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Synopsis

The variation of moisture content, both horizontally and vertically, in individual specimens and in separate layers of a clay mass 105 feet thick is presented. Two hundred and thirty-eight soil specimens 2 in. diameter by 4 in. high were tested in the laboratory. Four moisture determinations, two in the top half and two in the bottom half, were made on each soil specimen for a total of 932 moisture determinations. The moisture was of primary concern in this investigation but as the samples were available, numerous other tests, such as grading analysis, Atterberg Limits, triaxial and unconfined compression, were made. It is shown how much the moisture content does vary within a 4 in. high sample. There is no significant migration of moisture from bottom to top of sample during the time elapsed between sampling in the field and testing in the laboratory. The moisture content is higher in the bottom half just as often as it is higher in the top half of the 4 in. high test specimen. The shearing strength of the clay soil was determined by unconfined compression and quick-undrained triaxial compression tests.

It is shown that the range of moisture content in a test specimen is much greater in the vertical direction than in the horizontal direction. There is no significant difference in the average strength-versus-moisture pattern, whether the moisture is the average of the strength test specimen or the highest of four moisture determinations made on the specimen.

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MOISTURE AND STRENGTH VARIATION in a THICK, UNIFORM CLAY LAYER

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Presented at
The Third Pacific Area National Meeting of ASTM
San Francisco, California
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INTRODUCTION

Soils engineers are always faced with the question whether a soil sample tested in the laboratory is truly representative of a mass considerably larger than the laboratory test specimen. To minimize the possibility of over-all error a large number of primary soil tests such as moisture, density, Atterberg Limits, etc., are usually performed to determine a soil profile in a foundation investigation. For reasons of economy, a fewer number of the more important and expensive tests such as consolidation and strength are performed and these test results are applied to layers or areas in the soil mass whose limits are determined by the cheaper primary tests.

This investigation presents data to show the variation that does exist in what would ordinarily be considered a thick layer of uniform material. In order to make a comprehensive investigation of this type, it was felt that a layer of considerable thickness should be explored. From previous sampling and testing operations it was known that a suitable soil mass exists along the northern shore of San Pablo Bay. This bay is

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the northerly part of the same water area that makes up San Francisco Bay which is located on the west coat of California at approximate latitude of 37 degrees. Figure 1

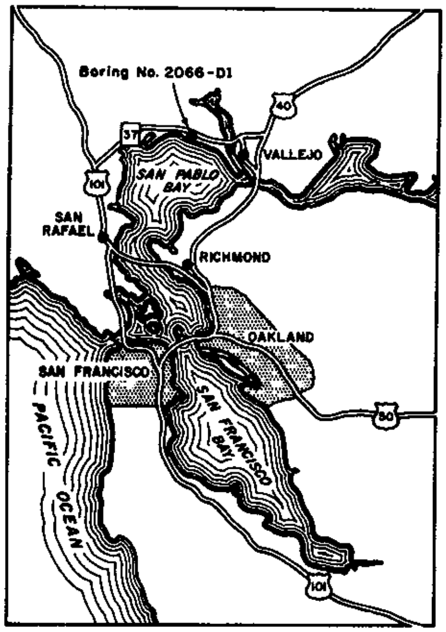

Fig. 1 LOCATION MAP

is a map showing the location of the boring that was made for this investigation. The soil in this area, soft enough to be of concern to the soils engineer, is as much as 100 feet thick and previous investigation showed it to be as uniform for such a thickness as could be expected. Also, the ease of access with sampling equipment made it an ideal location for the field operations.

GEOLOGICAL DESCRIPTION OF THE AREA

The soil in this area of Recent Age, consists of estuarine clays, clayey silts and silts with a high organic content. These deposits are frequently referred to as "Bay Mud" and extend to depths of eighty feet or more. A thin soil cover of alluvium and marsh vegetation overlies the estuarine deposits. The upper forty feet of these deposits is highly compressible and is still in an active state of natural consolidation. Below the soft deposits at an average elevation of -80 the deposits consist of stiff to very stiff silty clay and clayey silt with occasional layers of highly organic silt.

SOIL DESCRIPTION

The ground surface at the location of the boring is at approximate elevation +2 above mean sea level so that the top five feet or so is subject to alternate cycles of saturation and dryness. At the time of sampling this layer was relatively dry. Below this layer and to a depth of approximately 40 feet the soil is a very soft, highly compressible, moderate to highly plastic clay or silty clay with a small percentage of sand, the clay content ranging from 28 per cent to 71 per cent and with a scattering of lenses or pockets of peat or organic matter. The wet densities range from 75 to 108 pounds per cubic foot, and the moisture contents range from 18 per cent to 186 per cent. From 40 feet to 103 feet the material is a soft to firm or stiff, compressible, moderately plastic, clay or silty clay, with a very small percentage of sand and a notable absence of organic material. This layer is considered quite uniform in density and moisture content. The wet densities range from 94 to 108 pounds per cubic foot and the moisture contents range from 39 per cent to 61 per cent. Within this layer there is a gradual increase in shearing strength and clay content with depth. At 103 feet there is an abrupt change to lower moisture content, higher density and higher strength.

The sampling was completed after a penetration of two feet of the stiff or hard material. The test data discussed in this paper is confined to the upper two layers, i.e., from the ground surface to a depth of 40 feet and from a depth of 40 to 100 feet.

FIELD OPERATIONS

The sampling was done with a 2 inch Modified California-

Type Soil Sampler shown in Figure 2. The sampler was pushed hydraulically with a truck-mounted Joy Model 250 drill. The hydraulic ram of the drill has a traveling length of three feet and a maximum rate of travel of approximately four inches per second. The maximum rate and distance of travel was used on each individual sampling operation. The entire sampling operation was carried out as a routine operation. The usual care in handling soil samples was exercised. Continuous sampling was done throughout the boring rather than by the normal procedure of sampling only 30 per cent to 60 per cent of the soil layer.

