front tire of the tractor in every case has a lower number than the rear tire. Thus, since the soil conditions were the same, the front tire caused more applied pressure to be transmitted than the rear tire. The number for the sprayer wheel was the smallest of all the ratios calculated. Thus more applied pressure was transmitted below the surface than for either tractor tire. The sprayer tire was an eight-ply tire with an internal pressure of 31 psi. The front tire of the tractor was a four-ply tire carrying 36 psi, while the rear tractor tire, also a four-ply tire, had only 16 psi. Thus it seems possible that the flexibility of the tire may have something to do with the magnitude of pressure transmitted through the soil.

Ratios were not calculated for the tamper or roller since they would be meaningless. It was possible to double the load carried on the tamper or roller without increasing the value of the measured pressure since not all of the

load was contributing to the pressure at a given point. This was caused by not having the total load in one concentrated area as was the case for the tractor and sprayer tires.

It is interesting to note that the pressure measured in the soil under the tamping feet was considerably less than under the rear tractor tire while plowing. This was true even though much of the time the tamping feet penetrated the soil so they were probably much closer to the cells than the tire was. The estimated contact areas for the rear tire while plowing and the tamper feet should be quite accurate; thus the applied pressures should be quite accurate. Both the tire and tamper applied about the same unit pressure, but the measured pressure in the soil was much less under the tamper. This bears out Soehne's observation that the pressure at a point is determined both by the applied unit pressure and the contact area of the applied pressure. With the rear tractor tire the pressure was applied over a fairly large area compared to the tamping feet. The contact area of the rear tractor tire was 84 square inches but the contact area of each tamper foot was only 6.5 square inches. The center of the next adjacent area was 12 inches away since the tamping feet were spaced one foot apart on center. Thus the small scattered contact areas did not cause as much pressure at a given depth in the soil as the single larger concentrated contact area even though all areas applied approximately the same unit pressure.

It should be noted that the observations made from the ratio numbers and applied unit pressures were not accepted as fact, but only as indications of what appears to have occurred. Further investigations under varying soil conditions would be necessary before definite conclusions could be made.

Pressure Distribution Under Tractor Tires

It was hoped at the start of this project that the pressure distribution under the tractor tires could be determined. The investigators believed it would be possible to plot the pressure cell readings with respect to vertical and horizontal distances from the center of each tire and thus have a visual picture of the pressure distribution. Such an attempt was made but variations in the data would not permit connecting points of equal pressure with a smooth curve. The variations in the measurements could have been due to inability to measure accurately the horizontal and vertical distances between tires and cells, the variation in soil from test to test and the position of maximum applied pressure by the tires with respect to their centers.

One reason for the uncertainty of the distance measurements was that in all operations the actual tracks of the tractor wheels were disturbed by the trailing implement. Also, time did not permit precise measurement to each wheel track but only to some reference point. Thus, if the

implements were not perfectly aligned behind the tractor when passing over the cells, the measured location to each wheel would be in error. Similarly, time did not permit measuring the depth of soil between tires and cells during each pass. Therefore, the total depth of soil was measured at the end of each demonstration cycle. By measuring depth of plowing or depth of wheel track, a close approximation of soil depth under each wheel was possible. During plowing it was felt that these measurements were quite accurate since the tires did not penetrate the soil.

Inspection of the data showed that in every case where the tire passed near the center of the cells, one of the cells had a higher reading than the others. The two adjacent cells had lesser readings and the further the cells were from the highest reading the lower pressures they indicated. The only exception was under the rear tractor tires when less than three inches of soil separated tires and cells. Under this condition it was observed on occasions that two peak readings occurred instead of one. Under the rear tractor tires at shallow depths, the peak reading depended on where the lugs made contact with the soil above the cells. At shallow depths it was possible for two lugs on opposite sides of the tire to cause two peaks.

Since usually one cell clearly indicated a peak reading, it was decided to arbitrarily assume that this cell was

under the center of the tire even though horizontal measurements might not indicate it was under the center. This assumption seemed justified for two reasons. First, even though the highest reading was not under the center of the tire, it was probably under the center of the load applied by the tire. Secondly, by assuming the highest reading was under the center, average values of pressure under the center should result from a number of readings. This procedure was followed separately for each tractor tire using only data in which a single peak was indicated by the readings. These points were plotted with recorded pressure (psi) on the ordinate and depth (in.) on the abscissa. A smooth curve was drawn through the points and labeled "center of tire" (Figs. 10 and 11.)

Similarly the average pressure recorded by the two cells adjacent to the one having the highest reading was plotted on the same graph. A smooth curve was drawn through these points and labeled "0.4-of-a-foot-from-center" (Figs. 10 and 11.) Since the cells were spaced 0.4 of a foot apart, this curve would represent the average pressures 0.4 of a foot from the center of the tire. A similar procedure was used on the next pair of adjacent cells and the resulting curve labeled "0.8-of-a-foot-from-center." This procedure was followed until zero pressures were encountered. It was believed that by plotting in this way and drawing a

Fig. 10

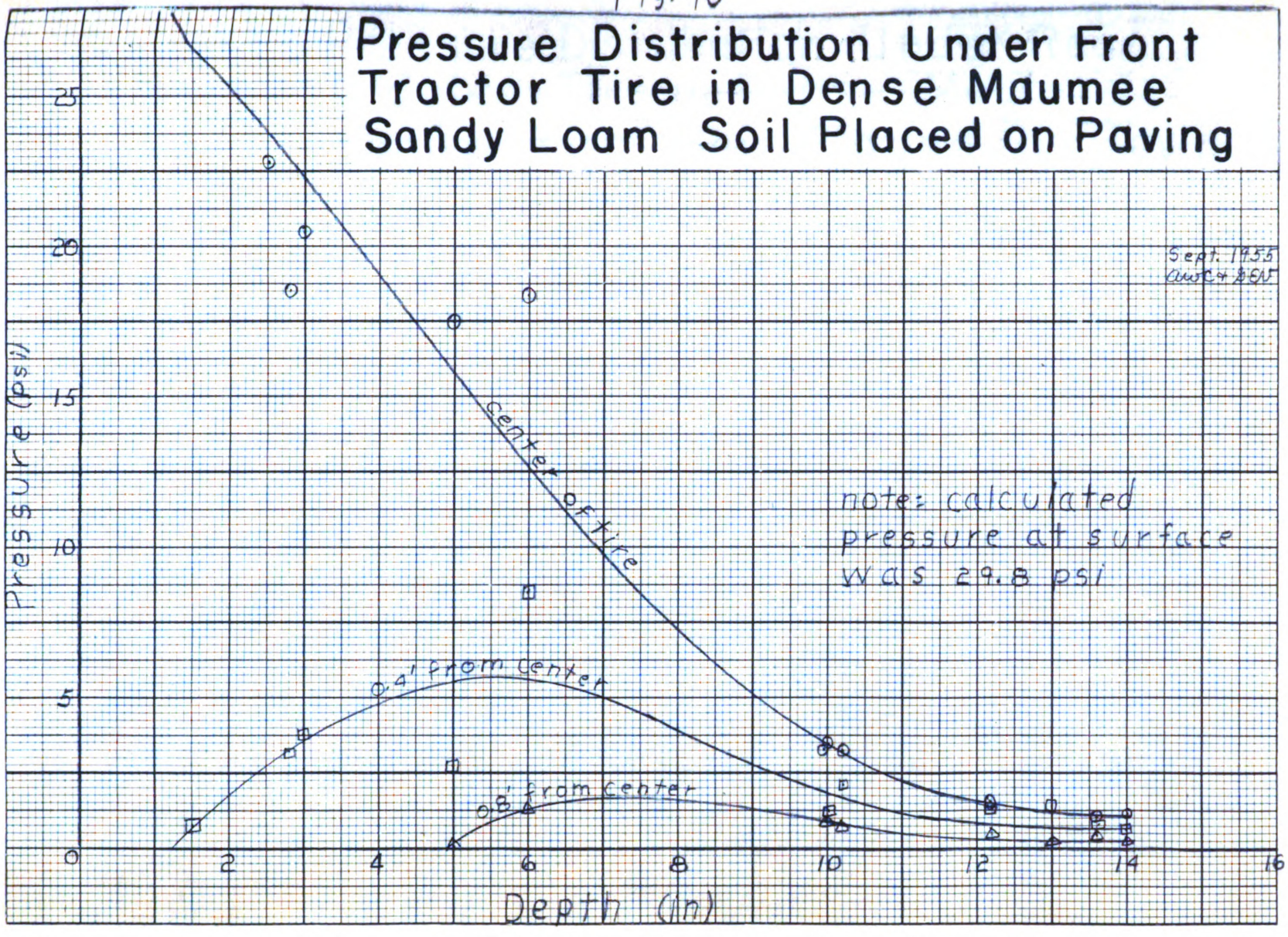
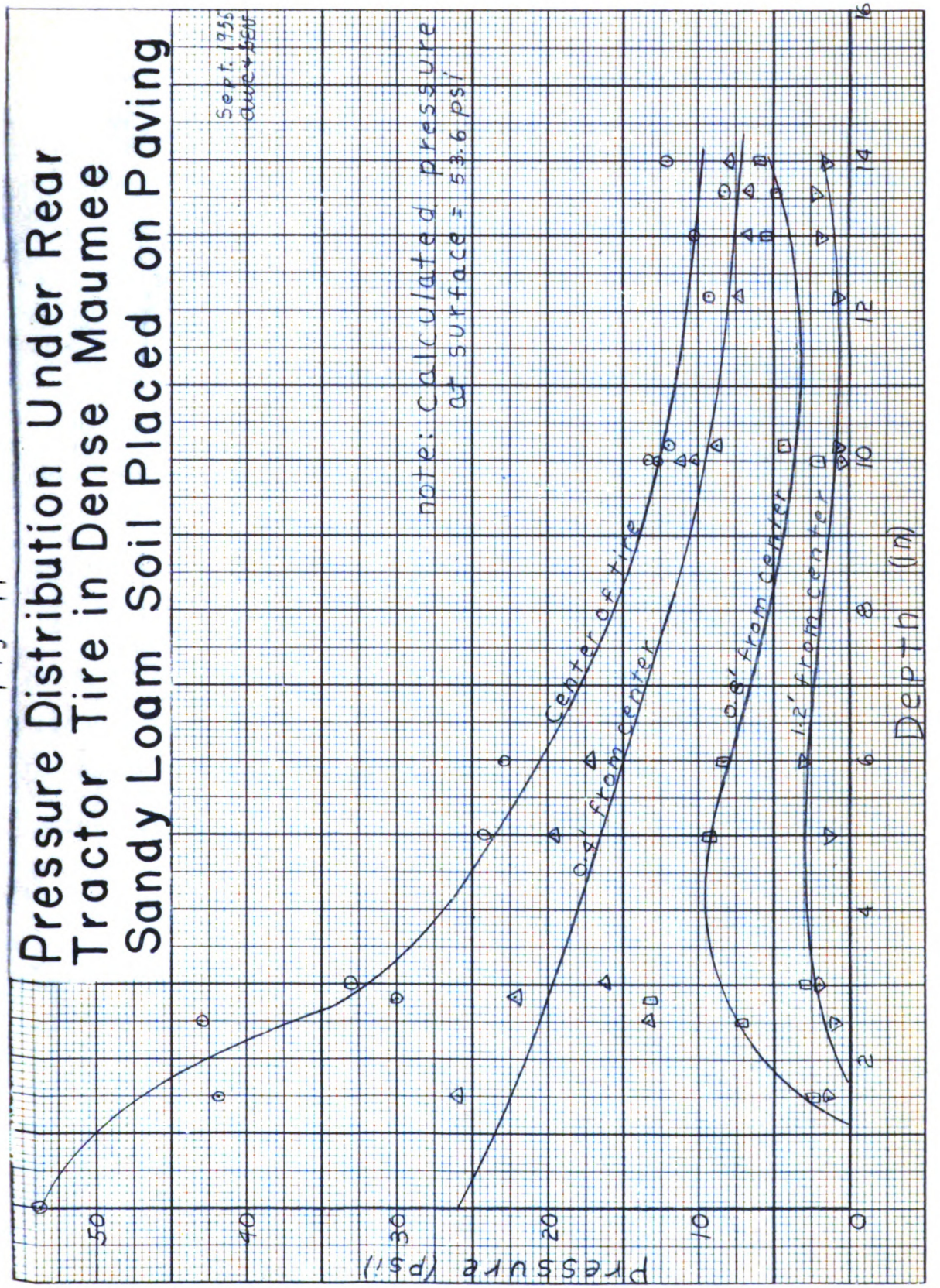

