TEST PROCEDURE FOR THE DETERMINATION OF MAXIMUM MOISTURE CONTENT TO BE EXPECTED UNDER FOOTINGS LOCATED IN PERMEABLE SOIL ABOVE WATER TABLE.

Thesis by

Harold J. Alwart
and
Abdurrahim Servet

In partial fulfillment of the requirement for

the Degree of Master of Science in Civil Engineering

California Institute of Technology
Pasadena, California

June 11, 1937

ACKNOWLEDGMENT

The authors hereby wish to express their great indebtedness and thanks to Professor F.J. Converse for his kind assistance and guidance in the research work connected with this paper, without which it would have been impossible to accomplish the present work.

INDEX

CHAPTER I

INTRODUCTION

The problem of determining the bearing value of a soil has long caused considerable trouble among foundation engineers. One of the main features of this problem is the determination of the probable minimum bearing value of a California soil when tested during the summer or dry season. It is a known fact that the bearing value of the soil will vary with the moisture content. It is also quite generally known that the present tests of bearing value do not give true results. By true results are meant, results which accurately check field determinations. There are certain cases in which the saturated tests now in use give value far too low as well as inconsistant values. By means of the tests outlined, the authors believe that more accurate and reliable results may be obtained in the future.

These tests are mainly concerned with the bearing values of soils under shallow footings. Deep footing, cassions and piles are eliminated from the tests. The reason for this being that the authors believe that the more specialized cases should be more thoroughly investigated. However, in the case of the shallow footings, as used for school buildings and homes, a limited amount of investigation and time for testing is required. With this point in mind, work has been concentrated on this point.

As a preliminary step along this line, moisture contents were taken at a number of places before the rainy season began. This was done so that the increase in moisture of a number of definite soils could be obtained and checked in the laboratory. Samples were taken at various depths and places, concentration being in the poorer soils of the district. Later after an unusually heavy rainy season, which it was fortunate to encounter, the sampled places were revisited and the moisture content of the soil again obtained. With this data it was assumed that laboratory checks for these values would hold for any similar soil.

The laboratory work was divided into two main categories. First being the determination of the type of soil in use and its various properties, and the second, the technique and type of test suited for this subject. This first part consisted of the standard tests which are hydrometer and sieve analysis, liquid and plastic limits, shear, compression, shrinkage and sp-gravity. The second part was split up into three divisions, percolation, rainfall and capillary rise tests. All results were reduced to a common base, but due to the large number of variables, such as compaction, types of soil, density, etc. and the limited time, this could not be carried to the completion desired by the authors.

CHAPTER II

LOCALITIES INVESTIGATED AND TYPES OF SOILS USED

Most of the soils sampled were those from the vicinity of public school buildings in the Metropolitan Los Angeles area. At this point it is thought advisable to give a short description of the sites and types of soil used. A large percentage of the samples were taken just a few feet from the outside of the foundation of the buildings. However, in two special cases, samples were taken both inside and outside of the footing in order that some idea of the amount of moisture drawn under the footing itself might be available for further laboratory tests. These samples were confined to the campus of the California Institute of Technology. All samples were taken in approximately the same relative position as regards to the building foundation so that at least one of the variables was eliminated. Samples were taken at varying depths depending on the log of the soil, that is, they were taken at the point at which the poorest or governing soil was to be found.

Following is a short description of the samples used, their classification, depth, and position with respect to the footings. All samples will be numbered with the same system used in the laboratory, and hereafter will be referred to by those numbers only.

Sample No. 1001: Dabney House, California Institute of Technology, inside basement near North entrance on West wall. Sample taken at a point 1 foot East of West wall, 3 feet South of South wall of entrance and at a depth of 2 feet.

Sample No. 1002: Dabney House, California Institute of Technology, outside of building near North entrance on West wall. Sample taken at a point 10 feet South of South wall of entrance, 1 foot West of wall, and at a depth of 10 feet.

Sample No. 1003: Fleming House, California Institute of Technology, inside basement near center entrance on North side. Sample taken at a point 2 feet South of North wall of hallway, 2 feet East of West wall of vestibule and at a depth of 2 feet.

Sample No. 1004: Jefferson School, Pasadena, East side of school building. Sample taken at a point 3 feet from curbing on Sierra Bonita Avenue, 12 feet North of South line of school, and at a depth of 6 feet.

Sample No. 1005: California Institute of Technology lot just East of Tournament Park, Pasadena. Sample taken at a point 20 feet South and 6 feet East of South end of I beam testing apparatus, and at a depth of 6 feet.

Sample No. 1006: Lankershim Elementary School, North Hollywood, near Northwest corner of center building. Sample taken at a point 3 feet North of corner and 6 feet East of corner at depths of $3\frac{1}{2}$ and 5 feet.

Sample No. 1007: Van Nuys Elementary School, Van Nuys, near Northwest corner of Northwest building. Sample taken at a point 2 feet North of corner, 15 feet East of corner and at a depth of 6½ and 7½ feet.

Sample No. 1008: Van Nuys High School, Van Nuys, near Southeast corner of Southeast building. Sample taken at a point 10 feet East of corner, 16 feet North of corner, and at depths of 4 and 5 feet.

Sample No. 1009: Miles Avenue School, Huntington Park, near center of Main building. Sample taken at a point 60 feet South of main doorway, 4 feet West of West wall and at depths of 4 and 5 feet.

Sample No. 1010: Huntington Park High School, Huntington Park, near Main building. Sample taken at a point 6 feet North of Southeast corner and 6 feet East of Southeast corner of building and at depths of 6 and 7 feet.

Sample No. 1011: Holmes Avenue School, Huntington Park, Southwest corner of school building. Sample taken at a point 6 feet West of corner and 20 feet North of corner, at a depth of 3 feet.

Sample No. 1012: Gage Avenue School, Huntington Park, near Second building East of Miles Avenue on Gage Avenue. Sample taken at a point 3 feet North of and 6 feet East of Northwest corner of building at a depth of 4 feet.

Sample No. 1013: 49th Street School, Vernon near Northeast corner of main building. Sample taken at a point 10 feet West of corner and 3 feet North of wall at a depth of 5½ feet.

Sample No. Ex. Las Lunas and Hartelo Streets, Pasadena. Sample taken in large quantities at a depth of 5 feet for experiments in the laboratory. All preliminary laboratory tests run on this sample.

CHAPTER III

FIELD NOTES AND OBSERVATIONS

The results of the moisture content samples taken in the field both before and after the rainy season give the following values. With these are noted a few of the field observations with regard to the soil, sub-surface and surface conditions.

Sample No. 1001: Moisture content Dec. 18, 1936 was 8.26%. Moisture content Apr. 15, 1937 was 8.46%. The slight change in the moisture was probably due to the fact that the soil had a tendency to dry out quite rapidly being inside the building where the air was very dry.

Sample No. 1002: Moisture content Dec. 18, 1936 was 12.30%. Moisture content Apr. 15, 1937 was 12.57%. This small variation of the moisture content in this case might be due to the fact that the sample was taken at such a depth that surface conditions had little to do with the change in moisture.

Sample No. 1003: Moisture content Dec. 18, 1936 was 10.24%. Moisture content Apr. 15, 1937 was 10.62%. This slight change is due to the same cause as sample no. 1001.

Sample No. 1004: Moisture content Nov. 27, 1936 was 4.65%. Moisture content Jan. 4, 1937 was 4.78% and Apr. 15, 1937 was 4.83%.

Sample No. 1005: Moisture content Dec. 21, 1937 was 6.02%. Moisture content Jan. 4, 1937 was 13.18% and Apr. 15, 1937 was 11.81%. The increase in moisture on the second test was due to the fact that shortly before there had been a very large rainfall and the drainage of the area was such that the sample became saturated. The later sample was taken after the area had drained for a considerable period.

Sample No. 1006: Moisture content Dec. 22, 1936 was 6.90%. Moisture content Apr. 6, 1937 was 12.88%. The top soil above this sample had been spaded and might be considered to account for part of the increase in moisture.

Sample No. 1007: Moisture content Dec. 22, 1936 was 9.02%. Moisture content Apr. 6, 1937 was 8.68%. The small change in the moisture content was probably due to the depth at which the sample was taken.

Sample No. 1008: Moisture content Dec. 22, 1936 was 16.32%. Moisture content Apr. 6, 1937 was 20.73%. The top soil had been continually spaded to help the growth of shrubbery above.

Sample No. 1009: Moisture content Jan. 9, 1936 was 11.64%. Moisture content Apr. 17, 1937 was 14.89%.

Sample No. 1010: Moisture content Jan. 9, 1937 was 11.64%. Moisture content Apr. 17, 1937 was 14.89%. Sample taken in between shrubbery which had been spaded.

Sample No. 1011: Moisture content Jan. 9, 1937 was 7.60%. Moisture content Apr. 17, 1937 was 13.49%.

Sample No. 1012: Moisture content Jan. 9, 1937 was 16.86%. Moisture content Apr. 17, 1937 was 7.70%. Reason for the decrease as shown by the tests not determined.

Sample No. 1013: Moisture content Jan. 9, 1937 was 6.70%. Moisture content Apr. 17, 1937 was 6.18%. Small change in moisture due to depth at which sample was taken. Decrease probably due to a variation in the soil.

Sample No. Ex.: No field notes on this sample as it was used in either the air dried or definite moisture content as made in the laboratory. All work with this sample was entirely under control of the experimenters.

CHAPTER IV

TEST PROCEDURE

Tests can be divided into two groups, namely field tests and laboratory tests. First let us consider the field tests. In the selection of sites for the field tests, consideration was given to localities where the soil was known to have poor bearing values. These sites were obtained from previous tests run in conjunction with the reconstruction of Public School Buildings after the Long Beach Earthquake of Mar. 10, 1933. At this time the usual dry and saturated bearing tests were run for the determination of the proper value for reconstruction. From these tests, a log of the soil at the given site was obtained, which was helpful in determining the depth at which the required sample should be taken. This considerably reduced the preliminary work necessary and gave the authors the confidence of having some of the poorest soil available in this section of the country, as well as that of the critical type.

Sampling of the soil on the site was carried out in the following manner. The sampling device was carried to the point at which the sample was to be taken and then a hole was dug to the desired depth with an eight inch soil auger. The sampler was then assembled and dropped into the hole. The number of taps necessary to fill the eight inch tube of the sampler was recorded. A sample at least four inches in length was placed in the field compression machine and there tested for its compression value. Part of this sample was placed in an air tight container to be taken into the laboratory for further testing. The sampler was reassembled and another sample was taken at the same place. The major part of this sample was retained in the original rings and firmly packed with extra soil taken from the sample hole. These rings were weighed before being packed for the purpose of determining the field density of the material. After the samples were packed in the tin containers used to transport them to the laboratory, they were tightly sealed so that no moisture would be lost during transportation. As soon as the laboratory was reached, each can was carefully opened and a moisture content sample was taken out, weighed and placed in the oven to dry. After six days in the oven at 110 degrees Fahrenheit, the sample was again weighed and then the moisture content determined. This procedure was followed for all field samples taken before the rainy season began, and again repeated after a total rainfall of 21.7 inches had been recorded. These values were later used to check the results obtained in the laboratory tests.

After the moisture contents were taken, the first test run of the soil was the hydrometer test for the classification of the type of soil being used. This test consisted of the following procedure according to the ASTM specifications.

Scope.

This method covers the quantitative determination of the distribution of particle sizes in soils.

Apparatus.

The apparatus shall consist of the following:

(a) Balance - An analytical balance sensitive to 0.001 g.

(b) Stirring Apparatus - A special stirring apparatus (Fig. 1)

(c) Hydrometer - A hydrometer graduated in grams of soil per liter of suspension (Fig. 4) or a hydrometer with special shape bulb, graduated in specific gravity, having a range of 0.995 to 1.050 specific gravity and reading 1.000 at 67 F. (19.4C) (Fig. 2).

(e) Thermometer - A Fahrenheit thermometer accurate to 1 F. (0.5 C.).

(f) Sieves - A series of sieves, conforming to the requirements of the Standard Specifications for Sieves for Testing Purposes (A.S.T.M. Designation: E11) of the American Society for Testing Materials. The sieves required are Nos. 20,40,60,140 and 200.

(g) Water Bath - A water bath for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory device is an insulated zinc tank which maintains the temperature of the suspension at faucet-water temperature. Such a device is illustrated in Fig. 2 and Fig. 3.

(h) Beaker - A tall form beaker of 400-ml. capacity.

Sample.

A sample of soil shall be selected by the method of quartering or by the use of a sampler from the material passing the No. 10 sieve. The weight of each sample shall be approximately 115 g. for sandy soils and 65 g. for silt and clay soils.

Hygroscopic Moisture.

A 15-g portion of the sample selected for mechanical analysis shall be used for the determination of the hygroscopic moisture. This portion of the sample shall be weighed, dried to constant weight in an oven at 110 C., weighed, and the results recorded.

Hydrometer Test. - Dispersion of Soil Sample.

The remainder of the sample selected for mechanical analysis shall be weighed and dispersed by one of the two methods A or B described below. The method to be used depends on the plasticity index of the soil.

For Soils Having a Plasticity Index Less Than 20.

The soil shall be placed in a tall-form beaker, and 200 ml. or more of distilled water added slowly and with constant stirring until the soil is thoroughly wetted. The mixture shall be allowed to stand for a period of at least 18 hr. It shall then be washed into the special dispersion cup and distilled water added until the cup is within 2 in. of being filled. A deflocculating agent, 20 ml. of a solution of sodium silicate crystals ($Na_2SiO_3 \cdot 9\ H_2O$)shall be added. The density of this solution shall be that indicated by one of the following hydrometer readings: hydrometer A 36.5 at 67 F. (19.4 C.); hydrometer B, 1.023 at 67 F. (19.4 C.); Baume hydrometer, 3 deg. at 76 F. (24.4 C). The contents of the cup shall be mixed by the special stirring apparatus for a period of 1 min.

Hydrometer Test.

(a) After dispersion, the mixture shall be transferred to the glass graduate, and distilled water having the same temperature as the constant temperature bath added until the mixture attains a volume of 1000 ml. The graduate containing the soil suspension shall then be placed in the constant temperature bath. The suspension shall be stirred frequently with a glass rod to prevent settlement of particles in suspension. When the soil suspension attains the temperature of the bath the graduate shall be removed and its contents thoroughly shaken for 1 min., the palm of the hand being used as a stopper over the mouth of the graduate.

(b) At the conclusion of this shaking the time shall be recorded, the graduate placed in the bath, and readings taken with the hydrometer at the end of both 1 and 2 min. The hydrometer shall be read at the top of the meniscus formed by the suspension around its stem. Hydrometer shall be read to the nearest 0.0005 specific gravity. Subsequent readings shall be taken at intervals of 5,15,30,60,250 and 1440 min. after the beginning of sedimentation. Readings on the thermometer placed in the constant temperature bath shall be made coincidentally with the hydrometer readings and recorded.

