

RAPID COMPACTION CONTROL TESTING USING WET METHOD

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The California rapid wet weight method using the sand cone and nuclear gauge for determining the percentage of relative compaction is discussed. Oven drying operations, true density relationships, and optimum moisture determinations were eliminated. This permits test results to be available in a matter of hours instead of by the following day. The validity of the method was confirmed by mathematical calculations and by field correlation tests. Comparisons were made between the wet and the conventional dry method to obtain the percentage of relative compaction. This comparison was made by using the California nuclear procedure in which average test results are used. Using the wet method expedites construction testing in many cases by eliminating the need to determine test maximum density and optimum moisture. This is possible because test results are available as soon as a specimen is compacted and answers do not depend on overnight oven-dry moistures. The application of the wet method to tests such as those of the American Society for Testing and Materials and the American Association of State Highway and Transportation Officials, in which fixed volume test molds are used, is demonstrated.

•IN August 1929, the then California Division of Highways was the first organization in the United States to adopt a test procedure for evaluating compaction of soils and aggregates (1). Basically, the method consisted of determining dry in-place density and of relating it to a dry laboratory test maximum density compacted according to a uniform procedure.

The original concept known as relative compaction is still being used by California and other states as a construction control test. Modifications to the test procedure have been made to improve the test and keep pace with the increased production brought about by modern construction methods and equipment. Such things as the use of nuclear gauges, the use of wet weight instead of dry density, and the averaging of test results have improved the test in terms of test accuracy, precision, and time required. The wet weight procedure eliminates all measurement of moisture in the field and laboratory.

This paper deals primarily with the California wet weight method for rapid construction control of compaction. The use of mathematical relationships between the wet and dry methods field correlation tests are discussed. The method was originally used with sand volume testing but was later applied to nuclear testing by using the area concept that averages test results.

In some cases where the material is generally the same, the wet method can still be used, but a moisture correction may be necessary. The application of the wet method to the ASTM and AASHTO test procedures is also presented.

BACKGROUND

Sand Volume Test

The in-place density is determined with a sand cone. The laboratory test (Calif. 216) maximum density is calculated on compacted specimens $2\frac{7}{8}$ in. (72 mm) wide and from 10 to 12 in. (25 to 30 cm) high.

The laboratory test maximum density determination is based on testing all material passing the $\frac{3}{4}$ -in. (19-mm) sieve. A rock correction is applied when the retained $\frac{3}{4}$ -in. (19-mm) fraction exceeds 10 percent. The degree of correction depends on the amount and specific gravity of the retained $\frac{3}{4}$ -in. (19-mm) material.

Wet Method

In 1956, California adopted an optional wet method for determining relative compaction for those soils with less than 10 percent of the material retained on the $\frac{3}{4}$ -in. (19-mm) sieve. This procedure eliminated the need for oven-drying the in-place and laboratory test maximum density samples. Field test results normally became available in several hours instead of by the following day. The procedure eliminated drying equipment, did not require any alteration of existing equipment, simplified the test, made it more accurate by eliminating the variable of moisture, and did not require any special training of test operators. The test results from the wet method are essentially the same as those obtained by the dry method within limits of test variability.

In 1971, the dry method was dropped, and the wet procedure was modified to include those materials that contained more than 10 percent retained on the $\frac{3}{4}$ -in. (19-mm) sieve. The elimination of part or all of the moisture measurements from the compaction test has been reported by other organizations (2, 3, 4).

FUNDAMENTAL CONCEPTS

The original work on the wet method consisted of developing the mathematical relationships to show that the wet and dry methods gave the same test results. True volume measurements were used instead of the traditional unit weights to denote density. Then the same concept was applied by using weight instead of volume. A misconception developed in this case because true densities were not involved in all cases. The details of the method are explained in the following discussions.

A sample of soil is excavated from the earthwork and weighed. The volume of the excavation is determined by filling the hole with calibrated sand. Care is exercised to maintain the moisture content of the excavated material at the condition that prevailed at the time of test. Next, a series of equal weight representative impact test specimens are weighed out of the excavated sample (Figure 1). Being of equal weight and water content, each impact test specimen (A, B, and C) will have the same proportional relationship of soil volume and water as the excavated sample.

$$\frac{W_1}{W_2} = \frac{V_1}{V_2} \quad (1)$$

where

- W_1 = weight of impact test specimen in lb (g),
- W_2 = weight of total excavated sample in lb (g),
- V_1 = volume of impact test specimen in in.³ (cm³), and
- V_2 = volume of total excavated sample in in.³ (cm³).

