Experimental research on the problem of determining the maximum moisture content of soils under footings by means of laboratory vacuum tests.

In partial fullfillment of the requirement for the degree of Master of Science in Civil Engineering.

California Institute of Technology

Pasadena, California

June 1, 1939

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Introduction

Within the last twenty years the study of soil, and its behavior as related to building construction, has become increasingly important. Of particular importance is the determination of allowable soil loadings which may be applied without disastrous results. Every year more buildings must be erected on soils which may be of a questionable nature, and thus the need of more information concerning bearing values. Lack of such information may lead to disastrous results as exemplified by the failure of many large and important structures of Mexico City.

Closely related to the problem of bearing values for differnt soils is the problem of determining the maximum moisture content which the soil is apt to have in its natural and undisturbed position. It is generally acknowledged that the shearing value of a soil plays an important part in the determination of bearing values, and in turn the moisture content of a soil affects the shearing values. If there were some manner of determining what maximum moisture content could be expected in different soils, by laboratory tests, probable bearing values of soils could be obtained more easily and accurately.

As a preliminary thought, it must be recognized that soil above the water table is seldom saturated except for a few inches at the surface during exceptional rains. Also, the soil is seldom dry, since some water is very closely bound to the soil particles. Somewhere between these two extremes, it is believed, there is a natural maximum moisture content which will not be exceeded. This value in general will not be exceeded since the various forces acting on the moisture such as capillary forces, gravity, molecular attraction, etc., strike a balance preventing the storage of more moisture.

Several research projects have been undertaken at the California Institute of Technology to determine what the maximum moisture contents of soils are and how such moisture contents can be duplicated by laboratory process. George M. Dorwart and Walter L. Moore in the year 1938 were very fortunate to obtain data on the maximum moisture content of certain soils, since in that year an unusually wet season was experienced. In 1937 Harold J. Alwart and Abdurrahim Servet made several tests to try to correlate maximum moisture contents with laboratory tests. Some of the tests attempted were large percolation tests and small percolation tests, and vacuum tests.

The tests of Dorwart and Moore indicated that the vacuum test showed fairly good results for maximum moisture content if a vacuum of eight inches of mercury was held for about thirty minutes. These tests however were made on only one general type of soil. After a consultation with Professor F. J. Converse of the California Institute of Technology, Civil Engineering Department, it was concluded that the results of the vacuum tests looked promising of results if used on different types of soils. Thus the authors of this thesis, R. W. Folkins and A. W. Sidler, decided to continue the research of maximum moisture content hoping to find the vacuum test an answer to the problem.

Thus the more direct object of this research was to gather soils of varying type and to test them under vacuums of different strength and for different periods of time so as to attempt to determine a standard test for groups of soil or separate soils. Also, it was hoped by the authors that the seasonal rainfall would be sufficiently heavy so as to enable collection of data on maximum moisture contents. However, the seasonal rainfall was light and the collection of such data was discarded.

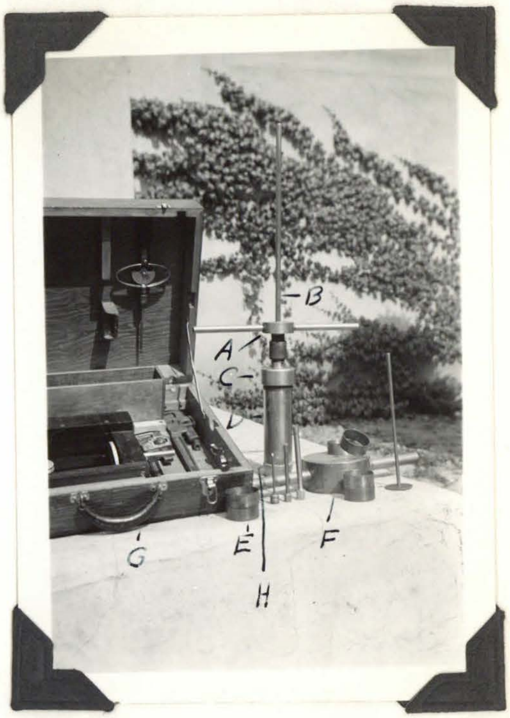
Apparatus

Soil Auger:

The soil auger, used in boring holes to the desired depth at which soil samples were taken, was of standard design, having an effective diameter of six inches and length of nine inches. Rigidly attached to the boring head was a three foot length of three quarter inch pipe. Additional three foot lengths of pipe were available so that by coupling the parts together holes could be bored to any desired depth. The handle consisted of a wooden cross bar with a screw connection for fastening to the pipe extensions. The probable maximum depth to which holes could be effectively bored would be approximately 18 to 20 feet.

Soil Sampler:

The soil sampler consisted of a cylindrical steel barrel, $2\frac{1}{2}$ inches inside diameter and $8\frac{3}{4}$ inches in length. The bottom edge had a sharpened lip for cutting and penetrating the soil, and the top end was threaded with fine threads so that a steel cap could be screwed on the barrel. The cap had a threaded projection to which a one inch pipe coupling was attached. Three foot lengths of one



—Soil Auger—

A. Extensions

B. Auger Head

—Soil Sampler—

A Driving Head

B. Guide Rod

C. Barrel Cap

D Sampler Barrel

E Sampler Rings

F Driving Hammer

G Sampler Case

H Driving Edge

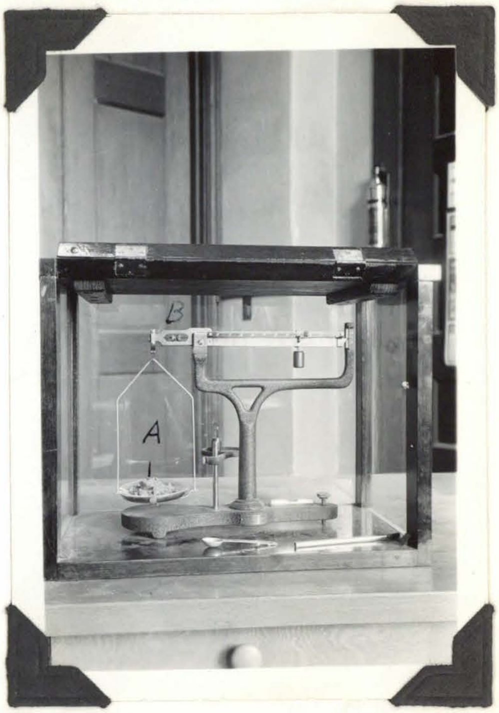
inch pipe were available so that they could be attached to the head and to each other making the stem extension as long as desired. To the top end of the pipe stem was applied a driving head which was of steel about one inch thick and three inches in diameter. Two horizontal rod projections from this head served as handles and one vertical projecting rod served as a guide for the driving weight. The guide was of such a length as to enable the hammer to drop 18 inches. The driving hammer was a 22pound steel cylinder with a small hole in the center to enable the hammer to slide down the vertical guide. Two steel handles were attached to the hammer for lifting purposes.

Sampler Rings:

The sampler rings were made of machined brass. Each ring had an outside diameter of $2\frac{1}{2}$ inches and a depth of one inch. The inside area of the rings was 4.56 square inches. Eight rings, slipped into the sampler after oiling, made up the charge of the sampler. These same rings were of just the correct size to fit the permeometer and the shear machine.

Oven:

The oven used in drying samples for moisture



— Oven —

A. Heat Control

B. Tongs

— Scales —

A. Sample

B. Rider

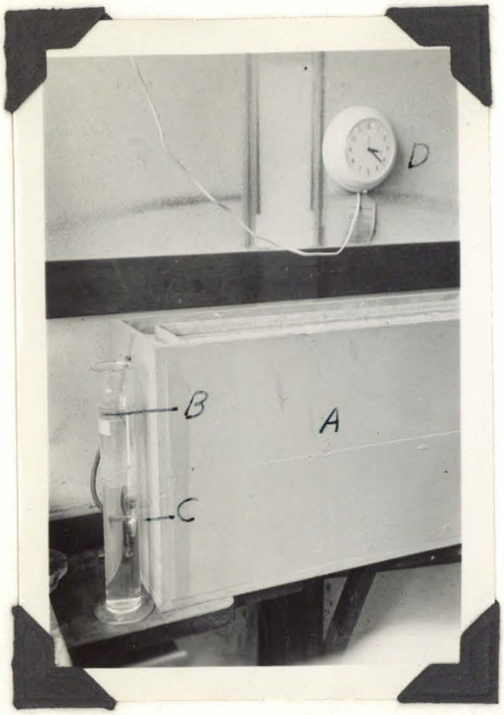
content determinations was a Thelco electric oven with dimensions of twelve inches high, twelve inches deep, and eighteen inches wide. The oven was equiped with a heat control unit which regulated the temperature and held it constant. The temperature maintained in all tests was 110 degrees Centigrade.