Pressure Distribution Under Front Tractor Tire in Dense Maumee Sandy Loam Soil Placed on Paving
Sept. 1955
AwCa BEN
Pressure (psi)
25
20
15
10
5
0
2
4
6
8
10
12
14
16
Depth (in)
center of tire
4" from center
8" from center
note: calculated pressure at surface was 29.8 psi

Fig. 11


Pressure Distribution Under Rear Tractor Tire in Dense Maumee Sandy Loam Soil Placed on Paving
Sept. 1955
note: calculated pressure at surface = 53.6 psi
Center of tire
0" from center
6" from center
12" from center
Pressure (psi)
Depth (in)
50
40
30
20
10
0
2
4
6
8
10
12
14
16

smooth curve through the points an average value of the pressures would be represented by the curves.

The distribution of pressures under the tires was hard to visualize from the above mentioned curves (Figs. 10 and 11.) Thus it was decided to take values from these curves and use these values to determine isobars under the tires. This was done for both the front and rear tractor tires. The isobars were plotted on a graph having depth below the tire on the ordinate and distance from the center of the tire on the abscissa (Figs. 12 and 13.)

To plot one isobar, a chosen single pressure value was selected. On the pressure versus depth graphs (Figs. 10 and 11) the chosen value was followed across the graph and if crossed by the "center" curve, a point was plotted on the isobar graph (Figs. 12 and 13) under the center of the tire at a depth indicated by the "center" curve. If the pressure value was also crossed by the "0.4-of-a-foot-from-center" curve, a point was plotted on the isobar graph 0.4 of a foot from the center of the tire at a depth indicated by the "0.4-of-a-foot-from-center" curve. This was continued until all points from curves that crossed the chosen pressure value had been plotted. A smooth curve drawn through these points was the isobar representing the chosen pressure value. Other isobars representing other pressure values were drawn in the same manner. Since the pressure versus depth curves did not

