EFFECT OF COMPACTION ON THE CONSOLIDATION PROPERTIES OF A SILTY - CLAY

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Christopher David Couzens

1957

This is to certify that the

thesis entitled

Effect of Compaction on the Consolidation
Properties of a Silty - Clay

presented by

Christopher David Couzens

has been accepted towards fulfillment
of the requirements for

Masters degree in Civil Engineering

Major professor

Date July 17, 1957

EFFECT OF COMPACTION ON THE CONSOLIDATION

PROPERTIES OF A SILTY-CLAY

By

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A THESIS

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

MASTER OF SCIENCE

Department of Civil Engineering

1957

9-2-57
G-2637

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The author would like to express his sincere thanks to Dr. T. H. Wu, of the Civil Engineering Department of Michigan State University, for his kind help and advice with both the experimental work and the preparation of the manuscript.

TABLE OF FIGURES

INTRODUCTION

Compaction means the artificial increase of the density of a natural soil by mechanical means, and should not be confused with consolidation which means an increase in density due to the gradual expulsion of water by some continuous load.

The fact that compaction is likely to improve the strength and stability of a soil must have been realised for many thousands of years, in fact, ever since primitive man used soil as a construction material. At the present time, whenever soil is used in a highway, airfield, embankment or dam it will always, wherever possible, be compacted. Nevertheless, all real attempts to put the process of compaction on a rational basis and to evaluate scientifically the exact effects of compaction on various soil properties (such as ultimate strength, deformation modulus, compressibility and permeability), have been confined to the last twenty years.

Laboratory tests can show the value of the dry density obtainable with a given soil, and at what optimum moisture content this density can be reached under specified methods of compaction. In order that embankments and subgrades of roads and runways may be in the most suitable state for carrying traffic, these laboratory conditions must be translated into practice as far as possible. The two necessary factors are:

(i) The adjustment of the natural moisture content in the soil to a suitable figure.

(ii) The provision of adequate compacting equipment suitable for use on the site.

In silty or gravelly soils, frequent use is made of disc harrows (with or without the addition of water) for adjustment of the moisture content. Heavier equipment and spring tooth harrows may, however, be required for heavy clays.

In the field, the method of applying the necessary energy to compact the soil will fall into one of the following three classifications.

(1) Pressure: Rolling by smooth wheel, pneumatic tyred or sheepsfoot rollers.

(2) Impact: Rammers such as pile driving equipment, or the internal combustion and pneumatic type.

(3) Vibration: Out of balance weight type and pulsating hydraulic type.

Whichever method is used, the process is continued until a previously specified dry density is attained.

The first attempt to put the process of compaction on a rational basis was that of R. R. Proctor*(1) and now,

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*Numbers in parentheses are references listed at the end of this paper.

twenty years later, the Procter soil-compaction test is a standard specification in many different parts of the world.

The apparatus consists of a cylindrical metal mould having a capacity of 1/30 cubic foot. The soil is compacted by a $5\frac{1}{2}$ lb. weight falling through a height of twelve inches, twenty-five times on each of three layers. The soil is then trimmed to the top of the mould and weighed. A sample is taken from the mould and its moisture content determined.

The test is repeated several times with the same soil at a different moisture content. Dry density is plotted against moisture content, giving a curve as shown in Figure 1.

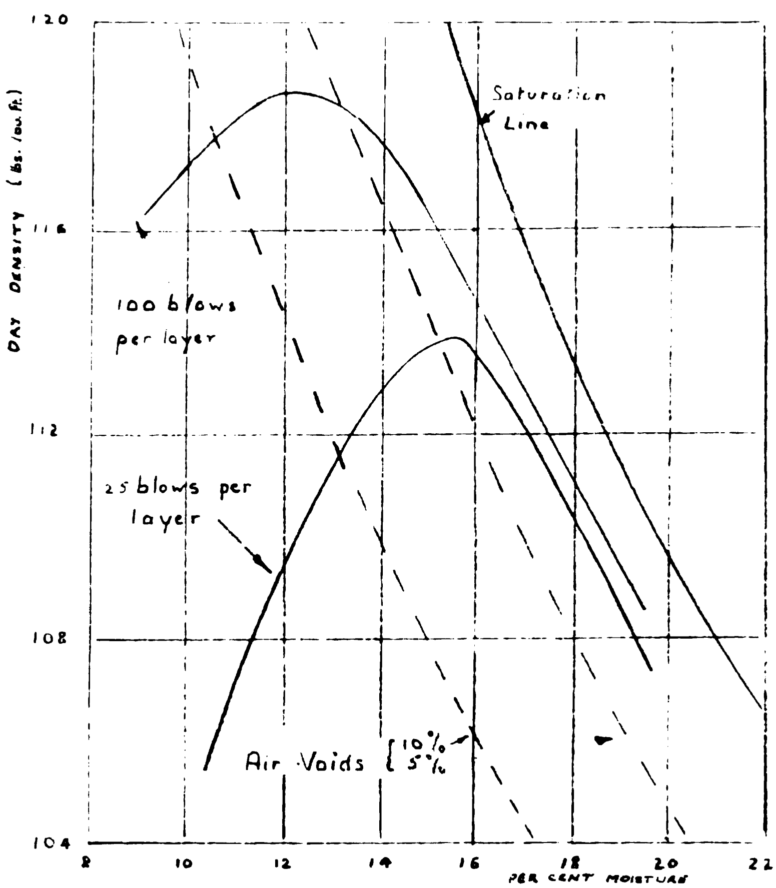


FIGURE 1 : MOISTURE CONTENT /DRY DENSITY CURVES FOR TWO COMPACTIVE EFFORTS

It is seen that there exists a certain optimum moisture content at which a maximum dry density may be achieved for a given amount of compaction.

It was thought at that time that compaction to the maximum density automatically gave a soil the best properties it could have for use as an engineering material.

Since then, a great deal of work has been done to determine what the exact effects of compaction are on the various relevant soil properties such as ultimate strength, deformation modulus, compressibility and permeability, and it is no longer widely held that compaction at optimum moisture content to maximum dry density will in all cases, necessarily, give the most desirable soil properties. Various workers in this field have, from time to time, developed laboratory methods of compaction which, they feel, duplicate field conditions more closely than the standard Procter test.

The validity of their conclusions as related to field compaction remains uncertain as long as it is not known how closely their various compaction methods resemble field conditions or resemble each other, or in other words, to what extent the properties of a compacted soil are, in fact, properties of the compaction method used.

This paper reports the results of tests made to compare the moisture-density curves produced by three widely used methods of compaction and to investigate their different effects on the consolidation properties of a soil.

DEVELOPMENT OF CURRENT KNOWLEDGE

The relationship between moisture content and dry density for a particular compaction effect is shown in Figure 1, and the behaviour of the soil at different moisture contents can best be explained as follows. When the moisture content is low, the soil is stiff and difficult to compress: thus, low dry densities and high air contents are obtained. As the moisture content increases, the water acts as a lubricant, causing the soil to soften and become more workable. This results in higher dry densities and lower air contents. As the air content becomes less, the water and air combination tend to keep the particles apart and prevent any appreciable decrease in air content. The total voids, however, continue to increase with the moisture content, and thence the dry density of the soil falls.

To the right of the peak of the dry density/moisture content curve the saturation line (the theoretical curve relating dry density with moisture content for soil containing no air voids) is approached but never reached, since it is never possible to expel all the air from a soil by compaction.

The exact shape of the moisture content/dry density curve is regulated by the grading of the soil, a pronounced peak being given by a well-graded soil and a flat curve by a closely-graded soil. (See Figure 2).(2)

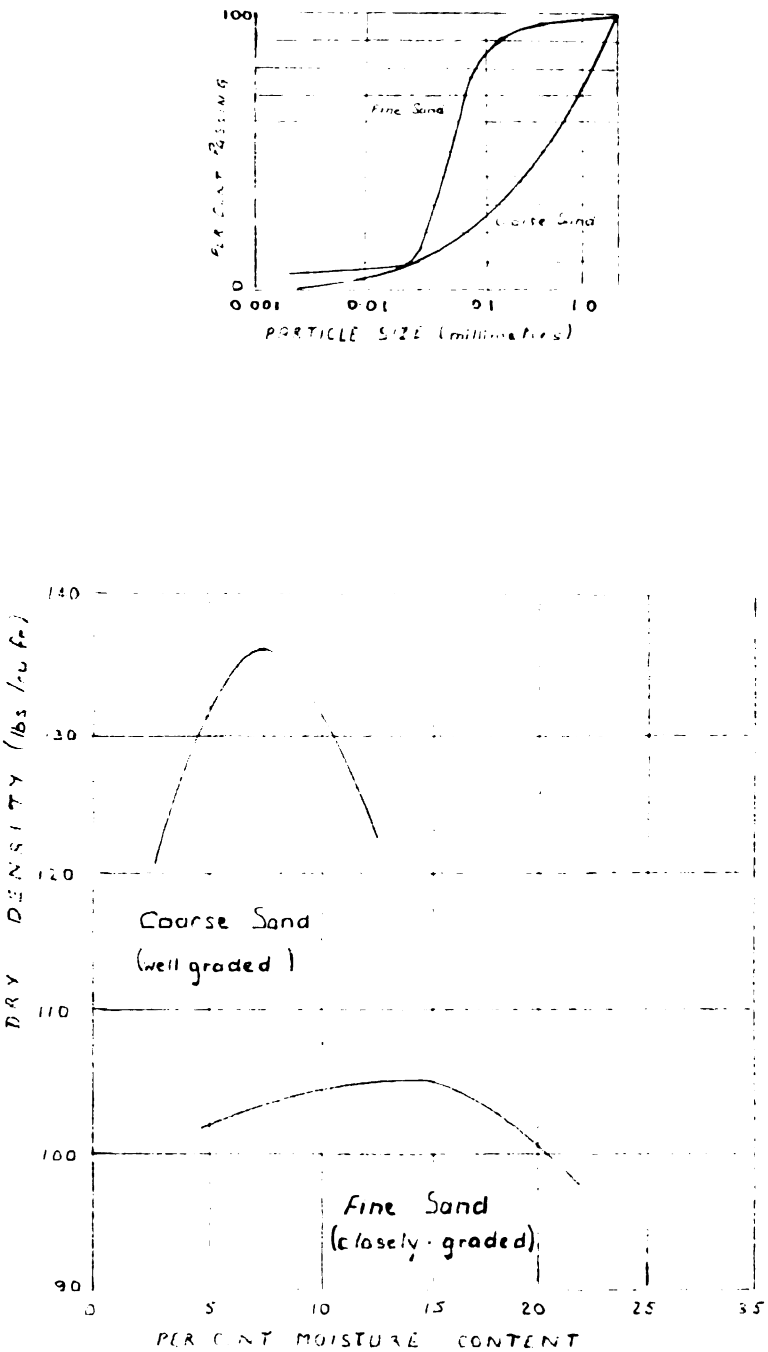


FIGURE 2 : EFFECT OF PARTICLE-SIZE DISTRIBUTION ON THE MOISTURE-DENSITY RELATIONSHIP

This means that the influence of moisture content on the dry density of a closely-graded soil is relatively much less than on the dry density of a well-graded soil. This is to be expected since the process of compaction, in attempting to reduce the volume of the soil must invariably tend to force the small particles into the voids which exist in the skeleton of larger particles. Thus, the difference in dry density produced by the changing from random orientation of the varying-sized particles in a well-graded soil, to the selected orientation brought about by compaction, is much greater than the difference caused by the same change in particle orientation in a closely-graded soil.

