DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

MISSISSIPPI RIVER COMMISSION

FIELD MOISTURE CONTENT INVESTIGATION

T. M. 3-401

INTERIM REPORT NO. 1

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

MRC-WES-50-5-48

MAY 1948

CONTENTS

	Page
PREFACE	
PART I: INTRODUCTION	
Authorization	2
Purpose	2
Scope	2
Definitions	3
Acknowledgments	3
PART II: PRELIMINARY INVESTIGATION	
Preliminary Tests on Bouyoucos Moisture Block	5
Test procedure	6
Soil temperature	7
Salinity of soil water	7
Soil grading	7
Trial installations	8
PART III: FIELD INSTALLATIONS	
PART IV: CALIBRATION TESTS	
Sample Preparation	11
Specimen Water Contents	12
Resistance Readings	12
Calibration Curves	13
PART V: DISCUSSION	
Field Resistance Readings	15
Laboratory Calibrations	15
Variations in calibration curves	17
PART IV: CONCLUSIONS	
TABLE 1	
PLATES 1-8	
APPENDIX A: LITERATURE OF SOIL MOISTURE STUDY	
APPENDIX B: INSTALLATION OF MOISTURE BLOCKS	

FIELD MOISTURE CONTENT INVESTIGATION

Interim Report No. 1

PREFACE

The Field Moisture Content Investigation is a continuing study of moisture movement under airfield pavements. The initial phase of the investigation was a review of published accounts of methods of observing in-place soil moisture content. As a result of this review the Bouyoucos resistance block was selected for trial. The block appeared to be satisfactory as a tool for measuring moisture contents in soil. Installations of a number of Bouyoucos blocks were made at three airfields in the Albuquerque District, CE, located at Albuquerque (Kirtland Field), Clovis, and Santa Fe, New Mexico, and periodic readings were taken for 18 months. The block installations did not yield satisfactory results. Laboratory calibrations of moisture blocks with compacted soils were unsuccessful and field block resistances did not correspond systematically with field moisture contents as determined by direct sampling. A review of the work that has been accomplished with moisture blocks and an analysis of the failure of the blocks to produce reliable moisture content information is presented in this interim report.

PART I: INTRODUCTION

Authorization

1. A study of moisture movement in base course and subgrade materials under flexible airfield pavements was authorized by the Office, Chief of Engineers, in the 10th indorsement to a letter to the President, Mississippi River Commission, dated 22 August 1944, subject: "Field Moisture Content Investigation".

Purpose

2. The general purpose of this study is the determination of changes in moisture content which may occur over a period of time in base courses and subgrades under airfield pavements. In this study the following information is sought:

a. Moisture gradients under the pavement, with depth and with distance from the pavement edge.

b. Amount of moisture of condensation under the wearing course, if any occurs.

c. Extent of influence of leakage from the surface, through the wearing course, on base course and subgrade moisture contents.

d. Extent and rate of capillary movement of water under the pavement.

e. Effect of drainage systems on moisture content of the subgrade, as determined by visual inspection.

Scope

3. The scope of the investigation to the present time has been:

a. Review of the literature of in-place soil moisture measurement.

b. Preliminary laboratory tests with the Bouyoucos moisture block.

c. Installation of Bouyoucos moisture blocks at three airfields in the Albuquerque District: Kirtland Field (Albuquerque), Clovis and Santa Fe.

d. Periodic readings of the moisture blocks referenced in c together with limited moisture tests in a few places at each airfield by direct sampling methods.

e. Laboratory calibrations of the moisture blocks with representative base and subgrade materials from the field installations.

Definitions

4. Terms to which unusual or special meaning is attached in this report are defined as follows:

Moisture block. A porous block made of plaster of Paris and containing two electrodes (unless another type is specifically mentioned) used in the determination of soil moisture content by the electrical resistance method.

Temperature gage. A small glass bulb containing two electrodes immersed in an organic liquid by means of which soil temperature can be determined by the electrical resistance method.

Molding water content. The water content of a soil specimen at the time it was compacted or molded, expressed as a per cent of the dry weight of the soil.

A unit of blocks. All moisture blocks placed in one vertical line.

An installation of blocks and gages. All blocks and gages placed in one pavement profile.

Direct sampling. The method of determining soil moisture content by drilling a hole and taking a sample of the materials for direct laboratory testing.

Acknowledgments

5. The investigational program for this study was performed by

the Flexible Pavement Branch of the Soils Division of the Waterways Experiment Station for the Airfield Branch of the Office, Chief of Engineers. Representatives of the Albuquerque District participated in the planning and carrying out of the moisture block installations, and made periodic readings of the blocks following their placement.

PART II: PRELIMINARY INVESTIGATION

6. The initial phase of the preliminary investigation was a study of the literature of in-place methods of observing soil moisture content. This study is outlined in detail in Appendix A, with a bibliography of the references consulted. Of the various gravimetric, electrical and mechanical devices used for soil moisture measurement, the method which appeared to be most suitable for this investigation was the plaster of Paris resistance block developed by Dr. G. J. Bouyoucos of Michigan State College, (Reference No. 10, Bibliography, Appendix A) and extensively studied and used by several investigators. It was initially concluded that the Bouyoucos moisture block would be the most satisfactory method for observation of in-place soil moisture contents under pavements, and that direct sampling was the only dependable alternative method. The resistance block method presents the following advantages over the direct sampling method:

- a. Moisture contents are measured at identical points in successive readings.
- b. A minimum of interruptions to plane traffic occurs when moisture determinations are made.
- c. A minimum disturbance of the wearing course is entailed.
- d. After installation is complete the succeeding observations are quickly and easily secured.

Preliminary Tests on Bouyoucos Moisture Block

7. The Bouyoucos moisture block is described in detail in Appendix A. Briefly, the resistance between two electrodes mounted in a small

plaster of Paris block is measured by connecting the leads to a special Wheatstone bridge. This resistance varies with water content of the block which in turn varies with water content of the surrounding soil. The block resistance is therefore a measure of the water content of the soil when equilibrium exists between the water in the block and the water in the soil and all other factors influencing the resistance have been evaluated. At the start of the present investigation other studies indicated that the variation of moisture block resistance with soil moisture content was affected by: (a) soil temperature; (b) salinity of the soil water; and (c) grading of the soil. Initial laboratory tests were directed toward a brief study of these effects and included a trial installation and calibration of the blocks.

Test procedure

8. Preliminary tests with the moisture blocks were conducted according to the methods proposed by Dr. Bouyoucos. In each test the block was bedded in loose soil in a small pan, the soil was saturated and compacted with the fingers to insure good contact with the block, after which the pan was filled with soil, saturated and allowed to soak for 24 hours. At this time the block resistance was read, the soil temperature was observed, and a specimen for water content determination was taken from soil immediately above and below the block. This process was repeated, except that the soil was dried to a lower percentage of water each time, until a series of resistance readings was obtained for a range of soil moisture contents.

Soil temperature

9. Moisture block resistances were observed at various temperatures and were corrected to resistances at a standard temperature of 70 degrees F using correction data developed by Dr. Bouyoucos which are shown on plate 1. Dr. Bouyoucos found that the variation of resistance with temperature was systematic in the soils studied by him, and his results were confirmed in several series of tests at the Waterways Experiment Station.

Salinity of soil water

10. The effect of saline soil water on the calibration of block resistance with soil moisture content was studied by preparing several calibration test specimens in the manner described in paragraph 8 above, with the exception that measured amounts of sodium chloride were added to the water used in saturating the specimens. In tests with two different concentrations of sodium chloride, it was found that a salinity of 0.3 per cent of the dry soil weight had no immediate effect on block resistances, while a salinity of 2.0 per cent lowered block resistances from 500 to 1,000 ohms below those of similar specimens with distilled water. Since each soil has its own solution constant and tests were to be made calibrating each different soil with the blocks, no further study of dissolved salts in the soil water was undertaken.

Soil grading

11. The moisture block resistance characteristics of soils have been shown by Dr. Bouyoucos to vary with their grain-size distribution. The effect of soil grading on resistance variation with soil moisture content was dealt with in this investigation by making complete tests on each

distinct soil grading encountered in field installations. No compaction or density control was used in the preliminary tests, since available information indicated that the density of soil specimens influenced only the time required for the block resistance to reach equilibrium with a change in soil water content.

Trial installations

12. A technique for installation of moisture blocks under field conditions was developed after several blocks were placed in natural and compacted ground. It was found that to insure against cracking the plaster, the blocks should be placed in material all of which passed the No. 10 sieve, and covered with about 3 in. of soil before starting compaction. Tamping was accomplished with a 10-lb drop-hammer of the type used in Modified AASHO compaction, fitted with a special 4-1/2-in.-diameter foot.

PART III: FIELD INSTALLATIONS

13. Moisture blocks were installed at three airfields in the Albuquerque District (Kirtland Field, Albuquerque, and Clovis and Santa Fe Airfields) in the manner described in the preceding paragraph. In-place CBR, moisture and density tests were conducted near each installation, and large samples of each material encountered were obtained for laboratory tests and block calibrations. Table I indicates moisture conditions present at each airfield at the time of block installation. Block

TABLE 1

PER CENT SATURATION AND MOISTURE CONTENT

Kirtland, Clovis, and Santa Fe Airfields
at Time of Moisture Cell Installations

Layers	Saturation Per Cent	Moisture, Per Cent of Dry Wt
	Kirtland Airfield	
Natural ground	20	5
Base	50 - 70	4 - 7
Subgrade	30 - 75	6 - 11
	Clovis Airfield	
Natural ground	25 - 90	6 - 15
Base	50 - 70	8 - 11
Subgrade	30 - 75	8 - 12
	Santa Fe Airfield Sta. 38+10 (well drained section)	
Natural ground	25 - 50	7 - 16
Base	35 - 50	3 - 5
Subgrade	35 - 50	6 - 17
	Sta. 41+50 (poorly drained section)	
Base	60 - 80	5 - 7
Subgrade	60 - 80	15 - 22

NOTE: Above percentages are approximate, being based on a relatively small number of tests resistance readings and a limited number of moisture content checks by direct sampling have been obtained periodically since the installations were made. Typical field resistance data, with moisture contents obtained by direct sampling, are shown on plates 2-4. (These plates are discussed in detail in Part V of this report.) The plotted points and connecting lines on these graphs represent variation in block resistance with time while the numbers beside some of the plotted points give the corresponding moisture content as determined by direct sampling. A detailed discussion of the field installations is contained in Appendix B.

PART IV: CALIBRATION TESTS

14. Tests to calibrate the soil samples obtained from the field installations at Kirtland Field, Clovis Airfield and Santa Fe Airport, with the Bouyoucos moisture block comprised a major portion of the work performed in the phase of the study covered by this report. Progress of these tests was closely followed and the procedure was varied, as a method was sought of successfully calibrating soil moisture content with block resistance.

Sample Preparation

15. Moisture block calibration of soil samples from the three airfields was undertaken in accordance with the Bouyoucos method (paragraph 8), modified to employ a larger specimen which was compacted to simulate field conditions and which was not disturbed during the test. Each soil sample was first quartered down to a convenient size, separated on the No. 10 sieve, and the coarse fraction discarded. This measure duplicated the treatment of material backfilled around the blocks in the field installation and was intended to avoid damage to blocks. The minus 10 material was wetted and compacted in three 1-in. layers in an 18-gage aluminum pan large enough to contain a specimen of from 3,000 to 5,000 grams. Compaction was carried out using a 2-lb wood block of 2- x 4-in. cross section, dropped with uniform stroke and coverage until the soil layer reached a constant thickness. The moisture block was saturated and placed in a horizontal position, centered in the middle layer on a level surface of compacted soil, and material was pressed over and around it,

using only the operators' hands. A top layer of soil was then placed and compacted in the manner just described. The completed specimen was weighed, the moisture content of the material was determined and the initial dry weight of soil was computed.

Specimen Water Contents

16. In preliminary tests the water content of specimens was changed rapidly, either by air-drying or by flooding the specimen surface with a measured increment of water, and block resistance was believed to reach equilibrium within a few days of water content change. Later, it was found that in soils compacted to approximate the field density the moisture blocks required from two weeks to two months to reach equilibrium with a change in water content of the surrounding soil. To prevent loss of moisture during this time, the surface of the soil was sealed with paraffin, applied in thin layers over a sheet of paraffined paper, after each wetting or drying. The paraffin was removed for the next water content change without disturbing the specimen. In a few tests the specimen boxes were covered with wooden lids which permitted a slow, continuous drying of the specimen, and paraffin was not used. This method of covering allowed closer control of water contents than the paraffin method, since it was possible to control the rate of change by covering and uncovering the specimen at intervals. Use of this latter method was limited to tests near the conclusion of the calibration study.

Resistance Readings

17. The moisture block resistance was read at the start of each

test, using a special Wheatstone bridge, and thereafter from three to five times a week until block resistance had attained equilibrium. The last resistance reading was taken as representative of the specimen water content. The specimen was then uncovered and dried, or wetted, to the next water content at which a resistance reading was desired, the seal was replaced, and readings were continued as before. When resistance observations were made, the weight and temperature of the specimen were also observed and recorded. From these data, the specimen water content and resistance corrected to 70 degrees F were computed. Temperature observations were made on an electrical thermometer embedded in one of the specimens, and frequent checks were made by inserting a mercury thermometer in the corners of other specimens. No special control of the room temperature or humidity was exercised, but observations were made at specimen temperatures between 65 and 80 degrees F. Duration of most of the calibration tests was four to eight months. Progress of typical calibration tests is shown on plate 5 by a plot of the variations of resistance and water content with time for two tests. In one of these tests the water content was changed by incremental drying of the specimen and in the other by wetting in increments. These data are discussed in subsequent paragraphs in this report.

Calibration Curves

18. The calibration curve for each test was prepared by plotting resistance, on a logarithmic scale, against specimen water content, on a uniform scale, and drawing a smooth curve through the test points. This curve may be used to obtain soil moisture contents corresponding

to field block resistances in the same soil, provided that the calibration specimen and the soil surrounding the field block have the same characteristics with respect to block resistivity and soil moisture content. In addition to many preliminary tests, from one to three calibration tests were completed on each of 26 samples of base course and subgrade materials from the three airfields. The data obtained from these tests are not presented, but typical calibration curves are shown on plates 6 and 7, and are discussed later in the report.

PART V: DISCUSSION

Field Resistance Readings

19. The resistance readings of moisture blocks at typical locations in the field installations are shown on plates 2-4 for Kirtland, Clovis and Santa Fe Airfields, respectively. In these diagrams, the block resistance in ohms is plotted on the vertical logarithmic scale against the elapsed time in months since the installations were made on the horizontal arithmetic scale. Successive readings from each block are connected by straight lines which are identified as to hole number and depth. Wherever the field moisture content was determined by direct sampling at the time the block resistance was read, the moisture content obtained is shown beside the corresponding resistance point. It is apparent from a review of the data presented on plates 2-4 that it was not possible to determine the moisture content in a base or a subgrade knowing the resistance of the moisture block. Further it does not appear possible even to determine if the moisture content either increased or decreased with time. While the reasons for lack of correlation between resistance and moisture content are not known, the following causes are suggested: moisture blocks may lag behind changes in soil moisture; natural moisture differentials may exist between the soil at the blocks and the soil at the points of direct sampling; and distribution and daily range of ground temperatures may contribute to variations in block resistances or in moisture contents.