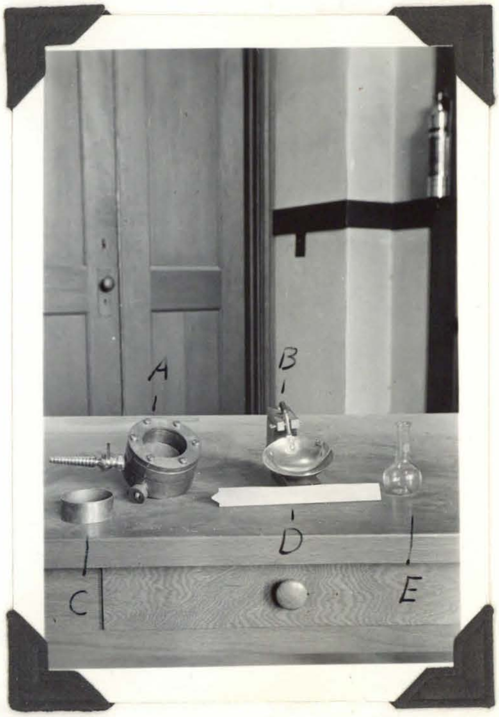
Scales:

Scales used in weighing samples were of a beam balance type with a capacity of 200 grams. A threaded rider was fixed to the beam so as to balance the scales at the zero reading. The scales were placed in a glass case to prevent disturbances due to air currents. A bubble level on the scales enabled the operator to bring the scale to a level position for accurate weighing. The scale could be read to 0.01 grams.

Liquid Limit Device:

The liquid limit device consisted of a light metal dish about $4\frac{1}{2}$ inches in diameter and about one inch deep, mounted by means of a hinge to a flat wooden block which absorbed the shocks of the falling dish. A cam device working against the hinge lifted and dropped the dish against the wooden block. A small handle rotated the cam and provided an easy and uniform method of jarring the dish.





— Hydrometer - Bath —

A. Bath

B. Graduate

C. Hydrometer

D. Clock

A Permeometer

B. Liquid Limit Device

C Sampler ring

D Grooving Tool

E Specific Gravity Flask.

A metal (brass) bar about four inches long with a triangular end with the height and base both equal to three eighths of an inch served as the grooving instrument. (See picture on page 10)

Plastic Limit and Field Moisture Equivalent equipment:

Equipment for the Plastic limit test consisted of a plate glass one foot square and a blotter. An eye dropper was used to add water to the sample.

Equipment for the F. M. E. tests consisted of a watch glass to hold the pat of soil and an eye dropper to add water to the sample.

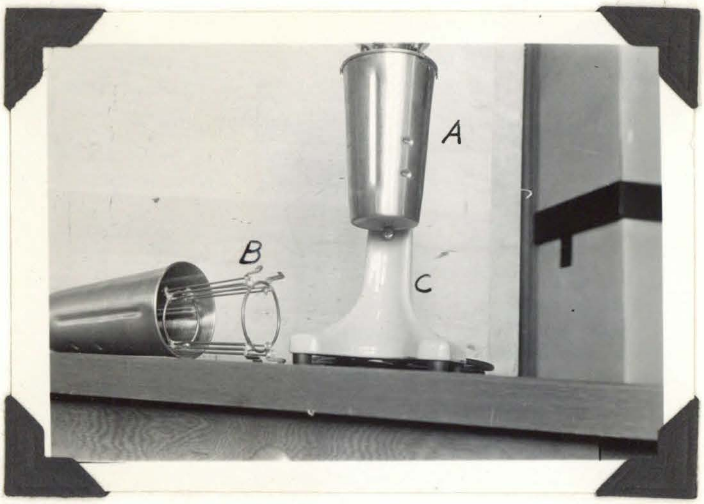
Hydrometer and Graduates:

The hydrometer used in the mechanical analysis tests was a Durac hydrometer manufactured by the H-B Instrument Co., Philadelphia. The graduations on the hydrometer were to 0.0005, and the scale ranged from 0.9950 to 1.0500.

The graduate used in the mechanical analysis tests had a capacity of one liter and was eighteen inches tall. It was graduated to 10 c.c. divisions.

Mixer:

The mixer used in the mechanical analysis was an ordinary electric drink mixer. The container



— Mixer —

A. Container

B. Baffles.

C. Mixer

was also a metal mixer container such as is used commercially. However, the container was fitted with baffles to aid in the dispersion of the sample.

Hydrometer bath:

The hydrometer bath was a metal tank twelve inches deep, six inches wide, and thirty seven inches long, provided with $2\frac{1}{2}$ inches of insulation on the outside. An overflow was provided near the top to maintain a certain level in the tank.

Adjacent to the constant temperature bath was an electric clock, reading to seconds, which aided in timing the hydrometer readings.

Permeometer:

The permeometer consisted of four parts. (1) A brass base with a cylindrical cut in the bottom which admitted a porous stone. Into the cut, from the side, a stop-cock was available for admitting water or applying a vacuum as desired. (2) A hollow brass cylinder one inch deep into which fitted the ring and soil sample described under sampler rings. This cylinder sat on the base, the sample against the porous stone, and the cylinder screwed to the base. (3) On top of this cylinder fitted a ring surrounding a porous stone which rested on top of the sample. (4) A brass plate was placed on top of the porous stone and securely clamped.

Vacuum:

For vacuums under four inches of mercury an aspirator attached to a water faucet was used. The vacuum line passed through a water trap and terminated at several stop-cocks.

For vacuums over four inches of mercury a vacuum pump driven by a $\frac{1}{4}$ H. P. electric motor was used, attached to the system described above. Vacuum was read on a dial guage reading to 27 inches of mercury and calibrated to one inch of mercury.

Sieves:

The sieves used in the sieve analysis were standard laboratory sieves, ten inches in diameter and two inches deep. Sieves used were numbers 10, 20, 40, 60, 140, and 200, having respective openings of 2.00mm, 0.84, 0.42, 0.25, 0.105, and 0.074. The sieves were shaken by hand due to the fact that the Ro-Tap shaker was out of order.

Test Procedures

Sampling:

In obtaining samples, the soil auger was used to bore a hole down to the depth at which it was desired to take a sample. The auger was then removed and the sampler lowered into the hole. The sampler barrel was then driven into the earth until the rings were full, as sensed by the feel of the hammer. The sampler was then brought to the surface and the sampler rings removed from the barrel. Care was used in removing the sampler rings so that the core of soil in the rings was kept intact. The sample and rings together were carefully wrapped in wax paper, and then were placed in a coffee can. To prevent the sample from being ruptured, dirt was carefully packed about the sample. As a second precaution against moisture escaping from the sample while in transit between field and laboratory, the coffee can was sealed with wax paper. All of the sampling done in this research and classified as undisturbed was done as described above.

Moisture Content:

The natural moisture content of the soil was obtained by taking one ring of the undisturbed samples and weighing a portion of its contents on a watch glass. The weighed portion and glass were then placed in the oven and held over night at a temperature of 110°C., until the sample was oven dry. The sample and watch glass were then removed from the oven and weighed. The ratio of the weight of moisture to that of the oven dried sample expressed as a percent was the moisture content.

Field Moisture Equivalent:

A sample of approxomately 50 grams was selected and mixed with water in an evaporating dish. When the wetted soil formed into ballsunder manipulation, the sample was smoothed off with a stroke of the spatula. Drops of water were applied to the smooth surface until they did not immediately disappear but spread out over the smooth surface and left a shiny appearance. A portion of the sample was then placed on a watch glass and weighed. It was then oven dried and the moisture content determined. This percentage gave the F. M. E.