Figure 1 also shows the effect of different compactive efforts (i.e. different amounts of energy expended per unit weight of soil) and it is seen here that an increased compactive effort produces a greater dry density at all moisture contents but a lower optimum moisture content. As far as is known this is true for all soils and for all methods of compaction. However, comparing these curves it is seen that increased compaction has little effect on the dry density above the optimum moisture-content but below this the effect is considerable.

The object of compaction (3) in the field is to improve the desirable properties of the soil. These are:

(i) high shear strength;

(ii) high deformation modulus;

(iii) low permeability and water absorption;

(iv) low volume compressibility

<u>Effects of laboratory compaction on soil properties</u>

S. D. Wilson investigated the effect of water content (for a particular compactive effort) on the various significant properties of a clayey sand.

The effect of water content on compressive strength is shown in Figure 3. He found that compaction at the optimum moisture content did give maximum strength as given by consolidated quick triaxial tests, but that there was no relationship between optimum water content and strength in the "as-moulded" condition.

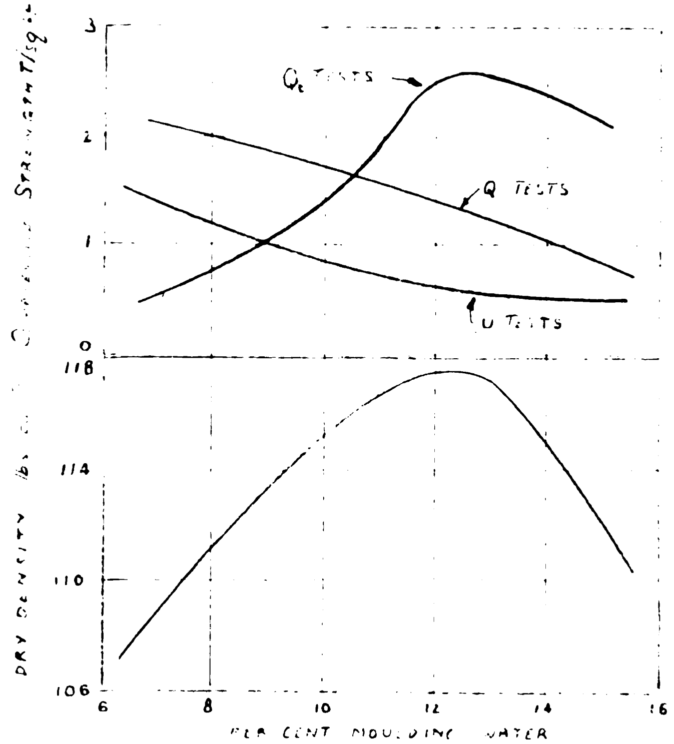


FIGURE 3 : EFFECT OF COMPACTION ON STRENGTH

In the same series of tests he found that the maximum resistance to deformation (stress at 0.5% strain) occurred on the dry side of the optimum moisture content when measured by the consolidated quick triaxial test as shown in Figure 4.

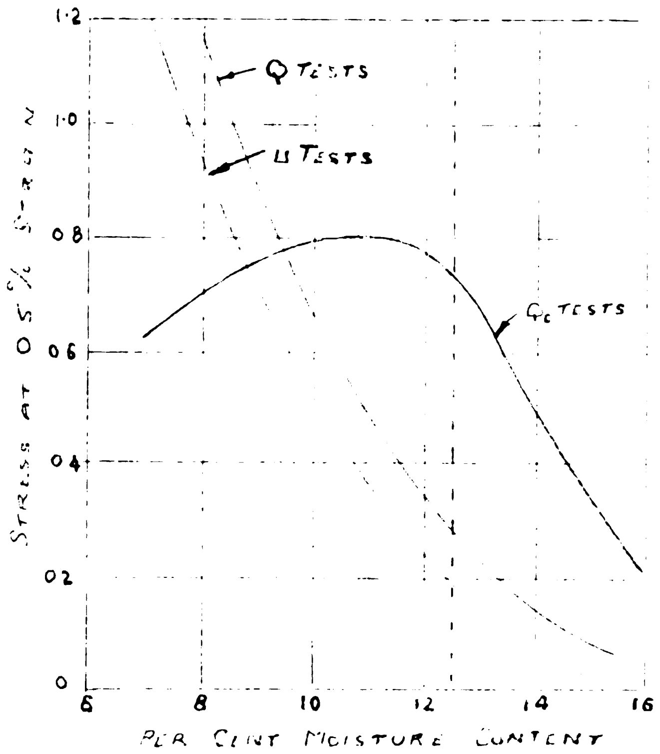


FIGURE 4 EFFECT OF COMPACTION ON RESISTANCE TO DEFORMATION

It was also found that compaction reduced the permeability of the soil, particularly when compacted on the wet side of the optimum, and that soils compacted on the wet side of the optimum were more compressible.

Wilson in these tests used the Harvard miniature compaction device described in Ref. 7.

From the results of these tests it is seen that compaction, at or below the optimum moisture content, will in general, tend to give the desired soil properties listed earlier. However, in the field, compactive effort as well as moisture content may be varied and the determination of an economic amount of compaction, and the most desirable moisture content to give the best combination of the various soil properties is a much more complex problem.

H. B. Seed and Carl L. Monismith (10) investigated the relationship between density, stability and moisture content for soils compacted by the Triaxial Institute kneading compactor described on page 13. and by static load compaction. Stability was measured both by the Hveem Stabilometer and by triaxial compression tests, where the index of stability was the stress at a certain strain. Their conclusions are as follows:

(i) For a particular dry density, a reduction in moisture content always results in an increase in stability. It must be remembered, however, that a greater compactive effort would be required by a drier soil to obtain the same dry density.

(ii) For samples compacted by kneading compaction at a particular moisture content, an increase in density may cause either an increase or a decrease in stability, depending on the range of density considered, the moisture content and the strain above which a sample is considered unstable. In general, the lower the moisture content, the lower the range of density considered, and the greater the permissible strain, the greater will be the possibility that an increase in density will cause an increase in stability.

(iii) Samples of a sandy clay compacted by static pressure always show an increase in stability, as measured by the Hveem Stabilometer, for an increase in density at constant moisture content, even though samples compacted by kneading action showed no consistent relationship.

From this it is seen that compactive effort, type of compaction, moisture content and the criterion used to define stability all independently affect the stability of a soil.

Leonards (11), however, from the results of many hundreds of triaxial tests carried out under widely varying conditions, deduced that for a given set of initial conditions, the compressive strength of a compacted clay depends only on the void ratio at failure. This relationship was found to be independent of the confining pressure, the amount of drainage permitted, the water content and the degree of saturation, even when the degree of saturation is increased by the addition of water from an external scource.

<u>Compaction Methods used in the Laboratory</u>

1) <u>The Proctor Method</u> - The standard Proctor test is the oldest and probably still the most widely used compaction test. The apparatus and method were described on page 3 and in Ref. 1. The modified American Association of State Highway Officials Compaction Test was developed to give a heavier standard of compaction for airfield construction. The apparatus used is fundamentally the same as that used for the standard Proctor test except that the rammer, weighing 10 lbs., falls through eighteen inches, twenty-five

times on each of five layers.

2) <u>The Dietert Test</u> (8) - This method, like the Proctor method, is one in which the compaction energy is supplied by impact. The soil is compacted into the two inches diameter mould by means of a piston, through which the compacting energy is indirectly applied by dropping, by means of a cam, a cylindrical weight of 18 lbs. through a height of two inches on to a steel plate rigidly attached to the piston through a reel. The soil is compacted by the application of ten blows of the weight, after which the mould is inverted and a further ten blows are applied.

3) <u>The California Static Load Compaction Test</u> (9) - This test was developed about 1935 by O. J. Porter of the California Division of Highways in connexion with the California bearing ratio test. Samples at different moisture contents are compacted in a mould 6 inches in diameter and 8 inches high through a piston 5 inches long. The compactive effort is supplied by a hydraulic press, the final load being 2,000 lbs./sq.in. and its rate of application from 1,000 lbs./sq.in. to 2,000 lbs./sq.in. being such that the rate of strain is .05 ins./min. The pressure of 2,000 lbs./sq.in. is maintained for one minute and released over a period of 20 seconds.

4) <u>The Harvard Miniature Compaction Method</u> (7) - Stanley D. Wilson developed this compaction apparatus at Harvard University, and claims, among its virtues, that the time, effort and quantity of material required to produce

moisture-content dry density curves are substantially reduced, and in addition, that this type of compaction duplicates more closely the kneading action of sheepsfoot rollers than do dynamic (impact) methods.

The compaction mould is 1.313 inches in diameter and 2.816 inches in length. Its volume is 1/454th of a cubic foot with the result that the net weight of the compacted specimen in grams is numerically equal to its unit weight in lbs per cubic foot.

The tamper consists of a one half inch diameter brass rod, with a handle at one end containing a compressed spring. As the operator pushes down on the handle, the load is transferred through the spring to the tamper. As soon as the load equals the prestress, the spring starts to deform. The operator soon learns to recognize this condition by "feel", and can control the load accurately. The tamping force can be changed over wide limits using springs of different stiffnesses. A suitable range of compactive efforts may be obtained by varying the spring prestress between 20 lbs. and 40 lbs., the number of layers between three and ten and the number of blows per layer between ten and fifty.

