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A STUDY OF THE LATERAL PRESSURES INDUCED
IN A SOIL
DUE TO COMPACTION
UNDER CONFINED CONDITIONS

A THESIS

Presented to

the Faculty of the Graduate Division

Georgia Institute of Technology

In Partial Fulfillment

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Master of Science in Civil Engineering

By

Andrew Dewar Robb

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ABSTRACT

Observations at the time of the construction of a retaining wall in the Atlanta area led to the suspicion that the compaction of a fill as carried out in modern soil work could induce lateral pressures capable of tilting walls or other structures.

Experiments on a small scale showed pressures to be set up under some conditions by compaction. The present investigation was undertaken as the first or laboratory part of a research program aimed eventually at dealing with full-scale tests. The object of these small-scale tests was to find the nature of any pressures which might be induced in a soil subjected to compaction and to determine the factors which influence them.

The equipment used was a thin-walled compaction cylinder on the sides of which electric strain gages were fitted and calibrated to measure lateral pressure. Three soils, two sands and a silty clay, were compacted by static and dynamic procedures and residual pressures for each soil were measured.

The experiments showed that in sand, no residual lateral pressures are developed unless it is fine and moist, and even then they are of small magnitude. In a clay, residual pressures may be developed which depend on the moisture content and on the compactive procedure, being greatest slightly below the optimum moisture content for the procedure being used.

It is recommended that a subsequent investigation be carried out using sensitive pressure cells in a full-scale fill to measure pressures.

In order to have pressures of a measurable magnitude, clay will be required in a fairly dry condition and the compactive effort should be as large as practicable. It may be possible to work out further some relationship between residual lateral pressures and shear strength of a soil.

A subsidiary part of the research program was to measure Poisson's ratio in the soils tested. This was done by recording active, as well as residual, lateral pressures in the static tests and calculating the ratio by way of the coefficient of earth pressure at rest. This work showed an average value of 0.34 in sands, the individual figures being independent of soil moisture content; and a range of 0.28 to 0.42, increasing in general with moisture content, in the case of Georgia clay.

CHAPTER I

INTRODUCTION

General Background.--In order to deal with the problems involved in modern construction, the science known as Soil Mechanics has been developed. Starting from modest beginnings, working with mathematical formulae based on doubtful assumptions and correlating them with the practical and empirical results of past and current practice, analytical, or at least semi-analytical procedures have been worked out for the design of earth structures. But the science is still in its early stages, and considerable work remains to be done which may be of use in eliminating chance from engineering design.

A field in which considerable work has been done is that of soil compaction. Since the work of Proctor[1] in the 1930's, procedures for regulating the compaction of soil in construction work have come into common use. In addition, a steady stream of articles dealing with work on various aspects of compactive processes has been published in engineering literature.

In general, this work can be split into two parts: (1) that dealing with laboratory testing and control procedures; and (2) that covering the more practical problem of the application of theory and laboratory tests to field construction.

A second field which has been given considerable attention is that of earth pressures, especially as applied to retaining structures.

Theories and even experiments on this problem date back well beyond the days of the beginning of soil mechanics as it is now understood, and an interesting summary of this work has been compiled by Jacob Feld[2]. The classic mathematical analyses of Coulomb and Rankine (later extended by Résal and Bell) in the 18th and 19th centuries have survived to modern times and are still widely used in design. In recent years their scope has been widened by the work of Terzaghi and others.

Use of these theories requires values of the angle of internal friction, the cohesive strength and the density or unit weight of the soil employed as backfill material. Each of these properties, however, may be a variable depending, for example, on the moisture content and, in the case of a compacted fill, on the compactive procedure.

In the case of a retaining wall, two distinct possibilities are seen. A wall may be built against an existing fill with any additional material between the two being thrown in and allowed to consolidate naturally. Alternatively, the backfill may be forcefully compacted in place. One retaining wall, which was so designed and constructed in the Atlanta area, developed a pronounced outward lean shortly after completion. The suggestion was made that the action of a compacted backfill on a structure might not be the same as that of a natural deposit of like soil properties and that lateral pressures resulting from such compaction might have been sufficient to cause tilting.

<u>Preliminary Tests</u>--To investigate the residual lateral pressures which could be induced by compaction, a small-scale apparatus was produced for the soil mechanics laboratory of the Georgia Institute of Technology. This consisted essentially of a compaction cylinder on

the sides of which electric strain gages were fitted to measure outward deflections. The merit of the small-scale apparatus over a full-scale test is that hydrostatic pressures, due to the weight of overburden, are reduced to very small values which can be neglected and any pressures recorded may be assumed to be the result of compaction. The disadvantage of such an apparatus, when pressures are to be measured, is that the effects of confinement may make the results completely erroneous for any other condition.

A few rough tests with the apparatus nevertheless encouraged the author to look further into the matter. From these tests it appeared that any comprehensive program would best be carried out in two parts: (1) do further work with the small apparatus involving confined conditions to define the nature of any stresses induced by so compacting a soil, and to determine the effect of variation of moisture content and compactive procedures on these stresses with as few variables to confuse the issue as possible; (2) make full-scale tests using pressure cells to determine the relationship, if any, between the lateral stresses present in a compacted soil, the natural lateral pressure and the residual lateral pressures found by the small-scale tests.

The author set about the first part of this program and the present thesis gives an account of his work.

Published Work--A literature research was first undertaken to find any material which could be of help in the work. This revealed no record whatsoever of residual pressures found as a result of soil compaction. Equipment capable of recording such pressures has been developed only in recent years. A report by the Waterways Experiment

Station[3] on pressure cell installations in dams was studied early in the investigation, and while this dealt with full-scale tests and was not specifically concerned with residual pressures, (though these may have affected the results) it gave an idea of the inherent scattering to be expected in this kind of work.

A related field in which some work has been done is that of the measurement of Poisson's ratio--the ratio of lateral to longitudinal strain--for soils. A number of references showed that work done in the past had been largely on sands, and in general the attention which the property has received has been very inadequate. Thus, in 1920, Terzaghi[4] published results of tests made on sand using its friction on steel bands to investigate pressure ratios. The main difficulty with his rather crude apparatus seems to have been the attainment of a homogeneous fill which can be most easily achieved in the case of coarse sands. This is apparently why he and other investigators have worked principally on these soils. Terzaghi later did some research on clays[5] but his results are now thought to have been rather high. Tschebotarioff[6] has done a good job in putting many of the earlier experiments into perspective.

The small scale of the author's apparatus, made possible by the use of electric strain gages, permits a greater degree of homogeneity to be obtained, although the difficulty of a lack of homogeneity is still present, as will be discussed later.

During the period of testing in this investigation, the Corps of Engineers published a preliminary notice of very exhaustive tests being run to determine Poisson's ratio for sands. Their equipment, similar to that used here, involved a cylinder which may be fitted with any one of three floating rings of different sizes and fitted with electric strain gages. The testing was still at an early stage, but results to date indicated a value of Poisson's ratio of 0.28 to 0.41 on the loading cycle and as high as 0.93, larger than the theoretical limit of 0.50, for the rebound condition. No explanation was offered for this result. The procedure used was apparently similar to that followed by the author, though more variables were included. The Corps of Engineers' values provided a useful comparison with those found by the author.

CHAPTER II

EQUIPMENT

The major items of equipment used in the work are listed below:

A. Soils

1. Ottawa Standard Sand. This is a natural deposit of rounded quartz grains. It is artifically graded to pass a No. 20 standard U. S. sieve while being retained on a No. 30 sieve.

2. A fine, slightly micaceous natural beach sand with sub-angular grains. Its properties are given in the appendix.

3. Georgia clay, a reddish, inorganic silty clay of low plasticity. It was taken from a pit behind the Civil Engineering building of the Georgia Institute of Technology. Its physical properties are listed in the appendix.

B. Compaction Devices

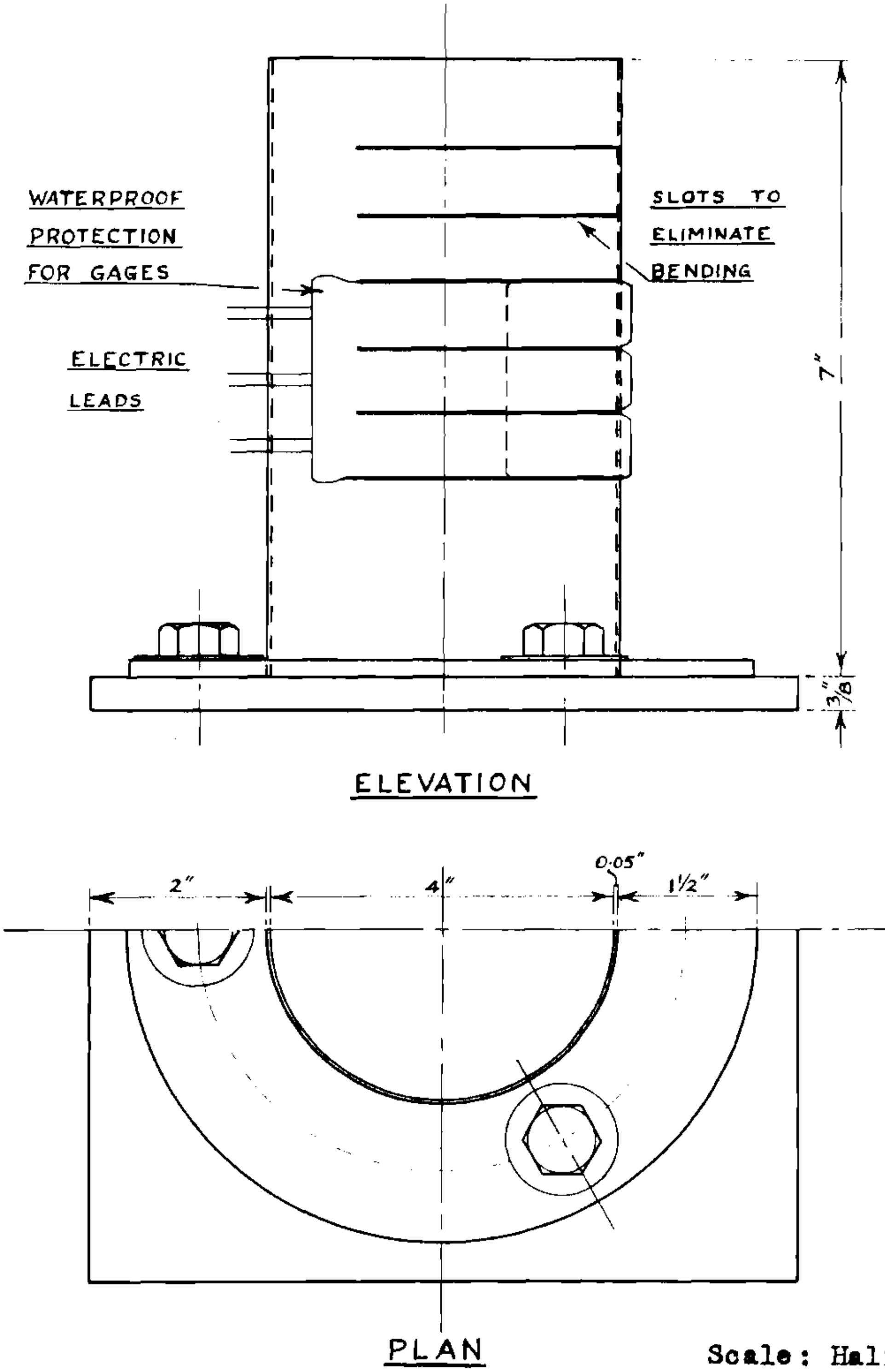
1. A 10,000 pound capacity hydraulic testing machine equipped with an electric motor transmitting its load through a 3-3/4 inch diameter piston. A proving ring calibrated up to 10,000 pounds was used to measure the loads.

