should not be considered as "limiting" the application of the model law, but rather as deserving joint consideration with such applications. A true design procedure for a drainage problem, although admittedly ideal for most applications, might include the following steps:

(1) Establish the supporting power to be required of the soil.

(2) Determine from strength tests what maximum moisture content in the soil will permit satisfaction of that requirement.

(3) Determine from a "moisture sorption curve" for the soil how deep the groundwater surface must be so that the proper moisture content at the surface will not be exceeded under equilibrium moisture conditions.

(4) Determine from an application of the model law and these or other model tests what installation and what length of time will be necessary to satisfy requirement (3).

Either of the last two steps may clearly indicate that drainage is not economically feasible and that some other method of correction should be applied.

# WEIGHT-IN-WATER METHODS OF DETERMINING THE MOISTURE CONTENT OF SOIL-CEMENT MIXTURES IN THE FIELD

MILES D. CATTON AND E. J. FELT

*Portland Cement Association*

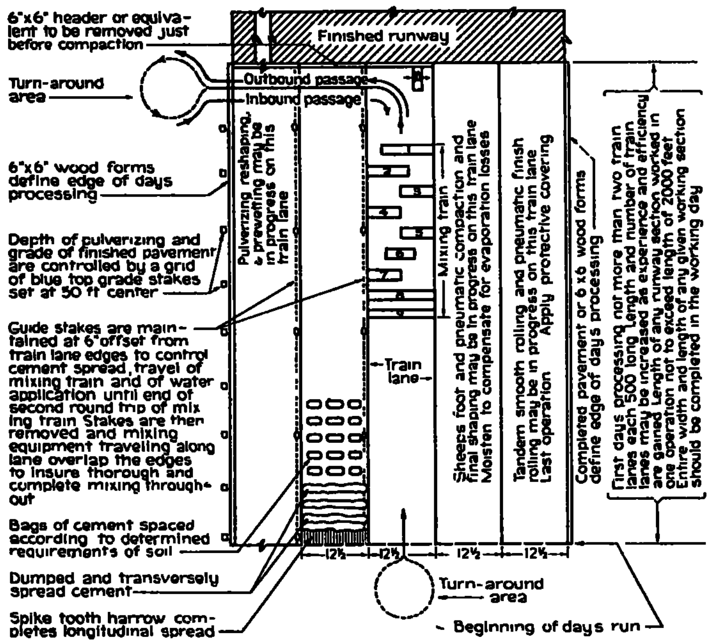
## SYNOPSIS

During the last two years soil-cement airport facilities have been constructed at rates of 10,000, 20,000 and more square yards of 6-in pavement per day. At this speed the control of moisture content for such a large volume of material becomes a very important item requiring careful planning and efficient testing technique Field moisture content determinations are generally made by drying a representative sample over a kerosene or gasoline burner, a system which has proved adequate in most instances. However, since this method is relatively slow, a continued search is being made for more rapid methods of determining these moisture contents This report discusses two "Weight-In-Water" methods which serve this purpose

The principle of these methods has been applied to moisture and specific gravity tests of concrete aggregates, but its application to soil-cement is relatively new. The methods are based on the fundamental that a sample of soil-cement when weighed in water weighs the same regardless of its moisture content After the weights of the sample in air and in water are obtained, the specific gravity of the mixture is used to aid in the calculation of its dry weight and moisture content.

The fact that cement is a powerful flocculating agent is instrumental in making possible the use of a pycnometer-syphon weight-in-water method applicable to soil-cement mixtures even though they are composed of fine textured soils.

During the past two years a number of soil-cement projects have been built at rates of 10,000 to 20,000 and more sq. yd of six-inch pavement a day. Much of this yardage was built using the "train lane" processing method, the fundamentals of which are shown in Figure 1. In this method, processing equipment completes the construction of each lane in a relatively short time and, therefore, rapid moisture determinations are required after the dry mix in order to control subsequent moisture application. Some additional moisture content determinations may be required during water application. Final moisture content checks are needed during final rolling so that a large number of moisture tests are required each day. As an illustration, if one moisture sample is taken for every 350 sq. yd. of




## Preparation of Runway for Processing

First the runway section is graded to line and grade required in completed section All such grading must be completed before pulverizing and processing operations start Outside edges of runway and lanes to be pulverized are defined with guide stakes in the same manner as for processing A section is then loosened and pulverized to 5½" depth with road rooter scarifier on motorized road grader plows, etc as needed Should soil be dry and hard it may be made mellow for rapid pulverizing by repeated water applications which are permitted to soak into the soil After soil characteristics are learned pulverizing may be completed on some soils as part of mixing operations after cement is added The day before processing sufficient water is applied on the section and mixed in so that 3 to 6 water applications per lane during processing operations will fulfill water requirements The section is then leveled prior to cement spread After cement is spread on a lane start the routine of mixing by train method