5) The Triaxial Institute Kneading Compactor (10) - This is a larger refinement of the Harvard compaction apparatus in which the tamping is done mechanically through a toggle press mechanism and in which samples up to 6 inches in diameter and 12 inches in height may be prepared. The shape of the tamper is that of a segment of a circle having the

same diameter as the forming mould; its area is approximately one fourth that of the cross-sectional area of the mould. The rate of application, duration of application, and rate of release of the load are regulated by a hydropneumatic control system, the action of which is such that in any one tamp, the pressure is gradually built up and then allowed to dwell on the sample for a fraction of a second, before being released. For calibration purposes a dynamometer is inserted above the tamping foot and oscillograms are obtained of load versus time. A typical oscillogram is shown in Figure 5, and the authors of Ref. 10 believe this to correspond closely to the load sequence given in the field by a pneumatic tyred roller.

The five laboratory methods of compaction described are those which have most frequently been used in compaction research in the last ten years.

In each, the compactive energy is supplied either by impact (falling weight), static load (in which a chosen pressure is applied uniformly across the area of the top of the sample), or kneading (in which the pressure is applied repeatedly to different small parts of the area of the sample).

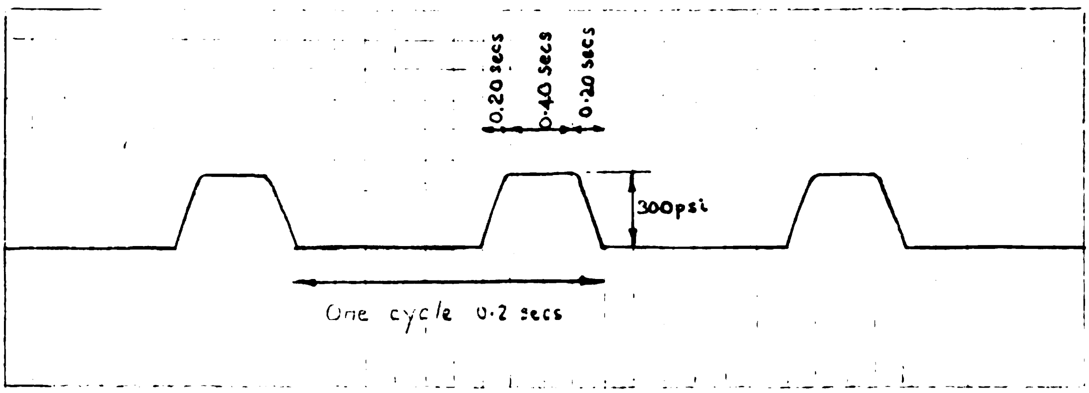


FIGURE 5 LOAD VS TIME RELATIONSHIP FOR TRIAXIAL INSTITUTE KNEADING COMPACTOR

Scope of Present Investigation

The study by Seed and Monismith indicates that stability may either increase or decrease with increasing density, depending on the method of compaction. This is in general agreement with Leonard's conclusion that the ultimate strength of a compacted soil depends only on the void ratio at failure. As changes in void ratio occur during shear a low initial void ratio does not necessarily result in a high ultimate strength. The void ratio can either increase or decrease during the application of a shear stress.

Because of the importance of the void ratio in interpreting the strength of compacted clays, it is considered desirable to investigate the void ratio/pressure relationship. In the present investigation, this relationship was studied by means of consolidation tests.

METHOD OF INVESTIGATION

Soil Studied: The soil studied (11) was a Pleistocene Aeolian silty-clay from Vicksburg, Mississippi. The soil is light buff when dry but turns medium brown on the addition of water. It has a plastic limit of 23, a liquid limit of 37, and the mean specific gravity of the particles is 2.72. The grain-size distribution curve is shown in Figure 6.

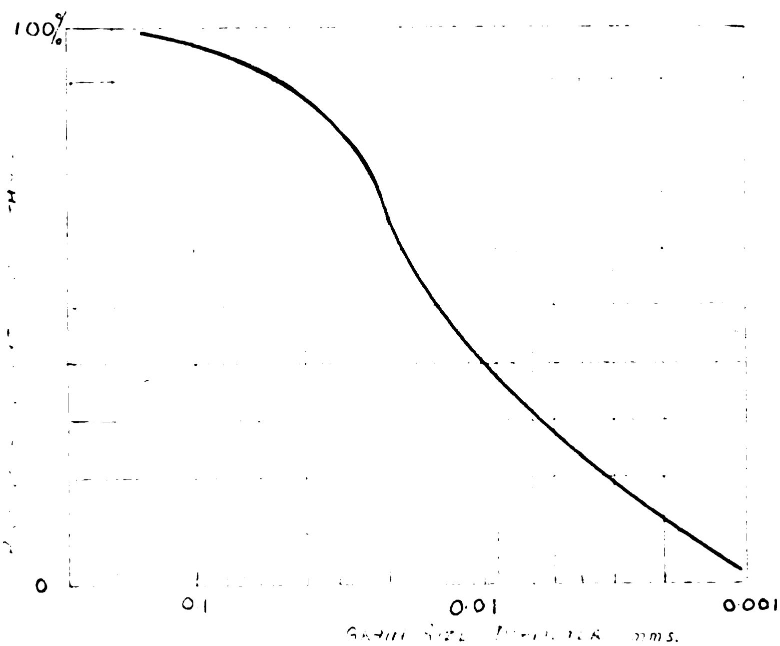


FIGURE 6

Preparation of Raw Soil: The soil was received at the laboratory in the dry state and after pulverizing by hand with a heavy weight the portion passing a No. 16 standard U.S. sieve was used. During the winter months the humidity of the laboratory was so low that it was found impossible to mix up large quantities of soil having a reasonably uniform moisture content. For this reason, mixing was carried out in a moist room having a humidity close to 100%. Six four kilogram batches were mixed to have approximate moisture contents of 16, 18, 20, 22, 24 and 26 per cent. After the addition of the water the soil was first mixed by hand and then, to break up the larger lumps and to achieve a more uniform moisture content, the moist soil was forced through a No. 16 standard U.S. sieve with the back of a trowel, and then mixed again thoroughly by hand. The soil processed in this manner was placed in metal containers and stored in the moist room.

Although this method was tedious and time-consuming the resulting moisture content of each batch was found to be constant to within 0.3%.

Later, in the spring, the humidity of the laboratory was not so low, and when it was found necessary to mix up some smaller (200 gram) batches this was done by hand mixing in the laboratory and the results were entirely satisfactory.

Compaction:

(1) Proctor - The Proctor test was carried out according to standard procedure.

(2) Static Load Compaction - Soil, in these tests, was compacted by a Tinius Olsen hydraulic testing machine fitted with a load pacer and an electronic load-holding device.

The rate of application of the load was 500 lbs per minute; the load was then held for one minute and released instantaneously. The soil was compacted directly into a standard consolidation test mould (of 1.875 inches inside diameter and 0.75 inches depth) which was fitted with a deep brass collar as shown in Figure 7 together with the piston. After

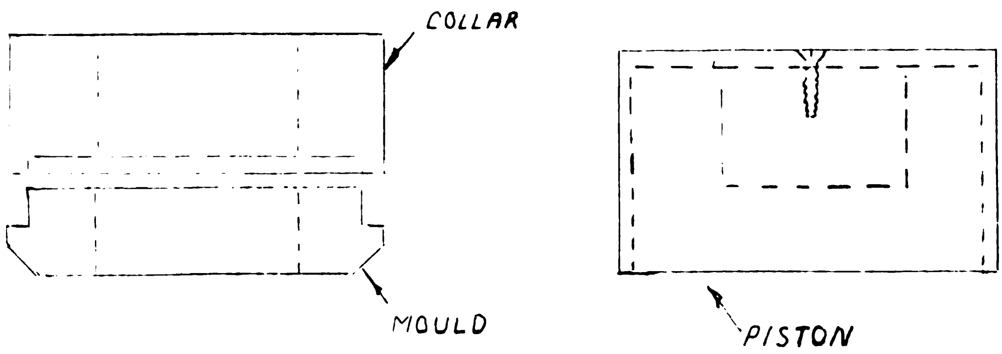


FIGURE 7: MOULD, COLLAR AND PISTON USED IN STATIC LOAD COMPACTION

compaction, the collar was removed and the soil was trimmed to the top of the mould. This known volume of compacted soil was then weighed, oven-dried at 100^{o}C for twenty-four hours and weighed again, thus enabling the dry density and final moisture content to be computed. Separate samples were prepared for consolidation tests and tests showed that for samples prepared under the same conditions, the maximum variation in dry density was 0.5 lbs./cu.ft.

(3) Kneading Compaction - Moisture content-dry density curves were prepared according to the standard procedure,

using the Harvard miniature compaction device mould and tamper, as described on page 12. This tamper was also used on soil contained in the consolidation mould and collar device described above in the static load compaction procedure. The compaction energy per unit volume was kept approximately the same for each mould by reducing the number of layers in the ratio of the lengths of the moulds and increasing the number of blows in the ratio of the cross-sectional areas of the moulds. As before, separate samples had to be prepared for consolidation testing, and although only three such samples were prepared, it is noticeable that their dry densities coincided exactly with those on the previously prepared moisture content-dry density curves.

Consolidation Tests:- The consolidation tests were carried out on three machines of the conventional type, two having a load multiplying factor of 8, giving a maximum permissible load of 28.48 kg/sq.cm., and one having a load multiplying factor of 40 giving a maximum permissible load of 72.0 kg/sq.cm. The time given for total consolidation varied from fifteen minutes for the smaller loads up to twenty-four hours at the end of the test. The initial load was 125 g. (giving a consolidating pressure of .056 kg/sq.cm.) and the subsequent increments were such that they doubled the existing load each time. There was no evidence of swelling in any of these tests.

RESULTS

(a) Compaction Tests

The moisture content-dry density curve obtained from the Procter test is shown in Figure 8. The maximum dry density is 100.75 lbs./cu.ft. occurring at an optimum moisture content of 18%.

Figures 9a and 9b show the results of kneading compaction in the Harvard miniature compaction device mould, and in the consolidation test mould.

Figure 10a is a plot of dry density against moulding water content for static load compaction, while Figure 10b shows the relation between dry density and final water content.

The lines of constant air voids are plotted from the following relationship:-

$$\frac{1 - V_a}{\gamma_d} = \frac{\quad}{\gamma_s} + \frac{m}{\gamma_\omega}$$

where γ_d = dry density, m = % moisture content, γ_s = density of the soil particles, γ_ω is the density of water and V_a is the percentage of air voids.

