Recommend Approval: Team Leader 07/13/11 Date Division Chief 07/13/11 Date	Maryland Department of Transportation State Highway Administration Office of Materials Technology MARYLAND STANDARD METHOD OF TESTS	
Approved: Director 08/08/11 Date	**MOISTURE - DENSITY RELATIONS OF PLAIN AND STABILIZED DENSE GRADED AGGREGATE**	**MSMT 321**

SCOPE:

This procedure is used to determine the maximum dry density and optimum moisture content of plain dense graded aggregate base course and dense graded aggregate base course stabilized with portland cement. It is also used to determine the design quantity of portland cement for dense graded stabilized aggregate base course by means of compressive strength testing.

REFERENCE DOCUMENTS:

D 1633	Test Methods for Compressive Strength of Molded Soil-Cement Cylinders
M 231	Weighing Devices Used in the Testing of Materials
T 11	Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
T 27	Sieve Analysis of Fine and Coarse Aggregates
T 85	Specific Gravity and Absorption of Fine Aggregate
T 180	Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm(18-in.) Drop
T 231	Capping Cylindrical Concrete Specimens

MATERIALS AND EQUIPMENT:

1. Automatic tamper with a rammer weighing 10 lb and capable of applying uniformly distributed blows to a 6 in. diameter specimen.

2. Rammer Face - Refer to T 180.

3. Molds - Cylindrical molds with detachable collars, having internal diameters of 6.0 ±0.005 in. and heights of 8.5 ±0.005 in.

4. Hydraulic press to extrude the sample from the mold.

5. Glass plates 8 x 8 in.

6. Steel rule accurate to 0.01 in.

7. Compressive strength machine capable of applying a uniformly increasing load up to 60 000 lb at a rate of 0.05 in. per minute.

8. Balance or scale conforming to M 231, Class G 20.

9. Drying oven, capable of maintaining a temperature of 230 ±9 F for drying moisture samples.

10. Moist room, capable of maintaining a temperature of 70 ±3 F and a relative humidity of 100 percent for 7 day storage of compacted specimens.

11. Miscellaneous tools such as a mixing pan, spoon, trowel, spatula, etc., and a suitable mechanical device for mixing the sample.

TEST PROCEDURE:

Method A - Procedure for Dense Graded Aggregate Base Course

1. A sample of dense graded aggregate weighing approximately 250 lb is submitted from an approved source. Obtain a representative sample weighing a minimum of 45 lb and perform a gradation as specified in T 27 and T 11. Record the results. Separate the remaining portion of the material into individual sieve sizes.

2. Prepare an 8.00 kg sample batch using the total gradation from the job mix formula. Compute the weight of each sieve size as shown in **Steps 1 and 2** of **CALCULATIONS**. Weigh the material for each individual size. Five individual batches are required for the moisture-density test.

3. Perform the moisture-density test as outlined in **Steps 4 through 18**, using a fresh batch for each step.

4. Mix the dry aggregate thoroughly.

5. Add the appropriate quantity of water to the aggregate and mix thoroughly. The appropriate quantity of water will vary in each batch as is customary for the moisture-density test.

6. Place a layer of approximately one quarter of the required amount of blended material in the assembled mold, and carefully spade the mix around the inside circumference of the mold with a spatula. The remaining portion of material shall be covered with a moist cloth to prevent loss of moisture.

7. Compact each layer using 122 uniformly distributed blows of the compaction rammer.

8. Repeat **Steps 6 and 7** until all of the required material has been compacted.

9. Following compaction, remove the extension collar and determine the height of the compacted specimen to the nearest 0.01 in., then weigh the mold and moist aggregate.

10. Remove the compacted specimen from the mold, place in a pan and weigh immediately. Dry the specimen in an oven at 230 ±9 F for at least 16 hours, or until a constant weight is reached, for moisture content determination.