2. A U. S. standard five-and-one-half-pound compaction hammer with a twelve inch free fall and a ram diameter of two inches.

3. A U. S. standard ten-pound hammer with an eighteen inch free fall and a two inch ram diameter.

C. Compaction Mold

A drawing of this is given in Fig. 1. A thin steel cylinder has



Scale: Half full size.

Sketch of Compaction Mold

Showing Leading Dimensions.

Fig. 1

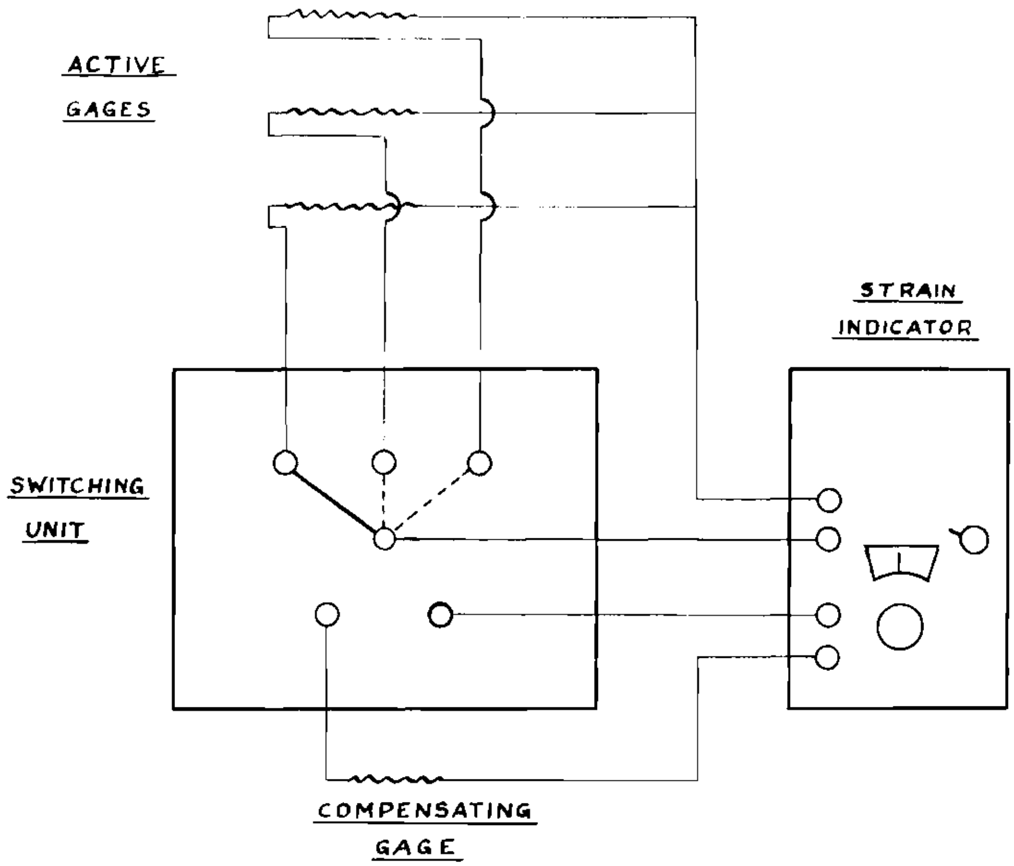
six horizontal slots cut half way through to eliminate the bending stresses otherwise associated with the bulging out of a compressed soil. Between slots, three SR-4 type electric strain gages were attached. These were of size A-9, six inches long to obtain average results. Their gage factor was 2.08.

The SR-4 strain gage consists of a very thin wire glued to a piece of paper which may be attached to surfaces in whose stress conditions one is interested. When a wire is stretched, its cross-sectional area decreases. Hence, as the electrical resistance of a conductor is inversely proportional to its cross-sectional area, the amount of strain on a surface can be calibrated in terms of the change in electrical resistance of the wire by means of a very sensitive Wheatstone Bridge. To allow for temperature variations, which also affect conductor resistances, a compensating gage is balanced in the circuit in parallel with the active or measuring gage.

D. Strain Recording Equipment

1. A Baldwin Type L strain indicator was used to record strain readings.

2. A switching box was put in the circuit, through which active and compensating gages were connected to the indicator. A circuit diagram is shown in Fig. 2. This arrangement allowed a quick change-over of gages when readings were taken. Photographs of the apparatus ready for a test are given in Figs. 3 and 4.



Diagrammatic Representation of

Strain Gage Connections.

Fig. 2

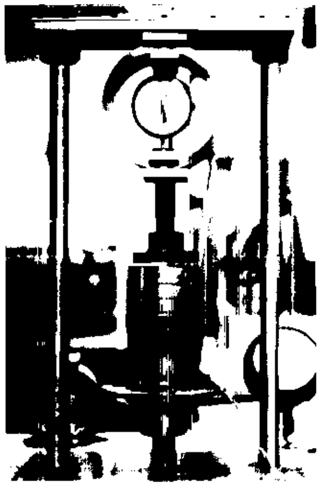


Fig. 3 Showing the compaction cylinder in position in the hydraulic testing machine.

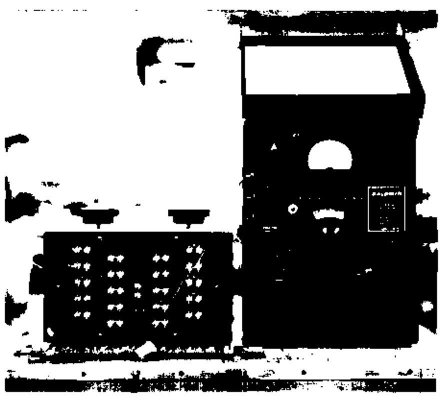


Fig. 4 Showing the strain-recording equipment.

CHAPTER III

PROCEDURE

Calibration of Equipment.--The first step in an investigation using strain gages, is the calibration of the equipment. The strains which the gages register must be accurately correlated with the pressures with which they are associated and which are the required unknowns.

Strains may often be correlated on a theoretical basis from the dimensions of the apparatus and this procedure was first followed here.

Thus, for a cylinder of length L inches, diameter D inches, thickness T inches with a pressure of P pounds per square inch (Psi.) on the inside:

$$P \times D \times L = 2F \times T \times L \times X$$

where F is the tensile stress in the steel; and X is a factor to allow for the slots in the sides.

But $F =$

$$e \times E \times 10^{-6}$$

where e is the strain in micro-inches per inch; and E is the modulus of elasticity, taken as 29×10^{6} psi. for steel.

Hence

$$P = \frac{2 \times e \times E \times T \times X \times 10^{-6}}{D} = 0.78\ e$$

for the cylinder used.

While this is a useful indication, a more accurate calibration was desired.

For the special test, the cylinder was bolted down firmly to its base plate against a layer of air-tight gasket cement. A heavy rubber sleeve was fitted inside the cylinder, being carefully thinned and cemented in position at the bottom and doubled over the top. A flat steel plate with a screwed-in air valve was placed on top and pressed down on the mold with the hydraulic jack to obtain an air-tight seal.

Compressed air was introduced into the cylinder, and the values of strain recorded by the gages were correlated with the pressure applied. The results of a number of runs were plotted as shown in Fig. 5 and found to be linear, the equations of the lines being:

for the Top gage: $P = 0.854 \times e$

Middle $P = 0.769 \times e$

Bottom $P = 0.703 \times e$

where P is the lateral pressure on the inside of the cylinder in Psi.; and e is the strain recorded for the gage by the strain indicator in micro-inches per inch.

These conversion constants were applied to subsequent experimental results, although in the case of the active pressures they often involved extrapolations outside the range tested.

Preliminary Test Program.--Of the three soils used, the two sands were dry. The Georgia clay was partly air-dried in large pans and passed through a No. 4 standard U. S. sieve before being stored ready