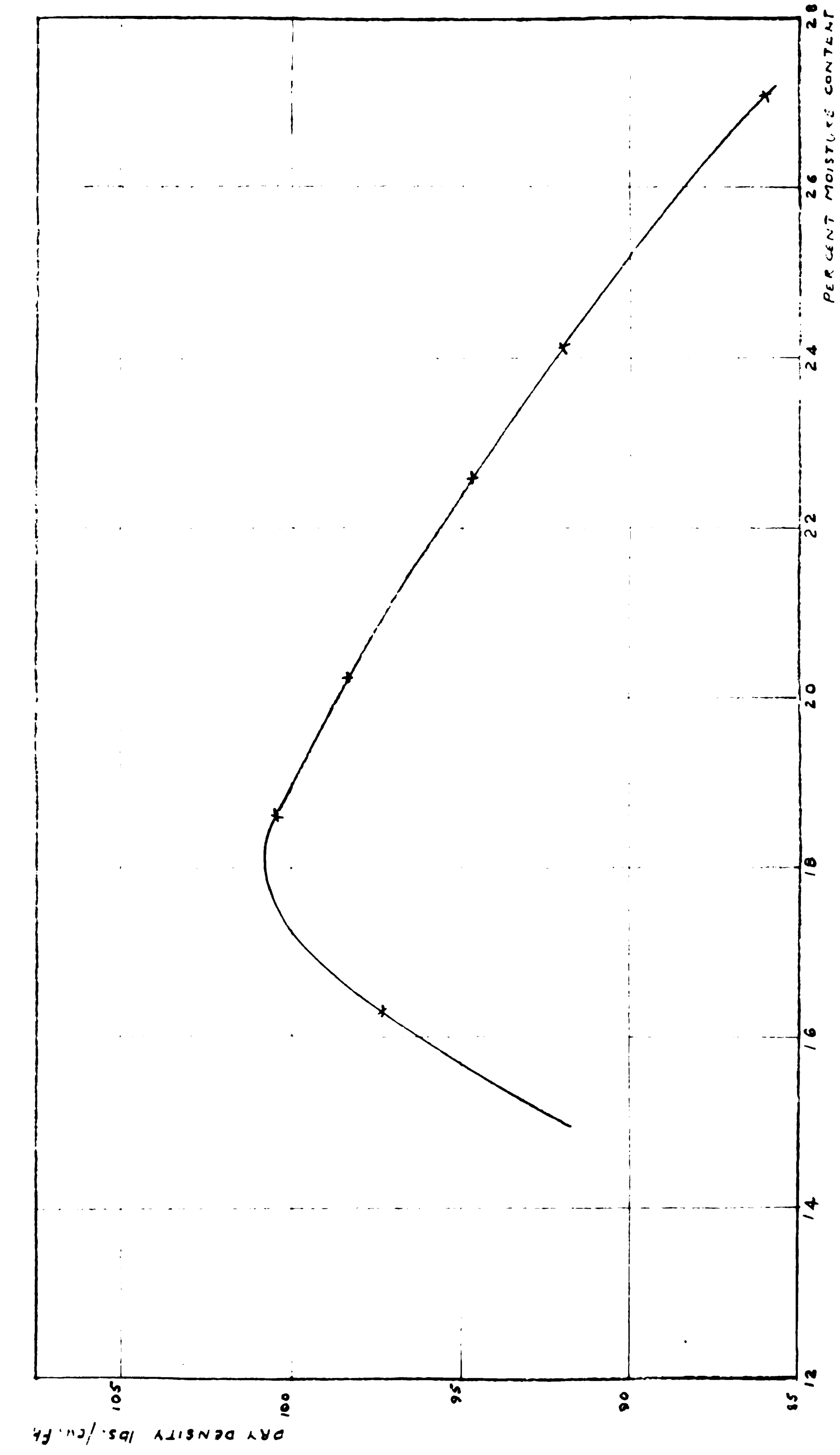


FIGURE 8 PROCTOR CURVE FOR MISSISSIPPI SILTY-CLAY

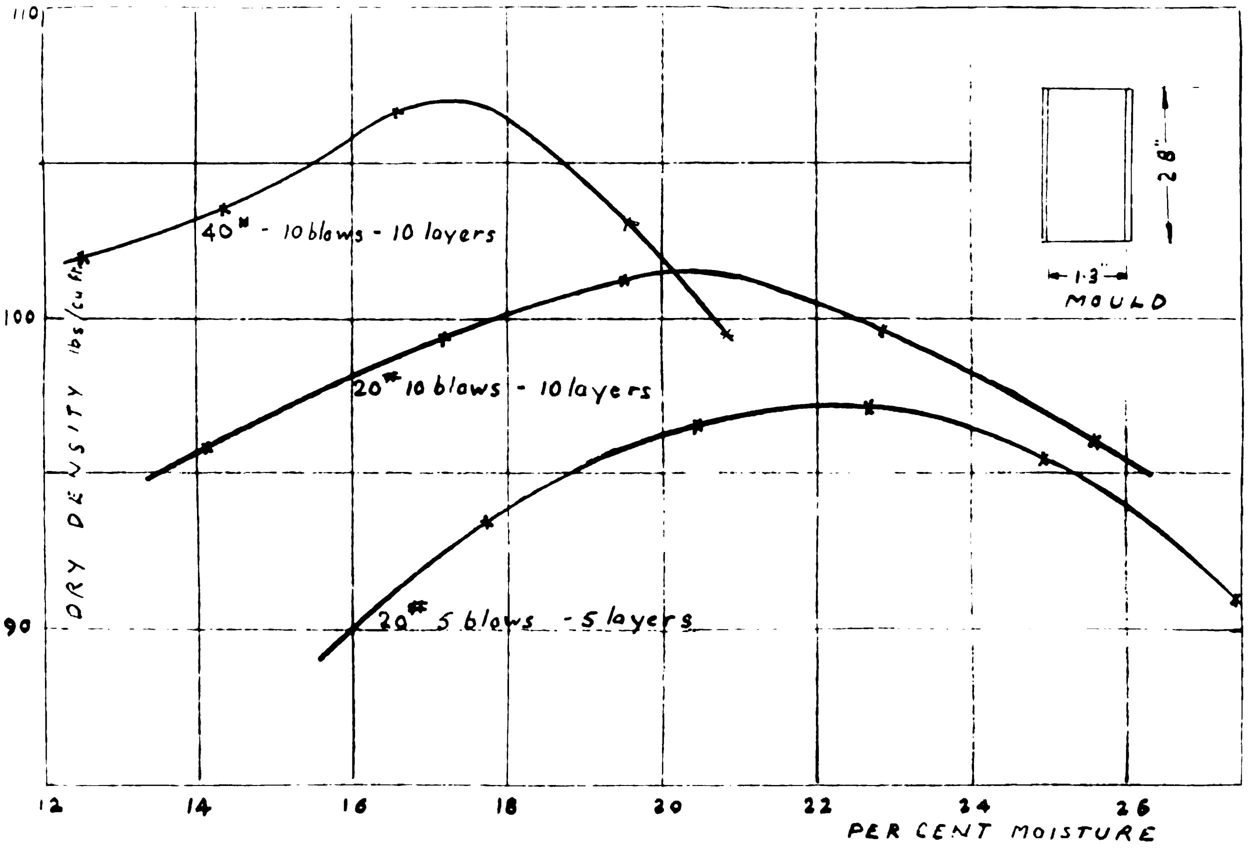


FIGURE 9a : MOISTURE CONTENT/DRY DENSITY CURVES FOR STANDARD HARVARD KNEADING COMPACTION

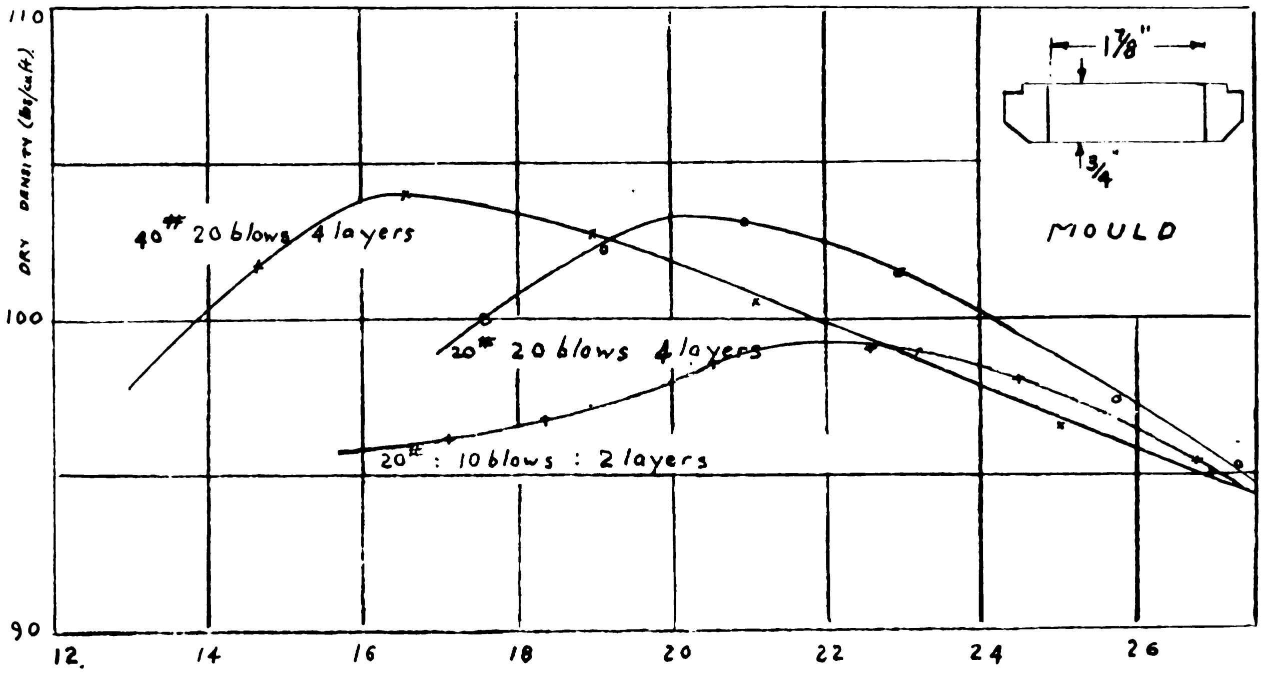


FIGURE 9b : MOISTURE CONTENT /DRY DENSITY CURVES FOR KNEADING COMPACTION IN A CONSOLIDATION RING

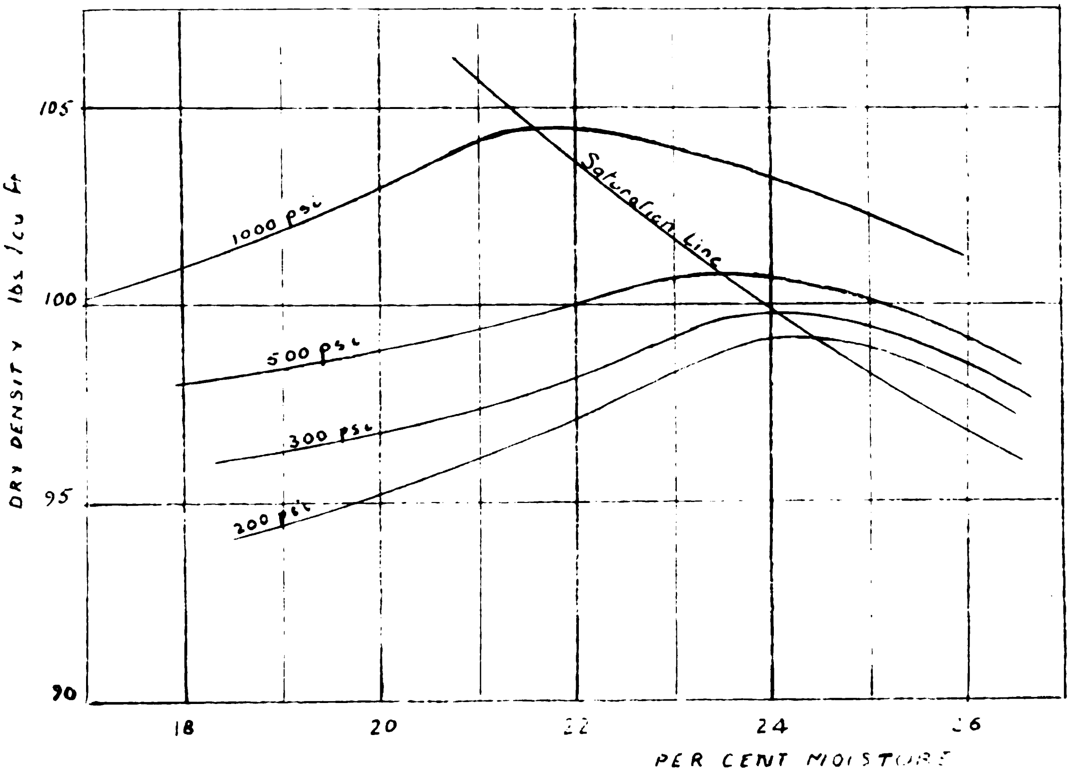


FIGURE 10a . DRY DENSITY / MOULDING WATER CONTENT FOR STATIC LOAD COMPACTION

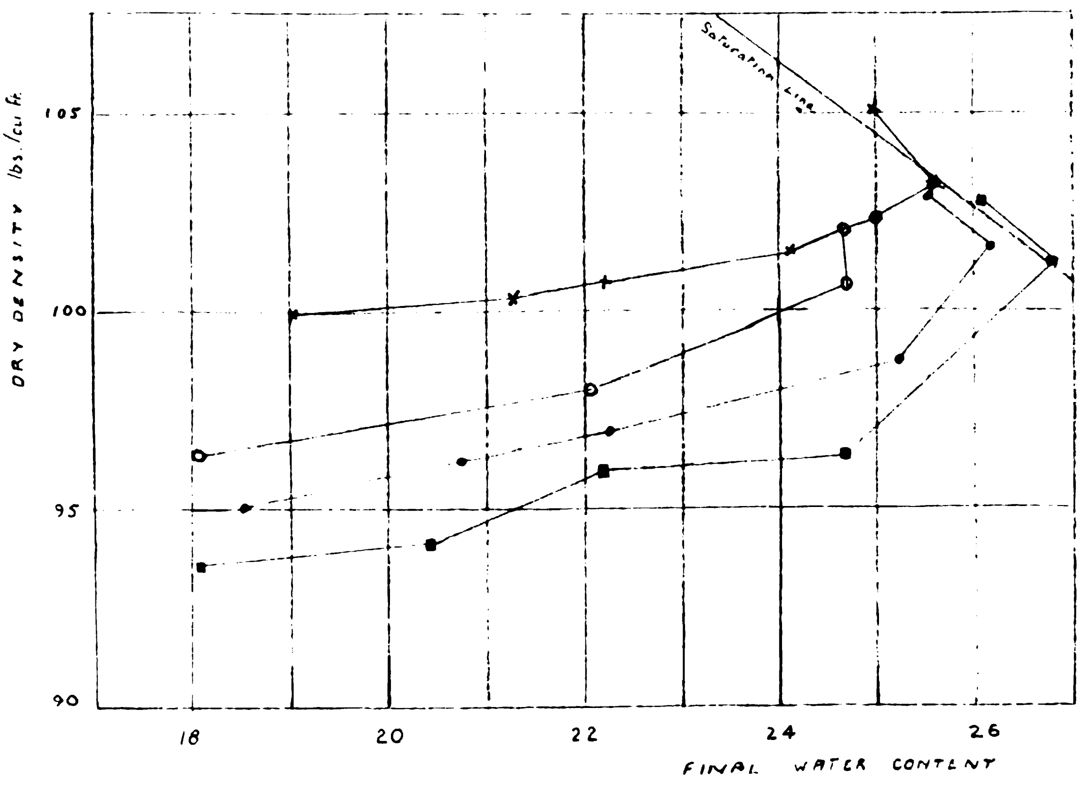


FIGURE 10b DRY DENSITY / FINAL WATER CONTENT FOR STATIC LOAD COMPACTION

<u>Effect of Mould Size</u>:- A comparison of Figures 9a and 9b shows that the optimum moisture content, for a particular compactive effort (of a specified type) is independent of mould size. This is supported by the knowledge that the optimum moisture content is that moisture content at which there is a maximum difference between the beneficial effects on compaction of the lubricating qualities of the water, and the detrimental effects of its tendency to reduce the ease with which air can be expelled. Thus the optimum moisture content represents that condition of the soil at which a particular compaction effort brings about the greatest reduction in volume, and is independent of the extent to which the magnitude of this volume reduction is controlled by external physical conditions.

In order to account for the difference in the dry densities obtained with the different moulds it is necessary to consider the effects of mould shape. The effect of friction between the mould and the soil is proportional to the ratio between the areas of the sides of the moulds and their volumes, i.e. 8.6 for the Harvard mould and .8 for the consolidation test mould. Thus the energy required to overcome side friction in order to bring about a particular percentage reduction in volume is much greater for the Harvard mould, and the effect of this is most evident for small amounts of compactive effort, where the work done against side friction is a larger fraction of the total compaction energy available.

For larger compactive efforts, however, a higher density was obtained with the Harvard mould and this is believed to be due to the different amounts of soil movement permitted by the two different moulds, as illustrated in Figure 11. If the tamper is considered as a circular footing at failure, sliding will take place along lines BC and B'C' as shown.