Laboratory Calibrations

20. Preliminary tests indicated that in uncompacted soils, block

resistances could be calibrated with moisture contents when the tests were conducted according to the Bouyoucos procedure which (a) started with wet soil pressed about the blocks and saturated, and (b) allowed drying of the soil. Soil structure adjacent to the block was chiefly dependent upon soil moisture content at the start of testing and upon shrinkage characteristics of the soil as the test progressed; this structure, whatever its nature, was reproduced in each test so long as the procedure was not varied and the same material was used. Calibration of compacted soils was undertaken with the supposition that reproducible curves representing the resistance-moisture content relationship in the field installation would be obtained in the laboratory test if the specimens were compacted to approximately the densities of the materials in the field. Most of the specimens tested were compacted with this end in view, while a few were prepared at water contents near saturation or near the air-dry state. Several typical laboratory calibration curves of two subgrade soils are shown on plates 6 and 7, respectively, together with a curve on each plate representing the field resistances obtained by reading the moisture block, and the moisture contents obtained by direct sampling adjacent to the block. The three curves shown on plate 6 are all on the same soil sample from Kirtland Field, and the six curves shown on plate 7 are all on the same soil sample at Clovis Airfield. Curve 3 on plate 6 and curve 6 on plate 7 are based on moisture contents obtained from field samples and field resistance readings. In these diagrams, the resistance in ohms is plotted on the vertical logarithmic scale against the soil moisture content in per cent of dry weight on the horizontal uniform scale. These plates indicate that different laboratory calibration curves may be obtained for a given soil, depending on the conditions of testing. Calibration curves for drying and for wetting soils are dissimilar, as shown by curves 1 and 2, plate 6. Calibration curves for a drying soil at different densities are similar in shape but the entire curve may be displaced horizontally or vertically on the coordinates, as shown by curves 2, 3, and 5 of plate 7. Comparison of laboratory curves with field resistance and direct sampling moisture content data do not indicate a correlation. These data are typical and are substantiated by a volume of similar data not presented herein. On the basis of these tests it is not believed possible to satisfactorily calibrate moisture block resistance with soil moisture content to adequately meet the objectives of this study.

Variations in calibration curves

21. The causes of variations among calibration curves of the soils tested have not been completely isolated, but several factors have been observed to influence the results in the tests. These factors are described in the paragraphs which follow.

22. Specimen preparation. The molding water content and dry density at which a calibration specimen is prepared for testing may affect the test results in some soils. Since the strength and other characteristics of many compacted soils are known to be sensitive to density and molding water content, it is reasonable to suggest that the same factors may influence moisture block resistances. A comparison of block resistances with soil density and molding water content in tests on the subgrade material at Kirtland Field is presented in plate 8. Here

the molding water content and dry density of 16 block calibration specimens are compared with the moisture contents of these specimens which correspond to block resistances of 1,000 and 10,000 ohms. Figure A of plate 8 shows the molding water content of each specimen plotted against the specimen water content as indicated by the calibration curve at 10,000 ohms block resistance; the dry density of each specimen is shown adjacent to its plotted point. Curves have been drawn through points of equal density as illustrated. The curve representing soil at 105 lb per cu ft dry density indicates that if the specimen were compacted to this density at 18 per cent molding water content, the moisture content at a block resistance of 10,000 ohms would be 8 per cent. Following the "105 lb" curve through the diagram, it will be seen that an increase in molding water content at this same density is accompanied by an increase in the water content at 10,000 ohms block resistance, as shown below:

Molding Water Content		Water Content at 10,000 Ohms Block Resistance	
Per Cent of Dry Wt	Per Cent Saturation	Per Cent of Dry Wt	Per Cent Saturation
18	83	8.0	37
19	87	11.0	51
20	92	13.0	60
21	97	14.3	66

It can be seen that other curves would show the same trends as are presented for the 105-lb curve. In figure B of plate 8 the specimen molding water contents are similarly plotted against specimen water contents at 1,000 ohms block resistance. Figure C of plate 8 shows the specimen dry density plotted against the specimen water content at 10,000 ohms block resistance. In this figure the number beside each plot is the moisture content at which the specimen was molded. Curves have been drawn through points of equal water content as illustrated. The curve of 20 per cent specimen molding water content indicates that a specimen compacted at this moisture content to a density of 102 lb per cu ft will reach a block resistance of 10,000 ohms at a water content of 9.5 per cent. Continuing along the 20 per cent curve, it will be seen that an increase in the compaction of the specimen will increase the water content of the specimen at 10,000 ohms resistance, as follows:

Specimen Dry Density Lb Per Cu Ft	Specimen Molding Water Content, Per Cent Saturation	Water Content at 10,000 Ohms Block Resistance	
		Per Cent of Dry Wt	Per Cent Saturation
102	41	9.5	41
103	42	10.8	48
104	43	12.0	54
105	44	13.0	60

It can be seen that the same trend may also be shown for any other curve. In figure D of plate 8 the specimen densities are plotted in a like manner against specimen water contents at 1,000 ohms block resistance. While all of these diagrams represent a limited range of soil conditions, they indicate that within the range studied the relation of moisture block resistance to soil moisture content is influenced by the specimen density and molding water content.

23. Wetting and drying specimens. The difference between calibration curves of wetting and drying soil specimens, indicated in the preceding paragraphs, is further illustrated on plate 5, which presents the day-to-day range of resistances during progress of two typical calibration tests. The curve representing incremental drying of a specimen ranged from 380 ohms resistance at a moisture content of 16.3 per cent of dry weight, or 96 per cent saturation, to between 4 and 5 million ohms

at 6.7 per cent of dry weight, or 39 per cent saturation, in 4 months time. The curve representing incremental wetting of a specimen ranged from about 2 million ohms resistance at a moisture content of 4.0 per cent of dry weight, or 17 per cent saturation, to a temporary low point of 680 ohms at 12.2 per cent of dry weight, or 51 per cent saturation, after which it wandered between 1,000 and 2,000 ohms, insensitive to further wetting of the specimen. It is shown that: (1) calibration curves of wetting and of drying soils are not comparable; and (2) calibration of wetting specimens cannot be carried to completion, as the resistances became insensitive to water content changes within the range under study.

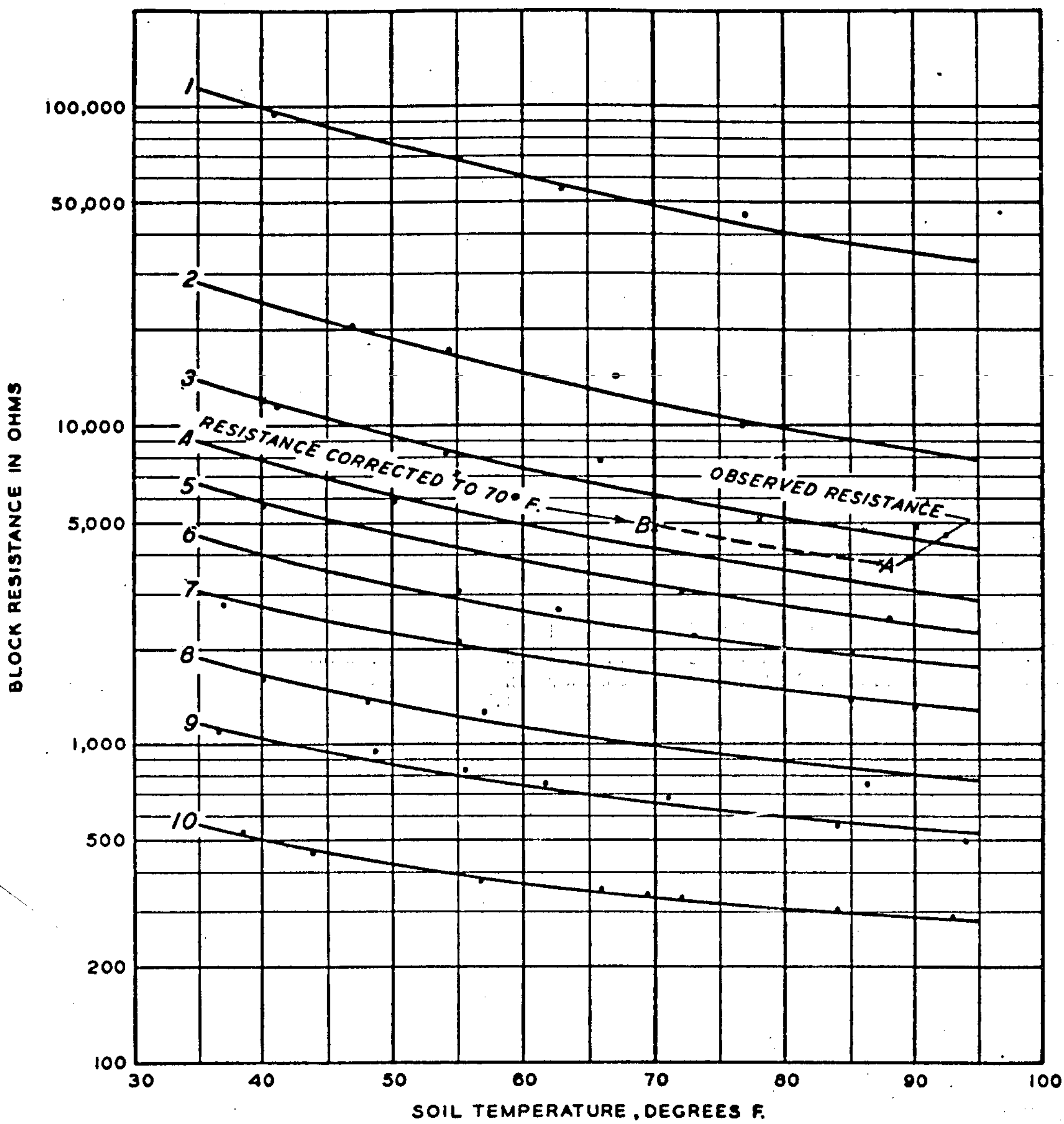
24. Block equilibrium time. The range of resistance during calibration tests, shown on plate 5 and discussed in the preceding paragraph, also indicates the time allowed for moisture block resistance to reach equilibrium with each change in soil moisture content. The specimen which was dried incrementally never reached complete equilibrium with moisture contents drier than 60 per cent of saturation, while the specimen which was wetted shows a resistance pattern of a large decrease followed by a recovery of lesser magnitude for each moisture content. Moisture equivalents on this plot are shown both in per cent of dry weight and as a per cent of saturation. It is apparent that equilibrium points in these tests must be selected arbitrarily, with the aid of diagrams similar to the one shown, and that the selection of equilibrium points for each water content may affect the shape of the calibration curve. A true equilibrium of resistance with soil moisture content may require from several weeks to several months.

PART VI: CONCLUSIONS

25. Based on the results of this study it is concluded that the Bouyoucos moisture block is not satisfactory for the measurement of soil moisture contents under bituminous pavements.

26. In addition, the following specific conclusions regarding the Bouyoucos moisture block are believed warranted from the results of this study.

- a. The resistance readings of the moisture blocks placed under pavements did not correlate with the actual moisture contents obtained by direct sampling.
- b. The moisture block resistance reading at a given moisture content is different depending on whether the moisture content of the soil is increasing or decreasing.
- c. The moisture block resistance reading at a given moisture content varies with the unit weight density of the soil.
- d. The molding moisture content and molding density appear to affect the moisture block resistance readings throughout the entire range of moisture contents to which a soil may be later subjected.

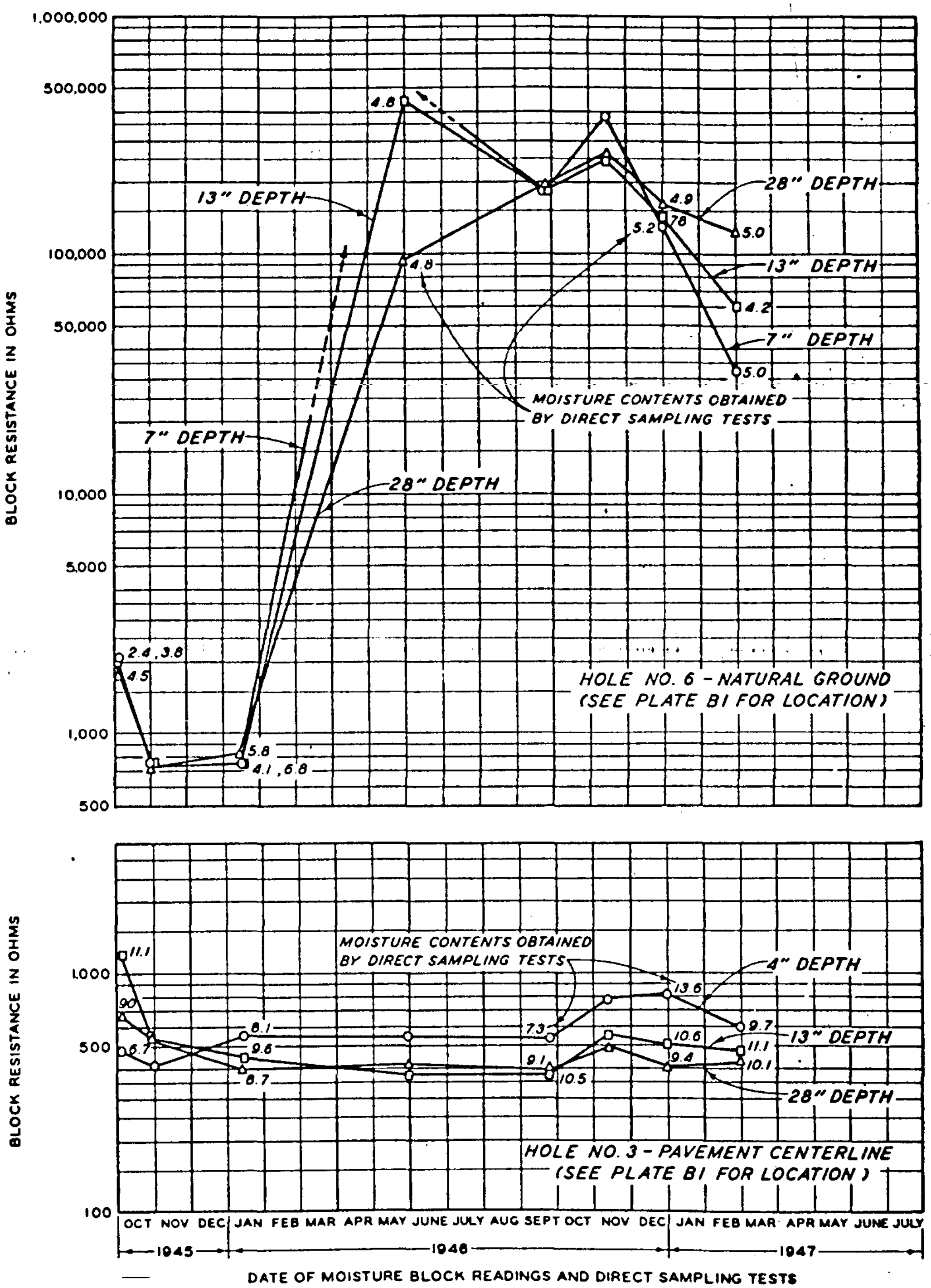


REPRODUCED FROM G.J. BOUYOUCOS AND A.H. MICK "AN ELECTRICAL RESISTANCE METHOD FOR THE CONTINUOUS MEASUREMENT OF SOIL MOISTURE UNDER FIELD CONDITIONS", TECHNICAL BULLETIN NO. 172, MICHIGAN STATE COLLEGE AGRICULTURAL EXPERIMENT STATION.