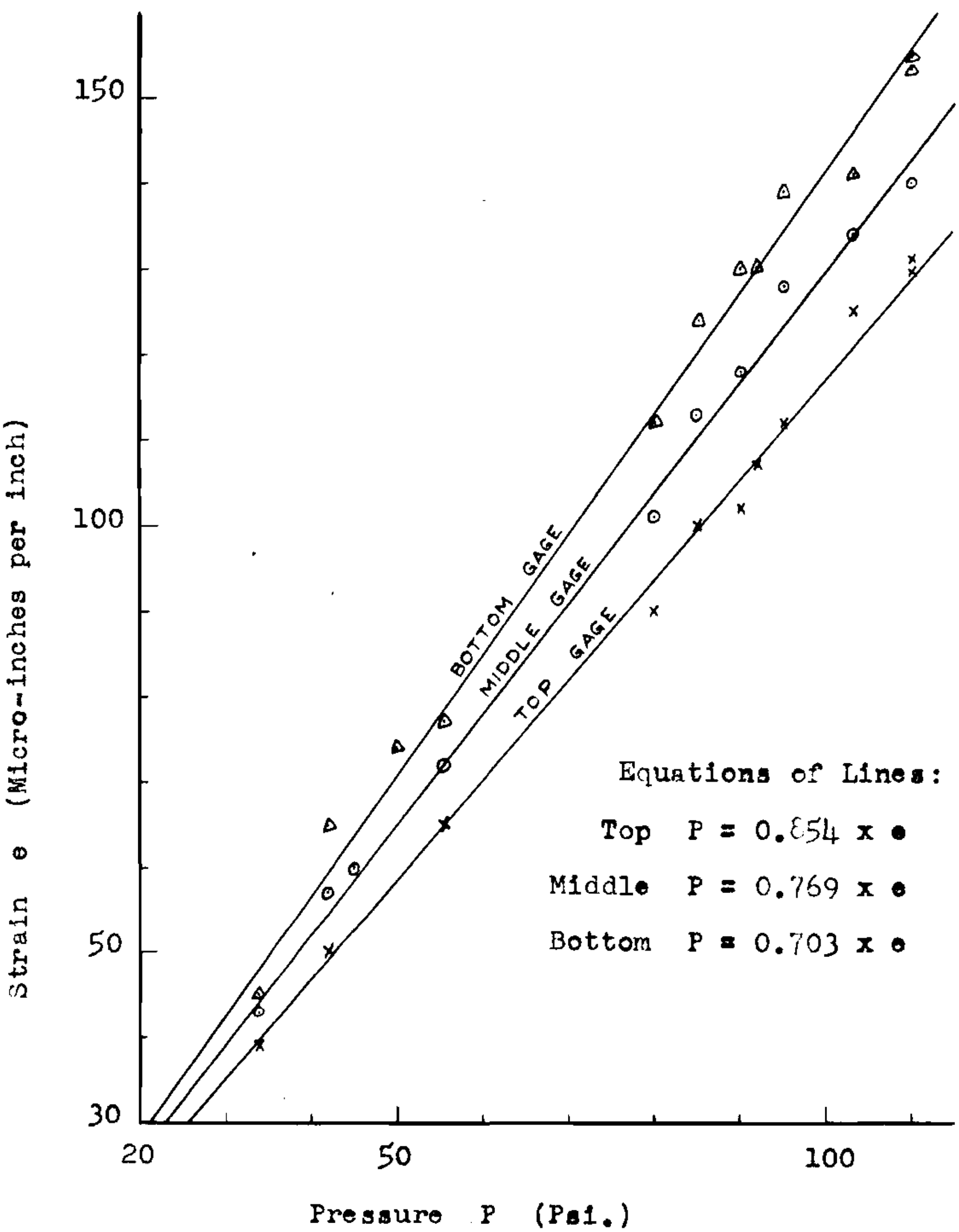


Fig. 5

Equipment Calibration Curves.

for testing.

The first test run was a preliminary to find the magnitude of the residual stresses for different amounts of compactive effort. The Georgia clay was used for this with its moisture content kept as constant as possible. A number of dynamic procedures were used to compact the clay by different methods. Each test was run in duplicate, and the energy per blow applied was calculated as the product of the hammer weight and its fall.

A graph of residual pressure against compactive effort is shown in Fig. 6 and is seen to be almost linear, though with considerable scattering of points. This relationship means that larger and hence more accurate values can be expected of greater compactive efforts.

Final Test Program.--With this in mind, a program was planned to test all three soils at various moisture contents, using static loads of 5,000 and 10,000 pounds (425 and 850 Psi.), and two dynamic procedures. However, as a result of the static tests on sand which showed no residual pressure, the dynamic tests on sand were not carried out. The program as completed is shown in Table 1.

Each test was carried out in such a way as to introduce as few variables as possible. In the 5,000 pound static test the soil was compacted in three layers of approximately equal thickness, the thickness of each layer being measured. Readings were taken on strain gages before a layer had been compacted, at maximum load, and after compaction. Density and moisture content determinations were made after every test, and most tests were run in duplicate. The 10,000 pound loading was carried out similarly, with the exception that compaction was done in

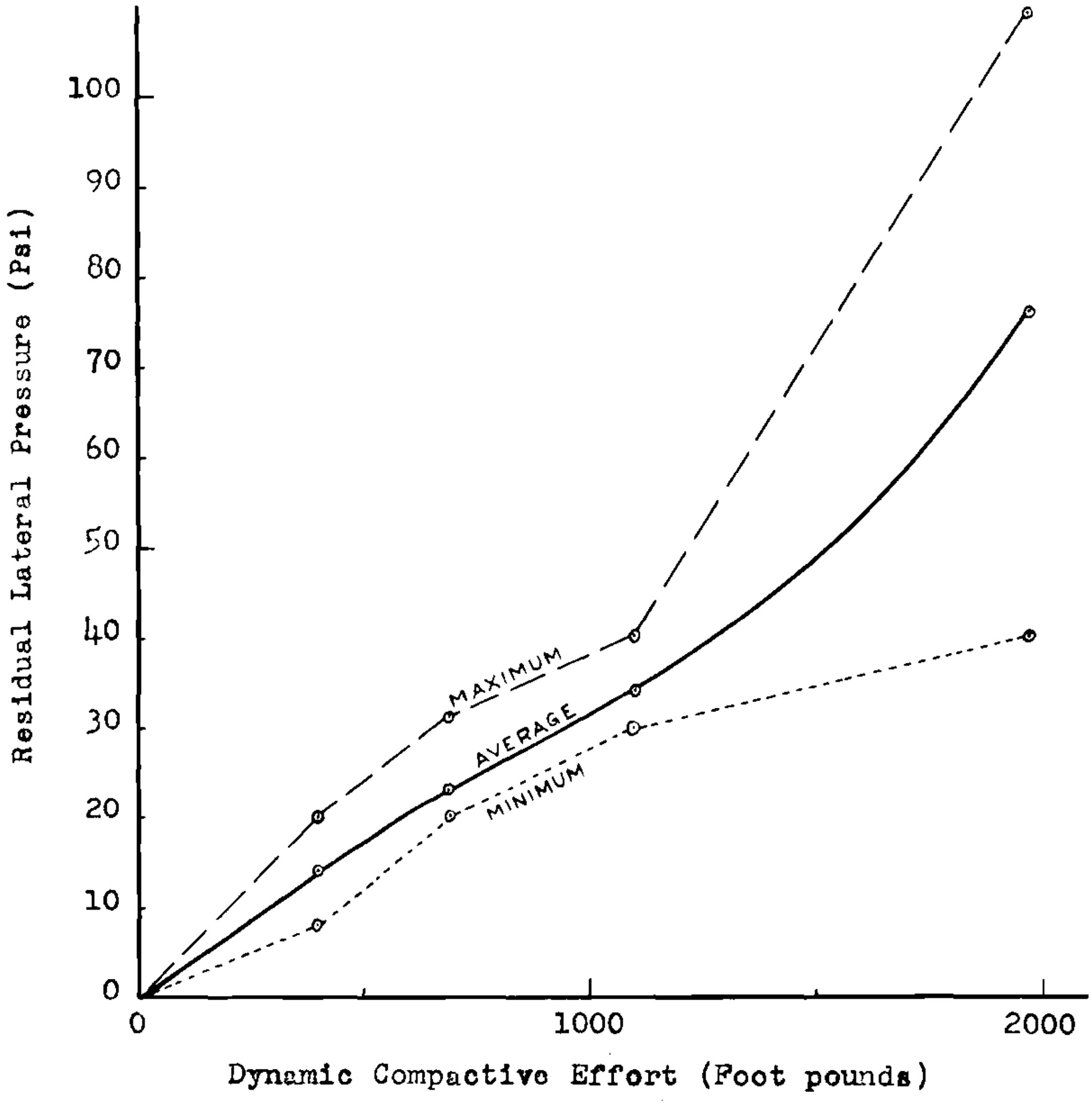


Fig. 6

Relationship between Dynamic Compactive Effort and Residual Lateral Pressures Resulting from Compaction of Georgia Clay at Constant Moisture Content.

Table 1. Details of Testing Program

Soil	Compacting Procedure		Average Moisture Content	Number of Test Runs
Ottawa standard sand	Static load	425Psi.	0	1
			3.8	1
		850Psi.	0	1
			5.5	2
Fine beach sand	Static load	425Psi.	0	1
			7.7	1
		850Psi.	0	1
			8.1	1
Georgia clay	Static load	425Psi.	2.5	2
			11.9	2
			13.4	1
			18.3	2
			24.7	2
		850Psi.	2.1	2
			12.6	2
			16.0	2
			18.2	1
	Dynamic compaction	Light hammer	10.5	3
			12.0	2
			13.7	3
			15.7	2
			16.2	2
			17.8	2
			22.4	3
		Heavy hammer	12.0	4
			19.3	2
			20.2	1

five layers instead of three.

The dynamic testing procedures used on the clay were: (1) 25 blows of the light hammer on each of five layers and (2) 25 blows of the ten-pound hammer, again on each of five layers. Strain measurements were recorded before and after compaction and the thickness of each layer was measured. Particularly at high soil moisture contents, the residual pressures recorded were observed to vary with the position of the last hammer blow on the surface of the soil. This variation is a factor which probably explains the extreme variety in these results.

CHAPTER IV

THEORY

Consider first the cylinder containing compacted soil in equilibrium under a pressure P_o.

Let the cross-sectional area of the cylinder be of area A, and circumference C.

Examine an element of soil of thickness dH at depth H below the surface, and having a pressure P on the upper face and P dP on the lower.

Let K be the coefficient of earth pressure at rest; μ be the coefficient of friction of the soil on the cylinder walls; and γ the unit weight of the soil.

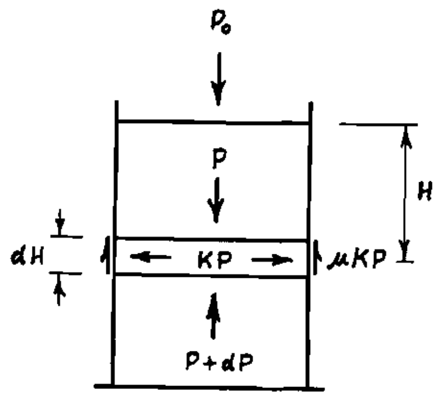


Fig. 7

$$\text{Then:}\quad (P + dP) \times A - P \times A + \mu \times K \times P \times C \times dH = \gamma \times A \times dH$$

$$\text{or}\quad dP = (\gamma - \mu \times K \times C/A \times P) \times dH$$

$$\text{Hence} \int_{P_o}^{P} \frac{dP}{\gamma - \mu \times K \times C/A \times P} = \int_{o}^{H} dH$$

$$\text{Integrating}\quad \log_e \left(\frac{\gamma - \mu \times K \times C/A \times P}{\gamma - \mu \times K \times C/A \times p_o} \right) = - \frac{H \times \mu \times K \times C}{A}$$

If P_o is very large, γ becomes negligible by comparison

Therefore
$$\log_e \left(\frac{P}{P_o}\right) = - \frac{H \times \mu \times K \times C}{A}$$

Hence
$$P = P_o \times e^{-\frac{H \times \mu \times K \times C}{A}} \quad \text{or}$$

$$K \times P = K \times P_o \times e^{-\frac{H \times \mu \times K \times C}{A}}$$

This is a development of the theory worked out for bin and silo design by Jannsen, whose work has been presented in English by Ketchum[7]. In the original solution, no pressure force was applied on the surface and the only reactions were due to weight of the soil. In the present analysis these are neglected as being small in comparison with the forces due to surface pressure.

