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MICHIGAN
STATE HIGHWAY DEPARTMENT
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PAVEMENT AND SUBGRADE MOISTURE

Michigan Test Road

Research Project 39 F-7 (2)

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Knowledge of prevailing moisture conditions in both the concrete slab and subgrade soil is necessary for an adequate appraisal of pavement behavior and is of considerable value in road design. In order to obtain a progressive record of the amount of moisture in the pavement and subbase of the Michigan Test Road, the electrical resistance method of Bouyoucos and Mick* was used. This method has the advantage of simplicity and rapidity of field determinations but is subject to definite limitations in some of its applications, some of which will be discussed in more detail later on. In spite of these disadvantages, however, a great deal of helpful information has been gained which may be applied to the interpretation of observed behavior of the test road. Since both the amount and distribution of moisture in slab and subgrade depend to a great extent on the characteristics of the soil underneath the pavement, some time should first be devoted to this phase of the study to serve as a background for the analysis of observed moisture data.

Soil Conditions

The subgrade and subbase materials supporting the concrete slab in the design project are mostly composed of well drained sandy or gravelly soils with the exception of two areas, from station 88+00 to 129+00 and from station 170+00 to 225+06, where it was necessary to construct a 12

*G. J. Bouyoucos and A. H. Mick - "Electrical Resistance Method for Continuous Measurement of Soil Moisture under Field Conditions" - Michigan State Agricultural Experiment Station, Technical Bulletin No. 172, April, 1940.

inch sand subbase on the existing subgrade material. At other sections of the road, where the right of way passed through low lying areas of Saugatuck and Newton soil, suitable drainage of the subbase was obtained by filling to grade with sand borrowed from neighboring pits. Moisture cell and thermocouple assemblies were installed at four convenient points along the project so that temperature and moisture observations might be made concurrently with displacement measurements. The installations are located at stations 772+10, 851+80, 1055+75 and 61+05. Samples of soil were taken from underneath the concrete pavement at each of these locations for standard tests and for calibration of the moisture cells. A summary of the physical properties of the four soils is given in Table I.

In addition to the laboratory examination of the soil itself, there are several other factors to be taken into account when interpreting observed data. Such factors have to do with the particular features of location and environment which also largely influence moisture conditions at a given point. In Table II are given pertinent data both on natural soil conditions and modifications due to construction procedure. These observations were made during the latter part of June 1944 following a half year period of abnormally low precipitation and probably indicate a subnormal level of the water table. In exceptionally wet years the water table may rise considerably higher, and at some locations may even reach the lower surface of the pavement slab.

<u>Method of Measurement</u>

The method of determining moisture content developed by Bouyoucos and Mick consists essentially of measuring the internal resistance of a plaster of paris block under varying moisture conditions by means of a specially

TABLE I

SOIL CHARACTERISTICS AT MOISTURE CELL STATIONS

Michigan Test Road
Design Project

	Station 772+10	Station 891+80	Station 1055+75	Station 61+05
Gravel, percent retained, No. 10 sieve.	15	5	6	26
Sand, percent retained, No. 270 sieve.	84	91	90	74
Silt, percent retained, 0.005 mm.	1	3	3	2
Clay, percent retained, 0.001 mm.	0	1	1	0
Liquid Limit	19	19	20	18
Plasticity Index	Non-Plastic	Non-Plastic	Non-Plastic	Non-Plastic
Specific Gravity	2.62	2.62	2.65	2.63
Shrinkage Limit, %	No Shrinkage	No Shrinkage	No Shrinkage	No Shrinkage
Loss on Ignition, %	0.67	0.89	1.39	0.61
Organic Content, %	0.62	0.64	1.36	0.45
Capillary Rise, inches	7	12.0	10	10.5
Field Moisture Equivalent,%	19	18	20	17
Moisture, Bottom inch of rise %	24.9	23.9	23.0	20.2
Moisture, top inch of rise %	6.7	4.7	5.4	5.0
Coefficient of Permeability Feet per day	26	52	38	40
Weight on Sample lbs. per square inch	0.6	0.6	0.6	0.6
Voids, %	30.8	32.0	32.0	30.8