FIELD MOISTURE CONTENT INVESTIGATION

VARIATION OF BLOCK RESISTANCE WITH TEMPERATURE

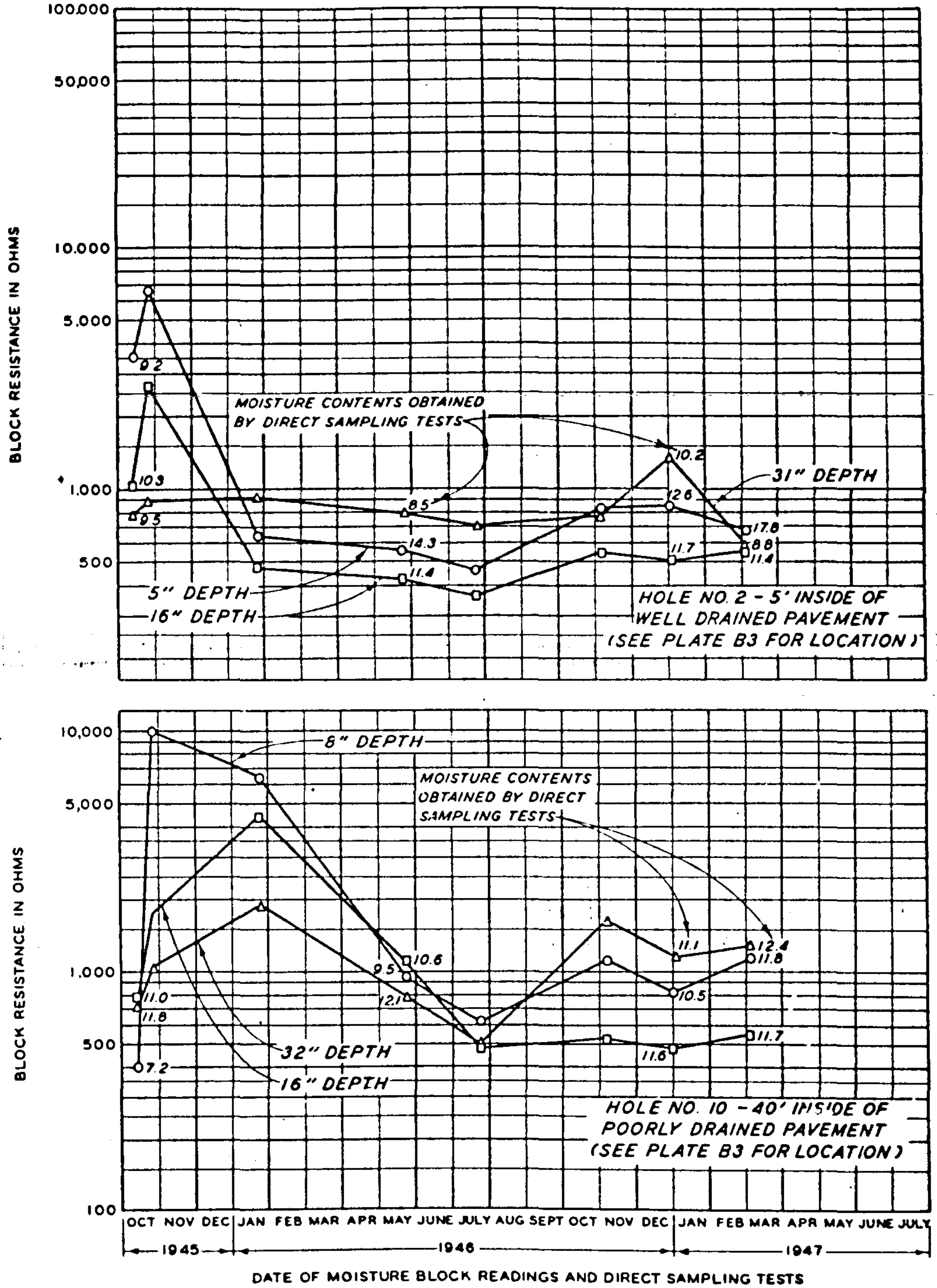
PLATE 1



FIELD MOISTURE CONTENT INVESTIGATION

FIELD BLOCK RESISTANCE READINGS VS ELAPSED TIME

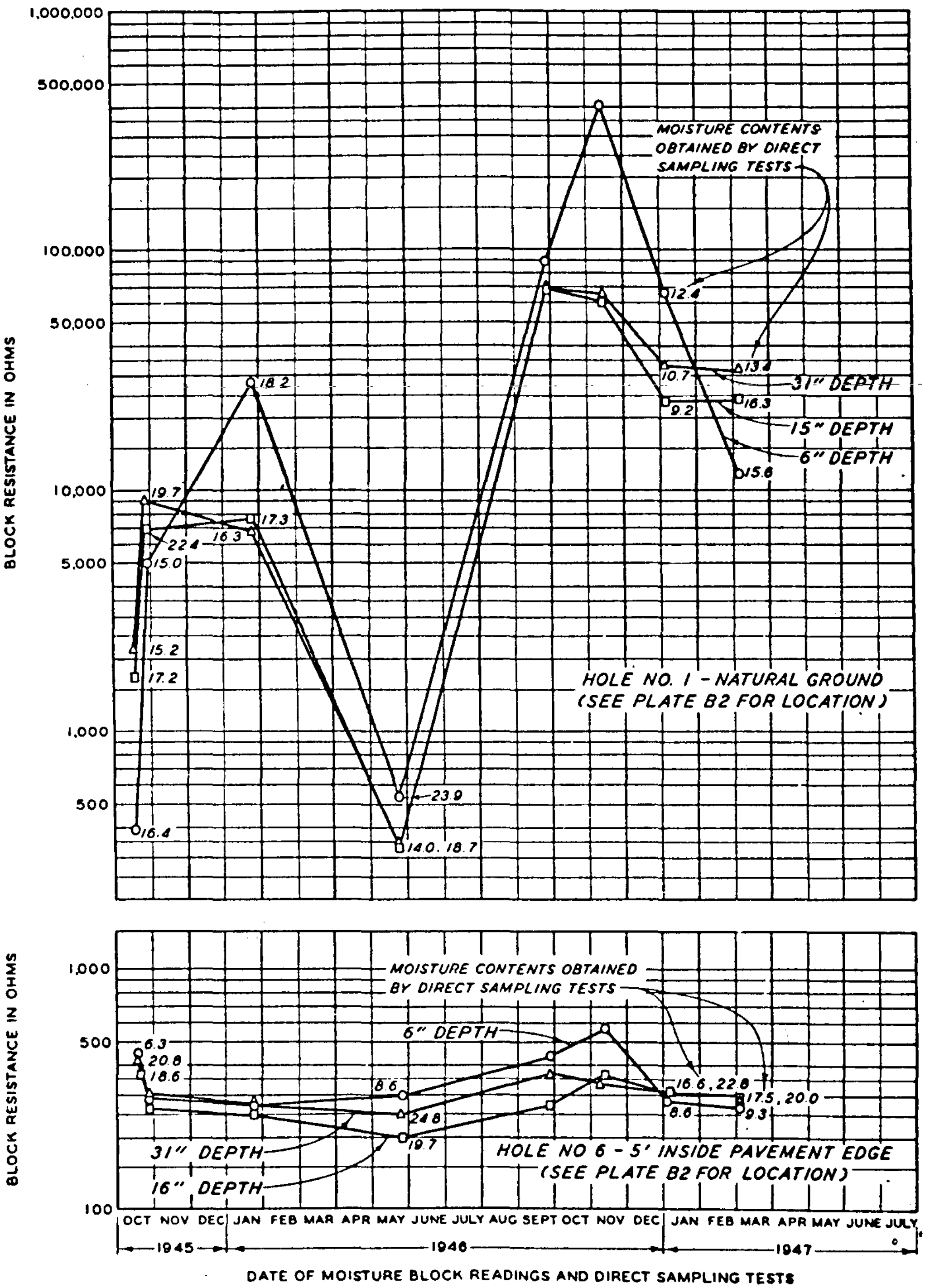
KIRTLAND FIELD, ALBUQUERQUE, N.M.



FIELD MOISTURE CONTENT INVESTIGATION

FIELD BLOCK RESISTANCE READINGS

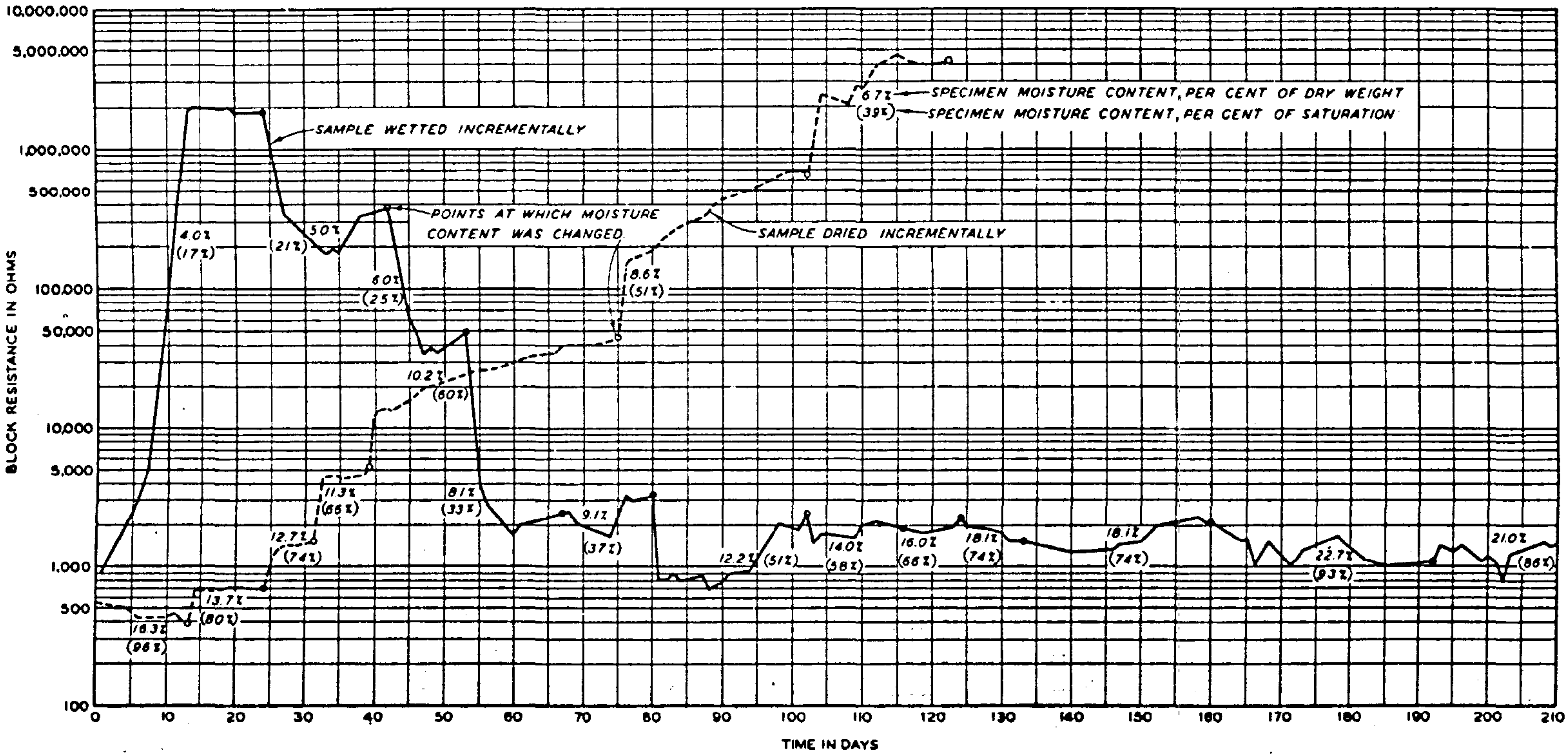
CLOVIS AIRFIELD, CLOVIS, N.M.



FIELD MOISTURE CONTENT INVESTIGATION

FIELD BLOCK RESISTANCE READINGS

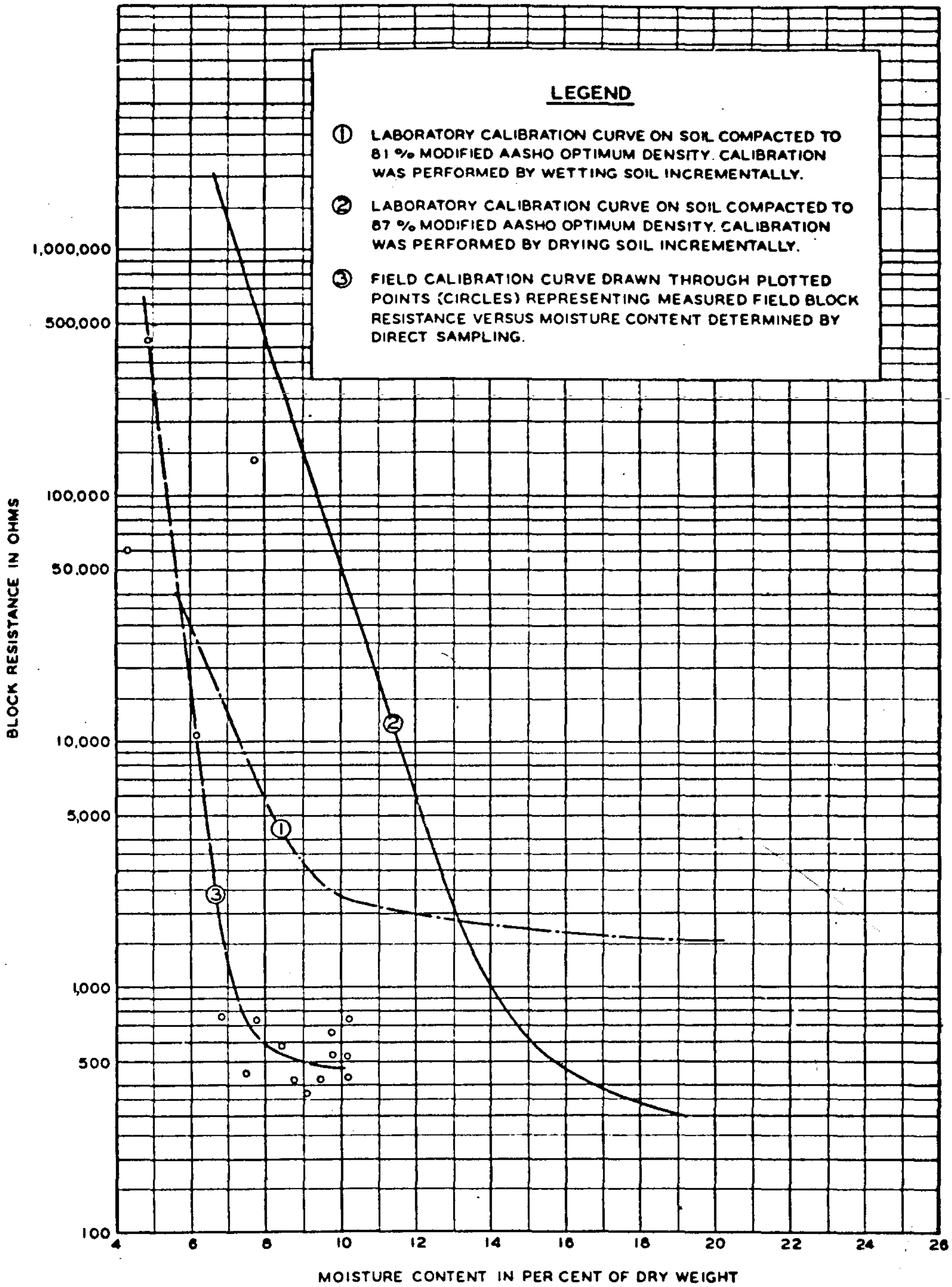
SANTA FE AIRPORT, SANTA FE, N.M.