(c) After each reading except the 1-min. reading, the hydrometer shall be very carefully removed from the soil suspension in such a manner as to cause no disturbance in the suspension, wiped clean, and laid aside. About 15 or 20 sec. before the time for a reading it shall again be slowly and carefully placed in the soil suspension. The reading shall not be taken until the hydrometer has come to rest.

Sieve Analysis.

At the conclusion of the final reading the suspension shall be washed on a No. 200 sieve. That fraction retained on the No. 200 sieve shall be dried and then analyzed in a nest of sieves consisting of one each of the following: Nos: 20,40,60,140 and 200.

Hygroscopic Moisture.

The hygroscopic moisture shall be expressed as a percentage of the weight of the oven-dried soil and shall be determined by the following formula:

$$\text{Hygro. moisture} = \frac{\text{wt. of air-dried soil} - \text{wt. of oven-dried soil}}{\text{wt. of oven-dried soil}} \times 100$$

To correct the weight of the air-dried sample for hygroscopic moisture the given value shall be multiplied by the expression:

$$\frac{100}{100 \quad \text{percentage of hygroscopic moisture}}$$

Percentage of soil in Suspension.

Readings of hydrometer B shall be corrected by adding temperature-correction factors shown as R in Fig. 4. The temperature-correction curve for hydrometer B is determined by plotting the differences between the density of water at the various temperatures and that at 67 F. (19.4 C.) against temperatures from 40 to 100 F. (4.4 to 37.8C.).

The percentage of the dispersed soil in suspension represented by different corrected hydrometer readings depends upon both the amount and the specific gravity of the soil dispersed. The percentage of dispersed soil remaining in suspension may be obtained from the following formulas:

$$\text{For hydrometer B: } P = \frac{1606\ (R-1)a}{W} \times 100$$

where P = the percentage of originally dispersed soil remaining in suspension

R = the corrected hydrometer reading

W = the weight of soil originally dispersed, in grams

a = constant depending on the density of the suspension

For hydrometer, the value of a for an assumed density of 1.0000 at 67 F. (19.4 C.) may be obtained from the following formula:

$$a = \frac{2.6500 - 1.0000}{2.6500} \times \frac{G}{G - 1.0000}$$

The values of a given by the two equations for different values of the specific gravity of soil G, are the same to two decimal places, and are given in Fig.

Diameter of Soil Particles in Suspension.

(a) The maximum diameter of the particles in suspension, corresponding to the percentage indicated by a given hydrometer reading, shall be as indicated by Stokes' law.

According to Stokes' law: $d = \frac{30nL}{980\,(G - G_1)T}$

where d = the maximum grain diameter in millimeters

n = the coefficient of viscosity of the suspending medium (in this case water) in poises. Varies with changes in temperature of the suspending medium.

L = the distance in centimeters through which soil particles settle in a given period of time

T = the time in minutes, period of sedimentation

G = the specific gravity of soil particles

G_1 = the specific gravity of the suspending medium. In this case $G_1 = 0.9984$, or approximately 1.0

(b) In order to use Stokes' law to determine the diameter of the particles it is necessary to know the distance through which these particles fall in a given time. Since the density throughout a suspension is not uniform and varies with the grading of the material in suspension and the time of sedimentation, a fixed distance cannot be used. For hydrometer B the depth of the center of volume of the hydrometer below the surface of the suspension can be taken as the distance through which the particles may be assumed to fall. Values of the distance L for different hydrometer readings are given in Fig. 5.

Plotting.

The percentages of grains of different grain diameters shall be plotted on semilogarithmic paper to obtain a "soil grain diameter accumulation curve." A curve of this character is shown in Fig. 6.

HYDROMETER TEST

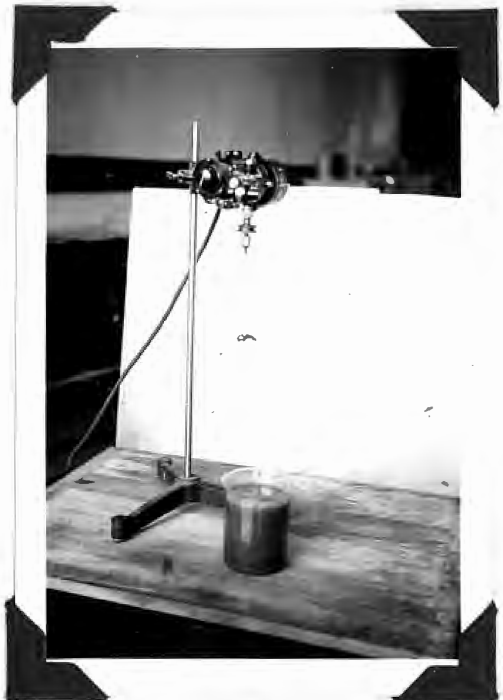


Fig. 1

Stirring Apparatus

Fig. 2

Hydrometer and Glass

HYDROMETER TEST

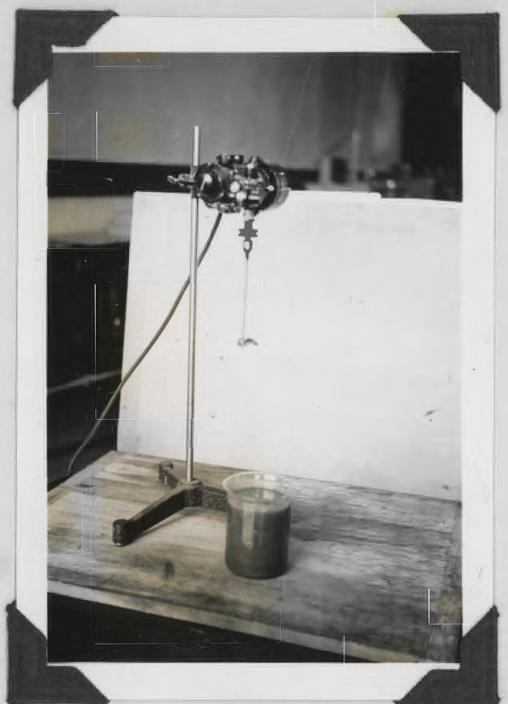


Fig. 1

Stirring Apparatus

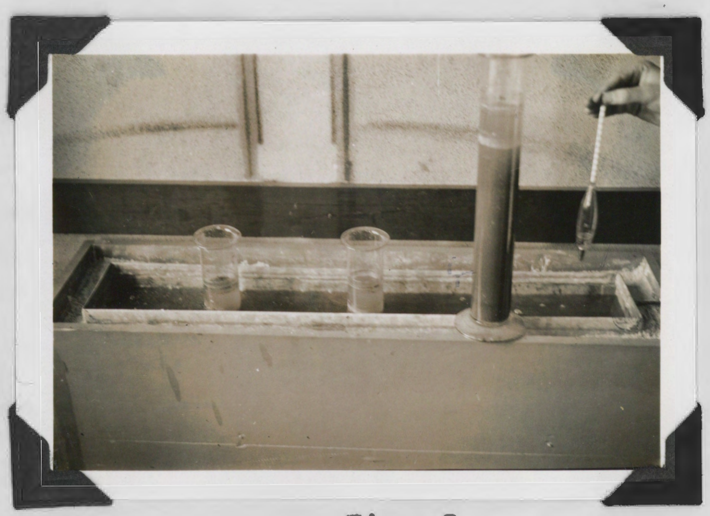


Fig. 2

Hydrometer and Glass

HYDROMETER TEST

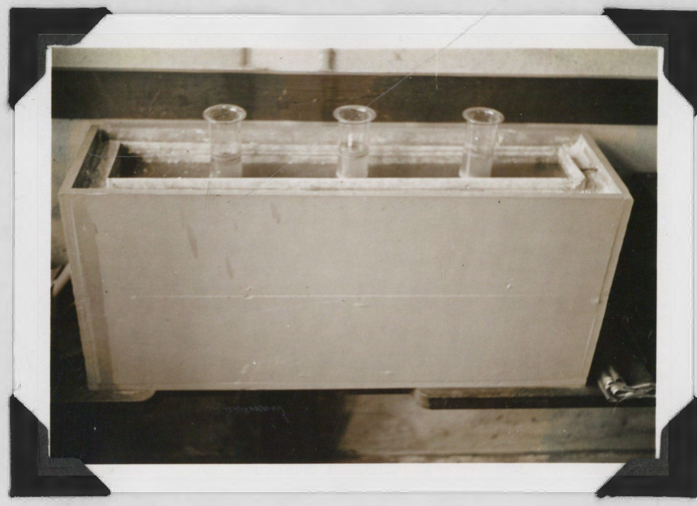


Fig. 3

Hydrometer Bath

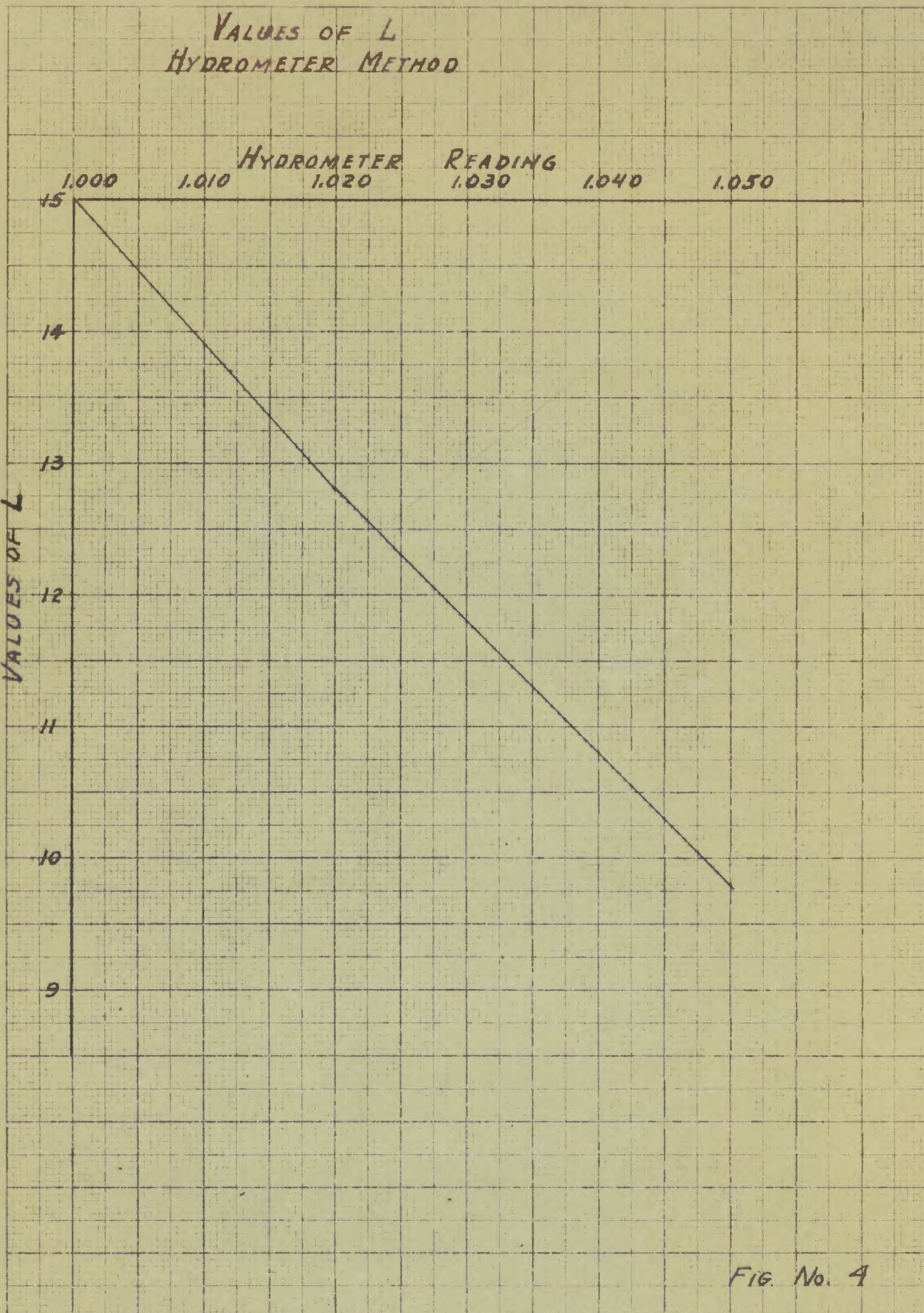


FIG. No. 4

KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 x 20 to the inch.

TEMPERATURE CORRECTIONS

Hydrometer Method

Temp. °F	Coeff. of Viscosity of water 7	Variation in Density of water from 67°F D
50	.0130	- .00137
51	.0128	- .001300
52	.01263	- .001231
53	.01245	- .001162
54	.01227	- .001093
55	.01210	- .001024
56	.01193	- .000955
57	.01175	- .000886
58	.01160	- .000817
59	.01140	- .000748
60	.01124	- .000679
61	.01110	- .000592
62	.01094	- .000485
63	.01079	- .000388
64	.01065	- .000291
65	.01050	- .000194
66	.01035	- .000097
67	.01020	0
68	.01005	.000118
69	.00993	.000236
70	.00980	.000354
71	.00966	.00048
72	.00953	.00060
73	.00940	.00075
74	.00928	.000885
75	.00916	.00103
76	.00905	.00119
77	.00893	.00133
78	.00883	.00147
79	.00872	.00160
80	.00861	.00173
81	.00851	.00195
82	.00840	.00217
83	.00830	.00239
84	.00820	.00261
85	.00810	.00283
86	.0080	.00305