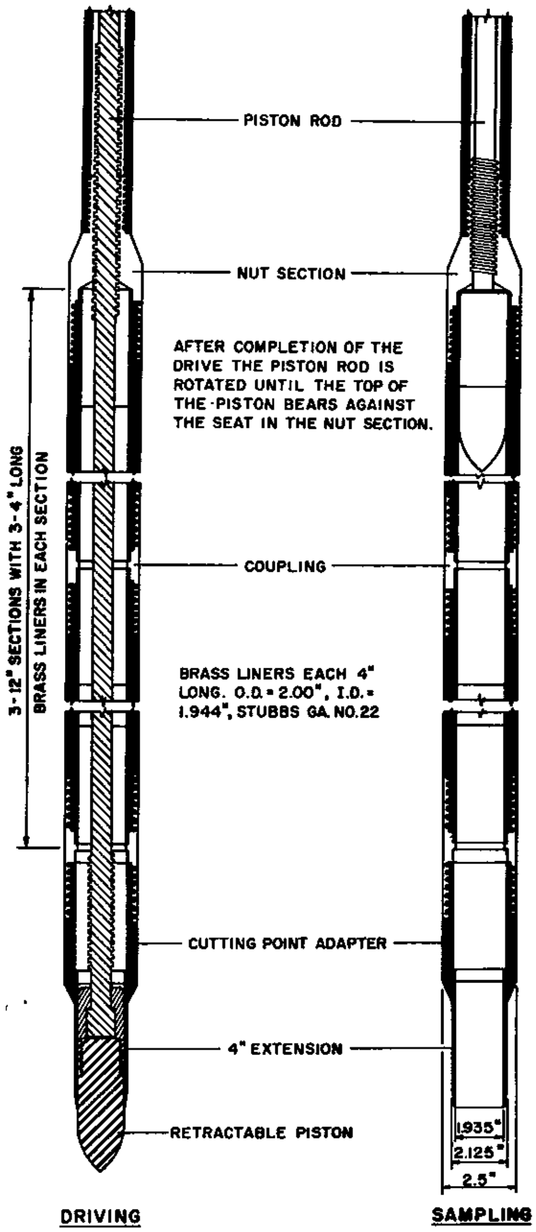

FIG. 2 CALIFORNIA TYPE 2" SOIL SAMPLER *(MOD. 1952)*

LABORATORY TEST PROCEDURES - GENERAL

All testing was done according to procedures published in the Materials Manual of Testing and Control Procedures issued by State of California, Department of Public Works, Division of Highways, Materials and Research Department, with one exception.

As previously stated, the moisture content determinations were of primary concern in this investigation so it was necessary to perform the mechanical analyses, and the liquid and plastic limit determinations on oven-dried soil fractions. It is realized that the ASTM procedures specify that such soil tests should be performed on air-dried soil fractions, so no attempt should be made to correlate these test results with results obtained in other laboratories. The results are primarily intended to show the range of test values for this particular investigation, and in no way affect the validity and significance of the moisture and strength values.

MOISTURE CONTENT DETERMINATIONS

Moisture contents were determined on each of the four quarter-sections of each 2 in. diameter by 4 in. high soil specimen received in the laboratory. After a strength test was performed, the specimen was cut into four sections as shown in Figure 3. In this manner, two moisture determinations were made on each 2 inch increment of soil. The moisture content of the top half could be compared with that of the bottom half; and any significant difference horizontally could be detected. A total of 932 moisture determinations were made and all of these data are plotted on Figure 4 except a few of the

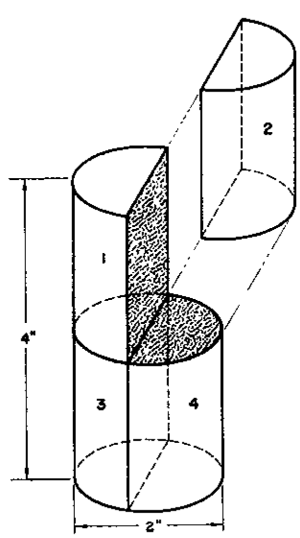

Fig. 3 TEST SPECIMEN CUT INTO FOUR SECTIONS FOR FOUR MOISTURE DETERMINATIONS

moistures in the zone 9 feet to 21 feet below the ground surface where there is a considerable amount of peat or organic material. Several moistures are above 200 per cent.

VARIATION OF MOISTURE IN THE VERTICAL DIRECTION

The subject of migration of moisture from bottom to top of a 4 inch high specimen during the time elapsed between sampling and testing was studied during this investigation. A comparison of the moisture in the vertical direction was made by using the average of quarters 1 and 2, and the average of quarters 3 and 4, as depicted in Figure 3. Figure 5 shows that the moisture in the bottom half was higher than the moisture in the top half just as often as the moisture in the top half was higher than in the bottom half. The moisture in the top half was the same, within 0.1 per cent, as the moisture in the bottom half in two per cent of the tubes. As an example of the moisture variation, Figure 5 shows that in seven per cent of the tubes the moisture content was greater by five per cent or more in the bottom half than in the top half; and in ten per cent of the tubes the moisture content was greater by five per cent or more in the top half than in the bottom half. In 80 per cent of the tubes the moisture contents of the top and the bottom halves of the tube were within five per cent moisture content of each other. In 95 per cent of the tubes the moisture contents of the top and bottom halves of the tubes were within ten per cent moisture contents of each other. The samples showing a difference in moisture content between the top and bottom halves of the tubes greater than ten per cent moisture content were generally from the top 40 feet of the soil layer and included peat in a portion of the sample. See Fig. 7. No samples below 40 feet in depth indicated moisture content differences greater than ten per cent between the top and bottom halves of the sample. Less than ten per cent of the samples indicated greater than five per cent moisture content difference between the top and bottom halves of the sample. See Fig. 8. The moistures in the vertical direction in the lower uniform clay layer are in close agreement and the moistures in the vertical direction, in the upper peaty clay layer are spread over a large range of values.

VARIATION OF MOISTURE IN THE HORIZONTAL DIRECTION

A comparison of the moisture in the horizontal direction was made by using the average of quarters 1 and 3, and the average of quarters 2 and 4 as depicted in Figure 3. The comparison of the average moistures in a horizontal direction showed that in five per cent of the tubes the moisture content varied by more than five per cent and in one per cent of the tubes it varied more than ten per cent. This variation in the horizontal direction for a four inch depth of sample is much smaller than the variation in the vertical direction.

The comparison of moisture in the horizontal direction was also made by considering the adjacent quarters as separate test specimens. See Fig. 6. As an example, this figure shows that eight per cent of the adjacent quarters have a variation greater than four per cent moisture content. The majority of the tubes that show greater than four per cent moisture content variation between adjacent quarters were in the upper 40-foot soil layer, see Figure 7. A total of only five samples from the lower uniform clay layer showed five per cent or greater moisture content variation in the horizontal direction, see Figure 8. This is about four per cent of the samples from this layer. Fifteen per cent of the samples showed greater than two per cent moisture content variation in the horizontal direction. The variation in moisture content in the horizontal direction for a two inch high sample is smaller than in the vertical direction for a four inch high sample. Neither the top or bottom half of the four inch high sample indicated a larger horizontal variation.

