Moisture Content Determination by the Calcium Carbide Gas Pressure Method

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This paper is concerned with a moisture testing instrument that employs a chemical in the rapid determination of moisture content in soils. A brief description of the moisture tester is given along with the recommended procedure for its use. A testing program that investigated temperature build-up in the moisture tester is described. Calibration curves of direct moisture tester readings versus oven-dry moisture contents and a description of the procedure used in checking the validity of the curves are presented. Some of the possible application of the moisture tester for determination of moisture contents at site locations and field laboratory locations are listed.

● A QUICK, ACCURATE METHOD of determining moisture contents in soil materials has long been one of the goals of soil engineers. Researchers have devoted much effort in developing gravimetric, chemical, electrical, nuclear, penetrometer, tension, and thermal methods for the determination of the moisture content of soils (1). Among these efforts, a chemical method using calcium carbide as a reagent has shown great promise.

The principle involved in this chemical method for moisture determination is that a given quantity of moisture will react with calcium carbide to produce a specific volume of gas (acetylene). The reaction is as follows: $C_aC_2 + 2H_2O = C_a(OH)_2 + C_2H_2$.

A device developed on this principle in England confines the gas produced from the reaction in a pressure vessel. A gauge located in the base of the vessel is calibrated to read the gas pressure in percent moisture based on the wet weight of the sample.

Although the device has been used in England for several years in connection with moisture determinations of foundry sand, it has only been used by highway engineers in the United States for about two years. This paper describes the results of a study by the Bureau of Public Roads to determine the accuracy and usefulness in highway soil testing of a commercially manufactured "Moisture Tester."

APPARATUS AND TESTING PROCEDURE

The moisture tester used in this study is a hollow aluminum vessel having a pressure gauge on one end and a cap with a clamping arrangement on the other. The manufacturer supplies two sizes of moisture testers, one for a 6-gm sample and the other for a 26-gm sample. Only the larger device, (Figure 1) having approximate external dimensions of 14 x 16 in. and a weight of 3.7 lb was used in this study. The moisture tester is equipped with a carrying case, a tared scale for weighing the sample to be tested, a small scoop for measuring the calcium carbide, and a table to convert the percent moisture to the dry weight basis used in soils work. Figure 2 shows the complete apparatus.

Preliminary tests using the procedure recommended by the manufacturer indicated that some changes in procedure were desirable. Consequently, a variety of soil samples passing the No. 4 sieve, and ranging from A-2 through A-7, were used in a procedure study. In order to arrive at a procedure that would give moisture contents as close as possible to those determined by oven-drying, the soil samples were tested at varying moisture contents in the moisture tester and by the standard oven-dry proce-