Fig. No. 4a

CORRECTION (a) FOR SPECIFIC GRAVITY OF SOIL
HYDROMETER METHOD

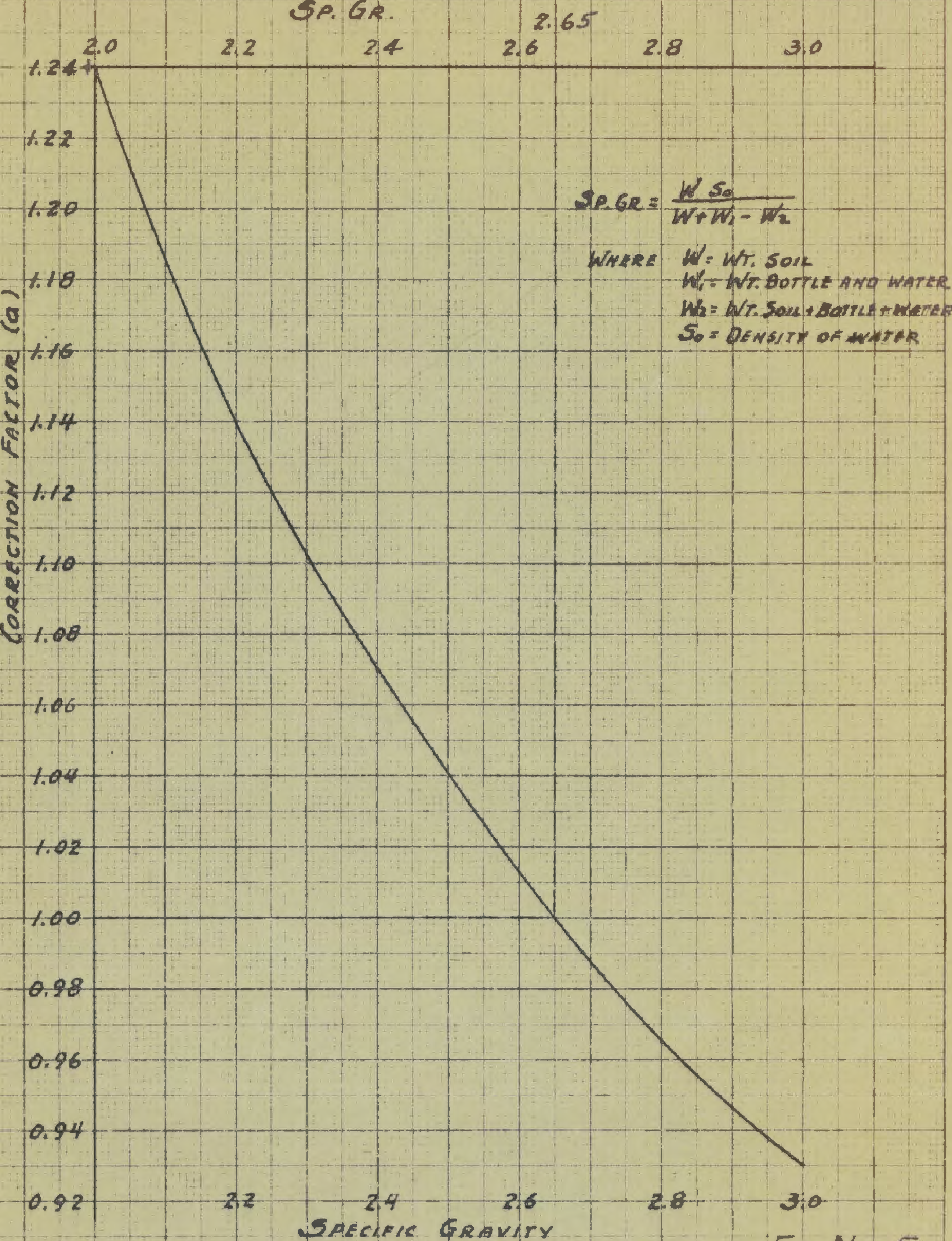


FIG. No. 5

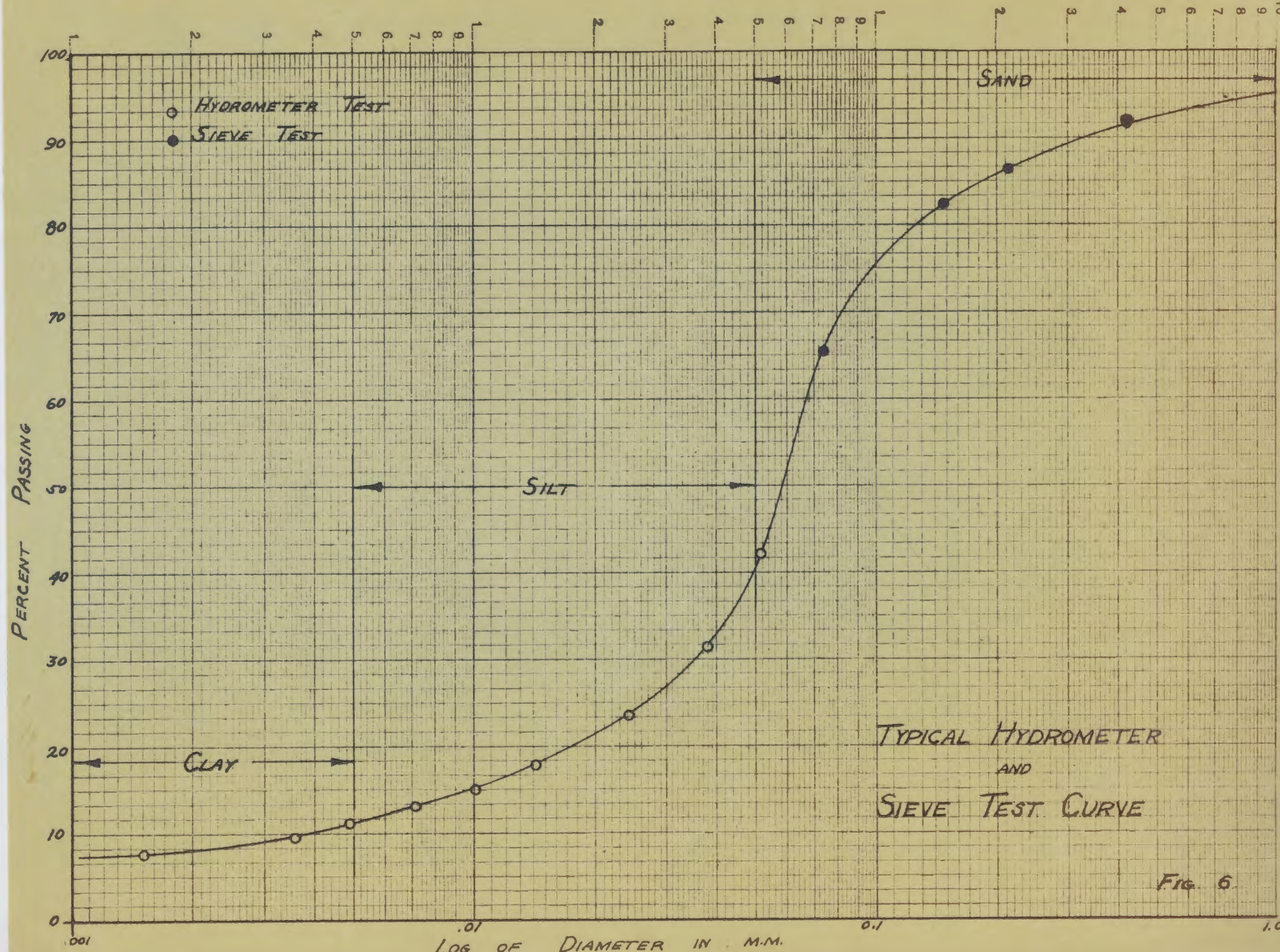


Fig. 6

KEUFFEL & ESSER CO. N.Y. NO. 359 70
Semi-Logarithmic, 3 cycles × 60 divisions
MADE IN U.S.A.

Liquid Limit.

The liquid limit of a soil is that moisture content, expressed as a percentage of the weight of the oven-dried soil, at which the soil will just begin to flow when lightly jarred ten times.

Apparatus.

The apparatus shall consist of the following:

(a) Evaporating Dish - A porcelain evaporating dish about $4\frac{1}{2}$ in. in diameter.

(b) Spatula - A spatula or pill knife having a blade about 3 in. in length and about 3/4 in. in width.

(c) Mechanical Device - A mechanical device consisting of a brass dish and carriage, constructed according to the plan and dimensions shown in Fig.

(d) Grooving Tool - A combined grooving tool and gage conforming to the dimensions shown in Fig.

(e) Watch Glasses - Matched watch glasses which are held together by a suitable clamp and fit sufficiently tight to prevent loss of moisture during weighing.

(f) Balance - An analytical balance sensitive to 0.001g.

Sample.

A sample weighing about 30 g. shall be taken from the thoroughly mixed portion of the material passing the No. 40 sieve.

Procedure.

(a) The air-dried soil shall be placed in the evaporating dish and thoroughly mixed with distilled water until the mass becomes pasty. The mass of soil shall then be shaped into a small layer about 3/8 in. in thickness at the center and divided into two portions with the grooving tool, as shown in the illustration at the top of Fig 7.

(b) The dish shall be held firmly in one hand, with the groove parallel to the line of sight, and tapped lightly with a horizontal motion against the palm of the other hand ten times. The intensity of the blows shall be such that the effect on the soil sample is equivalent to that produced by 25 shocks applied to a sample of the soil at the same moisture content by dropping the brass cup of the mechanical device through a distance of 1 cm. (0.3937 in.) at the rate of two drops per second.

(c) If the lower edges of the two soil portions do not flow together after ten blows have been struck, the moisture content is below the liquid limit. More water shall be added and the procedure repeated. If the lower edges meet before ten blows have been struck, the moisture content is above the liquid limit, and dry soil shall be added and the procedure repeated.

(d) When the lower edges of the two portions of the soil cake just flow together after ten blows have been struck, the moisture content equals the liquid limit. To determine definitely whether the two portions are actually joined, the spatula may be used to push one away from the other. If the two portions separate along the original line of division, the end point has not been reached, and the procedure shall be repeated with the addition of a small amount of water.

(e) A small quantity of soil from that portion of the soil cake which has flowed shall be removed and placed in a pair of watch glasses. The watch glasses and soil shall then be weighed and the weight recorded. The soil in the glasses shall be oven-dried to constant weight at a temperature of 110 C., and weighed. This weight shall be recorded and the loss in weight due to drying shall be recorded as the weight of water.

Calculation.

The liquid limit is expressed as the moisture content in percentage of the weight of the oven-dried soil and it shall be calculated by the following formula:

$$\text{Liquid limit} = \frac{\text{weight of water}}{\text{weight of oven-dry soil}} \times 100$$

Calibration of Mechanical Device.

By means of the gage attached to the grooving tool, and the adjustment plate, H, Fig. 7, the height to which the cup, C, is lifted shall be adjusted so that the point on the cup which comes in contact with the base is exactly 1 cm. (0.3937 in.) above the base. The adjustment plate, H, shall then be secured by tightening the screws, I.

Procedure.

(a) A sample weighing about 100 g. shall be taken from the thoroughly mixed portion of the air-dried soil passing the No. 40 sieve. This sample shall be placed in the evaporating dish and thoroughly mixed with a measured quantity of distilled water to a pasty consistency. A portion of this paste shall then be placed in the brass cup in the position shown in Fig. 7, leveled off to a depth of 1 cm., and divided by means of the grooving tool along the diameter through the centerline of the cam follower.

(b) The cup shall then be attached to the carriage and by turning the crank, F, at the rate of two rotations per second lifted and dropped until the two sides of the sample come into contact at the bottom of the groove along a distance of about $\frac{1}{2}$ in. The number of shocks shall be recorded. The moisture content of the soil shall then be determined on a portion taken from around the groove, by the method previously described in connection with the hand method.

(c) The foregoing operations shall be repeated with samples of the soil at two or more additional moisture contents both above and below that requiring about 25 blows for closure of the groove.

Preparation of Flow Curve.

A "flow curve" representing the relation between moisture contents and corresponding numbers of shocks shall be plotted on a semi-log graph with the moisture contents as abscissae on the arithmetical scale, and the numbers of shocks as ordinates on the logarithmic scale, Fig. 8.

Liquid Limit Determination.

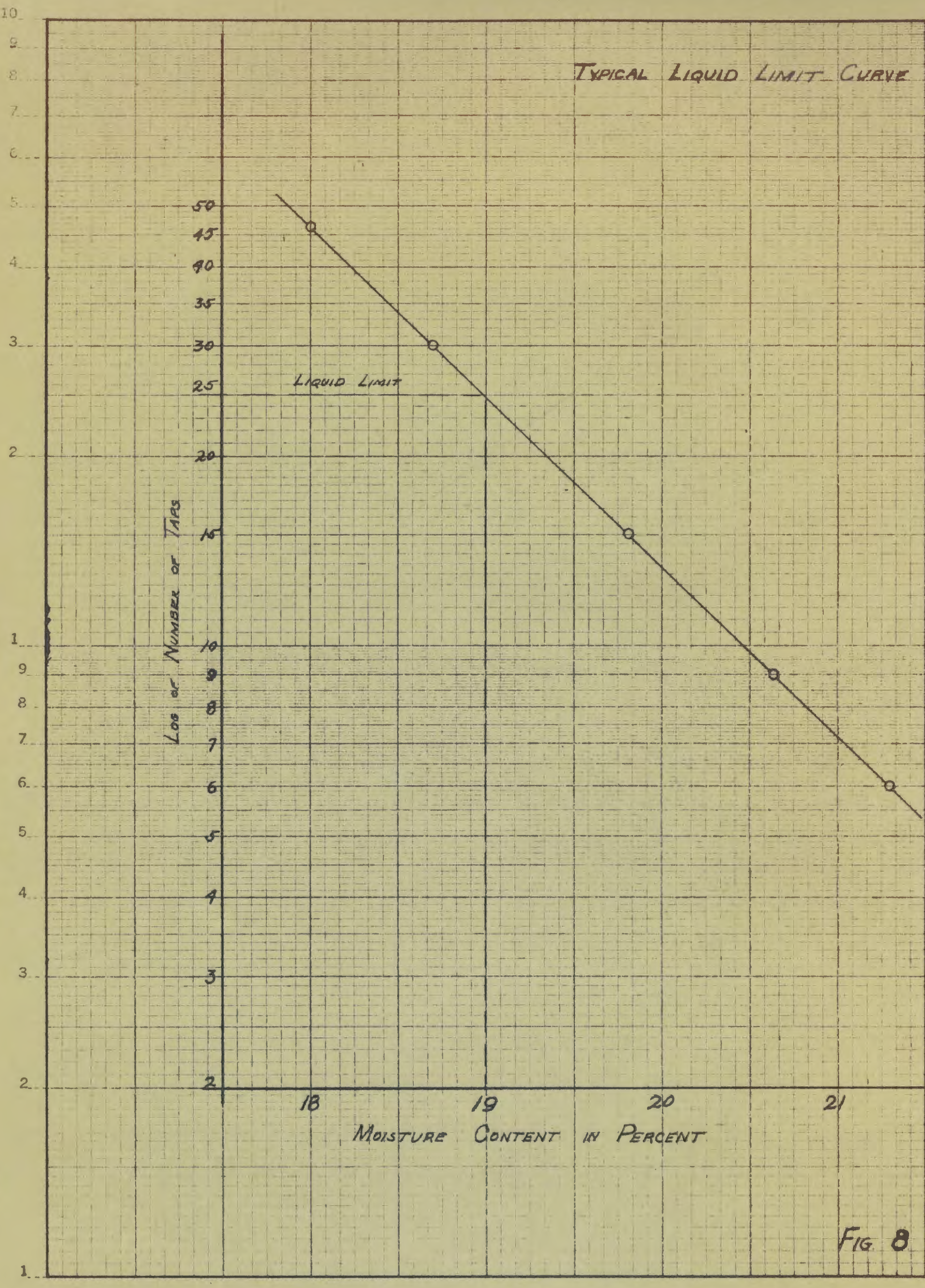
The moisture content corresponding to the intersection of the flow curve with the 25 shock ordinate shall be taken as the liquid limit of the soil.