Liquid Limit:

The liquid limit is defined as the moisture content, expressed as a percentage of the weight of the oven dried soil, at which the soil will just begin to flow when jarred 25 times. The soil is placed in the dish of the liquid limit device so that it forms a layer of about three eighths inch thickness, and then it is divided into two portions by a grooving tool. The cam device is used to tap the dish until the two edges of the sample just meet. This process is repeated two or more times with slightly different moisture contents, an attempt being made to make the necessary number of taps approach 25. If a sample requiring just 25 taps is obtained, the moisture content in that sample has reached the liquid limit. If a sample demanding just the required number of taps is not obtained, the moisture content of the other samples is determined and the values plotted against the log of the number of taps used. A straight line is drawn through these points and the moisture content for 25 taps is determined. This moisture content is the liquid limit.

Plastic Limit:

This test was made by rolling a portion of the soil previously wetted, on a piece of absorbant paper. When the material could no longer be rolled into a one eighth inch diameter thread, that is, it broke up, the plastic limit was reached. The moisture content at this point was recorded as the plastic limit.

Specific Gravity:

To determine the specific gravity of a soil sample a small 100cc flask was filled with distilled water up to the etched mark and weighed, (W_1). The water was poured out and a portion of the soil sample was carefully weighed (W_o) and corrected for hygroscopic moisture. This sample was placed in the flask and distilled water added until the etched mark on the flask was reached, care being taken to see that air was excluded from the mixture. The weight of the bottle, soil, and water was taken (W_2). The specific gravity was then calculated.

$$S.\ G. = \frac{W_o}{W_1 + W_o - W_2}$$

Hygroscopic Moisture:

The hygroscopic moisture was obtained by weighing an air dried sample, which was then placed in the oven at 110°C. until it was dry. The sample was then re-weighed and the moisture content expressed as a percentage of the oven dried weight. This moisture content represents the hygroscopic moisture.

Hydrometer Analysis:

About 50 grams of the air dried soil sample was passed through a no 10 sieve and that passing the sieve was covered with water in a beaker for about 18 hours. Then a 20cc portion of sodium silicate (3^{o} Baume at 76^{o}F.) was added and the mixture dispersed in the special stirring apparatus for one minute.

This dispersed mixture was then placed in a 1000cc graduate and distilled water added to bring the liquid level up to the 1000cc mark. The graduate was then placed in the constant temperature bath, being stirred frequently until the suspension was at the temperature of the bath. The graduate was then removed from the bath and with one hand over the end, the graduate was shaken vigorously for one minute. The graduate was then replaced in the hydrometer bath and hydrometer readings were taken at intervals of about 1,2, 5, 15, 30, 250, and 1440 minutes. At the time of each reading the temperature of the bath was taken. For all intervals over two minutes, the hydrometer was removed from the graduate and replaced 15 to 20 seconds before the next reading.

After all the readings were taken, the suspension was washed through a 200 mesh sieve and after drying was sieved through the 10, 20, 40, 60, and 140 mesh sieves. From formulas obtainable in text books on soil mechanics, the data derived from the hydrometer tests can be applied to give the percent of the sample in solution and the maximum grain size in suspension.

The grain size accumulation curve was plotted with the log of the particle size in m.m. as abscissas and the percentage of particles smaller than size shown, as ordinates.

Vacuum Tests:

The vacuum tests were the main objective of this research project. The soil samples were sealed in the permeometer with porous stone on both the top and the bottom of the soil sample. The only access of the undisturbed soil sample to the atmosphere was through the top porous stone. The stop cock of the permeometer was then connected to a supply of distilled water with a head of from four to twelve inches of water. The stop cock was then opened and water allowed to percolate up through the soil sample. When water flowed freely out of the top porous stone, the sample was assumed to be saturated and the stop cock was closed.

The stop cock was then connected to the vacuum stop cocks by means of a heavy rubber hose. The stop cocks on both the permeometer and the vacuum lines were opened and the water was started flowing through the aspirator. The flow was regulated until the vacuum as indicated on the gauge was of the desired value.

A moisture trap consisting of a small bottle in the vacuum line caught the moisture being drawn from the sample and moisture leaking back through the aspirator. The color of the water in this bottle gave indications of piping in the sample or wasted vacuum.

After the vacuum had been applied to the sample for the allocated length of time, the sample was removed, weighed, and then oven dried. The sample was then re-weighed and the moisture content was computed and tabulated.

Test Data and Results

Sampling:

The work done by Moore and Dorwart gave indications that the high maximum moisture contents in soils might be at depths ranging from six to nine feet. These values holding during the first fonths of the year as for instance January and February. After these months had passed the maximum moisture content region passed farther down into the earth to about the twelve to fifteen foot level. All of the sampling done for this research was done in January and February, thus it was decided to take borings at various levels down to nine feet. A list of the samples, the depths at which they were secured, and the location from which they were secured is shown on the following page. Little difficulty was encountered securing samples. The only difficulty encountered was the sand which occurred frequently alongside of beds of sandy loam necessitating the discarding of many samples. For instance samples taken at Huntington Park High School only a short distance apart were of such a nature.

Sample No.	Depth	Location
1	1'	Jefferson School, Pasadena
2	3	at corner of south east
3	6	property line
4	9	
5	2	Huntington Park High at
6	5	south east corner of Ad. Bldg.
7	1	Huntington Park High School
8	5	50' south of Auditorium
9	9	
10	1	Bell High School 30'
11	3	north of tennis court
12	6	
13	9	
14	1	Bell High School 50' south
15	3	of east end of the drive
16	6	on south of tennis courts
17	2	South Gate High just inside
18	4	gate in fence on west side of school
19	1	John C. Fremont High School
20	4	10' from street sidewalk on
21	6	north side of Administration
22	8	building.

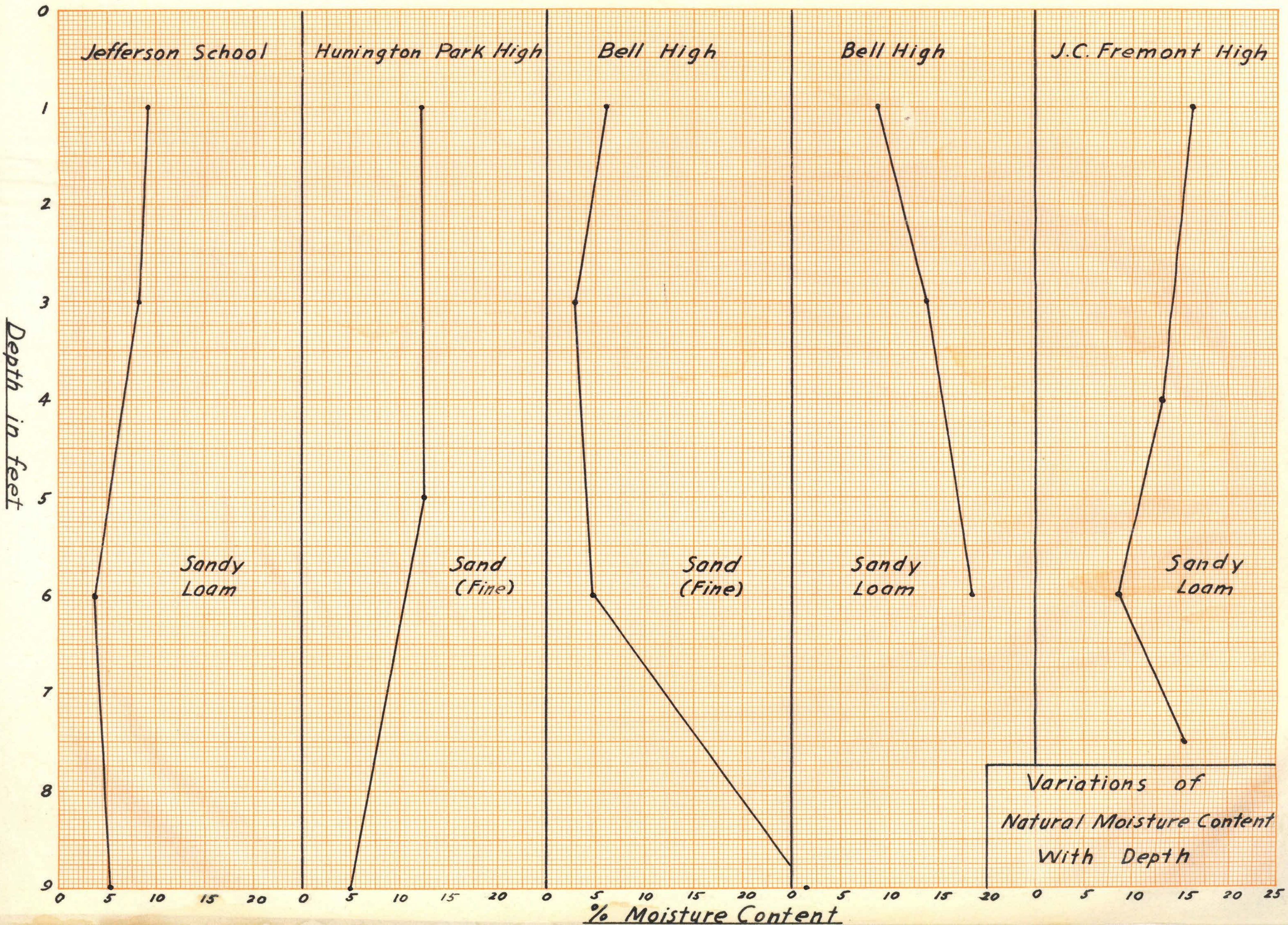
In all casses except one, sample number 13 from Bell High at a depth of 9 feet, the samples were taken from above the water table. The one exception was clearly below the water table as indicated by the sudden increase in moisture content between the 6 and 9 foot levels, the moisture contents being 4.8% and 26.4% respectively.