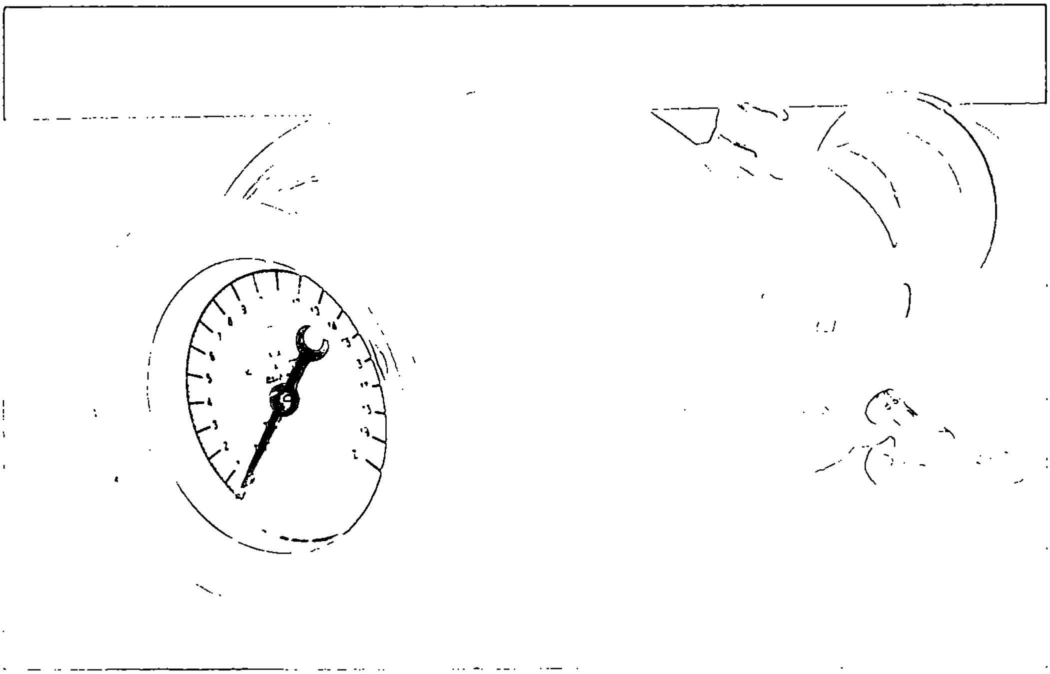

Figure 1. Moisture tester.

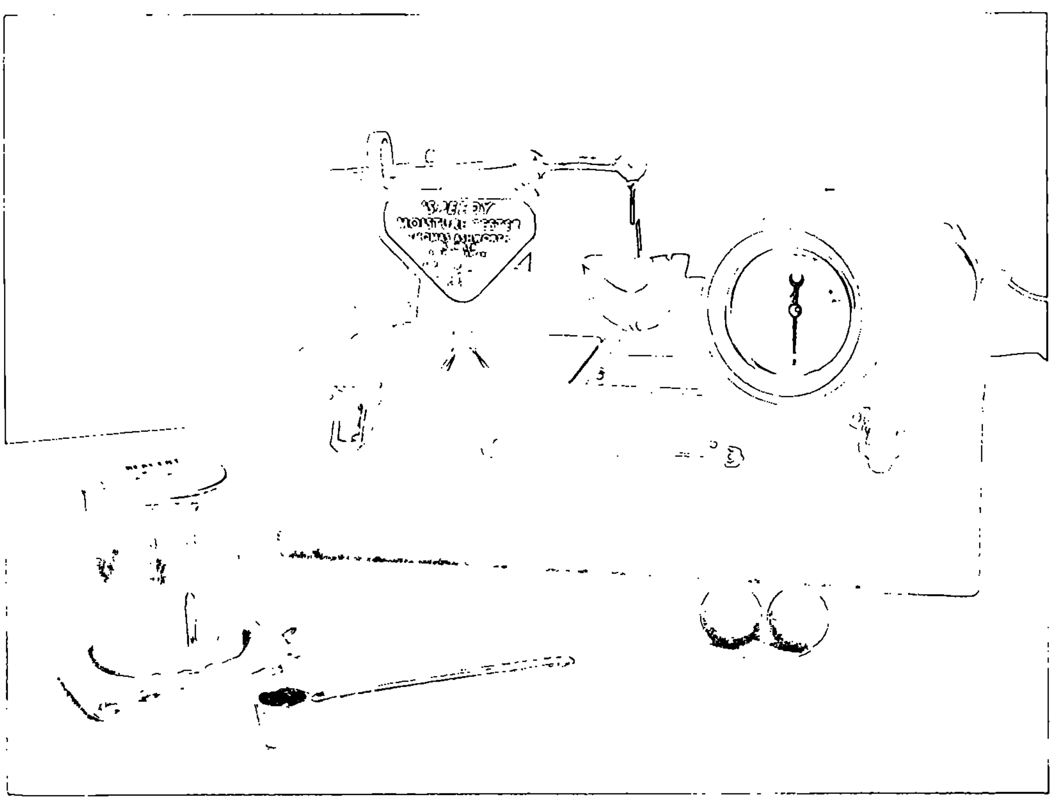

Figure 2. Moisture tester with accessories.

dure, and tests using varying combinations of shaking time, amount of reagent, and types (shape, size, and weight) of pulverizers to break up clay lumps were performed. The most effective pulverization of clay lumps was obtained by placing two $1\frac{1}{4}$ in. steel balls, weighing 0.4 lb each, in the moisture tester with the soil sample and calcium carbide. The procedure outlined in the Appendix was eventually adopted for use of the moisture tester.