The equation in the given form shows the lateral pressure set up in the cylinder at any depth H due to a pressure P_o applied on the surface, to vary directly with P_o. The lateral pressure also bears an exponential relationship with the quantities H, μ , K, C, and A, which are defined above, showing an increase with increase in A, and a decrease with larger values of the others.

CHAPTER V

DISCUSSION OF RESULTS

Residual Lateral Pressures.--The results of the tests, summarized in tabular form in the appendix, show that in the case of a drysand, compaction induces no residual lateral pressures whatever, although a moist angular sand develops small stresses. With Georgia clay, residual lateral pressures are developed as a result of compaction. Their magnitudes increase with greater compactive efforts as already noted for Fig. 6 and in general show a decrease with increasing soil moisture content as shown in Figs. 8 and 10. As moisture content and compacted density are interrelated by the Proctor-type curves presented in Figs. 16 and 17 in the appendix, residual pressures may also be shown as a function of density as in Figs. 9 and 11, and are found to reach their maximum values at densities rather below the maximum for a given compactive procedure. The larger scatter of points found in all of these graphs in which maximum, minimum and average values at any one condition are plotted, seems to be inherent in this type of work.

The values of lateral residual pressures may reach up to one-third, or even almost a half of the maximum active lateral pressure in confined clay statically compacted. The Maximum is reached about the middle of the range of moisture contents which can be compacted, and falls off sharply above this. It is believed that the results of the dynamic tests, which show a general fall-off in pressure with

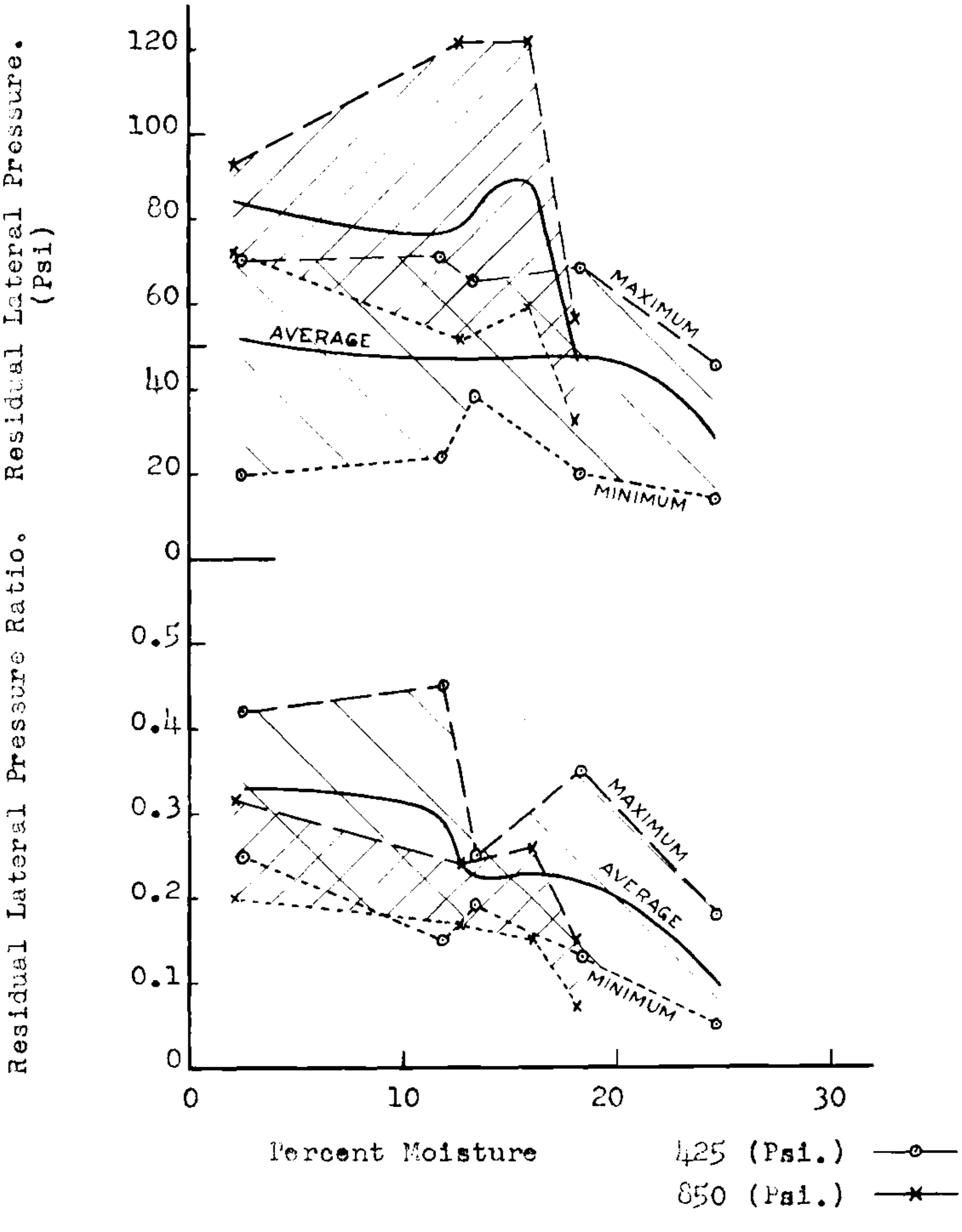


Fig. 8

Relationship between Moisture Content of Georgia Clay and Residual Lateral Pressures Resulting from Static Compacting Loads of 425 and 850 Psi.

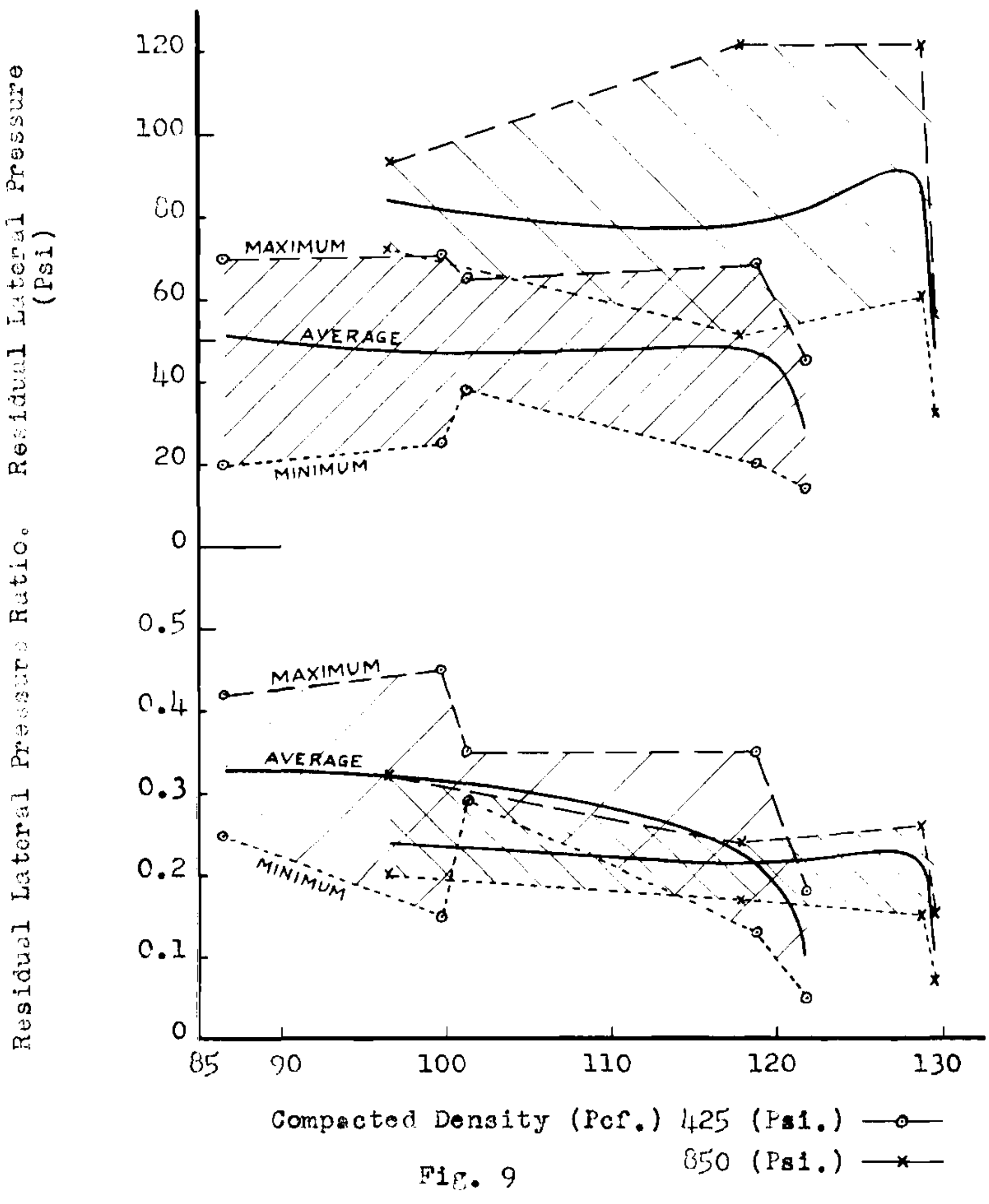


Fig. 9

Relationship between Compacted Density of Georgia Clay and Residual Lateral Pressures Resulting from Static Compacting Loads of 425 and 850 Psi.

increase in moisture, are clouded by the effect mentioned earlier when it was noted that the final residual pressures recorded depended on the position of the final blow on the surface. Consequently the average pressures are probably the significant ones here.

The theoretical equation

$$K \times P = K \times P_o \times e^{\frac{-H \times \mu \times K \times C}{A}}$$

derived above gives the equilibrium or active lateral pressure at any depth H due to a pressure P_o applied at the surface. It is, however, with the conditions prevailing on the subsequent removal of the surface pressure that this work is concerned.