Natural Moisture Contents:

There were great variations in the natural moisture contents found in the various samples, as indicated by the data and curves on the two following pages which show the variatin of moisture content with depth. However such results were expected due to the many factors influencing the moisture content such as type of soil, depth of water table, accumulative precipitation, and the time since previous rains.

However, it is of interest to note that the curve for Jefferson School has a similarity to the depth-moisture content curve of Dorwart and Moore, the main difference being in the magnitude of the moisture contents. The difference of magnitude, which is relatively small, could probably be explained by differences of time since previous rainfalls and differences in accumulative rainfall.

Sample No.	Date	Rainfall	Moisture Content
1	1-19-39	13.91"	9.3%
2			8.2
3			3.8
4			5.2
5	1-31-39	14.21	11.2
6			12.1
7	1-31-39	14.21	12.2
8			12.5
9			5.0
10	2-2-39	14.21	6.0
11			2.8
12			4.8
13			26.4
14	2-2-39	14.21	8.7
15			13.9
16			18.5
17	2-14-39		18.8
18			13.3
19			16.1
20			13.1
21			8.6
22			15.4


Jefferson School
Hunington Park High
Bell High
Bell High
J.C. Fremont High
Sandy Loam
Sand (Fine)
Sand (Fine)
Sandy Loam
Sandy Loam
Variations of Natural Moisture Content With Depth
Depth in feet
% Moisture Content
0 1 2 3 4 5 6 7 8 9
0 5 10 15 20 25

Curves such as are represented by Jefferson school and John C. Fremont High show a maximum moisture content near the surface, a decreasing moisture content down to a depth of six feet, and then an increasing moisture content as a depth of nine feet is approached. The curve of the sandy loam of Bell High shows an increase in moisture content between the depths on one foot and six feet. The sand samples of Bell High showed a decrease in moisture content to three feet and then a slight increase at six feet with a large increase when the water table was reached.

The moisture content of the soil at Huntington Park High remained close to 12.5% down to a depth of about five feet and then the moisture content dropped to a value of 5.0% at nine feet.

Liquid Limits:

Values for the liquid limits of the soil samples ranged between 16% and 27% as indicated on the chart on the following page which shows the limits for the various samples. Fred L. Plummer in his Notes on Soil Mechanics gives values for the liquid limit of sand as 20% and that of silt as 28%. All of the values obtained in this research fall in this region. For instance the liquid limit of

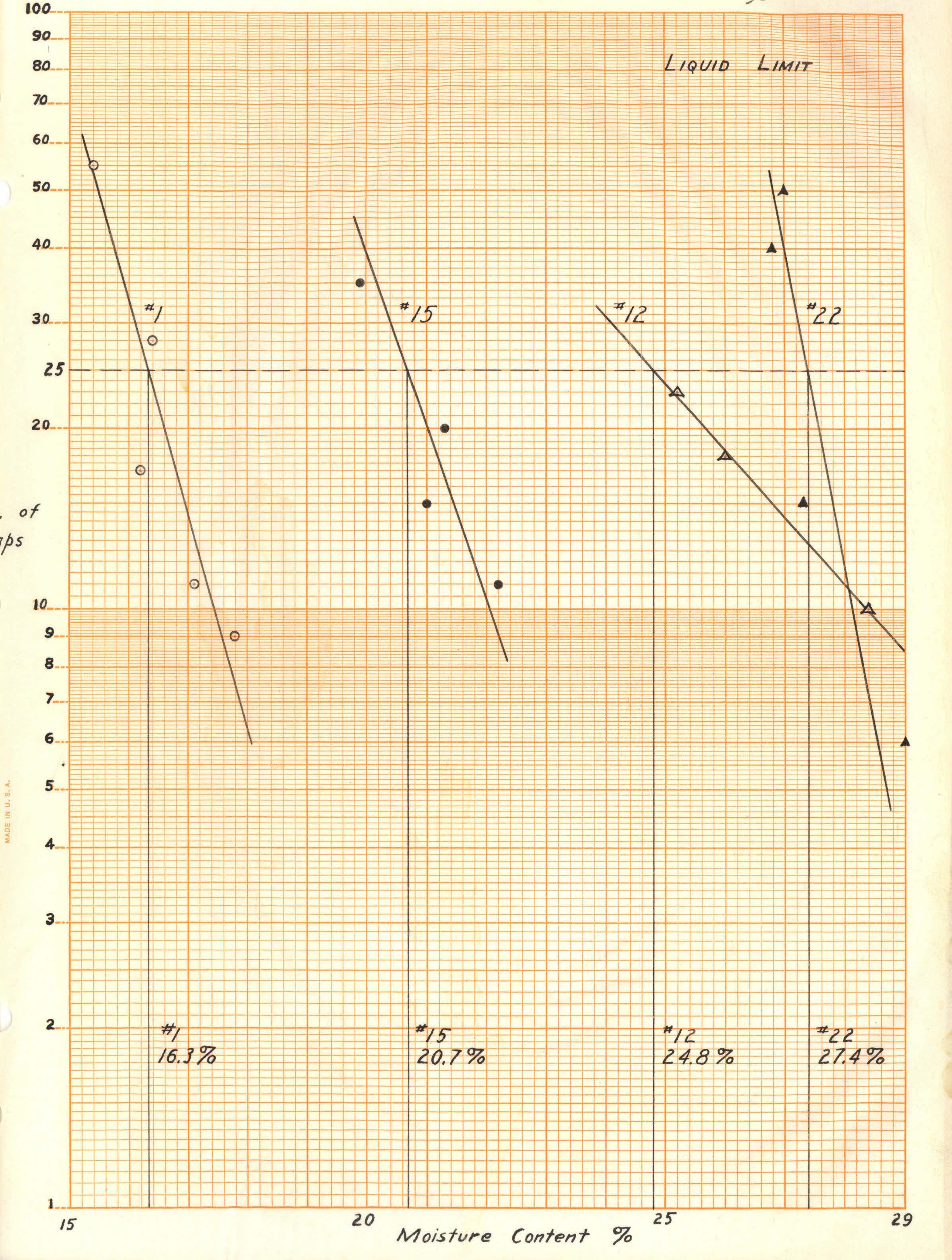
Liquid Limit Data

Sample No.	Taps	Moisture Content
1	9	17.8%
1	11	17.0
1	17	16.2
1	28	16.5
1	55	15.4
6	6	21.7
6	13	19.3
6	35	18.0
6	40	18.6
12	10	28.4
12	18	26.0
12	23	25.2
15	11	22.2
15	15	21.0
15	20	21.3
15	35	19.9
18	5	31.1
18	12	27.5
18	35	26.5
18	50	25.8

