**Transportation Technician**
**Qualification Program**

# *EMBANKMENT & BASE IN-PLACE DENSITY*

# *Participant Workbook*

WESTERN ALLIANCE FOR QUALITY
WAQTC
TRANSPORTATION CONSTRUCTION

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## "1998"
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# PREFACE

This module is one of a set developed for the Western Alliance for Quality Transportation Construction (WAQTC). WAQTC is an alliance supported by the western state Transportation Departments, along with the Federal Highway Administration (FHWA) and the Western Federal Lands Highway Division (WFLHD) of FHWA. WAQTC's charter includes the following mission.

## MISSION

Provide continuously improving quality in transportation construction.

Through our partnership, we will:

- Promote an atmosphere of trust, cooperation, and communication between government agencies and with the private sector.
- Assure personnel are qualified.
- Respond to the requirements of identified needs and new technologies that impact the products that we provide.

## BACKGROUND

There are two significant driving forces behind the development of the WAQTC qualification program. One, there is a trend to the use of quality control/quality assurance (QC/QA) specifications. QC/QA specifications include qualification requirements for a contractor's QC personnel and will be requiring WAQTC qualified technicians. Two, Federal regulation on materials sampling and testing (23 CFR 637, *Quality Assurance Procedures for Construction*, published in June 1995) mandates that by June 29, 2000 all testing technicians whose results are used as part of the acceptance decision shall be qualified. In addition, the regulation allows the use of contractor test results to be used as part of the acceptance decision.

## OBJECTIVES

WAQTC's objectives for its Transportation Technician Qualification Program include the following:

- To provide highly skilled, knowledgeable materials sampling and testing technicians.
- To promote uniformity and consistency in testing.
- To provide reciprocity for qualified testing technicians between states.
- To create a harmonious working atmosphere between public and private employees based upon trust, open communication, and equality of qualifications.

Training and qualification of transportation technicians is required for several reasons. It will increase the knowledge of laboratory, production, and field technicians – both industry and agency personnel – and increase the number of available, qualified testers. It will reduce problems associated with test result differences. Regional qualification eliminates the issue of reciprocity between states and allows qualified QC technicians to cross state lines without having the concern or need to be requalified by a different program.

The WAQTC Executive Board

## FOREWORD

This module is one of six developed to satisfy the training requirements prescribed by Western Alliance for Quality Transportation Construction (WAQTC) for technicians involved in transportation projects. The six modules cover:

- Aggregate
- Concrete
- Asphalt I
- Asphalt II
- Embankment and Base
- In-place Density

The modules are based upon AASHTO test methods along with procedures developed by WAQTC. They are narrative in style, illustrated, and include step-by-step instruction. There are review questions at the end of each test procedure, which are intended to reinforce the participants' understanding and help participants prepare for the final written and performance exams. Performance exam check lists are also included. The appendix includes WAQTC Field Operating Procedures (FOPs) in short form.

It is the technician's responsibility to stay current as changes are made to this living document.

The comments and suggestions of every participant are essential to the continued success and high standards of the Transportation Technician Qualification Program. Please take the time to fill out the Course Evaluation Form as the course progresses and hand it in on the last day of class. If you need additional room to fully convey your thoughts, please use the back of the form.

The WAQTC Executive Board

## GUIDANCE FOR COURSE EVALUATION FORM

The Course Evaluation Form on the following page is very important to the continuing improvement and success of this course. The form is included in each Participant Workbook. During the course introduction, the Instructor will call the participants' attention to the form, its content, and the importance of its thoughtful completion at the end of the course. Participants will be encouraged to keep notes, or write down comments as the class progresses, in order to provide the best possible evaluation. The Instructor will direct participants to write down comments at the end of each day and to make use of the back of the form if more room is needed for comments.

On the last day of the course, just before the written examination, the Instructor will again refer to the form and instruct participants that completion of the form after their last examination is a requirement before leaving. Should the course have more than one Instructor, participants should be directed to list them as A, B, etc., with the Instructor's name beside the letter, and direct their answers in the Instructor Evaluation portion of the form accordingly.

# WESTERN ALLIANCE FOR QUALITY TRANSPORTATION CONSTRUCTION COURSE EVALUATION FORM

The WAQTC Transportation Technician Qualification Program would appreciate your thoughtful completion of all items on this evaluation form. Your comments and constructive suggestions will be an asset in our continuing efforts to improve our course content and presentations.

Course Title: _____

Location: _____

Dates: _____

Your Name (Optional): _____

Employer: _____

Instructor(s) _____

## COURSE CONTENT

Will the course help you perform your job better and with more understanding? Yes Maybe No

Explain: _____

_____

Was there an adequate balance between theory, instruction, and hands-on application? Yes Maybe No

Explain: _____

_____

Did the course prepare you to confidently complete both examinations? Yes Maybe No

Explain: _____

_____

What was the most beneficial aspect of the course? _____

_____

What was the least beneficial aspect of the course? _____

_____

## GENERAL COMMENTS

General comments on the course, content, materials, presentation method, facility, registration process, etc. Include suggestions for additional Tips!

_____

_____

_____

_____

_____

_____

_____

## INSTRUCTOR EVALUATION

Were the objectives of the course, and the instructional and exam approach, clearly explained? Yes Maybe No

Explain: _____

_____

Was the information presented in a clear, understandable manner? Yes Maybe No

Explain: _____

_____

Did the instructors demonstrate a good knowledge of the subject? Yes Maybe No

Explain: _____

_____

Did the instructors create an atmosphere in which to ask questions and hold open discussion? Yes Maybe No

Explain: _____

_____

# EMBANKMENT AND BASE

## Learning Objectives

Instructional objectives for this course include:

- Being familiar with Quality Assurance (QA) concepts
- Developing a background in measurements and calculations
- Being knowledgeable in highway materials terminology
- Respecting safety issues
- Acquiring knowledge of random sampling techniques
- Understanding the basics of compaction and density control
- Becoming proficient in the following quality control test procedures:

  FOP for AASHTO T 255
  Total Moisture Evaporable Content of Aggregate by Drying;
  AASHTO T 265
  Laboratory Determination of Moisture Content of Soils

  FOP for AASHTO T 99
  Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-in.) Drop;
  AASHTO T 180
  Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and 457-mm (18-in.) Drop

  FOP for AASHTO R 75
  Developing a Family of Curves

  FOP for FOP for AASHTO T 85
  Specific Gravity and Absorption of Coarse Aggregate

The overall goals of this embankment and base course are to understand compaction and density control and to be competent with specific quality control test procedures identified for the Transportation Technician Qualification Program of the Western Alliance for Quality Transportation Construction (WAQTC). Additional studies beyond this course will be required for those desiring greater in-depth knowledge of the theory behind the test procedures included herein.

## Course Outline and Suggested Schedule (Embankment and Base)

### Day One

0800 Welcome
Introduction of Instructors
Introduction and Expectations of Participants

0815 WAQTC Mission and TTQP Objectives
Instructional Objectives for the Course
Overview of the Course
Course Evaluation Form

0830 Review of Quality Assurance Concepts

0845 Background in Measurements and Calculations

0945 Break

1000 Random Sampling

1030 Basics of Compaction and Density Control

1045 Total Evaporable Moisture Content of Aggregate by Drying
FOP for AASHTO T 255
Laboratory Determination of Moisture Content of Soils
FOP for AASHTO T 265

1115 Moisture-Density Relations of Soils:
Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-in.) Drop
FOP for AASHTO T 99
Using a 4.54-kg (10-lb) Rammer and 457-mm (18-in.) Drop
FOP for AASHTO T 180

1130 Review Questions
Questions and Answers

1200 Lunch

1315 Correction for Coarse Particles in the Soil Compaction Test
Annex to FOP for T 99 / T 180

1400 Laboratory Practice
Moisture Content and Moisture-Density Relations

1645 Evaluation
End of Day

## Day Two

0800 Questions from the Previous Day

0815 Developing a Family of Curves
FOP for AASHTO R 75

0830 Laboratory Practice
Moisture Content and Moisture-Density Relations (continued)

0945 Break

1200 Lunch

1315 Laboratory Practice
Moisture Content and Moisture-Density Relations (continued)

1645 Evaluation
End of Day

## Day Three

0800 Questions from Previous Day

0815 Specific Gravity and Absorption of Coarse Aggregate
FOP for AASHTO T 85

0845 Laboratory Practice
Specific Gravity and Absorption

0945 Break

1000 Laboratory Practice

1130 Review Questions
Questions and Answers

1200 Lunch

1315 Laboratory Practice
Completion of any Moisture Content Determinations

1645 Evaluation
End of day

## Day Four

0800 Questions from Previous Day

0815 Instruction on Use of AKDOT&PF ATM 12, ITD IT 74, WSDOT T 606, or WFLHD Humphres Curves

0845 Laboratory Practice
Open Lab to Practice Any Procedure

1200 Lunch

1315 Start of Exams

Participants will break into groups so that written and practical exams may be given concurrently.

Evaluation

# IN-PLACE DENSITY

## Learning Objectives

Instructional objectives for this course include:

- Being familiar with Quality Assurance (QA) concepts
- Developing a background in measurements and calculations
- Being knowledgeable in highway materials terminology
- Respecting safety issues
- Acquiring knowledge of random sampling techniques
- Understanding the basics of compaction and density control
- Becoming proficient in the following quality control test procedures:

  FOP for AASHTO T 255
  Total Moisture Evaporable Content of Aggregate by Drying;
  AASHTO T 265
  Laboratory Determination of Moisture Content of Soils

  FOP for AASHTO T 99
  Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-in.) Drop;
  AASHTO T 180
  Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and 457-mm (18-in.) Drop

  FOP for AASHTO R 75
  Developing a Family of Curves

  FOP for AASHTO T 272
  One-Point Method for Determining Maximum Dry Density and Optimum Moisture

  FOP for AASHTO T 85
  Specific Gravity and Absorption of Coarse Aggregate

  FOP for AASHTO T 310
  In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

  FOP for AASHTO T 209
  Theoretical Maximum Specific Gravity ($G_{mm}$) and Density of Asphalt Mixtures

FOP for AASHTO T 166
Bulk Specific Gravity ($G_{mb}$) of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens

FOP for AASHTO T 355
In-Place Density of Asphalt Mixtures Using by Nuclear Method

The overall goals of this embankment and base course are to understand compaction and density control and to be competent with specific quality control test procedures identified for the Transportation Technician Qualification Program of the Western Alliance for Quality Transportation Construction (WAQTC). Additional studies beyond this course will be required for those desiring greater in-depth knowledge of the theory behind the test procedures included herein.

Course Outline and Suggested Schedule (In-Place Density)

## Day One

0800 Welcome
Introduction of Instructors
Introduction and Expectations of Participants

0815 WAQTC Mission and TTQP Objectives
Instructional Objectives for the Course
Overview of the Course
Course Evaluation Form

0830 Review of Quality Assurance Concepts

0845 Background in Measurements and Calculations

0945 Break

1000 Random Sampling

1030 Basics of Compaction and Density Control

1045 Total Moisture Content of Aggregate by Drying
FOP for AASHTO T 255
Laboratory Determination of Moisture Content of Soils
FOP for AASHTO T 265

1115 Review Questions
Questions and Answers

1200 Lunch

1315 Moisture-Density Relations of Soils:
Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-in.) Drop
FOP for AASHTO T 99
Using a 4.54-kg (10-lb) Rammer and 457-mm (18-in.) Drop
FOP for AASHTO T 180

1345 Correction for Coarse Particles in the Soil Compaction Test
Annex to FOP for AASHTO T 99/T 180

1400 Laboratory Practice

1645 Evaluation
End of Day

## Day Two

0800 Questions from the Previous Day

0815 Specific Gravity and Absorption of Coarse Aggregate
FOP for AASHTO T 85

0845 Developing a Family of Curves
FOP for AASHTO R 75
One-Point Method for Determining Maximum Dry Density and Optimum Moisture
FOP for AASHTO T 272

0945 Break

1000 Review Questions
Questions and Answers

1015 Instruction on Use of AKDOT&PF ATM 12, ITD IT 74, WSDOT T 606, or WFLHD Humphres Curves

1045 In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
FOP for AASHTO T 310

1130 Review Questions
Questions and Answers

1200 Lunch

1315 Laboratory Practice
In-Place Density of Embankment and Base

1645 Evaluation
End of day

## Day Three

0800 Questions from the Previous Day

0815 Theoretical Maximum Specific Gravity ($G_{mm}$) and Density of Asphalt Mixtures
FOP for AASHTO T 209

0900 Bulk Specific Gravity ($G_{mb}$) of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens
FOP for AASHTO T 166

0945 Break

1000 Review Questions
Questions and Answers

1030 In-Place Density of Asphalt Mixtures by Nuclear Method
FOP for AASHTO T 355

1130 Review Questions
Questions and Answers

1200 Lunch

1315 Laboratory Practice
In-Place Density of Bituminous Mixes

1645 Evaluation
End of Day

## Day Four

0800 Start of Exams

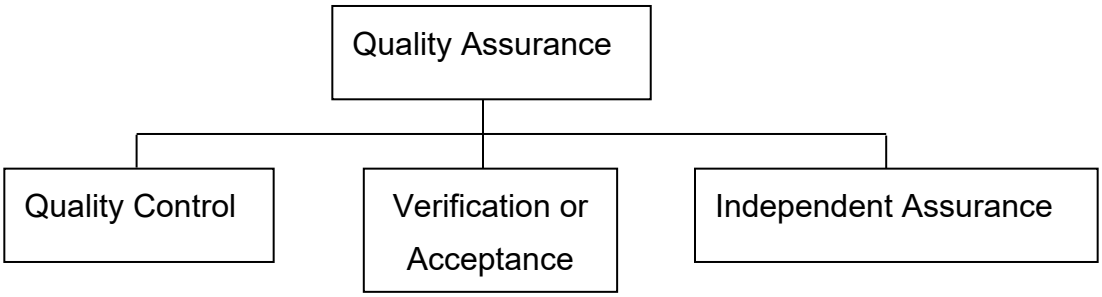
Participants will break into groups so that written and practical exams may be given concurrently.

Evaluation

## QUALITY ASSURANCE CONCEPTS

The Federal Highway Administration (FHWA) has established requirements that each State Transportation Department must develop a Quality Assurance (QA) Program that is approved by the FHWA for projects on the National Highway System (NHS). In addition to complying with this requirement, implementing QA specifications in a construction program includes the benefit of improvement of overall quality of highway and bridge construction. 01 02

A QA Program may include three separate and distinct parts as illustrated below.




03

**Quality Assurance (QA)** are those planned and systematic actions necessary to provide confidence that a product or service will satisfy given requirements for quality. 04

**Quality Control (QC)** are those operational, process control techniques or activities that are performed or conducted to fulfill contract requirements for material and equipment quality. In some states, the constructor is responsible for providing QC sampling and testing, while in other states the STD handles QC. Where the constructor is responsible for QC tests, the results may be used for acceptance only if verified or accepted by additional tests performed by an independent group. 05

**Verification/Acceptance** consists of the sampling and testing performed to validate QC sampling and testing and, thus, the quality of the product. Verification/Acceptance samples are obtained and tests are performed independently from those involved with QC. Samples taken for QC tests may not be used for Verification/Acceptance testing. 06

**Independent Assurance (IA)** are those activities that are an unbiased and independent evaluation of all the sampling and testing procedures used in QC and Verification/Acceptance. IA may use a combination of laboratory certification, technician qualification or certification, proficiency samples, or split samples to assure that QC and Verification/Acceptance activities are valid. Agencies may qualify or certify laboratories and technicians, depending on the state in which the work is done. 07

# BACKGROUND ON MEASUREMENTS AND CALCULATIONS

01

## Introduction

This section provides a background in the mathematical rules and procedures used in making measurements and performing calculations. Topics include:

- Units: Metric vs. English
- Mass vs. Weight
- Balances and Scales
- Rounding
- Significant Figures
- Accuracy and Precision
- Tolerance

Also included is discussion of real-world applications in which the mathematical rules and procedures may not be followed.

02

## Units: Metric vs. English

03

The bulk of this document uses dual units. Metric units are followed by Imperial, more commonly known as English, units in parentheses. For example: 25 mm (1 in.). Exams are presented in metric or English.

- Basic units in SI include:
- Length: meter, m
- Mass: kilogram, kg
- Time: second, s
-

**SI units**

04

Depending on the situation, some conversions are exact, and some are approximate. One inch is exactly 25.4 mm. If a procedure calls for measuring to the closest 1/4 in., however, 5 mm is close enough. We do not have to say 6.35 mm. That is because 1/4 in. is half way between 1/8 in. and 3/8 in. – or half way between 3.2 and 9.5 mm. Additionally, the tape measure or rule used may have 5 mm marks, but may not have 1 mm marks and certainly will not be graduated in 6 mm increments.

| Metric | English |
|---|---|
| 25 mm | 1 in. |
| 1 kg | 2.2 lb |
| 1000 kg/m$^3$ | 62.4 lb/ft$^3$ |
| 25 MPa | 3600 lb/in.$^2$ |

**Some <u>approximate</u> conversions**

In SI (Le Systeme International d'Unites), the basic unit of mass is the kilogram (kg) and the basic unit of force, which includes weight, is the Newton (N).

Mass in this document is given in grams (g) or kg. See the section below on "Mass vs. Weight" for further discussion of this topic.

## Mass vs. Weight

05 The terms mass, force, and weight are often confused. Mass, m, is a measure of an object's material makeup, and has no direction. Force, F, is a measure of a push or pull, and has the direction of the push or pull. Force is equal to mass times acceleration, a.

$$F = ma$$

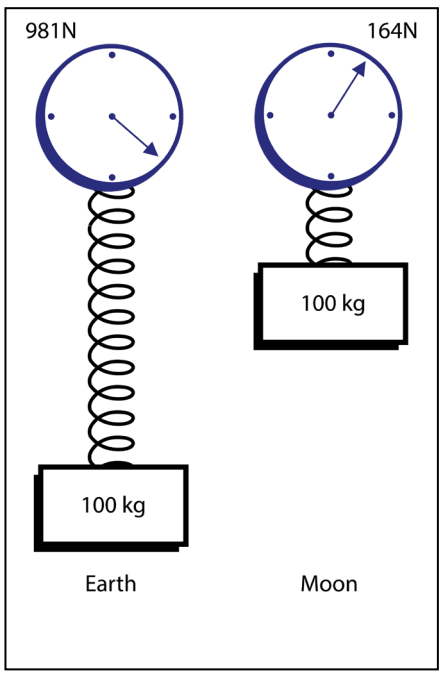
06 Weight, W, is a special kind of force, caused by gravitational acceleration. It is the force required to suspend or lift a mass against gravity. Weight is equal to mass times the acceleration due to gravity, g, and is directed toward the center of the earth.

$$W = mg$$

In SI, the basic unit of mass is the kilogram (kg), the units of acceleration are meters per square second ($m/s^2$), and the unit of force is the Newton (N). Thus a person having a mass of 84 kg subject to the standard acceleration due to gravity, on earth, of 9.81 $m/s^2$ would have a weight of:

$$W = (84.0\ kg)(9.81\ m/s^2) = 824\ kg\text{-}m/s^2 = 824\ N$$

In the English system, mass can be measured in pounds-mass ($lb_m$), while acceleration is in feet per square second ($ft/s^2$), and force is in pounds-force ($lb_f$). A person weighing 185 $lb_f$ on a scale has a mass of 185 $lb_m$ when subjected to the earth's standard gravitational pull. If this person were to go to the moon, where the acceleration due to gravity is about one-sixth of what it is on earth, the person's weight would be about 31 $lb_f$, while his or her mass would remain 185 $lb_m$. Mass does not depend on location, but weight does.



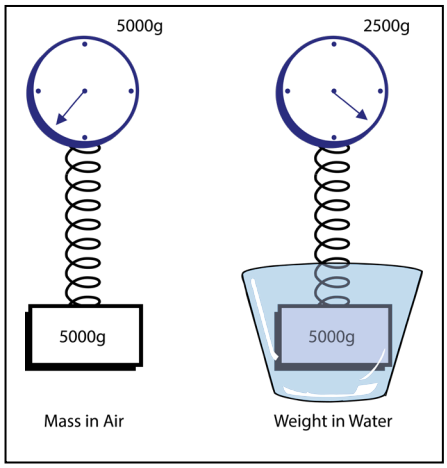

**Comparison of mass and weight**

07

08

While the acceleration due to gravity does vary with position on the earth (latitude and elevation), the variation is not significant except for extremely precise work – the manufacture of electronic memory chips, for example.

09 As discussed above, there are two kinds of pounds, $lb_m$ and $lb_f$. In laboratory measurements of mass, the gram or kilogram is the unit of choice. But, is this mass or force? Technically, it depends on the instrument used, but practically speaking, mass is the result of the measurement. When using a scale, force is being measured – either electronically by the stretching of strain gauges or mechanically by the stretching of a spring or other device. When using a balance, mass is being measured, because the mass of the object is being compared to a known mass built into the balance.




**Submerged weight**

10 In this document, mass, not weight, is used in test procedures except when determining "weight" in water. When an object is submerged in water (as is done in specific gravity tests), the term weight is used. Technically, what is being measured is the force the object exerts on the balance or scale while the object is submerged in water (or the submerged weight). This force is actually the weight of the object less the weight of the volume of water displaced.

11 In summary, whenever the common terms "weight" and "weighing" are used, the more appropriate terms "mass" and "determining mass" are usually implied, except in the case of weighing an object submerged in water.

12

## Balances and Scales

Balances, technically used for mass determinations, and scales, used to weigh items, were discussed briefly above in the section on "Mass vs. Weight." In field operating procedures, we usually do not differentiate between the two types of instruments. When using either one for a material or object in air, we are determining <u>mass</u>. For those procedures in which the material or object is suspended in water, we are determining <u>weight</u> in water.

13

AASHTO recognizes two general categories of instruments. Standard analytical balances are used in laboratories. For most field operations, general purpose balances and scales are specified. Specifications for both categories are shown in Tables 1 and 2.