From this relationship, the volume that A, B, and C occupied in the earthwork can be calculated. Assume that

$$\begin{aligned}W_1 &= 6 \text{ lb (2700 g)}, \\W_2 &= 20 \text{ lb (8975 g)}, \text{ and} \\V_2 &= 266 \text{ in.}^3 \text{ (4358 cm}^3\text{)}.\end{aligned}$$

From equation 1,

$$V_1 = \frac{6}{20} \times 266 = 79.8 \text{ in.}^3 \text{ (1311 cm}^3\text{)}$$

Impact test specimens A, B, and C are then compacted at different moisture contents to determine the optimum condition. In actual practice, the specimens may be compacted at field moisture, by adding water or by drying the specimen out. Changing the water content affects the void water content but does not affect the volume of soil solids in the impact test specimens.

After the specimens are compacted in the impact test apparatus, the specimen with the smallest test volume is related to the volume that the specimen occupied in the earthwork. The resultant value is multiplied by 100 for an end result in terms of the percentage of relative compaction (RC). Figure 1 shows specimen B as the impact test specimen with the minimum volume.

$$RC = \frac{V_3}{V_1} \times 100 \quad (2)$$

where

V_1 = volume that impact test specimen occupied in the earthwork, in in.³ (cm³), and
 V_3 = smallest volume determined after compacting specimens in the impact test, in in.³ (cm³).

Assume that V_3 = smallest impact specimen $B_1 = 73 \text{ in.}^3 \text{ (1196 cm}^3\text{)}$. Therefore,

$$RC = \frac{73}{79.8} \times 100 = 91$$

The above discussion on the determination of RC eliminated soil drying procedures and direct density relationships.

The current procedure uses the more common weight relationships. The mathematical relationship here is

$$D_w = \frac{W_1}{V} \quad (3)$$

where

D_w = wet weight of compacted specimen,
 W_1 = batched wet weight of test specimen before adjustment for water, and
 V = volume of compacted specimen.

Therefore,

$$RC = \frac{D_i}{D_w} \quad (4)$$

where D_i = in-place wet density D_w from equation 4.

Table 1 gives comparisons of the percentage of relative compaction calculations based on wet and dry methods using the California procedure. Table 1 is based on the following assumptions ($1 \text{ lb/ft}^3 = 0.016 \text{ g/cm}^3$):

In-place wet density = 100 lb/ft^3 ,
 Moisture content = $10.0 \text{ lb/ft}^3 = 11.1 \text{ percent}$, and
 In-place dry density = $100 - 10.0 = 90 \text{ lb/ft}^3$.

Lines 8 and 9 show the same RC for the dry and wet methods. In normal practice, the compaction curves are plotted for the data on line 6 or 7, and the maximum value is used to calculate RC for the test.

SINGLE SPECIMEN TESTS

For construction control purposes, there are occasions when only one impact test specimen is needed. If the first test result indicates a percentage of relative compaction below the specified minimum, there is no reason to compact additional specimens. If the second specimen showed a higher test result, it would only lower the percentage of relative compaction that already failed to meet specification. Thus, the complete compaction curve is not always necessary.

The single specimen test is easily adaptable to the wet method because no moisture measurements are made but is not readily adaptable to the dry method because of the time required to obtain oven-dry moistures.

NUCLEAR TEST

In November 1966, California adopted the nuclear procedure (Calif. 231-F) for determining relative compaction. The adoption of the nuclear method for determining in-place density caused considerable discussion about the precision of the nuclear gauge and comparison with the sand volume test. Studies by Utah (6), California (7), and others indicate the nuclear test to be equal to or have less variability than the sand volume test. In terms of accuracy, studies by California (8), Minnesota (9), and others have shown the nuclear test to be more accurate than the sand volume test.

Some pertinent features of test method Calif. 231-F are as follows:

1. The wet method is used exclusively,
2. All testing is performed in the direct transmission mode,
3. Nuclear gauges are calibrated from standard blocks (6),
4. The area concept is used,
5. A composite sample is used for test maximum determination, and
6. A common test maximum is used where conditions permit.

AREA CONCEPT

The area concept evolved from a statistical study performed on embankment material (10, 11). Figures 2 and 3 from the study (10) show random sand volume tests taken from jobs that had uniform and varied materials. The sand volume tests were

Figure 1. Wet method based on volume comparison.