An experienced efficient crew can build 6 12½ lanes 2000 feet long in 12 hour period (16 666 sq yd) with equipment listed, provided no time is lost on cement spread or water application Two days work by such an organized crew will complete a runway 4000 feet long and 75 feet wide as shown by contractors who have exceeded this production

## Mixing Train Units

| Unit No | No Req'd | Width | Description of Unit | Motive Power |
|---|---|---|---|---|
| 1 | 1 | 8' | Cultivator Heavy duty Springtooth fitted with 4" double pointed chisels | Tractor Crawler type Min 35 D B H P |
| 2 | 1 | 8 | Cultivator, Heavy duty Springtooth fitted with 4" double pointed chisels | Tractor Crawler type Min 35 D B H P |
| 3 | 1 | 5⅔ | Plow Tractor Heavy duty 5-14" bottoms (omit coulters) | Tractor Crawler type Min 35 D B H P |
| 4 | 1 | 5⅔ | Plow Tractor Heavy duty 5-14" bottoms (omit coulters) | Tractor Crawler type Min 35 D B H P |
| 5 | 1 | 6 | Rotary Speed Mixer self-powered, Trailer mounted | Tractor Crawler type Min 35 D B H P |
| 6 | 1 | 6 | Rotary Speed Mixer self-powered Trailer mounted | Tractor, Crawler type Min 35 D B H P |
| 7 | 1 | 6 | Rotary Speed Mixer self-powered, Trailer mounted | Tractor Crawler type Min 35 D B H P |
| 8(1) | 2 | 12½ | Distributor Water Pressure 1000 gallons | Self-powered |
| 9 | 1 | 12 | Harrow, Spike tooth 3 sections | Tractor, Rubber-tired Min 23 D B H P |
| 10(2) | 1 | 6 | Cultivator Chisel Power control (Attachment to tractor) | Tractor, Rubber-tired Min 23 D B H P |

## Routing of Mixing Train

First round trip – Use cultivators (Units 1 & 2) and Mixers (Units 5, 6 & 7) only These machines otherwise to maintain same relative positions each passage
Second round trip – Use entire train as shown All machines to maintain same relative positions Add about ¼ of water requirements on outbound & ¼ on inbound passage
Third round trip – Use entire train as before This round trip should about complete water application
Fourth round trip – Use entire train as before Add remaining water needs on outbound trip This enables thorough incorporation of moisture on inbound trip IF TOTAL WATER NEEDS CANNOT BE ADDED DURING FOUR TRIPS CONTINUE ENTIRE TRAIN UNTIL ALL WATER IS ADDED
Subsequent round trips – Necessary only to complete uniform water distribution in mix or to complete water addition requirements Mixing train then moves to next train lane Sheeps foot compaction may start on any train lane as soon as the mixing train has finished There should be no traffic intervening

(1) A second distributor (filled) should be available to replace unit 8 on inbound passage or if desired to follow unit 2 (cultivator) in mixing train Spray bars should be of the full width of the train lane
(2) Unit 10 (cultivator) completes mixing adjacent to previously finished pavement Works independent of mixing train 5 hand shovelers supplement mixing near header, keep ends even remove any raw soil from mix and return mixed soil-cement to section

On jobs that require processing in alternate lanes 25' wide and defined by 6"x6" wood forms, a special form plow with 23 D B H P tractor should be added to the equipment as listed The plow should be specially fitted with depth gage and 3' wing extention to the mold board to throw edge material away from form or finished pavement This plow makes 6 or more trips along each edge works independently of mixing train and assures thorough edge mixing

**Figure 1. Soil-Cement "Train" Processing. Airport Runway Construction in Train Lanes Each 12½' Wide. Successive Train Lane Method**

pavement for controlling water spread, and one sample taken at the same location to check moisture content just before final rolling, a total of about six tests are necessary for every 1,000 sq. yd. of pavement. For 12,000 sq yd. approximately 72 tests are made.

Results from these tests are required quickly if water spreading equipment is to be kept moving. For instance, when processing a train lane 1,200 ft. long and 10 ft. wide, it is frequently necessary to obtain four moisture samples, take them to the laboratory, determine moisture content, and deliver results to the water distributor foreman, in a matter of about 15 minutes This requires that moisture determination tests be made with dispatch.