Fig. 12

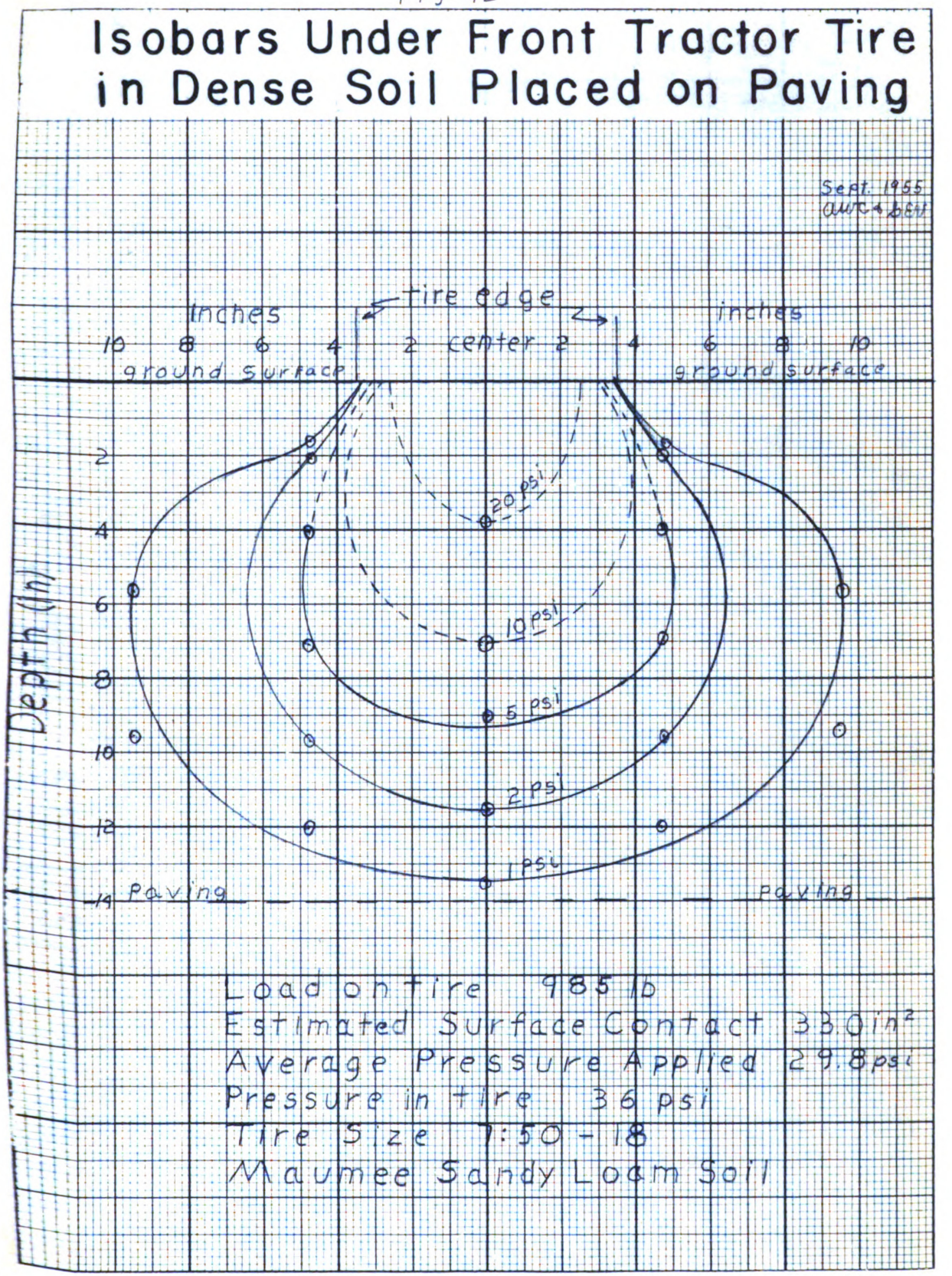
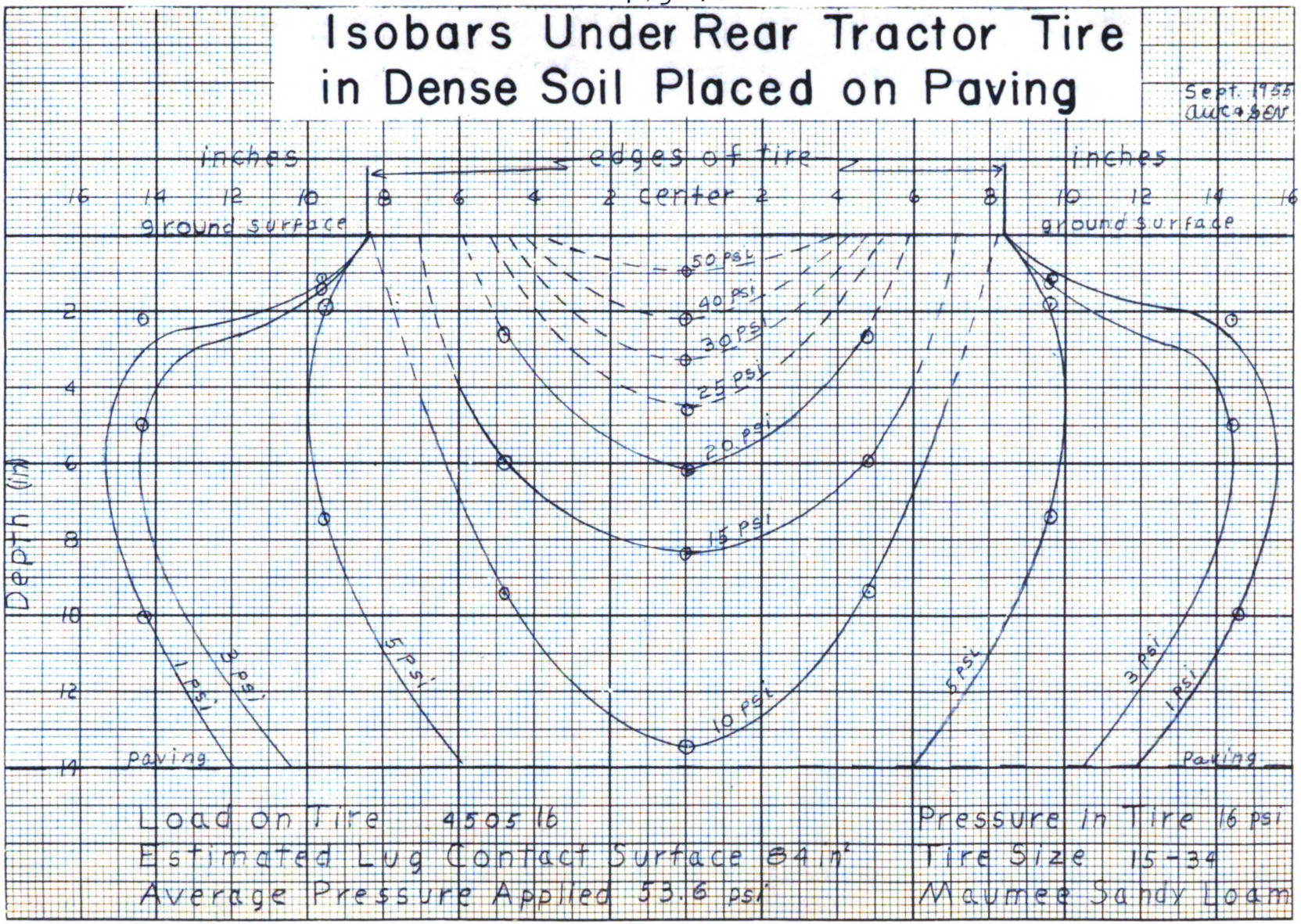

Isobars Under Front Tractor Tire in Dense Soil Placed on Paving
Sept. 1955
AWC & BEH
tire edge
inches
10 8 6 4 2 center 2 4 6 8 10
inches
ground surface
ground surface
Depth (in)
2
4
6
8
10
12
14
20 psi
10 psi
5 psi
2 psi
1 psi
Paving
Paving
Load on tire 985 lb
Estimated Surface Contact 33.0 in²
Average Pressure Applied 29.8 psi
Pressure in tire 36 psi
Tire Size 7:50 - 18
Maumee Sandy Loam Soil

Fig. 13


Isobars Under Rear Tractor Tire
in Dense Soil Placed on Paving
Sept. 1955
Auburn
inches
edges of tire
center
inches
ground surface
ground surface
Depth (in)
50 psi
40 psi
30 psi
25 psi
20 psi
15 psi
10 psi
5 psi
3 psi
1 psi
5 psi
3 psi
1 psi
Paving
Paving
Load on Tire 4505 lb
Estimated Lug Contact Surface 84 in²
Average Pressure Applied 53.6 psi
Pressure in Tire 16 psi
Tire Size 15-34
Maumee Sandy Loam

identify a left or right of a tire, the pressure distribution was assumed to be symmetrical and a point was plotted both to the left and right of the tire's center. Isobars under tractor tires could not be located for operations other than plowing because all pressure readings were made 10 inches or more below the tires except while plowing.

All isobars were determined by points from at least two curves except at shallow depths under the center of tires. There, because the distribution of pressure at the contact surface was not known, the isobars were drawn to the tire's contact surface arbitrarily. Since the family of isobars under each tire plotted smoothly the method of drawing them seemed justified.

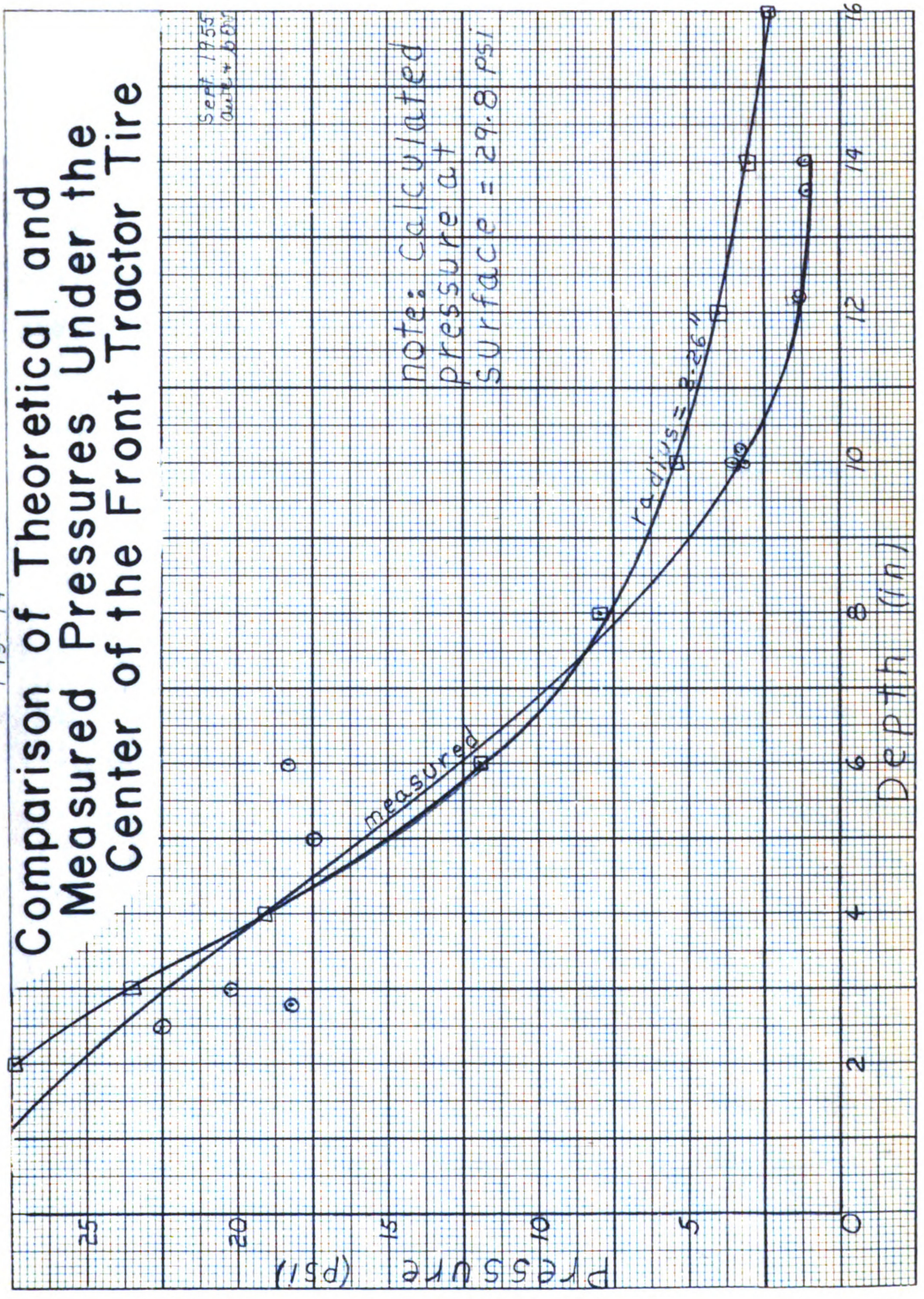
The Naumee sandy loam in which these pressures were measured was very densely compacted. The soil itself probably was influenced by the supporting paving and so could not represent a normal soil. However, the general distribution and magnitude of the pressures were probably an indication of what would be found in a similarly loaded field soil of the same physical characteristics. It is interesting to note that the general shape of the isobars is a sort of flattened circle. Soehne (1) observed that in a dense soil the isobars would be circular. Certainly this same soil at other moisture contents would have given different results. Thus the most we can say is that these isobars represent only the conditions