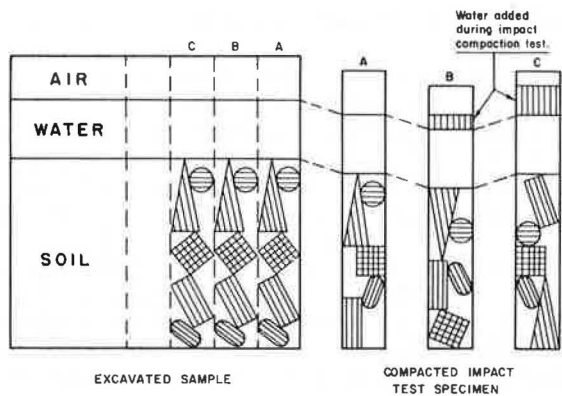


Table 1. Percentages of relative compaction based on wet and dry methods using the California procedure.

Line Number	Item	Impact Specimen		
		A	B	C
1	Equal weight of batched representative wet test specimen from excavated sample, lb	5.0	5.0	5.0
2	Dry weight ^a , lb	4.5	4.5	4.5
3	Adjustment for water to determine optimum, lb	0	-0.22	+0.22
4	Total wet weight before compaction ^b , lb	5.0	4.78	5.22
5	Compacted volume determined from test, ft ³	0.050	0.051	0.052
6	Dry density of compacted specimen ^c , lb/ft ³	90.0 ^d	88.2	86.5 ^d
7	Wet value of compacted specimen ^e	100.0	98.0	96.2
8	Relative compaction (dry basis) ^f , percent	100	102	104
9	Relative compaction (wet basis) ^g , percent	100	102	104

Note: Moisture adjustments were made but not included in calculations. 1 lb = 453.6 g. 1 ft³ = 0.03 m³. 1 lb/ft³ = 0.016 g/cm³.

^aLine 1 - field moisture.

^bLine 1 + line 3.

^cLine 2/line 5.

^dNot true densities.

^eLine 1/line 5.

^f(90 lb/ft³)/line 6 x 100.

^g(100 lb/ft³)/line 7 x 100.

Figure 2. Statistical study results based on random selection of uniform materials.

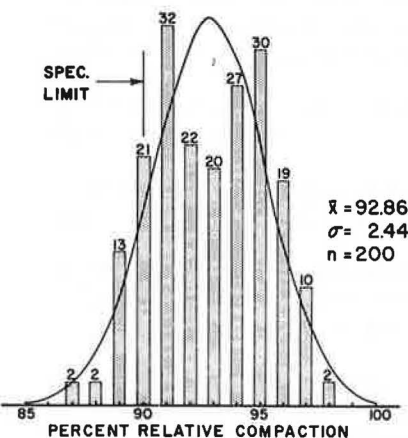
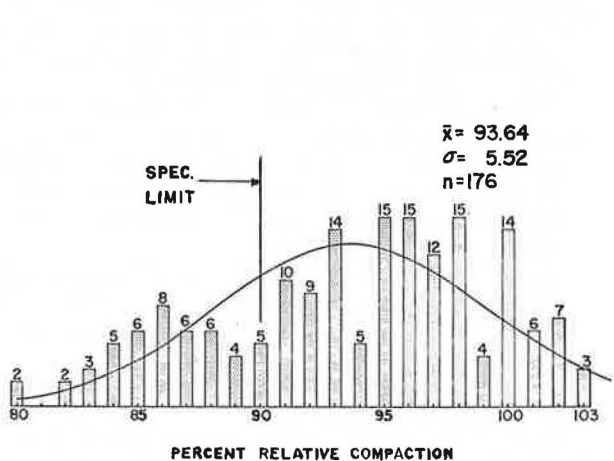


Figure 3. Statistical study results based on random selection of nonuniform materials.



performed after construction personnel had tested and accepted the compacted area as meeting specifications.

Data indicated that highways are constructed with a number of tests that do not meet specifications and that there is considerable variation in compaction (6, 12, 13, 14). The conclusion from these studies clearly showed that one test is not a satisfactory criterion for checking specification compliance. A more realistic approach is to average a small number of tests that would more nearly tend to reflect the average obtained if a large number of tests were performed in a given area. The average value would also tend to give a better picture of what is actually being constructed.