The method generally used in the field for determining moisture contents of soil-cement mixtures involves drying the sample out over a burner. This method is satisfactory and can be used on many jobs. However, it is relatively slow. For this reason the following methods for determining moisture contents of soil-cement mixtures have been worked out to give quicker answers to the moisture tests in the field than afforded by the usual drying-out process over gasoline or kerosene burners.

While not heretofore used in soil-cement testing, the same principles have been and are in practice in slightly different form in the determination of moisture contents and specific gravities of aggregates for concrete [1]

Apparatus for the Weight-in-Water Method is readily obtainable and at low cost The computations are simple; in fact a chart is presented from which the moisture content of the soil-cement can be read direct with no calculations required. The only factor that must be known in addition to the weight of the sample in air and in water, is the *specific gravity of the soil-cement mixture at the particular time the test is being made.* For this reason it is extremely important that the specific gravity determination be made with accuracy.

### DETERMINATION OF SPECIFIC GRAVITY

Specific gravity may be defined as the ratio of the dry weight of any volume of material to the weight of an equal volume of water Although the density of water varies with the temperature, it is sufficiently close in this work to assume that one gr. of water has a volume of one cc. The assumption that one gr. of water has a volume of one cc. permits a working range from 40 F. to 90 F. with only about a 0 01 error in specific gravity.

The specific gravity of soil-cement can be determined in the field by either of two common methods

(1) According to Archimedes' principle, a sample of soil-cement weighed while immersed in water will weigh less than it did in air by the amount of water displaced If weights are taken in grams, the specific gravity is then equal to the dry weight of the soil-cement divided by the weight of water displaced.

Example of (1). "Weight immersed in water" method

| | |
|---|---|
| Wt. of soil-cement sample in air (dry basis) . . | 1000 g. |
| Wt of soil-cement sample immersed in water . . | 634 g |
| Wt. of water displaced . | 366 g. |

And specific gravity $= \frac{1000}{366} = 2.73$

(2) Another way to determine specific gravity is to place a known weight of soil-cement in a pycnometer, the volume of which is known, and add water to fill the pycnometer (to the gage mark of known volume). The volume of the soil-cement or weight of water displaced is then calculated as follows·

Example of (2). "Pycnometer" method.

| | |
|---|---|
| Wt. of soil-cement sample (dry basis) | 1000 g. |
| Wt. of pycnometer + soil-cement + water to fill to gage mark = (a) .... .. | 3162 g. |
| Wt. of pycnometer + water to fill to gage mark = (b) | 2528 g. |

Wt. of water displaced $= b - (a - 1000)$
$= 2528\text{–}2162 =$
366 g.

And specific gravity $= \frac{1000}{366} = 2.73$

### *Effect of Hydration Upon Specific Gravity*

When soil, moisture, and cement are intimately mixed by processing, a combination of substances is formed, the specific gravity of which will differ slightly from what might be

[1] R. W. Crum, "Control of Materials and Mixtures for Concrete for Pavements," *Proceedings*, Highway Research Board, Vol. 9, p. 276 (1929)

calculated from the combination of the specific gravities of the soil and the cement One of the reasons for this is that water taken up by the chemical hydration of the cement changes the specific gravity of the cement and may also affect the water of hydration in the soil. Therefore, the specific gravity of the product is affected. The change is gradual and as it is dependent upon the hydration of the cement, the amount of change is dependent upon the amount of water present in the soil-cement mixture and the period for which the water has been in contact with the soil-cement.

In some instances, the processing of soil-cement may require several hours during which the specific gravity of the mix will change slightly. Therefore the specific gravity of the mixture should be determined for, say, one, two and three hours of mixing at moisture contents likely to be present after processing those particular times. When making a moisture content test the specific gravity value is used which most nearly fits the moisture condition and time interval in which the sample was taken.

Preliminary specific gravity tests can be completed prior to processing by mixing small batches of soil, cement, and water for the proper periods, after which the tests are made. Or if desired, specific gravities can be determined at the same time that the first moisture content tests are made during processing. In either case when determining specific gravity, best results are obtained by using the soil-cement in the same condition as obtained from the project, or as prepared for preliminary tests The moisture content may range from air-dry to above optimum. As a suggested procedure, weigh in air 1000-gr. of soil-cement as sampled and then weigh it in water. Simultaneously select a 200 to 400 g. sample of the same material and determine its moisture content by drying over the field kerosene or gasoline stove Next calculate the dry weight of the large sample, after which its specific gravity can be calculated as in (1) or (2). The specific gravity must be determined by the same procedure and with the same equipment as will be used in making the moisture tests next to be described.