TEMPERATURE STUDY

The chemical reaction of the calcium carbide with the moisture in some soils caused a rapid rise in temperature in the moisture tester, hence it was decided to study this thermal effect more fully. An experimental program was carried out to determine if a correlation could be made between temperature and moisture tester readings. The characteristics of the 11 selected soils, ranging from A-2-4(0) to A-7-5(20), are given in Table 1.

A thermometer was taped to the outer surface of the moisture tester at about its midpoint. Although the thermometer was insulated from external temperatures, it was recognized that the temperature recorded was not the actual temperature inside the moisture tester. However, for purposes of determining whether a correlation existed between temperature and moisture tester readings, it was not considered essential to know the actual inside temperature of the tester. After adding water to the soil, the moisture content was determined by (1) the standard oven-dry method, and (2) the moisture tester, using the procedure in the Appendix, except that readings were taken at 1-min intervals. When a soil was tested in the moisture tester, the temperature prior to mixing the soil and the calcium carbide was recorded. The soil and chemical were then mixed and readings of the pressure gauge and thermometer were recorded at 1-min intervals until the temperature returned within 5 degrees F of the initial temperature. Moisture was added to the selected soil in increments of about 2 percentage points until the moisture content was past the optimum moisture content.

TABLE 1

PHYSICAL CHARACTERISTICS OF SOILS USED IN TEMPERATURE STUDY

Soil Classification	Liquid Limit	Plasticity Index	Optimum Moisture Content [a] (%)	Range of Moisture Contents Tested [b] (%)
A-2-4(0)	24	6	14 [c]	8.8 - 16.9
A-3(0)	NP	NP	9 [c]	4.3 - 15.2
A-4(2)	30	6	17 [c]	11.8 - 22.0
A-4(2)	20	1	10	5.8 - 15.2
A-4(8)	26	3	15	9.6 - 19.8
A-4(3)	35	9	15	11.1 - 22.3
A-5(8)	41	8	20	14.1 - 25.5
A-7-5(6)	42	11	20	15.1 - 28.0
A-7-5(14)	52	18	23	18.4 - 29.1
A-7-5(19)	66	27	27	23.8 - 34.4
A-7-5(20)	82	47	33 [c]	29.4 - 41.9

[a] AASHO Designation T 99-57, Method A.
[b] Moisture contents determined by standard oven-dry method.
[c] Estimated optimum moisture content.

Two successive tests were performed with the moisture tester for each increment of moisture tested. The readings were often identical or within 0. 1 percentage point of each other, and most were within 0. 5 percentage point of each other. The range of moisture contents tested for each soil is shown in Table 1. If the moisture contents of the soils exceeded the limit of pressure gauge, half-size samples (13 gm) were used and the percentage indicated on the gauge was then doubled. There were 1, 598 recordings of moisture tester readings and temperature for the selected soils in the temperature study.

The moisture tester readings were converted to a dry-weight basis using the conversion chart supplied by the manufacturer. Diagrams of moisture content versus temperature were plotted for 1-min intervals until the temperature returned to within about 5 deg of its initial value. The oven-dry moisture content was also plotted as a vertical line on each diagram. Some typical diagrams are shown in Figure 3. The curves fall to the right of the oven-dry moisture content line, indicating that the moisture contents determined by the moisture tester were greater than by oven-drying. The greatest moisture content values were at the 1-min moisture tester observations. Those moisture content determinations made from the moisture tester observations at