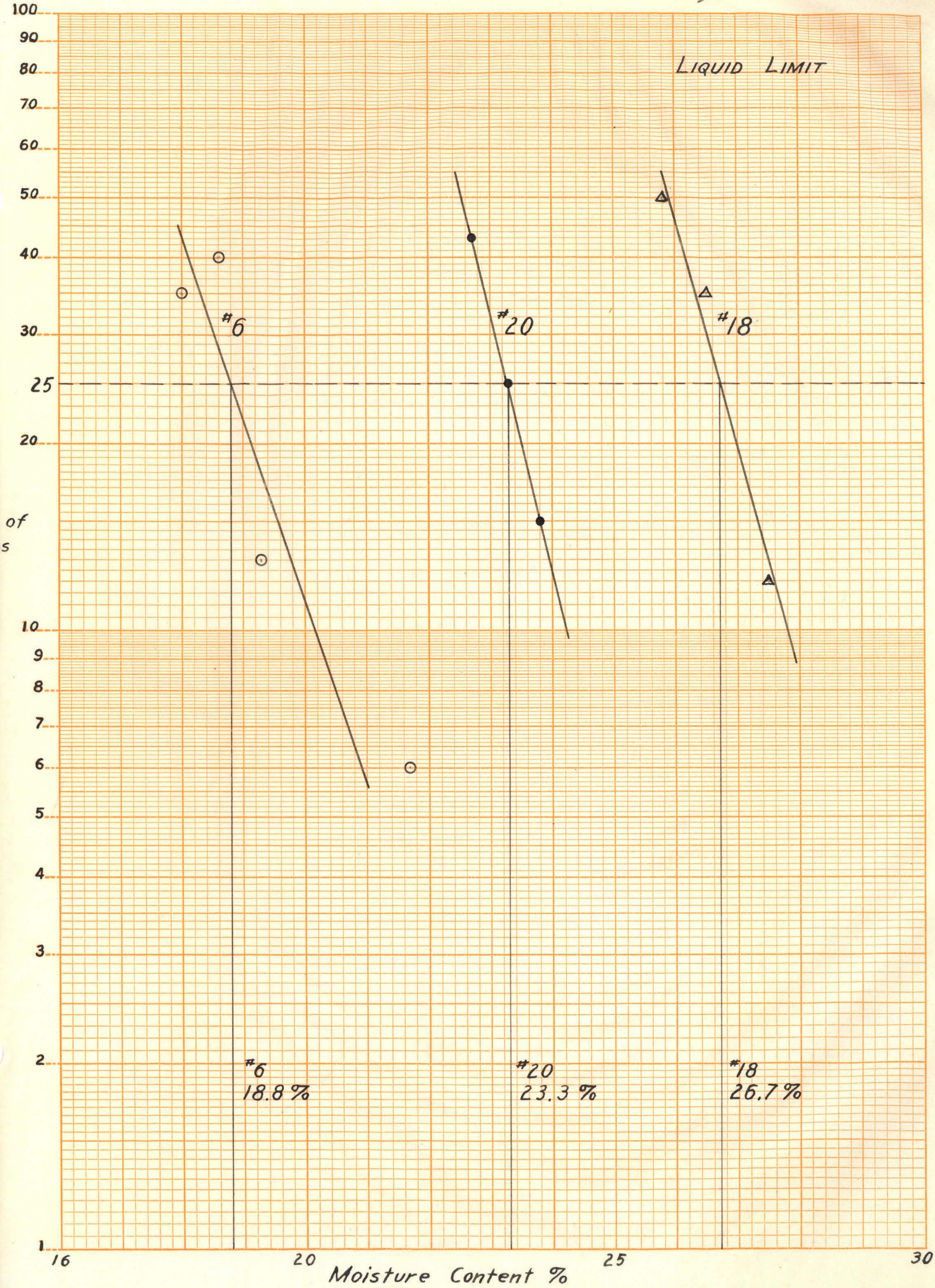
Liquid Limit Data

(continued)

Sample No.	Taps	Moisture Content
20	14	25.0%
20	15	23.8
20	25	23.3
20	43	22.7
22	6	29.2
22	15	27.2
22	40	26.8
22	50	27.0



LIQUID LIMIT
#1
#15
#12
#22
#1 16.3%
#15 20.7%
#12 24.8%
#22 27.4%
of
ps
Moisture Content %
MADE IN U.S.A.


LIQUID LIMIT
100
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80
70
60
50
40
30
25
20
of
s
10
9
8
7
6
5
4
3
2
1
#6
#20
#18
#6
18.8 %
#20
23.3 %
#18
26.7 %
16
20
25
30
Moisture Content %

the sandy loam of Jefferson School was 16.3% and the liquid limit of the sandy loam of South Gate High was 26.7%. These values show that the soil samples were of a nature to absorb water readily with a rapid loss of stability.

Field Moisture Equivalent:

In determining the F. M. E. of some of the soils such as samples number 9, 12, and 15, some difficulty was experienced. These soils, being quite sandy, would expand and slump before an indication of the F. M. E. could be obtained. After slumping, it was an impossibility to determine the F. M. E. since loose water surrounded the deformed sample. All of the values obtained, an indicated on the chart of limits, were fairly high, ranging from 25 to 40%. These values indicate a fairly high amount of moisture to satisfy the pore space of the soil.

Mechanical Analysis:

There was little difficulty experienced in the mechanical analysis of the samples. Representative samples of each different type of soil, as determined by estimating, were chosen and an analysis of them made. In all, seven samples were chosen, numbers

Limit Chart

Sample No.	Specific Gravity	Liquid Limit	Plastic limit	F. M. E.
1	2.59	16.3%	19.7%	34.1%
6	2.79	18.8	22.7	25.1
9	2.63	sandy	sandy	sandy
12	2.77	24.8	sandy	sandy
15	3.47	20.7	sandy	sandy
18	2.59	26.7	27.0	30.1
20	3.40	23.3	27.2	30.8
22	2.51	27.4	31.8	40.4

3, 6, 12, 15, 18, 20, and 22. The results of the analysis, utilizing both hydrometer and sieve methods, are shown on the next few pages of this thesis. It is given in graph form as well as in tabulated form so that a visual picture may be obtained.

With the data obtained the % of sand, silt, and clay of each sample was determined by finding the % of the sample by weight less than 0.005mm (clay), the % less than 0.05mm and greater than 0.005mm (silt), and the % greater than 0.05mm (sand). With the percentage of each known the soils were classified as to type, sandy loam or sand, using the method of Fred L. Plummer in his "Notes on Soil Mechanics" (Pg 32b). In his article he classifies sandy loam and sand as given below:

Type	% sand	% silt	% clay
sand	80-100	0-20	0-20
sandy loam	50-80	0-50	0-20

All of the samples analyzed fell into either the group sandy loam or sand.