Initially, an area of work is carefully delineated. This area may be either very small, such as backfill around pipes, or more than 0.5 mile (0.8 km) of roadway. Some factors to consider when an area is selected are uniformity of materials, conditions of production, and compaction. Portions of the area that may be observed or that are suspected to be different are excluded from the total area and are treated as separate small areas.

A minimum of five test sites are randomly selected for areas greater than 1,000 yd² (836 m²), and a minimum of three test sites are randomly selected for areas less than 1,000 yd² (836 m²).

MAXIMUM DENSITY TEST

Equal representative portions of material from each test site are combined to form one composite sample. A laboratory wet test maximum value is determined on the composite sample and is related to the average wet in-place density to get a percentage of relative compaction. In many cases when the material is generally the same from one area to the next, a common wet composite test maximum value may be used. A moisture correction may be necessary.

In some cases, a single test specimen is satisfactory where it signifies a failing test. The compaction of additional specimens to determine a test maximum value would not be necessary since the test had already failed to meet the minimum specification.

PRINCIPLES OF WET METHOD

The principles of the wet method for compaction control are the same for the nuclear test and the sand volume test. However, since the California procedure uses multiple in-place tests, a composite test maximum value, and a common density, further discussion on the wet method is presented.

Figure 4 shows comparative field test data from one area evaluated on the basis of both wet and dry methods. The use of composite test maximum values compared with individual test maximum values is also compared.

Line 1 shows the percentage of relative compaction calculated by dividing the individual dry in-place density by the individual dry test maximum density. This average is 90.9 for the six test sites.

Line 7 shows the percentage of relative compaction calculated for each test site by dividing the individual wet in-place density by the composite test maximum density. This average is 91.3 percent, which compares closely to the 90.9 percent relative compaction for the dry method.

Figure 5 shows data from 75 test areas where the comparative percentages of relative compaction based on the wet and dry methods were determined as described previously. The scatter diagram indicates that there is no significant difference between the wet and dry methods when a composite test maximum and average in-place density are used instead of individual tests.

Figure 4. Test plan data of comparison of percentage of relative compaction based on wet and dry methods.

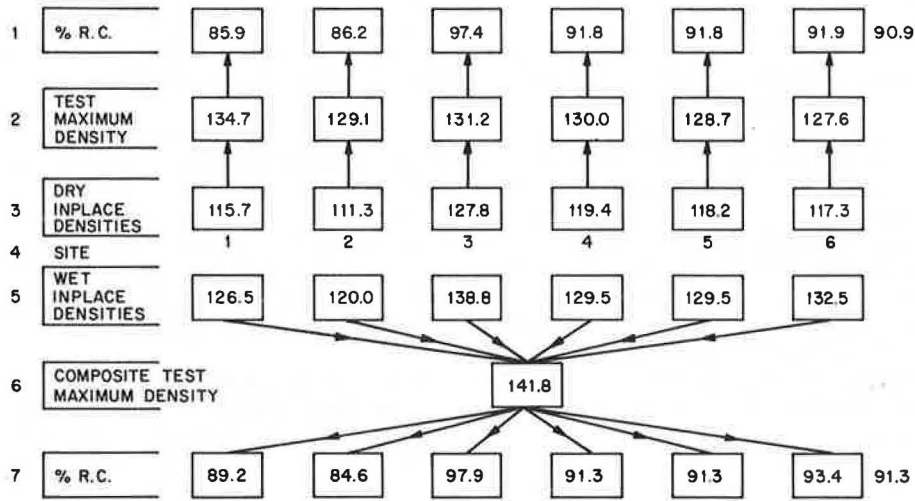


Figure 5. Nuclear gauge tests for wet versus dry method.