14

**Table 1**
**Standard Analytical Balances**

| Class | Capacity | Readability and Sensitivity | Accuracy |
|---|---|---|---|
| A | 200 g | 0.0001 g | 0.0002 g |
| B | 200 g | 0.001 g | 0.002 g |
| C | 1200 g | 0.01 g | 0.02 g |

**Table 2**
**General Purpose Balances and Scales**

| Class | Principal Sample Mass | Readability and Sensitivity | Accuracy |
|---|---|---|---|
| G2 | 2 kg or less | 0.1 g | 0.1 g or 0.1 percent |
| G5 | 2 kg to 5 kg | 1 g | 1 g or 0.1 percent |
| G20 | 5 kg to 20 kg | 5 g | 5 g or 0.1 percent |
| G100 | Over 20 kg | 20 g | 20 g or 0.1 percent |

15

## Rounding

Numbers are commonly rounded up or down after measurement or calculation. For example, 53.67 would be rounded to 53.7 and 53.43 would be rounded to 53.4, if rounding were required. The first number was rounded up because 53.67 is closer to 53.7 than to 53.6. Likewise, the second number was rounded down because 53.43 is closer to 53.4 than to 53.5. The reasons for rounding are covered in the next section on “Significant Figures.”

If the number being rounded ends with a 5, two possibilities exist. In the more mathematically sound approach, numbers are rounded up or down depending on whether the number to the left of the 5 is odd or even. Thus, 102.25 would be rounded down to 102.2, while 102.35 would be rounded up to 102.4. This procedure avoids the bias that would exist if all numbers ending in 5 were rounded up or all numbers were rounded down. In some calculators, however, all rounding is up. This does result in some bias, or skewing of data, but the significance of the bias may or may not be significant to the calculations at hand.

## Significant Figures

- General

16 A general-purpose balance or scale, classified as G20 in AASHTO M 231, has a capacity of 20,000 g and an accuracy requirement of ±5 g. A mass of 18,285 g determined with such an instrument could actually range from 18,280 g to 18,290 g. Only <u>four</u> places in the measurement are significant. The fifth (last) place is <u>not</u> significant since it may change.

17 Mathematical rules exist for handling significant figures in different situations.

An example in Metric (**m**) or English(**ft**), when performing addition and subtraction, the number of significant figures in the sum or difference is determined by the least precise input. Consider the three situations shown below:

| Situation 1 | Situation 2 | Situation 3 |
|---|---|---|
| 35.67 | 143.903 | 162 |
| + 423.938 | - 23.6 | +33.546 |
| | | - .022 |
| = 459.61 | = 120.3 | = 196 |
| not 459.608 | not 120.303 | not 195.524 |

Rules also exist for multiplication and division. These rules, and the rules for mixed operations involving addition, subtraction, multiplication, and/or division, are beyond the scope of these materials. AASHTO covers this topic to a certain extent in the section called "Precision" or "Precision and Bias" included in many test methods, and the reader is directed to those sections if more detail is desired.

18 • Real World Limitations

While the mathematical rules of significant digits have been established, they are not always followed. For example, AASHTO Method of Test T 176, *Plastic Fines in Graded Aggregates and Soils by the Use of the Sand Equivalent Test*, prescribes a method for rounding and significant digits in conflict with the mathematical rules.

In this procedure, readings and calculated values are always rounded up. A clay reading of 7.94 would be rounded to 8.0 and a sand reading of 3.21 would be rounded to 3.3. The <u>rounded</u> numbers are then used to calculate the Sand Equivalent, which is the ratio of the two numbers multiplied by 100. In this case:

$$\frac{3.3}{8.0} \times 100 = 41.250 \ldots$$

rounded to 41.3 and reported as 42

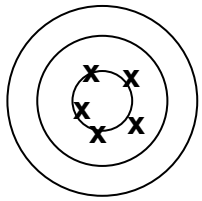
$$Not\text{:}\ \frac{3.21}{7.94} \times 100 = 40.428 \ldots$$

rounded to 40.0 and reported as 40

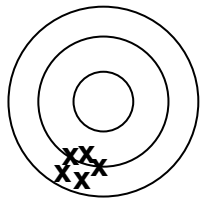
It is extremely important that engineers and technicians understand the rules of rounding and significant digits just as well as they know procedures called for in standard test methods.

## Accuracy and Precision

19 Although often used interchangeably, the terms accuracy and precision do not mean the same thing. In an engineering sense, accuracy denotes nearness to the truth or some value accepted as the truth, while precision relates to the degree of refinement or repeatability of a measurement.



ACCURATE BUT NOT PRECISE, SCATTERED



PRECISE BUT NOT ACCURATE, BIASED

20 Two bulls-eye targets are shown to the left. The upper one indicates hits that are scattered and, yet, are very close to the center. The lower one has a tight pattern, but all the shots are biased from the center. The upper one is more accurate, while the lower one is more precise. A biased, but precise, instrument can often be adjusted physically or mathematically to provide reliable single measurements. A scattered, but accurate, instrument can be used if enough measurements are made to provide a valid average.

21 Consider the measurement of the temperature of boiling water at standard atmospheric pressure by two thermometers. Five readings were taken with each, and the values were averaged.

| Thermometer No. 1 | Thermometer No. 2 |
|---|---|
| 101.2° 214.2° | 100.6° 213.1° |
| 101.1° 214.0° | 99.2° 210.6° |
| 101.2° 214.2° | 98.9° 210.0° |
| 101.1° 214.0° | 101.0° 213.8° |
| 101.2° 214.2° | 100.3° 212.5° |
| AVG = 101.2° 214.2° | AVG = 100.0° 212.0° |

22 No. 1 shows very little fluctuation, but is off the known boiling point (100°C or 212°F) by 1.2°C or 2.2°F. No. 2 has an average value equal to the known boiling point, but shows quite a bit of fluctuation. While it might be preferable to use neither thermometer, thermometer No. 1 could be employed if 1.2°C or 2.2°F were subtracted from each measurement. Thermometer No. 2 could be used if enough measurements were made to provide a valid average.

23

24 Engineering and scientific instruments should be calibrated and compared against reference standards periodically to assure that measurements are accurate. If such checks are not performed, the accuracy is uncertain, no matter what the precision. Calibration of an instrument removes fixed error,
25 leaving only random error for concern.

## Tolerance

Dimensions of constructed or manufactured objects,
26 including laboratory test equipment, cannot be specified exactly. Some tolerance must be allowed. Thus, procedures for including tolerance in addition/subtraction and multiplication/division operations must be understood.

- Addition and Subtraction

  When adding or subtracting two numbers that individually have a tolerance, the tolerance of
  27 the sum or difference is equal to the sum of the individual tolerances.

  An example in Metric (**m**) or English (**ft**), if the distance between two points is made up of two parts, one being 113.361 ±0.006 and the other being 87.242 ±0.005 then the tolerance of the sum (or the difference) is:

  (0.006) + (0.005) = 0.011

  and the sum would be 200.603 ±0.011.

- Multiplication and Division

  To demonstrate the determination of tolerance
  28 again in either Metric (**m**) or English (**ft**) for the product of two numbers, consider determining the area of a rectangle having sides of 76.254 ±0.009 and 34.972 ±0.007. The percentage variations of the two dimensions are:

$$\frac{0.009}{76.254} \times 100 = 0.01\% \quad \frac{0.007}{34.972} \times 100 = 0.02\%$$

  The sum of the percentage variations is 0.03 percent – the variation that is employed in the area of the rectangle:

Area =

$$266.8\ (m^2 or\ ft^2) = \pm 0.03\%$$
$$= 2666.8 \pm 0.8 (m^2 or\ ft^2)$$

- Real World Applications

29 Tolerances are used whenever a product is manufactured. For example, the mold used for determining soil density in AASHTO T 99 has a diameter of 101.60 ±0.41 mm(4.000 ±0.016 in) and a height of 116.43 ±0.13 mm(4.584 ±0.005 in).

Using the smaller of each dimension results in a volume of:

$$\left(\frac{\pi}{4}\right)(101.19mm)^2(116.30\ mm)$$
$$= 935{,}287\ mm^3 or\ 0.000935 m^3$$

$$\left(\frac{\pi}{4}\right)(3.984\ in)^2(4.579\ in)$$
$$= 57.082\ in^3 or\ 0.0330\ ft^3$$

Using the larger of each dimension results in a volume of:

$$\left(\frac{\pi}{4}\right)(102.01\ mm)^2(116.56\ mm)$$
$$= 952.631\ mm^3 or\ 0.000953\ m^3$$

$$\left(\frac{\pi}{4}\right)(4.016\ in)^2(4.589\ in)$$
$$= 58.130\ in^3 or\ 0.0336\ ft^3$$

The average value is 0.000944 $m^3$ (0.0333), and AASHTO T 99 specifies a volume of:

0.000943 ±0.000008 $m^3$

or a range of

0.000935 to 0.000951 $m^3$

0.0333 ±0.0003 $ft^3$

or a range of

0.0330 to 0.0336 $ft^3$

Because of the variation that can occur, some agencies periodically standardize molds, and make adjustments to calculated density based on those calculations.

## Summary

30 Mathematics has certain rules and procedures for making measurements and performing calculations that are well established. So are standardized test procedures. Sometimes these agree, but occasionally, they do not. Engineers and technicians must be familiar with both but must follow test procedures in order to obtain valid, comparable results.

## TERMINOLOGY

Many of the terms listed below are defined differently by various agencies or organizations. The definitions of the American Association of State Highway and Transportation Officials (AASHTO) are the ones most commonly used in this document.

**Absorbed water –** Water drawn into a solid by absorption, and having physical properties similar to ordinary water.

**Absorption** – The increase in the mass of aggregate due to water being absorbed into the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass.

**Acceptance** – See verification.

**Acceptance program** – All factors that comprise the State Transportation Department's (STD) determination of the quality of the product as specified in the contract requirements. These factors include verification sampling, testing, and inspection and may include results of quality control sampling and testing.

**Admixture** – Material other than water, cement, and aggregates in Portland cement concrete (PCC).

**Adsorbed water** – Water attached to the surface of a solid by electrochemical forces, and having physical properties substantially different from ordinary water.

**Aggregate** – Hard granular material of mineral composition, including sand, gravel, slag or crushed stone, used in roadway base and in Portland cement concrete (PCC) and asphalt mixtures.

- **Coarse aggregate** – Aggregate retained on or above the No. 4 (4.75 mm) sieve.
- **Coarse-graded aggregate** – Aggregate having a predominance of coarse sizes.
- **Dense-graded aggregate** – Aggregate having a particle size distribution such that voids occupy a relatively small percentage of the total volume.
- **Fine aggregate** – Aggregate passing the No. 4 (4.75 mm) sieve.
- **Fine-graded aggregate** – Aggregate having a predominance of fine sizes.
- **Mineral filler** – A fine mineral product at least 70 percent of which passes a No. 200 (75 µm) sieve.
- **Open-graded gap-graded aggregate** – Aggregate having a particle size distribution such that voids occupy a relatively large percentage of the total volume.
- **Well-Graded Aggregate** – Aggregate having an even distribution of particle sizes.

**Aggregate storage bins –** Bins that store aggregate for feeding material to the dryer in a hot mix asphalt (HMA) plant in substantially the same proportion as required in the finished mix.

**Agitation** – Provision of gentle motion in Portland cement concrete (PCC) sufficient to prevent segregation and loss of plasticity.

**Air voids ($V_a$)** – Total volume of the small air pockets between coated aggregate particles in asphalt mixtures; expressed as a percentage of the bulk volume of the compacted paving mixture.

**Ambient temperature** – Temperature of the surrounding air

**Angular aggregate** – Aggregate possessing well-defined edges at the intersection of roughly planar faces

**Apparent specific gravity ($G_{sa}$)** – The ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of water at a stated temperature.

**Asphalt** – A dark brown to black cementitious material in which the predominate constituents are bitumens occurring in nature or obtained through petroleum processing. Asphalt is a constituent of most crude petroleums.

**Asphalt emulsion –** A mixture of asphalt binder and water.

**Asphalt binder** – An asphalt specially prepared in quality and consistency for use in the manufacture of asphalt mixtures.

**Asphalt mixtures** – A controlled mix of aggregate and asphalt binder.

**Automatic cycling control** – A control system in which the opening and closing of the weigh hopper discharge gate, the bituminous discharge valve, and the pugmill discharge gate are actuated by means of automatic mechanical or electronic devices without manual control. The system includes preset timing of dry and wet mixing cycles.

**Automatic dryer control** – A control system that automatically maintains the temperature of aggregates discharged from the dryer.

**Automatic proportioning control** – A control system in which proportions of the aggregate and asphalt binder fractions are controlled by means of gates or valves that are opened and closed by means of automatic mechanical or electronic devices without manual control.

**Bag (of cement)** – 94 lb of Portland cement (Approximately 1 $ft^3$ of bulk cement)

**Base** – A layer of selected material constructed on top of subgrade or subbase and below the paving on a roadway.

**Bias** – The offset or skewing of data or information away from its true or accurate position as the result of systematic error.

**Binder** – Asphalt binder or modified asphalt binder that binds the aggregate particles into a dense mass.

**Boulders** – Rock fragment, often rounded, with an average dimension larger than 300 mm (12 in.).

**Bulk specific gravity**– The ratio of the mass, in air, of a volume of aggregate ($G_{sa}$) or compacted HMA mix ($G_{mb}$) (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of water at a stated temperature.

**Bulk specific gravity** (SSD) – The ratio of the mass, in air, of a volume of aggregate ($G_{sa}$ *SSD*) or compacted asphalt mixtures ($G_{mb}$ *SSD*), including the mass of water within the voids (but not including the voids between particles), to the mass of an equal volume of water at a stated temperature. (See saturated surface dry.)

**Cementitious Materials** – cement and pozzolans used in concrete such as: Portland cement, fly ash, silica fume, and blast-furnace slag.

**Clay** – Fine-grained soil that exhibits plasticity over a range of water contents, and that exhibits considerable strength when dry, also, that portion of the soil finer than 2 µm.

**Cobble** – Rock fragment, often rounded, with an average dimension between 75 and 300 mm (3 and 12 in.).

**Cohesionless soil** – Soil with little or no strength when dry and unconfined or when submerged, such as sand

**Cohesive soil** – Soil with considerable strength when dry and that has significant cohesion when unconfined or submerged.

**Compaction** – Densification of a soil or asphalt mixtures by mechanical means.

**Compaction curve (Proctor curve or moisture-density curve)** – The curve showing the relationship between the dry unit weight or density and the water content of a soil for a given compactive effort.

**Compaction test (moisture-density test)** – Laboratory compaction procedure in which a soil of known water content is placed in a specified manner into a mold of given dimensions, subjected to a compactive effort of controlled magnitude, and the resulting density determined.

**Compressibility** – Property of a soil or rock relating to susceptibility to decrease in volume when subject to load.

**Constant mass** – The state at which a mass does not change more than a given percent, after additional drying for a defined time interval, at a required temperature.

**Constructor** – The builder of a project. The individual or entity responsible for performing and completing the construction of a project required by the contract documents. Often called a contractor, since this individual or entity contracts with the owner.

**Cutback asphalt –** Asphalt binder that has been modified by blending with a chemical solvent.

**Crusher-run** – The total unscreened product of a stone crusher.

**Delivery tolerances** – Permissible variations from the desired proportions of aggregate and asphalt binder delivered to the pugmill.

**Density** – The ratio of mass to volume of a substance. Usually expressed in $lb/ft^3$ ($kg/m^3$).

**Design professional** – The designer of a project. This individual or entity may provide services relating to the planning, design, and construction of a project, possibly including materials testing and construction inspection. Sometimes called a "contractor," since this individual or entity contracts with the owner.

**Dryer** – An apparatus that dries aggregate and heats it to specified temperatures.

**Dry mix time** – The time interval between introduction of aggregate into the pugmill and the addition of asphalt binder.

**Durability** – The property of concrete that describes its ability to resist disintegration by weathering and traffic. Included under weathering are changes in the pavement and aggregate due to the action of water, including freezing and thawing.

**Dust Proportion – DP (Dust to Effective (asphalt) Binder Ratio)** – The percent passing the No. 200 sieve divided by the percent of effective asphalt binder.

**Effective specific gravity ($G_{se}$) –** The ratio of the mass in air of a unit volume of a permeable material (excluding voids permeable to asphalt binder) at a stated temperature to the mass in air (of equal density) of an equal volume of gas-free distilled water at a stated temperature.

**Effective diameter (effective size)** – $D_{10}$, particle diameter corresponding to 10 percent finer or passing.

**Embankment** – Controlled, compacted material between the subgrade and subbase or base in a roadway.

**End-result specifications** – Specifications that require the Constructor to take the entire responsibility for supplying a product or an item of construction. The Owner's (the highway agency's) responsibility is to either accept or reject the final product or to apply a price

adjustment that is commensurate with the degree of compliance with the specifications. Sometimes called performance specifications, although considered differently in highway work. (See performance specifications.)

**Family of curves –** a group of soil moisture-density relationships (curves) determined using AASHTO T 99 or T 180, which reveal certain similarities and trends characteristic of the soil type and source.

**Field operating procedure (FOP)** – Procedure used in field testing on a construction site or in a field laboratory. (Based on AASHTO or NAQTC test methods.)

**Fineness modulus** – A factor equal to the sum of the cumulative percentages of aggregate retained on certain sieves divided by 100; the sieves are 150, 75, 37.5, 19.0, 9.5, 4.75, 2.36, 1.18, 0.60, 0.30, and 0.15 mm. Used in the design of concrete mixes. The lower the fineness modulus, the more water/cement paste that is needed to coat the aggregate.

**Fines** – Portion of a soil or aggregate finer than a 75 µm (No. 200) sieve. Also silts and clays.

**Fractured Face –** An angular, rough, or broken surface of an aggregate particle created by crushing or by other means. A face is considered a "fractured face" whenever one-half or more of the projected area, when viewed normal to that face, is fractured with sharp and well defined edges. This excludes small nicks.

**Fractured particle –** A particle of aggregate having at least the minimum number of fractured faces specified.

**Free water** – Water on aggregate available for reaction with hydraulic cement. Mathematically, the difference between total moisture content and absorbed moisture content.

**Glacial till** – Material deposited by glaciation, usually composed of a wide range of particle sizes, which has not been subjected to the sorting action of water.

**Gradation (grain-size distribution)** – The proportions by mass of a soil or fragmented rock distributed by particle size.

**Gradation analysis (grain size analysis or sieve analysis)** – The process of determining grain-size distribution by separation of sieves with different size openings.

**Hot aggregate storage bins** – Bins that store heated and separated aggregate before final proportioning into the mixer.

**Hot mix asphalt (HMA)** – High quality, thoroughly controlled hot mixture of asphalt binder and well-graded, high quality aggregate.

**Hot Mix Asphalt (HMA) batch plant** – A manufacturing facility for producing hot mix asphalt (HMA) that proportions aggregate by weight and asphalt by weight or volume.

**HMA continuous mix plant** – A manufacturing facility for producing HMA that proportions aggregate and asphalt binder by a continuous volumetric proportioning system without specific batch intervals.

**Hydraulic cement –** Cement that sets and hardens by chemical reaction with water.

**Independent assurance** – Unbiased and independent evaluation of all the sampling and testing procedures, equipment, and technicians involved with Quality Control (QC) and Verification/Acceptance.

**In situ** – Rock or soil in its natural formation or deposit.

**Liquid limit** – Moisture content corresponding to the boundary between the liquid and plastic states.

**Loam** – A mixture of sand, silt or clay, or a combination thereof, with organic matter.

**Lot** – A quantity of material to be controlled. It may represent a specified mass, a specified number of truckloads, or a specified time period during production.

**Manual proportioning control** – A control system in which proportions of the aggregate and asphalt binder fractions are controlled by means of gates or valves that are opened and closed by manual means. The system may or may not include power assisted devices in the actuation of gate and valve opening and closing.

**Materials and methods specifications** – Also called prescriptive specifications. Specifications that direct the Constructor to use specified materials in definite proportions and specific types of equipment and methods to place the material.

**Maximum size** – One sieve larger than nominal maximum size.

**Mesh** – The square opening of a sieve.

**Moisture content** – The ratio, expressed as a percentage, of the mass of water in a material to the dry mass of the material.

**Nominal maximum size** – One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.
***Note:*** The first sieve to normally retain more than 10 percent of the material usually is the second sieve in the stack but may be the third sieve.

**Nuclear gauge** – Instruments used to measure in-place density, moisture content, or asphalt binder content through the measurement of nuclear emissions.

**Optimum moisture content (optimum water content)** – The water content at which a soil can be compacted to a maximum dry density by a given compactive effort.

**Organic soil** – Soil with a high organic content.

**Owner** – The organization that conceives of and eventually operates and maintains a project. A State Transportation Departments (STD) is an Owner.

**Paste** – Mix of water and hydraulic cement that binds aggregate in Portland cement concrete (PCC).

**Penetration** – The consistency of a bituminous material, expressed as the distance in tenths of a millimeter (0.1 mm) that a standard needle vertically penetrates a sample of the material under specified conditions of loading, time, and temperature.

**Percent of Absorbed (asphalt) Binder ($P_{ba}$) –** The total percent of the asphalt binder that is absorbed into the aggregate, expressed as a percentage of the mass of aggregate rather than as a percentage of the total mass of the mixture. This portion of the asphalt binder content does not contribute to the performance of the mix.

**Percent aggregate (stone) ($P_s$) –** The percent aggregate (stone) content, expressed as a percentage of the total mass of the sample.

**Percent of Effective (asphalt) Binder ($P_{be}$)** – The total asphalt binder content of a paving mixture minus the portion of asphalt binder that is lost by absorption into the aggregate particles, expressed as a percentage of the mass of aggregate. It is the portion of the asphalt binder content that remains as a coating on the outside of the aggregate particles.

**Percent compaction** – The ratio of density of a soil, aggregate, or asphalt mixtures in the field to a maximum density determined by a standard compaction test, expressed as a percentage.