FIELD MOISTURE CONTENT INVESTIGATION

RANGE OF BLOCK RESISTANCE IN TYPICAL CALIBRATION TEST

PLATE 5

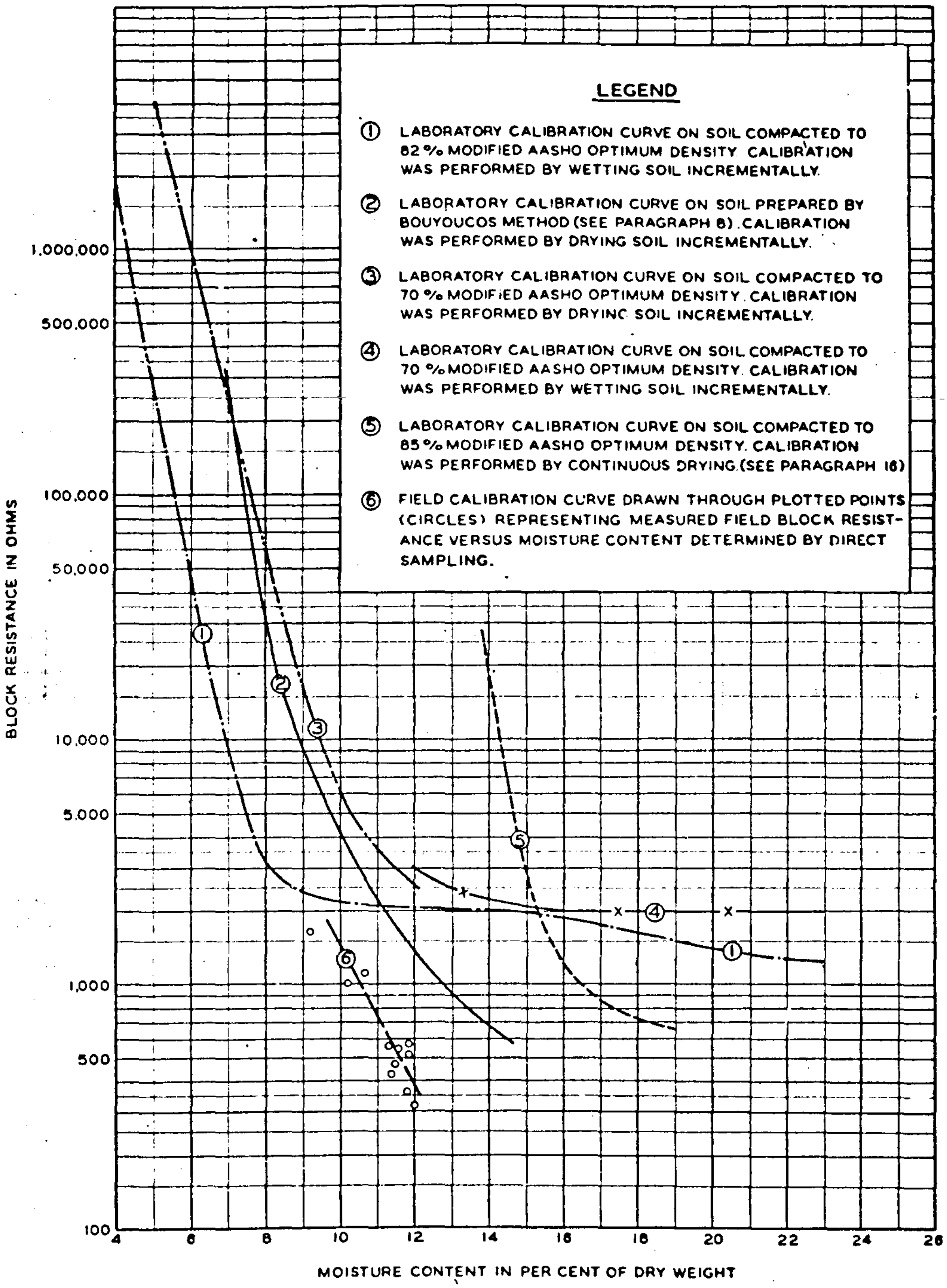


FIELD MOISTURE CONTENT INVESTIGATION

TYPICAL CALIBRATION CURVES OF BLOCK RESISTANCE WITH SPECIMEN MOISTURE CONTENT

KIRTLAND FIELD - HOLE NO. 6 - 13" DEPTH

PLATE 6



FIELD MOISTURE CONTENT INVESTIGATION

TYPICAL CALIBRATION CURVES OF BLOCK RESISTANCE WITH SPECIMEN MOISTURE CONTENT

CLOVIS AIRFIELD - HOLE NO. 4 - 16" DEPTH

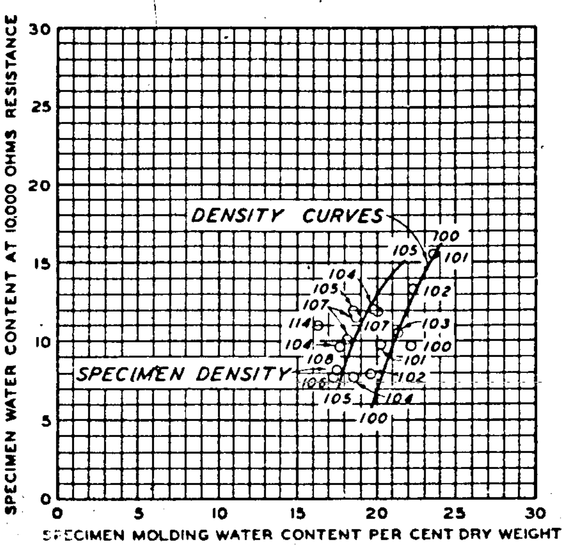


FIG. A

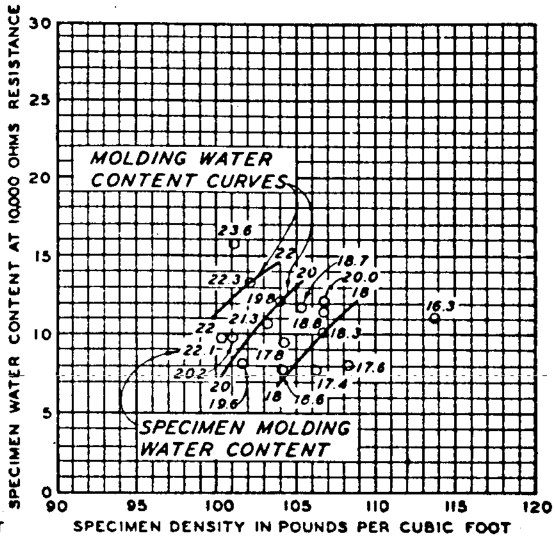


FIG. C

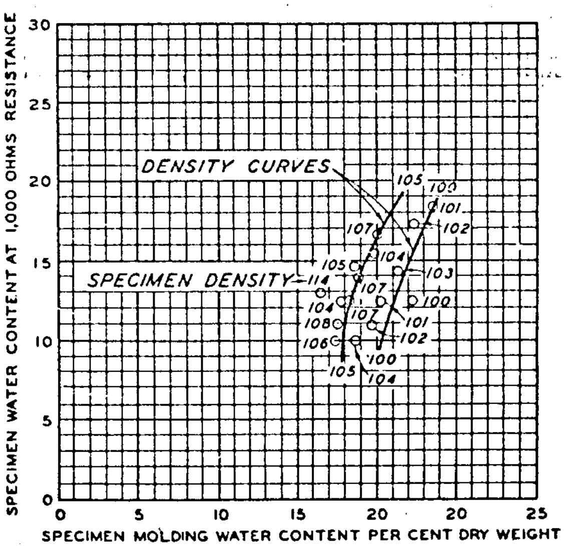


FIG. B

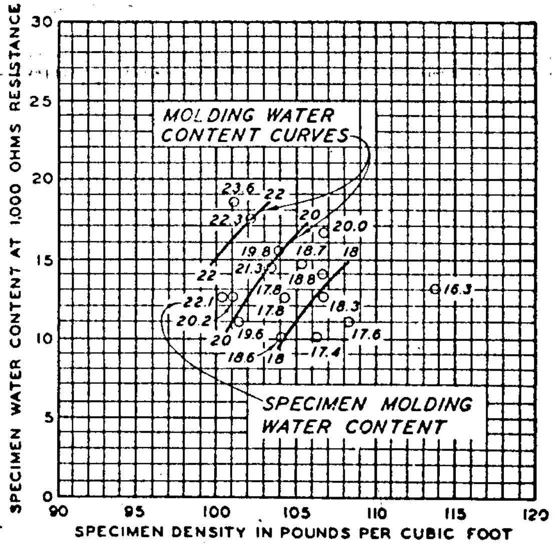


FIG. D

MOISTURE BLOCK RESISTANCE WITH MOLDING WATER

MOISTURE BLOCK RESISTANCE WITH DENSITY

FIELD MOISTURE CONTENT INVESTIGATION

VARIATION OF MOISTURE BLOCK RESISTANCE WITH DENSITY AND MOLDING WATER CONTENT

APPENDIX A

APPENDIX A

LITERATURE OF SOIL MOISTURE STUDY

1. A review of the literature of in-place soil moisture observations preceded the selection of the plaster of Paris (Bouyoucos) resistance blocks used in the field moisture content investigation. Several published articles have been received and reviewed since the installations were made. This appendix presents a summary of the articles reviewed and contains: (a) a brief outline of the present understanding of soil moisture; (b) a discussion of methods of in-place soil moisture measurement; (c) a description of the method selected for field use; and (d) a bibliography of references consulted. The selection of material presented and the opinions offered are those of the Waterways Experiment Station.

Present Understanding of Soil Moisture

Nature of soil moisture

2. Moisture in soil may exist as free-moving ground water, as capillary water, as water vapor in soil voids, and as adsorbed films on particle surfaces to which it is held in compressive stress. The affinity of soil for water depends on the surface area of the soil particles, on the physico-chemical properties of the internal surface and on the density and structure of the soil system. The sum of all the forces attracting water to a soil is frequently called its "capillary potential". This is a measure of the tightness with which soil holds water and is obtained by observing the suction, or tensile force, necessary to pull a unit mass of water away from a unit mass of soil. It is also described as the work

required to move a unit mass of water from a free water surface to some point above the surface. Capillary potential is expressed in atmospheres of pressure or in centimeters of water: the height of a column of water which balances the potential force. The logarithm of the height of the water column, in centimeters, is sometimes used to express potential, designated as the "pF". For example, a soil moisture tension of one atmosphere pressure or 1,000 centimeters of water is referred to as a pF of 3.0, since the logarithm of 1,000 is 3.

3. The variations of capillary potential with moisture content of a soil may be determined experimentally by such devices as the tensiometer, suction plate, pressure plate, or centrifuge, which in one way or another measure the capillary potential as an equivalent negative pressure or tension. The graph of capillary potential with moisture content, termed the "sorption curve", has been studied for many soils and is reproducible under constant conditions save for a hysteresis between wetting and drying specimens. Since the unsaturated flow of moisture is governed by the relative potentials of adjacent soil regions, or of soil and a porous substance, the various methods of obtaining in-place soil moisture content observations are all dependent on the relationship between soil moisture content and soil moisture tension. The success of such observations requires that the moisture potentials remain balanced long enough for moisture contents to approach an equilibrium, as, for instance, in the gradient above a stationary ground-water table wherein each level may have an equilibrium moisture content.

Soil moisture movement

4. Water in the soil moves in response to the net pressure gradient,

which is the resultant of a complex series of forces, including gravity, the capillary potential, film or sheet flow, and diffusion of vapor. Near the ground surface the non-gravitational components are strongly influenced by daily reversals of the soil temperature gradient. At the surface there occur intermittent precipitation, condensation or evaporation of water, and interchange by convection of soil air and atmosphere, all influenced by water affinity of the uppermost soil layer.

5. In compacted soil systems where density is comparatively high and uniform the moisture movement is slow. Well-compacted soils are able to absorb very little additional water without modification of the structure and they do not become fully saturated even when submerged for a long period. Their slow rate of change suggests that compacted soils near the surface may perhaps never reach moisture content equilibrium but may continue in gradual fluctuations that never overtake the change in moisture at the surface. The structure of compacted soils is materially affected by the molding water content and the type and manner of application of the compactive effort.

In-Place Measurement of Soil Moisture

Methods

6. Numerous methods have been used to measure the moisture content of the soil in place. Some of them are scarcely applicable to the objectives of the study as outlined in the main report, and none of them has proven completely satisfactory over the range of water contents and conditions which are found in natural soils. The methods described in the literature will be discussed briefly, as they are outlined below:

a. Gravimetric methods

(1) Gravimetric plugs

(2) Tensiometers

b. Electrical methods

(1) Soil resistance electrodes

(2) Porous resistance blocks

(3) Capacitance measurements

(4) Thermal conductivity

c. Mechanical methods

Gravimetric apparatus

7. General characteristics. Gravimetric apparatus, both gravimetric plugs and tensiometers, have had extensive use in soil moisture studies, and they possess several characteristics in common. They require close observation and protection from disturbance. Both instruments require a vertical tube opening at the surface, which exposes them to condensation or evaporation of moisture in the tube. Their placement under a pavement is regarded as unduly hazardous as to results, although it can be done.