Sieve Analysis

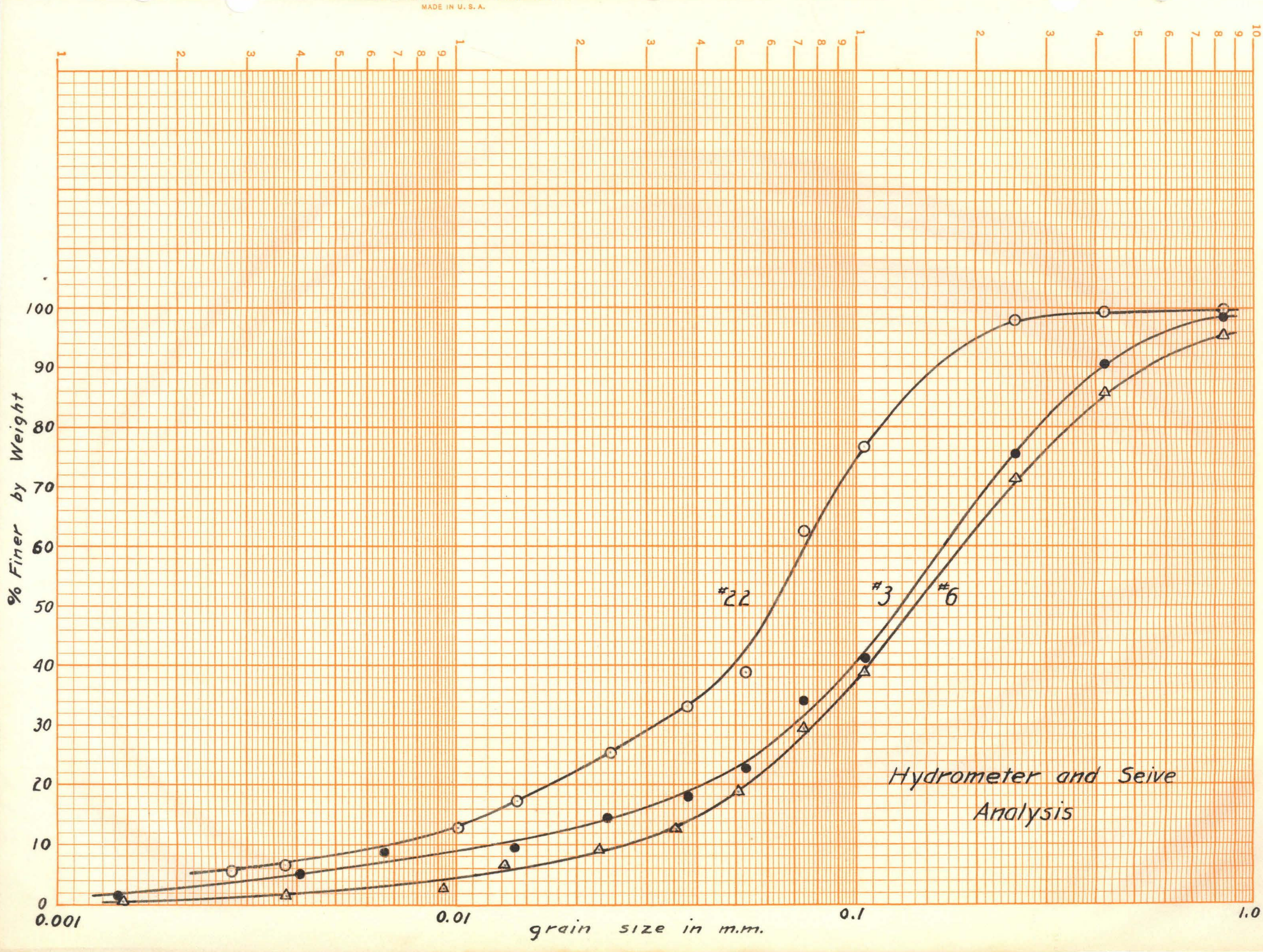
% Finer by weight

Size	Sample #3	#6	#12	#15	#18	#20	#22
2.00mm	100%	99.2%	100%	100%	100%	100%	100%
0.84	98.2	95.7	99.1	99.8	99.9	99.7	99.8
0.42	90.2	86.0	96.0	99.0	99.4	98.6	99.5
0.250	75.2	71.7	66.7	93.5	98.2	93.2	98.0
0.105	41.3	38.4	10.9	53.7	84.8	64.8	76.7
0.074	34.1	29.7	7.33	41.7	71.6	54.6	62.6

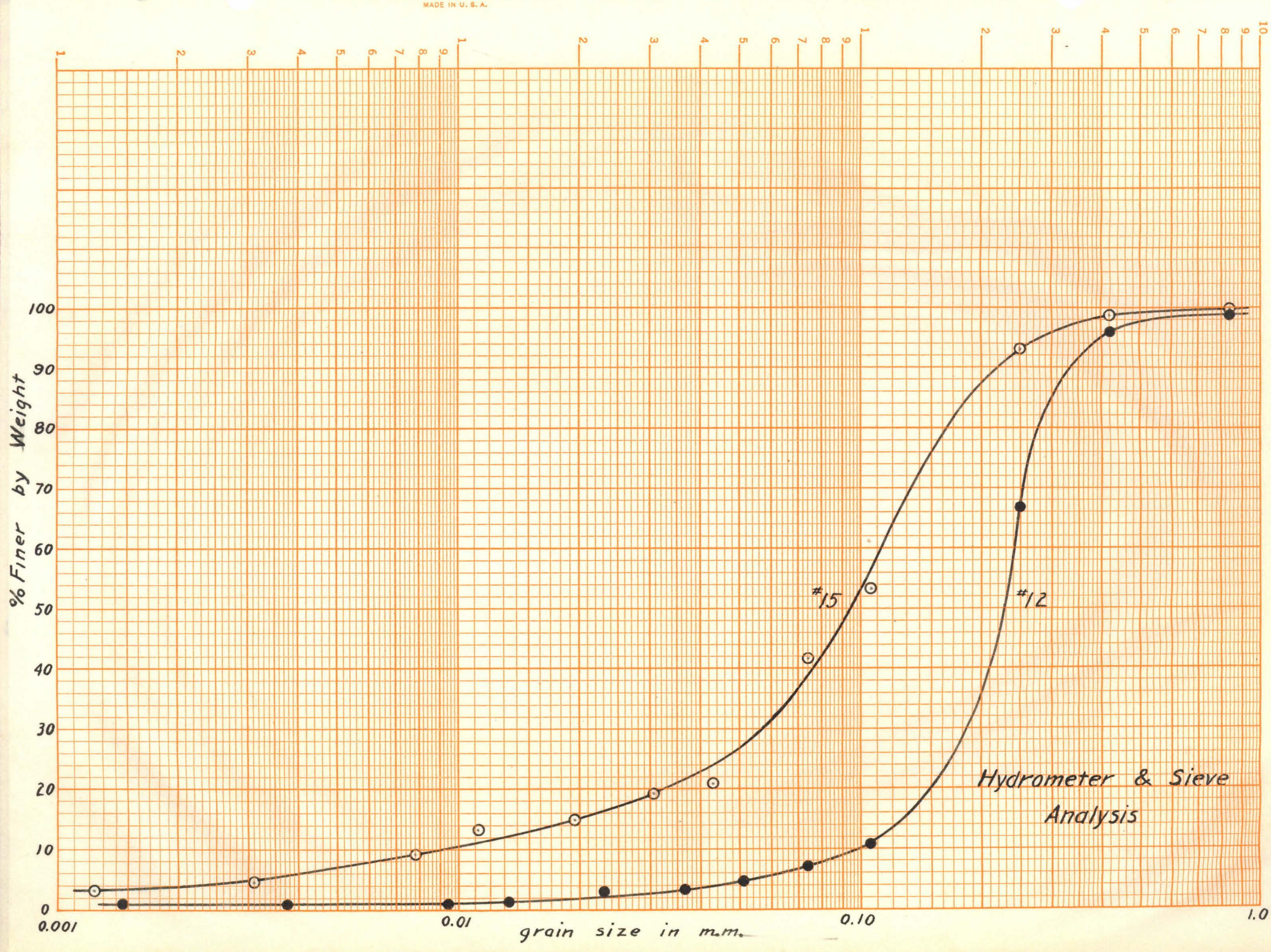
Hydrometer Analysis

Sample No.	Grain size	% finer by weight
3	0.05300mm	22.85
	.03775	17.90
	.02400	14.63
	.01395	9.69
	.00667	8.22
	.00408	4.93
	.00141	1.84
6	.05020	18.88
	.03580	12.50
	.02280	9.35
	.01314	6.18
	100933	3.01
	.00377	1.58
	.00145	0.19
12	.05100	4.61
	.03620	3.83
	.02290	3.05
	.01320	1.875
	.00942	0.704
	.00374	0.782
	.00146	0.875
15	.04250	21.0
	.03050	19.5

Sample No.	Grain Size	% Finer by Weight
15	0.01910	14.95
	.01107	13.45
	.00790	8.92
	.00310	4.53
	.00122	3.20
18	.05170	44.8
	.03700	36.4
	.02370	28.1
	.01377	19.8
	.00981	14.8
	.00379	7.32
	.00139	4.36
20	.04230	35.6
	.03020	29.65
	.01935	25.2
	.01120	19.22
	.00797	13.25
	.00302	7.45
	.00124	4.65
22	.05340	38.7
	.03800	33.9
	.02425	25.75
	.01415	17.66
	.01005	12.80
	.00377	6.48
	.00273	5.05