**Performance specifications** – Specifications that describe how the finished product should perform. For highways, performance is typically described in terms of changes over time in physical condition of the surface and its response to load, or in terms of the cumulative traffic required to bring the pavement to a condition defined as "failure." Specifications containing warranty/guarantee clauses are a form of performance specifications.

**Plant screens** – Screens located between the dryer and hot aggregate storage bins that separate the heated aggregates by size.

**Plastic limit** – Moisture content corresponding to the boundary between the plastic and the semisolid states.

**Plasticity** – Property of a material to continue to deform indefinitely while sustaining a constant stress.

**Plasticity index** – Numerical difference between the liquid limit and the plastic limit and, thus, the range of water content over which the soil is plastic.

**Portland cement –** Hydraulic cement produced by pulverizing Portland cement clinker.

**Portland cement concrete (PCC)** – A controlled mix of aggregate, Portland cement, and water, and possibly other admixtures.

**PCC batch plant** – A manufacturing facility for producing Portland cement concrete.

**Prescriptive specifications** – See Materials and Methods specification.

**Proficiency samples** – Homogeneous samples that are distributed and tested by two or more laboratories. The test results are compared to assure that the laboratories are obtaining the same results.

**Pugmill** – A shaft mixer designed to mix aggregate and cement.

**Quality assurance** – Planned and systematic actions necessary to provide confidence that a product or service will satisfy given requirements for quality. The overall system for providing quality in a constructed project, including Quality Control (QC), Verification/Acceptance, and Independent Assurance (IA).

**Quality assurance specifications** – Also called QC/QA specifications. A combination of end-result (performance) specifications and materials and methods (prescriptive) specifications. The Constructor is responsible for quality control, and the Owner (highway agency) is responsible for acceptance of the product.

**Quality control (QC)** – Operational, process control techniques or activities that are performed or conducted to fulfill contract requirements for material or equipment quality.

**Random sampling** – Procedure for obtaining non-biased, representative samples.

**Sand** – Particles of rock passing the No. 4 (4.75 mm) sieve and retained on the No. 200 (75 µm) sieve.

**Saturated surface dry (SSD)** – Condition of an aggregate particle, asphalt mixtures or Portland cement concrete (PCC) core, or other porous solid when the permeable voids are filled with water, but no water is present on exposed surfaces. (See bulk specific gravity.)

**Self-Consolidating Concrete (SCC) –** A highly flowable non-segregating concrete mix that spreads into place and is able to flow and fill all corners of the formwork, even in the presence of congested reinforcement by means of its own mass with no mechanical vibration.

**Segregation** – The separation of aggregate by size resulting in a non-uniform material.

**Sieve** – Laboratory apparatus consisting of wire mesh with square openings, usually in circular or rectangular frames.

**Silt** – Material passing the (75 µm) sieve that is non-plastic or very slightly plastic, and that exhibits little or no strength when dry and unconfined. Also, that portion of the soil finer than 75 µm and coarser than 2 µm.

**Slump** – Measurement related to the workability of concrete.

**Soil** – Sediments or unconsolidated accumulations of solid particles produced by the physical and chemical disintegration or rocks, and which may or may not contain organic matter.

**Specific gravity** – The ratio of the mass of a volume of a material to the mass of an equal volume of water at a stated temperature.

- $\mathbf{G_{mm}}$ – theoretical maximum specific gravity (Gravity $_{\text{mix max}}$)
  The ratio of the mass of a given volume of asphalt mixtures with no air voids to the mass of an equal volume of water, both at a stated temperature.

- $\mathbf{G_{mb}}$ – measured bulk specific gravity (Gravity $_{\text{mix bulk}}$)
  The ratio of the mass, in air, of a volume of compacted HMA mix (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of water at a stated temperature.

- $\mathbf{G_{sb}}$ – oven-dry bulk specific gravity of aggregate (Gravity $_{\text{stone bulk}}$)
  The ratio of the mass, in air, of a volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of water at a stated temperature.

- $\mathbf{G_{sa}}$ – apparent specific gravity of aggregate (Gravity $_{\text{stone apparent}}$)
  The ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of water at a stated temperature.

- $\mathbf{G_{se}}$ – effective specific gravity of aggregate (Gravity $_{\text{stone effective}}$ )
  The ratio of the mass in air of a unit volume of a permeable material (excluding voids permeable to asphalt binder) at a stated temperature to the mass in air (of equal density) of an equal volume of gas-free distilled water at a stated temperature.

- $\mathbf{G_{b}}$ – specific gravity of the binder (Gravity $_{\text{binder}}$)
  The ratio of the mass of a volume of asphalt binder to the mass of an equal volume of water at a stated temperature.

**Spine –** smooth line extending through the point of maximum density/optimum moisture content of a family of moisture-density curves.

**Stability** – The ability of an asphalt mixture to resist deformation from imposed loads. Stability is dependent upon internal friction, cohesion, temperature, and rate of loading.

**Stratified random sampling** – Procedure for obtaining non-biased, representative samples in which the established lot size is divided into equally-sized sublots.

**Subbase** – A layer of selected material constructed between the subgrade and the base coarse in a flexible HMA roadway, or between the subgrade and Portland cement concrete (PCC) pavement in a rigid PCC roadway.

**Subgrade** – Natural soil prepared and compacted to support a structure or roadway pavement.

**Sublot** – A segment of a lot chosen to represent the total lot.

**Superpave™** – Superpave™ (Superior Performing Asphalt Pavement) is a trademark of the Strategic Highway Research Program (SHRP). Superpave™ is a product of the SHRP asphalt research. The Superpave™ system incorporates performance-based asphalt materials characterization with design environmental conditions to improve performance by controlling rutting, low temperature cracking and fatigue cracking. The three major components of Superpave™ are the asphalt binder specification, the mix design and analysis system, and a computer software system.

**Theoretical maximum specific gravity ($G_{mm}$)** – The ratio of the mass of a given volume of asphalt mixtures with no air voids to the mass of an equal volume of water, both at a stated temperature.

**Topsoil** – Surface soil, usually containing organic matter.

**Uniformity coefficient** – $C_u$, a value employed to quantify how uniform or well-graded an aggregate is: $C_u = D_{60}/D_{10}$. 60 percent of the aggregate, by mass, has a diameter smaller than $D_{60}$ and 10 percent of the aggregate, by mass, has a diameter smaller than $D_{10}$.

**Unit weight** – The ratio of weight to volume of a substance. The term "density" is more commonly used.

**µm** – Micro millimeter (micron) Used as measurement for sieve size.

**Vendor** – Supplier of project-produced material that is other than the constructor.

**Verification** – Process of sampling and testing performed to validate Quality Control (QC) sampling and testing and, thus, the quality of the product. Sometimes called Acceptance.

**Void in the mineral aggregate (VMA)** – The volume of inter-granular void space between aggregate particles of compacted asphalt mixtures that includes air and asphalt binder; expressed as a percentage of the bulk volume of the compacted paving mixture.

**Voids filled with asphalt (VFA)** – The portion of the void in the mineral aggregate (VMA) that contains asphalt binder; expressed as a percentage of the bulk volume of mix or the VMA.

**Wet mixing period** – The time interval between the beginning of application of asphalt binder and the opening of the mixer gate.

**Zero air voids curve (saturation curve)** – Curve showing the zero air voids density as a function of water content.

## SAFETY

The procedures included in this manual may involve hazardous materials, operations, and equipment. The procedures do not address all of the safety issues associated with their use. It is the responsibility of the employer to assess workplace hazards and to determine whether personal protective equipment (PPE) must be used. PPE must meet applicable American National Standards Institute (ANSI) standards, and be properly used and maintained. The employer must establish appropriate safety and health practices, in compliance with applicable state and federal laws, for these procedures and associated job site hazards. Hazardous materials must be addressed in a Hazard Communication program, and Material Safety Data Sheets (MSDS) must be obtained and available to workers. Supervisors and employees should be aware of job site hazards, and comply with their employer's safety and health program. The following table identifies some areas that may affect individuals performing the procedures in this manual.

| Body Part Affected | Potential Hazards | PPE/Procedures That May Be Appropriate |
|---|---|---|
| Head | Falling or fixed overhead objects; electrical shock | Hard hat or other protective helmet |
| Eyes and Face | Flying objects, radiation, molten metal, chemicals | Safety glasses, goggles, face shields; prescription or filter lenses |
| Ears | Noise | Ear plugs, ear muffs |
| Respiratory System | Inhalation of dusts, chemicals; $O_2$ deficiency | Properly fit and used respiratory protection consistent with the hazard |
| Skin | Chemicals including cement; heat | Appropriate chemical or heat resistant gloves, long-sleeve shirts, coveralls |
| Mouth, digestive system | Ingestion of toxic materials | Disposable or washable gloves, coveralls; personal hygiene |
| Hands | Physical injury (pinch, cut, puncture), chemicals | Appropriate gloves for physical hazards and compatible with chemicals present |
| Feet | Falling, sharp objects; slippery surfaces, chemicals | Safety shoes or boots (steel toed, steel shank); traction soles; rubber boots – chemicals, wet conditions |
| Joints, muscles, tendons | Lifting, bending, twisting, repetitive motions | Proper training and procedures; procedure modifications |
| Body/Torso | Falls; Burial | Fall protection; trench sloping or shoring |
| Miscellaneous | Traffic | Visibility, awareness, communication; driver training, safety awareness |
| Whole body | Radiation | Radiation safety training |

# RANDOM SAMPLING OF CONSTRUCTION MATERIALS

01

## Significance

Sampling and testing are two of the most important functions in quality control (QC). Data from the tests are the tools with which the quality of product is controlled. For this reason, great care must be used in following standardized sampling and testing procedures.

In controlling operations, it is necessary to obtain numerous samples at various points along the production line. Unless precautions are taken, sampling can occur in patterns that can create a bias to the data gathered. Sampling at the same time, say noon, each day may jeopardize the effectiveness of any quality program. This might
02 occur, for example, because a material producer does certain operations, such as cleaning screens at an aggregate plant, late in the morning each day. To obtain a representative sample, a reliable system of random sampling must be employed.

## Scope

The procedure presented here eliminates bias in sampling materials. Randomly selecting a set of numbers from a table or calculator will eliminate the possibility for bias. Random numbers are used to identify sampling times, locations, or points within a lot or sublot. This method does not cover how to sample, but rather how to determine sampling times, locations, or points.

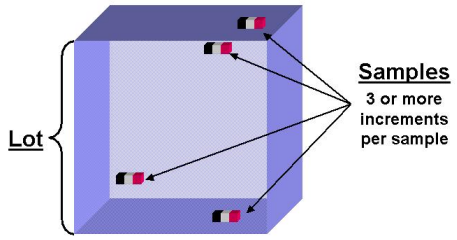
## Sampling Concepts

03
04 A lot is the quantity of material evaluated by QC procedures. A lot is a preselected quantity that may represent hours of production, a quantity or number of loads of material, or an interval of time. A lot may be comprised of several portions that are called sublots or units. The number of sublots comprising a lot will be determined by the agency's specifications.

05

**Straight Random Sampling**

One or more sample locations may be selected, using the entire lot as a single unit

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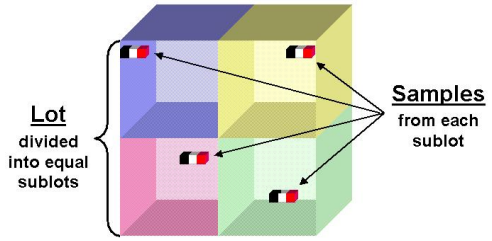
**Stratified Random Sampling**

The lot is divided into two or more equal sublots. Samples are taken from each sublot




**Straight Random Sampling vs. Stratified Random Sampling:** Straight random sampling considers an entire lot as a single unit and determines each sample location based on the entire lot size. Stratified random sampling divides the lot into a specified number of sublots or units and then determines each sample location within a distinct sublot. Both methods result in random distribution of samples to be tested for compliance with the agency's specification.

Agencies stipulate when to use straight random sampling or stratified random sampling. AASHTO R 90, Sampling Aggregate Products, for example, specifies a straight random sampling procedure.

## Picking Random Numbers from a Table

07 Table 1 contains pairs of numbers. The first number is the "pick" number and the second is the Random Number, "RN". The table was generated with a spreadsheet and the cells (boxes at the intersection of rows and columns) containing the RNs actually contain the "random number function." Every time the spreadsheet is opened or changed, all the RNs change.

1. Select a Pick number in a random method. The first two or last two digits in the next automobile license plate you see would be one way to select. Another would be to start a digital stop watch and stop it several seconds later, using the decimal part of the seconds as your Pick number.
2. Find the RN matching the Pick number.

## Picking Random Numbers with a Calculator

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09 Many calculators have a built-in random number function. To obtain a random number, key in the code or push the button(s) the calculator's instructions call for. The display will show a number between 0.000 and 1.000 and this will be your random number.

**TABLE 1**
**Random Numbers**

| Pick | RN | Pick | RN | Pick | RN | Pick | RN | Pick | RN |
|---|---|---|---|---|---|---|---|---|---|
| 01 | 0.998 | 21 | 0.758 | 41 | 0.398 | 61 | 0.895 | 81 | 0.222 |
| 02 | 0.656 | 22 | 0.552 | 42 | 0.603 | 62 | 0.442 | 82 | 0.390 |
| 03 | 0.539 | 23 | 0.702 | 43 | 0.150 | 63 | 0.821 | 83 | 0.468 |
| 04 | 0.458 | 24 | 0.217 | 44 | 0.001 | 64 | 0.187 | 84 | 0.335 |
| 05 | 0.407 | 25 | 0.000 | 45 | 0.521 | 65 | 0.260 | 85 | 0.727 |
| 06 | 0.062 | 26 | 0.781 | 46 | 0.462 | 66 | 0.815 | 86 | 0.708 |
| 07 | 0.370 | 27 | 0.317 | 47 | 0.553 | 67 | 0.154 | 87 | 0.161 |
| 08 | 0.410 | 28 | 0.896 | 48 | 0.591 | 68 | 0.007 | 88 | 0.893 |
| 09 | 0.923 | 29 | 0.848 | 49 | 0.797 | 69 | 0.759 | 89 | 0.255 |
| 10 | 0.499 | 30 | 0.045 | 50 | 0.638 | 70 | 0.925 | 90 | 0.604 |
| 11 | 0.392 | 31 | 0.692 | 51 | 0.006 | 71 | 0.131 | 91 | 0.880 |
| 12 | 0.271 | 32 | 0.530 | 52 | 0.526 | 72 | 0.702 | 92 | 0.656 |
| 13 | 0.816 | 33 | 0.796 | 53 | 0.147 | 73 | 0.146 | 93 | 0.711 |
| 14 | 0.969 | 34 | 0.100 | 54 | 0.042 | 74 | 0.355 | 94 | 0.377 |
| 15 | 0.188 | 35 | 0.902 | 55 | 0.609 | 75 | 0.292 | 95 | 0.287 |
| 16 | 0.185 | 36 | 0.674 | 56 | 0.579 | 76 | 0.854 | 96 | 0.461 |
| 17 | 0.809 | 37 | 0.509 | 57 | 0.887 | 77 | 0.240 | 97 | 0.703 |
| 18 | 0.105 | 38 | 0.013 | 58 | 0.495 | 78 | 0.851 | 98 | 0.866 |
| 19 | 0.715 | 39 | 0.497 | 59 | 0.039 | 79 | 0.678 | 99 | 0.616 |
| 20 | 0.380 | 40 | 0.587 | 60 | 0.812 | 80 | 0.122 | 00 | 0.759 |

## Examples of Straight Random Sampling Procedures Using Random Numbers

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**Sampling from a Belt or Flowing Stream:** Agencies specify the frequency of sampling in terms of time, volumes, or masses. The specification might call for one sample from every 1,000,000 kg(1000 t) or 1100 Tons(T) of aggregate. If the random number was 0.317, the sample would be taken at (0.317)(1,000,000 kg) = 317,000 kg (317 t). Or (.317) (1100 T) = 349 T.

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One sample per day might also be specified. If the day were 9 hours long and the random number 0.199, the sample would be taken at (0.199) (9 hrs) = 1.79 hr = 1 hr, 48 minutes into the day.

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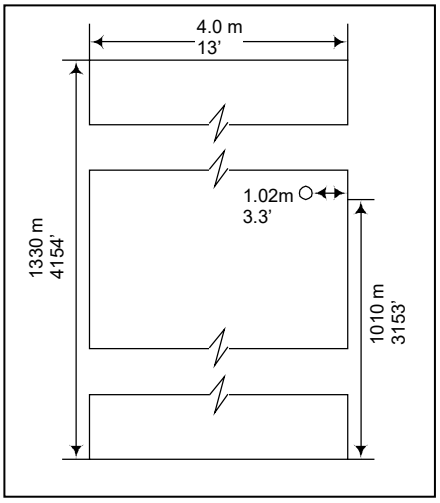
**Sampling from Haul Units:** Based on the agency's specifications – in terms of time, volume, or mass – determine the number of haul units that comprise a lot. Multiply the selected random number(s) by the number of units to determine which unit(s) will be sampled.

For example, if 20 haul units comprise a lot and one sample is needed, pick one RN. If the RN were 0.773, then the sample would be taken from the (0.773) (20) = 15.46, or 16th haul unit.




**Sampling from a roadway**

**Sampling from a Roadway with Previously Placed Material:** The agency's specified frequency of sampling – in time, volume, or mass – can be translated into a location on a job. For example, if a sample is to be taken every 800 $m^3$ (1000$yd^3$) and material is being placed 0.15 m (0.50 ft) thick and 4.0 m (13 ft) wide, then the lot is 1330 m (4154 ft) long. You would select two RNs in this case. To convert $yd^3$ to $ft^3$ multiply by 27.

The first RN would be multiplied by the length to determine where the sample would be taken along the project. The second would be multiplied by the width to determine where, widthwise, the sample would be taken. For example, a first RN of 0.759 would specify that the sample would be taken at (0.759)(1330 m) or (4154 ft) = 1010 m or 3153 ft from the beginning. A second RN of 0.255 would specify that the sample would be taken at (0.255)(4.0 m) or (13 ft) = 1.02 m or 3.3 ft from the right edge of the material. To avoid problems associated with taking samples too close to the edge, no sample is taken closer than 0.3 m (1 ft) to the edge. If the RN specifies a location closer than 0.3 m (1 ft), then 0.3 m (1 ft) is added to or subtracted from the distance calculated.

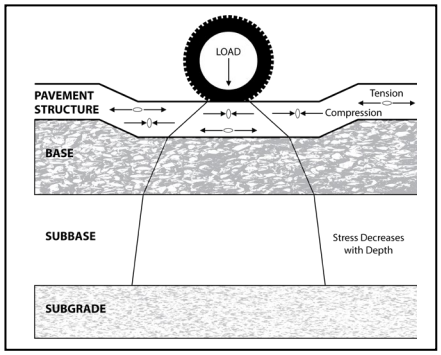
**Sampling from a Stockpile:** AASHTO R 90 recommends against sampling from stockpiles. However, some agencies use random procedures in determining sampling locations from a stockpile. Bear in mind that stockpiles are prone to segregation and that a sample obtained from a stockpile may not be representative. Refer to AASHTO R 90 for guidance on how to sample from a stockpile.

**In-Place Density Testing:** Agency specifications will indicate the frequency of tests. For example, one test per 500 $m^3$ (650 $yd^3$) might be required. If

18 the material is being placed 0.15 m (0.50 ft) thick and 10.0 m (33 ft) wide, then the lot is 333 m (1090 ft) long. You would select two RNs in this case.

19 The first RN would be multiplied by the length to determine where the sample would be taken along the project. The second would be multiplied by the width to determine where, widthwise, the sample would be taken. For example, a first RN of 0.387 would specify that the sample would be taken at (0.387)(333 m) or (1090 ft) = 129 m or (422 ft) from the beginning. A second RN of 0.558 would specify that the sample would be taken at (0.588)(10.0 m) or (33 ft) = 5.88 m or (19 ft) from the right edge of the material. To avoid problems associated with taking samples too close to the edge, no sample is taken closer than 0.3 m (1 ft) to the edge. If the RN specifies a location closer than 0.3 m (1 ft), then 0.3 m (1 ft) is added to or subtracted from the distance calculated.

# BASICS OF COMPACTION AND DENSITY CONTROL




**Load distribution in roadway cross section**

**Grading**

## Introduction

Roadways are constructed in layers. The first layer is the subgrade, or naturally present material. Next comes the subbase, material usually having better structural, drainage, and other properties than the subgrade. This material is sometimes a select material. Above the subbase is placed the base, material of even better quality than the subbase. Finally, there is the pavement consisting of either asphalt mixture or portland cement concrete (PCC). In this layered system, structural or load bearing properties improve as we move up from subgrade to pavement. The result is a roadway structure that supports traffic without undergoing excessive surface deflection and/or long term settlement.

Variations to this layering can occur as in roadways constructed on high quality subgrade in which the subbase layer is eliminated. Also to be considered is "embankment," material between the naturally occurring subgrade and the subbase or base that is added in "fill" sections of the roadway where the finished road is substantially above original grade.

Stability and durability of roadways is greatly dependent on the finished density of the various components. Low-density subgrade, subbase, base, or embankment will lead to excessive surface deflection under load and/or long term settlement in an amount higher than anticipated. However, compacting these elements to densities higher than necessary is expensive in both time and money.

Quality of roadways also depends greatly on the pavement. In asphalt mixture roadways, the density of the asphalt mixture plays a significant role in the overall ability to support load and provide long term service. Asphalt mixture pavement specifications include detail on density as well as percent voids. Under-compaction results in low density and high void content. An under-compacted pavement will have low strength, reduced durability, high

deformation, and high permeability leading to problems such as rutting, ravelling, and freeze-thaw damage. Over-compaction results in high density and low void content. This pavement may bleed, rut, crack, or have premature failure.