at Powerama. However, the techniques used in this study should be useful when applied to other projects which have general aims related to effects of pressure on soil compaction.

The formula $\sigma_z = P_m(1-\cos^4\alpha)$ was applied to the front and rear tires of the tractor while plowing. The radius of a circle whose area was equal to the contact area of the front tire was used in calculating the angle α for the front tire. The radius used was 3.26 inches. The tangent of α was equal to the radius of the area divided by the distance below the tire. The average pressure applied was 29.8 psi and this was used for P_m in the formula. The values calculated by this formula represented the theoretical pressure distribution under the center of the front tire while plowing. These values were plotted in Fig. 14 along with the measured pressure values under the center of the tire.

A similar procedure was followed for the rear tire except for the radius used. The radius of a circle whose area is 84 square inches is 5.16 inches. Using this in the formula results in a curve which indicates higher pressures than were measured. However, since the lugs applied the pressure under the rear tire, the contact area must have been scattered somewhat. Thus, considering the load as concentrated in one area does not truly represent the conditions under the rear

Fig. 14


Comparison of Theoretical and Measured Pressures Under the Center of the Front Tractor Tire
Sept. 1955
Pressure (psi)
Depth (in)
measured
radius = 8.26"
note: Calculated pressure at surface = 29.8 psi
0
5
10
15
20
25
2
4
6
8
10
12
14
16

tire. Therefore a smaller radius - 3.0 inches - was arbitrarily selected. Using 3.0 inches with P_m = 53.6 psi results in a curve which approximates very closely the measured pressures. The fact that a smaller radius was needed to get a close approximation of the measured pressures shows the same effect as was noticed under the tamper feet. There the spread feet resulted in lower pressures, which is apparently what occurred under the rear tractor tire. This same effect may be the cause of the higher ratio numbers under the rear tractor tire than under the front tractor tire. The curves for the rear tire are shown in Fig. 15.

Magnitude of Pressures in Loose Soil

It was observed by Soehne (1) that the more pliable a soil the more concentrated will be the compressive stresses towards the load axis. This is primarily due to the lateral giving way or flowing of the soil from under the load. Thus we would expect to record larger pressures under the center of a tire in loose soil. Such was the case during the watering operation. There the tractor was traveling over freshly plowed soil which was very loose compared to the unplowed soil. Two graphs (Figs. 16 and 17) were drawn showing the maximum pressures under the center of both the front and rear tires of the tractor while plowing and while watering. It can be readily seen that the pressures recorded while watering were higher for both front and rear tires.

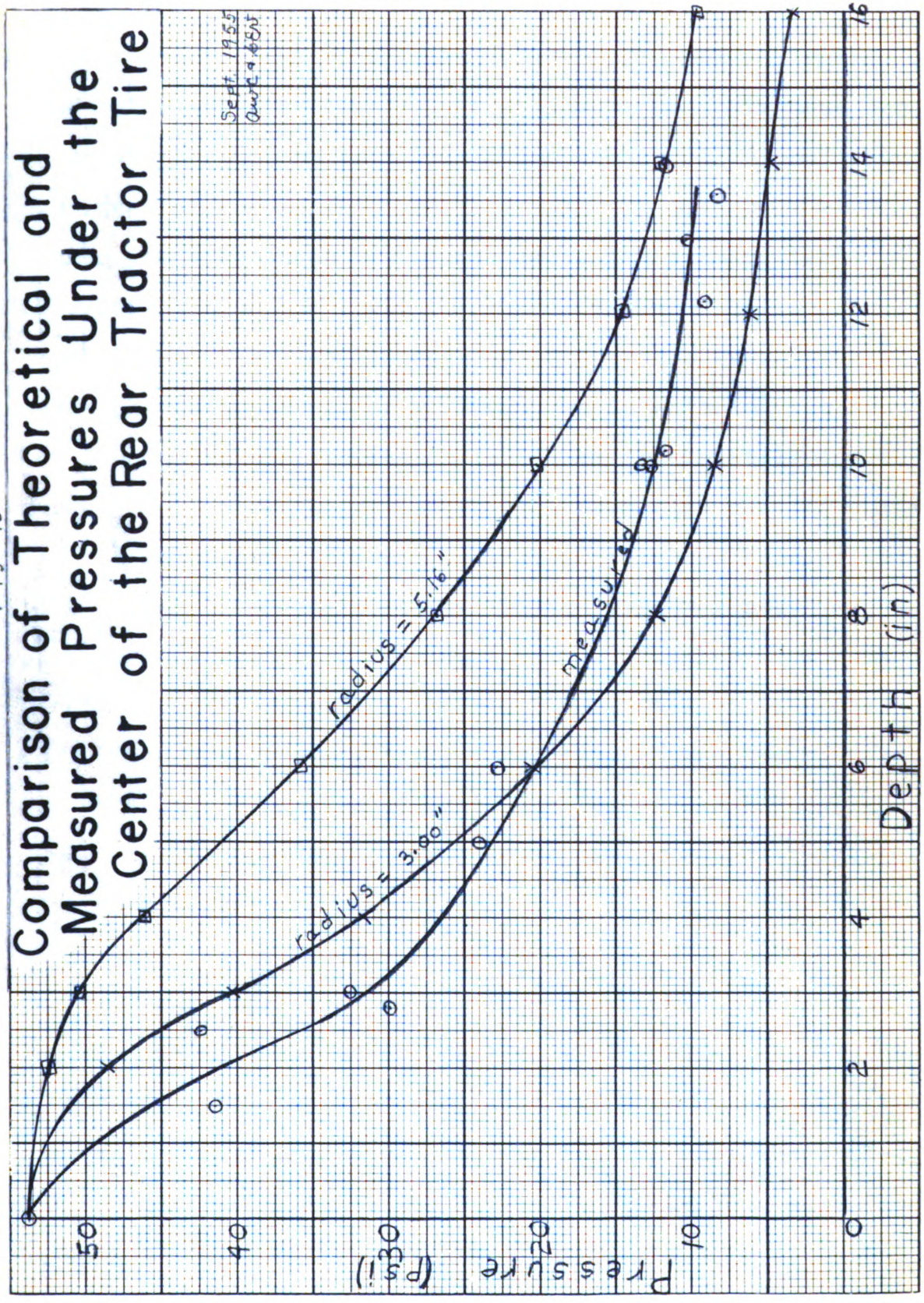

Comparison of Theoretical and Measured Pressures Under the Center of the Rear Tractor Tire
Sept. 1955
Quart 4 45hp
radius = 5.16"
radius = 3.00"
measured
Pressure (psi)
Depth (in)
0
2
4
6
8
10
12
14
16
10
20
30
40
50

Fig. 15

It is true that the front tractor tire had a larger load while watering than plowing. The opposite is true for the rear tire but watering pressures were still higher than plowing pressures. The fact that watering pressures were higher was also shown by the ratios in the summary table. Remembering that the lower the number the more pressure transmitted to the cells, we see that for the front tire while plowing this number was 282. While watering the number dropped to 233, indicating a higher transmittal of pressure. Similarly, the number for the rear tire was 360 while plowing and 294 while watering. Thus it seemed conclusive that larger pressures were transmitted deeper through a pliable soil than through a dense soil. It should be remembered that while watering the cells were still in a dense soil. The pressure was transmitted through the loose soil to the depth of plowing and the last few inches through the dense soil to the cells. This undoubtedly lowered the value of the indicated pressure slightly.