8. Gravimetric plug. This device consists of a dry, porous plug, or cup, which is placed in a container of the same porous material in the soil to be tested, with a vertical opening to the surface through a tube or shaft. The amount of water the plug absorbs, from time to time, is a measure of the water tension in the adjacent soil. Measurement is made by engaging the plug with a hook, and weighing it, suspended in the tube or removed to the surface, with a sensitive balance. The gravimetric

plug has been found accurate and consistent over the middle range of soil moisture contents; it becomes insensitive at the wet and dry extremes. Weighing of the cup requires a balance too precise for extensive field use. The device is made of plaster of Paris and should be replaced periodically.

9. Tensiometer. In this instrument a saturated porous cup is connected through a continuous water column to a mercury manometer. Placed in the soil to be tested, the cup reaches equilibrium with the soil by movement of part of its water into the soil, so that the capillary potential of the soil is balanced by the tension in the instrument. The manometer then reads directly the capillary potential of the adjacent soil. The tensiometer measures the suction or negative pressure of the soil water directly and has been used in a great number of studies both in the field and in the laboratory. It performs well near the field capacity of soils and upwards to the saturation point. It does not operate satisfactorily at low moisture contents. Tensions greater than one atmosphere may cause the water column to separate. The mercury manometer has been on occasions replaced with a Bourdon gage, which reduces the space requirement of the instrument and also diminishes its accuracy. The tensiometer must be observed for leaks; otherwise its life is indefinite, limited by that of tubing and connections.

Electrical apparatus

10. General characteristics. A marked advantage of the electrical methods of in-place moisture measurement is that they do not require an opening to the ground surface at the instrument. Apparatus may be placed

at any location and the leads may be carried underground to a control box near the installations. Thus, units may be placed under a pavement, in cultivated land, in areas where ice forms or snow accumulates, and in many locations which cannot be occupied by other devices. The chief difficulties inherent in these methods are selection of serviceable block and electrode or heater materials, and calibration of the instruments which involves a chain of sensitive relationships.

11. Soil resistance electrodes. Experiments with electrodes placed directly in the soil to be tested were made as early as 1896. Elimination of large resistance variations at the soil-electrode contacts and in the resistance field of the surrounding soil has never been accomplished.

12. Porous resistance blocks. This apparatus is a block of porous material containing two or more electrodes. The resistance of the block is a function of the water content of the block and of its moisture potential. The block is placed in the soil to be tested, and the resistance is read by connecting the leads from the electrodes to a special Wheatstone bridge. When the moisture potentials of the block and the surrounding soil have attained equilibrium, the resistance of the block is a function of the soil moisture content. Since electrical resistance is also a function of the temperature of the medium, temperature observations are necessary. Porous electrical resistance blocks are simple and inexpensive. They must be calibrated with samples of the prototype soil and the resistances must be corrected to a standard temperature to permit comparisons. Early experiments compared numerous porous block materials; among them were clay, cement, concrete, marble dust, dental casting compound, and plaster of Paris. The superiority of the plaster of Paris was

so outstanding that it has been used in all of the recent investigations which have been reviewed, with one exception, in which a continuing search for better materials has brought forth a fiber glass block. Plaster of Paris blocks have been satisfactory in a number of studies of plant growth and soil moisture utilization. Their range of activity is from nearly air-dry soil to soil which has been soaked and drained by gravity. The life of the blocks has been reported as from one to several years, according to the length of the periods of high moisture contents. Principal features of the plaster of Paris type moisture block are as follows:

a. Properties of gypsum. The plaster of Paris composing the moisture block is gypsum which is a hydrated calcium sulphate, slightly soluble in water. Gypsum also partially dissociates in water so that water entering the plaster block is supplied with a concentration of gypsum and also of calcium and sulphate ions, and the presence of other salt solutions in the soil water is overshadowed. Each soil has a solution constant which depends on the equilibrium of its minerals. While part of the soil salts leach rapidly, the rest do not. The performance of the plaster of Paris block is related to maximum salt or ionic concentrations of various kinds of minerals in the soil water, and the best method of predicting success or failure at present is trial in the field with the soils and waters to be tested.

b. Resistance equilibrium time. The time required by plaster resistance blocks to attain equilibrium after a change in soil moisture content has been variously reported as from one or two days to one or two months. Some investigators believe that a moisture gradient between the plaster block and the soil surrounding it, such as the gradient maintained by the roots of actively transpiring plants, is necessary to obtain rapid response of the block resistance to soil moisture change. This is also indicated in laboratory tests to calibrate block resistance with soil moisture content. When the soil is dried an increment and sealed again, the block resistance usually comes to a new equilibrium in one to two months. If a more rapid change in a soil moisture content occurs, so that the block resistance lags behind, the resistance then changes with approximately the speed of the moisture content change. This delay and pick-up in resistance is detrimental in plant moisture supply studies, but in other investigations it becomes less important. It suffices to recognize that the rate of change in soil moisture as well as the gradient between soil and block affect the time required for block equilibrium to be established.

c. Block resistance near saturation. As the soil moisture content approaches saturation, block resistance usually becomes constant at the minimum or saturated value for the block. This point, together with the resistances representing initial drying, is not reproducible, and may be affected by the manner of starting tests. One investigator pre-saturated his plaster blocks under vacuum and found the initial resistances about 300 ohms lower than before, with the entire curve of resistance with moisture content displaced. It is now believed that the wet end of such curves might be better developed or even extended a little by allowing more time for the block resistance to reach an equilibrium with high moisture contents, and perhaps by evacuation of the blocks to insure that they are without entrained air at the start of testing.

13. Capacitance measurements. Measurements of electrical capacitance can be made on the porous block electrodes, or on larger blocks or condenser plates, buried directly in the soil or in porous material. Capacitance of a porous medium varies as its moisture content changes with the soil moisture content. Correlations of capacitance with soil moisture have not usually been successful, since the electrical field includes both porous material and surrounding soil and water.

14. Thermal conductivity device. This instrument consists of a coil of high-resistance wire mounted with leads, for placing directly in the soil or for casting in a porous block before placing in soil. In reading the unit, a small current is first used to balance the circuit. A larger current is admitted, and sufficient time is allowed for the temperature of the coil and of the surrounding material to reach equilibrium. A detector current is measured through a micro-ammeter to indicate

the increased resistance of the coil. The increase in resistance is related to the equilibrium temperature of the element, which in turn is a function of the heat conductivity of the surrounding soil. Finally, the heat conductivity of the soil must be related to its water content. Several resistance-heater devices for measurement of thermal conductivity in soils have operated well in laboratory tests. While none have been reported as successful in field investigations, this method appears to have possibilities. The failure of field installations has been attributed to irregular contacts between instruments and soil. If this is indeed the difficulty, it may be overcome by placing the heater in a porous block. Such a device depends on a complex chain of relationships, since the heat transfer within the block which is measured by the change in the resistance of the element must be correlated with the moisture content of the surrounding soil. It is known that small thermal gradients in the soil produce movement of soil moisture as vapor, and that heat transfer in soil may occur by mass vapor movement as well as by thermal conductivity.

Mechanical methods

15. At least two methods have been offered for estimating soil moisture content by its relation to some measurement of the strength of the material. One is the method introduced in 1933 by R. R. Proctor, in which the resistance of the soil to penetration by a calibrated penetrometer needle is compared with water content and density of the soil. In another test, described more recently, the strength of the soil is determined by driving a diamond-shaped blade into the soil, rotating the

blade and its shaft with a handle incorporating a gage, and observing the torque developed in turning the device. The torque of the instrument gage must be calibrated with the soil water content and other characteristics. Attempts to relate in-place soil water content to in-place soil strength have proved unsuccessful because of the numerous variables present in such strength measurements.

Selection of the Bouyoucos Plaster Resistance Block

16. The plaster of Paris resistance block, as developed by Dr. G. J. Bouyoucos of Michigan State College, was selected for use in the field moisture content investigation after the survey of methods of in-place moisture observation had revealed the flexibility and the background of experimentation and field use of this device. The tensiometer and gravimetric plug were found to be useful in precise work in sheltered locations, but not desirable under airfield pavements. Mechanical methods were judged unsatisfactory and the electro-thermal method was found unready for field installations at present.

Description of the Bouyoucos Block and Associated Equipment

17. The equipment used in this phase of the field moisture content investigation consisted of plaster of Paris resistance blocks, temperature gages and a special Wheatstone bridge for taking readings of the blocks and gages. The field installations also required cast-iron boxes containing terminals for the lead wires and bridge connection, and suitable switches for connecting moisture block circuits to the bridge. The

moisture blocks, temperature gages and the bridge modification were developed by Dr. G. J. Bouyoucos of Michigan State College.

Moisture block

18. The Bouyoucos moisture block is 2-1/2 in. by 1-3/8 in. by 1/2 in. The electrodes imbedded in the block are formed by tinning with solder the ends of the wires. The wires may be of any length required, except that it is desirable to keep them less than 100 ft long because of the increasing electrical capacitance of the circuit. Where the wire is very long additional capacity may have to be incorporated in the capacity balance of the bridge.

Temperature gage

19. The temperature gage consists of a glass bulb, about 3/16 in. in diameter and 1/2 in. long, containing two electrodes spaced about 1/8 in. apart in an organic fluid. The effect of capacity is even more pronounced on the operation of the temperature gages than on the moisture blocks.

Wheatstone bridge

20. The bridge used in reading the blocks and cells is an adaptation of the Wheatstone bridge. An electron tube oscillator, operating from dry batteries, supplies power to the bridge. Sufficient variable capacity is connected in parallel with one arm of the bridge to balance the wire capacity. The variable resistance is balanced and read on a graduated dial while a dial multiplier switch permits operation over four overlapping resistance ranges between zero and 5.5 million ohms.

Temperature corrections

21. A change of electrical resistance in the moisture block is dependent upon a change in temperature or moisture content, since the density, texture, and content of dissolved solids of the block are constant for a particular temperature and water content. In order to correlate block resistance with water content, the temperature of the block must be observed at the time of reading and the resistance must be corrected to a standard temperature. The temperature gages, which were provided for this purpose, required calibration of resistance with change of temperature and this was carried out prior to placement in the field installations. Variation of block resistance with temperature for a number of typical soils, developed by Dr. Bouyoucos, is shown graphically on plate 1 of the main report. It was found that this variation was so uniform for different soils that temperature corrections could be made directly from this graph. A log-log graph of observed resistance with corrected resistance may be prepared from the data of the figure, if it is desired.

Bibliography of References Consulted

1. Allyn, R. B. A calibrated soil probe for measuring field soil moisture. Soil Science 53:273. 1942.

2. Anderson, A. B. C. A method of determining soil moisture content based on the variation of the electrical capacitance of soil, at a low frequency, with moisture content. Soil Science 56:29. 1943.

3. Anderson, A. B. C., and Edlefsen, N. E. The electrical capacity of the 2-electrode plaster of Paris block as an indicator of soil moisture content. Soil Science 54:35. 1942.

4. Anderson, A. B. C., and Edlefsen, N. E. Laboratory study of the response of 2- and 4-electrode plaster of Paris blocks as soil moisture content indicators. Soil Science 53:413. 1942.

5. Anderson, H. W. Effect of freezing on soil moisture and on evaporation from a bare soil. American Geophysical Union Transactions 27:863. 1946.

6. Baver, L. D. Soil physics. N. Y., John Wiley & Sons. 1940.

7. Bliss, D. E., Moore, D. C., and Bream, C. E. Air and soil temperatures in a California date garden. Soil Science 53:55. 1942.

8. Bodman, G. B., and Colman, E. A. Moisture and energy conditions during downward entry of water into soils. Soil Science Society of America Proceedings, p. 116. 1943.

9. Bouyoucos, G. J., and Mick, A. H. Comparison of absorbent materials employed in the electrical resistance method of making a continuous measurement of soil moisture under field conditions. Soil Science Society of America Proceedings, p 77. 1940.

10. Bouyoucos, G. J., and Mick, A. H. An electrical resistance method for the continuous measurement of soil moisture under field conditions. Michigan State College Agricultural Experiment Station Technical Bulletin 172. 1940.

11. Proctor, R. R. Description of field and laboratory methods. Second of four articles on rolled-earth dams. Engineering News Record, p. 286. 7 September 1933.

12. Colman, E. A. The place of electrical soil moisture meters in hydrologic research. American Geophysical Union Transactions 27:847. 1946.

13. Cummings, R. W., and Chandler, R. F., Jr. A field comparison of electrothermal and gypsum block electrical resistance methods with the tensiometer method for estimating soil moisture in situ. Soil Science Society of America Proceedings, p. 80. 1940.

14. Day, P. R. The moisture potential of soils. Soil Science 54:391. 1942.

15. Dreibelbis, F. R., and Harrold, L. L. An accounting of the daily accretion, depletion and storage of soil water as determined by weighing monolithic lysimeters. American Geophysical Union Transactions 26:283. 1945.

16. Edlefsen, N. E., Anderson, A. B. C., and Marcum, W. B. Field study of response of the electrical resistance of 2-electrode and 4-

electrode plaster of Paris blocks to variations in soil moisture. Soil Science 54:275. 1942.

17. Edlefsen, N. E., and Smith, W. O. The determination of moisture in undisturbed soil. Soil Science Society of America Proceedings, p. 112. 1943.

18. Haise, H. R., and Kelley, O. J. Relation of moisture tension to heat transfer and electrical resistance in plaster of Paris blocks. Soil Science 61:411.

19. Hendrickson, A. H., and Veihmeyer, F. J. Soil density and moisture. Soil Science 62:451. 1946.

20. Hunter, A. S., and Kelley, O. J. A new technique for studying the absorption of moisture and nutrients from soil by plant roots. Soil Science 62:441. 1946.

21. Johnston, C. N. Water-permeable jacketed thermal radiators as indicators of field capacity and permanent wilting percentage in soils. Soil Science 54:123. 1942.

22. Kelley, O. J. A rapid method of calibrating various instruments for measuring soil moisture in sites. Soil Science 58:433. 1944.

23. Kersten, M. S. Survey of subgrade moisture conditions. Highway Research Board Proceedings 24:497. 1944.

24. Kersten, M. S. Subgrade moisture conditions beneath airport pavements. Highway Research Board Proceedings 25:450. 1945.

25. Richards, L. A. Soil moisture tensiometer materials and construction. Soil Science 53:241. 1942.

26. Richards, L. A., and Weaver, L. R. Moisture retention by some irrigated soils as related to soil-moisture tension. Agricultural Research Journal 69:215. 1944.

27. Russell, M. B. Utility of the energy concept of soil moisture. Soil Science Society of America Proceedings, p. 90. 1942.

28. Russell, M. B., and Spangler, M. G. Energy concept of soil moisture and the mechanics of unsaturated flow. Highway Research Board Proceedings 21:435. 1941.

29. Shaw, B., and Baver, L. D. An electrothermal method for following changes of the soil moisture in situ. Soil Science Society of America Proceedings 4:78. 1939.

30. Slater, C. S., and Bryant, J. C. A comparison of four methods of

soil moisture measurement. Soil Science 61:131. 1946.