LIQUID LIMIT TEST

Fig. 7

Liquid Limit Apparatus

A - Burrette
B - large flask
C - cup
D - Balance
E - watch glasses
F - glass plate
G - grooving tool
H - adjustment rod
I - adjusting screw
J - small flask



TYPICAL LIQUID LIMIT CURVE
LIQUID LIMIT
LOG OF NUMBER OF TAPS
50
45
40
35
30
25
20
15
10
9
8
7
6
5
4
3
2
18
19
20
21
MOISTURE CONTENT IN PERCENT

FIG. 8

PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

Plastic Limit.

The plastic limit of a soil is the lowest moisture content, expressed as a percentage of the weight of the oven-dried soil, at which the soil can be rolled into threads 1/8 in. in diameter without the threads breaking into pieces.

Apparatus.

The apparatus shall consist of the following:

(a) Evaporating Dish - A porcelain evaporating dish about 4½ in. in diameter.

(b) Spatula - A spatula or pill knife having a blade about 3 in. in length and about 3/4 in. in width.

(c) Surface for Rolling - A glass plate or piece of glazed paper on which to roll the sample.

(d) Watch Glasses - Matched watch glasses which are held together by a suitable clamp and fit sufficiently tight to prevent loss of moisture during weighing.

(e) Balance - An analytical balance sensitive to 0.001 g.

Sample.

A sample weighing about 15 g. shall be taken from the thoroughly mixed portion of the material passing the No. 40 sieve.

Procedure.

The air-dried soil shall be placed in the evaporating dish and mixed with distilled water until the mass becomes plastic enough to be easily shaped into a ball. The ball of soil shall then be rolled between the palm of the hand and the glass plate or piece of glazed paper with just sufficient pressure to form the soil mass into a thread. When the diameter of the resulting thread becomes 1/8 in. the soil shall be kneaded together and again rolled out. This process shall be continued until the crumbling of the soil prevents the formation of the thread. The portions of the crumbled soil shall then be gathered together and placed in watch glasses. The watch glasses and soil shall be weighed and the weight recorded. The soil in the glasses shall then be oven-dried to constant weight at a temperature of 110 C., and weighed. This weight shall be recorded and the loss in weight shall be recorded as the weight of water.

Calculation.

The plastic limit is expressed as the moisture content in percentage of the weight of the oven-dry soil and shall be calculated by the following formula:

$$\text{Plastic limit} = \frac{\text{weight of water}}{\text{weight of oven-dry soil}} \times 100$$

Plasticity Index.

The plasticity index of a soil is the difference between its liquid limit and its plastic limit.

The plasticity index shall be calculated by the following formula:

Plasticity index = liquid limit - plastic limit

Centrifuge Moisture Equivalent.

The centrifuge moisture equivalent of a soil is the amount of moisture, expressed as a percentage of the weight of the oven-dried soil, retained by a soil which has been first saturated with water and then subjected to a force equal to one thousand times the force of gravity for one hour.

Number of tests.

Tests shall be made in duplicate.

Procedure.

(a) The sample shall be placed in the Gooch crucible, in which has previously been placed a piece of wet filter paper which just covers the bottom of the crucible. The crucible shall be placed in a pan of distilled water and the sample allowed to take up moisture until completely saturated, as indicated by the presence of free water on the surface of the sample. It shall then be placed in a humidifier for at least 12 hr. to insure uniform distribution of moisture throughout the soil mass. All free water then remaining on the surface of the sample shall be poured off, and the crucible placed in a Babcock trunnion cup fitted as described.

(b) The sample shall be centrifuged for a period of 1 hr. at a speed which, for the diameter of head used, will exert a centrifugal force one thousand times the force of gravity upon the center of gravity of the soil sample. Immediately after centrifuging, the crucible and contents shall be weighed and the weight recorded as the weight of crucible and contents after centrifuging. The sample shall then be oven dried to constant weight at a temperature of 110 C., and weighed. This weight shall be recorded as the weight of crucible and contents after drying.

(c) Water-logging.

When free water is observed on the top of the sample after the centrifuging operation, the soil is said to have water-logged. This water shall not be removed but shall be weighed with the sample.

Calculation.

The centrifuge moisture equivalent of the soil shall be calculated by the following formula:

$$\text{Centrifuge moisture equivalent} = \frac{(A-b)-(A_1-b_1)}{A_1-(c \quad b_1)} \times 100$$

where A = the weight of crucible and contents after centrifuging

A_1 = the weight of crucible and contents after drying

c = the weight of crucible

b = the weight of filter paper wet

b_1 = the weight of filter paper dry

Permissible Variation in Duplicate Tests.

The variation between the two values obtained in the duplicate tests should not exceed 1 per cent for values of the moisture equivalent up to 15 and 2 per cent for values above 15.

Field Moisture Equivalent.

The field moisture equivalent of a soil is defined as the minimum moisture content, expressed as a percentage of the weight of the oven-dried soil, at which a drop of water placed on a smoothed surface of the soil will not immediately be absorbed by the soil but will spread out over the surface and give it a shiny appearance.

Apparatus.

The apparatus shall consist of the following:

(a) Evaporating Dish - A porcelain evaporating dish about $4\frac{1}{2}$ in. in diameter.

(b) Spatula - A spatula or pill knife having a blade about 3 in. in length and about 3/4 in. in width.

(c) Pipette - A pipette, burette, or similar device for adding water dropwise.

(d) Watch Glasses - Matched watch glasses, held together by a suitable clamp and fitting sufficiently tifht to prevent loss of moisture during weighing.

(e) Balance - An analytical balance sensitive to 0.001 g.

Sample.

A sample weighing about 50 g. shall be taken from the thoroughly mixed portion of the material passing the No. 40 sieve.

Procedure.

The air-dried sample shall be placed in the evaporating dish and mixed with distilled water. Distilled water shall be added in small amounts and the sample thoroughly mixed after each addition of water. When the wetted soil forms into balls under manipulation, the sample shall be smoothed with a light stroke of the spatula and a drop of water placed on the smoothed surface. If the water disappears in 30 sec. a few more drops of water shall be added, and the procedure shall be repeated until the water does not disappear in 30 sec. but spreads over the smoothed surface and leaves a shiny appearance. A small portion of the soil on which the last drop of water was placed shall then be removed and placed between two watch glasses. The weight of the watch glasses and wet soil shall be determined and recorded. The sample shall then be oven-dried to constant weight at a temperature of 110 C., and weighed. This weight shall be recorded and the difference in weight shall be recorded as the weight of water.

Calculation.

The field moisture equivalent shall be calculated by the following formula:

$$\text{Field moisture equivalent} = \frac{\text{weight of water}}{\text{weight of oven-dried soil}} \times 100$$

Shrinkage Factors of Soils

Scope.

This method furnishes the date from which the following subgrade soil constants may be calculated:

Shrinkage Limit
Shrinkage Ratio
Volumetric Change
Lineal Shrinkage
Specific Gravity (Approximate)

Apparatus.

The a pparatus shall consist of the following:

(a) Evaporating Dish - A porcelain evaporating dish about 4½ in. in diameter.

(b) Spatula - A spatula or pill knife having a blade about 3 in. in length and about 3/4 in. in width.

(c) Porcelain Dish - A circular porcelain milk dish having a flat bottom and being about 1-3/4 in. in diameter by about ½ in. in height.

(d) Straight Edge - A steel straight edge about 12 in. in length.

(e) Glass Cup - A glass cup about 2 in. in diameter and about 1 in. in height, the top rim of which is ground smooth and level.

(f) Glass Plate - A glass plate with three metal prongs for immersing the soil pat in mercury, as shown in Fig. 9.

(g) Graduate - A glass graduate having a capacity of 25 cc. and graduated to 0.2 cc.

(h) Balance - An analytical balance sensitive to 0.001g.

(i) Mercury - Sufficient mercury to fill the glass cup to overflowing.

Sample.

A sample weighing about 30 g. shall be taken from the thoroughly mixed portion of the material passing the No. 40 sieve.

Procedure.

(a) The sample shall be placed in the evaporating dish and thoroughly mixed with distilled water in amount sufficient to fill the soil voids completely and to make the soil pasty enough to be readily worked into the porcelain milk dish without the inclusion of air bubbles. The amount of water required to furnish friable soils with the desired consistency is equal to or slightly greater than the liquid limit, and the amount necessary to furnish plastic soils with the desired consistency may exceed the liquid limit by as much as 10 per cent.

(b) The inside of the porcelain milk dish shall be coated with a thin layer of vaseline or some other heavy grease to prevent the adhesion of the soil to the dish. An amount of the wetted soil equal to about one-third the volume of the milk dish shall be placed in the center of the dish, and the soil caused to flow to the edges by tapping the dish on a firm surface cushioned by several layers of blotting paper or similar material. An amount of soil shall be added approximately equal to the first portion, and the dish tapped until the soil is thoroughly compacted and all included air has been brought to the surface. More soil shall be added and the tapping shall be continued until the dish is completely filled and excess soil stands out about its edge. The excess soil shall then be struck off with a straight edge, and all soil adhering to the outside of the dish shall be wiped off.

(c) The dish when filled and struck off shall be weighed immediately and the weight recorded as the weight of dish and wet soil. The soil pat shall be allowed to dry in air until the color of the pat turns from dark to light. It shall then be oven-dried to constant weight at 110 C. and weighed, the weight being recorded as the weight of dish and dry soil. The weight of the empty dish shall be determined and recorded. The capacity of the dish in cubic centimeters, which is also the volume of the wet soil pat, shall be determined by filling the dish to overflowing with mercury, removing the excess by pressing a glass plate firmly over the top of the dish, and measuring by means of a glass graduate the volume of mercury held in the dish. This volume shall be recorded as the volume of the wet soil pat, V.

(d) The volume of the dry soil pat shall be determined by removing the pat from the porcelain milk dish and immersing it in the glass cup full of mercury in the following manner: The glass cup shall be filled to overflowing with mercury and the excess mercury shall be removed by pressing the glass plate with the three prongs (Fig. 9) firmly over the top of the cup. Any mercury which may be adhering to the outside of the cup shall be carefully wiped off. The cup, filled with mercury, shall be placed in the evaporating dish, and the soil pat shall be placed on the surface of the mercury. It shall then be carefully forced under the mercury by means of the glass plate with the three prongs (Fig. 9) and the plate shall be pressed firmly over the top of the cup. It is essential that no air be trapped under the soil pat. The volume of the mercury so displaced shall be measured in the glass graduate and recorded as the volume of the dry soil pat, V_o).

Calculation of Moisture Content.

The moisture content of the soil at the time it was placed in the dish expressed as a percentage of the dry weight of the soil shall be calculated from the formula:

$$w = \frac{W - W_o}{W_o} \times 100$$

where w = the moisture content of the soil when placed in the dish.

W = the weight of the wet soil pat obtained by subtracting the weight of the porcelain milk dish from the weight of the dish and wet pat.

W_o = the weight of the dry soil pat obtained by subtracting the weight of the porcelain milk dish from the weight of the dish and dry pat.

Shrinkage Limit.

The shrinkage limit of a soil is that moisture content, expressed as a percentage of the weight of the oven-dried soil, at which a reduction in moisture content will not cause a decrease in the volume of the soil mass, but at which an increase in moisture content will cause an increase in the volume of the soil mass.

Calculation of Shrinkage Limit.

(a) The shrinkage limit, S, shall be calculated from the data obtained in the volumetric shrinkage determination by the following formula:

$$S = w - \frac{V - V_o}{W_o} X 100$$

where S = the shrinkage limit

w = the moisture content of the wet soil, in percentage of the weight of oven-dried soil

V = the volume of wet soil pat

V_o = the volume of dry soil pat

W_o = the weight of oven-dried soil pat

(b) Optional Method. - When both the true specific gravity, G, and the shrinkage ratio, R, are known, the shrinkage limit may be calculated from the following formula:

$$S = \frac{1}{R} - \frac{1}{G} X 100$$

Shrinkage Ratio.

The shrinkage ratio of a soil is the ratio between a given volume change, expressed as a percentage of the dry volume, and the corresponding change in moisture content above the shrinkage limit, expressed as a percentage of the weight of the oven-dried soil. It equals the apparent specific gravity of the dried soil pat.

Calculation of Shrinkage Ratio.

The shrinkage ratio, R, shall be calculated from the data obtained in the volumetric shrinkage determination by the following formula:

$$R = \frac{W_o}{V_o}$$

Volumetric Change.

The volumetric change of a soil for a given moisture content is the volume change, expressed as a percentage of the dry volume, of the soil mass when the moisture content is reduced from the stipulated percentage to the shrinkage limit. This stipulated moisture content is usually taken as the field moisture equivalent.

Calculation of Volumetric Change.

The volumetric change shall be calculated from the data obtained in the volumetric shrinkage determination by the following formula:

$$\text{Volumetric change} = (w_1 - S)R$$

where w_1 = the given moisture content.

If, as is customary, the volumetric change from the field moisture equivalent is desired, the formula assumes the following form:

Volumetric change, C_f = volumetric change from field moisture equivalent

Volumetric change = (field moisture equivalent-S)R

Specific Gravity.

The specific gravity of a soil is the weight of the oven-dried soil divided by the true volume of the soil particles.

Calculation of Specific Gravity.

The specific gravity may be calculated from the data obtained in the volumetric shrinkage test by the following formula:

$$\text{Sp.Gr.} = \frac{1}{\frac{1}{R} - \frac{S}{100}}$$

SHRINKAGE LIMIT

Fig. 9
Shrinkage Limit Apparatus

A - large flask
B - Balance
C - small flask
D - glass dish
E - shrinkage cup
F - glass cup and plate
G - mercury
H - eye drop

Specific Gravity Test of Soils

The apparatus consists of a small flask, spatula, watch glasses, and a vacuum system. The flask is to be marked with a line on the neck. The weight of the flask in the empty condition is recorded. The flask is then filled to the line with distilled water and again weighed. Then about fifty grams of soil to be tested are placed in the empty flask and the remainder is filled with distilled water. This is first filled about one-half full and then stirred until the soil is thoroughly wetted. The flask is then filled to the line. After this has been done, the flask is attacked to the vacuum system until all the air has been removed from the suspension. The suspension is then weighed and recorded.

A sample of the soil placed in the flask is taken and placed on a watch glass, weighed and then placed in the oven. This is for the purpose of determining the moisture content of the sample of soil being tested to make the correction in the amount of soil tested to be the dry weight. The weight of soil placed in the flask is thus corrected.

The specific gravity of the soil is found by the equation:

$$Sp.Gr. = \frac{W\ S_o}{W\ W_1 - W_2}$$

where W = Weight of the soil
W_1 = Weight of flask and water
W_2 = Weight of soil, flask, and water
S_o = Density of the water.