11. Add water in sufficient amounts to increase the moisture content of the next batch by one or two percentage points and repeat **Steps 3 through 10** for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet weight per cubic foot of the compacted aggregate.

12. When free water is observed around the bottom of the mold and base plate during or after compaction of the sample, this shall be considered the last step of the moisture-density test, even if the criteria in **Step 11** is not met. Record the results.

13. Perform the calculations in **Step 10** to determine the moisture content and corresponding oven-dry density (unit mass) in lb/ft^3 for each of the compacted samples. Plot the oven-dry densities of the soil as ordinates and the corresponding moisture contents as abscissas.

14. Connect the plotted points with a smooth line, producing a parabolic shaped curve. The moisture content at the peak of the curve is considered the optimum moisture content and the corresponding maximum dry density is determined by a horizontal straight line from this peak point to the vertical axis.

15. In the event of free water as noted in **Step 12**, the plotted points may not produce a parabolic shaped curve; the optimum moisture is determined in **Steps 16, 17, and 18**.

16. Take one half of the difference between the moisture contents of the points where free water is observed and the point prior to it.

17. Add this value to the moisture content of the point prior to where free water is observed.

18. This optimum moisture content is plotted on the curve and the maximum dry density is found by taking a horizontal straight line from this point to the vertical axis.

Method B - Procedure for Portland Cement Additive Dense Graded Stabilized Aggregate Base Course

1. Conduct an absorption test as specified in T 85 on the graded material obtained in **Method A, Step 1.**

2. Using the total gradation from the job mix formula; compute the weight of each sieve size as shown in **Steps 1, 2, and 3** of **CALCULATIONS**.

3. Weigh out the material for each individual sieve size. Five individual batches are required for the moisture-density test.

4. Remove the material retained on the No. 4 sieve from each batch and individually soak each batch in water for a minimum of 16 hr.

5. Determine the required quantity equal to 4 percent of Type I portland cement, by weight, as shown in **Step 5 of CALCULATIONS**, for each batch based on the batch weight.

6. Prepare the fraction retained on the No. 4 sieve into a saturated-surface-dry condition by draining the excess water and applying a damp cloth to absorb any free surface moisture.

7. Thoroughly mix the cement and the aggregate passing the No. 4 sieve.

8. Add the appropriate quantity of water to the aggregate-cement batch and mix thoroughly. The appropriate quantity of water will vary from batch to batch, as is customary for the moisture-density test.

9. Add the saturated-surface-dry aggregate retained on the No. 4 sieve to the aggregate-cement and water and blend until a uniform mixture is obtained.

10. Follow procedures outlined in **Method A, Steps 6 through 18**.

11. Using the maximum dry density and optimum moisture content as determined in the moisture-density test (**Steps 6 through 10**), prepare duplicate batches of aggregate, water, and cement at 3, 4, and 5 percent (by weight) for molding specimens 6 inches in diameter by 8 inches in height as shown in **Steps 6, 7, 8, and 9** of **CALCULATIONS**.

12. Prepare and mix the material as outlined in **Steps 6 through 9**.

13. Lightly coat the mold with commercial form oil.

14. Follow procedures outlined in **Method A, Steps 6 through 8**.

15. Measure the height of the compacted specimen to the nearest 0.01 in. Compact the specimens to within ±2 percent of the maximum dry density. If there is a deviation of more

than ±2 percent in height or required maximum dry density of the specimen, a duplicate specimen shall be molded. The operations of mixing and compacting the compression test specimens shall be continuous and the elapsed time between the addition of water and final compaction shall not exceed 30 minutes, to prevent hydration of the cement additive.

16. Remove the compacted specimen from the mold by means of a hydraulic jack.

17. Place the compacted test specimen in a moist room for 7 day curing in a manner that protects it from dripping water.

18. At the end of the 6th day of curing, cap the specimens in conformance with T 231. After capping, the specimens shall be returned to the moist room for completion of the 7 day cure.