TABLE II

SUBBASE SOIL INFORMATION AT MOISTURE CELL STATIONS

Michigan Test Road
Design Project

Design Project

Station	Soil Type	Profile	Water Table	Cut	Fill	Depth of ditch
61+05	Grayling Sand	0-13.5' gravelly Sand	13.5'	1.2'		2'
772+10	Rubicon Sand	0-10.0 sand 10.0-12.0 gravel	12.0'	0.6'		2.5'
851+80	Newton Sand	0-4.0 sand	3.5'		2.4'	4.5'
1055+75	Saugatuck Sand	0-5.0 sand fill 5.0-5.5 loamy sand 5.5-7.5 sand 7.5-8.0 loamy sand	8.0'		4.8'	9.0'

constructed wheatstone bridge. Each moisture cell consists of two bare wire terminals separated one inch and cast in chemically pure plaster of paris to form blocks 1/2 inch by 1-1/2 by 2-1/2 inches in size. Moisture equilibrium between block and surrounding medium is attained rapidly and the indicated resistance is a function of the amount of water present. Alternating current is used in the measuring bridge to eliminate the effects of electrolysis and polarization.

Most of the difficulties in the use of the method arise from the fact that the measured resistance of the plaster of paris block depends not only on the moisture content of the block itself, but also upon the physical and chemical properties of the surrounding medium, particularly as they affect its electricial conductivity. This effect, which is due to the passage of stray currents outside the cell, is especially pronounced when the block is surrounded by an electrolyte, such as occurs when the cell is placed in concrete. The heterogeneous nature of the concrete mass enclosing the cell is an additional disturbing factor. Still another limitation lies in the fact that the resistance of the cell is affected only by the presence of water in its liquid state and is not sensitive to water in any other of its forms, nor to varying degrees of humidity.

Because of these inherent characteristics, the moisture cells must be calibrated individually in conjunction with the particular material whose moisture content is to be measured. The procedure involves imbedding the cell in the specimen with known initial moisture content, allowing the specimen to dry out gradually, and taking resistance readings which correspond to subsequent moisture values. After each change in moisture content, the specimen should be hermetically sealed for at least 36 hours before observing the corresponding resistance in order to allow complete equilibrium to be attained throughout the specimen. From the series of values thus obtained, the resistance-moisture function may be plotted. Such a curve is shown in Figure 1, which was derived from the calibration of a moisture cell in soil from station 651+80. Soils from all four stations were of a sandy type, exhibiting similar properties, and characterized by a relatively sharp break in the resistance-moisture curve in the region of 4 to 7 percent moisture content.

A typical calibration curve for concrete is given in Figure 2. This curve breaks very sharply upward at around 6 percent of moisture, the interval of 5.5 to 6 percent representing a resistance range of approximately 40,000 ohms. All readings were corrected to a temperature of 70°F in order to establish a common basis for comparison.

In the design project, the moisture cells were imbedded in the concrete at the top, middle and bottom of the slab at different distances from the pavement edge, and in the subgrade at depths of 1 inch, 6 inches and 12 inches below the pavement. Corresponding iron - constantan thermocouples were installed at the same time for temperature measurements. Photographs and details of these assemblies are shown in Figures 3, 4, and 5.

<u>Treatment and Presentation of Data</u>

All resistance and temperature measurements were first tabulated for each of the four installations separately in chronological order. After correcting each observed resistance to its equivalent at 70°F, the corresponding moisture content was read directly from the calibration curve for that location. In this way a series of moisture values was obtained for each location, for each season of the year, from the time of construction of the pavement up to the present time.