#### BASIS OF METHOD FOR MAKING MOISTURE TESTS

As previously discussed, when weights are in grams, the specific gravity of the soil-cement, $G = \dfrac{\text{Dry wt. in air}}{\text{Dry wt.} - \text{Wt. in water}}$

Since the specific gravity of water is taken as 1, use may be made of the equation:

$$\frac{\text{Dry wt. in air}}{\text{Wt. in water}} = \frac{G}{G-1}$$

or $\quad \text{Dry wt. in air} = \text{wt. in water} \times \dfrac{G}{G-1}$

Example using data from examples of (1) and (2) previously given:

$$\text{Dry wt. of soil-cement} = 634 \times \frac{2.73}{(2.73 - 1)} = 1000 \text{ g.}$$

Now if another sample of soil-cement having the same specific gravity, and containing an unknown amount of moisture is weighed in air and then weighed immersed in water, the dry weight of soil-cement can be obtained by multiplying the weight in water by $\dfrac{G}{G-1}$. After the dry weight is obtained, the moisture content can be calculated.

Example:

Wt. of moist soil-cement sample in air . . . . . . . . . . . . 1000 g.

Wt of soil-cement sample immersed in water . . . . . 552 g.

$$\text{Wt. of dry soil-cement} = 552 \times \frac{2.73}{2.73 - 1} = 871 \text{ gr.}$$

Then moisture content of soil-cement = 1000 − 871 = 129 g.

$$\text{And percentage of moisture} = \frac{129}{871} \times 100 = 14.8$$

$$(129 \div 871)\,100 = 14.8\%$$

In the foregoing illustration the assumption is made that the "weight of moist soil-cement immersed in water" is obtained directly by weighing the sample suspended in water. However, the same value is obtained when using a pycnometer by subtracting the weight of the pycnometer full of water from the weight of the pycnometer containing the soil-cement plus water to fill to the gage mark of known volume.

Example

Wt. of moist soil-cement sample 1000 g.

Wt of pycnometer + soil-cement sample + water to fill to gage mark . . . . . . . . . . . . 3080 g.

Wt. of pycnometer + water to fill to gage mark . . . . . . . . . . . . . 2528 g.

Then Wt. of soil-cement sample in water = 3080 − 2528 = 552 g.

And in this example, dry wt. of soil-cement =

$$552 \times \frac{2.73}{2.73 - 1} = 871 \text{ g.}$$

And moisture $= \left(\frac{1000 - 871}{871}\right) 100 = 14.8$ per cent.

APPLICATION OF METHOD TO FIELD USE

Undoubtedly some operators will prefer the "weight while suspended immersed in water" method for determining specific gravity and for making moisture tests, while others will prefer the "pycnometer" method. The technique involved with both methods is practically the same, and therefore in the following discussion, only the pycnometer method will be described in detail.

To make the pycnometer method workable in the field it is necessary that the following fundamentals in equipment and procedures be satisfied

(1) The opening, or mouth of the pycnometer must be large enough that the moist soil-cement can be put into it rapidly.

(2) The method of obtaining constant volume must be simple, rapid, and so workable that the outside of the pycnometer does not become wet, necessitating a slow drying process prior to weighing.

(3) A relatively large sample must be tested, precluding the quartering of samples and the necessity of a sensitive field balance.

(4) The equipment must be mobile enough to bring to the site of construction and thus permit rapid field tests.

In the method to be described, fundamental (1) is met by using a two-quart mason jar, and (2) is taken care of by using a simple syphon To meet requirement (3) a 1000-g. sample is used, with a balance sensitive to about one gram. As will be seen, the setup described is mobile so that it can be placed adjacent to the area being processed.

EQUIPMENT RECOMMENDED

1—gram scale, 5000 g capacity, about 1 g. sensitivity.
1—two-burner kerosene or gasoline field stove
6—two-quart Mason jars
1—copper tubing or other suitable syphon, $\frac{1}{8}$ or $\frac{1}{4}$ in. opening.
1—10-in. funnel, with wide, short spout fitting snugly in mouth of Mason jar.
6—one or two-quart sampling cans
1—water barrel for storing water.

The syphon can be made by bending the copper tubing as shown in Figure 2. The "stiffener" shown is not absolutely necessary, but it gives the tubing rigidity. If the end of the syphon at the water line is "belled-out" it facilitates a quick cut-off during syphoning.

The syphon must be constructed so that it will hang on the fruit jar in such a position that it will syphon water to exactly the same level each time This is a simple matter and offers no difficulties. A mark should be made on the neck of the jar so that the syphon is hung on the same spot each time. The six 2-qt. jars, full of water to the syphon line,


**Figure 2**

are then made to weigh exactly the same by winding copper wire around the neck of the lightest jars. (To insure that the syphon is working properly it should be checked each morning, and after any accident in which the syphon might have been bent, by syphoning water from one or two jars, and checking the weight of these jars full of water with their weight previously obtained).