Effect of Lugs on Rear Tire

Soehne (1) also stated that in a very pliable soil the difference in pressure under the lugs and under the slots between the lugs of a tire while in contact with the soil was very slight. It was easily seen that the lugs alone applied the pressure in a dense soil since the lugs did not

Fig. 16

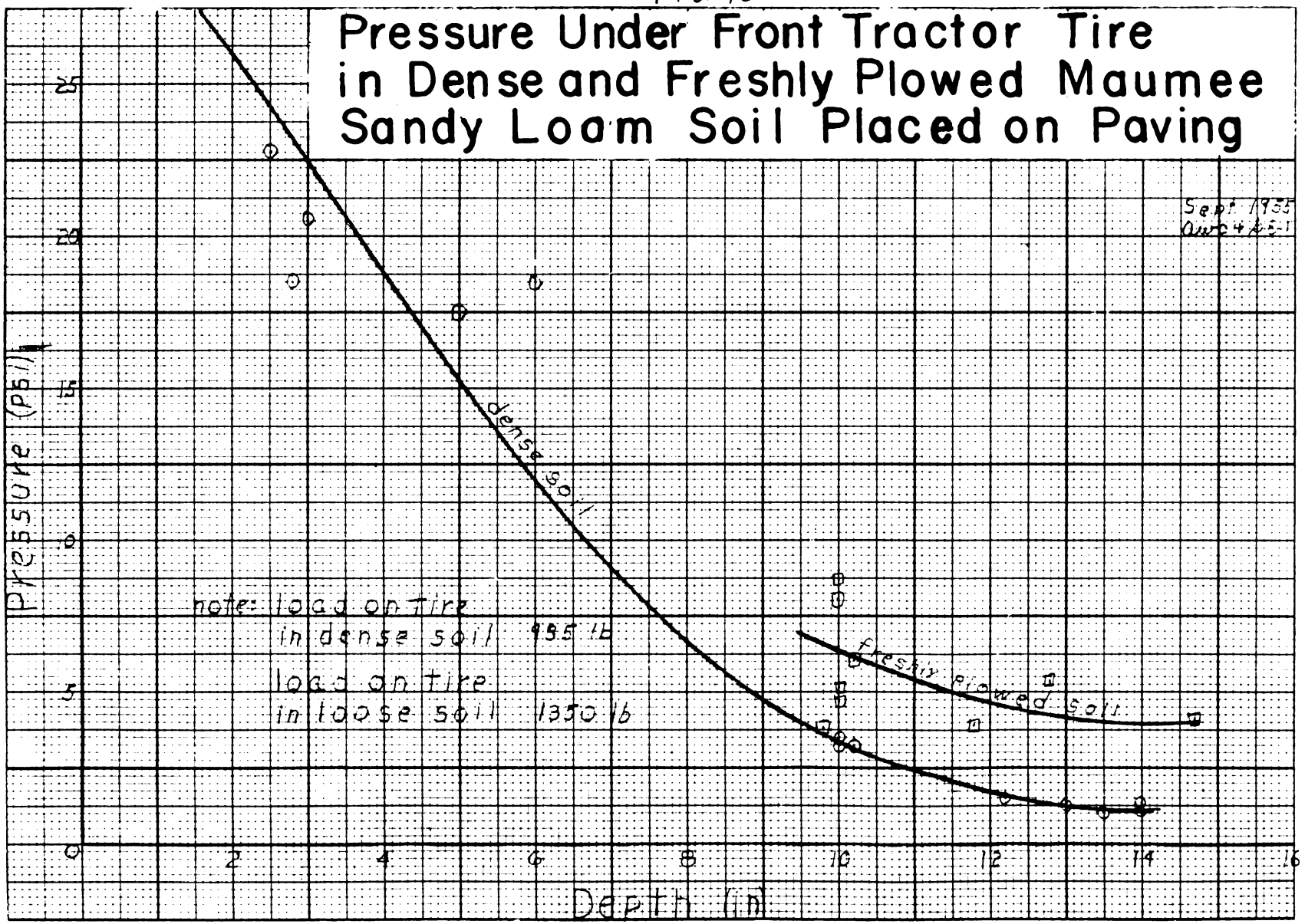
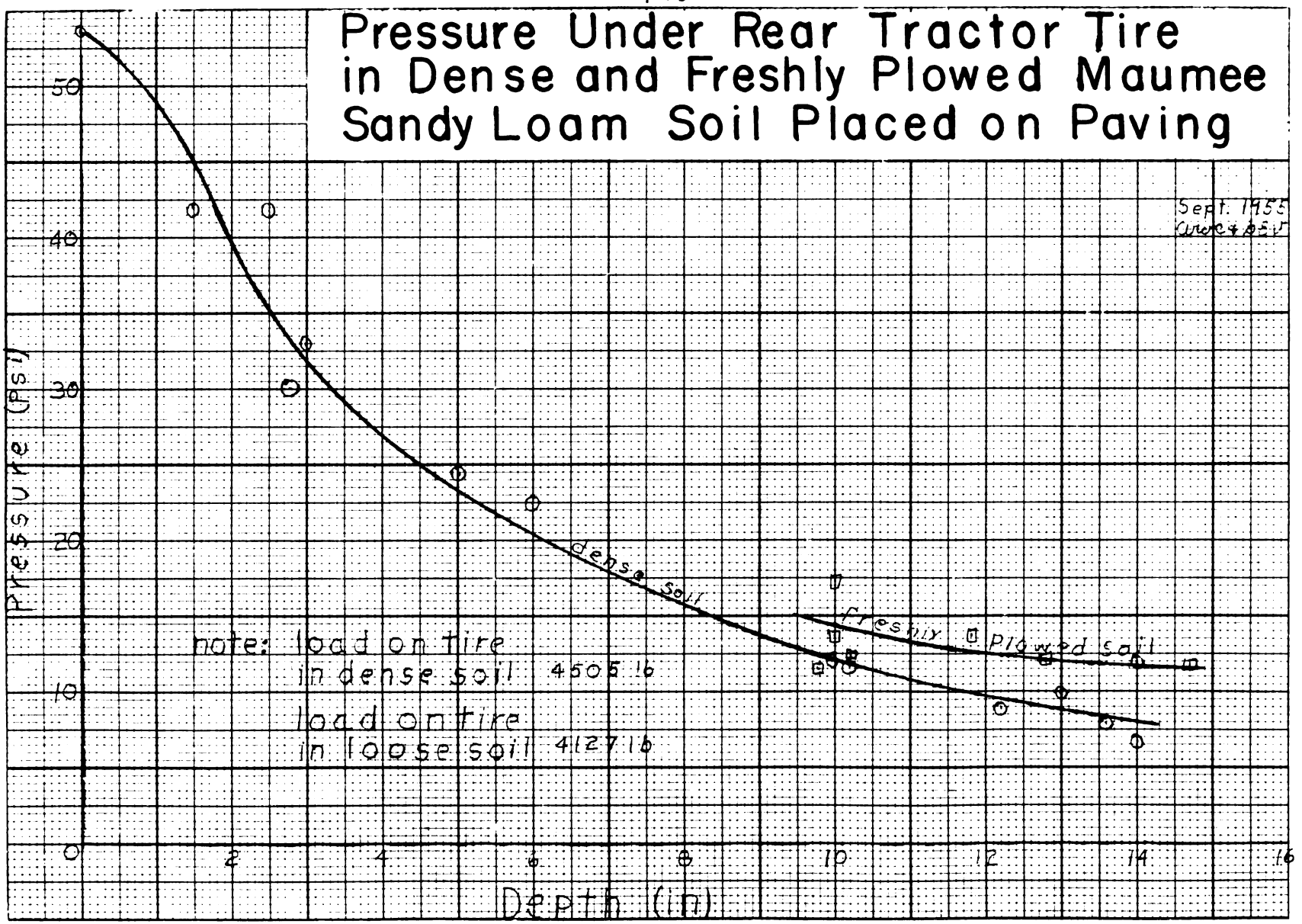

Pressure Under Front Tractor Tire
in Dense and Freshly Plowed Maumee
Sandy Loam Soil Placed on Paving
Sept 1955
Pressure (psi)
25
20
15
10
5
0
dense soil
note: load on tire
in dense soil 955 lb
load on tire
in loose soil 1350 lb
freshly plowed soil
2
4
6
8
10
12
14
16
Depth (in)

Fig 17


Pressure Under Rear Tractor Tire
in Dense and Freshly Plowed Maumee
Sandy Loam Soil Placed on Paving
Sept. 1955
Pressure (psi)
50
40
30
20
10
0
dense soil
freshly plowed soil
note: load on tire
in dense soil 4505 lb
load on tire
in loose soil 4127 lb
2
4
6
8
10
12
14
16
Depth (in)

penetrate the soil enough to permit the slots between lugs to touch the soil.