When the compacting pressure is removed, one of two things is possible: the pressure in the whole mass of soil may return to zero, leaving no residual pressure, as happened in the case of the sands; alternatively, a residual pressure may be left within the mass of soil. In this instance, as the surface pressure must be zero, a build-up of pressure must occur from the surface down with increasing depth. However, the active pressure, as shown by the above derivation, decreased with depth. On removal of the compacting force, expansion of the soil due to elastic swelling will cause a reversal of the friction forces on the cylinder walls to oppose movement, resulting in the reduction of all stresses. This means that the residual lateral pressures must, in general, decrease with depth.

The hypothesis suggested by the author is shown graphically in Fig. 12. It is assumed that a rapid build-up of residual pressure

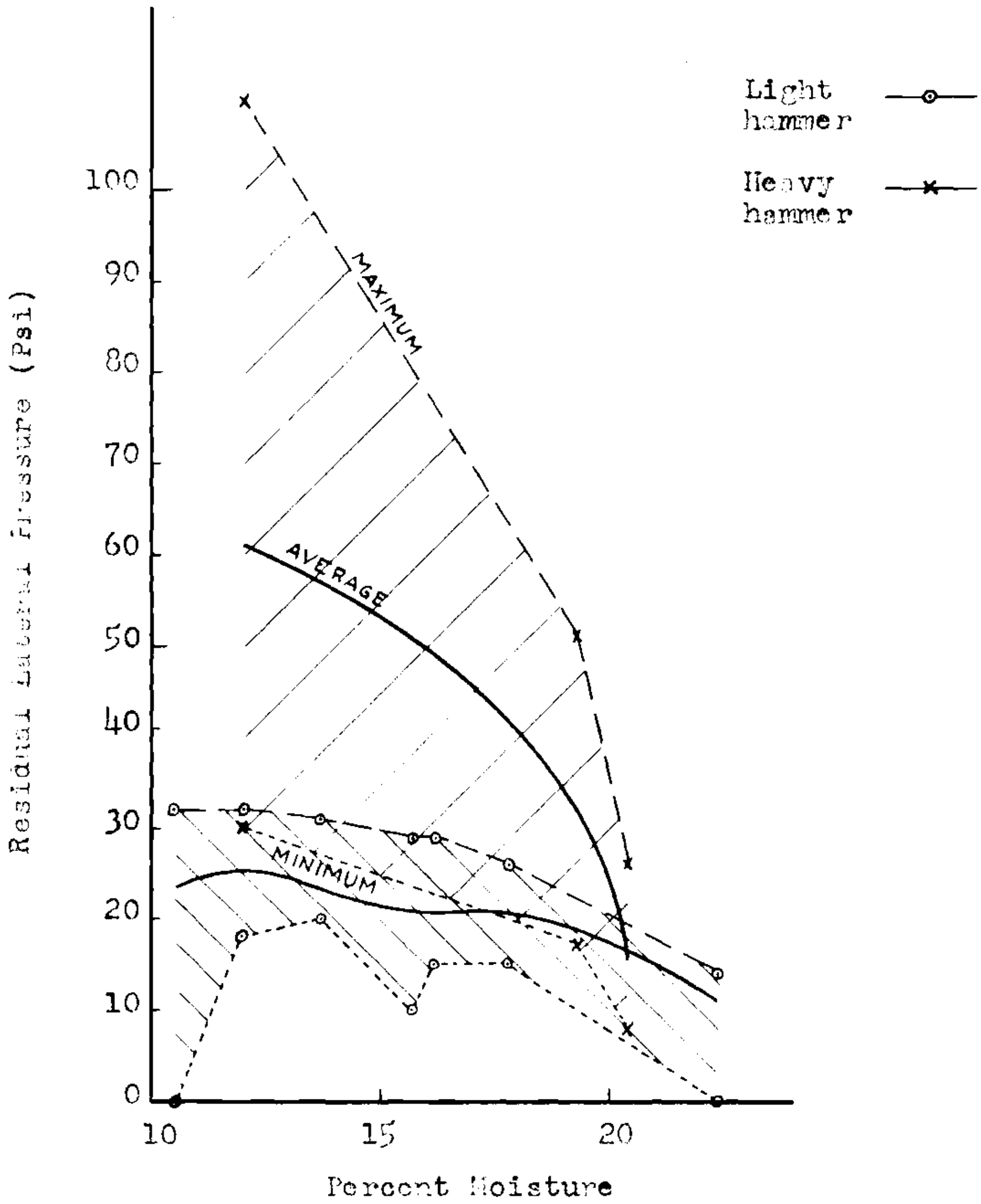


Fig. 10

Relationship between Moisture Content of Georgia Clay and Residual Lateral Pressures Resulting from Compaction by Heavy and Light Compactive Procedures.

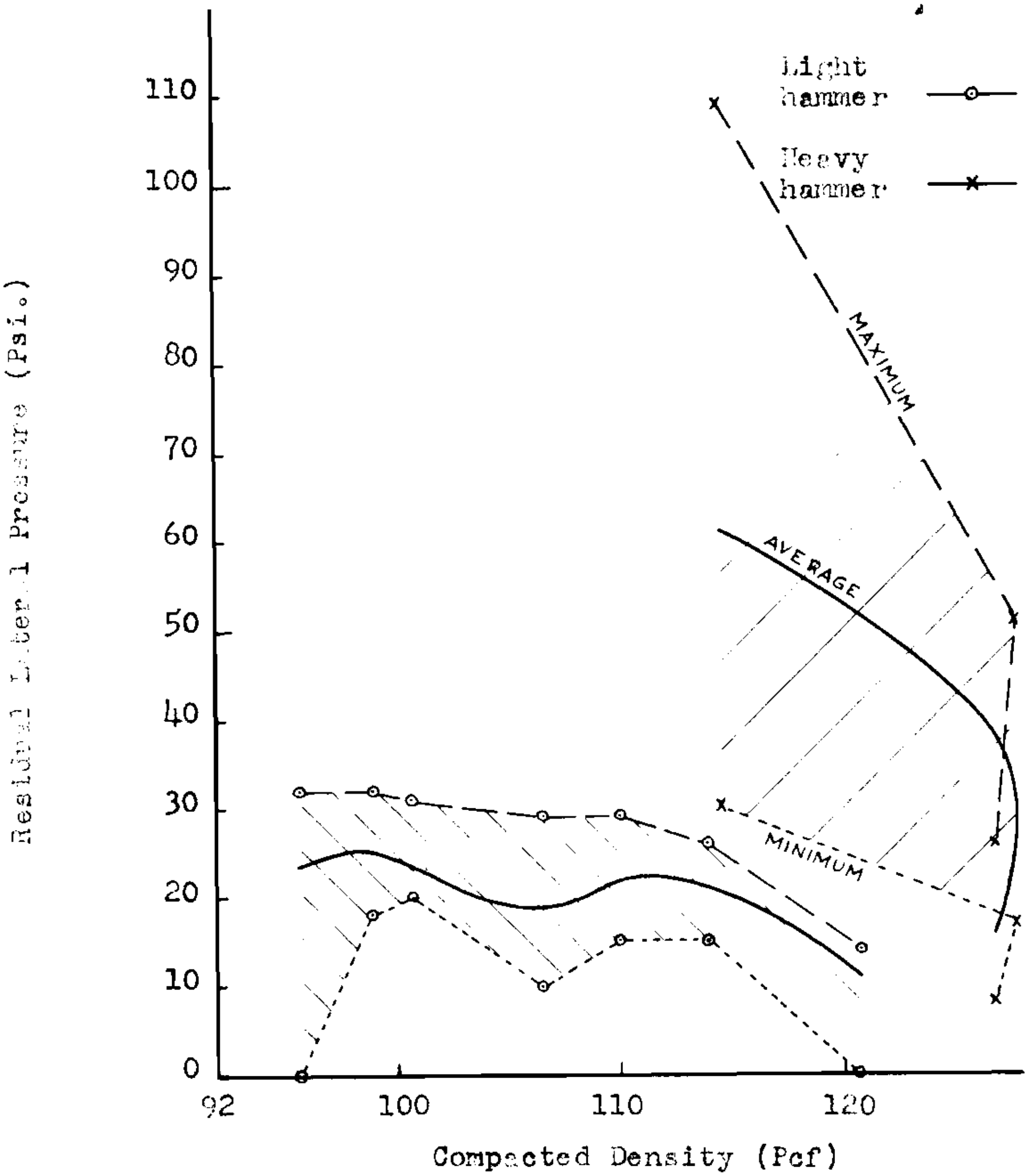


Fig. 11

Relationship between Compacted Density of Georgia Clay and Residual Lateral Pressures Resulting from Compaction by Heavy and Light Compactive Procedures.

with depth near the surface is explained by the lack of adequate confinement there. Below the immediate surface the residual pressure decreases with depth in a compaction layer and bears some relationship to the active pressure at any one point.

This conclusion is largely supported by the results obtained for Georgia clay. The tables presented in the appendix show, for each recording, the depth of the gage below the surface and the corresponding residual pressure ratio--the ratio of the residual, to the maximum active lateral pressure recorded on the same gage. It is noteworthy that this ratio increases considerably from the first to the second reading on any gage after which only slight increases or even steady conditions are found.