Mobility of the equipment can be obtained in several ways one of which is illustrated in the following setup.

Fill a barrel with sand and place on a sled-platform. From the barrel extend a vertical post on which a platform is built large enough to support the scale. Next, build a scale house with a glass window in the back and in the front door and fit it over the scale platform so that it rests on the sand barrel. This protects the scale from the wind Such an apparatus, with the scale removed, can be pulled from one section of the job to another. Another possibility for a scale platform is a heavy box, the inside of which could be sectioned off into shelves for storing jars and other equipment.

FIELD TEST PROCEDURE RECOMMENDED

Have all apparatus clean and conveniently arranged. The following steps are the same for either moisture content test or specific gravity test:

(a) Half fill the two-quart Mason jars with water.

(b) In the sampling cans, secure representative samples of the soil-cement to be tested.

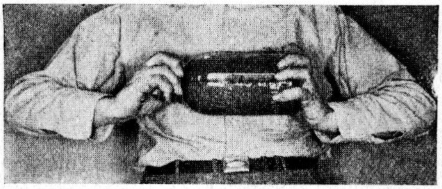


Figure 3

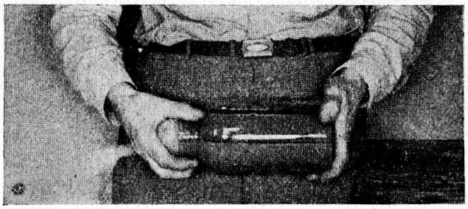


Figure 4

(c) Transfer the sample to a suitable receptacle and weigh out exactly 1000 g. If the sample contains soil lumps retained on a No. 4 sieve they should be pushed through the sieve. When the soil contains plus No. 4 aggregate, it is recommended that the moisture control be on the basis of the minus No. 4 portion of the material.

(d) Through the large funnel, transfer the entire weighed sample to the Mason jar half filled with water. Next, with one hand over the opening of the jar to prevent spillage, hold the jar horizontally and shake it vigorously about 25 times to assure that all the soil-cement particles are in suspension. Some operators have difficulty covering the top of the jar tightly with their hand, and find a solid soft rubber ball of proper size to be an excellent stopper. To free the air in the suspension, slowly rotate the jar 12 times, giving it a full half turn with each rotation. See Figures 3 and 4. Exactly the same procedure of "shaking" and "rotating" must be followed with each test. It is extremely important that sufficient time be taken in rotating the jar to insure practically complete removal of all entrapped air from the mixture. Set the jar upright. Rinse any sediment from the hand into the jar and fill the jar with water to within $\frac{1}{4}$ in. of the top. Allow the water-soil-cement suspension to settle for a minute or so. It is important that no soil-cement be in suspension at the top of the jar to come out of the syphon. With some fine grained soils caution will need to be exercised, even though the cement is a powerful flocculating agent. If, in an unusual case, the soil-cement is very slow in settling, better results may be obtained using the "weight suspended in water method." A possible field set up for this method is shown in Figure 5.

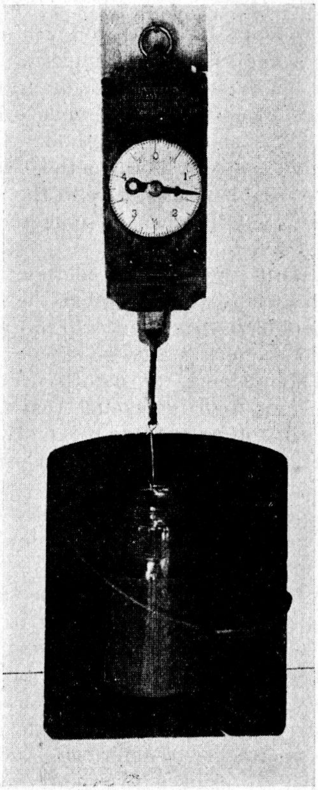


Figure 5

(e) Place syphon in proper position and remove water down to constant syphon level.

(f) Remove syphon and weigh the jar and contents.

The foregoing steps are the same for determining either the specific gravity or the moisture content of the sample. However, if the specific gravity is being obtained, it is necessary to complete one more operation, and that soon as the weight of the pycnometer jar plus water to fill is obtained. This weight can be added to each of the figures across the bottom of the chart, and this scale would then equal "the gross weight of the pycnometer plus soil-cement plus water to fill." Then when making a moisture test the moisture content could be read directly immediately after weighing the pycnometer plus soil-cement and water.