Using the total contact area of the rear tractor tire while watering, the calculated mean pressure applied was 10.4 psi. Obviously, more pressure than 10.4 psi must have been applied by the tire. Thus the load carried by the contact area could not have been uniform. Either the lugs carried more weight than the slots between the lugs or the pressure under the center of the tire was much greater than the mean applied pressure or both.

The area of the lugs in contact with the soil while plowing was 84 square inches. The elliptical area, including the space between the lugs, was 332 square inches. If we assume only the lugs supported the load while watering, the area of lugs in contact with the soil would be 84/332 of the measured elliptical area (396 square inches) since the ratio of lug area to total area is a constant. Assuming this lug area supported the load, the calculated applied pressure is 41.3 psi which seems much more logical in view of the measured pressure in the soil. This indicates that the load carried by the slots between lugs of the tires must have been small. Thus it seems likely that the lugs carried the majority of the load even in loose soil.

The apparent reversal of Soehne's findings does not indicate his work was in error, since the height of lugs on the tires he used is not known. The lugs on the tires

at Powerama were one and one half inches high, which may have been higher than the lugs on the tires he used. Thus it is entirely possible that for a lower lug height Soehne's findings could be right. However, we must conclude that under these soil conditions, with a lug height of one and one half inches, most of the load is supported by the lugs, even in loose soil.

Location of Point of Maximum Pressure With Respect to Wheel Axle

Three tests were run to try to determine the location of the point of maximum pressure under the tractor tires with relation to the axle of each tire. Each test was conducted in the following manner:

A transit was set up so that its vertical hairline determined the vertical plane in which the line of pressure cells laid. The chart speed on the recording instrument was set at ten centimeters per second. One observer held a pencil near the ends of the tracing pens and close to the chart. Another observer sighted through the transit and gave a verbal signal when the center of the rear axle of the passing tractor was in the vertical plane determined by the transit. As quickly as possible after hearing the signal, the first observer made a mark on the chart. Although this method was crude, its simplicity probably permitted reasonable accuracy at the slow tractor speeds used. Also time lost in human

reflexes was partially compensated for, since the pencil could not be held exactly adjacent to the points of the pens. Thus the chart had to travel a short distance before the exact point representing the axle was under the pencil.

The speed of the tractor as indicated by the tachometer on the tractor was also recorded on the chart. It was hoped to use the speed in determining the relation between distances representing the tractor and those recorded on the chart. An attempt to do this was only partially successful. It was noted that small changes in the recorded speed of the tractor would alter the results considerably and it was felt that the speed of the tractor had not been measured precisely enough.

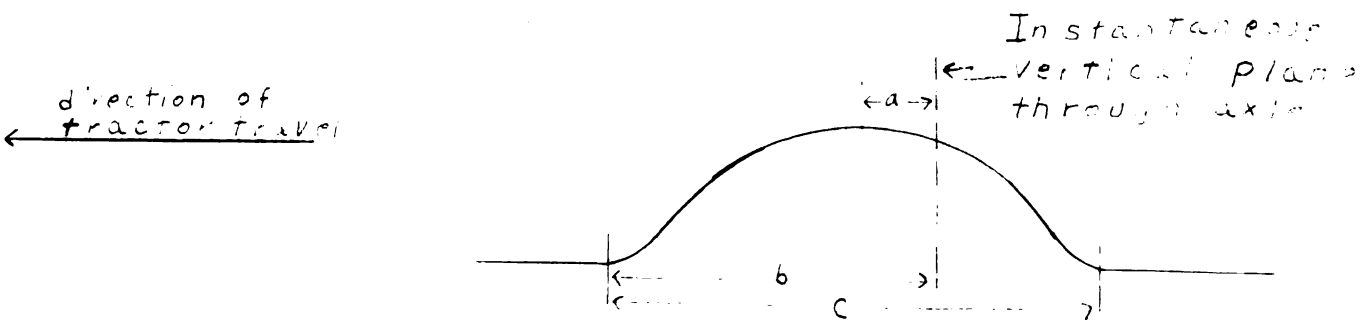
Therefore a different approach was tried. Pen traces were recorded under both the front and the rear tractor tires. Assuming the point of peak pressure occurred the same distance ahead of the front tire as the rear tire, the distance on the chart between the two peaks would represent the wheelbase of the tractor (80 inches.) Thus a ratio was established so that all distances on the chart could be converted to distances representing the tractor. Using the ratio, all distances on the chart could then be measured from the line locating the axle and converted to distances representing the tractor. This was done by averaging the three cells nearest the center of the tire to obtain each value recorded in Table II.

TABLE II

SOIL PRESSURES DETECTED AHEAD OF AND TO THE REAR OF THE TRACTOR AXLES WHILE THE TRACTOR WAS MOVING OVER THE SOIL

TEST	SPEED	POINT AT WHICH PEAK PRESSURE IN THE SOIL WAS DETECTED [a]	DISTANCE AT WHICH PRESSURE WAS FIRST DETECTED AHEAD OF AXLE * [b]		TOTAL TRAVEL DISTANCE DURING WHICH SOIL PRESSURES WERE EVIDENT [c]	
	(mph)	Rear (in.)	Front (in.)	Rear (in.)	Front (in.)	Rear (in.)
1	1.5	3.76	17.7	26.7	25.1	45.9
2	1.75	2.34	11.7	21.5	21.3	44.7
3	2.6	5.86	17.5	26.3	20.2	43.9
Average		3.99	15.6	24.8	22.2	44.8

* All peak pressures occurred ahead of the axle.



Note: Test 1 and 3 the soil was freshly plowed. Test 2 the soil was dense and ready to plow. Estimated depth of soil 10 to 12 inches.

It was noted that the peak pressures always occurred ahead of the axle. From this we must conclude that the major portion of the contact area lies ahead of the vertical plane containing the rear axle. This seems logical when remembering that the tire is compacting soil ahead of it as it moves over the soil. This would be especially true in a loose soil and that fact is observed in the data since during Test 2 the point of peak pressure ahead of the tractor was less than during the other two tests.

Pressures Under Plow Bottoms

Pressures under the plow bottoms were recorded while the plow was operating. These values were negative since the pen traces indicated a reduction in pressure. It was possible for the cells used to indicate such a reading since they were under a small pressure load while in the soil; this load would not be present if the cells were out in the atmosphere. Thus the cells indicated a negative pressure but in reality the negative pressure was a reduction in pressure already applied by the soil. At a depth of from 2.5 to 3.5 inches below the plow bottoms, the average of 24 cell readings was negative 1.05 psi with the maximum being 1.99 psi.

Not all pressures observed under the plow bottoms were negative. Small positive pressures were observed which may possibly have been caused by the falling of overturned soil

from the adjacent plow bottoms. The pen trace would jump up and down with great variability whereas the pen trace under the tractor tires was relatively smooth. Thus the impressed pressures under the plow bottoms changed very rapidly. Also rather large pressures were noted under the plow tires. Some of the pressures were as great in magnitude as those under the tractor tires. Therefore under the conditions of the tests, it seems that nearly all of the load on the plow was carried by its wheels whereas the plow bottoms did, in fact, create negative pressures. No attempt to include the plow tires in the analysis was made since the load carried by the tires was unknown.

The author feels that a characteristic of the pressure cells used to make the soil pressure readings should be mentioned. These cells measured only soil pressures that were normal to the face of the cells. It is highly probable that the pressures in the soil were not always vertical; thus the cells indicated only the vertical component of the soil pressure. However, under the center of the tires the soil pressures probably were vertical and there the cells indicated the total pressure. Also the soil pressures probably were close to vertical until they were past the edges of the tires. Therefore, the pressures indicated by the isobars beyond the tires' edges may be lower than actual pressures present in the soil. Other parts of the analysis would not be affected since pressures under the center of the tires were used.

CONCLUSIONS

1. The use of strain gage pressure cells with a multiple channel recorder provides an effective and rapid means for measuring pressures in soils.
2. The ratio number may be a quick way of evaluating effects of different tires in the same soil, or different soil conditions for the same tire.
3. The graphical analysis used to plot isobars results in a family of smooth curves clearly showing the distribution of pressures under a tire for a given condition. Since in any field work one would expect variations in soil conditions and loads applied as well as pressure measured, the method of graphical analysis may be a simple way to obtain smooth curves representing average values.
4. Froehlich's formula as used by Soehne apparently gives close approximations of pressure under the center of a tire.
5. The more pliable a soil the more pressure it transmits.
6. The high lugs on rear tractor tires carried the majority of the load in the Kaumee sandy loam soil.
7. Loads applied over scattered contact areas caused less pressure in the soil under the center of the load than loads applied over one continuous area.
8. The maximum pressure always occurred ahead of the axle

on each wheel.

9. The plow bottoms applied a slight negative pressure. The greatest part of the load of the plow was carried by its wheels.