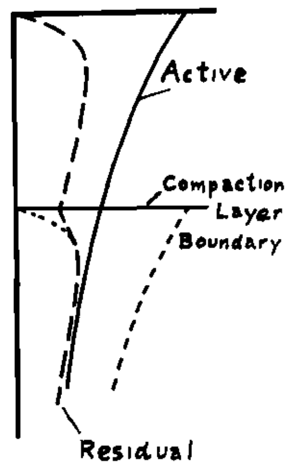


Fig. 12

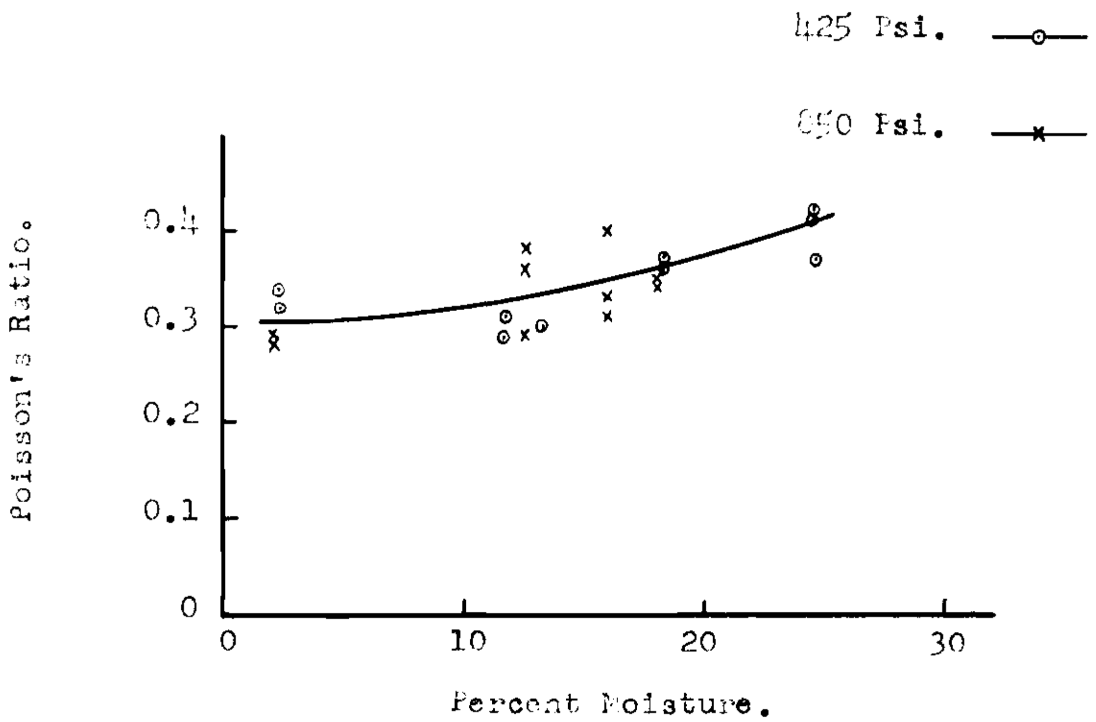
The advantage of the ratio is that it might be expected to compensate in the laboratory for the lack of homogeneity in a compacted soil by taking into account both the residual pressure and the maximum active pressure induced in the soil at the same level. Its disadvantage, however, is that it can be used only in the case of static compaction. In addition, the regulation of the curves accomplished by plotting the ratio instead of the residual pressures themselves, is considerably less than might have been expected.

This theory certainly does not give the whole picture. In the first place, the sands, when dry, showed no residual pressures whatsoever.

While they may have been present but of a magnitude smaller than the accuracy of the apparatus (about 10 Psi.), it is believed that the lack of cohesion in a sand, which makes its strength characteristics proportional to the confining pressure, may also be the reason for its lack of residual pressures. This explanation would indicate why a moist sand, which has a small amount of apparent cohesion, might have small residual pressures after compaction.

Even for cohesive soils, however, it may be doubted whether all factors are included. How far the theory holds good can be found only after full-scale tests have been conducted in an open fill. The theory as presented implies that residual stresses are developed in clay soils compacted in a cylinder because friction forces along the sides of the cylinder prevent the expansion of the soil after the release of the compacting forces. While this is likely to be part of the explanation for the small-scale equipment, in the field no such side friction is present and the pressures induced are likely to be reduced by the lack of this effect. The question is how much. As the problem evidently depends on the nature of the clay grains themselves, it will require to be investigated separately and by equipment capable of recording pressures even smaller than those found here. The present research has revealed the considerations of soil moisture and compactive procedures which should be a guide to such a venture in order to minimize the variables.

Poisson's Ratio.--Values of Poisson's ratio were determined for all three soils. With Ottawa standard sand the range of values found was 0.31 to 0.35. For the fine, slightly micaceous sand it was 0.31



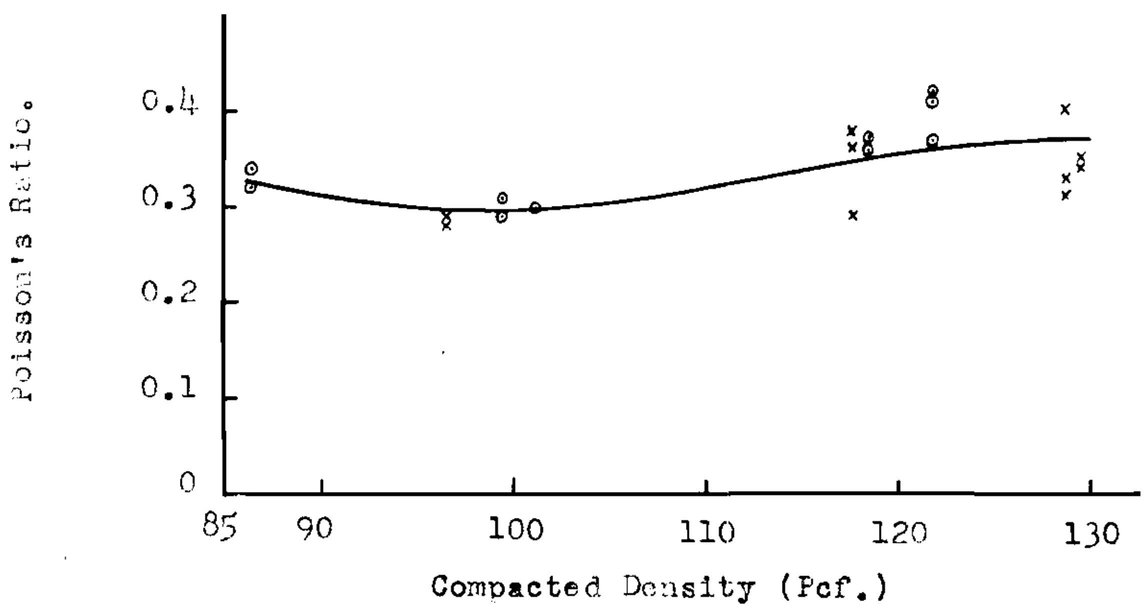


Fig. 13

Poisson's Ratio Relationships

to 0.36. As these variations were apparently completely random, not depending on moisture content or any other discernable factor, an average value of 0.34 is indicated as the value of Poisson's ratio for sands.

For Georgia clay, extreme values ranged from 0.28 to 0.42. The higher values, in general, corresponded to higher moisture contents and higher compacted density as shown in Fig. 13.

For the calculation of the ratio, the formula given with derivation by Krymine[8] was used:

$$= \frac{K}{1 + K}$$

in which K is the coefficient of earth pressure at rest. To obtain this coefficient, the ratio was taken of the maximum active lateral pressure and the active vertical pressure. The maximum value was usually that recorded on the gage immediately below the surface of a layer, but occasionally one below this was found to give higher results and was used to find the ratio. The discrepancy can be explained if the slot carrying the upper gage was not completely surrounded by soil. In such cases both values were worked out and plotted and it may be noted that this whole effect makes for errors all of which will cause results to be on the low side. Nevertheless this does not appear to have resulted in any large discrepancies in the values of Poisson's ratio obtained.

CHAPTER VI

CONCLUSIONS

The conclusions drawn from this work are the following:

1. When a soil is compacted under confined conditions, residual lateral pressures are induced.

2. The magnitude of these pressures depends on

   a. the soil itself

   b. its moisture content, and

   c. the method of compaction.

3. The value of Poisson's ratio for sands is about 0.34. For Georgia clay, it ranges from 0.28 to 0.42, increasing with increase in moisture content.

CHAPTER VII

RECOMMENDATIONS

This work has been carried out as the first part of a research program, the second part of which remains to be conducted. This will require the use of some sort of sensitive pressure cell to be placed in a fill which would be compacted by static or dynamic processes, the resulting residual pressures being measured by means of the cells.

Indications are that there might be some relationship between lateral residual pressures and the cohesion of a soil. A connection is shown here between residual pressures and compactive effort, which is related to cohesion for any particular soil. A relationship with cohesion may be found to be more fundamental and as such would be well worth investigating.

APPENDIX

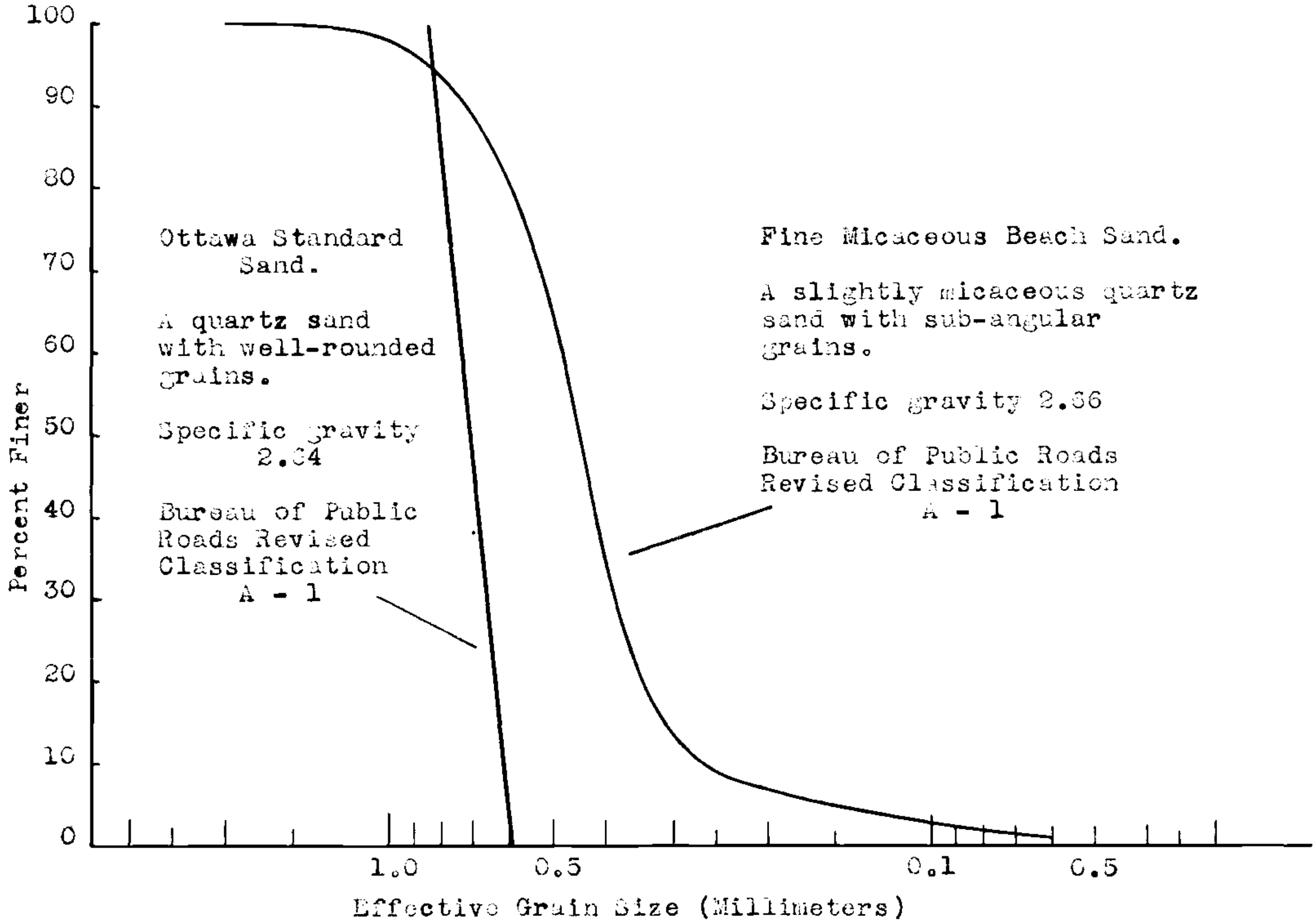


Fig. 14

Grain Size Distribution for Sands.