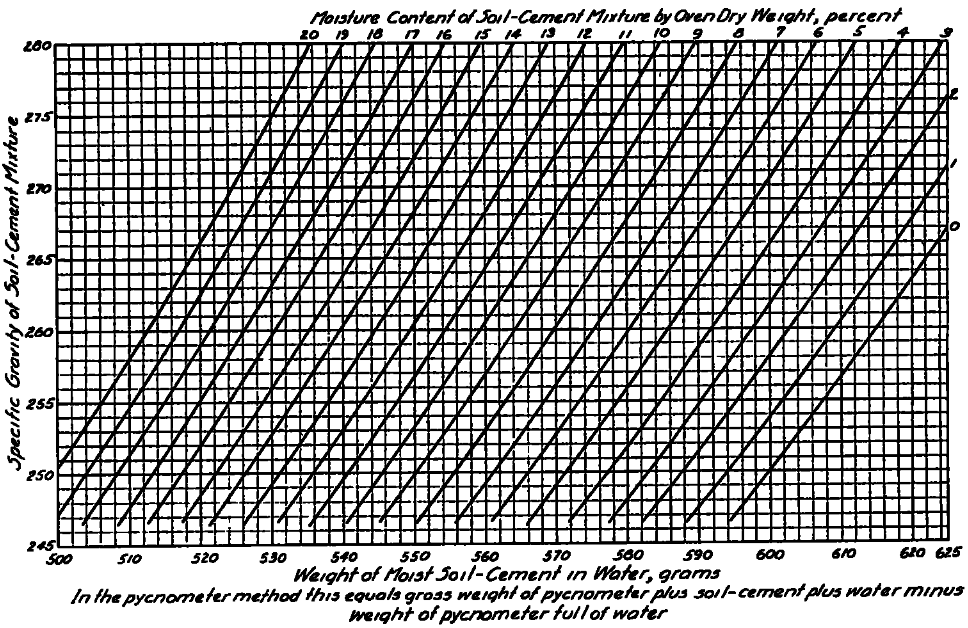



**Figure 6. Relation of Specific Gravity and Moisture Content of a Soil-Cement Mixture, when a 1000-g. sample (air wt.) is Weighed in Water**

is to calculate the dry weight of the sample used by drying out a small quantity of the original sample over a stove. The specific gravity is then calculated. When the specific gravity is known the moisture content is calculated.

### PREPARATION OF CHART

The moisture content of each soil-cement sample can be calculated individually as previously discussed, or to save time, the accompanying chart (Fig. 6) can be used Here the moisture content can be read directly, providing the specific gravity is known; or the specific gravity can be read directly if the moisture content is known.

When this chart is used with the pycnometer method one other time saver can be used as

### CONCLUSION

Although experience with the Weight-in-Water methods of determining moisture contents of soil-cement mixtures is confined to the last two construction seasons, considerable progress has been made. It is not unlikely that as more engineers become familiar with the method, additional short cuts will be developed.

The practicality of these methods is shown by a field experience where two men made tests necessary for moisture control of a job built at a rate up to 20,000 sq. yd. per day The accuracy of the methods has been proved both in the field and in the P C. A. soil-cement laboratory where tests were made on soil-cement mixtures composed of soils of different texture from sand to clay.

ACKNOWLEDGEMENT

Credit for the development of these weight-in-water methods for determining the moisture content of soil-cement mixtures in the field is due V. S. Brewer, P.C A Field Engineer, Des Moines Office; G. N. Lamb, P.C A. Soil-Cement Engineer, Soil-Cement Bureau, Chicago; and H. K. Vanderipe, P.C.A Office Engineer, Indianapolis Office

## DISCUSSION ON DETERMINATION OF MOISTURE IN SOIL-CEMENT

PROF. E. E. BAUER, *University of Illinois*: The writer has made a study of the effect on specific gravity of changes in the temperature of the water between the time the calibration of the pycnometer is made and the time the soil (or soil-cement) is weighed with the water in the pycnometer.[1] An extension of that study to this problem indicates that there may be some error introduced in determining the percentage of moisture if there is this same variation in temperature when the two weighings are made, even though the specific gravity value is correctly determined.

By calling attention to these possible errors, it is not the purpose of the writer to try to discourage the use of the proposed method. Rapid determination of values in the field is highly desirable, but those who use the method should realize that wide fluctuations in temperature of the water used in both the specific gravity and moisture tests may affect the percentage of moisture an appreciable amount.