**Cracking**

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For these reasons, a basic understanding of compaction theory and a thorough knowledge of testing methods is necessary for those involved with construction of embankments and bases, as well as asphalt mixture pavement. Compaction equipment and techniques depend on the type of material. Cohesive soils, such as clay, and cohesionless soils, such as gravel, require different compaction methods, and different equipment may be used on asphalt mixture than on soils.

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## Fine-Grained Soils

**Sheepsfoot roller**

For fine-grained soils that contain a significant amount of cohesion and little or no internal friction, density depends on compactive effort and moisture content. With these soils, moisture-density relations are key, and two similar test methods are used to determine the relationship between soil moisture and density.

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- AASHTO T 99, the standard Proctor test

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- AASHTO T 180, the modified Proctor test

**Proctor molds and hammer**

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In both methods, samples of soil are prepared at several moisture contents and compacted into molds of specified sizes using manual or mechanical rammers delivering a specified quantity of compactive energy. Knowing the moist masses of the compacted samples and the volume of the molds, moist densities can be determined. Moisture contents of the compacted samples are determined and used to obtain dry density values for the same samples. Maximum dry density and optimum moisture content for the soil are determined by plotting the relationship between dry density and moisture content.

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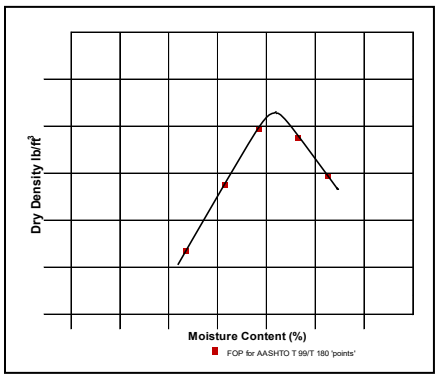


**Moisture-density curve**

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**Nuclear moisture-density gauge**

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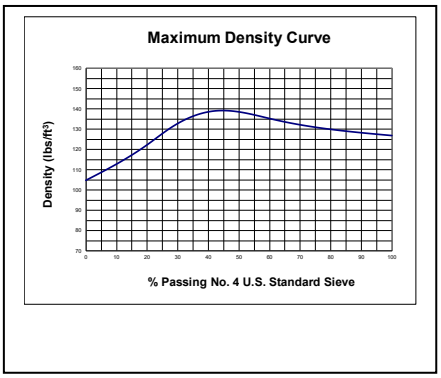


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**Maximum density curve**

Construction specifications generally require that the soil be compacted to some percentage of maximum dry density while being maintained at a moisture content close to the optimum. These specified values will be based on AASHTO T 99 or AASHTO T 180, depending on the agency. In the field, dry density and moisture content of the material will be determined using a nuclear moisture-density gauge. The field values will be compared to the specifications to determine conformance with the project requirements.

## Coarse-Grained Soils

For coarse-grained granular soils having little or no cohesion, compactive effort is the primary concern, and moisture content is not as significant an issue because these soils are free-draining and do not retain water. These soils are tested using two general classifications of procedures. The first includes the moisture-density methods discussed above under "Fine-grained Soils." The second includes procedures that relate density to gradation.

Granular, free-draining materials can be tested by procedures that combine compaction and vibration, as in the Relative Density test. However, various transportation agencies have developed specialized tests that are a hybrid of moisture-density test procedures and relative density determinations, including the following:

- AKDOT&PF's ATM 212
- ITD's IT 74
- WSDOT's T 606
- WFLHD's Humphres

In these tests, material is compacted in a mold and in a manner similar to those used in a Proctor test, after which the material is further compacted through a combination of applied loads and vibration. A laboratory maximum dry density is determined, as is the percent of material passing a certain sieve such as the 4.75 mm (No. 4). A number of determinations are made for different

percentages passing the specified sieve. A graph is developed in which dry density is plotted versus the percentage of material passing that sieve. These tests are conducted in the agency's central lab, and the curve developed is a central lab function.

Construction specifications will call out a percent of maximum dry density required for the granular materials used on the job. These specified values will be based on ATM-12, T-74, TM 606, and Humphry's depending on the agency. In the field, the density of the granular material will be determined using a nuclear moisture-density gauge. The percent of material passing the specified sieve will also be determined. These values will be compared with the curve developed in the lab to determine conformance with the project specifications.

## Correction for Oversize Material

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**Fine and coarse material**

AASHTO T 99 and AASHTO T 180 discussed above are conducted on materials below a certain size, either 4.75 mm (No. 4) or 19.0 mm (3/4 in.) depending on the method. If the material to be tested includes particles in excess of that size, corrections will be required to the maximum dry densities determined. The method used is in the Annexes for AASHTO T 99 and T 180, Correction of Maximum Dry Density and Optimum Moisture for Oversized Particles.

The corrected density is actually a weighted average of the density of the smaller material passing the specified sieve and the larger material retained on the sieve. The density of the smaller material is determined using one of the methods covered above. The density of the larger material is based on knowledge of its bulk specific gravity.

## Asphalt Mixture Pavement

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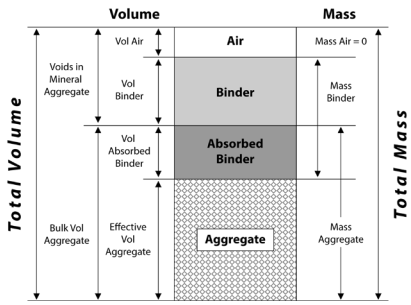
For asphalt mixtures, density depends on compactive effort as well as the mix design. The gradation and particle shape of the aggregate, the grade of asphalt binder, and the interaction of these

have major influences on density and percent voids. The level of compactive effort and the equipment used depend on the mix design properties, environmental conditions and lift thickness.




**Asphalt mixture phase diagram**

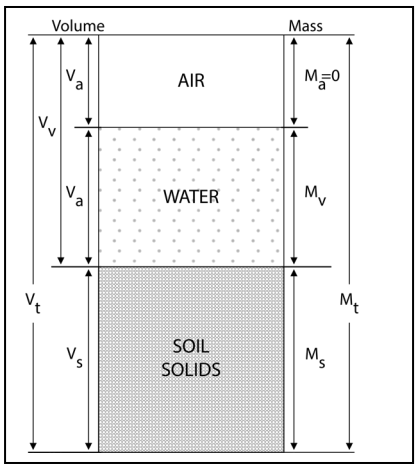
Construction specifications will call for obtaining a certain percentage of maximum voidless density, as determined in the mix design process, while maintaining voids within a certain range. A specification of 92 to 96 percent of maximum density and a corresponding void content between 8 and 4 percent is typical. In the field, the density of the compacted asphalt mixture will be determined with cores and/or calibrated nuclear density gauges, and, with this information, the percent voids will be calculated. These values will be compared to the specifications to determine conformance with the project requirements.

## Summary

Proper compaction of soil, aggregate, and asphalt mixtures is necessary for high-quality roadways. Understanding and proper performance of standardized density tests are paramount in obtaining that compaction. The Embankment and Base and/or In-Place Density technician must obtain samples and perform tests in the accepted manner in order to assure the quality of the finished roadway.

# TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING FOP FOR AASHTO T 255

# LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS FOP FOR AASHTO T 265




**Phase diagram**

**Apparatus**

**Forced Air Oven**

## Significance

The amount of water contained in many materials influences design and construction practices. Road bases are difficult to compact if they are too dry or too wet. If too dry, water must be added, and the amount to be added depends on how much is already present.

## Scope

This procedure covers the determination of moisture content of aggregate and soil in accordance with AASHTO T 255-00 and AASHTO T 265-15. It may also be used for other construction materials.

## Overview

Moisture content is determined by comparing the wet mass of a sample and the mass of the sample after drying to constant mass. The term constant mass is used to define when a sample is dry.

*Constant mass* – the state at which a mass does not change more than a given percent, after additional drying for a defined time interval, at a required temperature.

## Apparatus

- Balance or scale: capacity sufficient for the principle sample mass, accurate to 0.1 percent of sample mass or readable to 0.1 g., and meeting the requirements of AASHTO M 231
- Containers, clean, dry and capable of being sealed
- Suitable drying containers
- Microwave safe container with ventilated lid
- Heat source, controlled:
  - Forced draft oven

**Infrared Oven**

- Ventilated oven
- Convection oven

- Heat source, uncontrolled:
  - Infrared heater/heat lamp, hot plate, fry pan, or any other device/method that will dry the sample without altering the material being dried
  - Microwave oven (900 watts minimum)
- Utensils such as spoons
- Hot pads or gloves

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## Sample Preparation

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For aggregate, select the proper sample mass, in its existing condition based on Table 1 or other information that may be specified by the agency. Obtain the sample in accordance with the FOP for AASHTO R 90. Immediately seal or cover samples to prevent any change in moisture content.

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**TABLE 1**
**Sample Sizes for Moisture Content of Aggregate**

| Nominal Maximum Size* mm (in.) | Minimum Sample Mass g (lb) |
|---|---|
| 4.75 (No. 4) | 500 (1.1) |
| 9.5 (3/8) | 1500 (3.3) |
| 12.5 (1/2) | 2000 (4) |
| 19.0 (3/4) | 3000 (7) |
| 25.0 (1) | 4000 (9) |
| 37.5 (1 1/2) | 6000 (13) |
| 50 (2) | 8000 (18) |
| 63 (2 1/2) | 10,000 (22) |
| 75 (3) | 13,000 (29) |
| 90 (3 1/2) | 16,000 (35) |
| 100 (4) | 25,000 (55) |
| 150 (6) | 50,000 (110) |

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum.

For soil, select the proper sample size based on Table 2 or other information that may be supplied by the agency.

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**TABLE 2**
**Sample Sizes for Moisture Content of Soil**

| Maximum Particle Size mm (in) | Minimum Sample Mass g |
|---|---|
| 0.425 (No. 40) | 10 |
| 4.75 (No. 4) | 100 |
| 12.5 (1/2) | 300 |
| 25.0 (1) | 500 |
| 50 (2) | 1000 |

Immediately seal or cover samples to prevent any change in moisture content or follow the steps in "Procedure."

16

## Procedure

Determine and record the sample mass as follows:

- For aggregate, determine and record all masses to the nearest 0.1 percent of the sample mass or to the nearest 0.1 g.
- For soil, determine and record all masses to the nearest 0.1 g.

When determining the mass of hot samples or containers or both, place and tare a buffer between the sample container and the balance. This will eliminate damage to or interference with the operation of the balance or scale.

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1. Determine and record the mass of the container (and lid for microwave drying).
2. Place the wet sample in the container.
   a. For oven(s), hot plates, infrared heaters, etc.: Spread the sample in the container.
   b. For microwave oven: Heap sample in the container; cover with ventilated lid.

3. Determine and record the total mass of the container and wet sample.
4. Determine and record the wet mass of the sample by subtracting the container mass as determined in Step 1 from the mass of the container and sample in Step 3.

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5. Place the sample in one of the following drying apparatus:
   a. For aggregate –
      i. Controlled heat source (oven): at 110 ±5°C (230 ±9°F).
      ii. Uncontrolled heat source (Hot plate, infrared heater, etc.): Stir frequently to avoid localized overheating.
   b. For soil – controlled heat source (oven): at 110 ±5°C (230 ±9°F).

***Note 1:*** Soils containing gypsum or significant amounts of organic material require special drying. For reliable moisture contents, dry these soils at 60°C (140°F). For more information see AASHTO T 265, Note 2.

6. Dry until sample appears moisture free.
7. Determine mass of sample and container.
8. Determine and record the mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 7.

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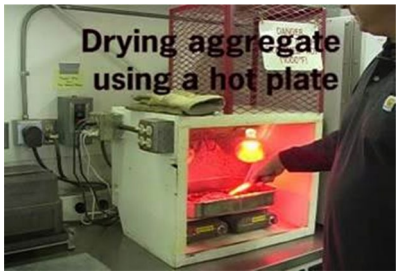


**Hotplate**

9. Return sample and container to the heat source for additional drying.
   a. For aggregate –
      i. Controlled heat source (oven): 30 minutes
      ii. Uncontrolled heat source (Hot plate, infrared heater, etc.): 10 minutes
      iii. Uncontrolled heat source (Microwave oven): 2 minutes

**Caution:** Some minerals in the sample may cause the aggregate to overheat, altering the aggregate gradation.

   b. For soil – controlled heat source (oven): 1 hour

10. Determine mass of sample and container.
11. Determine and record the mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 10.

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12. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$) divide by the previous mass determination ($M_p$) multiply by 100.

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13. Continue drying, performing steps 9 through 12, until there is less than a 0.10 percent change after additional drying time.
14. Constant mass has been achieved; sample is defined as dry.
15. Allow the sample to cool. Immediately determine and record the total mass of the container and dry sample.
16. Determine and record the dry mass of the sample by subtracting the mass of the container determined in Step 1 from the mass of the container and sample determined in Step 15.

22

17. Determine and record percent moisture (w) by subtracting the final dry mass determination ($M_D$) from the initial wet mass determination ($M_W$) divide by the final dry mass determination ($M_D$) multiply by 100.

**Table 3**
**Methods of Drying**

| **Aggregate** | | |
|---|---|---|
| **Heat Source** | **Specific Instructions** | **Drying intervals to achieve constant mass (minutes)** |
| **Controlled:**<br>Forced draft (preferred), ventilated, or convection oven | 110 ±5°C (230 ±9°F) | 30 |
| **Uncontrolled:** | | |
| Hot plate, infrared heater, etc. | Stir frequently | 10 |
| Microwave | Heap sample and cover with ventilated lid | 2 |
| **Soil** | | |
| **Heat Source** | **Specific Instructions** | **Drying increments (minutes)** |
| **Controlled:**<br>Forced draft (preferred), ventilated, or convection oven | 110 ±5°C (230 ±9°F) | 1 hour |

## Calculation

**Constant Mass:**

Calculate constant mass using the following formula: 24

$$\%\,Change = \frac{M_p - M_n}{M_p} \times 100$$

Where:

$M_p$ = previous mass measurement

$M_n$ = new mass measurement

**Example:**

Mass of container: 1232.1 g
Mass of the container and sample after first drying cycle: 2637.2 g
Mass, $M_p$, of possibly dry sample: 2637.2 g - 1232.1 g = 1405.1 g
Mass of container and dry sample after second drying cycle: 2634.1 g
Mass, $M_n$, of dry sample: 2634.1 g - 1232.1 g = 1402.0 g

$$\%\ Change = \frac{1405.1\ g - 1402.0\ g}{1405.1\ g} \times 100 = 0.22\%$$

*0.22 percent is not less than 0.10 percent, so continue drying*

Mass of container and dry sample after third drying cycle: 2633.0 g
Mass, $M_n$, of dry sample: 2633.0 g - 1232.1 g = 1400.9 g

25

$$\%\ Change = \frac{1402.0\ g - 1400.9\ g}{1402.0\ g} \times 100 = 0.08\%$$

*0.08 percent is less than 0.10 percent, so constant mass has been reached.*

## Moisture Content Aggregate and Soils:

Calculate the moisture content, as a percent, using the following formula:

$$w = \frac{M_W - M_D}{M_D} \times 100$$

Where: w = moisture content, percent
$M_W$ = wet mass
$M_D$ = dry mass

26

Example:

| | |
|---|---|
| Mass of container: | 1232.1 g |
| Mass of container and wet sample: | 2764.7 g |
| Mass, $M_W$, of wet sample: | 2764.7 g - 1232.1 g = 1532.6 g |
| Mass of container and dry sample **(COOLED)**: | 2633.5 g |
| Mass, $M_D$, of dry sample: | 2633.5 g - 1232.1 g = 1401.4 g |

$$w = \frac{1532.6\ g - 1401.4\ g}{1401.4\ g} \times 100 = \frac{131.2\ g}{1401.4\ g} \times 100 = 9.36\%$$

$$report\ 9.4\%$$

27

## Report

- Results on forms approved by the agency
- Sample ID
- $M_W$, wet mass
- $M_D$, dry mass
- w, moisture content to the nearest 0.1 percent

28

## Tips!

- Let the sample cool before determining final dry mass.
- Divide by $M_D$, not $M_W$.

## REVIEW QUESTIONS

1. What extra care should be taken when using a microwave to dry aggregates?

2. What is the maximum temperature that a sample should be allowed to attain for each of the various types of ovens?

3. How is "constant mass" defined according to this FOP:

   For Aggregate?

   For Soil?

## PERFORMANCE EXAM CHECKLIST

## TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING FOP FOR AASHTO T 255

## LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS FOP FOR AASHTO T 265

Participant Name _____ Exam Date _____

**Record the symbols "P" for passing or "F" for failing on each step of the checklist**.

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 1. Representative sample of appropriate mass obtained? | _____ | _____ |
| 2. Mass of container determined to 0.1 g? | _____ | _____ |
| 3. Sample placed in container and mass determined to 0.1 g? | _____ | _____ |
| 4. Test sample mass conforms to the required mass? | _____ | _____ |
| 5. Wet sample mass determined to 0.1 g? | _____ | _____ |
| 6. Loss of moisture avoided prior to mass determination? | _____ | _____ |
| 7. Sample dried by a suitable heat source? | _____ | _____ |
| a. Describe suitable heat sources for aggregate? | _____ | _____ |
| b. Describe suitable heat sources for soils? | _____ | _____ |
| 8. If aggregate heated by means other than a controlled oven, is sample stirred to avoid localized overheating? | _____ | _____ |
| 9. For microwave, aggregate heaped and covered with a ventilated lid? | _____ | _____ |
| 10. For aggregate, heated for the additional, specified time? | _____ | _____ |
| a. Forced draft, ventilated, convection ovens – 30 minutes; | | |
| b. Microwave – 2 minutes | | |
| c. Other – 10 minutes | | |
| 11. For soil: | | |
| a. Heated for at least 1hour additional drying time using a controlled heat source? | _____ | _____ |
| 12. Mass determined and compared to previous mass - showing less than 0.10 percent loss? | _____ | _____ |
| 13. Sample cooled, dry mass determined and recorded to the nearest 0.1 percent? | _____ | _____ |
| 14. Moisture content calculated correctly and recorded to the nearest 0.1 percent? | _____ | _____ |

**OVER**

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

_____

_____

_____

_____

Examiner Signature _____WAQTC #:_____

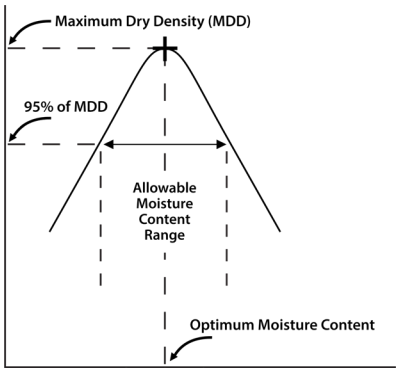
# MOISTURE-DENSITY RELATIONS OF SOILS:

## USING A 2.5 kg (5.5 lb) RAMMER AND A 305 mm (12 in.) DROP FOP FOR AASHTO T 99

## USING A 4.54 kg (10 lb) RAMMER AND A 457 mm (18 in.) DROP FOP FOR AASHTO T 180

**Steel roller**

**Adding water**




**Moisture vs. dry density**

## Significance

The density or degree of compaction, of soil or soil-aggregate mixtures has a significant influence on the stability and durability of roadways. Low density subgrade, subbase, base or embankment will lead to excessive deflection under load or long-term settlement in an amount higher than anticipated, or both. Obtaining proper density depends on two major factors: compactive effort and moisture content.

Compactive effort relates to the type and weight of compaction equipment, along with the thickness of the "lift" being compacted and the number of times each lift is passed over by the compaction equipment. Equipment includes static and vibratory rollers, smooth and sheepsfoot steel rollers, and pneumatic tire rollers of varied weights yielding many different compactive efforts.

Density also depends upon moisture content. The moisture content corresponding to maximum dry density of the soil or soil-aggregate mixture under a given compactive effort is known as optimum water content. As the water content increases or decreases from this optimum value, the dry density decreases.

Agency specifications commonly require that a certain percentage of maximum dry density be obtained while the moisture content of the soil or soil-aggregate mixture is held within certain limits. For example, a specification might call for 95 percent of maximum dry density with a moisture content of the optimum value ± 2 percent. For these reasons, it is critical to understand the various test methods and equipment used in determining the moisture-density relations of soil.

## Scope

This procedure covers the determination of the moisture-density relations of soils and soil-aggregate mixtures in accordance with two similar test methods:

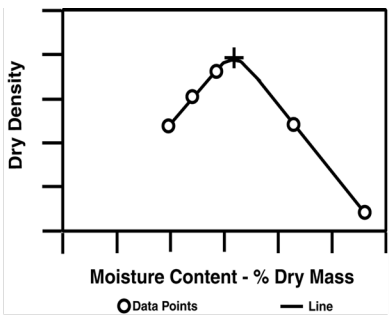
09

- AASHTO T 99-19: Methods A, B, C, and D
- AASHTO T 180-19: Methods A, B, C, and D

This test method applies to soil mixtures having 40 percent or less retained on the 4.75 mm (No. 4) sieve for methods A or B, or, 30 percent or less on the 19 mm (¾ in.) with methods C or D. The retained material is defined as oversize (coarse) material. If no minimum percentage is specified, 5 percent will be used. Samples containing oversize (coarse) material that meet the percent retained criteria should be corrected by using *Annex A, Correction of Maximum Dry Density and Optimum Moisture for Oversized Particles*. Samples of soil or soil-aggregate mixture are prepared at several moisture contents and compacted into molds of specified size, using manual or mechanical rammers that deliver a specified quantity of compactive energy. The moist masses of the compacted samples are divided by the volume of the mold to determine wet density values. Moisture contents of the compacted samples are determined and used to obtain the dry density values of the same samples. Maximum dry density and optimum moisture content for the soil or soil-aggregate mixture is determined by plotting the relationship between dry density and moisture content.