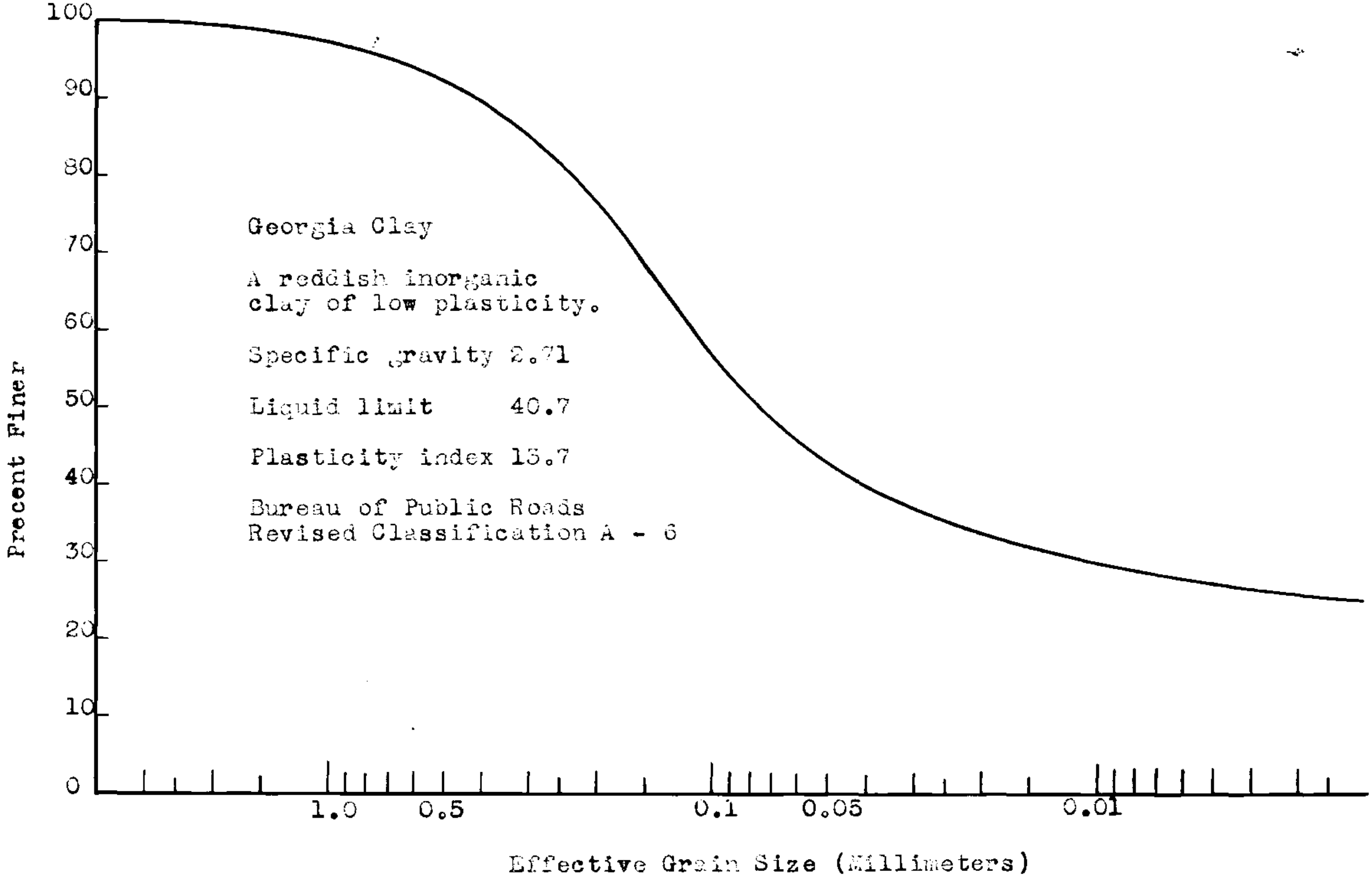
Table 2. Results of Static Tests on Standard

Ottawa Sand

Gage	Depth of gage below piston face (Inch)	Active horizontal pressure (Psi)	Residual horizontal pressure (Psi)	Poisson's ratio
(1)	Compacting pressure 425 Psi.; Moisture content 0% ; Compacted density 100.7 Pcf.			
T	0.6	197	0	0.32
T	2.8	134	0	
M	3.6	85	0	
B	4.3	64	0	
(2)	Compacting pressure 425 Psi.; Moisture content 3.8% ; Compacted density 101.9 Pcf.			
T	0.6	230	0	0.35
T	2.6	166	0	
M	3.3	109	0	
B	4.1	76	0	
(3)	Compacting pressure 850 Psi.; Moisture content 0% ; Compacted density 104.5 Pcf.			
T	1.0	430	0	0.34
T	2.7	298	0	
M	3.4	226	0	
B	4.2	168	0	
(4)	Compacting pressure 850 Psi.; Moisture content 5.5% ; Compacted density 104.7 Pcf.			
M	0.6	425	0	0.33
T	2.7	316	0	
M	3.4	227	0	
B	4.2	169	0	
B	0.6	382	0	0.31
T	2.6	327	0	
M	3.3	216	0	
B	4.1	173	0	

Table 3. Results of Static Tests on Fine Sand

Gage	Depth of gage below piston face (Inch)	Active horizontal pressure (Psi)	Residual horizontal pressure (Psi)	Poisson's ratio
(1)	Compacting pressure 425 Psi.; Moisture content 0% ; Compacted density 88.1 Pcf.			
B	0.7	190	0	0.31
T	1.1	237	0	0.36
T	2.6	142	0	
M	3.3	77	0	
B	4.1	60	0	
(2)	Compacting pressure 425 Psi.; Moisture content 7.7% ; Compacted density 94.9 Pcf.			
T	0.3	229	0	0.35
T	2.3	119	0	
M	3.1	96	0	
B	3.8	44	0	
(3)	Compacting pressure 850 Psi.; Moisture content 0% ; Compacted density 93.6 Pcf.			
M	0.4	410	0	0.33
T	0.8	411	0	0.33
T	2.6	253	0	
M	3.3	202	0	
B	4.1	138	0	
(4)	Compacting pressure 850 Psi.; Moisture content 0% ; Compacted density 102.8 Pcf.			
M	0.4	436	12	0.34
T	2.1	260	14	
M	2.8	222	22	
B	3.6	148	14	



Grain Size Distribution for Georgia Clay.

Fig. 15

Table 4. Results of Static Tests on Georgia Clay

Gage	Depth of gage below piston face (Inch)	Active horizontal pressure (Psi)	Residual horizontal pressure (Psi)	Residual pressure ratio	Poisson's ratio
	A. Compacting pressure 425 Psi.;				
	(1) Moisture content 2.5% ; Compacted density 86.5 Pcf.				
T	0.5	223	59	0.26	0.34
T	1.8	188	70	0.31	
M	2.6	138	59	0.35	
B	3.3	71	20	0.25	
T	0.6	203	40	0.20	0.32
T	2.1	174	58	0.29	
M	2.8	138	61	0.36	
B	3.6	88	39	0.42	
	(2) Moisture content 11.9% ; Compacted density 99.6 Pcf.				
T	0.3	176	20	0.12	0.29
T	2.1	135	26	0.15	
M	2.8	133	52	0.31	
B	3.6	74	25	0.25	
T	0.6	189	27	0.14	0.31
T	2.0	172	50	0.26	
M	2.7	163	71	0.39	
B	3.5	97	45	0.45	
	(3) Moisture content 13.4% ; Compacted density 101.3 Pcf.				
M	0.8	184	54	0.29	0.30
T	1.8	143	41	0.29	
M	2.6	147	65	0.35	
B	3.3	86	38	0.33	
	(4) Moisture content 18.3% ; Compacted density 118.6 Pcf.				
M	0.8	238	25	0.10	0.36
T	1.5	156	20	0.13	
M	2.2	147	39	0.16	
B	3.0	127	54	0.28	

Table 4. continued.

Gage	Depth of gage below piston face (Inch)	Active horizontal pressure (Psi)	Residual horizontal pressure (Psi)	Residual pressure ratio	Poisson's ratio
M	0.8	250	48	0.19	0.37
T	1.3	163	42	0.26	
M	2.1	189	65	0.26	
B	2.8	148	68	0.35	
(5) Moisture content 24.7% ; Compacted density 121.8 Pcf.					
M	0.6	247	29	0.12	0.37
B	0.9	297	19	0.06	0.41
T	1.1	362	29	0.08	
M	1.8	268	45	0.18	
B	2.6	214	31	0.10	
M	0.3	292	20	0.07	0.41
B	1.1	304	15	0.05	0.42
T	1.5	341	17	0.05	
M	2.2	254	24	0.08	
B	3.0	211	25	0.08	

B. Compacting pressure 850 Psi.;

(1) Moisture content 2.1% ; Compacted density 96.5 Pcf.

M	0.7	348	78	0.22	0.29
T	2.1	315	93	0.28	
M	2.8	269	93	0.27	
B	3.6	206	72	0.30	
B	0.3	244	67	0.27	0.22
M	0.8	330	65	0.20	0.28
T	2.2	284	90	0.29	
M	2.9	251	76	0.20	
B	3.7	214	81	0.32	

Table 4. continued.