COMPARISON OF MOISTURES IN THE TWO LAYERS

Due to the difference in the moisture variation in the two clay layers each layer was studied separately. See Figure 7 and 8. The variation in moisture content in the top layer is shown in Figure 7. The number of samples showing a vertical variation greater than four per cent moisture content was about twice the number showing the same horizontal variation. The variation in moisture content in the lower layer is shown in Figure 8. The number of samples showing a vertical variation greater than four per cent moisture content was about ten times the number showing the same horizontal variation. In both layers the vertical variation in moisture content is much larger than the horizontal variation.

A study of the vertical moisture variation of all the samples in both layers shows that about 50 per cent of the samples have a moisture variation of two per cent or less. At four per cent or greater moisture content variation, the tests from the upper 40-foot layer indicated 35 per cent of the samples, and the tests from the lower layer indicated 20 per cent of the samples. In the upper layer 20 per cent and the lower layer five per cent of the samples show a moisture content variation greater than eight per cent. In the lower layer about 90 per cent of the samples had less than six per cent variation and in the upper layer about 75 per cent of the samples had less than six per cent variation.

The horizontal variation in moisture content in the lower layer was less than the variation in the upper layer. In the lower layer 98 per cent of the samples showed less than four per cent variation in horizontal moisture content and in the upper layer 82 per cent of the samples showed less than four per cent variation in horizontal moisture content. The variation of the horizontal moisture content was minor in the lower layer and more striking in the upper layer.

In both layers the major moisture variation occurred in the vertical direction, with much smaller variation in moisture in the horizontal direction. The horizontal moisture variation in the upper layer was about equal to the vertical moisture variation in the lower layer. The moisture variations in both the horizontal and vertical directions were much greater in the upper layer than in the lower layer. The indications are that in a uniform clay layer as represented by the lower layer in this investigation, moisture content variations of four per cent or greater may be expected in twenty per cent of 2 in.

diameter by 4 in. high samples. The upper layer of clay, with pockets or lenses of peat had moisture content variations of eight per cent or more in twenty per cent of the tubes.

COMPARISON OF SOIL PROPERTIES AND MOISTURE

In soil mechanics work it is often convenient to consider the moisture content of a soil layer as constant or varying along some curve with depth. The moisture contents of each quarter sample are shown in Figure 4. A wide scatter exists above a depth of 30 feet with the moisture content varying from 50 to over 100 per cent. These high moistures are in the layers containing peat. From 30 to 40 feet in depth the soil decreases in moisture content from 80 to about 50 per cent. Below a depth of 40 feet the moisture content varies from 40 to 60 per cent until the stiff silty clay is encountered at a depth of about 103 feet. The general engineering practice would be to call this layer, from 40 to 103 feet in depth, a uniform moisture layer.

Figure 9 shows a comparison of the maximum and minimum moistures with the per cent clay and the plastic and liquid limits. The clay contents and the plastic and liquid limits were determined on oven-dried specimens, thus these determinations were not made in compliance with ASTM standards. It is believed that they are valid for indicating trends only. The indicated clay contents tend to follow the moisture changes to a limited extent. The plastic limits are almost constant and indicate no tendency to follow the moisture changes. The liquid limits tend to follow the limits of the moisture variations closely. It appears that the variations in moistures obtained are accounted for by the variations in the physical properties of the soil from point to point.

This variation in the physical properties of the soil would also be expected to cause variations in the strength and compressibility of the soil. No attempt was made to study the compressibility of this soil. Strength tests were run on the samples prior to the determination of the moisture contents.

VARIATIONS IN THE STRENGTH OF THE SOIL WITH DEPTH

Two types of strength tests were performed on this soil, the unconfined compression and quick undrained triaxial compression tests. The variation of strength with depth is shown on Figure 10. The unconfined compression tests and the triaxial quick undrained tests both indicate the same range of strengths. The strengths show a tendency to increase with depth for the first forty feet. This upper soil layer has a wide range of moisture contents and the strength values vary from an average strength by about 100 to 125 pounds per square foot. Below a depth of 40 feet the strength continues to increase with depth and the range of test values becomes wider with depth. At a depth of 90 feet the limits of variability are about 350 pounds per square foot from the average strength The strength values are quite scattered within the above limits but do indicate a trend toward increase with depth.

Figure 10 also shows the cohesion/pressure ratio for all strength tests. In the ten to twenty foot depth layer, the c/p ratio ranges from 0.95 to 0.39, showing a definite decrease with depth. From 20 to 102 feet, the c/p ratio ranges from

0.67 to 0.13, with most of the values falling between 0.3 and 0.4.

COMPARISON OF SHEARING STRENGTH AND MOISTURE CONTENT

The shearing strength was plotted against moisture content and the points tend to form two groups, one for the soils above forty feet in depth and one for the soil below forty feet in depth. See Figure 11. The top forty feet of this soil has a small increase in strength with decreasing moisture content and the points are scattered to some extent. The soil below forty feet has higher strength, but this strength varies considerably over a narrow range of moisture content. There is only a slight indication of increase in strength with decrease in moisture content.

The average moisture of all four quarters in each tube was used in determining the strength-moisture relationship. The use of the moisture content of the quarter showing the greatest moisture resulted in almost identical curves and grouping of points about the curve. There did not appear to be a reduction in the spread of the points about the strength-moisture curves that would have indicated increased reliability for the curve. The triaxial and unconfined compression tests are in the same grouping indicating no significant difference between the two tests.

The per cent moisture variation between the four quarters of the sample is also shown in Figure 11. The variation of moistures within the sample does not form any trend in the strength-moisture relationship. The data from samples with less than one per cent moisture variation are intermixed with the samples showing greater than six per cent moisture variation. The use of the average moisture for the sample tested appears to be a reliable value to use in strength-moisture relationships.

CONCLUSIONS

The results of this study indicate that soil layers that appeared to be "uniform" have small variations in soil properties within the layer. The moisture content was affected by small changes in clay content and liquid limit. The moisture content variation within the 2 in. diameter by 4 in. high tubes were found to be less than four per cent in 80 per cent of the tubes and greater than ten per cent in less than five per cent of the tubes. This moisture content variation found in this study did not have a noticeable affect upon the strength tests performed on this soil.

The upper peaty clay layer showed a much higher variation in moisture content than the lower 60 foot layer. The moisture content variation within the 2 in. diameter by 4 in. high tubes was found to be less than eight per cent in 80 per cent of the tubes with some tubes indicating up to 50 per cent moisture content variation. This moisture variation may have had some effect upon the strength of the soil.