SPECIFIC GRAVITY TEST

Fig. 10
Specific Gravity Apparatus

Field Sampling Device

The field sampling device was made up of a soil sampler designed at California Institute of Technology and other equipment that it was thought necessary to carry to the field. This equipment consisted of a field compression machine, penetration needle, and other accessories. The sampler proper (A) was a steel tube about 10 inches long with a sharpened edge on one end, and threaded onthe other. This tube had a smooth inside diameter of $2\frac{1}{2}$ inches into which fit the sampling rings (B). These rings were of brass and were a slip fit to the tube. The rings were in $\frac{1}{2}$,1,$2\frac{1}{2}$ and 8 inch lengths. The purpose of this being that samples for various tests require different lengths and thus lead to greater convenience. The top of the steel tube was fitted with a cap on which was attacked an ordinary pipe couple. The depth at which a sample could be taken was thus adjustable by adding lengths of pipe, which were used at 3 feet each, to the sampler tube. In this way any desired depth could be reached. To the top of this pipe was fitted a drop guide (E). This guide was used for the purpose of guiding the drop weight (F) so that the load was applied axially to the sampler. It was a steel rod of $\frac{1}{2}$ inch diameter and 18 inches in length. This was attached to a steel plate, which fitted into the pipe used.

The drop weight used for the purpose of forcing the sampler into the soil was a steel cylinder with a hole in the center of 5/8 inch and two 1 inch round bars as handles. The weight of the drop weight was 35 pounds and since it was always dropped from the top of the guide rod, the force necessary to obtain the sample could be found. The wrenches (I) carried were used to assemble the sampler and separate the lengths of pipe. The grease was used inside the sampler tube so that the sample rings could be removed more easily.

The field compression machine (C) is a wooden frame, having slits along a groove on one side spaced at 1 inch each. These were needed to cut the 1 inch rings apart smoothly with the spatula (H). The base of the compression machine has a number of concentric circles which help to line the sample for the test. The plate on the top of the machine is fitted so that the one needle of the penetration needle (D) will fit into it. After the sample has been placed, the upper plate is lowered to the top of the sample and the needle placed, a force is applied to the needle until the sample fails. The needle records the failing load of the soil, which in turn is recorded in the field notes. The carrying case was designed for the purpose of simplifying the handling of the testing device in the field.

FIELD SOIL SAMPLING DEVICE

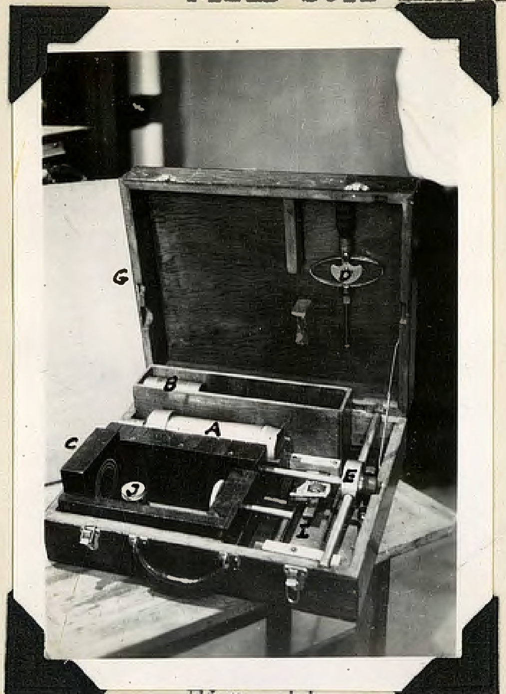


Fig. 11

In field case

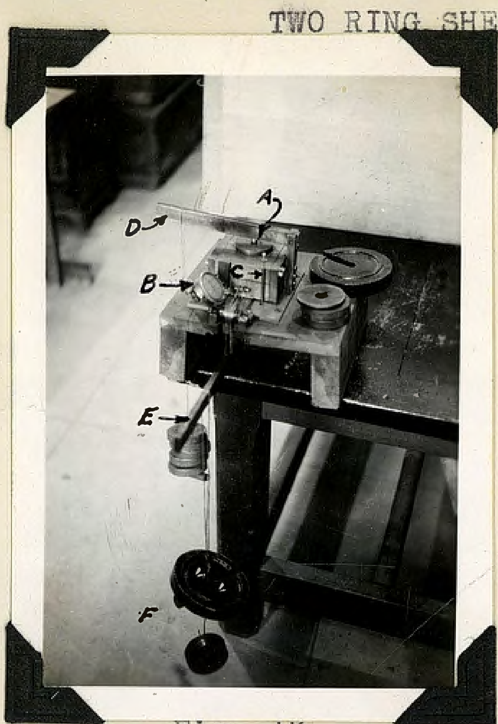
A - Soil sampler
B - Sample rings
C - Field comp. machine
D - Penetration needle
E - Drop guide
F - Drop weight
G - Carrying case
H - Spatula
I - Wrenches
J - Grease jar

Fig. 12

Dismantled

There were two different shear machines used in the laboratory. The two ring machine for single shear, (Figs. 13 and 14) and the three ring machine for double shear,(Figs. 15 and 16. The two ring machine was made up in the following manner. The soil sample (A) is placed into the larger rings of the machine, which in turn fit into the stationary and movable portions of the machine. After the sample was placed, the top, or stationary portion of the machine was screwed to the framework. The Ames dial (B) was attached to the rod on the front of the machine frame and was allowed to bear on the movable section to record the deflections of this under load. The normal load on the sample was then applied through the normal loading bar (D). A plate was placed on the top of the sample and on top of that a ball bearing so that the applied load would be a point load. The normal loading bar was placed on this ball and then loaded by means of one pound weights at a lever arm of 5 inches. The horizontal load is applied by means of the bar (E). The bar is attached to the lower, or movable plate of the shear machine by a wire over a roller bearing. The load is then applied to this bar in increments of one-half pound weights, at either a 4 or 7 inch lever arm. As the horizontal pull is increased by loading this bar, the deflections are read on the Ames dial.

TWO RING SHEAR MACHINE



A - Soil sample
B - Ames dial
C - Pin
D - Normal loading arm
E - Shear loading arm
F - Weights
G - Rings for sample

Fig. 13

Assembled

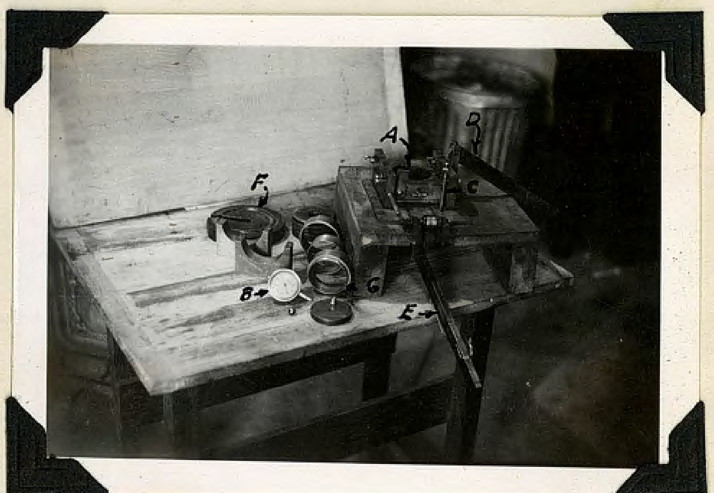


Fig. 14

Disassembled

The three ring shear machine, used for double shear is made up in the following manner. The soil sample (A) is placed in the shearing rings (G&H). It is then loaded by the normal loading device (K), which device by means of the spring (J) is calibrated so that any desired normal load can be applied. The machine is then set up with the stand (D) being placed on the scale (C), the springs (I) are attached to the scale and carried to the loading bar (E) through the threaded screws. As the screws are pulled up, the load on the shearing ring(H) is increased. The Ames dial is attached to the other two rings of the shear machine by the dial holder (F). As the load on the loading bar is increased, the load is read on the scale and the deflection of the shearing ring is read on the Ames dial.

THREE RING SHEAR MACHINE

Assembled

A - Soil sample
B - Ames dial
C - Scale for shear loads
D - Machine stand
E - Shear loading arm
F - Dial holder
G - Rings for sample
H - Shearing ring
I - Loading springs
J - Normal loading spring
K - Normal loading device

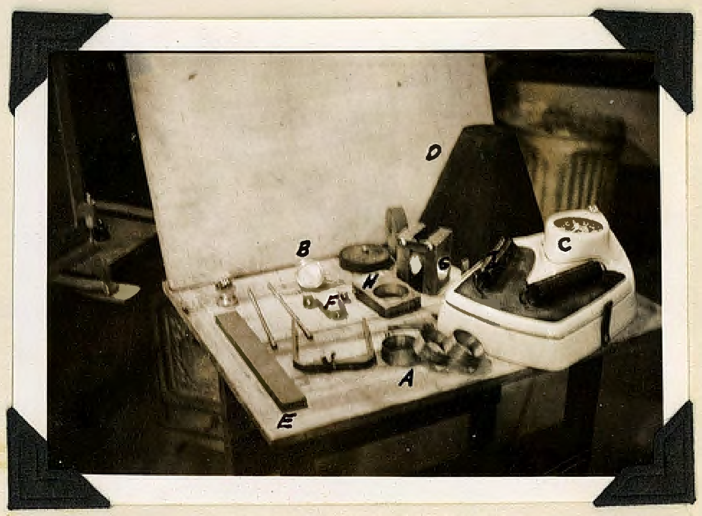


Fig. 16

Disassembled

Typical Load-Deflection Curve of Shear Test

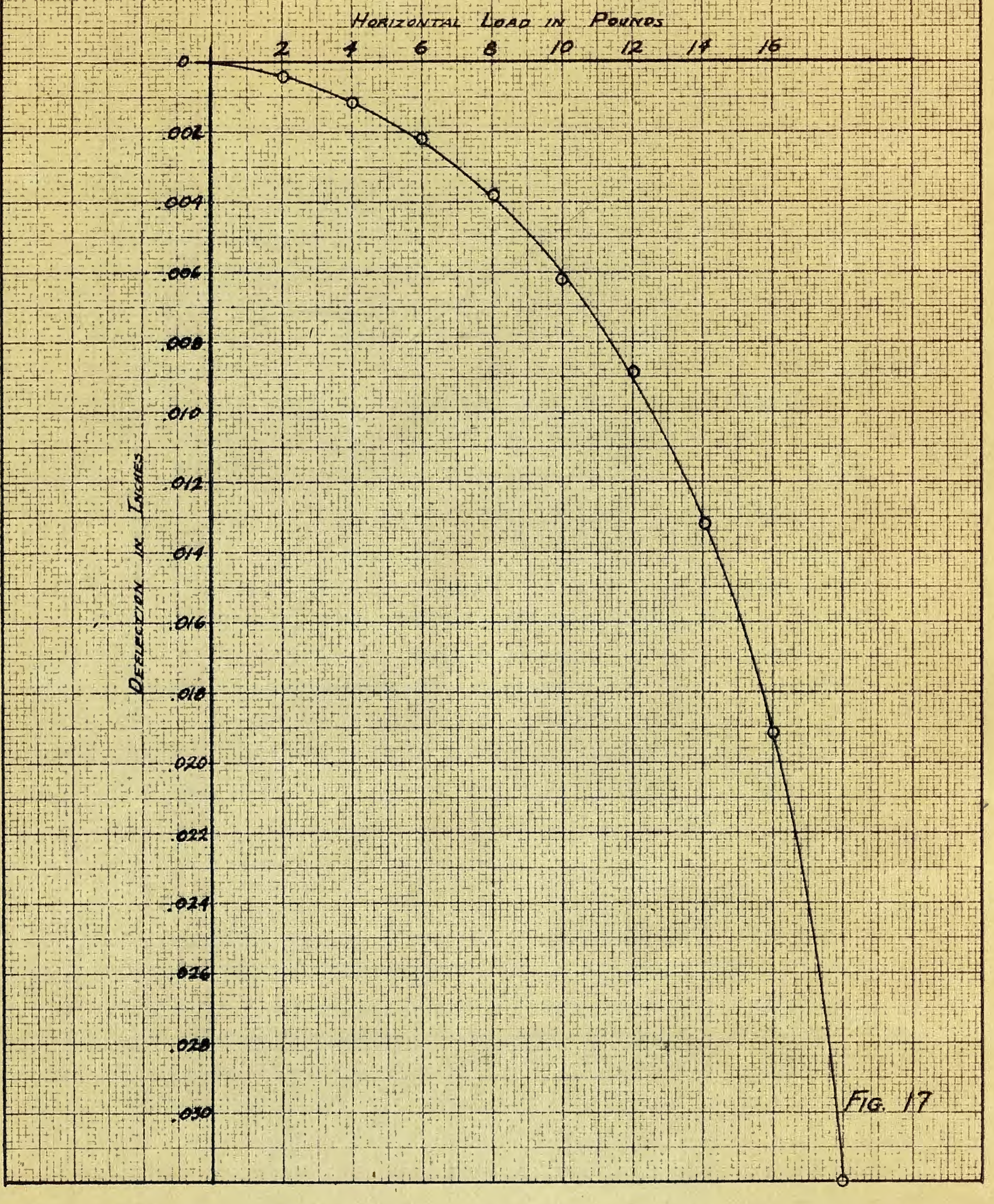
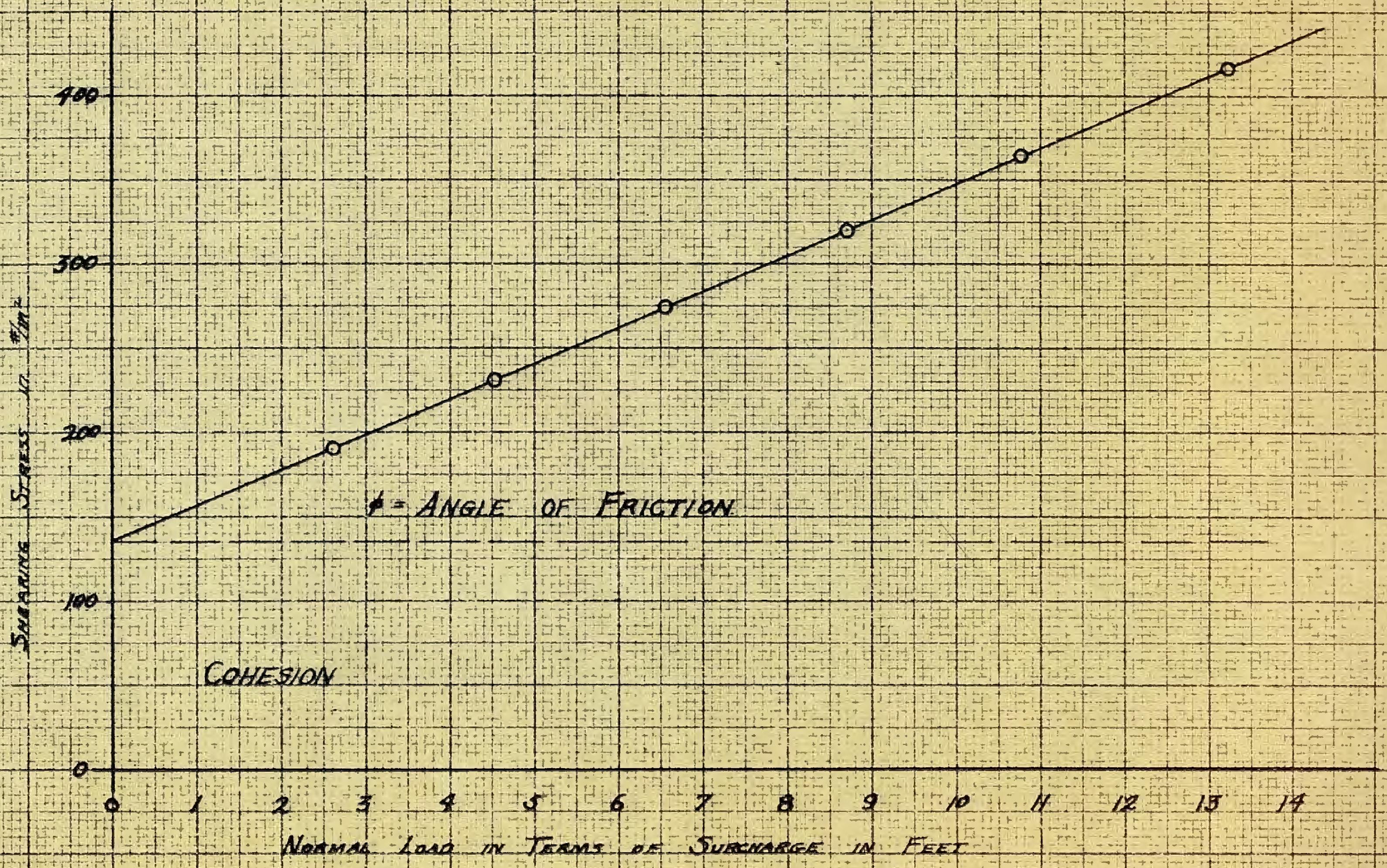


Fig. 17

KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 X 20 to the inch.
MADE IN U. S. A.