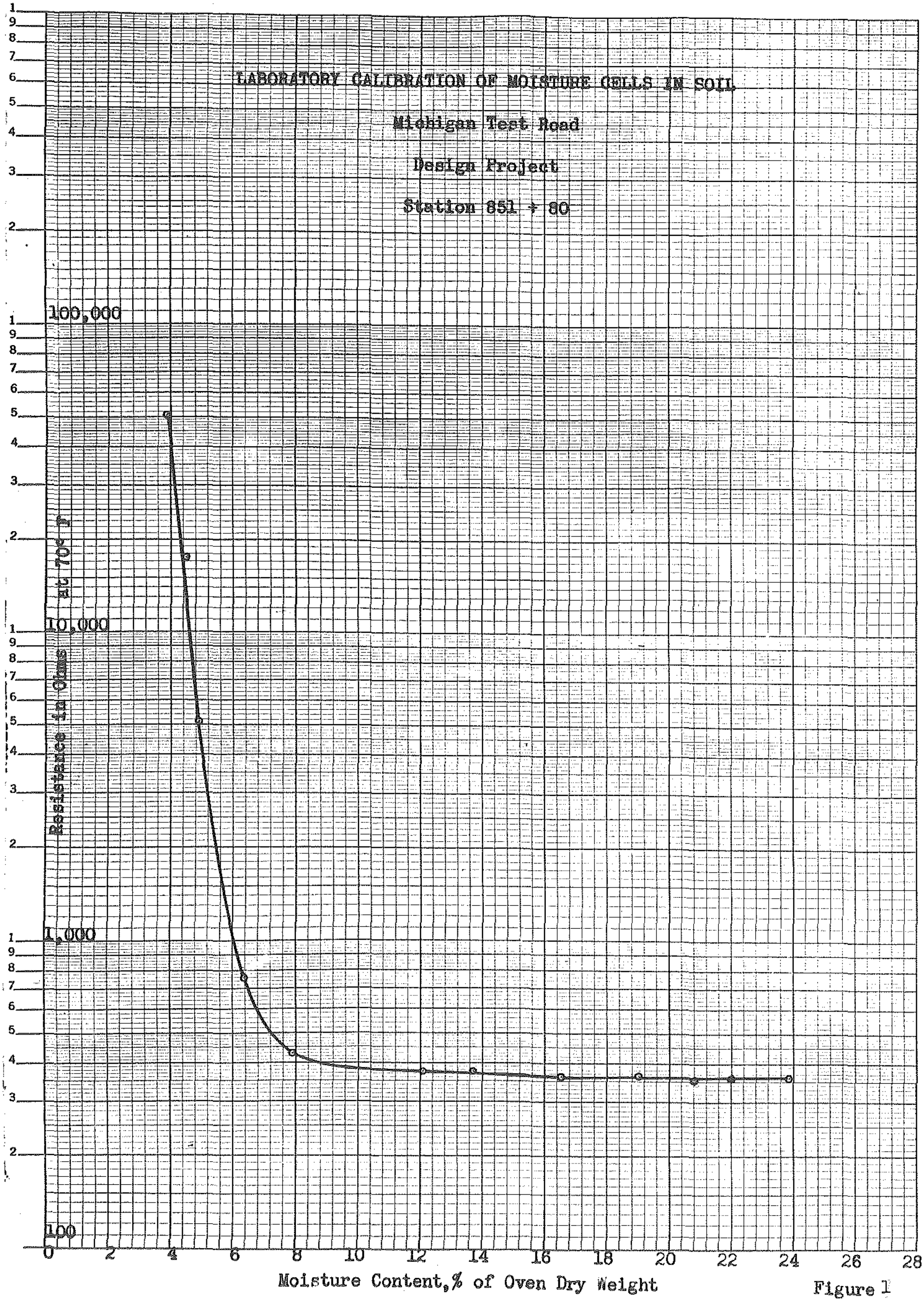
LABORATORY CALIBRATION OF MOISTURE CELLS IN SOIL
Michigan Test Road
Design Project
Station 851 + 80
Resistance in Ohms at 70° F
100,000
10,000
1,000
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
Moisture Content,% of Oven Dry Weight