It is quite possible that the calibration of the pycnometers might be made in the laboratory using tap water at a temperature of 20 C. (68 F.) or less. The water that is used in the field laboratory on a hot summer day might be 30 C. (86 F ) or above. The reverse temperature combination might be true under different circumstances.

### *Effect of Temperature on Specific Gravity*

In order to arrive at some specific values, temperatures of 20 and 30 C. have been selected and a condition in which the water occupies 90 per cent of the pycnometer when the second weight is secured The soil and cement occupy the other 10 per cent When the temperature of the water is 20 C. at the time of the calibration of the pycnometer and 30 C. at the time the second weighing is made, the specific gravity obtained is 2.546 for a soil having a specific gravity of 2 600 based on water at 4 C. When the temperatures are reversed (30 C. for the first weighing and 20 C. for the second), the specific gravity obtained for this same soil is 2.673. This same soil has a specific gravity value of 2.604 when the temperature is 20 C. at the time of both weighings, and 2.611 if the temperature is 30 C.

For a value of 550 g. of "weight of moist soil-cement in water" (See Fig. 6), the percentages of moisture scaled off would be:

| Specific Gravity | Moisture % |
|---|---|
| 2 546 | 10.4 |
| 2.600 | 11 9 |
| 2.673 | 13.7 |
| 2.604 | 12.0 |
| 2.611 | 12.2 |

showing that the effect of a 10-deg. change in water temperature while making the specific gravity test has a noticeable effect on the determined moisture contents. On the other hand, if the temperature is the same when the two weights are taken, it makes little difference whether the temperature is 20 C. or 30 C., as shown by the last two values.

### *Effect of Temperature During Moisture Determination*

It is important also in making the moisture determination to watch the temperature of the water when the two weighings are made. The authors' illustration will be used as a basis for showing what might happen for the 20–30 C and the 30–20 C. combinations. The assumption is made that the specific gravity value of 2 73 is correct Since the weight of the empty pycnometer is not given, a value of 528 0 g. is assumed.

Consider the 20–30 C combination first. The pycnometer and water weigh 2528 g.

[1] "Factors Affecting Specific Gravity Values in the Proposed Method of Test for Soils," *Bulletin*, A S T.M , December, 1943

If the pycnometer weighs 528 g the weight of water is 2000 g. The relative density of water at 20 C. is 0.9982343, and the volume of 2000 g of water is 2003 6 ml

The soil-cement mix is placed in the pycnometer and the pycnometer filled with water. Assume that 871 g of dry soil-cement mix are in the sample. This weight of soil-cement has a volume of $\frac{871}{2\ 73} \times 319$ ml Assuming that the pycnometer and soil-cement particles do not change volume with change in temperature, the volume of water in the pycnometer is 2003.6 − 319 0 or 1684.6 ml.

TABLE 1

EFFECT ON CALCULATED MOISTURE PERCENTAGES OF CERTAIN VARIATIONS IN TEMPERATURE DURING SPECIFIC GRAVITY AND MOISTURE TESTS

| Temperatures | | Specific gravity test value | Calculated moisture |
|---|---|---|---|
| Specific gravity test | Moisture test | | |
| deg C | deg C. | | % |
| 20–20 | 20–20 | 2 735 | 14 8 |
| 20–30 | 20–20 | 2 676 | 13 3 |
| 30–20 | 20–20 | 2 803 | 16 4 |
| 30–30 | 20–20 | 2 742 | 15.0 |
| 20–20 | 20–30 | 2 735 | 15 7 |
| 20–30 | 20–30 | 2 676 | 14 2 |
| 30–20 | 20–30 | 2 803 | 17 3 |
| 30–30 | 20–30 | 2 742 | 15 9 |
| 20–20 | 30–20 | 2 735 | 13 7 |
| 20–30 | 30–20 | 2 676 | 12 3 |
| 30–20 | 30–20 | 2 803 | 15 3 |
| 30–30 | 30–20 | 2 742 | 13 9 |
| 20–20 | 30–30 | 2 735 | 14 6 |
| 20–30 | 30–30 | 2 676 | 13.2 |
| 30–20 | 30–30 | 2 803 | 16.2 |
| 30–30 | 30–30 | 2 742 | 14.8 |

The weight of water in the pycnometer at 30 C. is 1684 6 × 0.995678 or 1677.3 g. The weight of pycnometer and contents then is

1677.3 + 871.0 + 528 0 = 3076 3 g.

The "weight of moist soil-cement in water" is 3076.3 − 2528.0 or 548 3 g. Using a specific gravity of 2.73 the percentage of moisture from the chart is 15.6, whereas the correct value is 14.8 (The original moist sample weighed 1000.0 g. and the weight of dry soil-cement is 871.0 g.)