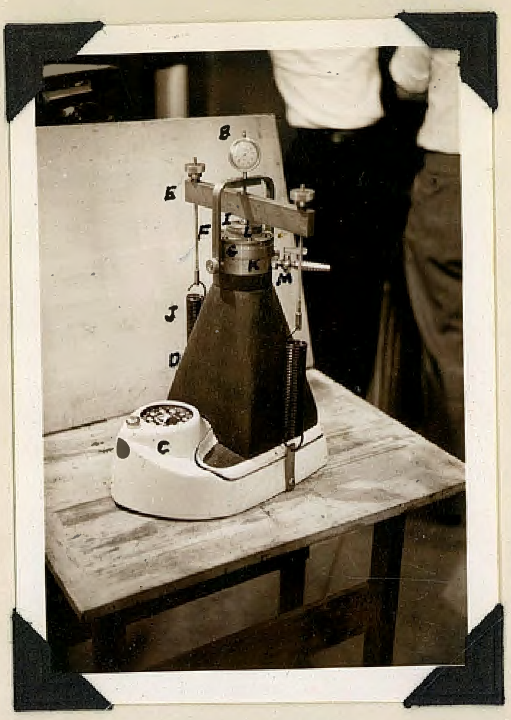


400
300
200
100
0
Shearing Stress in #/in²
φ = Angle of Friction
Cohesion
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Normal Load in Terms of Surcharge in Feet

Fig. 18

The compression machine shown in Figs. 19 and 20 is made up in the following manner. A one inch soil sample (A) is placed on the base plate (K). The ring that hold the sample from lateral expansion (G) is next screwed on the base plate. The top ring (L) is then put in place to hold the sample firm. A porous stone (H) is put on top of the soil sample, and on top of that is placed the loading plate (I). This plate is fitted for a ball bearing so that the load will be applied normally to the sample. The assembled machine is then placed on the stand (D), which in turn is put on the scale (C). The springs (I) are attached to the scale, and by means of the threaded rods are carried through the loading bar (E). The load is applied to the sample through the ball bearing on the loading plate. The dial holder (F) is attached to the base of the machine after the loading bar has been placed. The Ames dial (B) is fitted into the holder so that the shaft of the dial extends through the loading bar and touches the ball bearing. As the sample is loaded by means of the springs, the load is read on the scale and the deflection of the sample is read on the Ames dial. If the load could not be increased sufficiently as set up, either additions to the stand (M) are placed under the machine, or another set of heavier springs are used. In

COMPRESSION MACHINE



A - Soil sample
B - Ames dial
C - Scale for comp. load
D - Machine stand
E - Loading arm
F - Dial holder
G - Ring for sample
H - Porous stone
I - Loading plate
J - Loading springs
K - Base plate
L - Top plate
M - Additions to stand

Assembled

Fig. 20

Dismantled

the way, loads on the sample may have to vary from zero to 300 pounds. Above that point, the other compression machine must be used.

This second compression machine (Figs. 21 and 22) is generally used where heavier loads are necessary. The same one inch sample (A) can be placed on the base plate (F). The case (C) is then fastened to the base plate, and the top plate (D) is put into the case and allowed to touch the sample. Both the base and the top plate have porous stones (H) placed in them. When the machine is set up, the load is passed through a ball bearing to the top plate. The load bar (G) is loaded by one pound weights at a ten inch lever arm. The Ames dial (B) is attached to the base of the machine on a rod, and the deflections of the upper plate are measured on the dial due to the bar extending from this plate.

COMPRESSION MACHINE

Assembled

A - Soil sample
B - Ames dial
C - Case
D - Top plate
E - Loading arm
F - Bottom plate
G - Loading bar
H - Porous stone

Fig. 22

Dismantled

KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 × 20 to the inch.
MADE IN U. S. A.

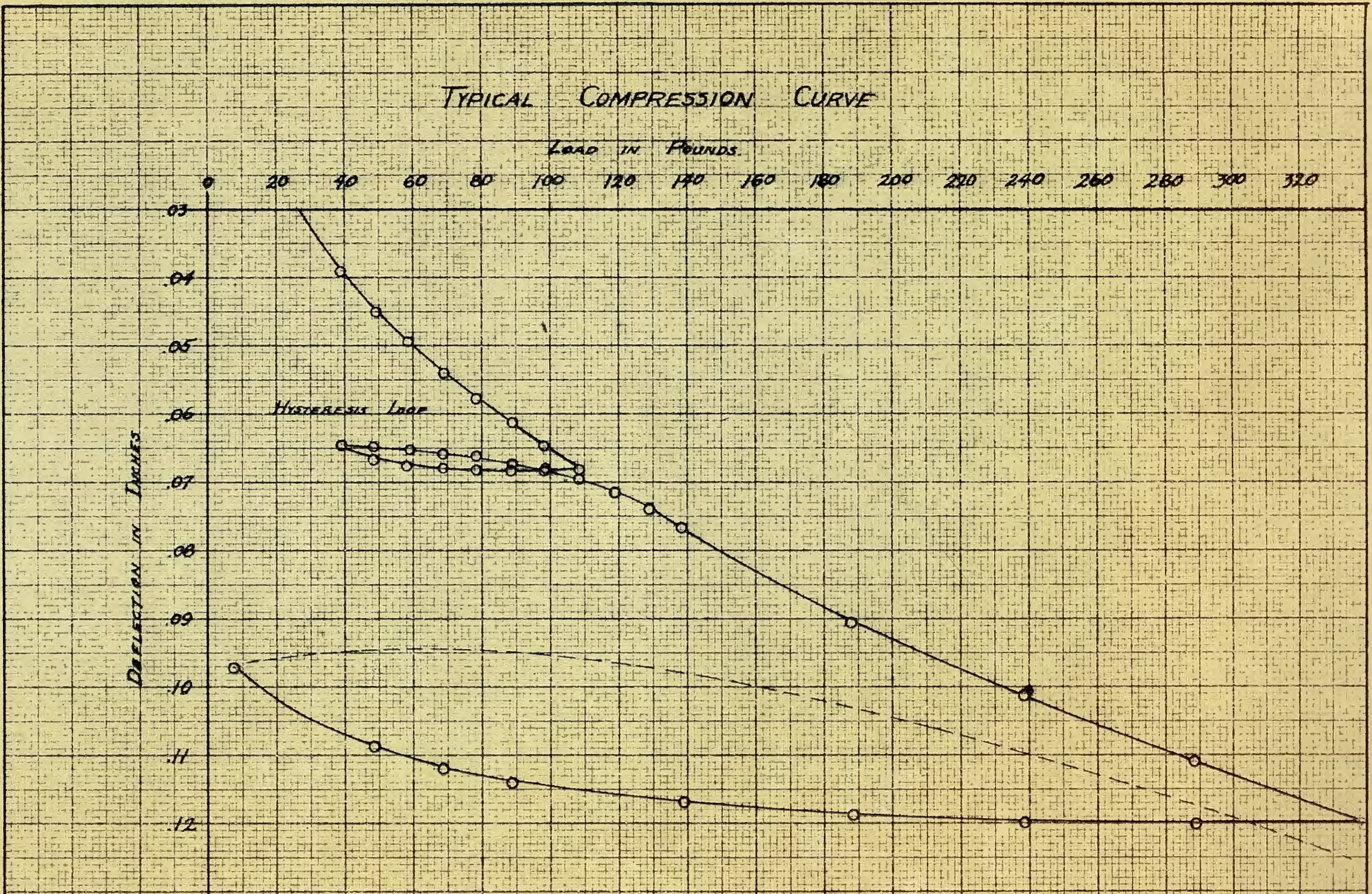


FIG. 23

Shear tests were run on samples taken from the sites both before and after the rainy season. The machine used for this purpose was the one described previously and the sample was broken in single shear only. The procedure in testing for shear is as follows: A two inch sample undisturbed is taken from the sampler and placed in the shear machine at (A). A surcharge equal to the weight of the earth above the original sample is placed in the normal loading device (D). The Ames dial(B) is set and the pin (C) is pulled out, which allows the lower plate to roll out as the horizontal load is applied to lever arm (E). The load is increased in one-half pound increments and the Ames dial is read after all horizontal movement has stopped. After each load has been applied, sufficient time is given for the total movement to take place, the Ames dial is read, and the reading of both the Ames dial and the load are recorded. This is repeated until the sample in the machine fails due to shear along the plane between the two rings. After the sample has been broken, a curve of the load vs. the deflection is plotted. Further testing of the same sample is done using different surcharge loads to determine the cohesion and friction angle of the soil. These tests, however, only require the final shearing load of the sample and the deflection is not read during the test. From these last results a curve is plotted of the shearing load against the normal as shown in Fig. From this curve the friction angle of the soil is found as well as the cohesion value of the soil.

One ring compression tests were run on the sample taken both before and after the rainy season. These tests were run in both of the compression machines described previously. A one inch ring of the undisturbed sample was taken from the sampler and placed on the porous plate of the compression machine. The upper porous plate and loading device were placed on top of the sample and the weight of these was taken to be the original load on the sample. An Ames dial was attached to the machine to record the deflection of the sample under the loads to be applied. After all was arranged, the loads were applied at the rate of five pounds per minute and readings were taken on the Ames dial every one-quarter minute. After the load had reached 80 pounds, it was released at the same rate. After the loading had again been reduced to zero and the deflections read each quarter minute, the loads were again increased. This time the load was allowed to reach 300 pounds and then taken off in the same manner as before. The sample was then loaded in 50 pound increments until 500 pounds were reached. Unloading took place back to 100 pounds and then reloading until deflections became too large to read on the Ames dial. A curve of the load vs. the deflection for each soil in both the dry and saturated stage was plotted. These curves clearly shows the hysteresis loop obtained by releasing and reapplying the load as was done in the test. From these curves some idea of the bearing value of the soil could be obtained and therefore proved very useful.

Now let us consider the tests that were run in the laboratory. These tests can be divided into three main classifications. First, let us take up the so-called rainfall tests. These tests were run on the eight inch pipes, six feet long. Soil was compacted in the pipes at three different compactions. The lower end of the pipe led into a funnel which in turn drained into a glass graduate. The top of the tubes were sealed with wax, allowing a few openings through which the water was allowed to pass. The tubes had $1\frac{1}{4}$ inch holes placed at every foot in elevation and through these holes samples were taken. All joints and openings were sealed with wax to prevent the evaporation of water from the experiment. The amount of water to be applied to the pipe was calculated on the basis of assuming that the entire rainfall of a season was dissipated within the top six feet of earth. After this volume had been computed, the distilled water was applied to the top of the pipe through the opening provided. The water was applied at the rate at which it percolated through the soil. A record was kept of the amount of water and time of placement. It was found that after 55% of the water had been applied to the surface, it began to flow from the bottom of the pipe. This meant that the rainfall test had turned into a true percolation test, and hereafter will be considered as such. Another scheme was used whereby the water was applied at a much slower rate, but this resulted in the same type of test after the same amount of water had been applied to the top of the pipes.

Before considering the percolation tests, let us briefly outline the capillary tests. These tests were run in the eight inch tubes, but having a length of nine feet. Due to the small amount of available information on the subject of capillary rise in soils, it was thought that a possible solution to the problem could be obtained in this manner. There was no definite available information as to the height of capillary rise in any soil, therefore, it was decided to use the nine foot tube to allow for what the authors believed to be the maximum possible rise in this type of soil. The tube was placed in a larger container which in turn was partially filled with pea size stones. On top of this was placed the tube which was packed with the soil to be tested. In the lower container, distilled water was placed as the capillary rise in the soil drew the water out. This was continued for 14 days after which time samples were taken at each 1 foot elevation of the pipe. After allowing to stand for another 7 days, samples were again taken. All the samples of these eight inch tubes were taken by means of a brass sampler especially constructed for the purpose of obtaining these samples. This sampler is a one inch brass tube, twelve inches long and has a removable handle. The corks which are used to plug the holes in the pipe were removed and the sampler inserted. This brought out a sample of soil of the entire cross-section of the pipe. The sample was then split up into six parts and every other one was placed on a watch crystal and weighed and placed in the drying oven to obtain the moisture content of the soil at the point tested. The precaution of dividing the sample in this manner was to assure an accurate representative sample being taken. This also allowed for any slight variation on the moisture of the soil along the sides of the pipe. Every precaution was taken so that true results along this line could be contained.