Figure 1

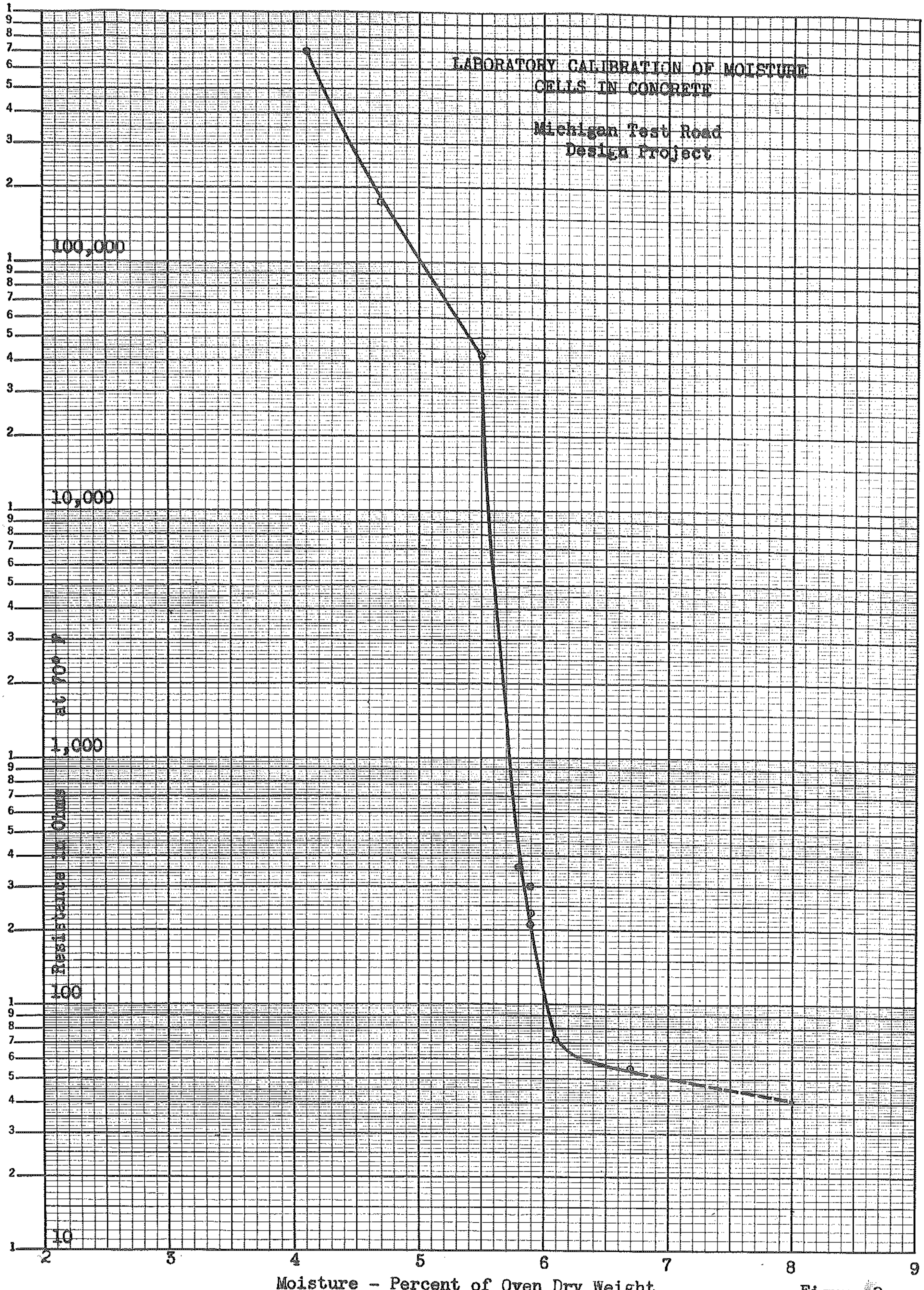
LABORATORY CALIBRATION OF MOISTURE CELLS IN CONCRETE
Michigan Test Road Design Project
Resistance in Ohms at 70° F
100,000
10,000
1,000
100
10
2
3
4
5
6
7
8
9
Moisture - Percent of Oven Dry Weight