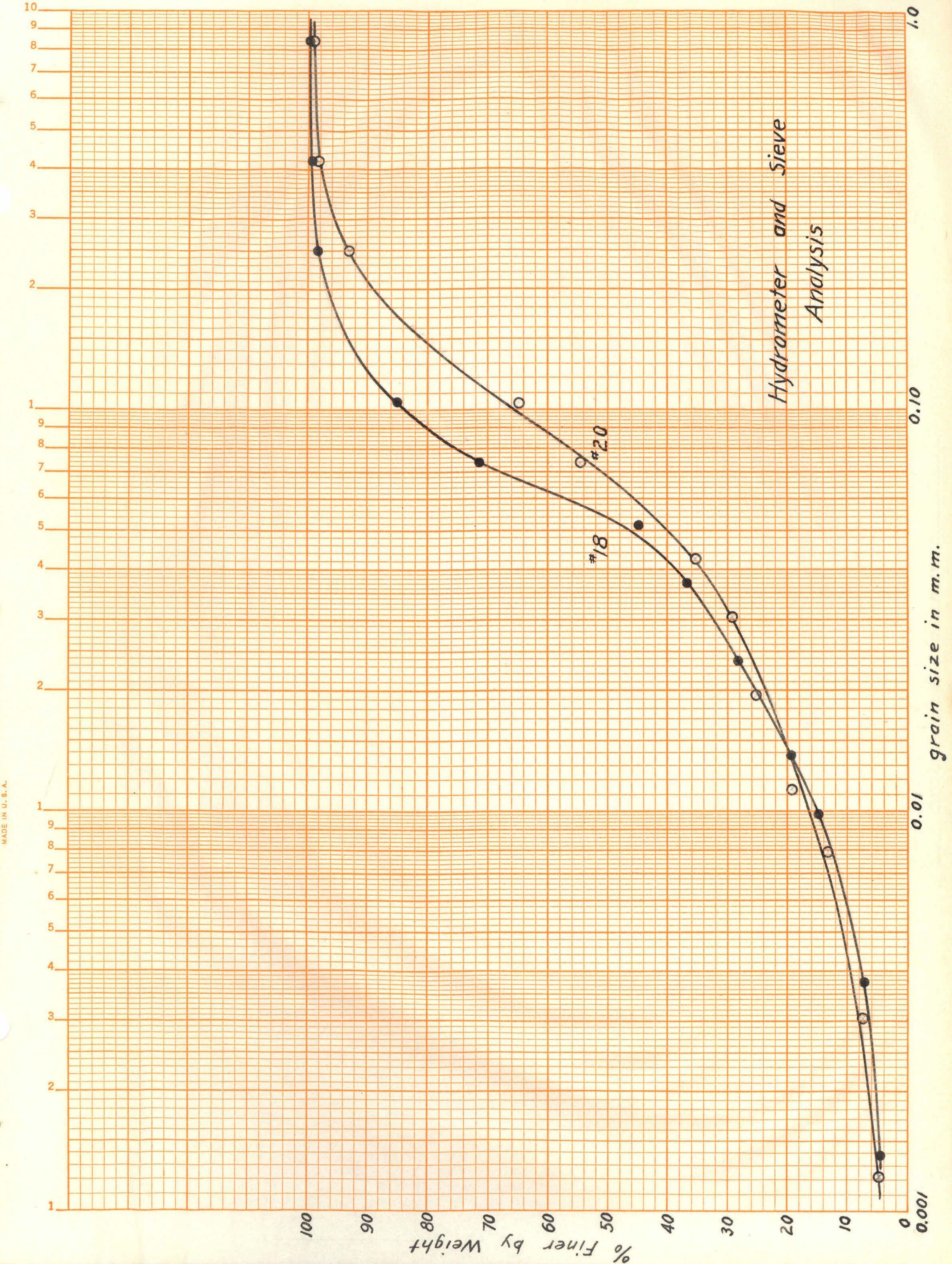


Hydrometer and Seive
Analysis
#22
#3
#6
% Finer by Weight
grain size in m.m.
0.001
0.01
0.1
1.0
0
10
20
30
40
50
60
70
80
90
100
MADE IN U.S.A.



Hydrometer & Sieve Analysis
% Finer by Weight
grain size in m.m.
#15
#12
0.001
0.01
0.10
1.0
100
90
80
70
60
50
40
30
20
10
0
MADE IN U. S. A.

39


Hydrometer and Sieve Analysis
grain size in m.m.
% Finer by Weight
#20
#18
1.0
0.10
0.01
0.001
100
90
80
70
60
50
40
30
20
10
0
MADE IN U.S.A.

Classification by types

Sample #3	sand	78%	
	silt	16	Sandy loam
	clay	6	
Sample #6	sand	82	
	silt	16	Sand
	clay	2	
Sample #12	sand	95	
	silt	4	Sand
	clay	1	
Sample #15	sand	63	
	silt	30	Sandy loam
	clay	7	
Sample #18	sand	53	
	silt	38	Sandy loam
	clay	9	
Sample #20	sand	60	
	silt	29	Sandy loam
	clay	11	
Sample #22	sand	60	
	silt	33	Sandy loam
	clay	7	

Vacuum Tests:

The vacuum tests were the principal objectives of this research. The samples which had been brought in from the field, each one being composed of an eight inch soil core inclosed in eight one inch rings, were carefully separated into samples one inch high by sawing through the soil at the jumcture of the rings. The sawing was cone with a small tightly drawn wire, care being taken not to disturb the sawed surface of the sample. In some cases, slight irregularities were present in the sawed surface, but these irregularities were carefully filled up.

In some of the samples with loose structures, principally the sandy soils, great care had to be taken to prevent disruption of the sample while water was perculating up through it when saturating the sample. In these cases the head of water above the permeometer was maintained between two and four inches.

When the vacuum was applied to the permeometer and the sample, in every case, a large volume of water was drawn from the sample in the first five to ten seconds. After that period the water drawn from the sample appeared in the water trap in the form of drops. This phenomenon indicated that a large portion of the moisture content was being drawn from the sample during the first few seconds. However the moisture which came through the vacuum tubes in the form of drops amounted to a fairly large amount. From volumetric observations, the amount of moisture which came out of the sample in the first few seconds ammounted to about 50 to 75% of the total moisture in the sample which could be drawn out.

When the vacuum was first applied by the aspirator to the sample, vacuums of 15 to 21 inches of mercury were attainable for the first few seconds, after which the vacuum dropped rather swiftly to about 8 inches of mercury. From this latter value the vacuum dropped more slowly down to values of from 3.3 to 5 inches of mercury. This gradual drop accurred over a period of from one to two minutes. After the lower values were obtained, the vacuum could be maintained at those figures for an indefinite period of time.

Undoubtedly the reason for the rapid drop in vacuum was the short samples used, which were only one inch high. As the vacuum was applied, the water was drawn down throughthe sample until the water seal was broken. After the seal was broken, the passages through the sample, not being long enough, allowed such a quantity of air to pass through the sample that a high vacuum could not be maintained. After consulting with Professor Converse, it was decided to obtain a vacuum pump in hopes that a higher vacuum could be maintained.

A vacuum pump was obtained and connected into the vacuum line in place of the aspirator. When the vacuum was first applied, vacuums of about 25 inches of mercury could be obtained for the first few seconds. After this period the vacuum dropped slowly to values of from 5 to 8 inches of mercury.