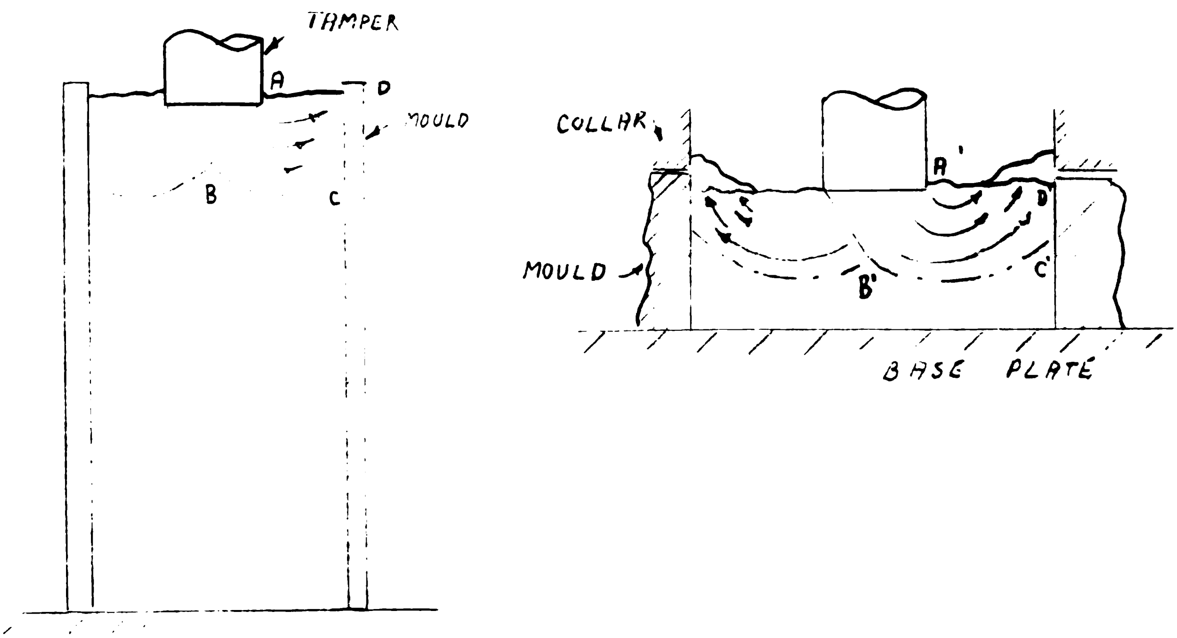


FIGURE 11 EFFECT OF MOULD SIZE ON PERMISSIBLE SOIL MOVEMENT DURING TAMPING

In the Harvard mould, the soil in the zone ABCD is restricted from lateral movement and is thus subjected to a compacting pressure. In the consolidation test mould, the soil in the zone A'B'C'D' is much more free to move, with the result that only the soil beneath the tamper is subjected to compacting pressure. Evidence of this was visible during compaction with a 40 lb. tamping force in the laboratory. When the soil in the consolidation mould was tamped in the centre, the upward movement of the soil around the edge of the mould was such that a considerable effort was required to keep the mould firmly held down on the base plate.

Effect of Compaction Type:- The moisture content dry density curve obtained by static compaction are interesting in view of the way in which the point of maximum dry density occurs on the saturation line for each compactive effort. This means that with this method of compaction, it is possible to exclude all the air voids from the samples, and obviously, the highest value the dry density can have for a particular moisture content is when the soil is completely saturated. After this, further compaction results in the condition of the soil being represented by a point moving along the saturation line in the direction of increasing density and reduced moisture content, as water is gradually expelled from the specimen. This last effect is really a consolidation rather than a compaction process.

From Figures 8, 9 and 10, it appears that the optimum moisture content for a particular dry density is a function of the time interval during which the individual units of compaction energy are applied. Under impact compaction (Figure 8), the compaction energy is applied almost instantaneously and the optimum moisture content is the lowest. With kneading compaction (Figures 9a and 9b), the interval of time over which load is applied and removed from the tamper is higher, and the optimum moisture content is seen to increase from 18 to 20 per cent for the same maximum density. With this type of static load compaction, where the energy is supplied continuously, the optimum moisture content increased as far as is possible, i.e. to the saturation point.