10

11



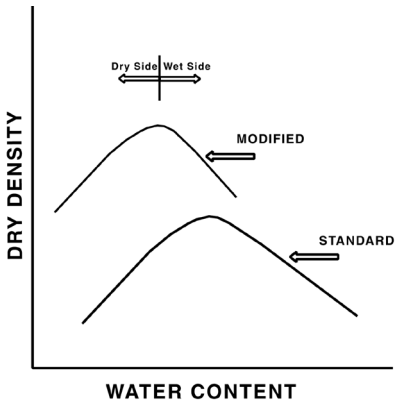

**Optimum water content**

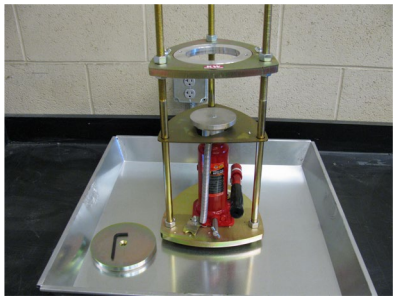
## Apparatus

- Mold – Cylindrical mold made of metal with the dimensions shown in Table 1 or Table 2. If permitted by the agency, the mold may be of the "split" type, consisting of two half-round sections, which can be securely locked in place to form a cylinder. Determine the mold volume according to *Annex B*, *Standardization of the Mold*.
- Mold assembly – Mold, base plate, and a detachable collar.

**Molds and Rammer**

**Mechanical Rammer**



**Sample extruder**

- Rammer – Manually or mechanically operated rammers as detailed in Table 1 or Table 2. A manually operated rammer shall be equipped with a guide sleeve to control the path and height of drop. The guide sleeve shall have at least four vent holes no smaller than 9.5 mm (3/8 in.) in diameter, spaced approximately 90 degrees apart and approximately 19 mm (3/4 in.) from each end. A mechanically operated rammer will uniformly distribute blows over the sample and will be calibrated with several soil types, and shall be adjusted, if necessary, to give the same moisture-density results as with the manually operated rammer. For additional information concerning calibration, see the FOP for AASHTO T 99/T 180.
- Sample extruder – A jack, lever frame, or other device for extruding compacted specimens from the mold quickly and with little disturbance.
- Balance(s) or scale(s) of the capacity and sensitivity required for the procedure used by the agency.

  A balance or scale with a capacity of 11.5 kg (25 lb) and a sensitivity of 1 g for obtaining the sample, meeting the requirements of AASHTO M 231, Class G 5.

  A balance or scale with a capacity of 2 kg and a sensitivity of 0.1 g is used for moisture content determinations done under both procedures, meeting the requirements of AASHTO M 231, Class G 5.
- Drying apparatus – A thermostatically controlled drying oven, capable of maintaining a temperature of 110 ±5°C (230 ±9°F) for drying moisture content samples in accordance with the FOP for AASHTO T 255/T 265.
- Straightedge – A steel straightedge at least 250 mm (10 in.) long, with one beveled edge and at least one surface plane within 0.1 percent of its length, used for final trimming.

**4.75 mm (No. 4) sieve - Straight edge**

- Sieve(s) – 4.75 mm (No. 4) and/or 19.0 mm (3/4 in.), meeting the requirements of FOP for AASHTO T 27/T 11.
- Mixing tools – Miscellaneous tools such as a mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device, for mixing the sample with water.
- Containers with close-fitting lids to prevent gain or loss of moisture in the sample.

**Table 1**
**Comparison of Apparatus, Sample, and Procedure - Metric**

| | T 99 | T 180 |
|---|---|---|
| Mold Volume, $m^3$ | Methods A, C: 0.000943 ±000014 | Methods A, C: 0.000943 ±000014 |
| | Methods B, D: 0.002124 ±000025 | Methods B, D: 0.002124 ±000025 |
| Mold Diameter, mm | Methods A, C: 101.60 ±0.40 | Methods A, C: 101.60 ±0.40 |
| | Methods B, D: 152.40 ±0.70 | Methods B, D: 152.40 ±0.70 |
| Mold Height, mm | 116.40 ±0.50 | 116.43 ±0.50 |
| Detachable Collar Height, mm | 50.80 ±0.64 | 50.80 ±0.64 |
| Rammer Diameter, mm | 50.80 ±0.64 | 50.80 ±0.64 |
| Rammer Mass, kg | 2.495 ±0.009 | 4.536 ±0.009 |
| Rammer Drop, mm | 305 | 457 |
| Layers | 3 | 5 |
| Blows per Layer | Methods A, C: 25 | Methods A, C: 25 |
| | Methods B, D: 56 | Methods B, D: 56 |
| Material Size, mm | Methods A, B: 4.75 minus | Methods A, B: 4.75 minus |
| | Methods C, D: 19.0 minus | Methods C, D: 19.0 minus |
| Test Sample Size, kg | Method A: 3<br>Method C: 5 (1) | Method B: 7<br>Method D: 11 (1) |
| Energy, kN-m/$m^3$ | 592 | 2,693 |

(1) This may not be a large enough sample depending on your nominal maximum size for moisture content samples.

**Table 2**
**Comparison of Apparatus, Sample, and Procedure - English**

| | T 99 | T 180 |
|---|---|---|
| Mold Volume, $ft^3$ | Methods A, C: 0.0333 ±0.0005 | Methods A, C: 0.0333 ±0.0005 |
| | Methods B, D: 0.07500 ±0.0009 | Methods B, D: 0.07500 ±0.0009 |
| Mold Diameter, in. | Methods A, C: 4.000 ±0.016 | Methods A, C: 4.000 ±0.016 |
| | Methods B, D: 6.000 ±0.026 | Methods B, D: 6.000 ±0.026 |
| Mold Height, in. | 4.584 ±0.018 | 4.584 ±0.018 |
| Detachable Collar Height, in. | 2.000 ±0.025 | 2.000 ±0.025 |
| Rammer Diameter, in. | 2.000 ±0.025 | 2.000 ±0.025 |
| Rammer Mass, lb | 5.5 ±0.02 | 10 ±0.02 |
| Rammer Drop, in. | 12 | 18 |
| Layers | 3 | 5 |
| Blows per Layer | Methods A, C: 25 | Methods A, C: 25 |
| | Methods B, D: 56 | 0.Methods B, D: 56 |
| Material Size, in. | Methods A, B: No. 4 minus | Methods A, B: No. 4 minus |
| | Methods C, D: 3/4 minus | Methods C, D: 3/4 minus |
| Test Sample Size, lb | Method A: 7<br>Method C: 12(1) | Method B: 16<br>Method D: 25(1) |
| Energy, lb-ft/$ft^3$ | 12,375 | 56,250 |

(1) This may not be a large enough sample depending on your nominal maximum size for moisture content samples.

| Mold \ Sieve | 4.75 mm (No. 4) | 19 mm (3/4") |
|---|---|---|
| 4" | A | C |
| 6" | B | D |

**Methods**

## Sample

If the sample is damp, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus maintained at a temperature not exceeding 60°C (140°F). Thoroughly break up aggregations in a manner that avoids reducing the natural size of individual particles.

Obtain a representative test sample of the mass required by the agency by passing the material through the sieve required by the agency. See Table 1 or Table 2 for test sample mass and material size requirements.

In instances where the material is prone to degradation, i.e., granular material, a compaction sample with differing moisture content should be prepared for each point.

If the sample is plastic (clay types), it should stand for a minimum of 12 hours after the addition of water to allow the moisture to be absorbed. In this case, several samples at different moisture contents should be prepared, put in sealed containers and tested the next day.

***Note 1:*** Both T 99 and T 180 have four methods (A, B, C, D) that require different masses and employ different sieves.

**Compacting**

**Typical mold**

## Procedure

During compaction, rest the mold firmly on a dense, uniform, rigid, and stable foundation or base. This base shall remain stationary during the compaction process.

22 1. Determine the mass of the clean, dry mold. Include the base plate but exclude the extension collar. Record the mass to the nearest 1 g (0.005 lb).

2. Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately 4 to 8 percentage points below optimum moisture content. For many materials, this condition can be identified by forming a cast by hand.

   a. Prepare individual samples of plastic or degradable material, increasing moisture contents 1 to 2 percent for each point.

   b. Allow samples of plastic soil to stand for 12 hrs.

23 3. Form a specimen by compacting the prepared soil in the mold assembly in approximately
24 equal layers. For each layer:

   a. Spread the loose material uniformly in the mold.

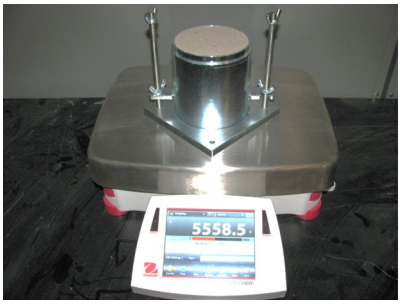
   b. Lightly tamp the loose material with the manual rammer or other similar device, this establishes a firm surface.

***Note 2:*** It is recommended to cover the remaining material with a non-absorbent sheet or damp cloth to minimize loss of moisture.

   c. Compact each layer with uniformly distributed blows from the rammer. See Table 1 for mold size, number of layers, number of blows, and rammer specification for the various test methods. Use the method specified by the agency.

   d. Trim down material that has not been compacted and remains adjacent to the walls of the mold and extends above the compacted surface.

**Trimming**




**Mass of mold and wet soil**

**Extruding the material**

25 4. Remove the extension collar. Avoid shearing off the sample below the top of the mold. The material compacted in the mold should not be over 6 mm (¼ in) above the top of the mold once the collar has been removed.

26 27 5. Trim the compacted soil even with the top of the mold with the beveled edge of the straightedge.

6. Clean soil from exterior of the mold and base plate.

28 7. Determine the mass of the mold, base plate, and wet soil to the nearest 1 g (0.005 lb) or better.

8. Determine the wet mass of the sample by subtracting the mass in Step 1 from the mass in Step 7.

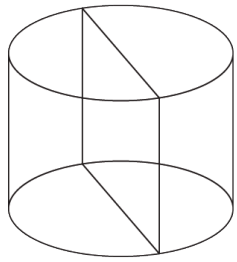
9. Calculate the wet density, in kg/m$^3$ (lb/ft$^3$), by dividing the wet mass by the measured volume ($V_m$).

29 30 10. Extrude the material from the mold. For soils and soil-aggregate mixtures, slice vertically through the center and take a representative moisture content sample from one of the cut faces, ensuring that all layers are represented. For granular materials, a vertical face will not exist. Take a representative sample. This sample must meet the sample size requirements of the test method used to determine moisture content.

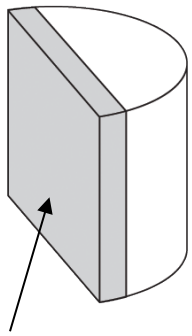
***Note 3:*** When developing a curve for free-draining soils such as uniform sands and gravels, where seepage occurs at the bottom of the mold and base plate, taking a representative moisture content from the mixing bowl may be preferred in order to determine the amount of moisture available for compaction.

11. Determine the moisture content of the sample in accordance with the FOP for AASHTO T 255 / T 265.

12. If the material is degradable or plastic, return to Step 3 using a prepared individual sample. If not, continue with Steps 13 through 15.



**Extruded material**



**Representative moisture content sample**

31 13. Thoroughly break up the remaining portion of
32 the molded specimen until it will again pass
33 through the sieve, as judged by eye, and add to the remaining portion of the sample being tested.

14. Add sufficient water to increase the moisture content of the remaining soil by approximately 1 to 2 percentage points and repeat the above procedure.

15. Continue determinations until there is either a decrease or no change in the mass. There will be a minimum of three points on the dry side of the curve and two points on the wet side. For non-cohesive, drainable soils, one point on the wet side is sufficient.

## Calculations

34

### Wet Density

$$D_w = \frac{M_w}{V_m}$$

Where:

$D_w$ = wet density, kg/m$^3$ (lb/ft$^3$)

$M_w$ = wet mass

$V_m$ = volume of the mold, Annex B

**Dry Density**

35

$$D_d = \left(\frac{D_w}{w + 100}\right) \times 100 \quad or \quad D_d = \frac{D_w}{\left(\frac{w}{100}\right) + 1}$$

Where:

$D_d$ = dry density, kg/m$^3$ (lb/ft$^3$)

w = moisture content, as a percentage

36

**Example for 4-inch mold, Methods A or C**

Wet mass, $M_w$ = 1.928 kg (4.25 lb)

Moisture content, w = 11.3%

Measured volume of the mold, $V_m$ = 0.000946 m$^3$ (0.0334 ft$^3$)

**Wet Density**

37

$$D_w = \frac{1.928\ kg}{0.000946\ m^3} = 2038\ kg/m^3 \quad D_w = \frac{4.25\ lb}{0.0334\ ft^3} = 127.2\ lb/ft^3$$

**Dry Density**

38

$$D_d = \left(\frac{2038\,kg/m^3}{11.3 + 100}\right) \times 100 = 1831\ \ kg/m^3 \quad D_d = \left(\frac{127.2\ \ lb/ft^3}{11.3 + 100}\right) \times 100 = 114.3\,lb/ft^3$$

Or

$$D_d = \left(\frac{2038\,kg/m^3}{\frac{11.3}{100} + 1}\right) = 1831\,kg/m^3 \quad D_d = \left(\frac{127.2\ \ lb/ft^3}{\frac{11.3}{100} + 1}\right) = 114.3\,lb/ft^3$$

39

## Moisture-Density Curve Development

When dry density is plotted on the vertical axis versus moisture content on the horizontal axis and the points are connected with a smooth line, a moisture-density curve is developed. The coordinates of the peak of the curve are the maximum dry density, or just "maximum density," and the "optimum moisture content" of the soil.

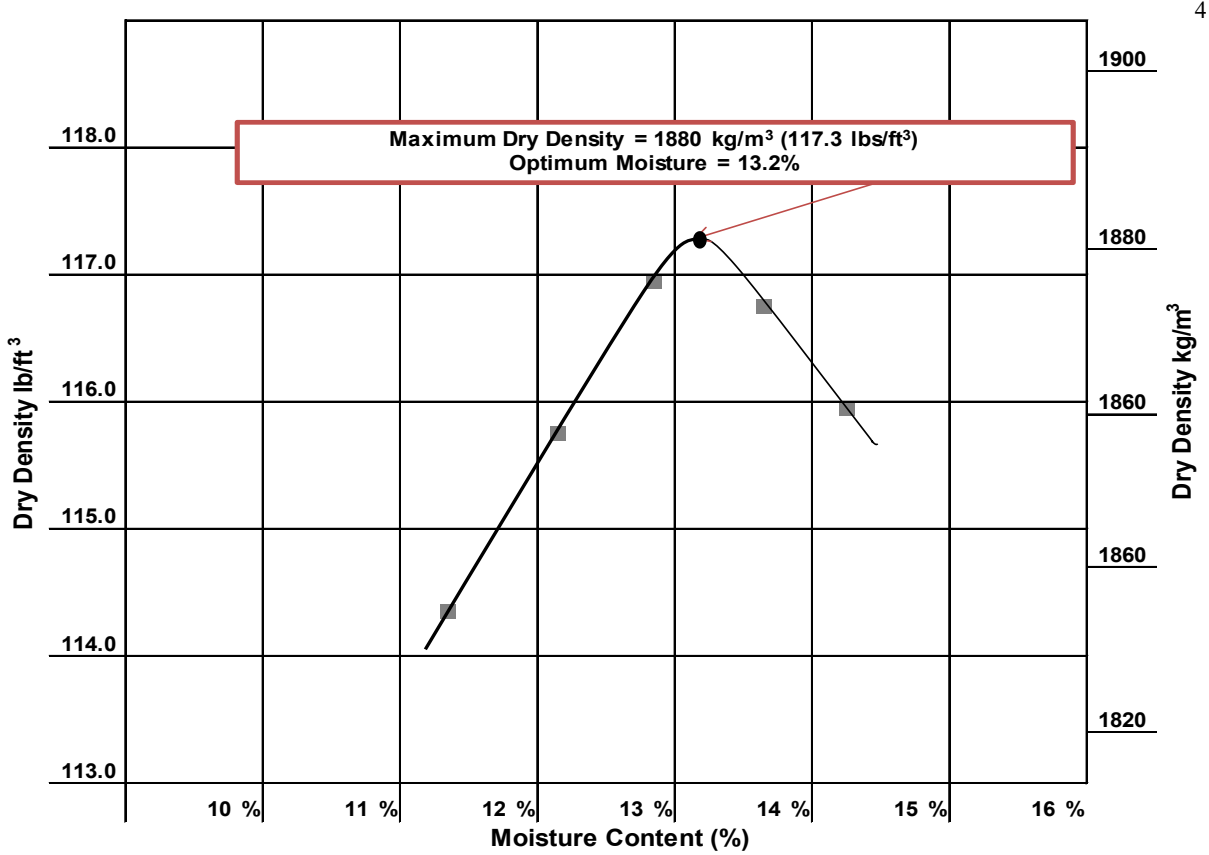
**Example**

Given the following dry density and corresponding moisture content values, develop a moisture-density relations curve and determine maximum dry density and optimum moisture content.

40

| **Dry Density,** | | **Moisture Content, %** |
|---|---|---|
| **kg/m³** | **lb/ft³** | |
| 1831 | 114.3 | 11.3 |
| 1853 | 115.7 | 12.1 |
| 1873 | 116.9 | 12.8 |
| 1869 | 116.7 | 13.6 |
| 1857 | 115.9 | 14.2 |

41




In this case, the curve has its peak at:

42

Maximum dry density = 1880 kg/m$^3$ (117.3 lb/ft$^3$)

Optimum moisture content = 13.2%

Note that both values are approximate, since they are based on sketching the curve to fit the points.

43

## Report

- Results on forms approved by the agency
- Sample ID
- Maximum dry density to the nearest 1 kg/m$^3$ (0.1 lb/ft$^3$)
- Optimum moisture content to the nearest 0.1 percent

44

## Tips!

- Ideally, obtain 3 dry points and 2 wet points. This produces a reliable moisture-density curve.
- Moisture-density curves are based on dry densities.
- If oversize material exists, corrections must be made.

## ANNEX A

## CORRECTION OF MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE FOR OVERSIZED PARTICLES 2

3

This section corrects the maximum dry density and moisture content of the material retained on the 4.75 mm (No. 4) sieve, Methods A and B; or the material retained on the 19 mm (¾ in.) sieve, Methods C and D. The maximum dry density, corrected for oversized particles and total moisture content, are compared with the field-dry density and field moisture content. 4

This correction can be applied to the sample on which the maximum dry density is performed. A correction may not be practical for soils with only a small percentage of oversize material. The agency shall specify a minimum percentage below which the method is not needed. If not specified, this method applies when more than 5 percent by weight of oversize particles is present. 5 6

Bulk specific gravity ($G_{sb}$) of the oversized particles is required to determine the corrected maximum dry density. Use the bulk specific gravity as determined using the FOP for AASHTO T 85 in the calculations. For construction activities, an agency established value or specific gravity of 2.600 may be used.

This correction can also be applied to the sample obtained from the field while performing in-place density.

1. Use the sample from this procedure or a sample obtained according to the FOP for AASHTO T 310. 7

2. Sieve the sample on the 4.75 mm (No. 4) sieve for Methods A and B or the 19 mm (¾ in.) sieve, Methods C and D.

3. Determine the dry mass of the oversized and fine fractions ($M_{DC}$ and $M_{DF}$) by one of the following:

   a. Dry the fractions, fine and oversized, in air or by use of a drying apparatus that is maintained at a temperature not exceeding 60ºC (140ºF).

   b. Calculate the dry masses using the moisture samples.

To determine the dry mass of the fractions using moisture samples. 8

1. Determine the moist mass of both fractions, fine ($M_{Mf}$) and oversized ($M_{Mc}$):

2. Obtain moisture samples from the fine and oversized material.

3. Determine the moisture content of the fine particles ($MC_f$) and oversized particles ($MC_C$) of the material by FOP for AASHTO T 255/T 265 or agency approved method.

4. Calculate the dry mass of the oversize and fine particles.

$$M_D = \frac{M_m}{1 + \mathrm{MC}} \quad 9$$

Where:

$M_D$ = mass of dry material (fine or oversize particles).

$M_m$ = mass of moist material (fine or oversize particles).

MC = moisture content of respective fine or oversized, expressed as a decimal.

5. Calculate the percentage of the fine ($P_f$) and oversized ($P_c$) particles by dry weight of the total sample as follows: See Note 2.

10

$$P_f = \frac{100 \times M_{DF}}{M_{DF} + M_{DC}} \qquad \frac{100 \ \times 15.4\ lb}{15.4\ lbs + 5.7\ lb} = 73\% \qquad \frac{100 \ \times 6.985\ kg}{6.985\ kg + 2.585\ kg} = 73\%$$

And

11

$$P_c = \frac{100 \times M_{DC}}{M_{DF} + M_{DC}} \qquad \frac{100 \ \times 5.7\ lb}{15.4\ lbs + 5.7\ lb} = 27\% \qquad \frac{100 \ \times 2.585\ kg}{6.985\ kg + 2.585\ kg} = 27\%$$

Or for $\mathbf{P_c}$:

$$P_c = 100 - P_f$$

Where:

$P_f$ = percent of fine particles, of sieve used, by weight

$P_c$ = percent of oversize particles, of sieve used, by weight

$M_{DF}$ = mass of dry fine particles

$M_{DC}$ = mass of dry oversize particles

## Optimum Moisture Correction Equation

12

1. Calculate the corrected moisture content as follows:

$$MC_T = \frac{(MC_F \times P_f) + (MC_c \times P_c)}{100}$$

13

$$MC_T = \frac{(10.6\% \times 73.0\%) + (2.1\% \times 27.0\%)}{100} = 8.3\%$$

Where:

$MC_T$ = corrected moisture content of combined fines and oversized particles, expressed as a % moisture

$MC_F$ = moisture content of fine particles, as a % moisture

$MC_C$ = moisture content of oversized particles, as a % moisture

***Note 1:*** Moisture content of oversize material can be assumed to be two (2) percent for most construction applications.

***Note 2:*** In some field applications agencies will allow the percentages of oversize and fine materials to be determined with the materials in the wet state.