LARGE PERCOLATION TEST

Fig. 24

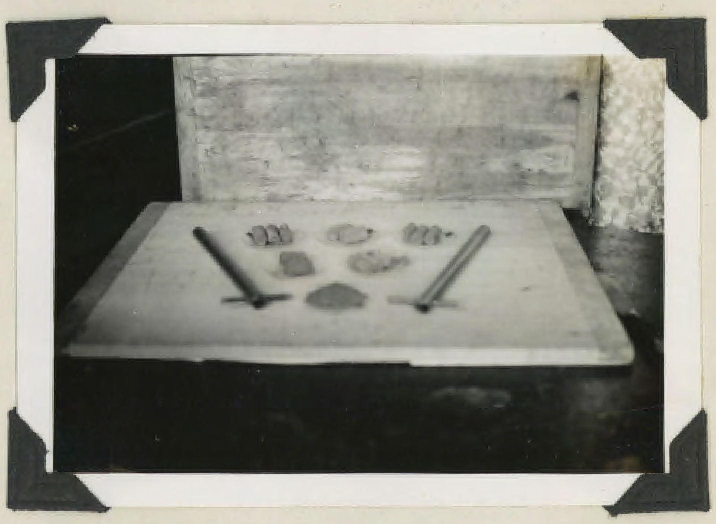


Fig. 25

Lastly let us look into the operation of the percolation tests. These tests were a result of the percolation of the water in the rainfall tests, and then were converted into the percolation tests here described. The water was allowed to percolate through the soil until a continuous flow was established. The outflow from the bottom of the pipe into the graduated cylinder was measured until the flow came through at a definite rate. This was measured a number of times and recorded. While the water was thus percolating through the soil, samples were taken at every foot by the sampling device in use. These samples were obtained in the manner previously described and tested for moisture content. The water entering the top of the pipe was stopped and the pipe allowed to drain into the glass graduate. After the pipe had drained for a period of 14 days samples were again taken and tested for moisture. This was again repeated after the pipes had stood for another 7 days.

In all there were four such percolation tests run, all having different compaction of the soil. In order to be sure that the soil in the pipe at the time of placing was in the same condition, the original moisture content was made the same in all pipes. The most optimum moisture for the raw soil was obtained by penetration tests. These tests were performed in the laboratory according to the procedure outlined by Proctor in his article on Soil Compaction.

From these tests were found the moisture content for greatest compaction of the soil, and it was at this moisture content that all of the pipes were compacted. That is all the tests that were run on the large tubes and it was felt that sufficient data was obtained from these so that smaller tests could be run and the data derived from them would be checked by the larger tests.

In the smaller percolation tests, there are three varities. First, there is the what the authors chose to call, true percolation tests. These tests consisted of placing the soil in an eight inch tall 2½ inch diameter brass ring and compacting to the desired density. These are the standard size rings used in all testing apparatus in the laboratory. The tube was placed on top of a porous stone, which in turn was placed in a special glass with proper drainage. Distilled water was allowed to flow into the top of the soil until percolation through the sample was established. As soon as this percolation was established, the water supply was cut off and the tube allowed to stand and drain for 24 hours. The soil was then sampled, both at the top and the bottom of the tube to determine the moisture content. This was done for the purpose of checking if the tube had drained until the moisture was at an equilibrium point throughout the soil. In case the percent moisture in the top and the bottom of the tube did not check the test was discarded. In this manner only the thoroughly drained tests were used.

In the second type of small tests we have what was called the vacuum drained tests. These tests consisted essentially of a percolation test, but instead of allowing the tube to stand for a period of 24 hours to drain, a vacuum was applied to draw out the excess moisture in 10 minutes. The setup for these tests is as follows: The eight inch tube is placed in the lower portion of the compression machine previously described and filled with compacted soil. Distilled water is placed on the top of the sample until flow is established by percolation. As soon as this flow is constant, the stopcock on the testing machine is applied to the vacuum device in the laboratory. This puts a vacuum on the bottom of the soil, through the porous stone, of 23 inches on Mercury.

This vacuum was allowed to draw on the soil for a period of 15 minutes. After this time, the soil was sampled at both the top and the bottom, and in all cases it was found that the moisture content of both samples were the same.

The last variation of this type of testing consisted of the vacuum percolation test. This was set up in the same manner as the previous test. The difference lies in the fact that instead of the water being allowed to percolate through the soil under its own head, it was drawn through the soil by means of the vacuum arrangement. The rest of this test was run in the same manner a s the vacuum dried test.

Results from this test indicate that it is not to be recommended for this purpose. The change in the nature of the compaction of the soil causes considerable trouble.

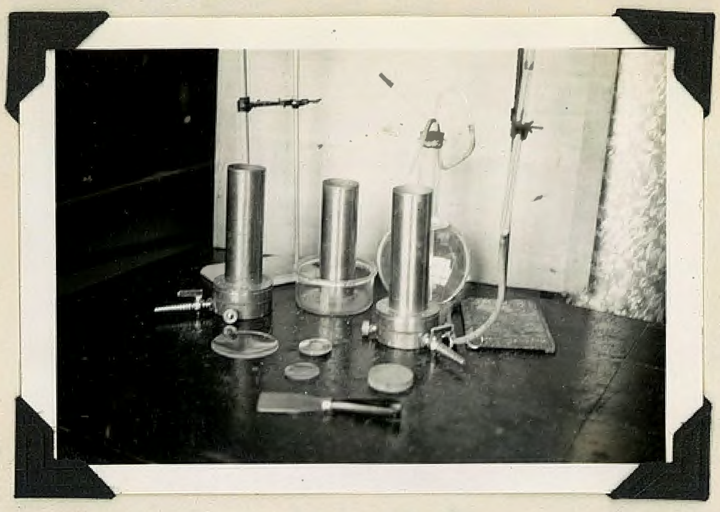


Fig. 26

Fig. 27

CHAPTER V

TEST RESULTS AND OBSERVATION

After ascertaining that the rainfall tests had turned into true percolation tests, new pipes were set up to run the percolation tests for various compactions. Tests for the moisture content at maximum compaction were run, and this moisture determined. In the percolation tests there were three compactions used. These were 35, 64, and 90 Kg/cm^2. Moisture contents at the 1,2,3,4, and 5 foot elevations of the pipe were taken. Following is a summary of the results obtained from these tests considering each compaction separately.

Sample Ex. tested at a compaction of 35 Kg/cm^2, and having an original moisture content of 3.20%. Soil sampled after percolation period of two days, during which time the water was percolating through the soil at a rate of 167 cc. per hour. The moisture content at 1,3, and 5 feet during this time was found to be 19.02, 18.05, and 18.13 percent. The increase in moisture at the one foot level was due to the retardation of the moisture in passing from the soil through the lower plate. The area of the holes in the plate did not appear to be sufficient to take care of the moisture at this rate of percolation and it had a tendency to pond at the bottom.

rate of percolation and it had a tendency to pond at the bottom.

At this time the supply of water at the top was stopped and the pipe allowed to drain under natural conditions. After 18 days of such drainage the soil was again sampled. This time samples were taken at each one foot elevation. The moisture contents at the 1,2,3,4 and 5 foot elevations give the following results: 21.26, 15.60, 12.10, 11.69, and 8.10 percent. Again it might be said that the increase in the moisture content of the one foot elevation is due to the retardation of the water at the base of the pipe. The percolation from the bottom of the pipe at the time these samples were taken, was less than 1 cc. per hour.

Sample Ex. tested at a compaction of 65 Kg/cm^2 and having an original moisture content of 6.45%. Soil sampled after the water had percolated through the soil at a rate of 167 cc. per hour. It was then allowed to stand for 8 more days and the water was percolating through at a rate of 50 cc. per hour and then sampled. Samples were taken at the 1,2,3,4 and 5 foot elevations and the corresponding moisture contents were 20.30, 15.10, 17.96, 12.40, and 12.88 per cent. After the soil had stood for another 12 days and the percolation had been reduced to less than 1 cc. per hour, the final samples were taken on this test. These samples resulted in the following values for the 1,2,3,4 and 5 foot elevations. Moisture content 19.12, 16.15, 12.79, 11.28

and 6.95 percent. The final samples were taken at this flow because it was believed that the soil had reached an almost stable condition at this time.

Sample Ex. tested at a compaction of 90 Kg/cm^2 and having a moisture content of 6.28 per cent. The first samples taken on this soil were after the water had percolated through at the same rate as through the previous samples. It was also allowed to stand for a period of 8 days before sampling at which time the percolation was 50 cc. per hour. Samples were taken at the 1,2,3,4 and 5 foot elevations gave the moisture contents of 19.51, 16.63, 12.57, 15.80 and 13.50 percent. After the soil was allowed to stand and drain for another 12 days and the percolation from the bottom was less than 1 cc. per hour, the final moisture content samples were taken. The values at the 1,2,3,4 and 5 foot elevations gave 18.62, 15.84, 12.27, 11.12 and 7.42 percent. This constituted the results obtained from the percolation tests in the large tubes.

Two large capillary tests were run in the laboratory at different compactions. The first run at a compaction of 35 Kg/cm^2 and having initial moisture content of 3.80 percent. Water was ponded in the container at the bottom of the pipe continuously during the test. A period of 5 days elapsed before any sampling was done. At this time samples were taken at the 1,3,5 and 7 foot elevation. The moisture content at these points was 15.59, 4.16, 3.77 and 3.79 percent. The tube was again sampled 9 days after the start of the test. This time the moisture content at 2 and 4 feet read 6.37 and 4.34. The final moisture test was taken 14 days after the test was started and values at 0,1,1½,2,2½ and 3 feet were measured. These were, 38.3, 20.2, 20.05, 15.37, 11.44 and 9.75 percent. The moisture at higher points was not measured because it was felt that it did not change enough to warrant the measurement of it.

The second capillary run was at a compaction of 95 Kg/cm^2 and had an original moisture content of 6.00 percent. The test was run in the same manner as the previous one. Only one set of samples were taken after the test had been running for 21 days. The soil was sampled at the 1,2,3,4 and 5 foot elevation. Moisture contents at these points were 19.88, 13.10, 8.18, 5.43 and 5.69. The soil above that point did not appear to be effected by the capillary water at all.

Two types of small tests were run in the laboratory. In the first, the compaction of the soil was varied and all the samples were allowed to percolate in a natural manner. Following is a summary of the results of these tests. All tests were run on sample Ex.

Results of Varying Compaction Tests

Tested in $2\frac{1}{2}$ inch tube.

Compaction in taps	Moisture content in %	Moisture at top in %	Moisture at bottom in %	Water put on soil in cc.	Time after Percolation minutes
1	6.98	21.00	13.13	26	30
1	6.98	22.21	21.64	52	30
3	6.98	21.60	13.88	26	30
3	6.98	23.40	23.90	52	30
3	6.98	20.79	21.40	52	1440
3	6.98	19.43	14.12	26	1440
3	6.27	24.60	28.10	perc	135
3	6.27	20.30	20.42	perc	1080
5	6.27	23.30	24.10	perc	135
5	6.27	21.45	19.40	perc	1080
10	1.44	21.10	21.15	52	15

The amount of water placed on these samples was calculated on the assumption that all the surface water remained in the top six feet of the ground. On this basis the water needed over the area of a test ring for an equivalent 20 inches of rainfall was 52 cc. It might be noted that although the compaction of the various tests were changed, the moisture content remained essentially the same in all cases. This is in support of the tests run on the large percolation tubes.

In the second set of tests, the compaction of the soil was kept constant and the method of permitting the water to flow from the sample was changed. There were three schemes used to accomplish this. The first was the simple percolation test, in which the water was allowed to pass out of the sample under gravitational forces only. In this case the period of permitting the sample to stand and percolate was varied. However, in this case, the sample was allowed to percolate under natural conditions before standing. Results from this test are given below, test run in eight inch tube. The second condition under which the sample was tested was to allow the water to percolate through the sample naturally, and then draw the excess moisture from the bottom of the tube by means of a vacuum placed at the bottom of the tube. The third test was to run the water through the sample by means of the vacuum and then exhausting the water by the same vacuum. A summary of the results on the three cases is shown below. These tests were run on Sample Ex. and show the same results as the other tests run on the larger tubes.

Results of Small Percolation Tests

Position of sample	Time after percolation	Original Moisture	True perc.	Vacuum Dried	Vacuum Test
Top	3600	5.32	18.04		
Bottom		5.32	20.70		
Top	3840	5.32	18.68		
Bottom			19.61		
Top	5	5.32		18.80	
Bottom				16.42	
Top	30	5.32		16.27	
Bottom				18.35	
Top	60	5.32		16.20	
Bottom				15.60	
Top	15	5.89		14.58	
Bottom				16.35	
Top	30	5.32		16.35	
Bottom				17.53	
Top	30	5.89			16.32
Bottom					18.13

A few tests were run on different field samples under the same conditions as the last set. These tests gave the following results which were to be expected of the soil tested. As more samples are tested, a more definite assurance of this method of testing can be had, and the results be proven. Up to the present time only the following two samples have been tested. Sample No. 1006 which was tested by percolation and then dried by the vacuum method. The moisture content at the top of the sample was 26.30% and at the bottom was found to be 23.75%. The tests run on sample No. 1009 gave the top moisture to be 31.00% and that at the bottom at 31.25%. Conditions for all of these tests were as nearly alike as it was possible to obtain them.

The results of the Standard Tests run on the soil samples are given in condensed form at this point. Only those values which the authors thought necessary are given in this table. The soil classification used is that of the United States Burear of Public Roads. The test results omitted were not completed due to lack of time and the pressing need of the other tests which were more directly connected with the research program.

<u>Standard Test Results</u>

Sample Number	Type of Soil	Density	Specific Gravity	Liquid Limit	Plastic Limit	Shrinkage Limit
1001	Sandy Loam		2.50	17.9	17.2	17.68
1002	Sandy Loam		2.57	17.4	16.6	17.50
1003	Loam		2.41	17.9	17.1	18.15
1004	Sandy Loam		2.46	13.0	12.1	19.50
1005	Sandy Loam		2.66	13.2	13.0	18.95
1006	Sandy Loam		2.75	16.9	15.1	31.60
1007	Sandy Loam		2.43	21.6	19.0	20.05
1008	Loam		2.30	19.0	16.7	20.85
1009	Sandy Loam		2.75	21.6	17,8	30.00
1010	Sandy		2.81	19.2	16.2	29.14
1011	Sandy Loam		2.81	--	--	25.81
1012	Sandy		2.95	--	--	33.11
1013	Sandy		2.71	--	--	--

KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 X 20 to the Inch.
MADE IN U. S. A.