Similar calculations for the 30–20 C. combination give the "weight of moist soil-cement in water" as 558 0 g, for which the percentage of moisture scaled from the chart is 13.6 (using a specific gravity value of 2.73).

Should the specific gravity test be made with a 10 C variation in temperature and a like variation occur during the performance of the moisture determination, an appreciable difference in the moisture percentage will be noted The worst conditions occur when the temperatures used in the specific gravity test are just opposite to those prevailing when the moisture determination is made, such as 20–30 C. for specific gravity and 30–20 C. for moisture. In Table 1 are given calculated moisture percentages for all the possible combinations of 20 and 30 C. temperatures in both tests. The specific gravity value calculated from the test data secured under the prevailing temperature condition is used in each case in the calculation of moisture content.

## *Conclusion*

It is important to have the temperature of the water used in making both the specific gravity and the moisture tests at relatively the same value.

## *Formula*

The authors refrained from showing any formula for computing the percentage of moisture and one is really not necessary although it is convenient at times to have one available. The writer desires to present the following formula.

$$\text{Per cent moisture} = \frac{W - \frac{W}{G}(W_b - W_a)}{W_b - W_a} 100$$

in which

$W$ = weight of moist sample, in g

$W_a$ = weight of pycnometer full of water, in g.

$W_b$ = weight of pycnometer, soil-cement and water, in g

$G$ = specific gravity of the soil-cement particles

The denominator of the fraction, $W_b - W_a$, is the value the authors have plotted as the abscissa in Figure 6.

The authors suggest that when a number of pycnometers are to be used interchangeably, the weight of the pycnometer full of water, $W_a$, be made the same for all by wrapping the necessary amount of wire around each pycnometer. If this is done, then this weight, $W_a$, can be counterbalanced out when weight, $W_b$, is taken The weight secured is $W_b$

– $W_a$, and the percentage moisture can be scaled from the chart without any calculation.

MR FELT Mr. Bauer has brought out the important fact that significant errors will be introduced in specific gravity and moisture content determinations if the weight of the pycnometer full of water to the syphon line is made at one temperature and the final weighing of soil-cement and water is made at a widely different temperature

The possibility of a significant error being introduced is removed, however, if the calibration of the pycnometer is made at the same temperature at which the test is made. This should always be the case in the specific gravity determination since *the pycnometer should be calibrated in the field using the same equipment and water as used in the specific gravity test.* By following this procedure a difference of only about 0 01 will be introduced into the specific gravity determination even though the temperature of the water varies from 40 to 90 F. Although this difference in specific gravity due to temperature is small, it is desirable that the temperature be recorded at which the test is made

When the specific gravity determination has been made properly, the only source of significant error will be confined to the moisture content test. The data in Table 2 show what this error is likely to be when the temperature varies over a practical range of 20 F

In Table 2 the correct moisture content of the soil-cement sample is that obtained at 70 F., or 13 5 per cent The total range in moisture content is 0.7 per cent as the temperature of the water varies from 60 F. to 80 F.; but the variation from the correct amount is only 0.4 per cent. This, perhaps, is the maximum error that would be reasonable for practical field construction operation. From this it may be concluded that a difference of plus or minus 10 F would be the maximum tolerance to permit between the temperature of the water used for making moisture content tests, and that used when determining the weight to fill the pycnometer When the difference exceeds 10 F , a new weight to fill the pycnometer must be obtained or calculated, or the temperature of the water changed

TABLE 2
VARIATION IN APPARENT MOISTURE CONTENT OF SOIL-CEMENT SAMPLE

Specific gravity of soil-cement at 70 F = 2 70
Weight of pycnometer full of water at 70 F = 1900 g , used as a constant during moisture content tests
1000 g wet weight sample, assumed to have dry weight of 881 3

| Temperature of water at which moisture content test is made | Wt in water of soil-cement sample | Moisture content of soil-cement |
|---|---|---|
| *deg F* | *g* | % |
| 60 | 556 5 | 13 2 |
| 65 | 555 8 | 13 3 |
| 70 | 554 9 | 13.5 |
| 75 | 553 9 | 13 7 |
| 80 | 552 7 | 13 9 |

There are three alternatives that may be taken in the field to eliminate the factor of temperature from test results.

1. A table or chart can be made showing the weight of water required to fill the pycnometer at different temperatures. The weight corresponding to the water temperature at the time of test is then used.

2. The barrel containing the water can be insulated to prevent significant changes in water temperature. A wet burlap on the outside may be satisfactory.

3. The temperature of the water can be controlled within reasonable limits by adding ice or warm water as the case may require.