## Density Correction Equation

14

2. Calculate the corrected dry density of the total sample (combined fine and oversized particles) as follows:

$$D_d = \frac{100\%}{\left[\left(\frac{P_f}{D_f}\right) + \left(\frac{P_c}{k}\right)\right]}$$

15

Where:

$D_d$ = corrected total dry density (combined fine and oversized particles) kg/m$^3$ (lb/ft $^3$)

$D_f$ = dry density of the fine particles kg/m$^3$ (lb/ft$^3$), determined in the lab

$P_c$ = percent of dry oversize particles, of sieve used, by weight.

$P_f$ = percent of dry fine particles, of sieve used, by weight.

K = Metric: 1,000 * Bulk Specific Gravity ($G_{sb}$) (oven dry basis) of coarse particles (kg/m$^3$).

K = English: 62.4 * Bulk Specific Gravity ($G_{sb}$) (oven dry basis) of coarse particles (lb/ft$^3$)

***Note 3:*** If the specific gravity is known, then this value will be used in the calculation. For most construction activities, the specific gravity for aggregate may be assumed to be 2.600.

## Calculation

**Example**

- Metric:

Maximum laboratory dry density ($D_f$): 1880 kg/m$^3$

Percent coarse particles ($P_c$): 27%

Percent fine particles ($P_f$): 73%

Mass per volume coarse particles (k): (2.697) (1000) = 2697 kg/m$^3$

$$D_d = \frac{100\%}{\left[\left(\frac{P_f}{D_f}\right) + \left(\frac{P_c}{k}\right)\right]}$$

$$D_d = \frac{100\%}{\left[\left(\frac{73\%}{1880\,kg/m^3}\right) + \left(\frac{27\%}{2697\,kg/m^3}\right)\right]}$$

$$D_d = \frac{100\%}{[0.03883\,kg/m^3 + 0.01001\,kg/m^3]}$$

$$D_d = 2047.5\,kg/m^3\ report\ \ 2048\,kg/m^3$$

- English:

Maximum laboratory dry density ($D_f$): 117.3 lb/ft$^3$ 16

Percent coarse particles ($P_c$): 27%

Percent fine particles ($P_f$): 73%

Mass per volume coarse particles (k): (2.697) (62.4) = 168.3 lb/ft$^3$

$$D_d = \frac{100\%}{\left[\left(\frac{P_f}{D_f}\right) + \left(\frac{P_c}{k}\right)\right]}$$

$$D_d = \frac{100\%}{\left[\left(\frac{73\%}{117.3\,lb/ft^3}\right) + \left(\frac{27\%}{168.3\,lb/ft^3}\right)\right]}$$ 17

$$D_d = \frac{100\%}{[0.6223\,lb/ft^3 + 0.1604\,lb/ft^3]}$$

$$D_d = \frac{100\%}{0.7827\,lb/ft^3}$$

$$D_d = 127.76\,lb/ft^3 \quad Report\ 127.8\,lb/ft^3$$

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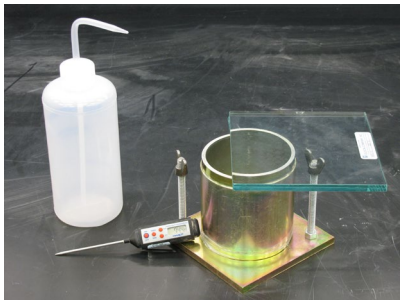
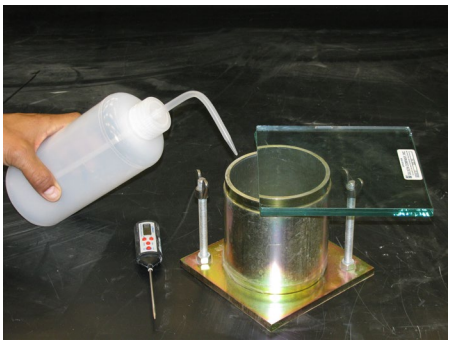
**Report**

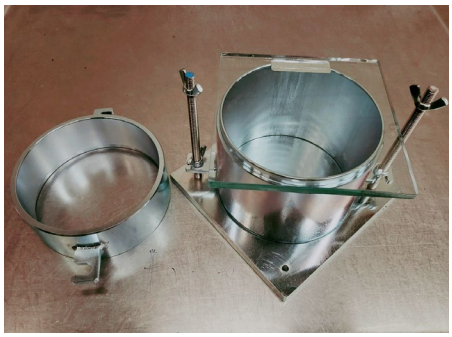
- Results on forms approved by the agency
- Sample ID
- Corrected maximum dry density to the nearest 1 kg/m$^3$ (0.1 lb/ft$^3$)
- Corrected optimum moisture to the nearest 0.1 percent



**Apparatus**



**Filling the mold**



**Dried filled mold**

## ANNEX B

## STANDARDIZATION OF THE MOLD

Standardization is a critical step to ensure accurate test results when using this apparatus. Failure to perform the standardization procedure as described herein will produce inaccurate or unreliable test results.

### Apparatus

- Mold and base plate
- Balance or scale – Accurate to within 45 g (0.1 lb) or 0.3 percent of the test load, whichever is greater, at any point within the range of use.
- Cover plate – A piece of plate glass, at least 6 mm (1⁄4 in.) thick and at least 25 mm (1 in.) larger than the diameter of the mold.
- Thermometers – Standardized liquid-in-glass, or electronic digital total immersion type, accurate to 0.5°C (1°F)

### Procedure

1. Create a watertight seal between the mold and base plate.
2. Determine and record the mass of the dry sealed mold, base plate, and cover plate.
3. Fill the mold with water at a temperature between 16°C and 29°C (60°F and 85°F) and cover with the cover plate in such a way as to eliminate bubbles and excess water.
4. Wipe the outside of the mold, base plate, and cover plate dry, being careful not to lose any water from the mold.
5. Determine and record the mass of the filled mold, base plate, cover plate, and water.
6. Determine and record the mass of the water in the mold by subtracting the mass in Step 2 from the mass in Step 5.

7. Measure the temperature of the water and determine its density from Table B1, interpolating as necessary.
8. Calculate the volume of the mold, $V_m$, by dividing the mass of the water in the mold by the density of the water at the measured temperature.

## Calculations

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$$V_m = \frac{M}{D}$$

Where:

$V_m$ = volume of the mold

M = mass of water in the mold

D = density of water at the measured temperature

**Example**

32

Mass of water in mold = 0.94367 kg (2.0800 lb)

Density of water at 23°C (73.4°F) = 997.54 kg/m$^3$ (62.274 lb/ft$^3$)

$$V_m = \frac{0.94367\ kg}{997.54\ \ kg/m^3} = 0.000946\ m^3 \qquad V_m = \frac{2.0800\ lb}{62.274\ \ lb/ft^3} = 0.0334\ ft^3$$

**Table B1**
**Unit Mass of Water**
**15°C to 30°C**

30

| °C | (°F) | kg/m$^3$ | (lb/ft$^3$) | °C | (°F) | kg/m$^3$ | (lb/ft$^3$) |
|---|---|---|---|---|---|---|---|
| 15 | (59.0) | 999.10 | (62.372) | 23 | (73.4) | 997.54 | (62.274) |
| 15.6 | (60.0) | 999.01 | (62.366) | 23.9 | (75.0) | 997.32 | (62.261) |
| 16 | (60.8) | 998.94 | (62.361) | 24 | (75.2) | 997.29 | (62.259) |
| 17 | (62.6) | 998.77 | (62.350) | 25 | (77.0) | 997.03 | (62.243) |
| 18 | (64.4) | 998.60 | (62.340) | 26 | (78.8) | 996.77 | (62.227) |
| 18.3 | (65.0) | 998.54 | (62.336) | 26.7 | (80.0) | 996.59 | (62.216) |
| 19 | (66.2) | 998.40 | (62.328) | 27 | (80.6) | 996.50 | (62.209) |
| 20 | (68.0) | 998.20 | (62.315) | 28 | (82.4) | 996.23 | (62.192) |
| 21 | (69.8) | 997.99 | (62.302) | 29 | (84.2) | 995.95 | (62.175) |
| 21.1 | (70.0) | 997.97 | (62.301) | 29.4 | (85.0) | 995.83 | (62.166) |
| 22 | (71.6) | 997.77 | (62.288) | 30 | (86.0) | 995.65 | (62.156) |

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## Report

- Mold ID
- Date Standardized
- Temperature of the water
- Volume, $V_m$, of the mold the nearest 0.000001 m$^3$ (0.0001 ft$^3$)

## REVIEW QUESTIONS

1. Describe how the plotted data is used to determine optimum moisture content and maximum dry density.

2. How many blows of the rammer are required per lift for the various procedures and methods?

3. Describe how the sample for moisture content is obtained.

4. What sample mass is required for Method A of the T 99 test?

   For Method C of the T 180 test?

5. Describe the purpose of Annex A.

6. The adjustment is based on the mass of material retained on what size sieve?

7. A soil-aggregate mixture has a maximum dry density of 138.6 lb/ft$^3$ English units and optimum moisture of 6.4 percent. The coarse particles make up 22 percent of the material, having a $G_{sb}$ of 2.631 and 1.7 percent moisture.

   What is the corrected maximum density?

   What is the corrected moisture?

## PERFORMANCE EXAM CHECKLIST

## MOISTURE-DENSITY RELATION OF SOILS
## FOP FOR AASHTO T 99

Participant Name _____ Exam Date _____

**Record the symbols "P" for passing or "F" for failing on each step of the checklist**.

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 1. If damp, sample dried in air or drying apparatus, not exceeding 60°C (140°F)? | _____ | _____ |
| 2. Sample broken up and an adequate amount sieved over the appropriate sieve (4.75 mm / No. 4 or 19.0 mm / 3/4 in.) to determine oversize (coarse particle) percentage? | _____ | _____ |
| 3. Sample passing the sieve has appropriate mass? | _____ | _____ |
| 4. If material is degradable: | | |
| a. Multiple samples mixed with water varying moisture content by 1 to 2 percent, bracketing the optimum moisture content? | _____ | _____ |
| 5. If soil is plastic (clay types): | | |
| a. Multiple samples mixed with water varying moisture content by 1 to 2 percent, bracketing the optimum moisture content? | _____ | _____ |
| b. Samples placed in covered containers and allowed to stand for at least 12 hours? | _____ | _____ |
| 6. Sample determined to be 4 to 8 percent below expected optimum moisture content? | _____ | _____ |
| 7. Determine mass of clean, dry mold without collar to nearest 1 g? | _____ | _____ |
| 8. Mold placed on rigid and stable foundation? | _____ | _____ |
| 9. Layer of soil (approximately one third compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 10. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 11. Material adhering to the inside of the mold trimmed? | _____ | _____ |
| 12. Layer of soil (approximately two thirds compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 13. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 14. Material adhering to the inside of the mold trimmed? | _____ | _____ |
| 15. Mold filled with soil such that compacted soil will be above the mold, loose material lightly tamped? | _____ | _____ |

**OVER**

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 16. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 17. Collar removed without shearing off sample? | _____ | _____ |
| 18. Approximately 6 mm (1/4 in.) of compacted material above the top of the mold (without the collar)? | _____ | _____ |
| 19. Soil trimmed to top of mold with the beveled side of the straightedge? | _____ | _____ |
| 20. Remove all soil from exterior surface of mold and base plate? | _____ | _____ |
| 21. Mass of mold and contents determined to appropriate precision (1 g)? | _____ | _____ |
| 22. Wet density calculated from the wet mass? | _____ | _____ |
| 23. Soil removed from mold using a sample extruder if needed? | _____ | _____ |
| 24. Soil sliced vertically through center (non-granular material)? | _____ | _____ |
| 25. Moisture sample removed ensuring all layers are represented? | _____ | _____ |
| 26. Moist mass determined immediately to 0.1 g? | _____ | _____ |
| 27. Moisture sample mass of correct size? | _____ | _____ |
| 28. Sample dried, and water content determined according to the FOP for T 255/T 265? | _____ | _____ |
| a. Remainder of material from mold broken up until it will pass through the sieve, as judged by eye, and added to remainder of original test sample? | _____ | _____ |
| b. Water added to increase moisture content of the remaining sample in approximately 1 to 2 percent increments? | _____ | _____ |
| c. Steps 7 through 29 repeated for each increment of water added? | _____ | _____ |
| 29. Process continued until wet density either decreases or stabilizes? | _____ | _____ |
| 30. Moisture content and dry density calculated for each sample? | _____ | _____ |
| 31. Dry density plotted on vertical axis, moisture content plotted on horizontal axis, and points connected with a smooth curve? | _____ | _____ |
| 32. Moisture content at peak of curve recorded as optimum water content and recorded to nearest 0.1 percent? | _____ | _____ |
| 33. Dry density at optimum moisture content reported as maximum density to nearest 1 kg/m$^3$ (0.1 lb/ft$^3$)? | _____ | _____ |
| 34. Corrected for coarse particles if applicable? | _____ | _____ |

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

_____

_____

_____

_____

Examiner Signature _____WAQTC #:_____

## PERFORMANCE EXAM CHECKLIST

## MOISTURE-DENSITY RELATION OF SOILS
## FOP FOR AASHTO T 180

Participant Name _____Exam Date _____

**Record the symbols "P" for passing or "F" for failing on each step of the checklist**.

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 1. If damp, sample dried in air or drying apparatus, not exceeding 60°C (140°F)? | _____ | _____ |
| 2. Sample broken up and an adequate amount sieved over the appropriate sieve (4.75 mm / No. 4 or 19.0 mm / 3/4 in.) to determine oversize (coarse particle) percentage? | _____ | _____ |
| 3. Sample passing the sieve has appropriate mass? | _____ | _____ |
| 4. If material is degradable: | | |
| a. Multiple samples mixed with water varying moisture content by 1 to 2 percent, bracketing the optimum moisture content? | _____ | _____ |
| 5. If soil is plastic (clay types): | | |
| a. Multiple samples mixed with water varying moisture content by 1 to 2 percent, bracketing the optimum moisture content? | _____ | _____ |
| b. Samples placed in covered containers and allowed to stand for at least 12 hours? | _____ | _____ |
| 6. Sample determined to be 4 to 8 percent below expected optimum moisture content? | _____ | _____ |
| 7. Determine mass of clean, dry mold without collar to nearest 1 g? | _____ | _____ |
| 8. Mold placed on rigid and stable foundation? | _____ | _____ |
| 9. Layer of soil (approximately one fifth compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 10. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 11. Material adhering to the inside of the mold trimmed? | _____ | _____ |
| 12. Layer of soil (approximately two fifths compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 13. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 14. Material adhering to the inside of the mold trimmed? | _____ | _____ |
| 15. Layer of soil (approximately three fifths compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 16. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |

**OVER**

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 17. Material adhering to the inside of the mold trimmed? | _____ | _____ |
| 18. Layer of soil (approximately four fifths compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 19. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 20. Material adhering to the inside of the mold trimmed? | _____ | _____ |
| 21. Mold filled with soil such that compacted soil will be above the mold, loose material lightly tamped? | _____ | _____ |
| 22. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 23. Collar removed without shearing off sample? | _____ | _____ |
| 24. Approximately 6 mm (1/4 in.) of compacted material above the top of the mold (without the collar)? | _____ | _____ |
| 25. Soil trimmed to top of mold with the beveled side of the straightedge? | _____ | _____ |
| 26. Remove all soil from exterior surface of mold and base plate? | _____ | _____ |
| 27. Mass of mold and contents determined to appropriate precision (1 g)? | _____ | _____ |
| 28. Wet density calculated from the wet mass? | _____ | _____ |
| 29. Soil removed from mold using a sample extruder if needed? | _____ | _____ |
| 30. Soil sliced vertically through center (non-granular material)? | _____ | _____ |
| 31. Moisture sample removed ensuring all layers are represented? | _____ | _____ |
| 32. Moist mass determined immediately to 0.1 g? | _____ | _____ |
| 33. Moisture sample mass of correct size? | _____ | _____ |
| 34. Sample dried, and water content determined according to the FOP for T 255/T 265? | _____ | _____ |
| 35. Remainder of material from mold broken up until it will pass through the sieve, as judged by eye, and added to remainder of original test sample? | _____ | _____ |
| 36. Water added to increase moisture content of the remaining sample in approximately 1 to 2 percent increments? | _____ | _____ |
| 37. Steps 2 through 20 repeated for each increment of water added? | _____ | _____ |
| 38. Process continued until wet density either decreases or stabilizes? | _____ | _____ |
| 39. Moisture content and dry density calculated for each sample? | _____ | _____ |
| 40. Dry density plotted on vertical axis, moisture content plotted on horizontal axis, and points connected with a smooth curve? | _____ | _____ |
| 41. Moisture content at peak of curve recorded as optimum water content and recorded to nearest 0.1 percent? | _____ | _____ |
| 42. Dry density at optimum moisture content reported as maximum density to nearest 1 kg/m$^3$ (0.1 lb/ft$^3$)? | _____ | _____ |

**OVER**

| **Procedure Element** | **Trial 1** | **Trial 2** |
|---|---|---|
| 43. Corrected for coarse particles if applicable? | _____ | _____ |

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

_____
_____
_____
_____
_____
_____
_____
_____

Examiner Signature _____WAQTC #:_____

# DEVELOPING A FAMILY OF CURVES FOP FOR AASHTO R 75

01

## Significance

02 Soils sampled from one source will have many different moisture-density curves, but if a group of these curves is plotted together, similarities or relationships are usually seen. A family of curves is a group of soil moisture-density relationships that reveal similarities characteristic of the soil type and source. Higher-density soils have curves with steeper slopes and maximum dry densities at lower optimum moisture contents, while the lower-density soils have flatter curves with higher optimum moisture contents.

## Scope

03 This procedure provides a method to develop a family of curves using multiple moisture density relationships developed using the same method, A, B, C, or D from the FOP for AASHTO T 99/T 180 in accordance with AASHTO R 75-16.

04 All curves used in a family must be developed using a single Method: A, B, C, or D of a procedure for AASHTO T 99 or T 180. See the FOP for AASHTO T 99/T 180.

| Mold \ Sieve | 4.75 mm (No. 4) | 19 mm (3/4”) |
|---|---|---|
| 4” | A | C |
| 6” | B | D |

**Methods of T 99 / T 180**

05

## Terminology

***family of curves*** — a group of soil moisture-density relationships (curves) determined using AASHTO T 99 or T 180, which reveal certain similarities and trends characteristic of the soil type and source.

***spine*** — smooth line extending through the point of maximum density/optimum moisture content of a family of moisture-density curves.

## Procedure

1. Sort the curves by Method (A, B, C, or D of the FOP for T 99/T 180). At least three curves are required to develop a family. 06
2. Select the highest and lowest maximum dry densities from those selected to assist in

determining the desired scale of the subsequent graph.

3. Plot the maximum density and optimum moisture points of the selected curves on the graph.
4. Draw a smooth, "best fit," curved line through the points creating the spine of the family of curves.
5. Remove maximum density and optimum moisture points that were not used to establish the spine.
6. Add the moisture/density curves associated with the points that were used to establish the spine. It is not necessary to include the portion of the curves over optimum moisture.

***Note 1***—Intermediate template curves using slopes similar to those of the original moisture-density curves may be included when maximum density points are more than 2.0 lb/ft$^3$ apart. Template curves are indicated by a dashed line.

7. Plot the 80 percent of optimum moisture range when desired:
   a. Using the optimum moisture of an existing curve, calculate 80 percent of optimum moisture and plot this value on the curve. Repeat for each curve in the family.
   b. Draw a smooth, "best fit," curved line connecting the 80 percent of optimum moisture points plotted on the curves that parallel the spine.