31. Smith, W. O. Thermal conductivity of dry soil. Soil Science 53: 435. 1942.

32. Smith, W. O. Thermal conductivity in moist soils. Soil Science Society of America Proceedings, p. 32. 1939.

33. Spangler, M. G. Some problems in subgrade moisture control. Highway Research Board Proceedings 54:434. 1945.

34. Whitney, M., Gardner, F. D., and Briggs, L. J. An electrical method of determining the moisture content of arable soils. U. S. Department of Agriculture, Division of Soils Bulletin 6. 1897.

35. Winterkorn, H. F., and Eyring, H. Theoretical aspects of water accumulation in cohesive subgrade soils. Highway Research Board Proceedings 25:422. 1945.

36. Report of the Committee on Physics of Soil Moisture, 1943-44. American Geophysical Union Transactions 1944, p. 699. 1945.

37. Report of Committee on Evaporation and Transpiration, 1945-46. American Geophysical Union Transactions 1946, p. 720. 1946.

38. Washington District, Corps of Engineers. Soil moisture measurement in place. Serial E, 31.1. 1947.

APPENDIX B

APPENDIX B

INSTALLATION OF MOISTURE BLOCKS

Purpose of Installations

1. The purpose of the moisture block installations was to determine whether or not the blocks would satisfactorily indicate changes in soil moisture content under field conditions, and to carry out the general purpose of the study, which is the observation of changes in the moisture content of base and subgrade materials under pavements, when and if the blocks yielded satisfactory results.

Scope of Installations

2. The program of investigation provided that at each pavement location to be tested, installation of moisture blocks were to be made in number and arrangement adequate to develop the necessary in-place soil moisture data, as follows:

- a. Moisture gradient under the pavement to be shown by horizontal lines of blocks at 3 elevations from the center line to the edge of the pavement.
- b. Moisture of condensation under the wearing course to be shown by blocks placed near the top of the base course.
- c. Surface leakage through the wearing course to be shown by blocks placed adjacent to an artificially produced crack.
- d. Capillary movement to be shown by blocks placed near the top of the subgrade and 18 in. below the top of the subgrade.

The effects of drainage systems were to be studied by visual observations. Five or six sets of observations were to be made during each year at times to be determined by the distribution of rainfall throughout the year.

3. The program included provisions for direct sampling, (a) as a means of spot checking the resistance block data, and (b) as an alternate method in the event of failure of one or more blocks or entire installations. In direct sampling, borings were made in a prescribed order in a standard grid or pattern about each block location.

Selection of Sites

4. Selection of airfields for installation of moisture blocks was made after study of the pavement evaluation reports of airfields in the Albuquerque District and consultation with District representatives. The factors considered in the selections were:

- a. Pavements tested must represent sand, silt and clay subgrade types in a region of low rainfall.
- b. Ground-water tables must be deep at the sites selected.
- c. Suitable pavement facilities to meet the objectives of the study must be available.
- d. An age differential between two pavements at each field was sought, but not required.
- e. There must be no maintenance or repair work on the wearing surface at the moisture block locations.
- f. Proximity to the Albuquerque District Office was desired, other factors being equal.

The airfields selected on this basis were Kirtland Field, Albuquerque, New Mexico, sand subgrade; Clovis Airfield, Clovis, New Mexico, silt subgrade; and Santa Fe Airport, Santa Fe, New Mexico, clay subgrade. Of these fields, only one, Kirtland Field, afforded pavements with a significant age differential. None of the fields had subsurface drainage systems.

Installation of Blocks

5. Moisture blocks were installed in 6-in. auger holes, in the manner developed during preliminary testing and as described in paragraph 12 of the main report. Recompaction of the backfilled material above the blocks to as near the original density as possible was checked by frequent tests with the proctor plasticity needle during excavation and filling. Bouyoucos temperature gages were placed in 3/4-in. pipe couplings for their protection. These temperature gages were developed by Dr. Bouyoucos for use with his moisture block such that both the temperature gage and moisture block could be read by the same Wheatstone bridge. Lead wires for the gages were placed in trenches beneath the wearing course and carried to a switch box placed flush with the ground surface outside the pavement. All openings in the wearing course were sealed watertight at the completion of installation except the artificial cracks which were cut with a pneumatic spade and were backfilled with clean sand.

Kirtland Field

6. The installations at Kirtland Field are located near the east end of taxiway T-2, as shown on plate B1. The south half of this pavement was constructed in June 1942, while the north half was built in March 1945. The block installations represent one profile across both pavements (Station 97+70) with a unit at the junction and one in natural ground outside the paved area, and two profiles at artificially produced cracks -- one in each pavement (Station 98+10). There had been no maintenance or repair work at these locations at the time of the block installation. Traffic in April 1945 consisted of 100 daily cycles of B-24

planes and 70 daily cycles of AT-11 planes. A strip of dust palliative 20 ft wide had been placed along each shoulder. The area had good surface drainage and a good crown. The ground outside the pavement was very dry, while the pavement subgrade was damp.

Santa Fe Airport

7. The installations at Santa Fe Airport are located on the N-S Runway as shown on plate B2. Normal pavement profiles are represented at Station 38+10, a cut section with good surface drainage, and at Station 41+50, a fill section with rather poor surface drainage. An installation at an artificial crack was made at Station 41+90, where the outside 25 ft of the wearing course showed signs of distress. Some rain fell during placement of the blocks. Traffic in May 1945 amounted to about 5 cycles per day of planes with an average wheel load of 12,500 lb.

Clovis Airfield

8. The installations at Clovis Airfield are located on N-S Runway "B" as shown on plate B3. Normal pavement profiles are represented by installations at Station 40+40, a cut section with good drainage, and at Station 20+00, a fill section with poor surface drainage conditions. A pavement profile near an artificial crack is represented at Station 40+00. No units were placed in the outside 75 ft of pavement, where the wearing course, an asphaltic concrete only 1/2 in. thick, was disintegrating and presented a non-uniform condition. Traffic for the field in May 1945 consisted of about 150 cycles daily, mainly B-29 planes. Rain fell at the field just prior to installation of the blocks.

Sampling and Testing

9. During installation of moisture blocks, in-place CBR, density and moisture content tests were made in test pits located as shown on plates B1, B2, and B3. A moisture content sample was also obtained at the point of installation of each block. Large samples were taken from the test pits for laboratory tests to determine the gradation, liquid and plastic limits, specific gravity and modified AASHO maximum density and optimum water content, as well as for calibration with the moisture blocks. The results of field tests are shown in tables B1 to B3, inclusive. The grading, liquid limit and plasticity index of the large samples are shown in plates B4 to B8, inclusive.

Field Observations

10. Field observations were made by Albuquerque District personnel at intervals of two to four months, according to the weather, as directed in the Instructions and Outline, for the investigation, and Addenda thereto. These observations consisted of reading resistances of moisture blocks and temperature gages, and boring holes and obtaining water content samples near some of the blocks. The water content samples were obtained to provide spot checks on the moisture content as measured by the moisture block. Records of the precipitation at each field were also obtained. During the first winter after making the field installations, the Bouyoucos temperature gages became erratic, yielding results which were considered unreliable, and subsequently ground temperatures were measured directly by a mercury thermometer. No determination was

made of the cause of failure of the temperature gages. All field data are not presented in detail in this report but are on file at the Waterways Experiment Station.

TABLE B1

RESULTS OF FIELD TESTS AT INSTALLATION OF MOISTURE BLOCKS

Kirtland Field

Depth Inches	Type of Material	CBR Per Cent	Dry Density Lb/Cu Ft	Moisture Content Per Cent of Dry Wt
Hole No. 1, Old Pavement, 45 Ft South of Center Line				
0- 8	Base	57	133	4.8
11-17	Subgrade	37	118	10.8
28-34	Subgrade	14	110	6.8
Hole No. 3, Junction of New and Old Pavements, Center Line				
5-11	Base	50	131	6.7
15-23	Subgrade	32	117	11.0
30	Subgrade	4	101	9.2
Hole No. 5, New Pavement, 45 Ft North of Center Line				
4-10	Base	109	139	3.6
14-21	Subgrade	19	114	7.2
28-34	Subgrade	3	105	6.4
Hole No. 6, Natural Ground, 45 Ft North of Pavement Edge				
5-13	-	33	105	3.9
13-21	-	19	100	4.8
28-34	-	18	97	5.1

TABLE B2

RESULTS OF FIELD TESTS AT INSTALLATION OF MOISTURE BLOCKS

Clovis Airfield

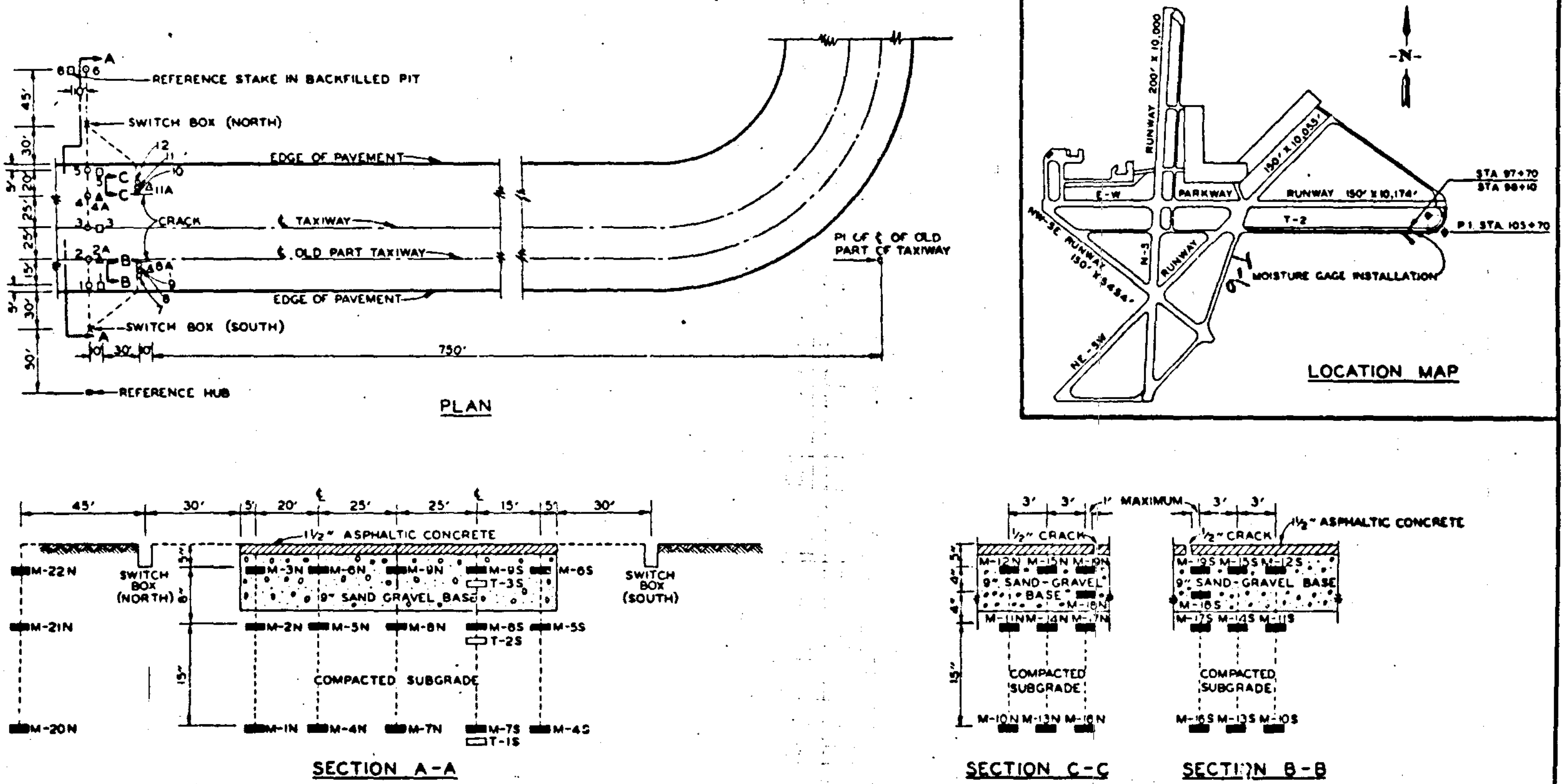
Depth Inches	Type of Material	CBR Per Cent	Dry Density Lb/Cu Ft	Moisture Content, Per Cent of Dry Wt
	Hole No. 2, Sta. 40+40, 70 Ft Right of Center Line			
2-11	Base	91	120	8.5
17-24	Subgrade	11	120	10.5
32-40	Subgrade	3	102	7.9
	Hole No. 4, Sta. 40+40, Center Line			
2-10	Base	52	118	10.4
15-23	Subgrade	23	126	9.0
33-42	Subgrade	5	100	9.6
	Hole No. 8, Sta. 20+00, Natural Ground, 15 Ft Outside Pavement			
5-14	-	14	116	14.1
20-29	-	1.4	97	13.4
32-40	-	4	100	6.2
	Hole No. 10, Sta. 20+00, 35 Ft Right of Center Line			
2.5-9.5	Base	90	117	8.1
19-28	Subgrade	17	93	11.2
32-40	Subgrade	13	121	11.8

TABLE B3

RESULTS OF FIELD TESTS AT INSTALLATION OF MOISTURE BLOCKS

Santa Fe Airport

Depth Inches	Type of Material	CBR Per Cent	Dry Density Lb/Cu Ft	Moisture Content, Per Cent of Dry Wt
Hole No. 1, Natural Ground, 40 Ft Left of Pavement Edge				
3-11	-	4	88	15.4
16-22	-	12	77	11.6
32-40	-	29	92	7.8
Hole No. 2, Sta. 38+10, 70 Ft Left of Center Line				
3- 9	Base	38	129	3.9
17-24	Subgrade	5	87	16.4
31-39	Subgrade	4	85	14.2
Hole No. 4, Sta. 38+10, 25 Ft Left of Center Line				
3- 9	Base	116	133	3.5
14-20	Subgrade	22	87	14.5
32-38	Subgrade	8	93	6.4
Hole No. 7, Sta. 41+50, 50 Ft Left of Center Line				
3-10	Base	39	132	5.6
15-23	Subgrade	9	92	22.0
32-40	Subgrade	7	103	14.9
Hole No. 9, Sta. 41+50, Center Line				
5-11	Base	37	134	6.5
15-23	Subgrade	14	104	15.2
3-41	Subgrade	8	103	18.1