Gage	Depth of gage below piston face (Inch)	Active horizontal pressure (Psi)	Residual horizontal pressure (Psi)	Residual pressure ratio	Poisson's ratio
	(2) Moisture content 12.6% ; Compacted density 117.8 Pcf.				
M	0.3	352	87	0.25	0.29
T	0.6	470	85	0.18	0.36
T	1.7	403	96	0.20	
M	2.5	265	68	0.22	
B	3.2	211	51	0.17	
M	0.3	344	92	0.27	0.29
T	0.6	511	102	0.20	0.38
T	1.6	428	111	0.22	
M	2.3	294	77	0.24	
B	3.1	232	58	0.21	
	(3) Moisture content 16.0% ; Compacted density 128.8 Pcf.				
M	0.7	419	76	0.14	0.33
T	1.8	375	60	0.15	
M	2.6	323	102	0.24	
B	3.3	227	69	0.24	
M	0.3	375	78	0.20	0.31
T	0.6	561	82	0.15	0.40
T	1.7	450	111	0.20	
M	2.5	300	97	0.26	
B	3.2	262	95	0.24	
	(4) Moisture content 18.2% ; Compacted density 129.5 Pcf.				
M	0.3	437	15	0.03	0.34
T	0.8	544	28	0.05	0.35
T	1.8	455	45	0.08	
M	2.6	322	32	0.07	
B	3.3	276	56	0.15	

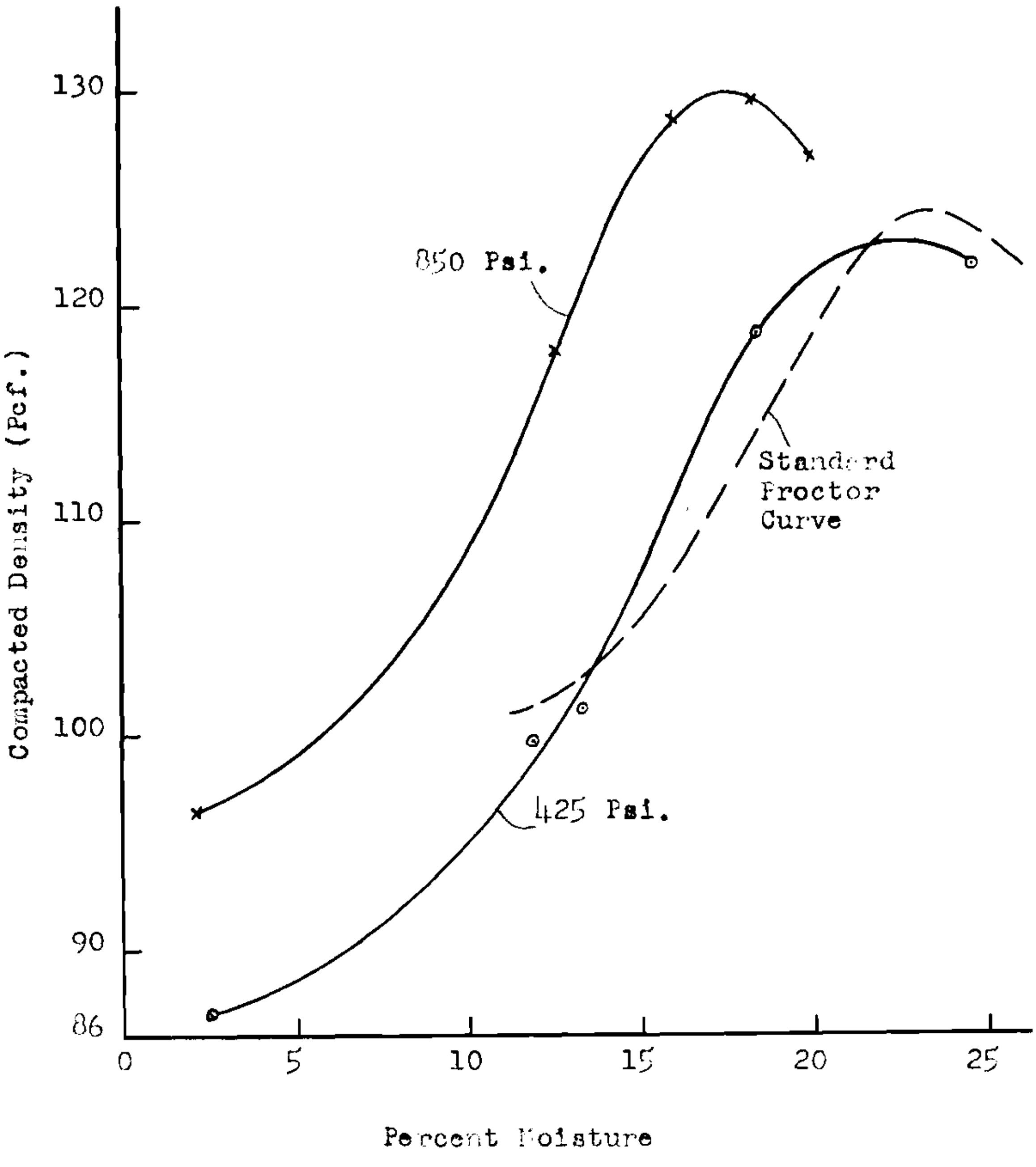


Fig. 16
Moisture - Density Curves for Static Compaction

of Georgia Clay.

Table 5. Results of Dynamic Tests on Georgia Clay

Moisture content %	Compacted density (Pcf)	Gage	Residual horizontal pressure (Psi)
A. Light hammer.;			
10.5	95.7	T	24
		M	29
		B	0
	98.2	T	22
		M	32
		B	30
	93.7	T	15
		M	31
		B	29
12.0	98.8	T	32
		M	21
		B	25
	99.1	T	18
		M	31
		B	27
13.7	100.6	T	20
		M	22
		B	22
	101.1	T	26
		M	21
		B	25
	-	T	20
		M	22
		B	31
15.7	105.5	T	16
		M	22
		B	10
	107.8	T	10
		M	25
		B	29

Table 5. continued.

Moisture content %	Compacted density (Pcf)	Gage	Residual horizontal pressure (Psi)
16.2	109.2	T	10
		M	25
		B	29
	110.7	T	26
		M	23
		B	29
17.8	115.3	T	26
		M	25
		B	15
	112.7	T	22
		M	18
		B	19
22.4	123.0	T	0
		M	13
		B	13
	121.5	T	4
		M	14
		B	13
	117.5	T	14
		M	14
		B	12
B. Heavy hammer.;			
12.0	114.5	T	93
		M	78
		B	109
	114.8	T	44
		M	71
		B	73
	114.7	T	44
		M	60
		B	30

Table 5. continued.

Moisture content %	Compacted density (Pcf)	Gage	Residual horizontal pressure (Psi)
12.0	113.2	T	27
		M	69
		B	37
19.3	127.9	T	20
		M	38
		B	51
	127.2	T	17
		M	31
		B	34
20.2	126.8	T	8
		M	15
		B	26

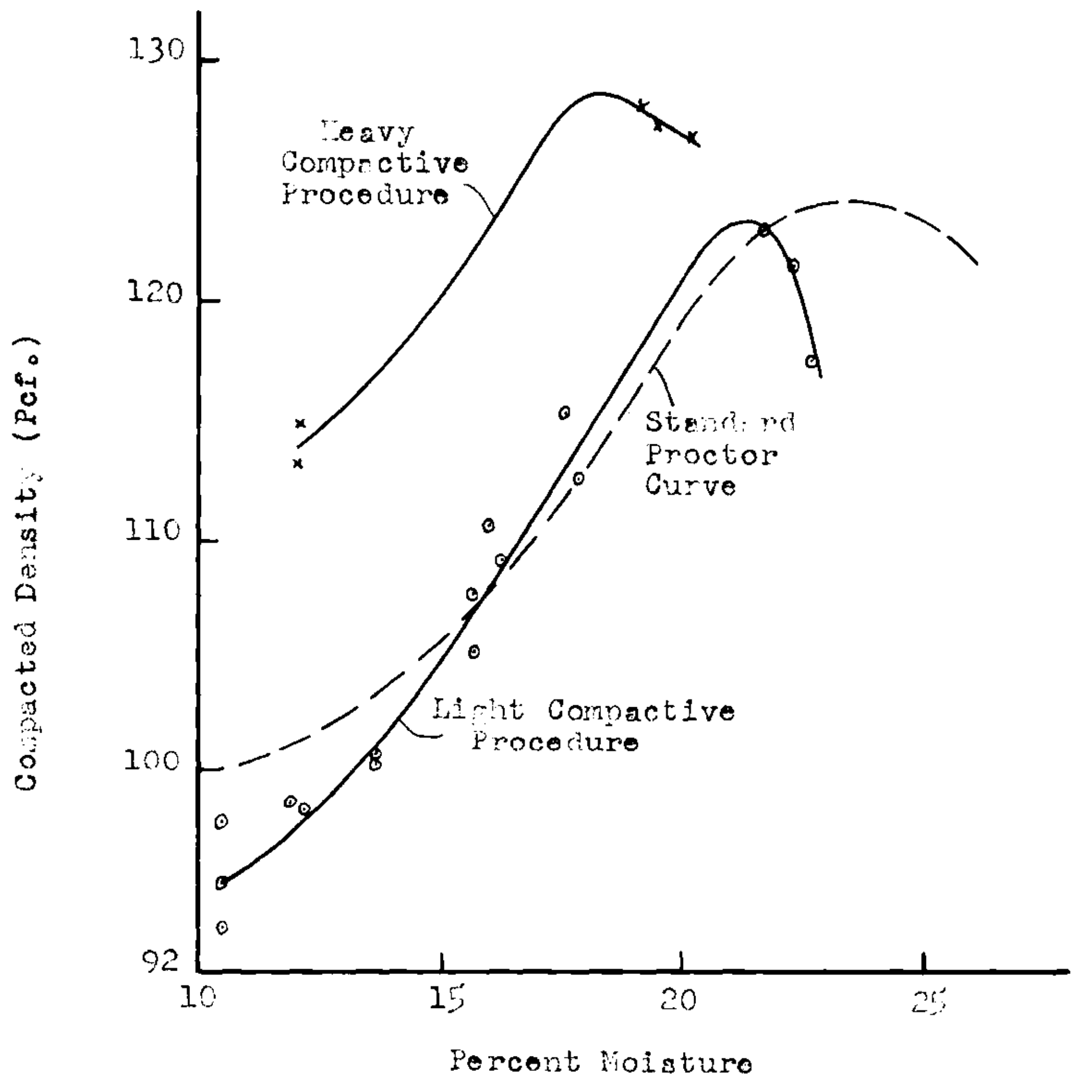


Fig. 17

Moisture - Density Curves for Dynamic Compaction

of Georgia Clay.

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