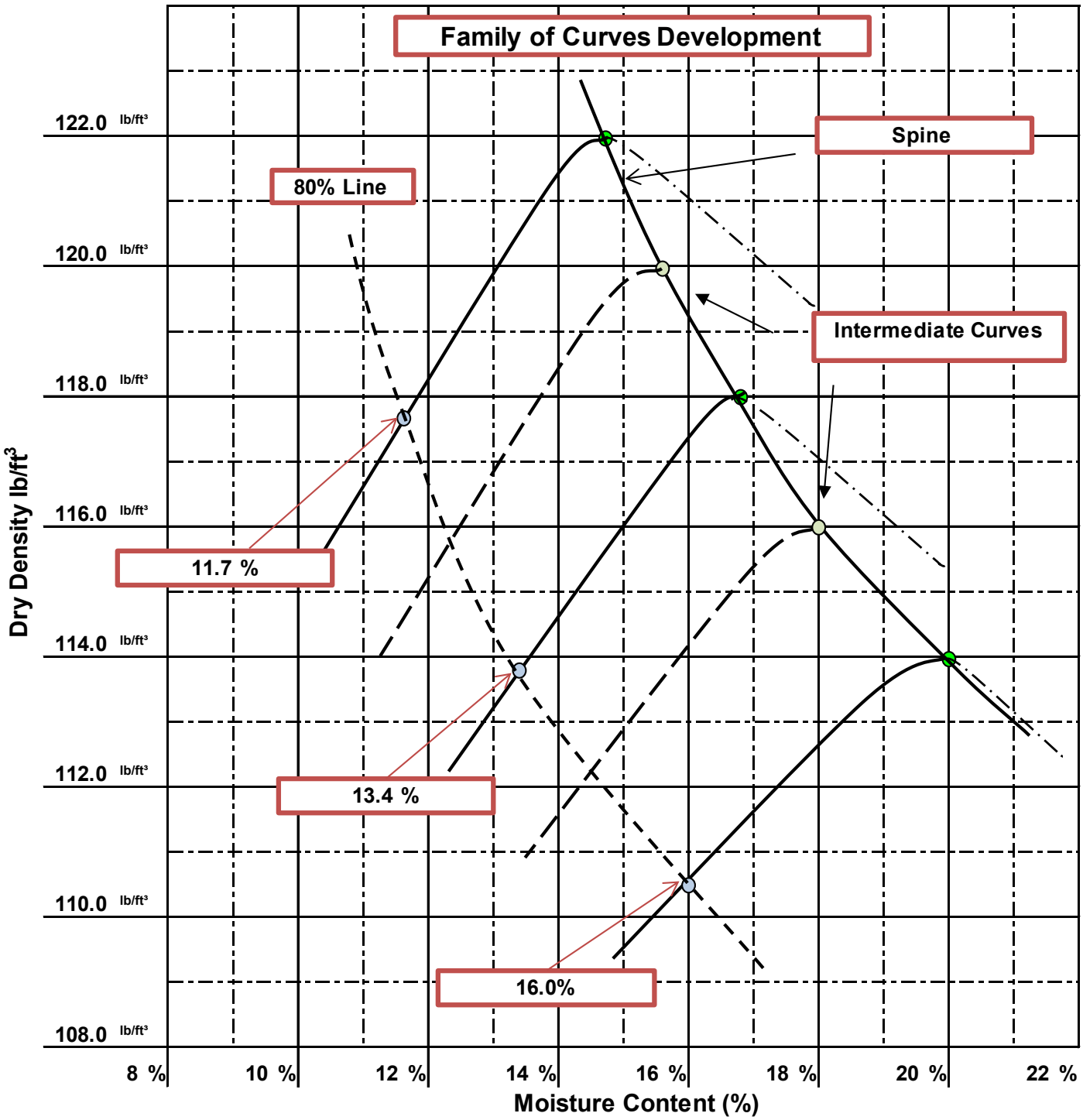
## Calculations

Calculate 80 percent of optimum moisture of each curve:

Example:

Optimum moisture of the highest density curve = 14.6%

$$80\%\ of\ optimum\ moisture = \frac{80\% \times 14.6\%}{100} = 11.7\%$$


Family of Curves Development
Spine
80% Line
Intermediate Curves
11.7 %
13.4 %
16.0%
122.0 lb/ft³
120.0 lb/ft³
118.0 lb/ft³
116.0 lb/ft³
114.0 lb/ft³
112.0 lb/ft³
110.0 lb/ft³
108.0 lb/ft³
Dry Density lb/ft³
8 %
10 %
12 %
14 %
16 %
18 %
20 %
22 %
Moisture Content (%)

**Tips!**

17

- Make sure that the selected moisture/density relationship curves were developed using the same method from the FOP for AASHTO T 99 / T 180 – A, B, C, or D

## REVIEW QUESTIONS

1. To what other procedure(s) is this procedure related?

2. What does the 'spine' of the curve mean?

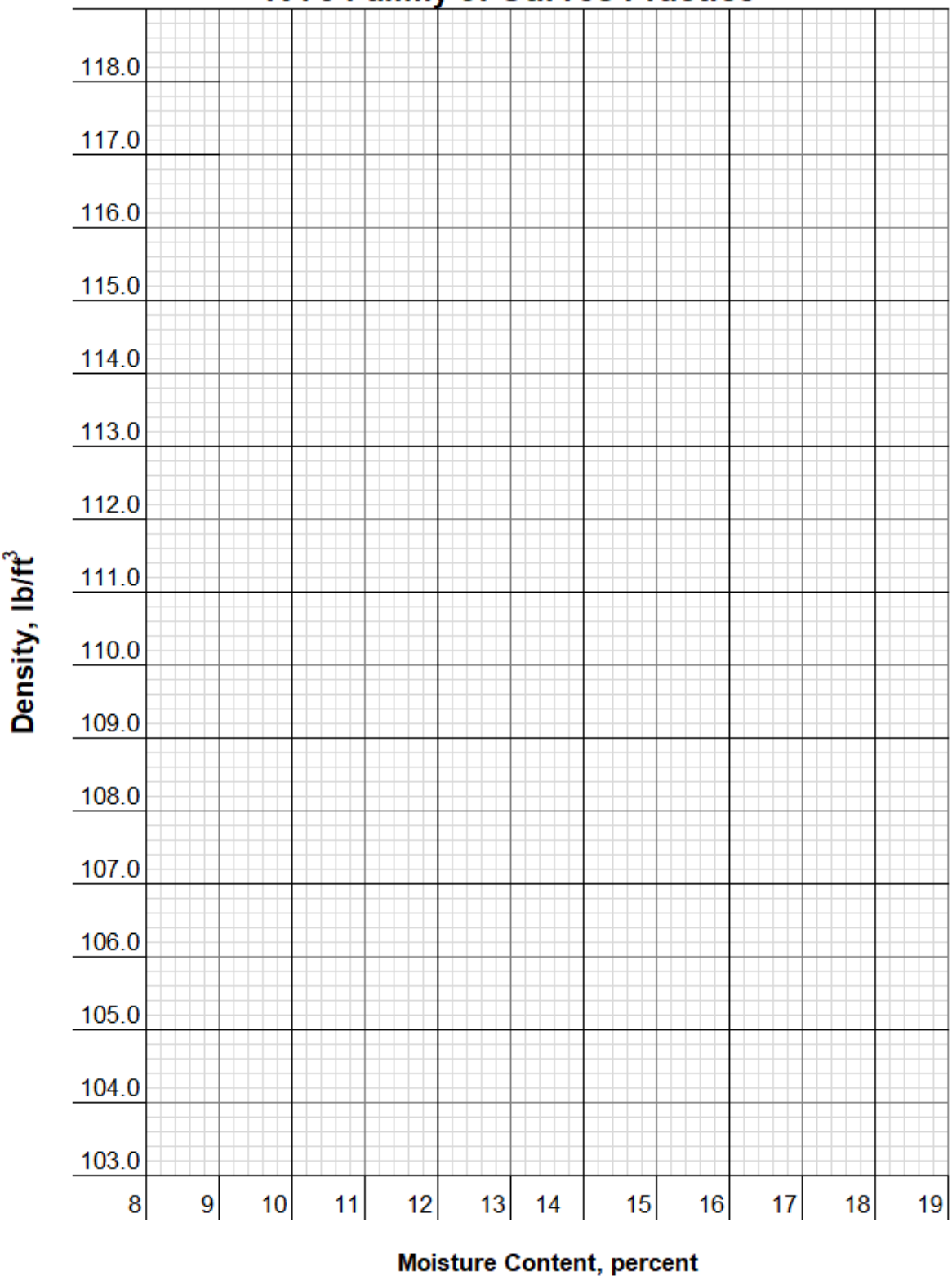
3. Describe the limitations of developing a family of curves.

## STEPS FOR DEVELOPING A FAMILY OF CURVES

1. Sort the curves by Test Procedure.
2. Sort the curves by Method.
3. Select a group of curves with three or more.
4. Determine the scale of the graph.
   a. For the vertical axis, identify the highest maximum dry density and the lowest point from the lowest dry density curve.
   b. For the horizontal axis, identify the lowest and highest percent moisture contents of the points of the curves.
5. Plot the maximum dry density and optimum moisture points of the selected curves on the graph.
6. Do at least three curves 'line up' to draw a 'spine?'
   a. Draw a smooth, 'best fit,' curved line through the points that line up creating the spine of the family of curves.
7. Remove the point of the curves that don't fit the spine.
8. Plot the full curve of the points on the spine (points over optimum moisture are not required).
9. Are intermediate template curves desired?
   a. Maximum dry density points more than 2.0 $lb/ft^3$ apart
   b. Draw template curves with dashed lines using a similar slope as the original curves
10. Plot the 80 percent of optimum moisture range when desired
    a. Using the optimum moisture of the existing curve, calculate 80 percent of optimum moisture and plot this value on the curve. Repeat for each curve in the family.
    b. Draw a smooth, "best fit," curved line connecting the 80 percent of optimum moisture points plotted on the curves that parallel the spine.

| Moisture – Density Curve ID | Dry Density lb/ft$^3$ | Dry Density lb/ft$^3$ | Dry Density lb/ft$^3$ | Maximum Dry Density lb/ft$^3$ | Dry Density lb/ft$^3$ | Dry Density lb/ft$^3$ |
|---|---|---|---|---|---|---|
| | Moisture Content, % | Moisture Content, % | Moisture Content, % | Optimum Moisture, % | Moisture Content, % | Moisture Content, % |
| #1 | 104.4 | 105.1 | 105.8 | 106.2 | 106.0 | 104.2 |
| T 99 A | 14.1 | 14.8 | 15.8 | 17.1 | 18.1 | 20.1 |
| #2 | 106.2 | 106.9 | 107.6 | 108.0 | 107.8 | 106.0 |
| T 180 A | 13.3 | 14.1 | 15.1 | 16.4 | 17.4 | 19.4 |
| #3 | 108.2 | 111.2 | 113.6 | 114.0 | 113.5 | 111.4 |
| T 180 A | 9.4 | 10.4 | 11.6 | 12.5 | 13.2 | 14.7 |
| #4 | 109.4 | 110.6 | 111.8 | 112.2 | 111.7 | 109.6 |
| T 99 A | 11.1 | 11.6 | 12.3 | 13.2 | 13.9 | 15.4 |
| #5 | 112.1 | 113.2 | 114.7 | 115.4 | 114.7 | 113.0 |
| T 99 C | 9.8 | 10.3 | 11.0 | 11.8 | 13.2 | 13.5 |
| #6 | 111.4 | 114.2 | 116.5 | 117.2 | 116.5 | 114.8 |
| T 180 A | 8.2 | 9.2 | 10.3 | 11.1 | 12.0 | 12.8 |
| #7 | 112.8 | 115.0 | 116.6 | 117.2 | 116.2 | 114.4 |
| T 180 A | 13.0 | 13.6 | 14.0 | 14.5 | 15.2 | 15.9 |
| #8 | 105.0 | 107.2 | 108.5 | 109.0 | 107.6 | 105.2 |
| T 180 A | 8.3 | 9.0 | 9.5 | 10.1 | 11.2 | 12.2 |
| #9 | 106.6 | 108.4 | 110.2 | 110.6 | 110.1 | 108.4 |
| T 180 A | 10.5 | 11.6 | 13.2 | 14.3 | 15.6 | 17.4 |
| #10 | 111.0 | 113.2 | 114.8 | 115.4 | 114.4 | 112.6 |
| T 99 C | 13.7 | 14.3 | 14.7 | 15.2 | 15.9 | 16.5 |

## R 75 Family of Curves Practice



## PERFORMANCE EXAM CHECKLIST

## DEVELOPING A FAMILY OF CURVES
## FOP FOR AASHTO R 75

Participant Name _____ Exam Date _____

**Record the symbols "P" for passing or "F" for failing on each step of the checklist**.

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 1. Curves sorted by method and procedure (A, B, C, or D of the FOP for T 99/T 180)? | _____ | _____ |
| a. At least three curves per family? | _____ | _____ |
| b. Curves within family are similar soil type and from same source? | _____ | _____ |
| 2. Maximum density and optimum moisture points plotted on the graph? | _____ | _____ |
| 3. Spine drawn correctly? | _____ | _____ |
| 4. Maximum density and optimum moisture points removed that were not used for the spine? | _____ | _____ |
| 5. Moisture/density curves added? | _____ | _____ |
| 6. Optimum moisture range? | _____ | _____ |
| a. 80 percent of optimum moisture calculated for each curve? | _____ | _____ |
| b. Curved line through 80 percent of optimum moisture drawn correctly? | _____ | _____ |

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

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Examiner Signature _____WAQTC #:_____

# ONE-POINT METHOD FOR DETERMINING MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE
# FOP FOR AASHTO T 272

01 ## Significance

02 Soils sampled from one source will have many different moisture-density curves, but if a group of these curves is plotted together, similarities or relationships are usually seen. A family of curves is a group of soil moisture-density relationships that reveal similarities characteristic of the soil type and source. Higher-density soils have curves with steeper slopes and maximum dry densities at lower optimum moisture contents, while the lower-density soils have flatter curves with higher optimum moisture contents.

03 In the field, density and moisture content are determined, and a single point is plotted on an individual moisture curve or family of curves graphs.

## Scope

04 This procedure provides for a rapid determination of the maximum dry density and optimum moisture content of a soil sample using a one-point determination in accordance with AASHTO T 272-18. This procedure is related to the FOP for AASHTO T 99/T 180 and R 75.

05 One-point determinations are made by compacting the soil in a mold of a given size with a specified rammer dropped from a specified height and then compared to an individual moisture/density curve (FOP for AASHTO T 99 or T 180) or a family of curves (FOP for AASHTO R 75). Four alternate methods – A, B, C, and D – are used and correspond to the methods described in the FOP for AASHTO T 99/T 180. The method used in AASHTO T 272 must match the method used for the reference curve or to establish the family of curves. For example, when moisture-density relationships as determined by T 99 - Method C are used to form the family of curves or an individual moisture density curve, then T 99 - Method C must be used to for the one-point determination.

## Apparatus

See the FOP for AASHTO T 99/T 180. Use the method matching the individual curve or Family of Curves. Refer to Table 1 of the FOP for AASHTO T 99/T 180 for corresponding mold size, number of layers, number of blows, and rammer specification for the various test methods.

## Sample

Sample size is determined according to the FOP for AASHTO T 310. In cases where the existing individual curve or family cannot be used, a completely new curve must be developed and the sample size determined by the FOP for AASHTO T 99/T 180.

06 If the sample is damp, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus maintained at a temperature not exceeding 60°C (140°F). Thoroughly break up aggregations in a manner that avoids reducing the natural size of individual particles.

07 ## Procedure

**Dense, uniform, rigid foundation**

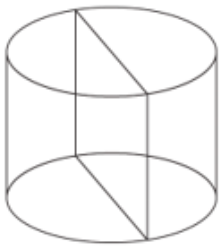
1. Determine the mass of the clean, dry mold. Include the base plate but exclude the extension collar. Record the mass to the nearest 1 g (0.005 lb). 08
2. Thoroughly mix the sample with sufficient water to adjust moisture content to 80 to 100 percent of the anticipated optimum moisture.
3. Form a specimen by compacting the prepared soil in the mold (with collar attached) in approximately equal layers. For each layer:
   a. Spread the loose material uniformly in the mold.

*Note 1:* It is recommended to cover the remaining material with a non-absorbent sheet or damp cloth to minimize loss of moisture.

   b. Lightly tamp the loose material with the manual rammer or other similar device, this establishes a firm surface.

**Trim soil**

09



**Extruded material**

10

11

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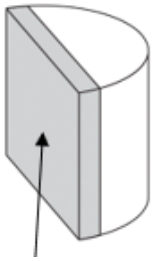

**Representative Moisture Content Sample**

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**Mass of mold and wet sample**

16

c. Compact each layer with uniformly distributed blows from the rammer.
d. Trim down material that has not been compacted and remains adjacent to the walls of the mold and extends above the compacted surface.

4. Remove the extension collar. Avoid shearing off the sample below the top of the mold. The material compacted in the mold should not be over 6 mm (¼ in.) above the top of the mold once the collar has been removed.
5. Trim the compacted soil even with the top of the mold with the beveled side of the straightedge.
6. Clean soil from exterior of the mold and base plate.
7. Determine the mass of the mold and wet soil to the nearest 1 g (0.005 lb) or better.
8. Determine the wet mass of the sample by subtracting the mass in Step 1 from the mass in Step 7.
9. Calculate the wet density as indicated below under “Calculations.”
10. Extrude the material from the mold. For soils and soil-aggregate mixtures, slice vertically through the center and take a representative moisture content sample from one of the cut faces, ensuring that all layers are represented. For granular materials, a vertical face will not exist. Take a representative sample. This sample must meet the sample size requirements of the test method used to determine moisture content.
11. Determine the moisture content of the sample in accordance with the FOP for AASHTO T 255 / T 265.

## Calculations

1. Calculate the wet density, in kg/m$^3$ (lb/ft$^3$), by dividing the wet mass by the measured volume of the mold (T 19).

   Example – Methods A or C mold: 17

   Wet mass = 2.0055 kg (4.42 lb)

   Measured volume of the mold = 0.0009469 m$^3$ (0.03344 ft$^3$)

$$Wet\ Density = \frac{2.0055\ kg}{0.0009469\ m^3} = 2118\ kg/m^3$$

$$Wet\ Density = \frac{4.42\ lb}{0.03344\ ft^3} = 132.2\ lb/ft^3$$

2. Calculate the dry density as follows. 18

$$\rho_d = \left(\frac{\rho_w}{w + 100}\right) \times 100 \quad or \quad \rho_d = \frac{\rho_w}{\left(\frac{w}{100}\right) + 1}$$

Where:

$\rho_d$ = Dry density, kg/m$^3$ (lb/ft$^3$)

$\rho_w$ = Wet density, kg/m$^3$ (lb/ft$^3$)

w = Moisture content, as a percentage

Example:

$\rho_w$ = 2118 kg/m$^3$ (132.2 lb/ft$^3$)

w = 13.5%

$$\rho_d = \left(\frac{2118\ kg/m^3}{13.5 + 100}\right) \times 100 = 1866\ kg/m^3 \quad \rho_d = \left(\frac{132.2\ lb/ft^3}{13.5 + 100}\right) \times 100 = 116.5\ lb/ft^3$$ 19

or

$$\rho_d = \left(\frac{2118\ kg/m^3}{\frac{13.5}{100} + 1}\right) = 1866\ kg/m^3 \quad \rho_d = \left(\frac{132.2\ lb/ft^3}{\frac{13.5}{100} + 1}\right) = 116.5\ lb/ft^3$$

## Maximum Dry Density and Optimum Moisture Content Determination Using an Individual Moisture / Density Curve

1. The moisture content must be within 80 to 100 percent of optimum moisture of the reference curve. Compact another specimen, using the same material, at an adjusted moisture content if the one-point does not fall in the 80 to 100 percent of optimum moisture range.

20

2. Plot the one-point, dry density on the vertical axis and moisture content on the horizontal axis, on the reference curve graph.

3. If the one-point falls on the reference curve or within ±2.0 lb/ft$^3$, use the maximum dry density and optimum moisture content determined by the curve.

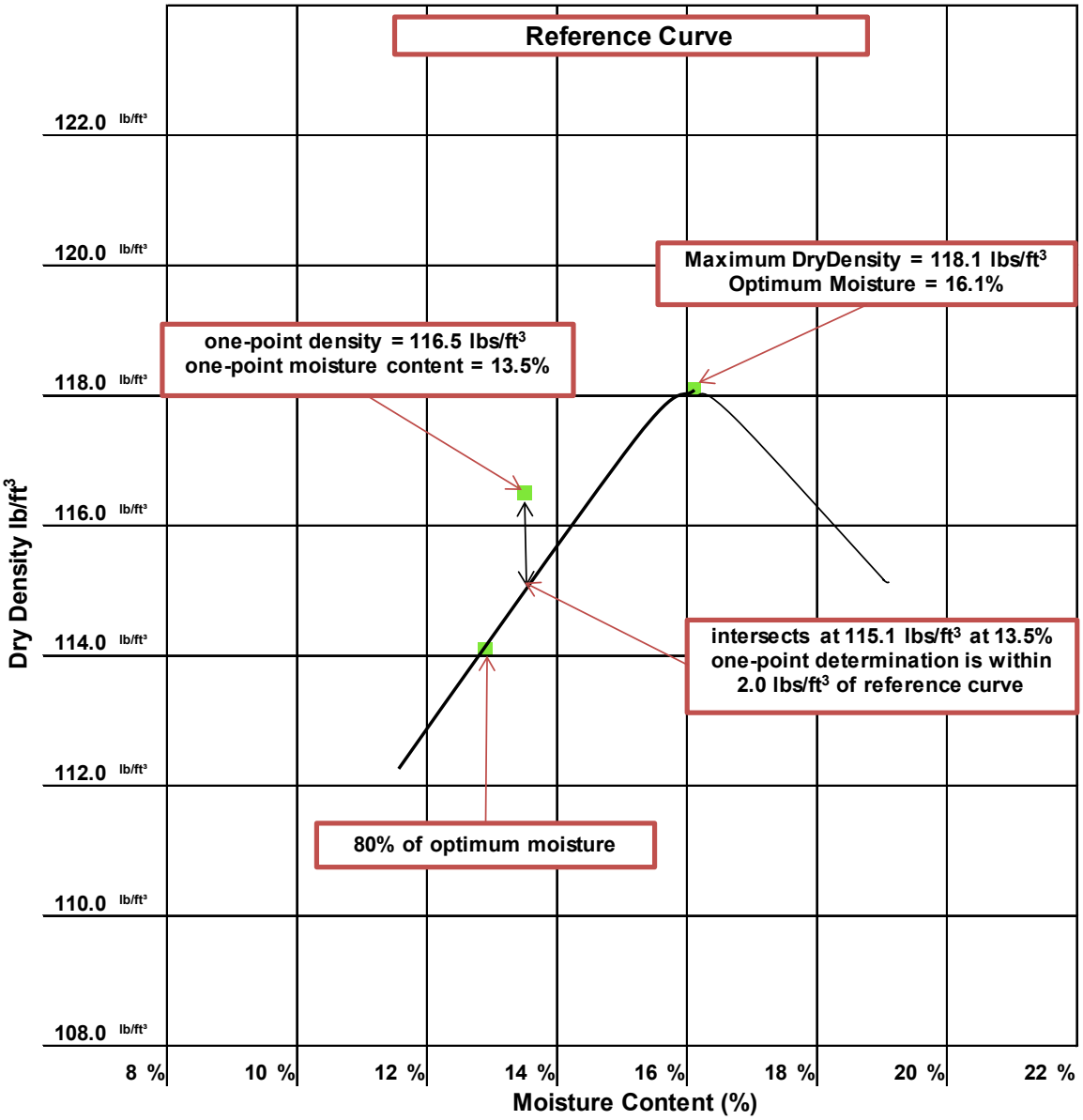
21

4. Use the FOP for AASHTO T 99/T 180 Annex A to determine corrected maximum dry density and optimum moisture content if oversize particles have been removed.

23

5. Perform a full moisture-density relationship if the one-point does not fall on or within ±2.0 lb/ft$^3$ of the reference curve at 80 to 100 percent optimum moisture.