LEGEND

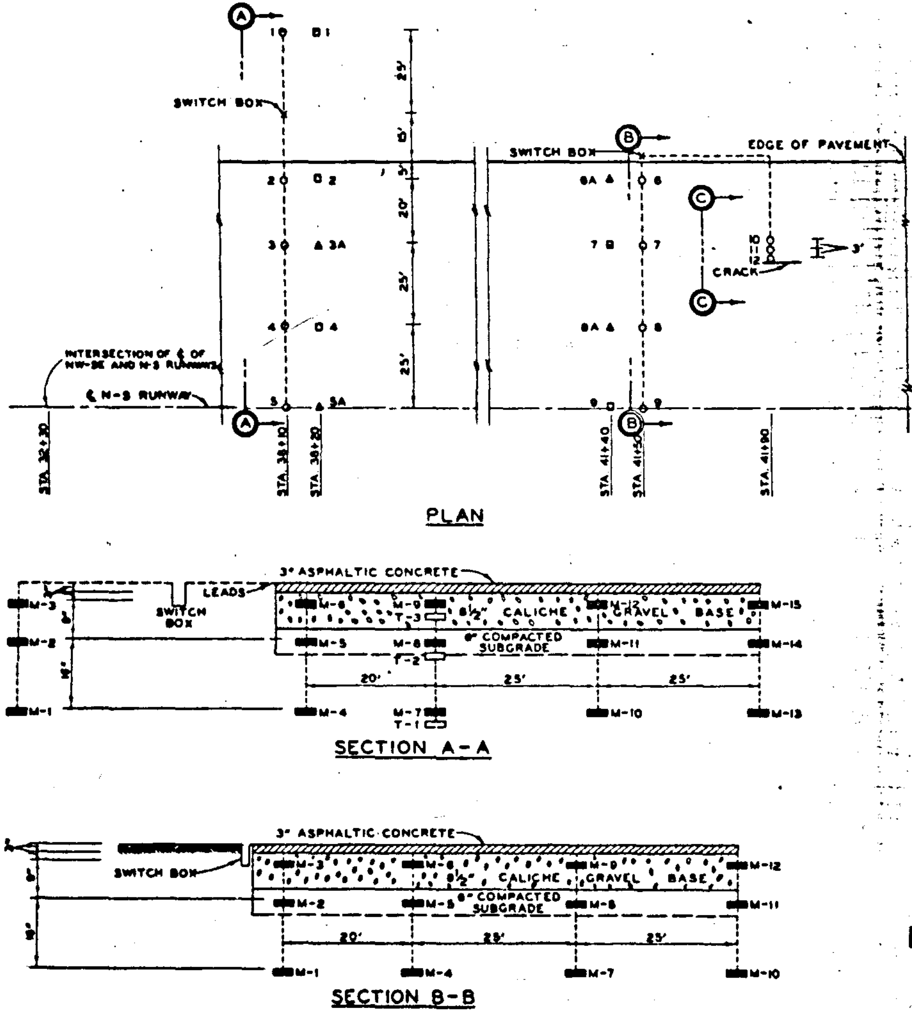
- ○ INSTALLATION OF CELLS
- ▲ MOISTURE CHECK HOLES (NO CELLS)
- ▫ TEST PIT (NO CELLS)
- x SWITCH BOX
- ------ LEADS TO SWITCH BOX
- ▭ TEMPERATURE GAGES
- ▬ MOISTURE BLOCK

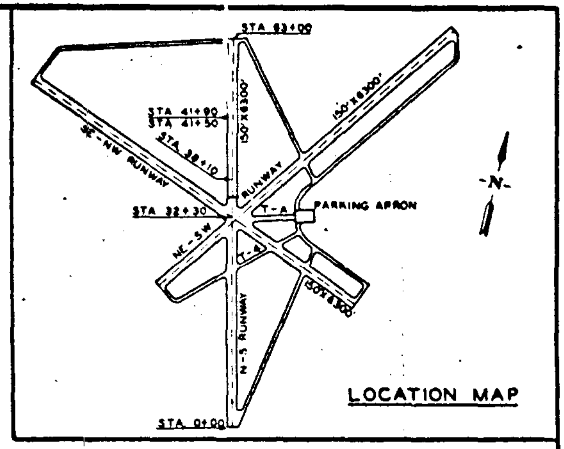
FIELD MOISTURE CONTENT INVESTIGATION

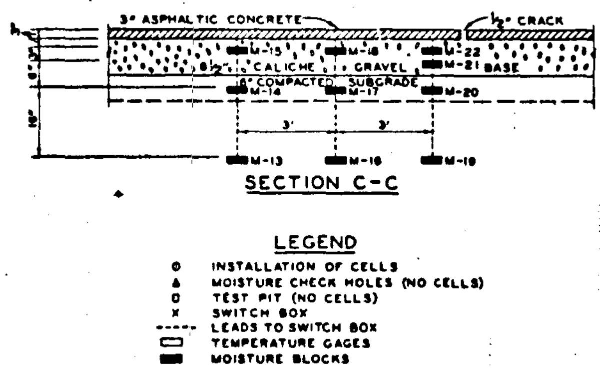
PLAN OF TESTING AND INSTALLATION

KIRTLAND FIELD
ALBUQUERQUE, NEW MEXICO

PLATE B1





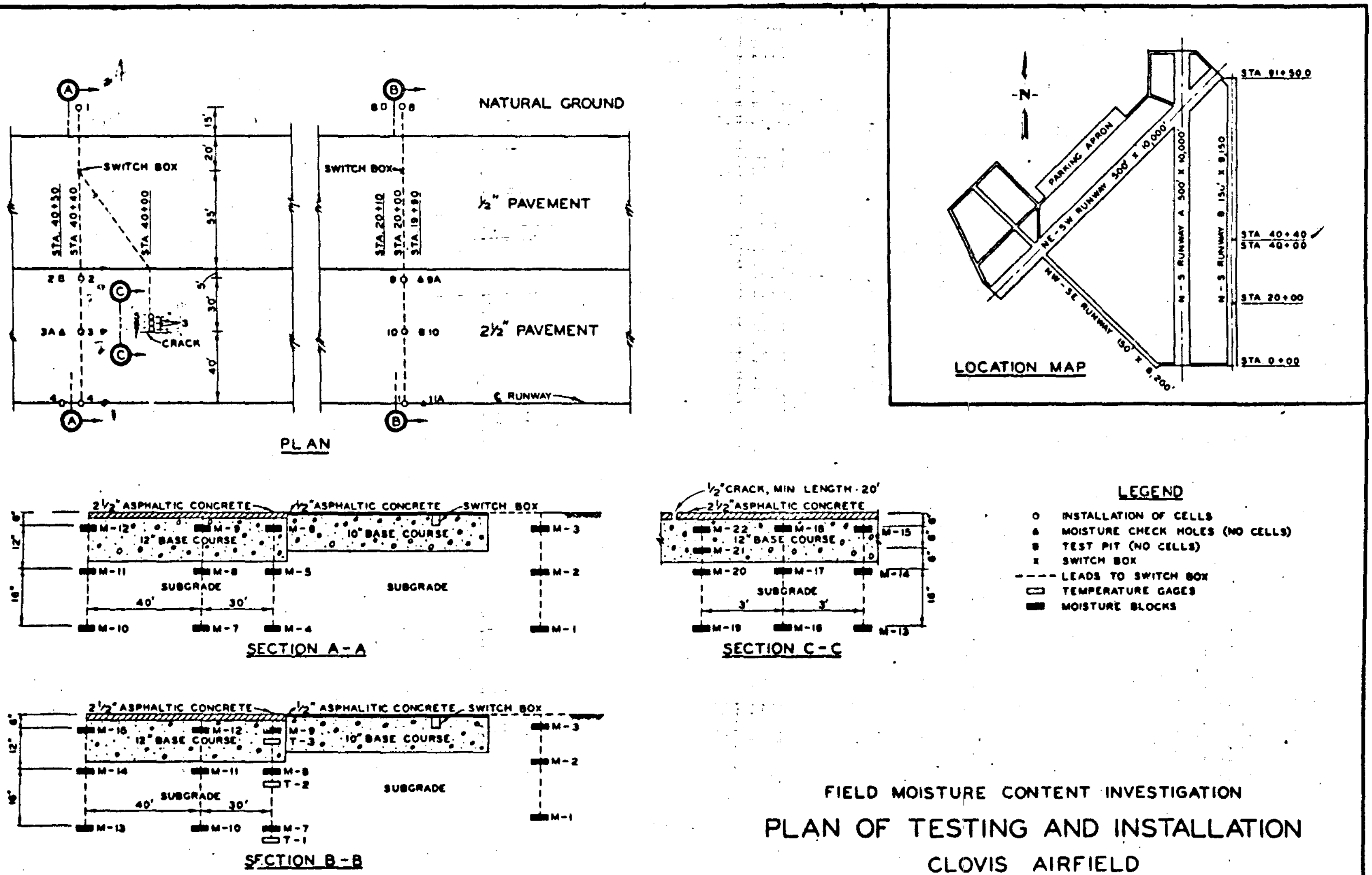


FIELD MOISTURE CONTENT INVESTIGATION

PLAN OF TESTING AND INSTALLATION

SANTA FE AIRPORT
SANTA FE, NEW MEXICO

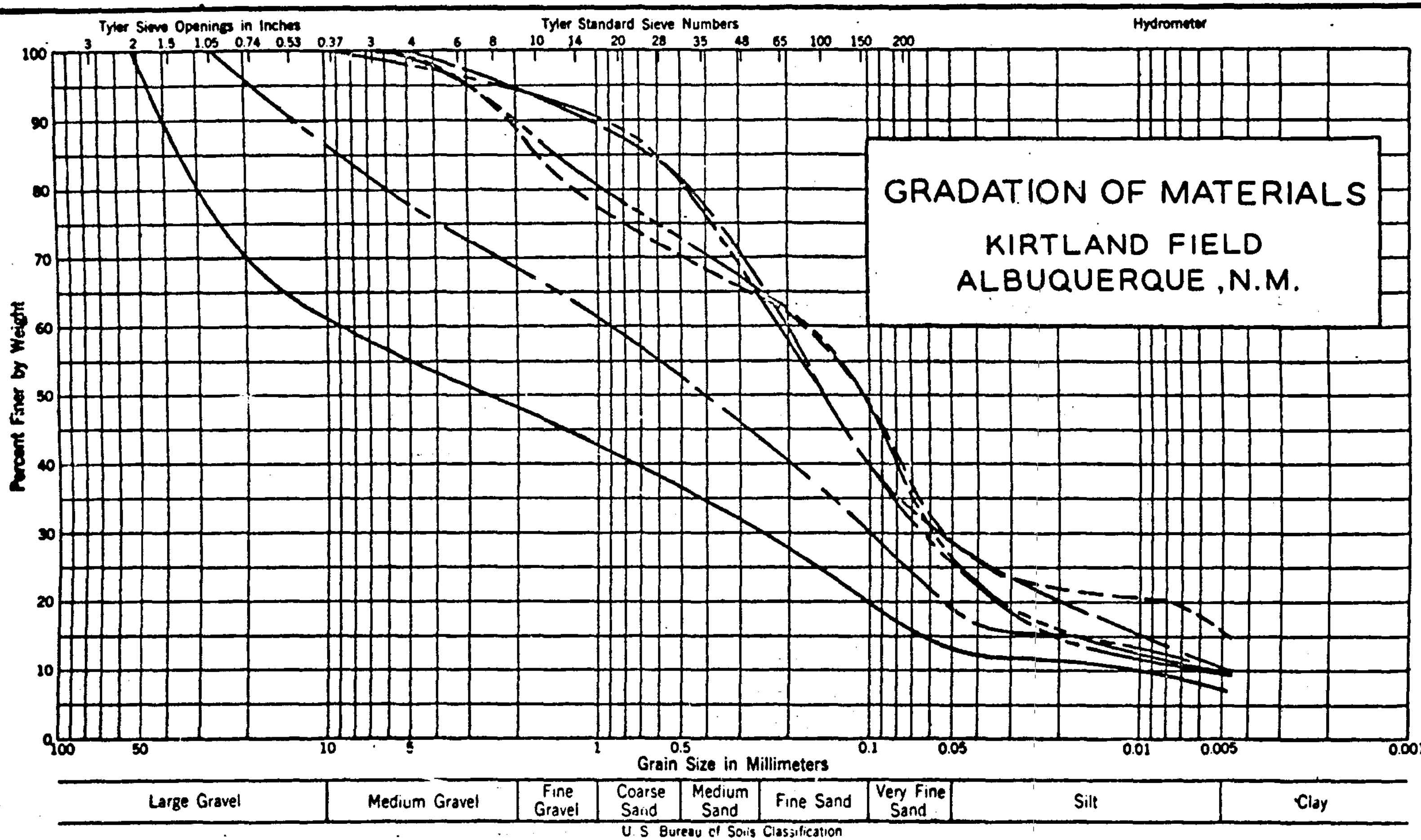
PLATE B2



FIELD MOISTURE CONTENT INVESTIGATION

PLAN OF TESTING AND INSTALLATION

CLOVIS AIRFIELD
CLOVIS, NEW MEXICO



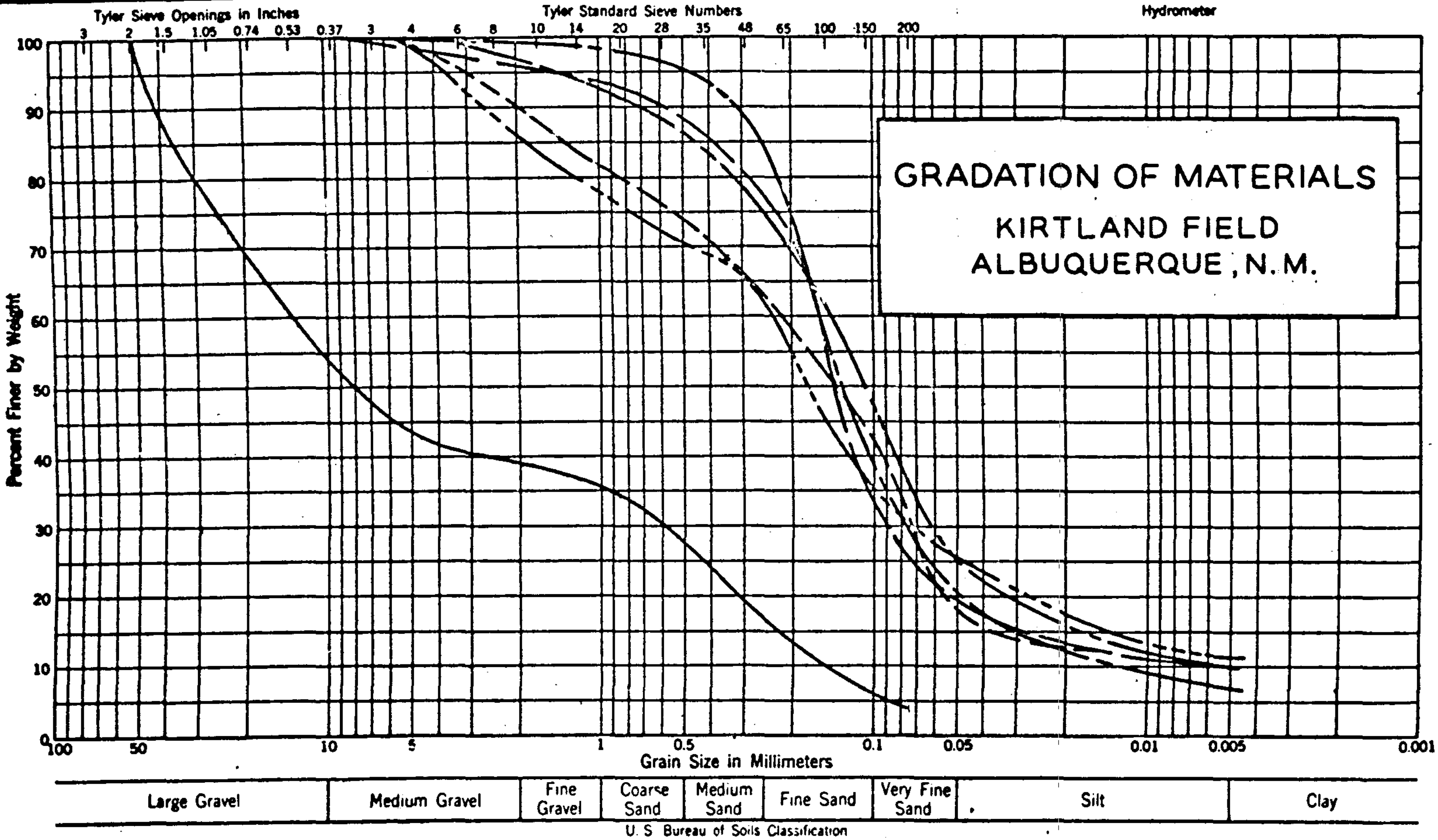
HOLE NO. 1

SYMBOL	SAMPLE NO.	DEPTH (IN.)	LIQUID LIMIT	PLAST. INDEX	SPEC. GRAV.
————————	883	5	20	5	2.64
— — — — — —	885	13	20	5	2.61
—— —— ——	884	28			