The moisture variation in the vertical direction was much greater than the moisture variation in the horizontal direction in both layers. The moisture tests represent a horizontal distance of two inches and a vertical distance of four inches.

Additional studies should be made in which the horizontal distance is the same as the vertical distance.

ACKNOWLEDGEMENTS

These studies were performed under the general supervision of Mr. F. N. Hveem, Materials and Research Engineer, California Division of Highways. Mr. George Ralph, Mr. David Eckhoff and Mr. William Yttrup assisted in the preparation of the charts and sketches. The writers wish to acknowledge, with sincere appreciation, the assistance given by all those who helped perform the tests and compile the data.

We wish to especially acknowledge Mr. Arthur W. Root and Mr. Travis W. Smith for their encouragement, suggestions and assistance in the work necessary for the preparation of this manuscript.

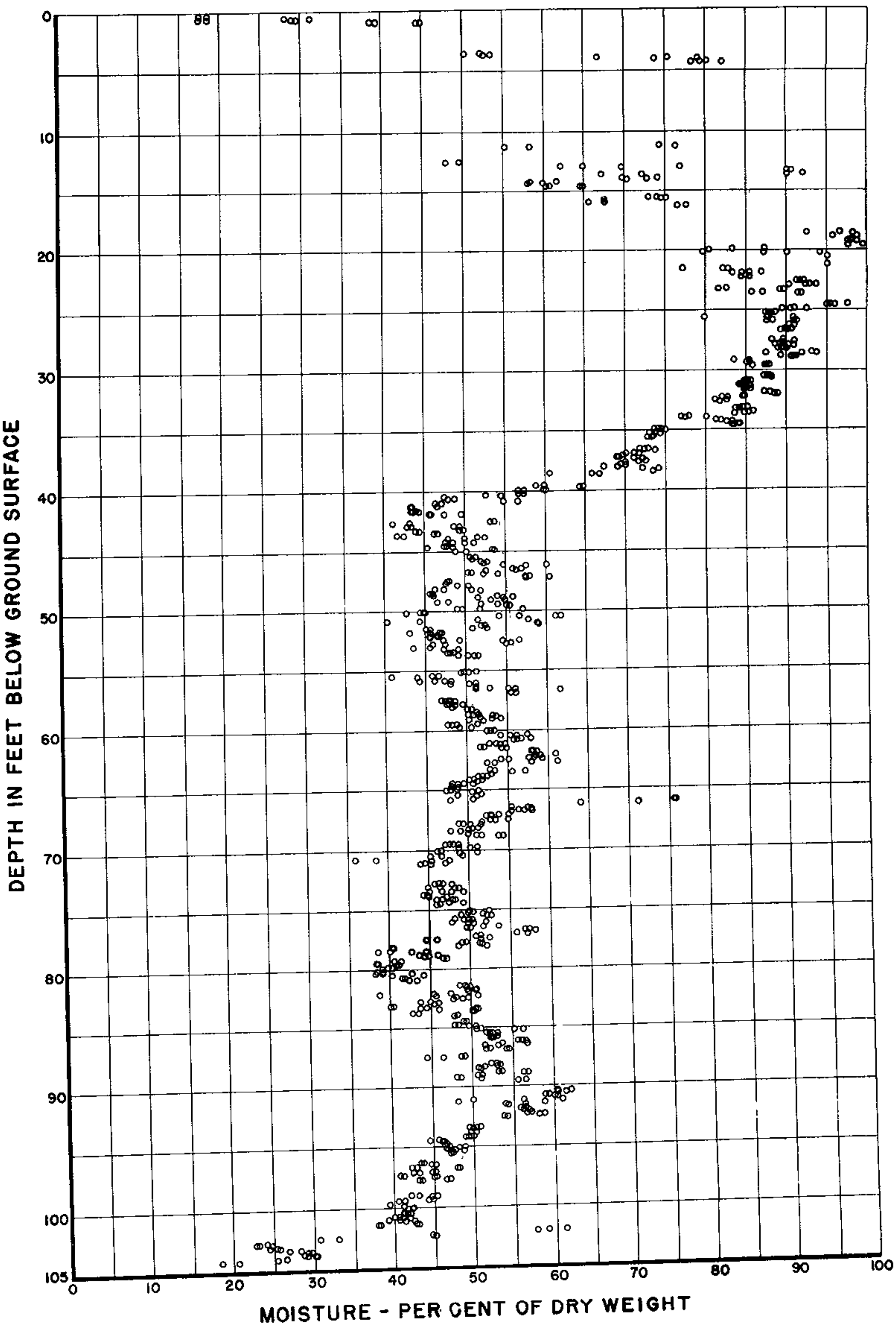

Figure 4. Range of moisture, horizontally and with depth, in a clay layer. Each pair of marks, in a horizontal direction represents the moisture in a 2" increment of depth.