RECOMMENDATIONS FOR FURTHER STUDIES

1. Determine the distribution of pressure at the contact surface of tires.
2. Determine the distribution of pressure in a normal field under various soils and soil conditions.
3. Investigate the effect of varying contact area for a given load on pressure in soil.
4. Investigate the possibility of using vector analysis to develop mathematical relationships representing pressure distribution in soil.
5. Determine the extent of soil compaction due to pressures in soil.
6. Investigate and develop means for lowering pressures in the soil under tires by using scattered contact areas or greater tire flexibility.

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APPENDIX

The weight transfer in the tractor while plowing was calculated as follows:

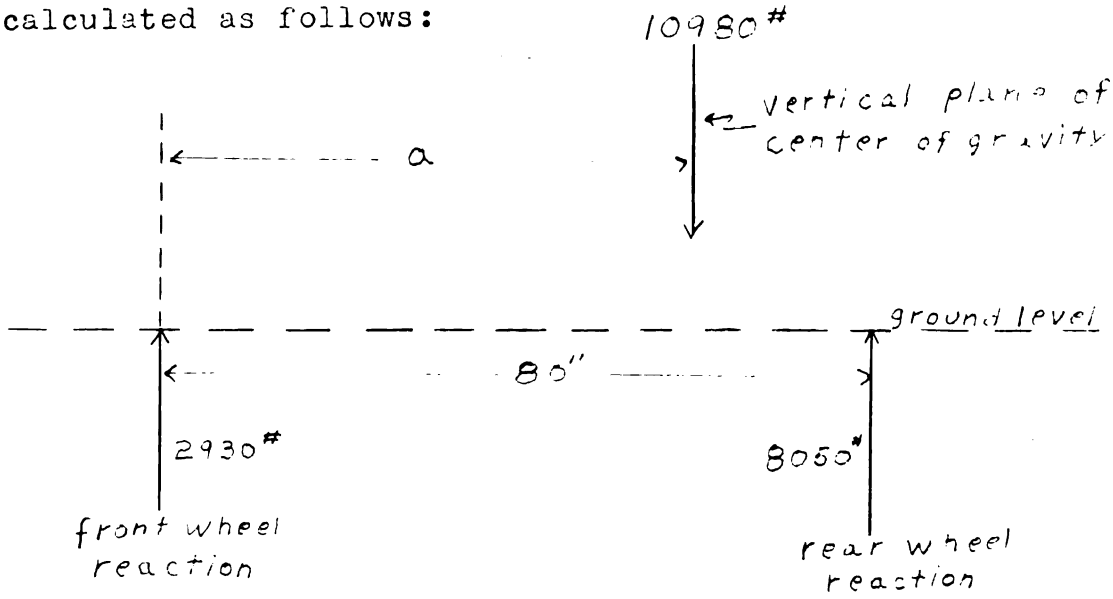


Fig. 18. Weight Distribution of Tractor Under Static Conditions

To determine location of center of gravity from Fig. 18:

$$\Sigma M_{\text{front wheel}} = 0 = 8050 \times 80 - 10980 \times a$$

$$a = \frac{8050 \times 80}{10980} = 58.6 \text{ in.}$$

Distance from rear axle to center of gravity will be 80" - 58.6" = 21.4"

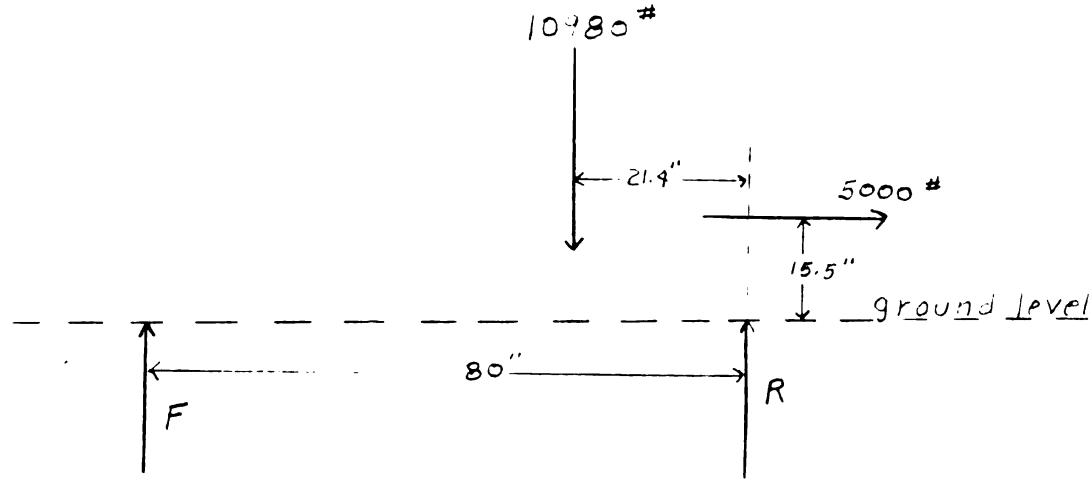


Fig. 19. Weight Distribution of Tractor while Plowing

To determine front tire reaction while plowing from Fig. 19:

$$\Sigma M_R = 0 = 10980 \times 21.4 - 5000 \times 15.5 - F \times 80$$

$$F = \frac{10980 \times 21.4 - 5000 \times 15.5}{80} = 1969^{+}$$

$$F = 1970 \text{ rounded off}$$

$$\Sigma V = 0 = 10980 - 1970 - R$$

$$R = 9010 \text{ lb.}$$

Thus each rear tire carried 4505 lb. and each front tire carried 985 lb. Weight transfer for other operations was calculated in a similar manner.

The elliptical contact areas were calculated by use of the formula:

$$A = \pi a b$$

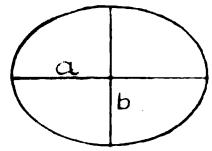


Fig. 20. Tire Contact Area

where a and b are semi-axes of an ellipse. Thus for the front tire on a hard surface:

$$\text{Area} = \pi \times \frac{6}{2} \times \frac{7}{2} = 33.0 \text{ in}^2$$

The weight of water in the sprayer tank was determined as follows:

At the start of the watering process the amount of water was $\frac{35 \times 69 \times 42}{1728} = 58.7 \text{ ft}^3$

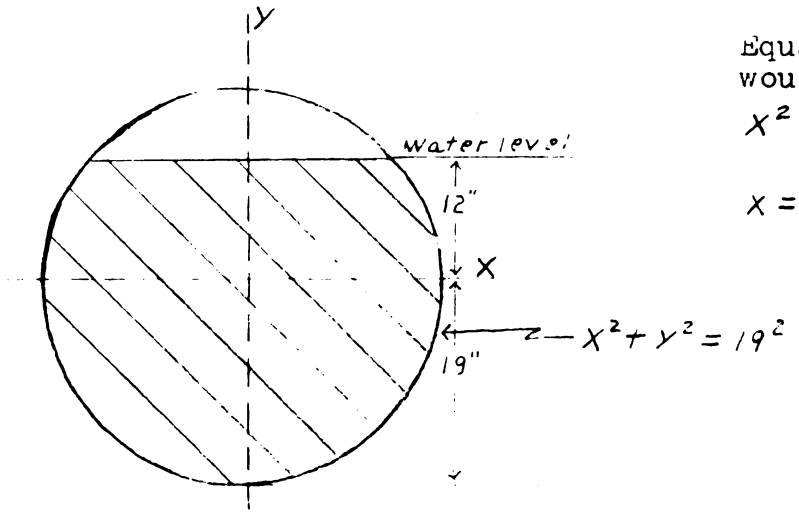
The amount of water at the end of the watering process was approximately $\frac{20 \times 69 \times 42}{1728} = 33.5 \text{ ft}^3$

Average water in the sprayer was then

$$\frac{58.7 + 33.5}{2} = 46.1 \text{ ft}^3$$

$$46.1 \text{ ft}^3 \times 62.4 \frac{\text{lb}}{\text{ft}^3} = 2880 \text{ lb Water}$$

The weight of water in the sheeps-foot tamper was calculated as follows:



Equation of curve would be:

$$X^2 + Y^2 = 19^2$$

$$X = \pm\sqrt{19^2 - y^2}$$

Fig. 21. Circular Curve Representing Drum of Sheeps-Foot Tamper

From the calculus we know the area would be:

$$A = \int_{-19}^{12}\int_{-\sqrt{19^2-y^2}}^{+\sqrt{19^2-y^2}} dx\,dy = \int_{-19}^{12} x\Big]_{-\sqrt{19^2-y^2}}^{+\sqrt{19^2-y^2}} dy$$

$$= 2\int_{-19}^{12}\sqrt{19^2-y^2}\,dy$$

$$= \frac{2}{2}\left[y\sqrt{19^2-y^2} + 19^2\sin^{-1}\left(\frac{y}{19}\right)\right]_{-19}^{12}$$

$$= \left[12\sqrt{361-144} + 361\sin^{-1}\left(\frac{12}{19}\right)\right] - \left[0 + 361\sin^{-1}\left(\frac{-19}{19}\right)\right]$$

$$= 177 + 361\left(\frac{\pi}{6}\right) - 361\left(-\frac{\pi}{2}\right) = 992\ in^2$$