Thus, as the time interval, during which the units of compactive effort are applied increases, the detrimental effect of moisture on the ease with which air can flow from the soil becomes less important. With this soil and this mould, the time interval of one minute used in these static compaction tests was sufficient to permit all the air to flow from the sample. It is possible that with a less permeable soil, or with a mould having a greater depth, complete saturation might not have been attained. Nevertheless, it would seem, from these results, that the value of the optimum moisture content would be higher than that obtained by impact or kneading compaction.

TABLE 1

TEST NO	DRY DENSITY lbs /cu ft	MOULDING WATER CONTENT	FINAL WATER CONTENT
20 S 200	95 5	20·2	20 2
20 S 500	99 0	20·2	20·2
20 H	94·9	20 2	20·2
22 S 200	96 0	22·6	22·6
22 S 500	100·1	22·6	22·6
22 H	99·5	22 6	22·5
23 S 500	102 0	23	
24 S 200	99·3	24·7	24·5
26 S 200	100·5	26·1	24·1
26 H	96·5	26 1	26·1

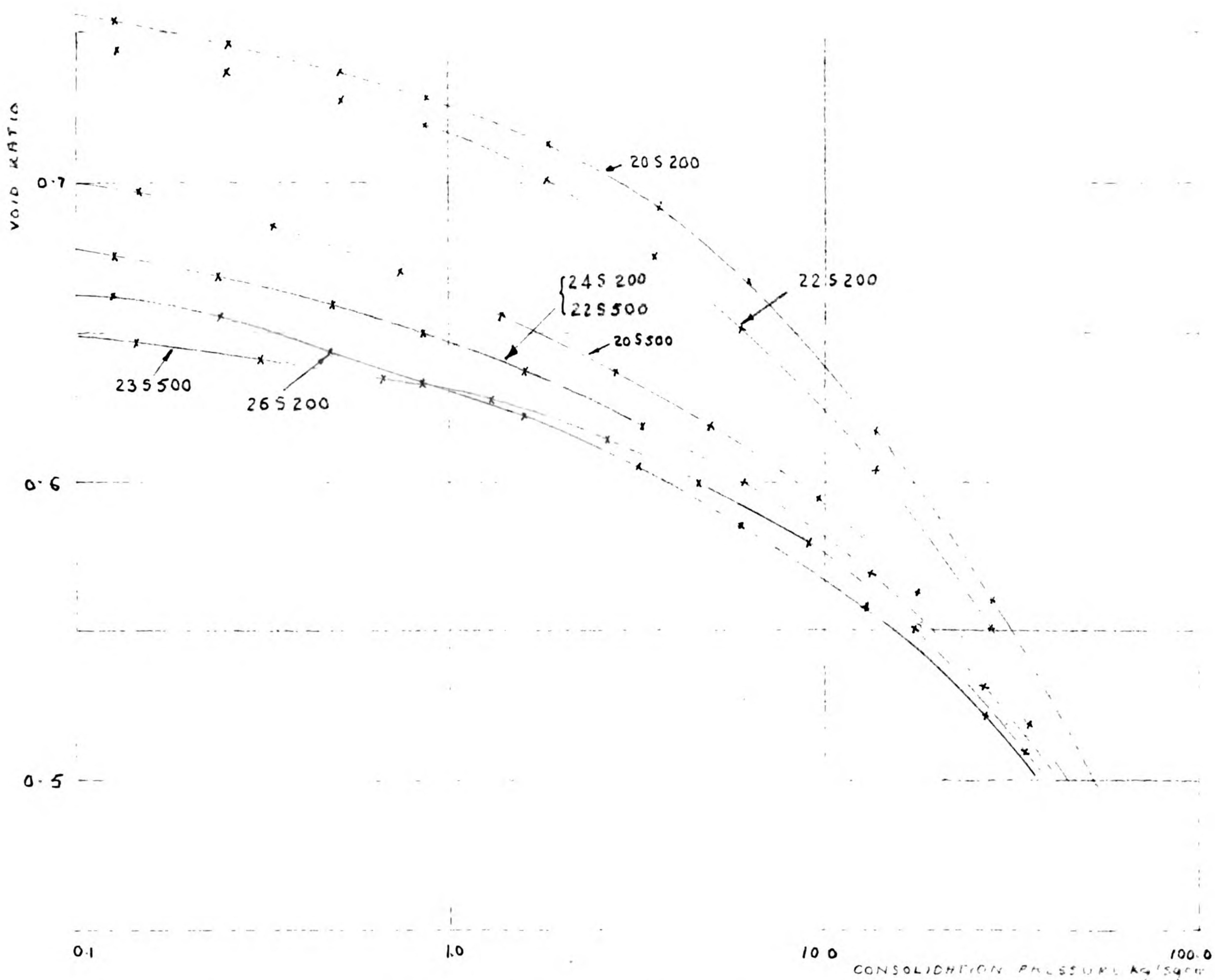


FIGURE 12 · VOID RATIO PRESSURE CURVES FOR ALL STATIC LOAD-COMPACTED SAMPLES

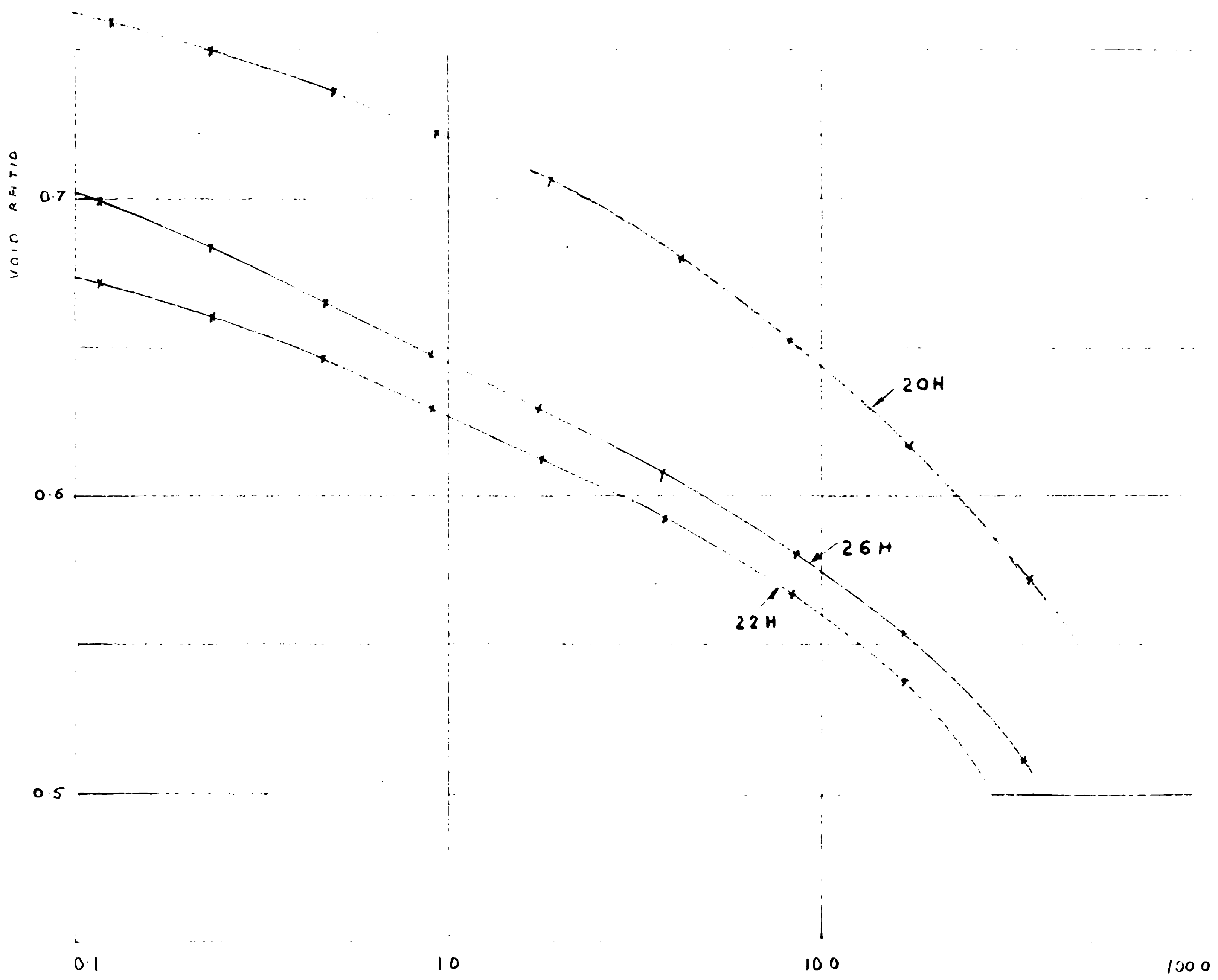


FIGURE 13 · VOID RATIO PRESSURE CURVES FOR ALL SAMPLES COMPACTED BY KNEADING

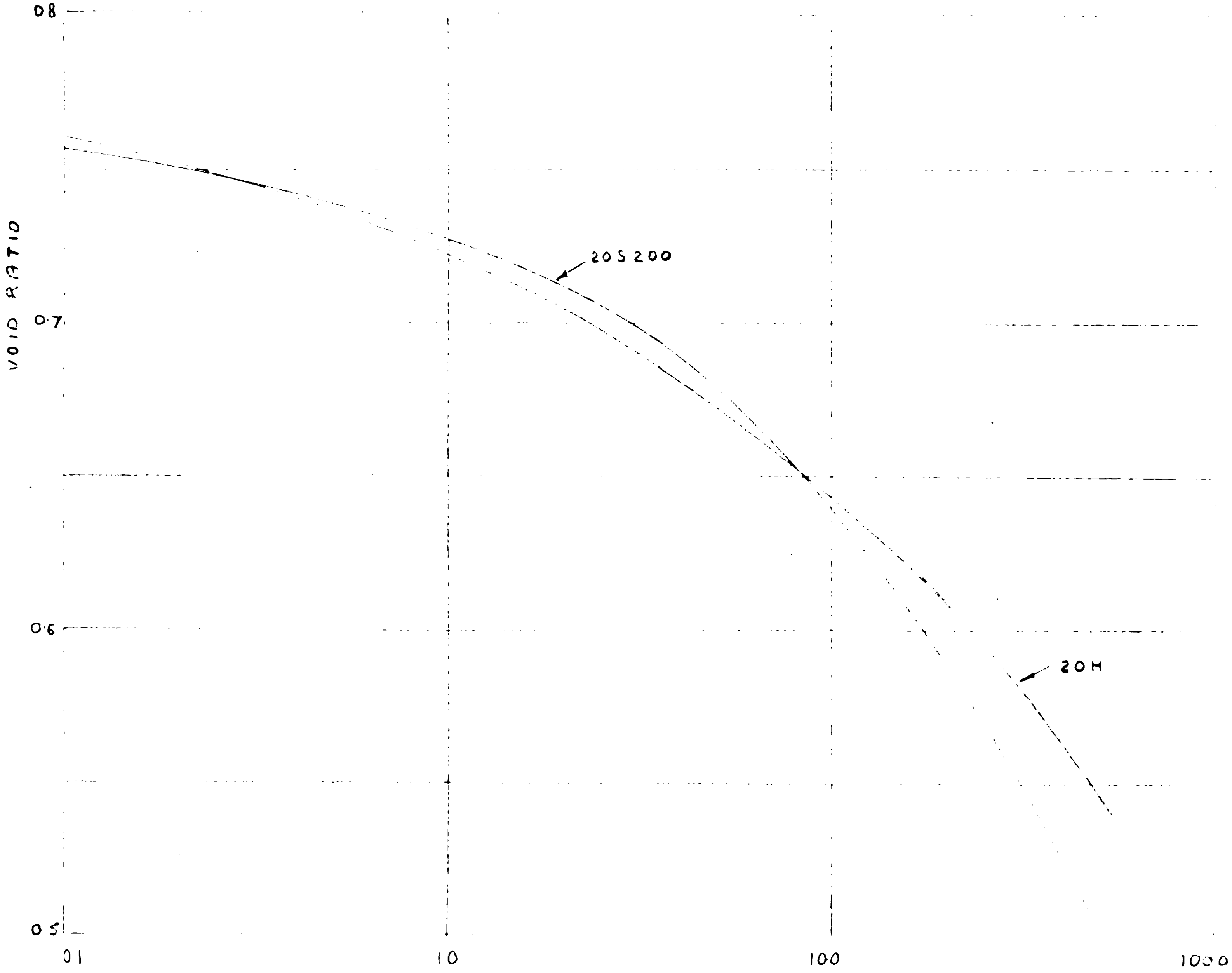


FIGURE 14a COMPARISON OF CONSOLIDATION CURVES FOR STATIC LOAD AND KNEADING COMPACTION

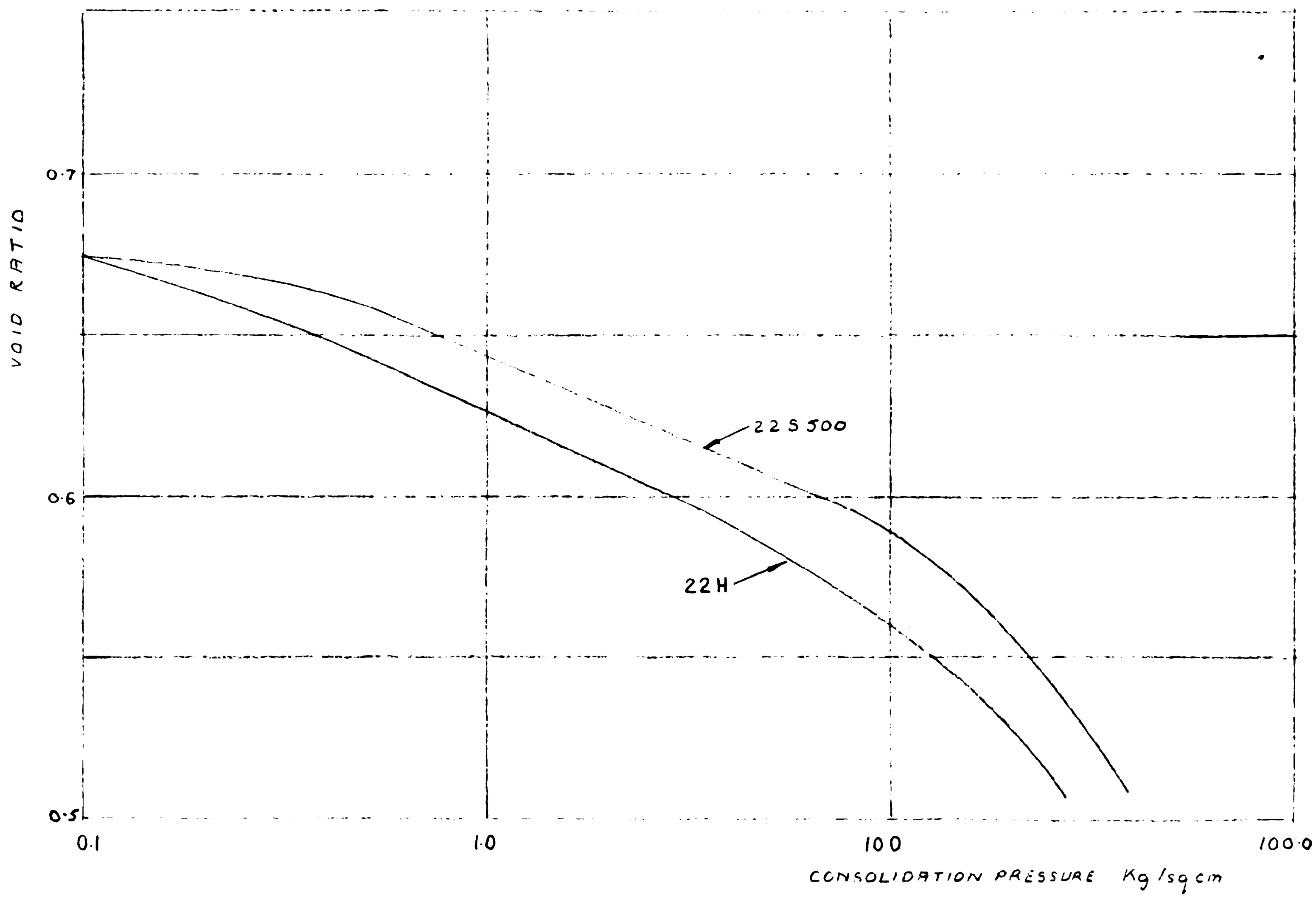


FIGURE 14b. COMPARISON OF CONSOLIDATION CURVES FOR STATIC LOAD AND KNEADING COMPACTION

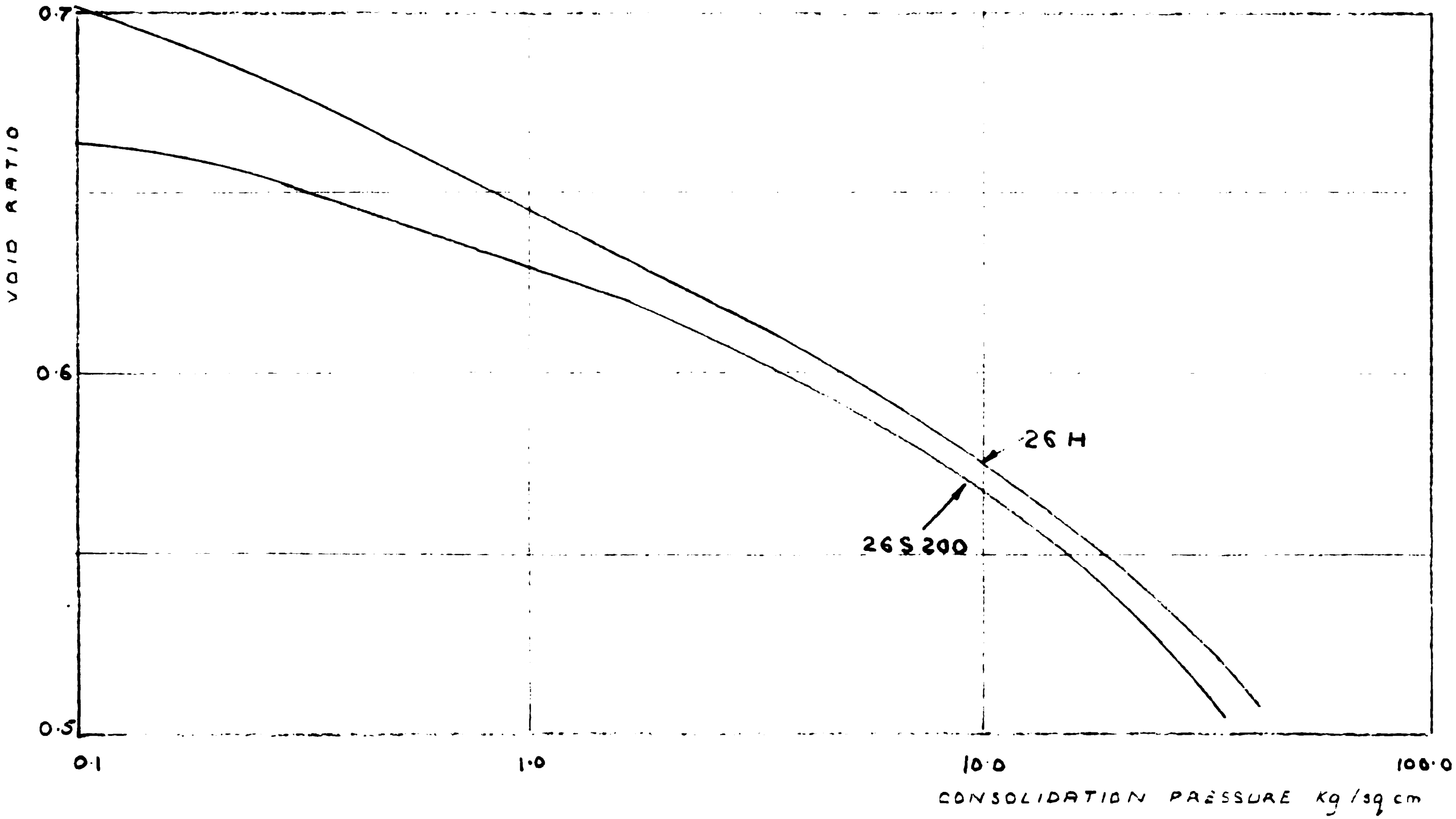
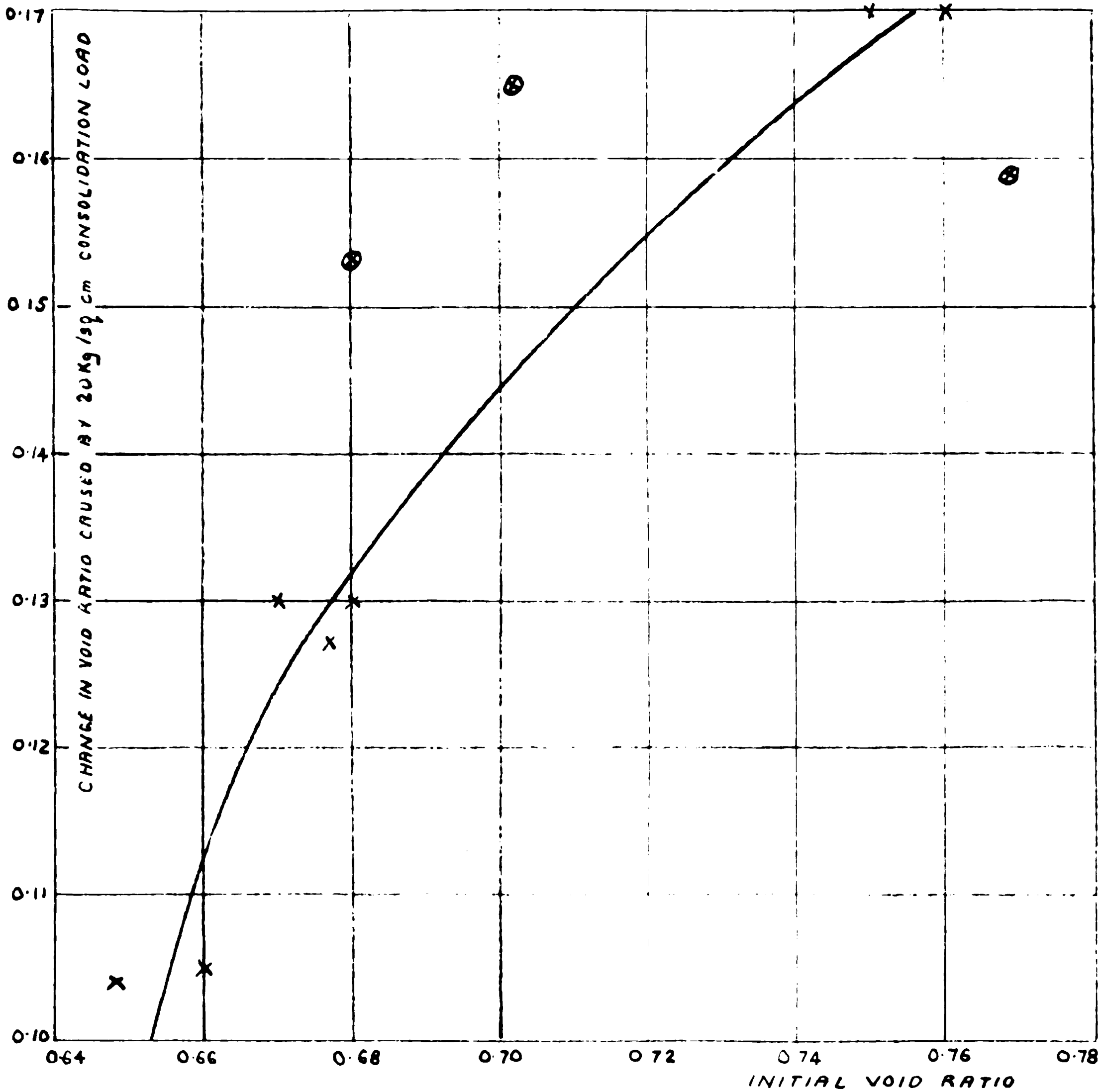