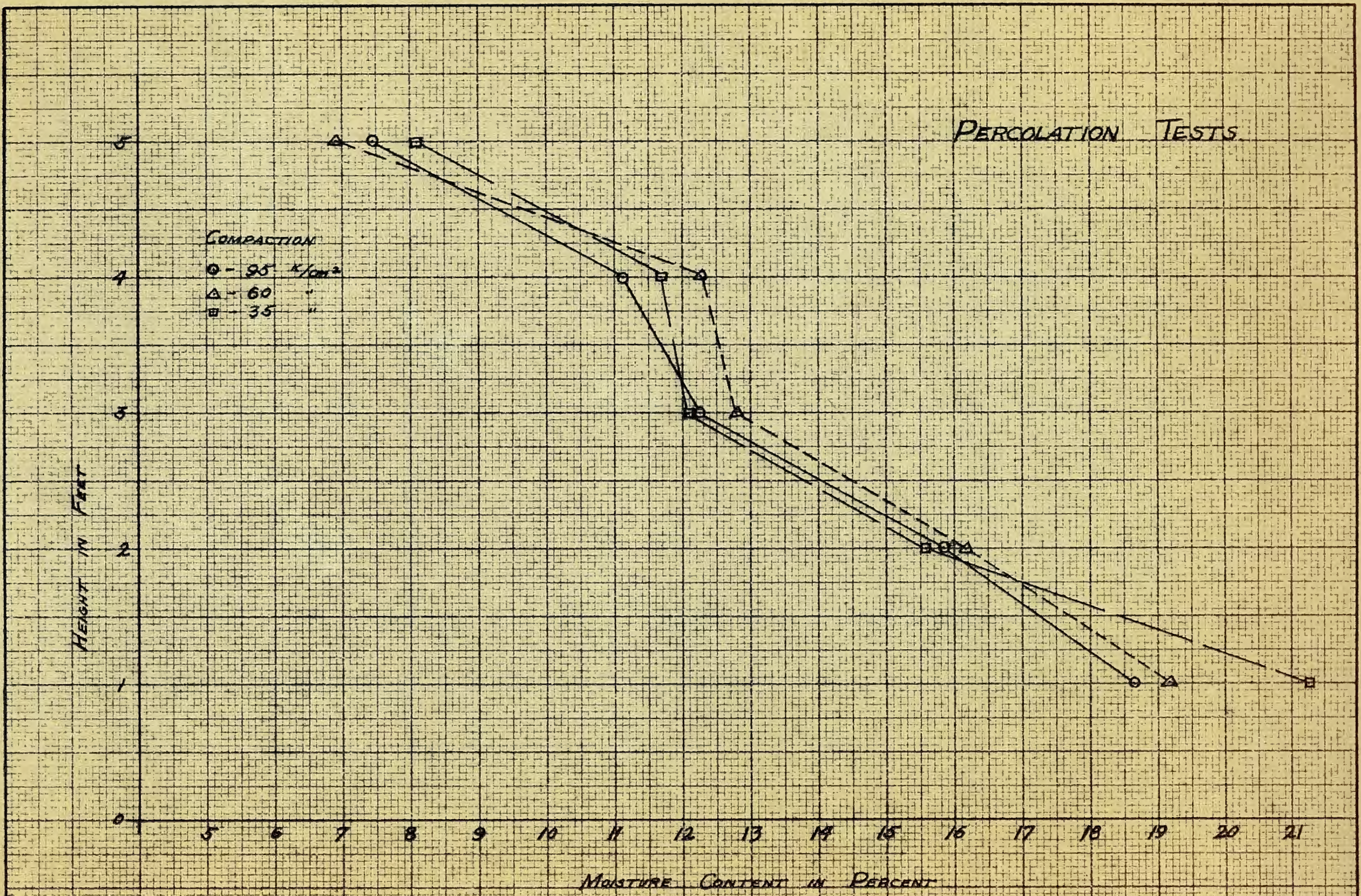


FIG. 28

KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 20 to the inch
MADE IN U. S. A.

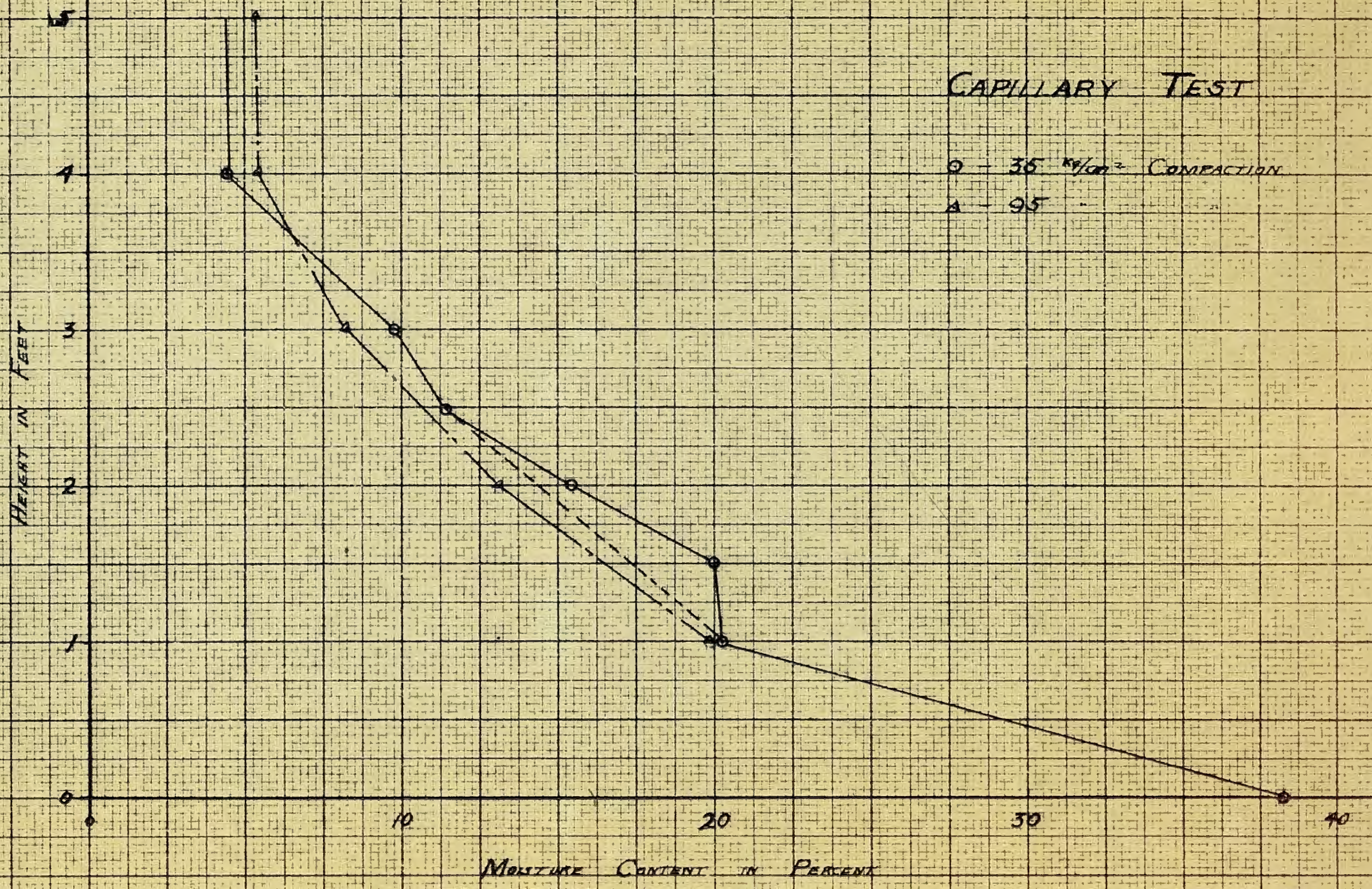
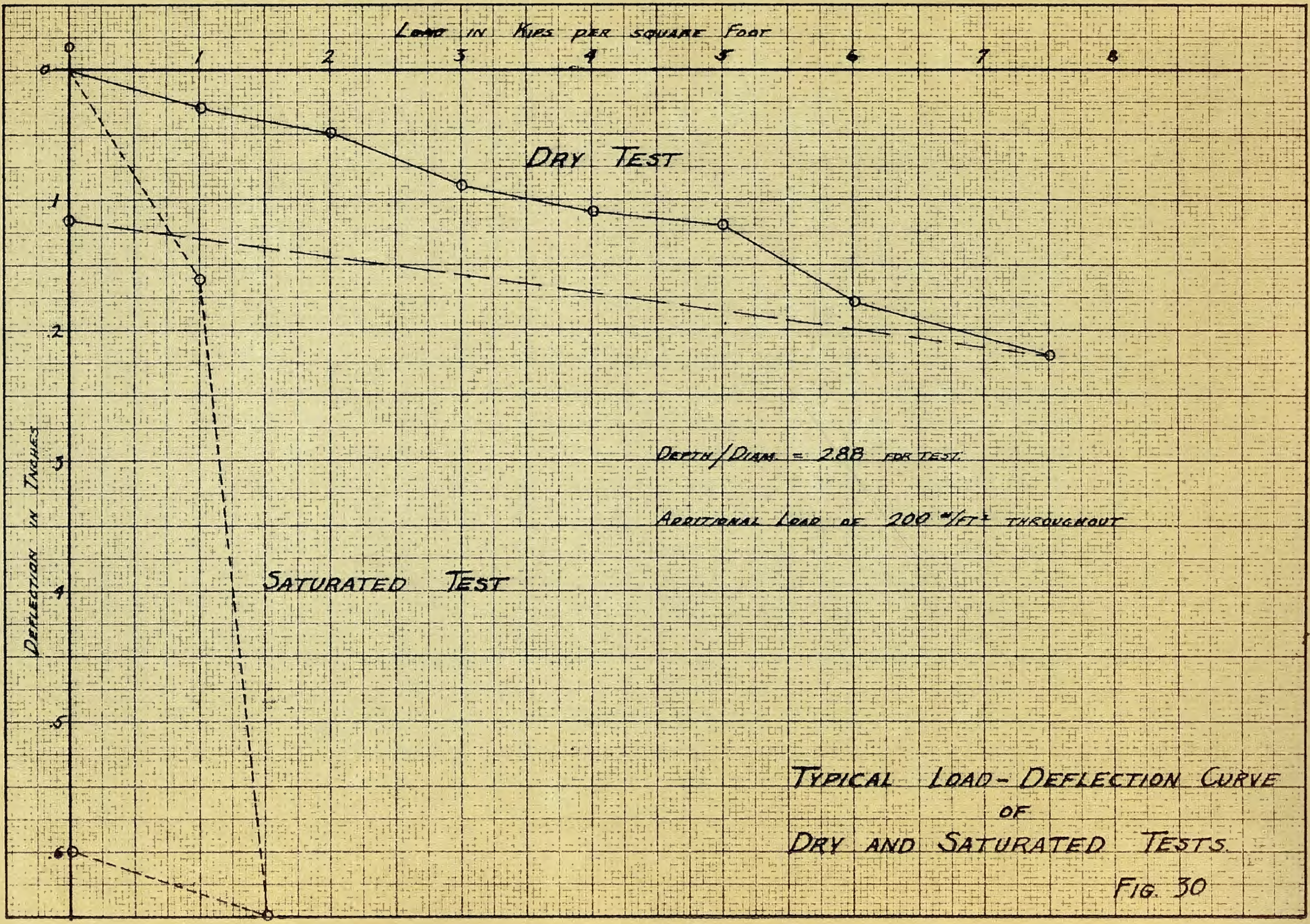


FIG. 29

KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 × 20 to the inch
MADE IN U. S. A.



TYPICAL LOAD-DEFLECTION CURVE
OF
DRY AND SATURATED TESTS.

FIG. 30

CONCLUSIONS

The following are tentative conclusions reached from the tests run in the laboratory and herewith written up in detail. It is the authors hope that these tentative conclusions might be augmented and verified at an early date by additional laboratory testing.

1. Percolation of the water through the soil is not affected by the compaction of the soil. The results of the tests run on the large percolation tube show that the varying compaction at which the soil was placed had little or no effect on the moisture content of the soil. This was true both during actual percolation of the water through the soil, and after the water had drained and a more or less stable moisture content had been reached. The curve plotted of the various compaction having the moisture content plotted against the height at which the sample was taken brings this out more clearly. The curve was not drawn in, due to lack of sufficient data along this line. From the point given by the tests it appears that the curves would be a reverse nature. However, the lower three points, and the upper two of each compaction can be connected by a straight line without much error. There appears to be a point at which the three curves cross; this cannot be explained yet. One point is clear from the values plotted and that is the slight variation in the moisture content for the three curves.

2. Capillary rise through a soil is not affected by the compaction of the soil. The graph of the compactions plotted of the height at which the sample was taken against the moisture content show that this is true. The lack of sufficient points on this curve again makes it necessary that the points plotted be connected by straight lines only. The moisture at zero elevation is the same in both cases. The point at the 4 foot elevation is the moisture content at which the soil was compacted in the pipe. The intermediate points seem to indicate that they could be on the same curve and thereby prove the compaction has no effect on capillary rise.

3. The small percolation tests indicate that the compaction as well as the type of test used has no effect on the final moisture content of the soil. From the tests run on the experimental soil having various compactions in the small tube, the results are sufficiently close as to lead the authors to believe that the variation in them might be due only to experimental errors. In the tests run on the eight inch under the true percolation, vacuum dried, and complete vacuum tests, the results are again such that they indicate that the tests all give the same result in the end.

4. Tests run on different soils show that they give value which might approximate actual conditions. The change in the moisture content of the few samples tested give

confidence to this type of testing. More samples must be tested before this can be definitely determined. The samples tested give value higher than those obtained from actual field conditions, and are therefore on the safe side in testing. A slight refinement to this test might give the actual field conditions desired.

5. Following is a suggested procedure for the testing of dried, or partially dried, field samples for bearing and settlement values under load during the rainy season. An eight inch sample should be taken out in the field. This sample was then placed in the compression machine. A vacuum percolation test is run on the sample to get the moisture content for the settlement test. The compression test is then run on this sample and values fairly near to actual conditions should be obtained. The curve shown here is of a field test of one of the soils used in the laboratory. It shows the values obtained from a dry test made during the summer season on the field moist soil, and one made under the present practice of a saturated soil test. The values obtained from the latter test are much too low as shown in this fact was proven when the building placed on this soil did not settle slthough the loading was much greater than that of the test. By the procedure outlined above, it is the belief of the authors that a test result very much nearer the actual conditions could be determined in the laboratory.

confidence to this type of testing. More samples must be tested before this can be definitely determined. The samples tested give value higher than those obtained from actual field conditions, and are therefore on the safe side in testing. A slight refinement to this test might give the actual field conditions desired.

5. Following is a suggested procedure for the testing of dried, or partially dried, field samples for bearing and settlement values under load during the rainy season. An eight inch sample should be taken out in the field. This sample was then placed in the compression machine. A vacuum percolation test is run on the sample to get the moisture content for the settlement test. The compression test is then run on this sample and values fairly near to actual conditions should be obtained. The curve shown here is of a field test of one of the soils used in the laboratory. It shows the values obtained from a dry test made during the summer season on the field moist soil, and one made under the present practice of a saturated soil test. The values obtained from the latter test are much too low as shown in this fact was proven when the building placed on this soil did not settle slthough the loading was much greater than that of the test. By the procedure outlined above, it is the belief of the authors that a test result very much nearer the actual conditions could be determined in the laboratory.