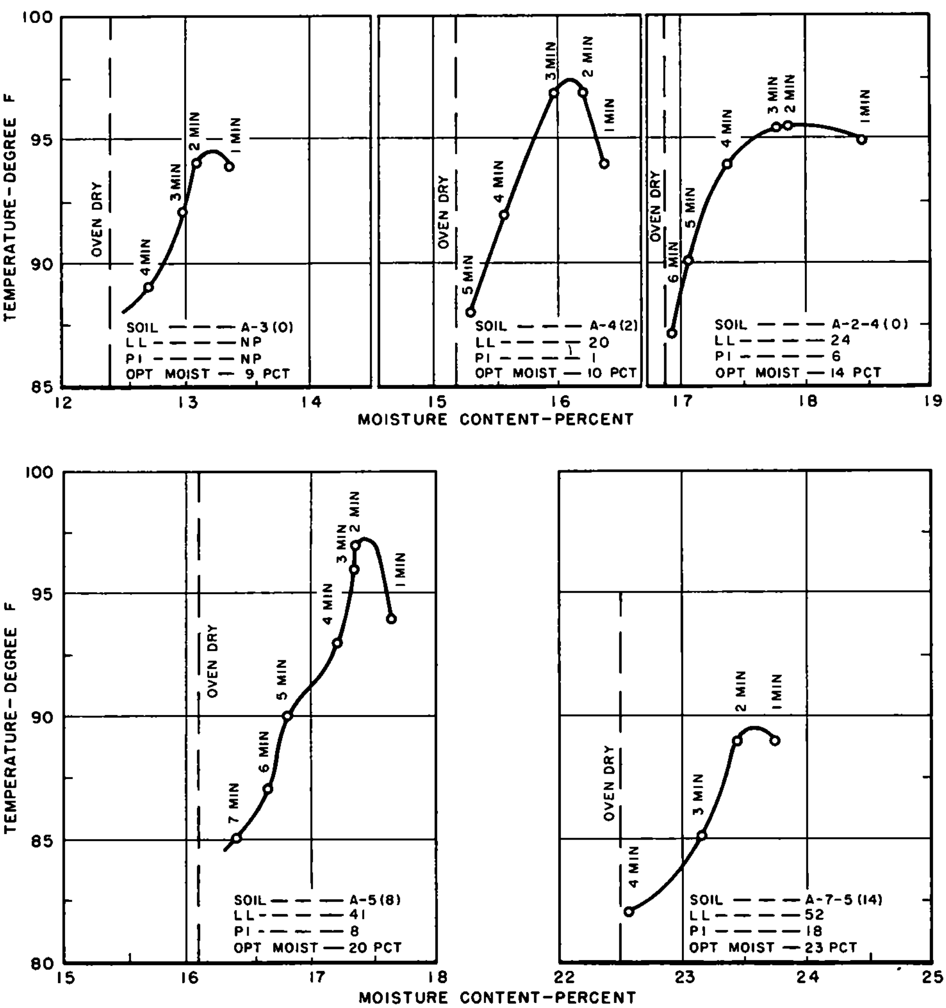

Figure 3. Moisture content by moisture tester versus temperature.

4, 5, and 6 min more nearly approach the oven-dry moisture content of the soil than those at lesser time intervals. It was anticipated that a relation might exist between the peak points of the curves and the oven-dry moisture contents; however, no such relation could be determined.

CALIBRATION CURVES

The moisture content data from this temperature-moisture program were used in developing two calibration curves of direct moisture tester readings versus oven-dry moisture contents. Tests covering a range of moisture contents from 4.3 to 41.9 percent were used in developing the calibration curves in Figures 4 and 5. The direct moisture tester readings at 1 min in Figure 4, and 3 min in Figure 5 are plotted versus oven-dry moisture contents. The 1-min readings were selected for a calibration curve since the first recordings of the pressure gauge of the moisture tester were taken at 1 min. A calibration curve was developed for the 3-min readings since this time is not considered to be excessive for running tests in the field and is adequate for the reaction of the calcium carbide with moisture to occur in clay soils. Either 13-gm or 26-gm samples were used in the development of the curves.