Each drum (two drums on the tamper) was 40 inches long. Therefore total volume was:

$$\frac{992 \times 2(40)}{1728} = 46.0\ ft^3$$

$$46.0 \times 62.4 = 2870\ lb\ of\ Water$$

TABLE III

PRESSURE CELL READINGS UNDER FRONT TRACTOR TIRE
IN DENSE MAUMEE SANDY LOAM SOIL PLACED ON PAVING

Depth (in.)	Location of Cells with Respect to Center of Tire									
	Center (psi)	0.4' from center			0.8' from center			1.2' from center		
		right (psi)	left (psi)	average (psi)	right (psi)	left (psi)	average (psi)	right (psi)	left (psi)	average (psi)
1.5	41.1 *	0	1.5	.8	0	0	0	-	0	0
2.5	22.8	-	22.3	11.1 *	0	-	0	0	-	0
2.8	18.5	0.5	5.9	3.2	0	-	0	0	-	0
3.0	20.6	7.7	0	3.8	0	0	0	-	0	0
5.0	17.5	2.9	2.5	2.7	0	0	0	-	0	0
6.0	18.4	7.1	9.9	8.5	0	1.4	1.4	0	-	0
10.0	3.3	-	2.4	2.4	-	1.0	1.0	-	0	0
10.0	3.5	-	2.4	2.4	-	2.1	2.1 *	-	0	0
10.2	3.2	2.4	2.1	2.2	0.8	0.7	.8	0	-	0
12.2	1.5	-	1.4	1.4	0.3	0.7	0.5	0	-	0
13.0	-	1.4	1.2	1.3	0.2	0.2	0.2	-	0.2	0.2
13.6	1.0	0.8	1.0	0.9	0.2	0.4	0.3	-	0.2	0.2
14.0	1.1	0.7	0.5	0.6	-	0.2	0.2	-	0	0

* These values not used because they did not seem to be in line with other readings.

TABLE IV

PRESSURE CELL READINGS UNDER REAR TRACTOR TIRE
IN DENSE MAUMEE SANDY LOAM SOIL PLACED ON PAVING

Depth (in.)	Location of Cells with Respect to Center of Tire									
	Center	0.4' from center			0.8' from center			1.2' from center		
	(psi)	right (psi)	left (psi)	average (psi)	right (psi)	left (psi)	average (psi)	right (psi)	left (psi)	average (psi)
1.5	41.8	28.9	23.5	26.2	2.3	2.6	2.4	-	1.5	1.5
2.5	42.9	13.2	2.8*	13.2	7.1	-	7.1	0.9	-	0.9
2.8	30.0	5.1*	22.4	22.4	1.7	25.1	13.4	0	-	0
3.0	33.0	18.6	14.0	16.3	-	2.9	2.9	-	2.0	2.0
5.0	24.3	17.1	22.4	19.8	2.0	16.5	9.2	-	1.4	1.4
6.0	22.8	21.4	13.2	17.3	13.2	3.4	8.3	3.3	-	3.3
10.0	13.2	11.9	10.7	11.3	-	2.0	2.0	-	0.3	0.3
10.0	12.8	9.2	11.4	10.3	-	2.0	2.0	-	0	0
10.2	11.8	7.2	10.7	8.9	2.5	6.2	4.3	0.7	-	0.7
12.2	9.2	8.8	5.5	7.2	-	-	-	0.6	-	0.6
13.0	10.3	-	6.6	6.6	6.9	4.0	5.4	1.8	-	1.8
13.6	8.1	7.6	5.5	6.5	6.6	3.3	4.8	2.1	-	2.1
14.0	12.1	6.0	9.6	7.8	-	5.7	5.7	-	1.5	1.5

* These values probably were low because lugs were not directly over them, thus not used in analysis.

\- No reading

TABLE V

PRESSURE CELL READINGS UNDER THE CENTER OF THE FRONT TRACTOR TIRE IN FRESHLY PLOWED MAUMEE SANDY LOAM SOIL PLACED ON PAVING

Depth (in.)	Cell Readings (psi)	Depth (in.)	Cell Readings (psi)
9.8	3.7	10.2	5.8
10.0	8.1	11.8	3.8
10.0	5.1	12.8	5.3
10.0	4.7	14.7	4.1
10.0	8.8		

TABLE VI

PRESSURE CELL READINGS UNDER THE CENTER OF THE REAR TRACTOR TIRE IN FRESHLY PLOWED MAUMEE SANDY LOAM SOIL PLACED ON PAVING

Depth (in.)	Cell Readings (psi)	Depth (in.)	Cell Readings (psi)
9.8	11.4	10.0	13.5
10.0	12.5	10.2	12.3
10.0	12.3	11.8	13.7
10.0	17.3	12.8	12.8
10.0	12.4	14.7	11.8

TABLE VII

THEORETICAL PRESSURE DISTRIBUTION UNDER THE CENTER OF THE FRONT TRACTOR TIRE [a]

Depth (in.)	tan α [b]	α (degrees)	cos α	cos$^4\alpha$	Pressure (psi)
2	1.63	58.5	0.522	0.074	27.6
3	1.09	47.5	0.676	0.209	23.6
4	.815	39.2	0.775	0.360	19.1
6	.543	28.5	0.880	0.600	11.9
8	.407	22.2	0.926	0.735	7.9
10	.326	18.0	0.952	0.822	5.3
12	.271	15.2	0.965	0.867	4.0
14	.233	13.1	0.974	0.900	3.0
16	.202	11.4	0.980	0.922	2.3

a. Calculated from formula $\sigma_z = P_m(1-\cos^4\alpha)$ with $P_m = 29.8$ psi and effective radius = 3.26 in.

b. α is arc tan $\frac{r}{x}$ where r is effective radius and x is depth.

TABLE VIII

THEORETICAL PRESSURE DISTRIBUTION UNDER THE CENTER OF THE REAR TRACTOR TIRE WITH 3.00" RADIUS [a]

Depth (in.)	tan α [b]	α (degrees)	cos α	$\cos^4 \alpha$	Pressure (psi)
2	1.50	56.3	0.555	0.095	48.5
3	1.00	45	0.707	0.250	40.2
4	.750	36.9	0.800	0.410	31.6
6	.500	26.5	0.885	0.614	20.7
8	.375	20.6	0.936	0.768	12.4
10	.300	16.7	0.958	0.842	8.5
12	.250	14.0	0.970	0.885	6.2
14	.212	12.0	0.979	0.919	4.8
16	.187	10.6	0.983	0.934	3.5

a. Calculated from formula $\sigma_z = P_m(1 - \cos^4 \alpha)$ with P_m = 53.6 psi and effective radius = 3.00 in.

b. α is arc tan $\frac{r}{x}$ where r is effective radius and x is depth.

TABLE IX

THEORETICAL PRESSURE DISTRIBUTION UNDER THE CENTER OF THE REAR TRACTOR TIRE WITH 5.16" RADIUS [a]

Depth (in.)	tan α [b]	α (degrees)	cos α	cos$^4\alpha$	Pressure (psi)
2	2.58	68.8	0.362	0.017	52.7
3	1.72	59.9	0.500	0.062	50.3
4	1.29	52.2	0.613	0.141	46.1
6	.860	40.6	0.759	0.332	35.8
8	.645	32.8	0.841	0.499	26.8
10	.516	27.3	0.888	0.622	20.2
12	.430	23.3	0.925	0.732	14.4
14	.368	20.2	0.938	0.774	12.1
16	.322	17.8	0.952	0.821	9.6

a. Calculated from formula $\sigma_z = P_m(1-\cos^4\alpha)$ with $P_m = 53.6$ psi and effective radius = 5.16 in.

b. α is arc tan $\frac{r}{x}$ where r is effective radius and x is depth.

TABLE X

SUMMARY OF STATIC LOADS, LOADS CARRIED, PULL AND SEMI-AXES OF CONTACT AREAS FOR TRACTOR AND IMPLEMENT TIRES

Tire or Implement	Static Load lb.	Pull Causing Weight Transfer lb.	Working Load lb.	Major Axis in.	Minor Axis in.
Front Tire Plowing	1465	5000	985	7	6
Rear Tire Plowing	4025	5000	4505	-	-
Front Tire Watering	1437	900	1350	17	7.5
Rear Tire Watering	4040	900	4127	28	18
Front Tire Tamping	1437	1800	1265	-	-
Rear Tire Tamping	4040	1800	4212	-	-
Front Tire Rolling	1437	800	1360	-	-
Rear Tire Rolling	4040	800	4117	-	-
Sprayer Tire	2852	-	2852	11	8
Tamper [b] Feet	8550	-	8550	3.25 [a]	2.0 [a]
Roller [c] Tire	4365	-	4365	8	6

a. Rectangular area calculated.

b. 24 feet in contact with soil. All other items in column were pneumatic tires.

c. 8 tires on the roller.