Figure 2

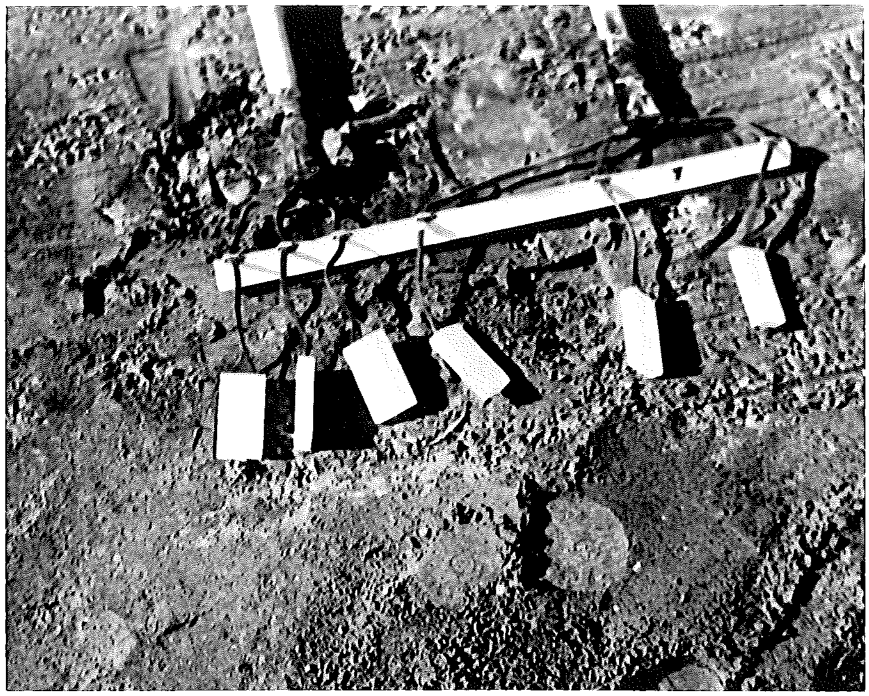

Figure 3. Moisture Cell Assembly.

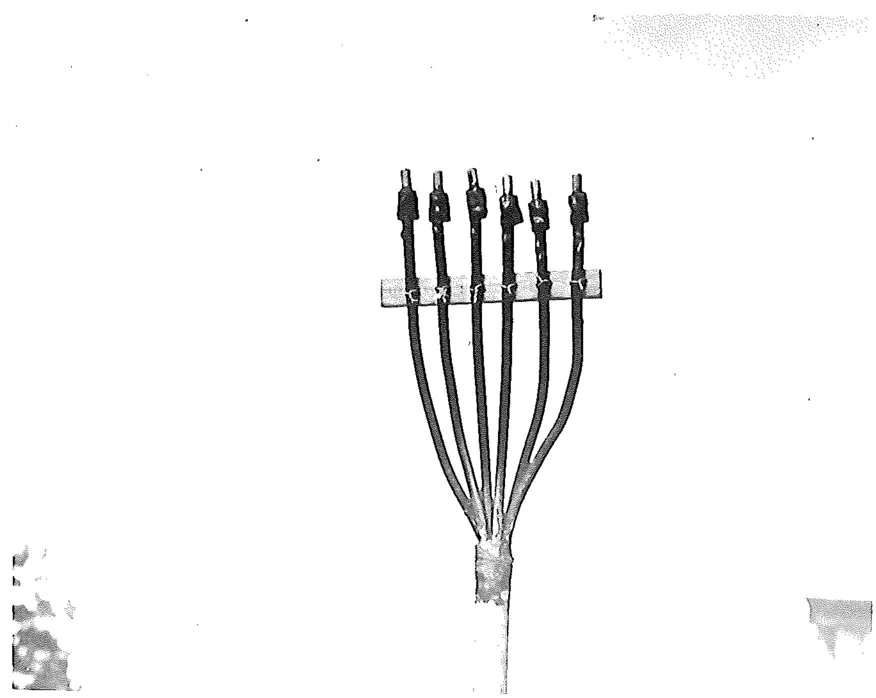

Figure 4. Thermocouple Assembly.