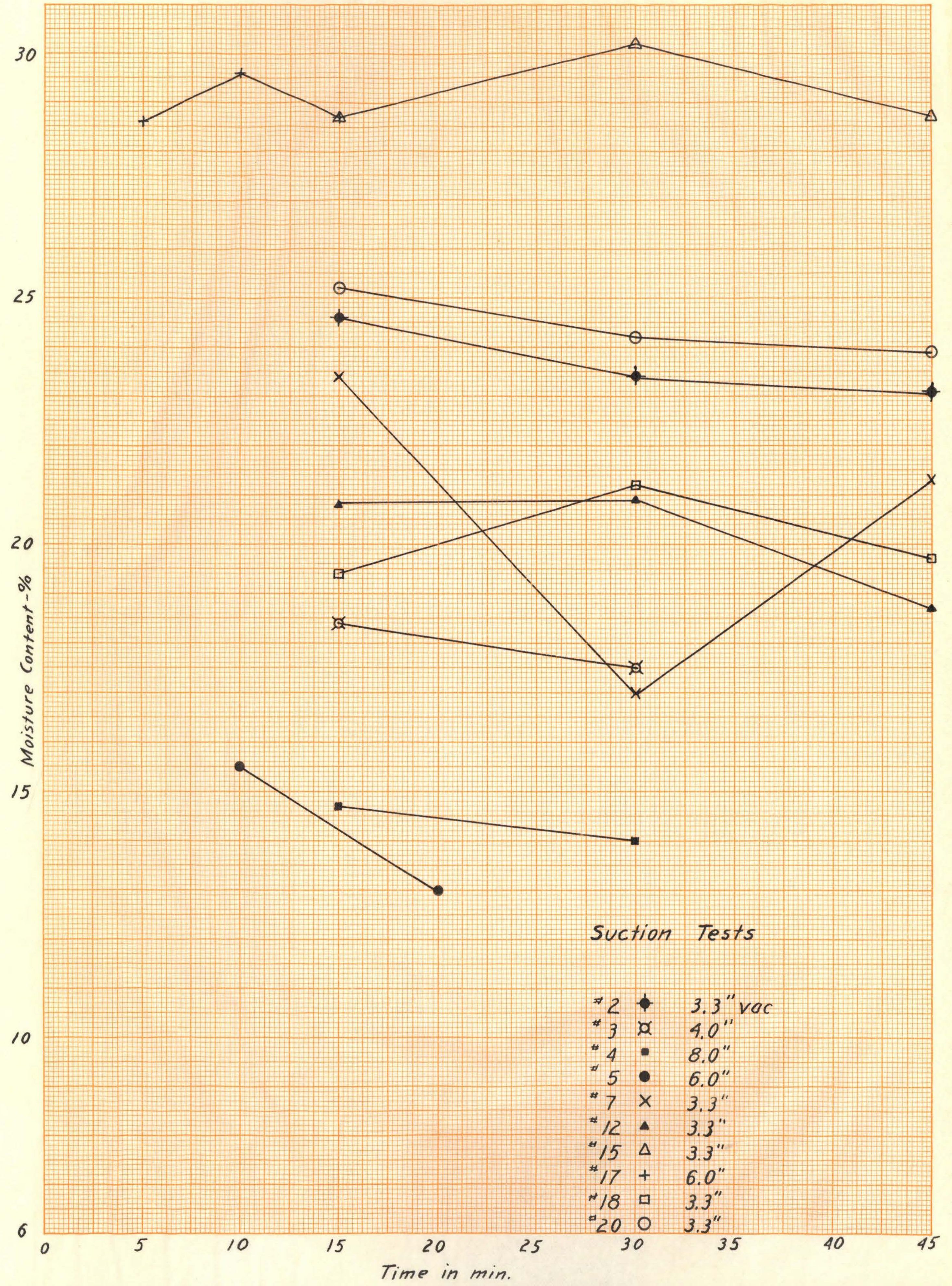
Using the water aspirator about twenty samples were given the vacuum test, with the vacuum ranging from 3.3 to 4.0 inches of mercury. It was difficult to regulate the vacuum at first but after the first minute or two the maximum vacuum attainable had dropped to these low values and the vacuum could be left at its maximum value. These values could be maintained for 45 minutes which was the longest time used in these tests. Two samples were put on the vacuum lines at the same time since it was observed that the additional sample did not lower the vacuum to any great extent when the vacuum was at a low value. As indicated in the chart showing the results of the vacuum tests, the time for each sample under vacuum was maintained for

Suction Tests

Sample No.	Vacuum	Time	Moisture Content
2	3.3" Hg.	15 min.	24.6%
2	3.3	30	23.4
2	3.3	45	23.1
3	4.0	15	18.4
3	4.0	30	17.5
4	3.5	15	17.8
4	8.0	15	14.7
4	8.0	30	14.0
5	3.5	30	18.5
5	5.5	10	15.5
5	6.0	20	13.0
6	3.5	30	16.3
7	3.3	15	23.4
7	3.3	30	17.0
7	3.3	45	21.3
12	3.3	15	20.8
12	3.3	30	20.9
12	3.3	45	18.3

Suction Tests (continued)

Sample No.	Vacuum	Time	Moisture Content
15 (compacted)	3.3" Hg.	15 min.	28.7%
15 (compacted)	3.3	30	30.2
15 (compacted)	3.3	45	28.7
17	6.0	10	29.6
17	6.0	15	28.7
17	7.0	5	28.6
17	21-5	10	30.1
18	3.3	15	19.4
18	3.3	30	21.2
18	3.3	45	19.7
18	7.0	10	17.1
19	5.0	15	22.3
19	8.0	15	22.8
20	3.3	15	25.2
20	3.3	30	24.2
20	3.3	45	23.9


30
25
20
15
10
6
Moisture Content-%
0
5
10
15
20
25
30
35
40
45
Time in min.
Suction Tests
#2 3.3" vac
#3 4.0"
#4 8.0"
#5 6.0"
#7 3.3"
#12 3.3"
#15 3.3"
#17 6.0"
#18 3.3"
#20 3.3"
MADE IN U.S.A.

15, 30, and 45 minutes. By varying the time in this manner while maintaining the vacuum constant for a series of samples, it was hoped to find what relation might exist between the time a vacuum was held on a sample, and the resulting moisture content. These values were plotted on the graph on page 47.

It was believed that, since a large portion of the water was drawn from the sample during the first few seconds, between the 15 and 45 minute intervals there should be a gradual reduction in moisture content. This deduction was verified by sample number 2 from Jefferson School, in which the moisture content dropped gradually during the 30 minute interval from 25.2 to 23.9%. Sample number 20 from J. C. Fremont School closely paralleled the curve of the number 2 sample. The majority of the remaining curves were highly erratic. The erratic nature of the curves may have been due to a lack of sufficient points, but was probably due to the short soil samples which made the vacuum difficult to be applied in any uniform manner throughout the sample. However the erratic nature of the curves only had a variation of about 2% in general which might be considered as experimental error. From the figures tabulated in the chart for the suction tests and from the curves showing the relation between the time and moisture content holding vacuum constant, it is probably safe to say that by adjusting the time various moisture contents can be obtained, but only within certain limits as dictated by the strength of the vacuum. The variation in moisture content due to the time element, especially at low vacuum pressures is small and in many cases might fall in the class of experimental error as caused by slight variations from one soil ring to another or by apparatus error.

It was hoped to get another set of data consisting of moisture contents due to variation in vacuum strength holding time constant. To get the vacuum higher than 4 inches of mercury the vacuum pump was utilized. Vacuums as high as 8 inches of mercury could be maintained on some of the samples, namely; those with low sand contents. This restriction made the collection of essential data extremely difficult. In order to maintain high vacuums, one sample was subjected to the vacuum at one time.

Good results were obtained as far as reduction in moisture content were concerned, by increasing the vacuum. For instance sample number 4 when held at 3 to 5 inches of mercury for 15 minutes gave a resulting moisture content of 17.8%, and when held at 8 inches of mercury for the same length of time gave a moisture content of 14.7%. It is of importance to note that the values obtained at 8 inches of mercury correspond to the values obtained by Moore and Dorwart a year previously. Also this value checked closely the value for the maximum moisture content of the soil as determined by Moore and Dorwart. Sample number 5 as indicated in the chart of vacuum test results also showed a reduction in moisture content from 18.5% to 13%, for corresponding vacuums of 3.5 inches to 6 inches of mercury. The few examples cited in the chart show that the method of vacuum variation might be used to determine the maximum moisture content of a soil by laboratory methods if a standard test consisting of an established value of vacuum and time could be determined experimentally which would agree with the values of maximum moisture content as obtained in the field. The authors of this thesis did not have sufficient time to complete this determination. The authors believe that the method shows promise because of the reductions possible with variations in vacuum and because of the close agreement with the results obtained on Jefferson School soil by Moore and Dorwart.

Conclusions

1. The method of collecting samples in the field and testing them in the laboratory should be altered in order to obtain workable results. A longer unit of sample should be taken and used in the permeometer in order to obtain workable values of vacuum. Longer samples would hold the water seal longer and increase the resistance of the movement of air through the sample.

2. Holding the vacuum constant and varying the time will reduce the moisture content, but over periods of 45 minutes the difference in moisture content is not enough to provide a laboratory test for attaining a value of the natural maximum moisture content.

3. Variations of vacuum strength offers good possibilities of obtaining a laboratory method for determining the natural maximum water content of a soil above the water table.

4. Soils of the sandy loam type of the Jefferson School may have their natural maximum moisture content determined in the laboratory by subjecting a one inch soil sample to a vacuum of 8 inches

of mercury for a time varying from 15 to 30 minutes.

5. More information is necessary concerning the natural maximum moisture content of soils in this vicinity, as determined by taking moisture contents after heavy seasonal precipitation.