N = 75

\bar{X} DRY = 94.6

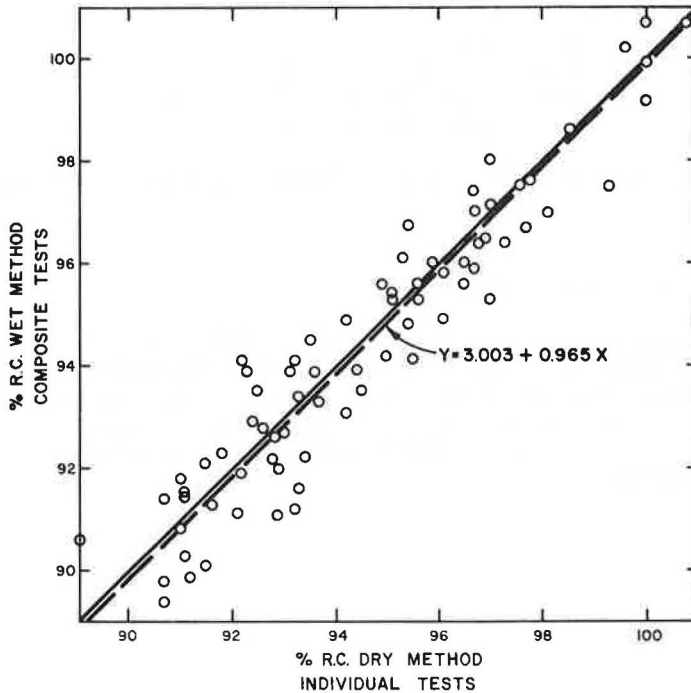
\bar{X} WET = 94.3

COEFF OF CORREL. = 0.94

STD. ERROR = .95

ANALYSIS OF VARIANCE INDICATES NO
SIGNIFICANT DIFFERENCE BETWEEN
X & Y VALUES.

EACH POINT IS THE AVERAGE OF 6
TESTS.



COMMON DENSITY

In many cases where the material from one area to the next is generally the same, a common density may be used, and a laboratory compaction test need not be run. Some of the criteria used for a common density are that the material must be from the same general source, must generally have the same visual characteristics, and must have the same moisture content.

A common density is established by averaging wet composite test maximum values from two consecutive areas. The difference in average moisture contents between the two consecutive areas must also be within 31.25 lb/ft^3 (0.05 g/cm^3) of the common value. Checks are performed at least every 7 days, and if the moisture content and test maximum values are within 31.25 lb/ft^3 (0.05 g/cm^3) of the common values, the two values are averaged to establish a new common test maximum value and moisture. If the previous criteria are not met, a compaction test is performed for each area being tested. Since a judgment factor is involved, an operator must be trained and experienced to effectively use the common density.

When a common density is used, the moisture content between areas must be the same, or adjustments must be made so that the wet procedure will be valid. In these cases, an average moisture content is determined for each area by nuclear tests at the same time the density tests are being performed. Nuclear moisture tests need only indicate the average relative difference between areas. Therefore, no special calibration relating to a standard such as oven-dry moisture is necessary. No moisture determinations are necessary for the laboratory test maximum specimens.

Following is an example of the moisture correction method ($1 \text{ lb/ft}^3 = 0.016 \text{ g/cm}^3$):

Common composite test maximum value = 137.5 lb/ft^3 ,
Average moisture = 6.9 lb/ft^3 ,

These data are used to complete the moisture content method for the test area:

Average in-place wet density (five tests) = 135 lb/ft^3 ,
Average in-place moisture (five tests) = 8.8 lb/ft^3 ,
Moisture correction = $6.9 - 8.8 = -1.9 \text{ lb/ft}^3$,
Adjusted in-place wet density = $135 - 1.9 = 133.1 \text{ lb/ft}^3$, and
RC = $(133.1/137.5) \times 100 = 97$.

This method became standard on April 2, 1973, and is now being used for all contracts using the nuclear method.

APPLICATION TO AASHTO AND ASTM METHODS

The same type of analysis made previously can be applied to the AASHTO and ASTM methods. The difference between the California method and the other methods is that the California method uses a fixed weight of material and measures the volume of compacted soil but the latter methods use a variable weight of material and a fixed volume.

Equation 5 shows the mathematical relationship between the wet and dry methods when the fixed volume molds are used:

$$RC = \frac{D_w}{T_w} \times 100 \quad (5)$$

where

D_w = in-place wet density by tests such as the sand cone or nuclear test, and
 T_w = laboratory compacted test specimen with highest wet weight as determined by the AASHTO or ASTM procedure.

T_w is calculated as shown in figure 6.

Based on Figure 6, the following relationships are developed:

$$\frac{B}{F} = \frac{S}{T_w}$$

$$T_w = \frac{F \times S}{0.033B} \quad (6)$$

where 0.033 ft^3 (943.9 cm^3) = constant volume based on a mold of the same size.

Assume that ($1 \text{ lb} = 453.6 \text{ g}$)

$F = 4.75 \text{ lb}$,
 $S = 5.29 \text{ lb}$, and
 $B = 5.63 \text{ lb}$.