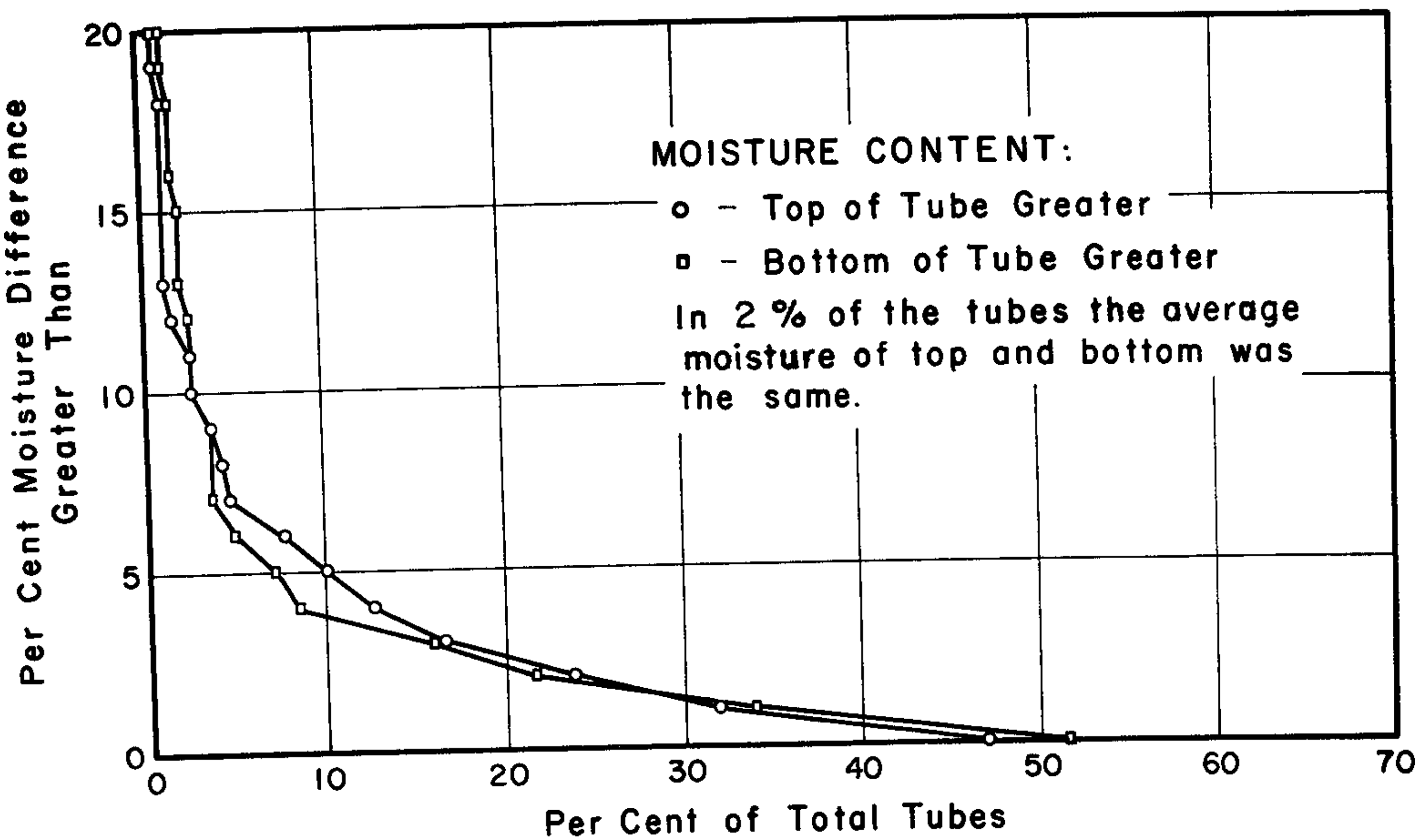

Fig. 5 **MOISTURE DIFFERENCE BETWEEN TOP AND BOTTOM OF TUBE**

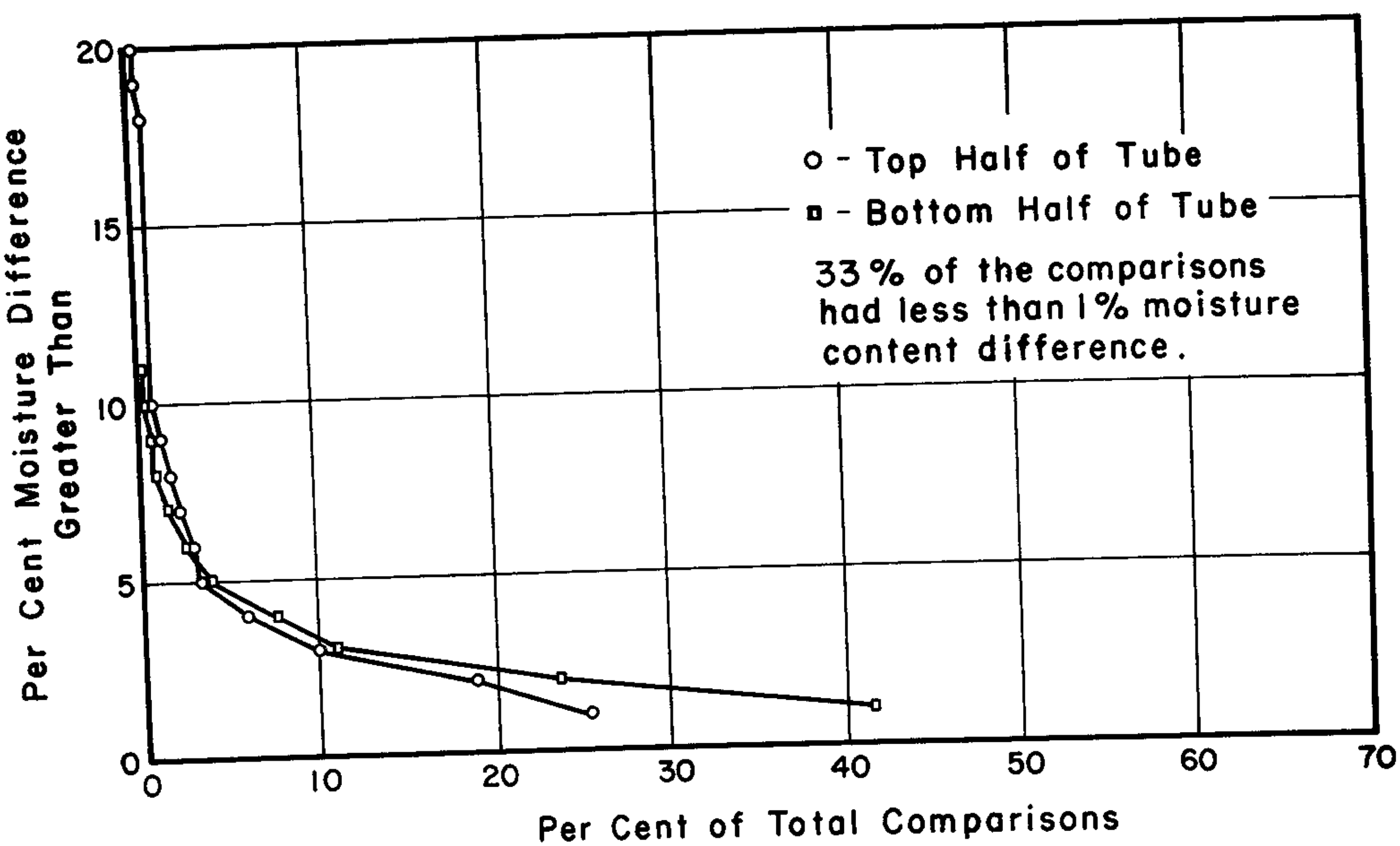

Fig. 6 COMPARISON OF HORIZONTAL MOISTURE DIFFERENCES IN