In order to establish the validity of the calibration curves and to compare the deviations using the 1- and 3-min curves, 6 additional soil samples (Table 2) were selected for the moisture testing. Each sample was tested at moisture contents bracketing the optimum (AASHO Designation T 99). The oven-dry moisture content was determined for each moisture increment added to the 6 soils. Using the direct moisture tester readings at 1 and 3 min and the 1- and 3-min calibration curves (Figures 4 and 5), a predicted oven-dry moisture content was determined. These predicted values, along

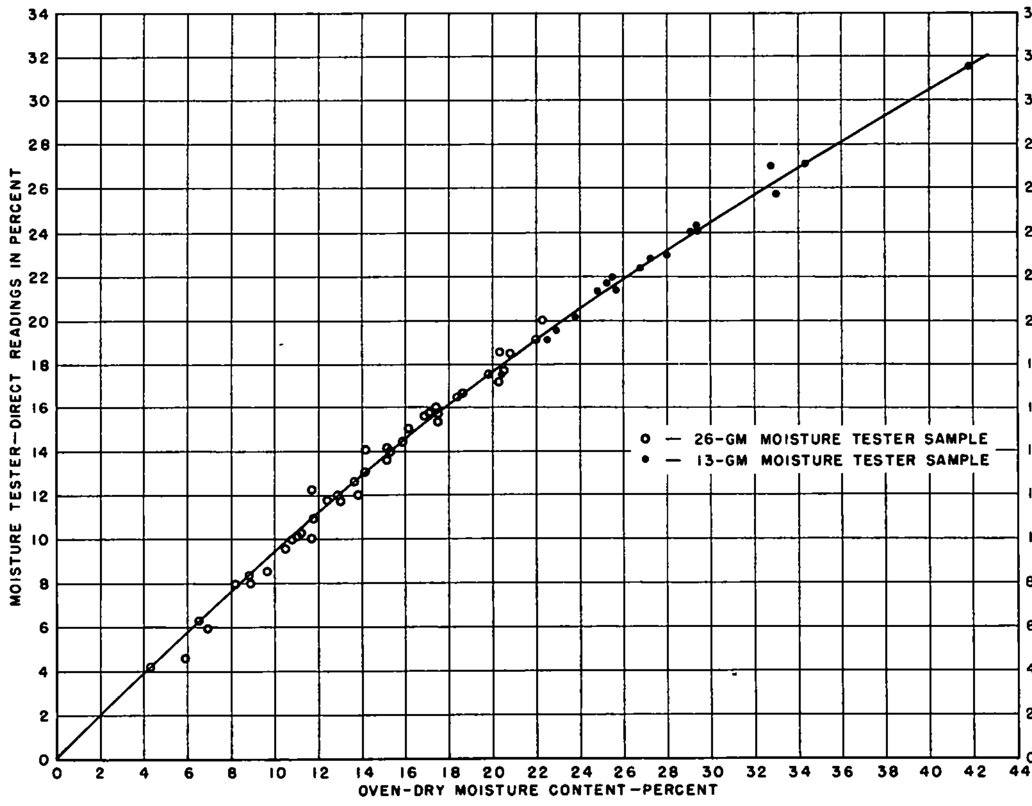

Figure 4. Calibration curve for 1-min moisture tester reading.