19. At the completion of the 7 day curing, immerse the specimens in water for a period of 4 hours at 70 ±3 F. At the completion of the soaking period, perform the compressive strength test as specified in D 1633, except that the rate of loading shall be 0.05 in./minute.

20. Upon failure of a test specimen, remove the capping material from both ends and weigh. Place the test specimen in the drying oven for a minimum of 16 hr or until a constant weight is reached for moisture content determination.

CALCULATIONS:

1. The gradation used shall be determined by the job mix formula.

Example:

JOB MIX FORMULA		
Sieve Size	**Percent Passing**	**Percent Retained**
2 in.	100	0
1½	88	12
¾	60	28
⅜	40	20
No. 4	25	15
No. 30	7	18
No. 200	0	7

Compute the percentage retained on each sieve size by subtracting the consecutive percentages passing each sieve size.

2. Calculate the weight of each sieve size as follows:

$B = (F \times W_a \div 100)$

where:

B = weight of sieve size material required,

F = percentage retained on sieve, and

W_a = weight of total air-dried test specimen.

3. Calculate the weight of each sieve size for the moisture-density test with additive as follows:

B = (F) MDD x 0.1309 x 453.6

where:

B = weight of sieve size material required,

F = percentage retained on sieve,

MDD = maximum dry density from test without additive,

0.1309 = volume of a 6 in. diameter and 8 in. high specimen, and

453.6 = g/lb.

4. Calculate the weight of cement required for each test specimen as follows:

$W_C = W_a \times C \div 100$

where:

W_C = weight of cement,

W_a = MDD x 0.1309 x 453.6 from Step 3, and

C = percent cement required.

5. Determine the batch weight quantities of air-dried aggregate for compressive strength specimens as follows:

$$A = MDD \times 0.1309 \times 453.6 \div \left(\frac{1 + C}{100}\right)$$

where:

A = batch weight of aggregate,

MDD = maximum dry density at 4 percent (by weight), and

C = 3, 4, or 5 percent (by weight).

The batch weight as computed shall be rounded off to the nearest 10 g.

6. Using the batch weight (A) in Step 6, compute the design quantities of each sieve size required as follows:

$$B = F \times A \div 100$$

7. Calculate the desired quantity of cement for each test specimen as follows:

$$W_C = MDD \times 0.1309 \times 453.6 \times C$$

where:

W_C = desired quantity of cement,

MDD = maximum dry density at 4 percent cement, and

C = 3, 4, or 5 percent cement (by weight).

8. Calculate the desired quantity of water for each test specimen as follows:

$$H = \frac{M}{100}(A + W_C) - \left(\frac{A \times F}{100} \times \frac{S}{100}\right)$$

where:

H = desired quantity of water,

M = optimum moisture for 4 percent (by weight),

A = batch weight of aggregate,

W_C = required weight of cement,

F = percent of plus No. 4 sieve material, and

S = percent absorption of plus No. 4 sieve material.

9. Calculate the moisture content and oven-dry density as follows:

$$W = \frac{T_W - T_D}{T_D - T} \times 100$$

$$\gamma D = \frac{\gamma W}{W + 100} \times 100$$

where:

W = percentage of moisture in the specimen,

T_W = weight of container and wet soil,

T_D = weight of container and dry soil,

T = weight of container,

γD = dry density in lb/ft^3 of compacted aggregate, and

γW = wet density in lb/ft^3 of compacted aggregate.

REPORT:

1. Gradation results.

2. Moisture density curve.

3. Moisture density curve with additive.

4. Summary of seven day compressive strength data.

5. Seven-day compressive strength vs. percent cement.

6. The designed cement content is based on the following criteria:

a) The design quantity of cement shall be within a range of 3.25 to 4.75 percent by weight.

b) The selected design quantity of cement shall be capable of providing compressive strength of not less than 750 psi as determined by the Maryland Standard Method of Test.