Therefore,

$$T_w = \frac{4.75 \times 5.29}{0.033 \times 5.63} = 135 \text{ lb/ft}^3 \text{ (2.16 g/cm}^3\text{)}$$

Let ($1 \text{ lb/ft}^3 = 0.016 \text{ g/cm}^3$)

$D_w = 130 \text{ lb/ft}^3$ and

$T_w = 135 \text{ lb/ft}^3$ = the highest wet density of a laboratory compacted test specimen.

Therefore,

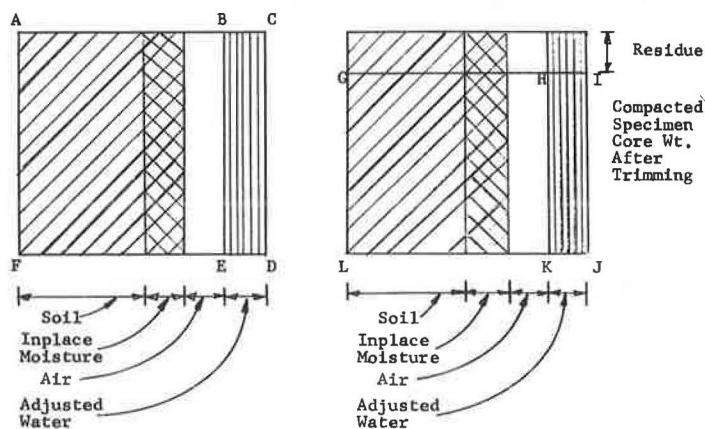
$$RC = \frac{130}{135} \times 100 = 96$$

Table 2 gives comparisons of the percentage relative compaction calculations based on wet and dry methods using the 0.033-ft^3 (934.5-cm^3) mold. Table 2 is based on the following assumptions ($1 \text{ lb/ft}^3 = 0.016 \text{ g/cm}^3$):

In-place moisture content = 10.0 percent,
 In-place wet density = 134.2 lb/ft^3 , and
 In-place dry density = 122.2 lb/ft^3 .

CONCLUSIONS

1. Mathematical calculations indicate that the wet and dry procedures for determining percent relative compaction give the same results.
2. Test data indicated that the wet method applied to multiple nuclear testing and use of a composite sample for determining laboratory test maximum density are essentially the same as the average of single tests when the dry method is used.
3. Application of the wet method to a common density by making moisture adjustments based on nuclear gauge measurements was developed.
4. In many cases, the wet method permits determination of specification compliance without the development of a compaction curve. Therefore, results can be obtained in several hours instead of by the following day.

Figure 6. Calculation of T_M .

Note:

ABEF = S = initial batched specimen weight in lb/ft³ (g/cm³) that has the moisture content that prevailed at the time of the in place test;

ACDF = B = initial batched specimen in lb (g) adjusted for added or subtracted water;

GIJL = F = final compacted core weight in lb(g) after trimming; and

GHKL = T_M = laboratory test specimen wet weight, an unknown value.

Table 2. Percentages of relative compaction based on wet and dry methods using the 0.033-ft³ (934.5-cm³) mold.

Line Number	Item	Impact Specimen		
		A	B	C
1	Equal weight of batched representative wet test specimen from excavated sample, lb	5.07	5.07	5.07
2	Dry weight, lb	4.61	4.61	4.61
3	Adjustment for water to determine optimum, lb	-0.11	0	+0.11
4	Total wet weight before compaction ^a , lb	4.96	5.07	5.18
5	Final compacted core weight after trimming, lb	4.46	4.63	4.63
6	Wet weight ^b , lb	136.8	138.9	136.0
7	Dry density ^c , lb/ft ³	124.2	126.3 ^d	123.6 ^d
8	Relative compaction (wet basis) ^e , percent	98	97	99
9	Relative compaction (dry basis) ^f , percent	98	97	99

Note: Moisture adjustments were made but not included in calculations. 1 lb = 453.6 g, 1 lb/ft³ = 0.016 g/cm³.

^aLine 1 + line 3.

^dNot true densities.

^b(Line 5 × line 1) 30/line 4.

^eIn-place wet density/line 6.

^c(Line 5) 30/percentage of moisture.

^fIn-place dry density/line 7.

5. The wet method could be applied to such tests as the ASTM or AASHTO procedures where a fixed volume mold is used to determine the laboratory test maximum density.

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