HOLE NO. 3

SYMBOL	SAMPLE NO.	DEPTH (IN.)	LIQUID LIMIT	PLAST. INDEX	SPEC. GRAV.
—— - ——	886	5	19	4	2.62
—— - - ——	881	15	21	7	2.64
—— - - ——	854	28			

PLATE B4



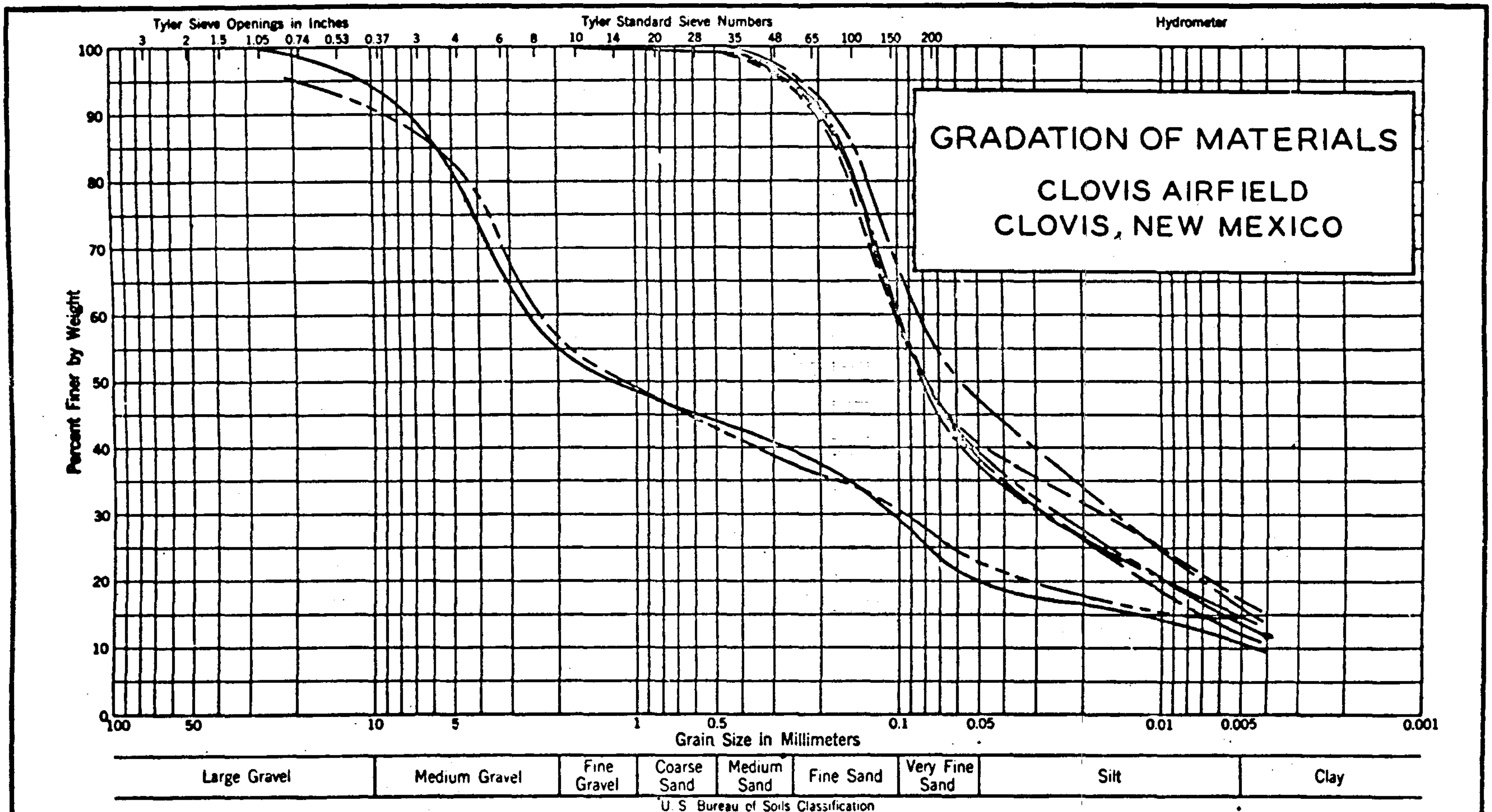
HOLE NO. 5

SYMBOL	SAMPLE NO.	DEPTH (IN.)	LIQUID LIMIT	PLAST. INDEX	SPEC. GRAV.
———— (solid)	879	5	18	4	2.61
— — — — (dashed)	887	13	20	4	2.62
—— —— (long dash)	882	28			

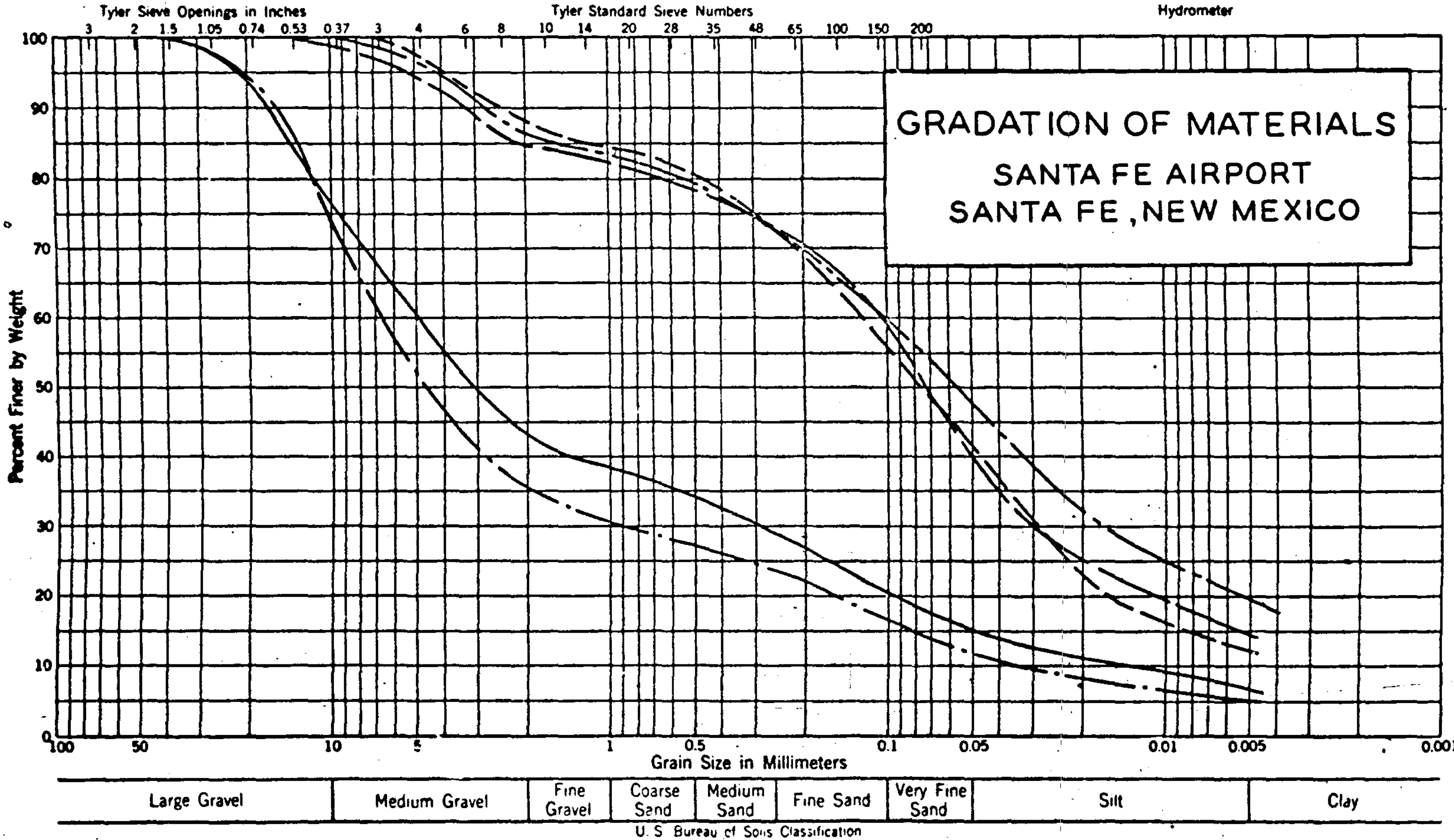
HOLE NO. 6

SYMBOL	SAMPLE NO.	DEPTH (IN.)	LIQUID LIMIT	PLAST. INDEX	SPEC. GRAV.
——— - ———	880	5	17	3	2.62
——— - - ———	853	13	18	4	2.62
——— - - - ———	855	28	21	6	2.64

PLATE B5

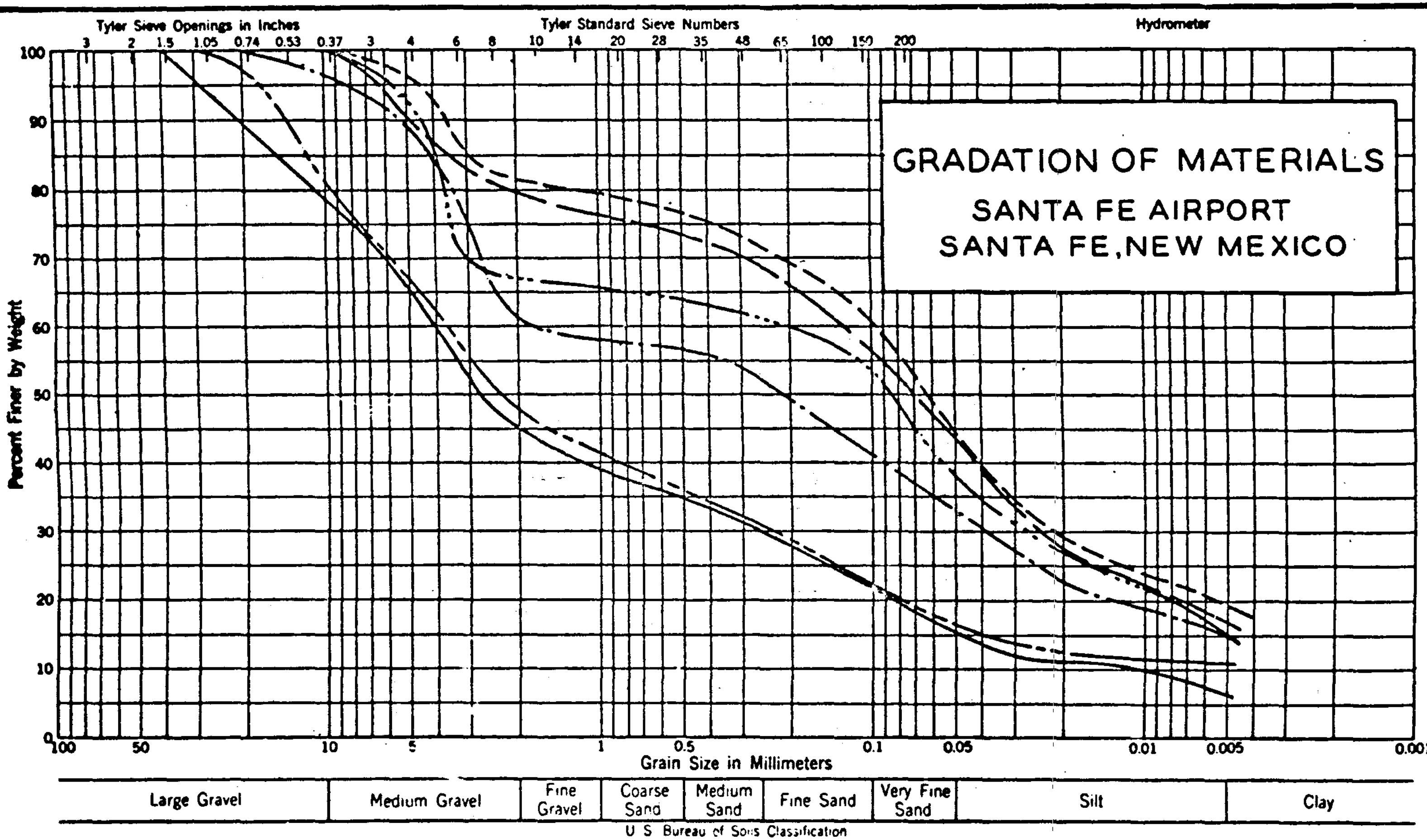


SYMBOL	SAMPLE NO	HOLE NO.	DEPTH (IN.)	LIQUID LIMIT	PLAST. INDEX	SPEC. GRAV.
——- - - -——	891	2	5	24	7	2.63
————————	889	4	5	24	7	2.63
——— ——— ———	892	4	16	23	9	2.62
- - - - - - - -	893	4	32			
——— - ——— - - ———	888	8	5			
——— - ——— - ———	890	8	16	28	13	2.64
- - ——— - - ———	894	8	32	22	8	2.64



SYMBOL	SAMPLE NO.	HOLE NO.	DEPTH (IN.)	LIQUID LIMIT	PLAST INDEX	SPEC. GRAV.
—— — ——	899	1	6	39	16	2.65
————	898	2	6			
— — — —	901	2	17	34	10	2.64
————	896	2	32	34	12	2.67
—·—·—	903	4	6	26	11	2.63

PLATE B7



HOLE NO. 7

SYMBOL	SAMPLE NO.	DEPTH (IN.)	LIQUID LIMIT	PLAST. INDEX	SPEC. GRAV.
———————	905	6			
— — — —	902	15			
— — — — — —	895	32	27	10	2.65

HOLE NO. 9

SYMBOL	SAMPLE NO.	DEPTH (IN.)	LIQUID LIMIT	PLAST. INDEX	SPEC. GRAV.
—— · —— · ——	900	6	29	12	2.65
—— - - ——	897	15	28	10	2.66
—— ··· —— ··· ——	904	32			

PLATE B8