MOISTURE CELL AND THERMOCOUPLE ASSEMBLIES

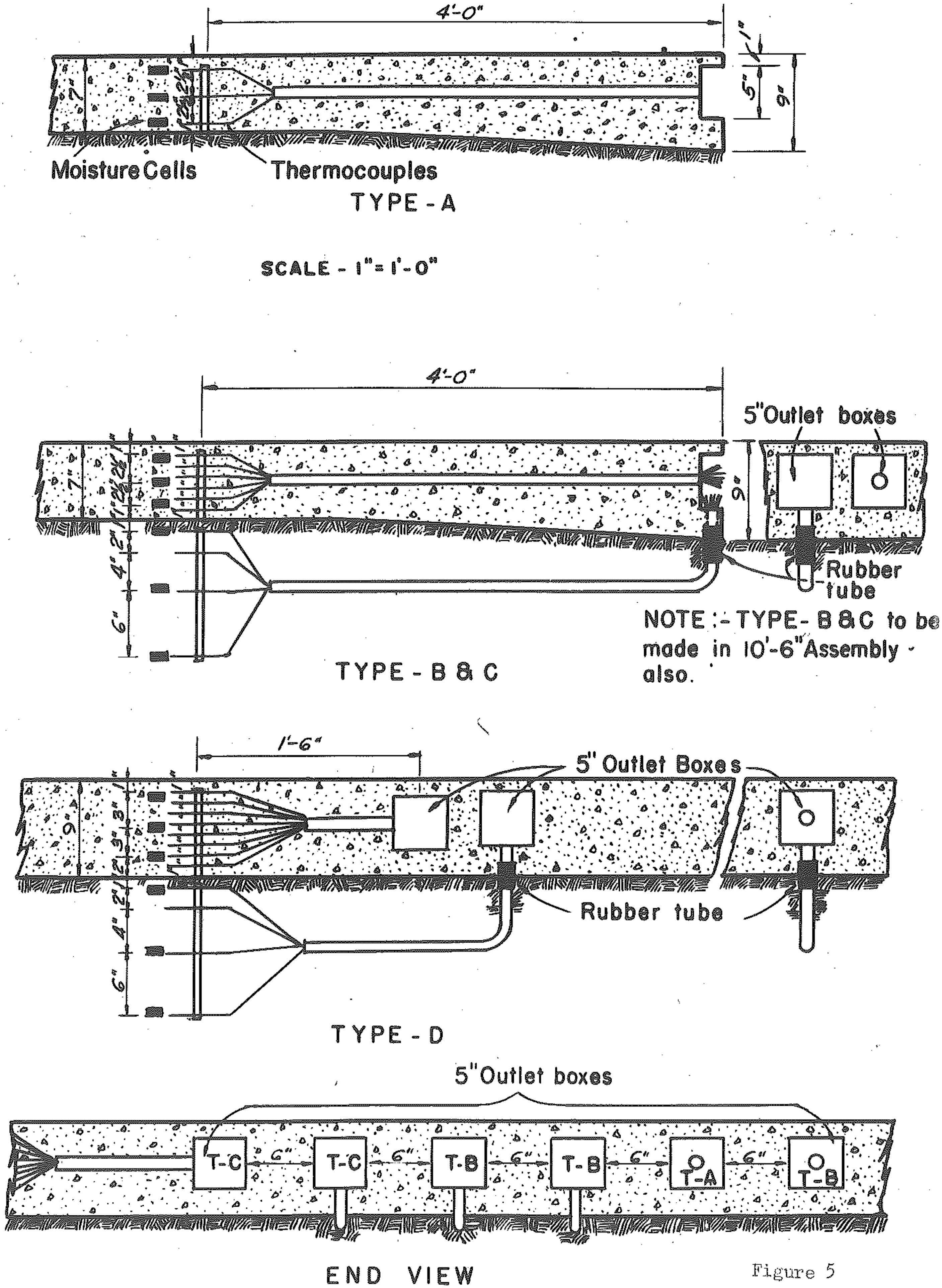

Figure 5

Subgrade moisture values are given in Table III along with seasonal and cumulative precipitation data. Only the data obtained from the moisture cells located 12 inches below the slab were used in the tabulation, since it is strongly suspected that the resistance characteristics of the two blocks immediately below the slab were appreciably affected by the overlying mass of concrete. Winter readings were also omitted since the method fails in subfreezing temperatures, although it may be used in conjunction with temperature observations to determine depth of frost penetration.

A summary of concrete moisture data appears in Table IV with seasonal and cumulative precipitation also included for convenience. In this table average seasonal moisture values are given for the top, middle and bottom of the slab at the four stations of observation.

Discussion of Results

The data given in Table III for moisture cell readings at the four stations show that the moisture content of the subbase normally varies from about 4.5 to 8 percent at the four locations observed and that there is a reasonably close correlation with the seasonal and cumulative precipitation. The data also indicate that the subbase is in general well drained, which condition would tend to maintain a relatively stable moisture content in the bottom of the slab throughout the year.

From Table IV it may be seen that the moisture in the top of the concrete slab varies between about 4 and 5.5 percent. In the middle the variation is somewhat less, moisture ranging from approximately 5 to 6 percent, while the bottom maintains a fairly stable state at about 5.7 to 6.8 percent moisture content.