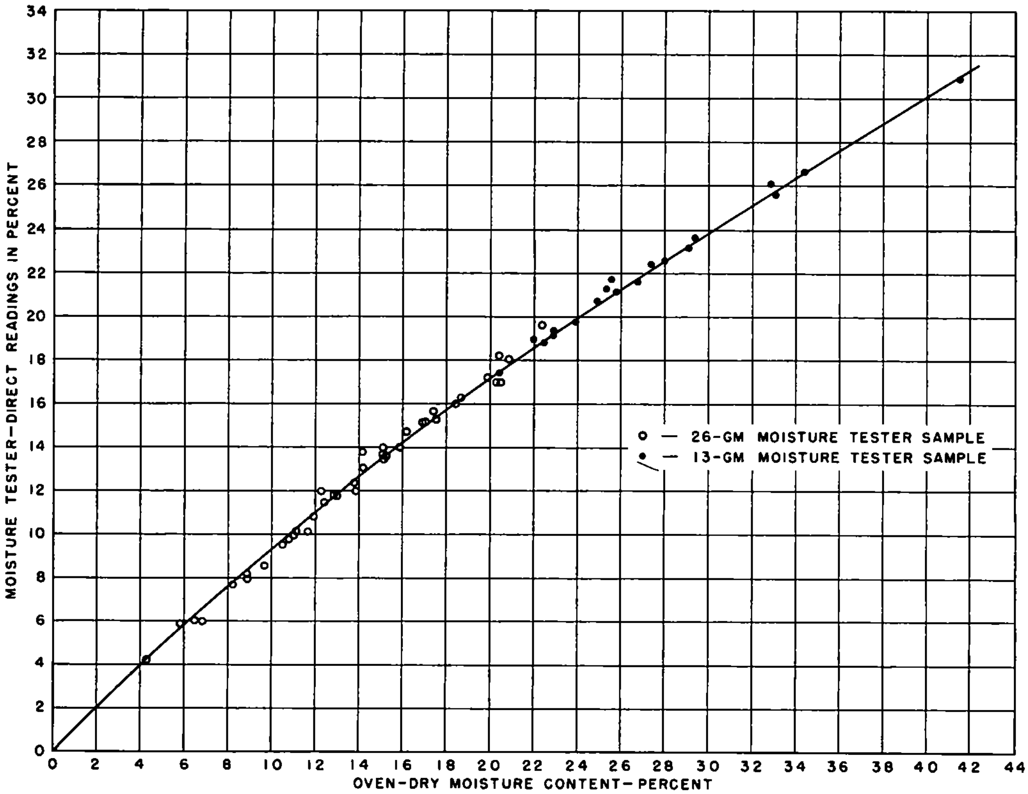

Figure 5. Calibration curve for 3-min moisture tester reading.

TABLE 2

COMPARISON OF MOISTURE CONTENTS BY MOISTURE TESTER AND OVEN-DRYING

AASHO Soil Classification	Moisture Content by: Dial Reading on Moisture Tester 1 Min (%)	3 Min (%)	Calibration Curves 1 Min (%)	3 Min (%)	Oven-drying (%)	Moisture-Content Difference[a] 1 Min (Percentage Point)	1 Min (Percentage Point)
A-2-4(0)	5 0	5 0	5 2	5 1	5 3	0 1	0 2
	10 7	10 5	11 4	11 3	11 2	-0 2	-0 1
	13 8	13 8	15 1	15 4	15 7	0 6	0 3
A-4(5)	8 9	8 7	9 5	9.3	9 1	-0 4	-0 3
	12 5	12 3	13 5	13 6	13 5	0 0	-0 1
	18 0	17 6	20 5	20 6	20 1	-0 4	-0 5
A-6(10)	11 8	11 6	12 6	12 6	12 8	0 2	0 2
	15 2	14.9	16 7	16 8	16 5	-0 2	-0.3
	19 2	18 7	22.0	22.1	21.4	-0 6	-0.7
A-7-6(9)	14.4	14 0	15 7	15 6	15 6	-0 1	0.0
	18.9	18 3	21 6	21 5	20 4	-1 2	-1.1
	22.4	21 9	26 7	26 8	26 7	0.0	-0 1
A-7-5(3)	19 6	19 4	22 6	23.1	24 5	1.9	1 4
	23 0	22 6	27 7	28 1	28 9	1 2	0 8
	27.0	26 4	34 2	34 0	35 0	0.8	1 0
A-7-5(20)	22.4	22.2	26 8	27 5	29 0	2.2	1.5
	25 2	24 8	31 2	31 4	32.4	1 2	1.0
	29 6	28.8	38.5	38.0	37 9	-0.6	-0 1
				Average deviation		0.7	0.5