FIGURE 14c COMPARISON OF CONSOLIDATION CURVES FOR STATIC LOAD AND KNEADING COMPACTION



	INITIAL VOID RATIO	VOID RATIO WITH 20 Kg/sq cm CONSOLIDATION LOAD	CHANGE IN VOID RATIO
20 S 200	0·760	0·590	0·170
20 S 500	0·660	0·555	0·105
20 H	0·769	0·610	0·159
22 S 200	0·750	0·580	0·170
22 S 500	0·667	0·550	0·127
22 H	0·680	0·527	0·153
23 S 500	0·648	0·544	0·104
24 S 200	0·680	0·550	0·130
26 S 200	0·670	0·540	0·130
26 H	0·711	0·545	0·165

(b) Consolidation Tests on Compacted Samples

Table 1 shows the conditions of the ten soil specimens for the consolidation tests. The first number of the code number is the percentage water content of the sample before compaction. The letter (S - static, H - Harvard kneading) indicates the type of compaction and the last number indicates the compaction pressure for those samples compacted by static load compaction. All samples compacted by kneading compaction were compacted by ten applications of a 20 lb. tamping force on each of two layers.

Figure 12 shows the relationship between soil ratio (plotted to an arithmetic scale), and consolidation pressure (plotted to a logarithmic scale), for all samples compacted by static load compaction. Figure 13 shows a similar plot for samples compacted by kneading compaction.

Figures 14a, 14b, 14c compare the pressure/void ratio relationship for samples of the same moisture content compacted to similar dry densities by the two different compaction methods.

In Figure 15 the change in void ratio of a sample caused by a 20 kg/sq.cm. consolidation pressure is plotted against the initial void ratio.

Static Load Compacted Samples:- Figure 12 shows that for all samples compacted by static load, the void ratio/pressure curves all tend to the same line which may be considered to be the equivalent of the virgin compression curves of natural soils. Thus the effect of static load compaction is, in this respect, similar to preconsolidation. In consolidation tests on preconsolidated clays, however, the reloading curve undergoes a fairly abrupt change of slope when it approaches the virgin curve. The value of the pressure at which this change of slope occurs is equal to the preconsolidation load. From these test results, the change in slope is gradual and no relationship was found between the static compaction pressure and the shape of the curve.

Figure 15 shows that the change in void ratio caused by a 20 kg/sq.cm. consolidation pressure is dependent only on the initial void ratio (or dry density) of the samples compacted by static loads. This relationship is independent of the static compaction load, and the initial and final water contents, except in so far as they influence the final void ratio obtained during a particular compaction process.

Kneading Compacted Samples:- Comparing Figures 12 and 13, the substantial effect of type of compaction is immediately apparent. The void ratio/pressure curves for samples compacted by kneading do not all merge into the same line. They do, however, become parallel and their final slopes are found to equal the final slopes of void ratio/pressure curves for static load compacted samples.

Figure 15 shows that the relationship found between initial void ratio and change of void ratio (caused by a 20 kg/sq.cm. consolidation pressure) for static load compacted samples does not exist for samples compacted by kneading. The least compressible sample (22H), is that compacted near the optimum moisture content of 22.5%. A slight increase in compressibility is obtained by compaction on the dry side of the optimum (20H) but a much greater increase in compressibility is obtained by compaction on the wet side of the optimum (26H), even though the difference in initial void ratio is not so great. This confirms the results obtained by S. D. Wilson (6) who states that samples compacted on the wet side of the optimum are more compressible than samples compacted on the dry side.

Comparison of Compaction Method:- Figures 14a, 14b and 14c show that for all moisture contents, samples compacted by static load are initially less compressible than those compacted by kneading, but that the final slope of the curve is independent of both water content and compaction methods.

Figure 14b shows conclusively that the two specimens are not identical if compacted by different methods, even though they may be compacted to the same dry density (void ratio) at the same moisture content. It is known that the relative quantities of water, air and soil must be the same, and therefore the difference in the two samples must be either a difference in distribution of the air or water through the soil or a difference in the orientation or distribution of the soil particles. No attempt was made to examine the nature of this difference.

SUMMARY AND CONCLUSIONS

1. The optimum moisture content for a kneading compaction process is independent of the size of the mould used providing the compactive energy per unit volume is constant.

2. The dry density obtainable at a particular moisture content with a fixed compaction energy per unit volume depends on the mould size: the exact nature of the effect being dependent on the relative importance of side friction and soil movement.

3. For different compaction processes the optimum moisture content corresponding to a particular dry density is a function of the time interval over which the individual units of compaction energy are applied. Thus the optimum water content is lowest for impact compaction, higher for kneading compaction and highest for a static load compaction process.

4. For specimens compacted by static load, their compressibility (as measured by the change in void ratio caused by a 20 kg/sq.cm. consolidation load) depends only on the initial void ratio.

5. With kneading compaction, minimum compressibility is found in samples compacted at optimum moisture content. While a small increase in compressibility is found in samples compacted on the dry side of the optimum, a greater

increase is found in those compacted on the wet side.

6. With the same water content and dry density, a sample compacted by kneading is more compressible than one compacted by static load. This proves conclusively that the consolidation characteristics of a compacted soil depend on both the soil and the compaction method used.

The Proctor compaction test has been widely used for many years as a standard specification. More recently various kneading compaction methods have been developed with a view to reproducing field conditions more closely. In recent research on the properties of compacted soils, static load compaction has frequently been used. Leonards (11) deduced that, for a given set of initial conditions, the compressive strength of a compacted soil depends only on the void ratio at failure. In view of the way in which the method of compaction influences the changes in void ratio which take place during consolidation, it can be assumed that the type of compaction used would also influence the strength characteristics of a compacted soil. Further research is needed, however, to confirm this assumption. Nevertheless, in evaluating the results of all research on the properties of compacted soils, the effect of method of compaction used should be taken into account.

LIST OF REFERENCES

1. Proctor, R. R. "Fundamental Principles of Soil Compaction". Engineering News-Record, 1933.

2. "Soil Mechanics for Road Engineers". H.M.S.O. London, 1954.

3. Copper, F. L. and W. F. Cassie. "The Mechanics of Engineering Soils". McGraw-Hill Book Co., 1953.

4. Burmister, D. M. "Some Investigations of the Shearing Resistance of Cohesionless and Cohesive Materials", Proceedings A.S.T.M., Vol. 39.

5. Tschebatarioff. "Soil Mechanics, Foundations, and Earth Structures". McGraw-Hill, 1951, Art. 7-20.

6. Wilson, S. D. Conference on Soil Stabilisation, M.I.T. 1952. "Effects of Compaction on Soil Properties".

7. Wilson, S. D. "Small Soil Compaction Apparatus Duplicates Field Results Closely", Engineering News-Record, November 2, 1949.

8. Little, A. L. "Laboratory Compaction Technique". Proceedings 2nd International Soil Mechanics Conference, 1948.

9. Porter, O. J. "Preparation of Subgrades". Proceedings of the Highway Research Board, Washington, 1938.

10. Seed, H . B. and Carl L. Monismith. "Relationship between Density and Stability of Subgrade Soils". Highway Research Board Bulletin 93. Washington D.C., 1954.

11. Leonards, G. A. "Strength Characteristics of Compacted Clays", Transactions A.S.C.E., 2780, Vol. 120, 1955.

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