TABLE III

SUMMARY OF SUBGRADE MOISTURE DATA

Michigan Test Road
Design Project

Year	Season*	Soil Moisture Percent 772+10	851+90	1055+75	61+05	Average	Precipitation inches	Cumulative Precipitation
1941	Winter	-	-	-	-	-	3.60	3.60
	Spring	6.8		6.6	7.3	6.9	9.12	12.72
	Summer	10.3	-	7.9	7.7	8.8	8.73	21.45
	Fall	7.2	7.0	6.5	6.9	6.9	8.58	31.03
1942	Winter	-	-	-	-	-	1.60	1.60
	Spring	4.4	7.1	6.2	6.9	6.1	8.99	10.59
	Summer	4.7	6.9	5.6	6.8	6.0	9.45	20.04
	Fall	7.1	8.0	7.4	7.2	7.4	8.77	28.91
1943	Winter	-	-	-	-	-	6.08	6.08
	Spring	7.7	13.7	6.2	7.4	8.8	11.76	17.84
	Summer	8.9	11.3	6.9	8.1	8.8	6.73	24.57
	Fall	6.5	7.3	6.3	7.4	6.9	4.92	29.49
1944	Winter	-	-	-	-	-	3.53	3.53
	Spring	4.8	-	5.5	6.7	5.7	7.95	11.48
	Summer	4.7	-	5.3	-	5.0	8.07	19.55

*Winter - January, February, March

Spring - April, May, June

Summer - July, August, September

Fall - October, November, December

TABLE IV

SUMMARY OF PAVEMENT MOISTURE DATA
Michigan Test Road
Design Project

Year	Season*	772 + 10 T	772 + 10 M	772 + 10 B	851 + 80 T	851 + 80 M	851 + 80 B	1055 + 75 T	1055 + 75 M	1055 + 75 B	61 + 05 T	61 + 05 M	61 + 05 B	Average T	Average M	Average B	Precipitation Inches	Cumulative Precipitation
		PAVEMENT MOISTURE PERCENT																
1941	Winter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.60	3.60
	Spring	6.0	6.5	6.4	5.5	5.8	6.0	5.4	5.9	6.1	5.3	5.1	5.8	5.6	5.8	6.1	9.12	12.72
	Summer	5.8	6.5	6.0	4.9	5.7	6.0	4.5	5.9	6.5	5.1	5.1	5.7	5.1	5.8	6.1	8.73	21.45
	Fall	5.7	5.9	6.0	5.2	5.5	5.9	5.2	5.8	6.0	-	-	5.8	5.4	5.7	5.9	9.58	31.03
1942	Winter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.60	1.60
	Spring	5.5	5.9	5.9	5.2	5.5	5.9	5.1	5.8	6.0	5.6	5.6	5.9	5.4	5.7	5.9	8.99	10.59
	Summer	5.5	5.9	6.0	4.3	5.1	5.8	4.2	5.8	6.0	5.2	4.8	5.9	4.8	5.4	5.9	9.45	20.04
	Fall	5.5	5.9	6.1	5.3	5.4	5.8	5.5	5.8	6.4	5.5	5.1	5.9	5.5	5.6	6.1	8.77	28.91
1943	Winter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.08	6.08
	Spring	5.5	5.7	6.0	5.2	5.5	5.8	4.8	5.7	6.3	4.8	5.6	6.6	5.1	5.6	6.2	11.76	17.84
	Summer	5.5	5.8	6.2	5.2	5.4	5.8	5.1	5.7	6.6	5.1	5.6	6.8	5.2	5.6	6.4	6.73	24.57
	Fall	5.5	5.7	6.0	5.5	5.5	5.7	5.5	5.6	6.0	5.4	5.6	6.0	5.5	5.8	5.9	4.92	29.49
1944	Winter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.53	3.53
	Spring	5.5	5.7	5.9	5.5	5.5	5.7	5.3	5.5	5.9	5.2	5.4	5.9	5.4	5.5	5.9	7.95	11.48
	Summer	5.5	5.6	5.9	-	-	-	5.0	5.3	6.0	-	-	-	5.3	5.5	6.0	8.07	19.55

* Winter - January, February, March Summer - July, August, September

Spring - April, May, June Fall - October, November, December

The overall moisture content of the slab was noticeably higher during the spring immediately following the construction of the pavement. During the first summer the bottom of the slab seems to have attained a relatively stable moisture equilibrium which has not changed appreciably with time. On the other hand, there has been a steady, though small, decline of moisture content at the center of the slab, amounting to about 0.4 percent, from the initially observed values. It was to be anticipated that the top surface of the pavement would exhibit somewhat wider fluctuations in moisture content due to its direct contact with a more variable environment. In general, however, the moisture variation at different depths in the slab was surprisingly small, the data indicating a maximum differential of 2 percent between top and bottom, but for most observations amounting to only 1 percent or less. The effect of seasonal weather conditions on total moisture content of the pavement concrete was also less than might have been expected, although we know that the migration of moisture through a hardened concrete of good grade is extremely slow.