[a] Deviation of moisture content by moisture tester (calibration curve) from oven-dry moisture content

with the oven-dry values and the deviation between the two sets of values, are shown in Table 2. The moisture contents obtained from the 3-min readings tend to be more accurate than those for 1-min readings. For example, the A-7-5(20) soil had the greatest deviations from true moisture content, but the deviation of moisture-tester from oven-dry moisture content was 2.2 percentage points for the 1-min reading and only 1.5 for the 3-min reading. The average deviation using the 1-min calibration curve in Figure 4 is 0.7 percentage point, while the average deviation using the 3-min calibration curve in Figure 5 is 0.5 percentage point. Although there is only a 0.2 percentage point difference in average deviations between the 1- and 3-min readings, it is recommended that the moisture tester readings be taken at 3 min, particularly for clay samples, (1) to insure complete reaction of the calcium carbide with the moisture, and (2) to achieve greater accuracy.

CONCLUSIONS AND APPLICATIONS

The moisture tester has been in use in the Soils Laboratory of the Bureau of Public Roads for over a year. It has proven to be a sturdy, dependable, and reasonably accurate instrument. Above all, it has proven to be fast and easy to operate. It is believed that by using the procedure outlined in the Appendix, an inexperienced operator will become proficient in a short time. By using the calibration curve in Figure 5, one can convert direct moisture tester readings to a dry-weight basis and obtain a moisture content that agrees closely with that obtained by oven-drying. Inasmuch as the calibration curve was developed for the specific moisture tester device, it is not known whether the curve is applicable to each tester supplied by the manufacturer. Consequently, a State highway department or other agency that purchases the moisture tester should either (1) perform check tests with each device to determine that the calibration curve in Figure 5 is applicable, or (2) develop a calibration curve for the specific moisture tester and local soils.

The calibration curve could be used in the production of a direct reading dial that would (1) expedite moisture content determinations, and (2) eliminate errors in reading the calibration curve.

There are many applications of the moisture tester in highway engineering. The moisture tester is well suited for the control of materials and construction practices where reasonable accuracy and rapid operations are required. The moisture tester can also be used as a quick check for field laboratory tests involving moisture content determinations. Some of the possible applications of the moisture tester are as follows:

<u>Site locations</u>

1. In-place density tests.
2. Auger and split-spoon samples.
3. Sands used in concrete mixtures.
4. Proper moisture content for earthwork.

<u>Field laboratory locations</u>

1. Hygroscopic moisture.
2. Development of compaction curves.
3. Low-value liquid and plastic limits.

Thirty-four State highway departments have reported that they have made tests with the calcium carbide moisture tester and several are using the testers in construction control. This interest by the State highway departments indicates that the calcium carbide moisture tester is rapidly being accepted by the construction industry and the engineering profession.

REFERENCES

1. Shaw, M.D., and Arble, W.E., "Bibliography on Methods for Determining Soil Moisture." Penn. State Univ., College of Eng. and Arch., Eng. Res. Bull. B-78 (1959).

APPENDIX

Procedure for Use of 26-gm Moisture Tester

1. Place three measures (approximately 22 gm) of calcium carbide and two 1¼ in. steel balls in the large chamber of the moisture tester.
2. Using the tared scale, weight a 26-gm sample of soil.[a]
3. Place the soil sample in the cap; then with pressure vessel in a horizontal position, insert the cap in the pressure vessel and tighten clamp to seal cap to unit.
4. Raise moisture tester to a vertical position so the contents from the cap fall into the pressure vessel.
5. Holding the moisture tester horizontally, rotate the device for 10 sec so that the steel balls are put into orbit around the inside circumference and then rest 20 sec. Repeat shake-rest cycle for a total of 3 min. Do not allow the steel balls to fall against and damage either the cap or orifice leading to the dial.
6. Read pressure gauge of the moisture tester and determine moisture content on a dry-weight basis from calibration curve.

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[a]If the moisture content of the 26-gm soil sample exceeds the limit of the pressure gauge, a half-size sample can be used; the percentage indicated on the gauge is then doubled. Since the sample to be tested is relatively small (13 or 26 gm), care must taken to obtain a representative soil sample.