TOP AND BOTTOM HALVES OF TUBES

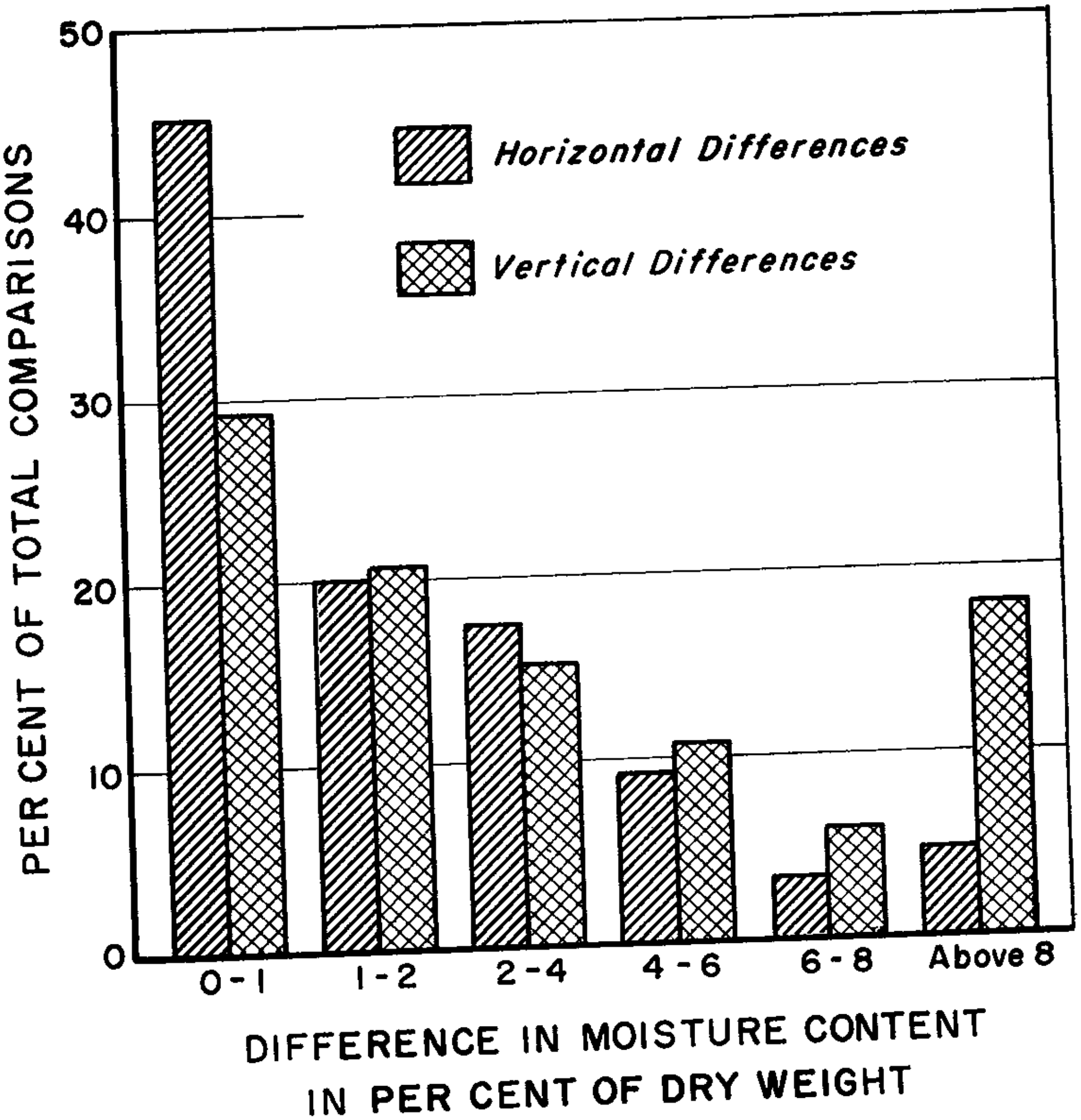

Fig. 7 COMPARISON OF HORIZONTAL AND VERTICAL MOISTURE DIFFERENCES IN THE UPPER 40 FEET

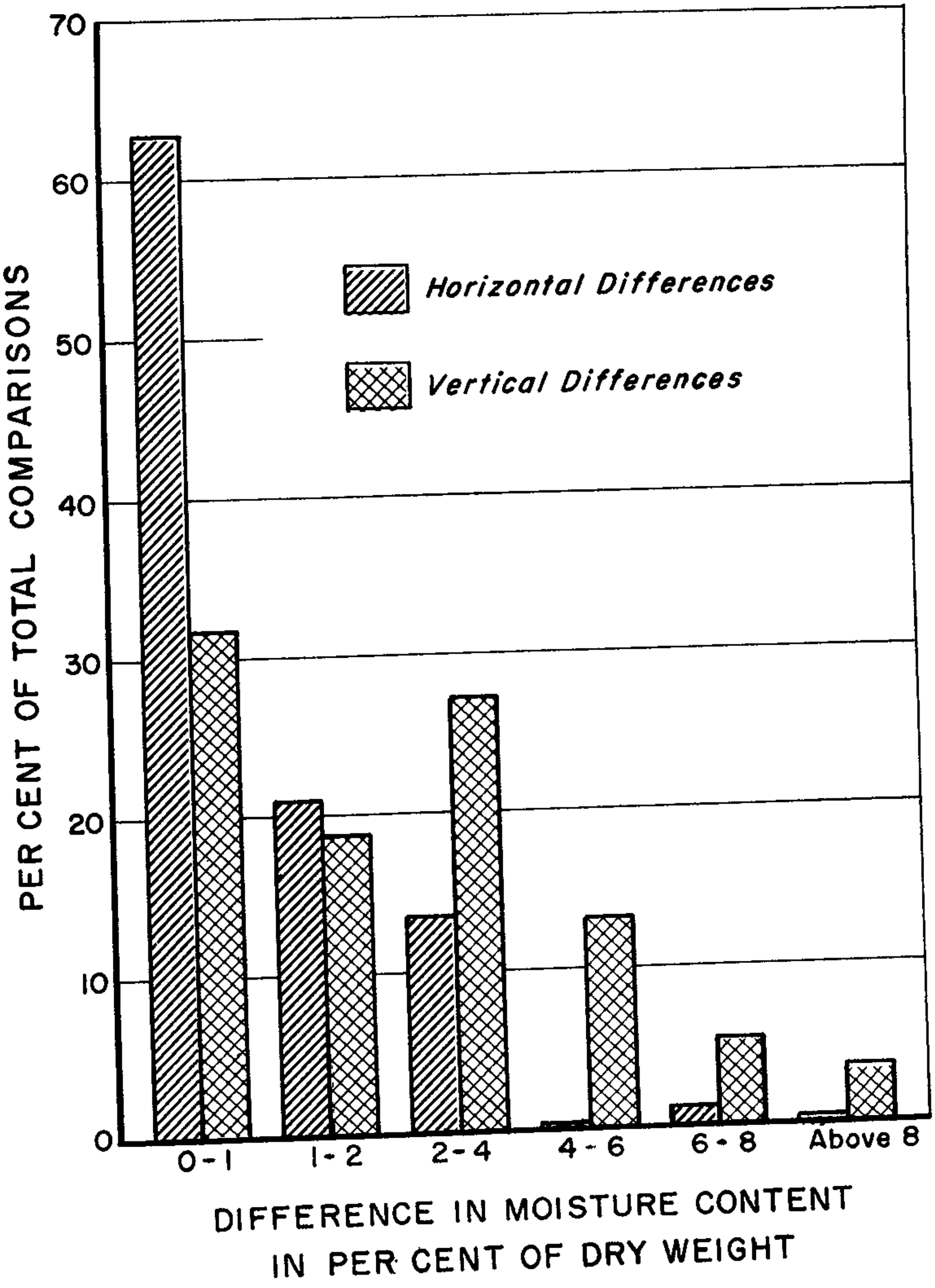

Fig. 8 COMPARISON OF HORIZONTAL AND VERTICAL MOISTURE DIFFERENCES IN THE LOWER 60 FEET

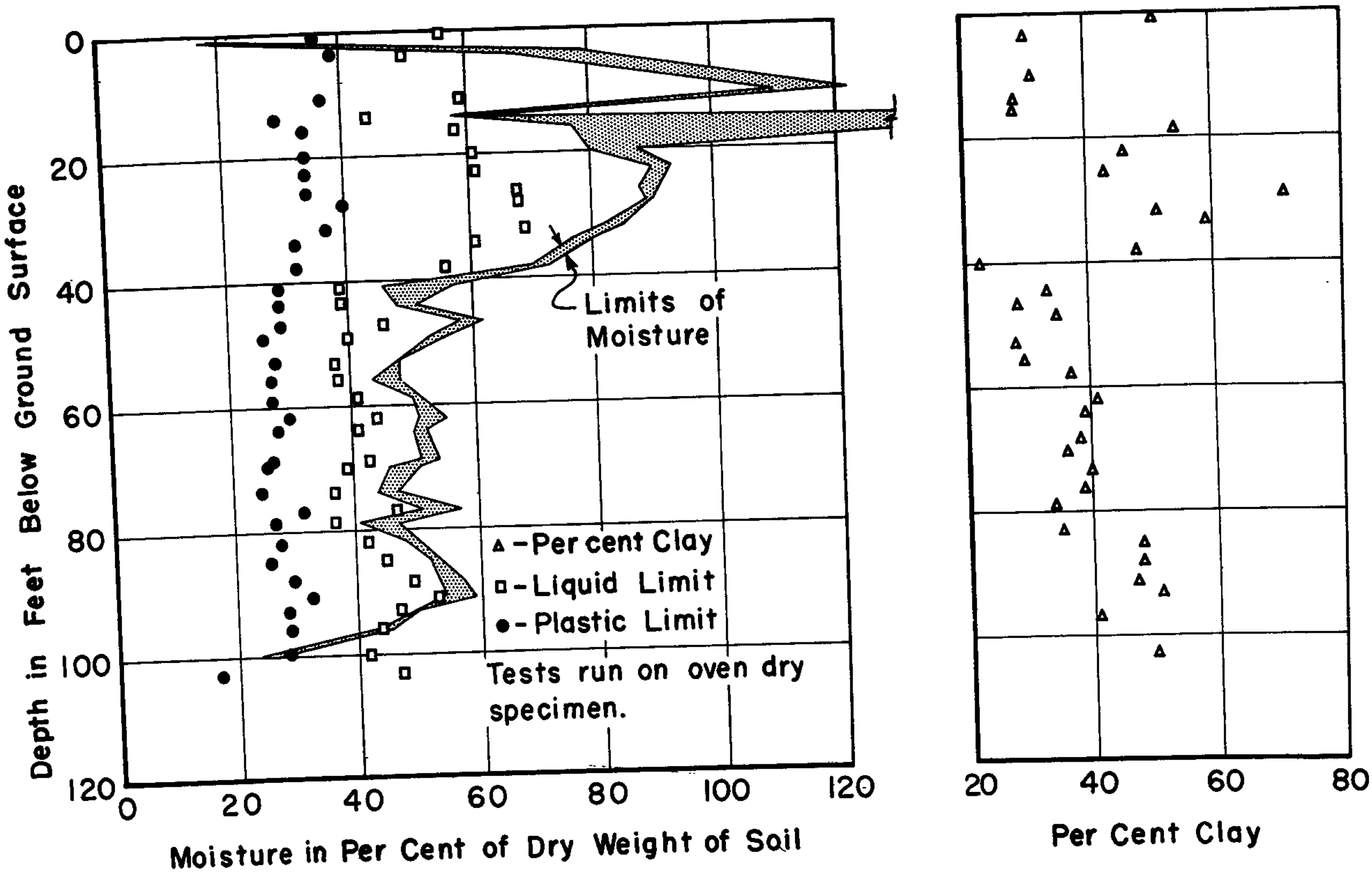

Fig 9. COMPARISON OF LIMITS OF MOISTURE CONTENTS, PLASTIC AND LIQUID LIMITS AND PER CENT CLAY

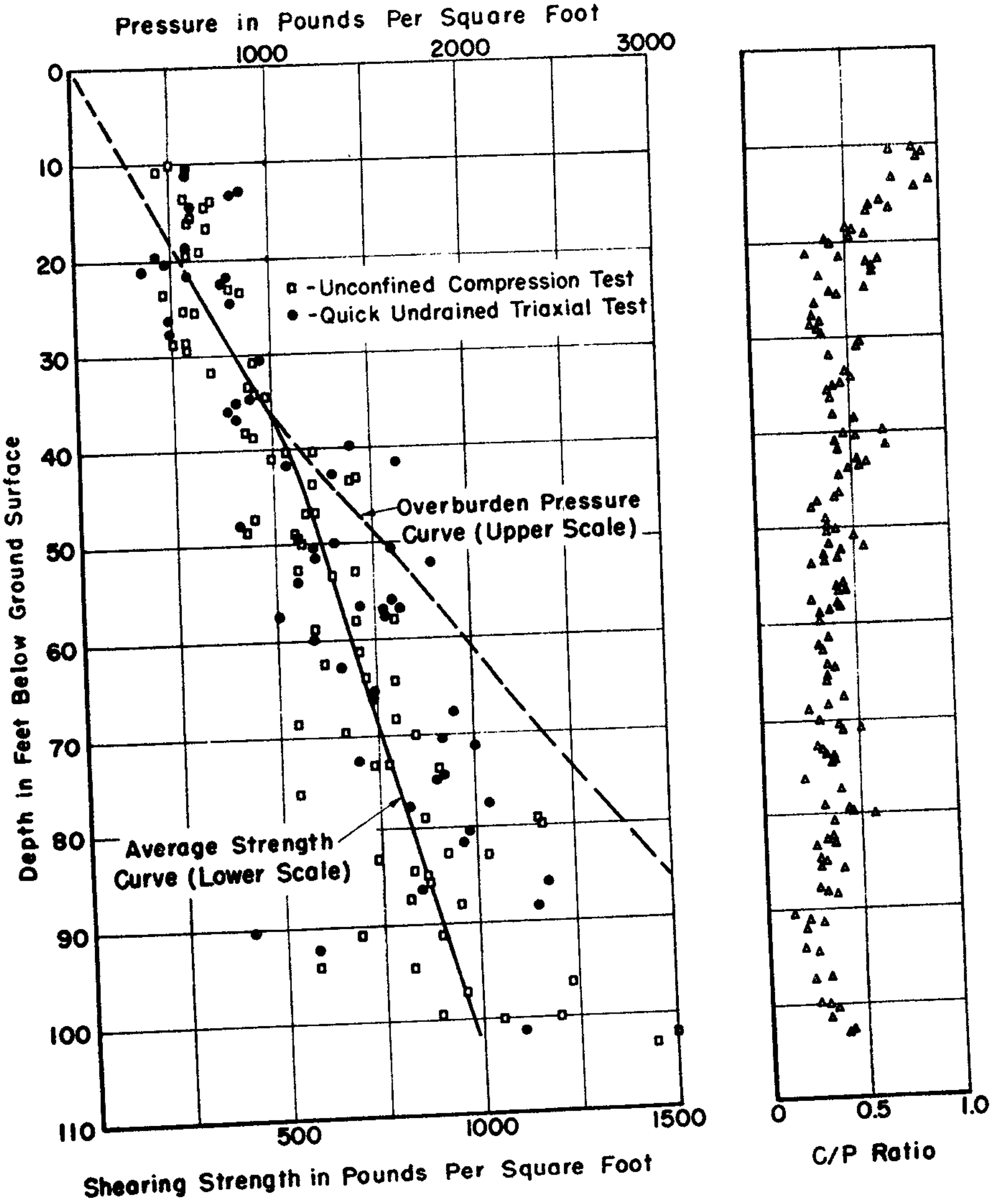

Fig 10 VARIATION OF STRENGTH WITH DEPTH

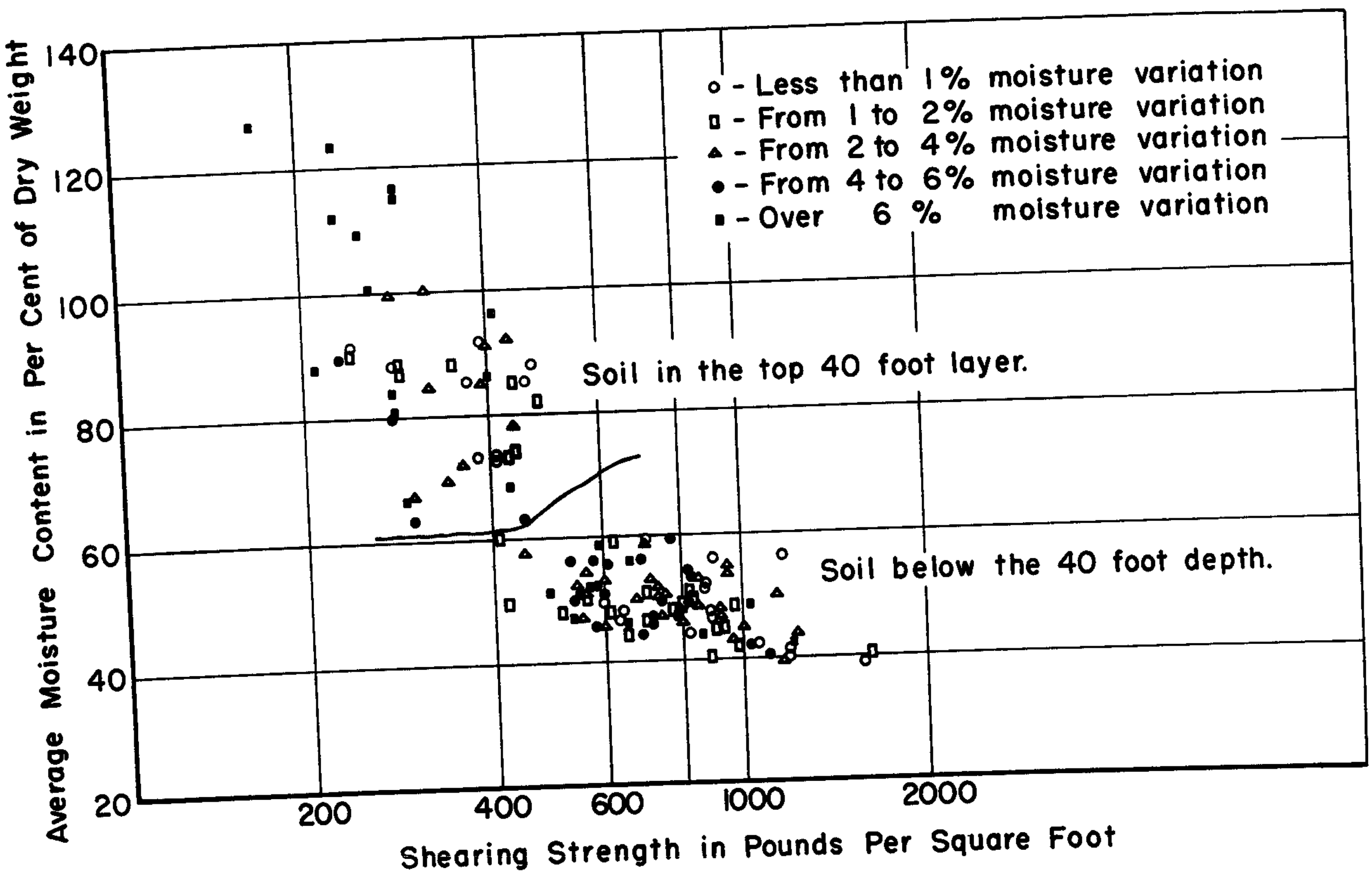

Fig. 11 VARIATION OF STRENGTH WITH AVERAGE MOISTURE