## Example




**Example:** 22

The results of a one-point determination were 116.5 lb/ft$^3$ at 13.5 percent moisture. The point was plotted on the reference curve graph. The point was plotted on the reference curve graph. The one-point determination is within 2.0 lb/ft$^3$ of the point on the curve that corresponds with the moisture content.

## Maximum Dry Density and Optimum Moisture Content Determination Using a Family of Curves

24 1. Plot the one-point, dry density on the vertical axis and moisture content on the horizontal axis, on the reference family of curves graph.

2. If the moisture-density one-point falls on one of the curves in the family of curves, use the maximum dry density and optimum moisture content defined by that curve.

25 3. If the moisture-density one-point falls within the family of curves but not on an existing curve, draw a new curve through the plotted single point parallel and in character with the nearest existing curve in the family of curves. Use the maximum dry density and optimum moisture content as defined by the new curve.

26 a. The one-point must fall either between or on the highest or lowest curves. If it does not, then a full curve must be developed.

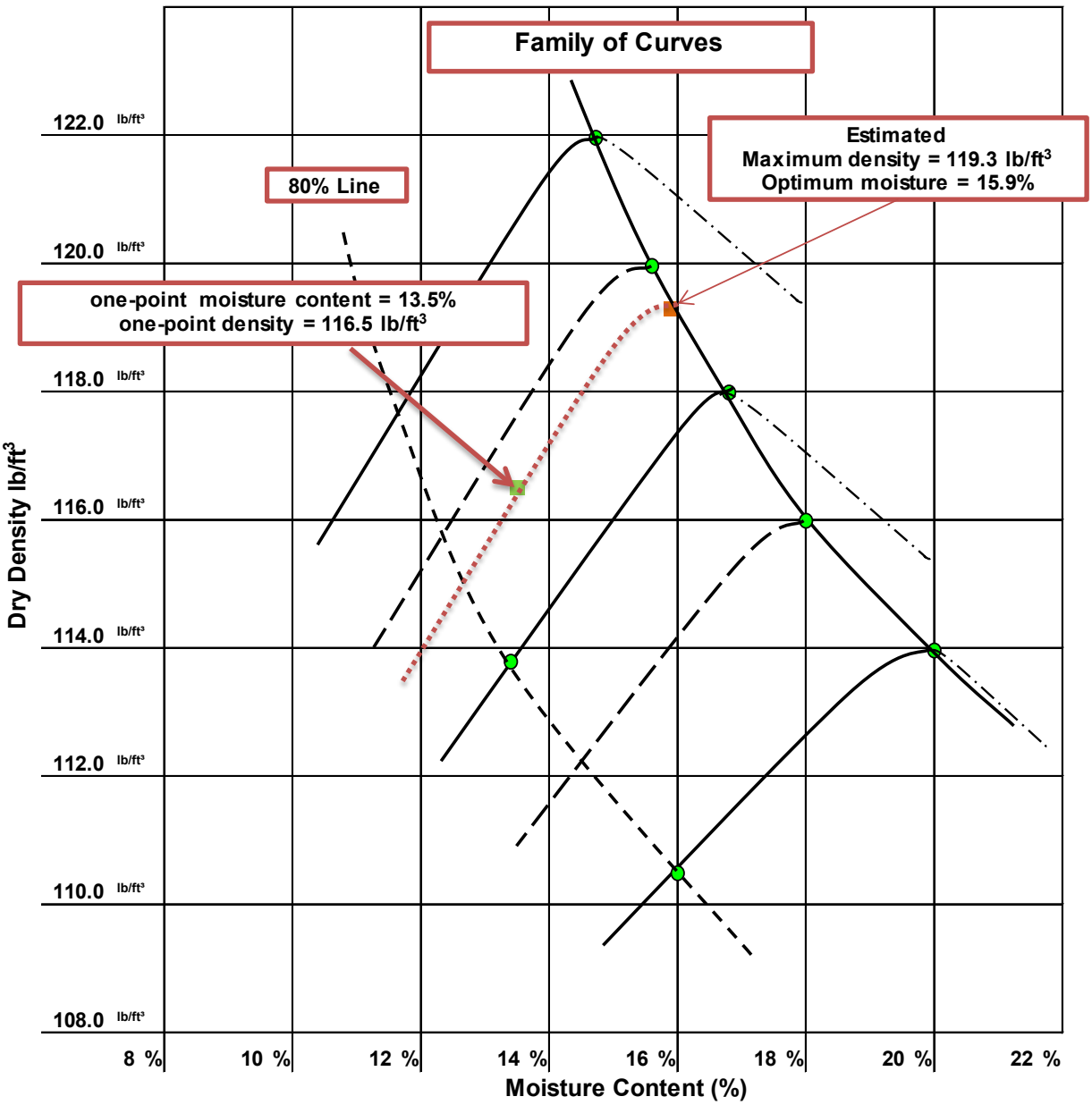
b. If the one-point plotted within or on the family of curves does not fall in the 80 to 100 percent of optimum moisture content, compact another specimen, using the same material, at an adjusted moisture content that will place the one-point within this range.

27 4. Use the FOP for AASHTO T 99/T 180 Annex A to determine corrected maximum dry density and optimum moisture content if oversize particles have been removed.

5. If the new curve through a one-point is not well defined or is in any way questionable, perform a full moisture-density relationship to correctly define the new curve and verify the applicability of the family of curves.

***Note 2:*** New curves drawn through plotted single point determinations shall not become a permanent part of the family of curves until verified by a full moisture-density procedure following the FOP for AASHTO T 99/T 180.

## EXAMPLE




The results of a one-point determination were 116.5 lb/ft$^3$ at 13.5 percent moisture. The point was plotted on the reference curve graph. The point was plotted on the appropriate family between two previously developed curves near and intermediate curve.

The "dotted" curve through the moisture-density one-point was sketched between the existing curves. A maximum dry density of 119.3 lb/ft$^3$ and a corresponding optimum moisture content of 15.9 percent were estimated.

29

## Report

- Results on forms approved by the agency
- Sample ID
- Maximum dry density to the nearest 1 kg/m$^3$ (0.1 lb/ft$^3$)
- Corrected maximum dry density (if applicable)
- Optimum moisture content to the nearest 0.1 percent
- Corrected optimum moisture content (if applicable)
- Reference curve or Family of Curves used

30

## Tips!

- Make sure that the moisture content of the one-point sample is between 80 and 100 percent of optimum moisture.
- Remember that a full moisture-density procedure shall be made if the curve drawn through the one-point is not well defined or is questionable.

## REVIEW QUESTIONS

1. To what other procedure(s) is this procedure related?

2. How are the two procedures used together?

3. Describe the limitations of using the one-point determination with a family of curves.

4. Describe the limitations of using the one-point determination with a single reference curve.

## PERFORMANCE EXAM CHECKLIST

## ONE-POINT METHOD
## FOP FOR AASHTO T 272 (T 99)

Participant Name _____ Exam Date _____

**Record the symbols "P" for passing or "F" for failing on each step of the checklist**.

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 1. One-point determination of dry density and corresponding moisture content made in accordance with the FOP for AASHTO T 99? | _____ | _____ |
| a. Correct size (4.75 mm / No. 4 or 19.0 mm / 3/4 in.) material used? | _____ | _____ |
| 2. If necessary, sample dried until friable in air or drying apparatus, not exceeding 60°C (140°F)? | _____ | _____ |
| 3. Sample broken up and an adequate amount sieved over the appropriate sieve (4.75 mm / No. 4 or 19.0 mm / 3/4 in.) to determine oversize (coarse particle) percentage? | _____ | _____ |
| 4. Sample passing the sieve has appropriate mass? | _____ | _____ |
| 5. Moisture content adjusted if needed? | _____ | _____ |
| 6. Determine mass of clean, dry mold without collar to nearest 1 g? | _____ | _____ |
| 7. Mold placed on rigid and stable foundation? | _____ | _____ |
| 8. Layer of soil (approximately one third compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 9. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 10. Material adhering to the inside of the mold trimmed? | _____ | _____ |
| 11. Layer of soil (approximately two thirds compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 12. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 13. Material adhering to the inside of the mold trimmed? | _____ | _____ |
| 14. Mold filled with soil such that compacted soil will be above the mold, loose material lightly tamped? | _____ | _____ |
| 15. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 16. Collar removed without shearing off sample? | _____ | _____ |
| 17. Approximately 6 mm (1/4 in.) of compacted material above the top of the mold (without the collar)? | _____ | _____ |
| 18. Soil trimmed to top of mold with the beveled side of the straightedge? | _____ | _____ |
| 19. Remove soil from exterior surface of mold and base plate? | _____ | _____ |
| 20. Mass of mold and contents determined to appropriate precision? | _____ | _____ |

**OVER**

| **Procedure Element** | **Trial 1** | **Trial 2** |
|---|---|---|
| 21. Wet density calculated from the wet mass? | _____ | _____ |
| 22. Soil removed from mold using a sample extruder if needed? | _____ | _____ |
| 23. Soil sliced vertically through center (non-granular material)? | _____ | _____ |
| 24. Moisture sample removed ensuring all layers are represented? | _____ | _____ |
| 25. Moist mass determined immediately to 0.1 g? | _____ | _____ |
| 26. Moisture sample mass of correct size? | _____ | _____ |
| 27. Sample dried and water content determined according to the FOP for T 255/T 265? | _____ | _____ |
| 28. One-point plotted on family of curves supplied? | _____ | _____ |
| a. One-point falls within 80 to 100 percent of optimum moisture content in order to be valid? | _____ | _____ |
| b. If one-point does not fall within 80 to 100 percent of optimum moisture content, another one-point determination with an adjusted water content is made? | _____ | _____ |
| c. Maximum dry density and corresponding optimum moisture content correctly estimated? | _____ | _____ |
| 29. One-point plotted on a single reference curve? | _____ | _____ |
| a. Does one-point plot within 2 lb/ft$^3$ in order to be valid? | _____ | _____ |
| b. Does one-point fall within 80 to 100 percent of optimum moisture content in order to be valid? | _____ | _____ |
| c. Maximum dry density and corresponding optimum moisture content determined from single reference curve? | _____ | _____ |

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

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Examiner Signature _____WAQTC #:_____

## PERFORMANCE EXAM CHECKLIST

## ONE-POINT METHOD
## FOP FOR AASHTO T 272 (T 180)

Participant Name _____ Exam Date _____

**Record the symbols "P" for passing or "F" for failing on each step of the checklist**.

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 1. One-point determination of dry density and corresponding moisture content made in accordance with the FOP for AASHTO T 180? | _____ | _____ |
| a. Correct size (4.75 mm / No. 4 or 19.0 mm / 3/4 in.) material used? | _____ | _____ |
| 2. If necessary, sample dried until friable in air or drying apparatus, not exceeding 60°C (140°F)? | _____ | _____ |
| 3. Sample broken up and an adequate amount sieved over the appropriate sieve (4.75 mm / No. 4 or 19.0 mm / 3/4 in.) to determine oversize (coarse particle) percentage? | _____ | _____ |
| 4. Sample passing the sieve has appropriate mass? | _____ | _____ |
| 5. Moisture content adjusted if needed? | _____ | _____ |
| 6. Determine mass of clean, dry mold without collar to nearest 1 g? | _____ | _____ |
| 7. Mold placed on rigid and stable foundation? | _____ | _____ |
| 8. Layer of soil (approximately one fifth compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 9. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 10. Material adhering to the inside of the mold trimmed? | _____ | _____ |
| 11. Layer of soil (approximately two fifths compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 12. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 13. Material adhering to the inside of the mold trimmed? | _____ | _____ |
| 14. Layer of soil (approximately three fifths compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 15. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 16. Material adhering to the inside of the mold trimmed? | _____ | _____ |
| 17. Layer of soil (approximately four fifths compacted depth) placed in mold with collar attached, loose material lightly tamped? | _____ | _____ |
| 18. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 19. Material adhering to the inside of the mold trimmed? | _____ | _____ |

**OVER**

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 20. Mold filled with soil such that compacted soil will be above the mold, loose material lightly tamped? | _____ | _____ |
| 21. Soil compacted with appropriate number of blows (25 or 56)? | _____ | _____ |
| 22. Collar removed without shearing off sample? | _____ | _____ |
| 23. Approximately 6 mm (1/4 in.) of compacted material above the top of the mold (without the collar)? | _____ | _____ |
| 24. Soil trimmed to top of mold with the beveled side of the straightedge? | _____ | _____ |
| 25. Remove soil from exterior surface of mold and base plate? | _____ | _____ |
| 26. Mass of mold and contents determined to appropriate precision? | _____ | _____ |
| 27. Wet density calculated from the wet mass? | _____ | _____ |
| 28. Soil removed from mold using a sample extruder if needed? | _____ | _____ |
| 29. Soil sliced vertically through center (non-granular material)? | _____ | _____ |
| 30. Moisture sample removed ensuring all layers are represented? | _____ | _____ |
| 31. Moist mass determined immediately to 0.1 g? | _____ | _____ |
| 32. Moisture sample mass of correct size? | _____ | _____ |
| 33. Sample dried and water content determined according to the FOP for T 255/T 265? | _____ | _____ |
| 34. One-point plotted on family of curves supplied? | _____ | _____ |
| a. One-point falls within 80 to 100 percent of optimum moisture content in order to be valid? | _____ | _____ |
| b. If one-point does not fall within 80 to 100 percent of optimum moisture content, another one-point determination with an adjusted water content is made? | _____ | _____ |
| c. Maximum dry density and corresponding optimum moisture content correctly estimated? | _____ | _____ |
| 35. One-point plotted on a single reference curve? | _____ | _____ |
| a. Does one-point plot within 2 lb/ft$^3$ in order to be valid? | _____ | _____ |
| b. Does one-point fall within 80 to 100 percent of optimum moisture content in order to be valid? | _____ | _____ |
| c. Maximum dry density and corresponding optimum moisture content determined from single reference curve? | | |

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

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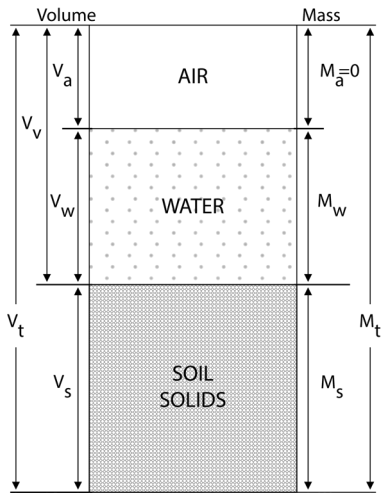
Examiner Signature _____WAQTC #:_____

# SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE FOP FOR AASHTO T 85




**Phase diagram**

01

## Significance

Bulk specific gravity is a characteristic used for calculating the volume occupied by the aggregate or various mixtures containing aggregate, including Portland Cement Concrete, bituminous mixes, and other materials that are proportioned or analyzed on an absolute volume basis. Specific gravity is the ratio of the mass of a material to the mass of an equal volume of water. Several categories of specific gravity are used relative to aggregate.

02

Bulk specific gravity (oven dry), $G_{sb}$, is used for computations when the aggregate is dry. Bulk specific gravity (saturated surface dry or SSD), $G_{sb}$ SSD, is used if the aggregate is wet. Apparent specific gravity, $G_{sa}$, is based solely on the solid material making up the constituent particles and does not include the pore space within the particles that is accessible to water.

03

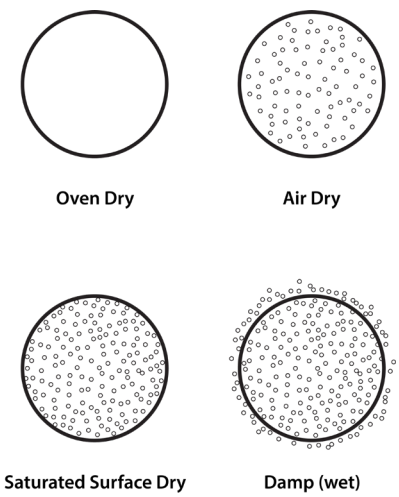
Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for between 15 to 19 hours in water. Aggregates mined from below the water table may have a higher absorption, when used, if not allowed to dry. Conversely, some aggregates, when used, may contain an amount of absorbed moisture less than the 15 hours soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture can be determined by deducting the absorption from the total moisture content.

The pores in lightweight aggregates may or may not become filled with water after immersion for 15 hours. In fact, many such aggregates can remain immersed in water for several days without satisfying most of the aggregates' absorption

potential. Therefore, this method is not intended for use with lightweight aggregate.

## Scope

This procedure covers the determination of specific gravity and absorption of coarse aggregate in accordance with AASHTO T 85-14. Specific gravity may be expressed as bulk specific gravity ($G_{sb}$), bulk specific gravity - saturated surface dry ($G_{sb}$ SSD), or apparent specific gravity ($G_{sa}$). $G_{sb}$ and absorption are based on aggregate after soaking in water. This procedure is not intended for use with lightweight aggregates.




**Moisture conditions**

## Terminology

Absorption – the increase in the mass of aggregate due to water being absorbed into the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. The aggregate is considered "dry" when it has been maintained at a temperature of 110 ±5°C (230 ±9°F) for sufficient time to remove all uncombined water.

Saturated Surface Dry (SSD) – the condition of an aggregate particle when the permeable voids are filled with water, but no water is present on exposed surfaces.

Specific Gravity – the ratio of the mass, in air, of a volume of a material to the mass of the same volume of gas-free distilled water at a stated temperature.

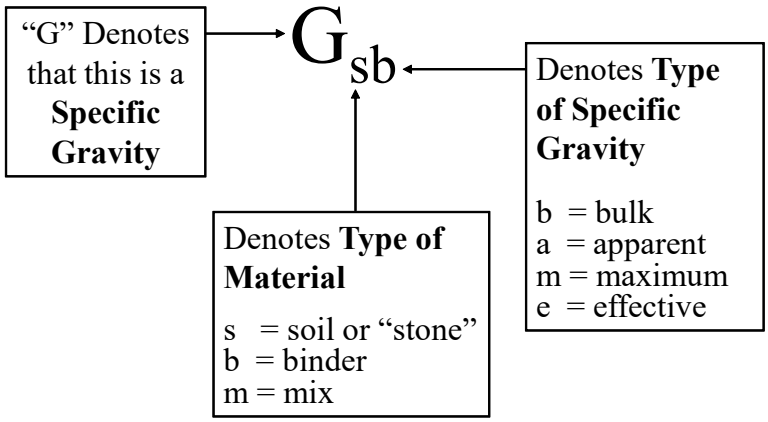
Apparent Specific Gravity ($G_{sa}$) – the ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of gas-free distilled water at a stated temperature.

Bulk Specific Gravity ($G_{sb}$ ) – the ratio of the mass, in air, of a volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of gas-free distilled water at a stated temperature.

Bulk Specific Gravity (SSD) ($G_{sb}$ SSD) – the ratio of the mass, in air, of a volume of aggregate,

including the mass of water within the voids filled to the extent achieved by submerging in water for 15 to 19 hours (but not including the voids between particles), to the mass of an equal volume of gas-free distilled water at a stated temperature.

## Definition: (Specific Gravity Symbols)




8

**Sample container and scale**

09

10

### Apparatus

- Balance or scale: with a capacity of 5 kg, sensitive to 1 g, and meeting the requirements of AASHTO M 231.
- Sample container: a wire basket of 3.35 mm (No. 6) or smaller mesh, with a capacity of 4 to 7 L (1 to 2 gal) to contain aggregate with a nominal maximum size of 37.5 mm (1 1/2 in.) or smaller; or a larger basket for larger aggregates, or both.
- Water tank: watertight and large enough to completely immerse aggregate and basket, equipped with an overflow valve to keep water level constant.
- Suspension apparatus: wire used to suspend apparatus shall be of the smallest practical diameter.
- Sieves: 4.75 mm (No. 4) or other sizes as needed, meeting the requirements of FOP for AASHTO T 27/T 11.
- Large absorbent towel

## Sample Preparation

11 1. Obtain the sample in accordance with the FOP for AASHTO R 90 (see Note 1).

2. Mix the sample thoroughly and reduce to the approximate sample size required by Table 1 in accordance with the FOP for AASHTO R 76.

3. Reject all material passing the appropriate sieve by dry sieving.

4. Thoroughly wash sample to remove dust or other coatings from the surface.

12 5. Dry the test sample to constant mass at a temperature of 110 ±5°C (230 ±9°F) and cool in air at room temperature for 1 to 3 hours.

***Note 1:*** Where the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement for initial drying to constant mass may be eliminated, and, if the surfaces of the particles in the sample have been kept continuously wet until test, the 15-to-19 hour soaking may also be eliminated.

6. Re-screen the sample over the appropriate sieve. Reject all material passing that sieve.

7. The sample shall meet or exceed the minimum mass given in Table 1.

***Note 2:*** If this procedure is used only to determine the $G_{sb}$ of oversized material for the FOP for AASHTO T 99 or T 180, the material can be rejected over the appropriate sieve. For T 99 / T 180 Methods A and B, use the 4.75 mm (No.4) sieve; for T 99 / T 180 Methods C and D, use the 19 mm (3/4 in).

**Table 1**

| Nominal Maximum Size*, mm (in.) | Minimum Mass of Test Sample, g (lb) |
|---|---|
| 12.5 (1/2) or less | 2000 (4.4) |
| 19.0 (3/4) | 3000 (6.6) |
| 25.0 (1) | 4000 (8.8) |
| 37.5 (1 1/2) | 5000 (11) |
| 50 (2) | 8000 (18) |
| 63 (2 1/2) | 12,000 (26) |
| 75 (3) | 18,000 (40) |

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

## Procedure

1. Immerse the aggregate in water at room temperature for a period of 15 to 19 hours.

***Note 3:*** When testing coarse aggregate of large nominal maximum size requiring large test samples, it may be more convenient to perform the test on two or more subsamples, and then combine values obtained.

2. Place the empty basket into the water bath and attach to the balance. Inspect the immersion tank to ensure the water level is at the overflow outlet height. Tare the balance with the empty basket attached in the water bath.

3. Remove the test sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually. If the test sample dries past the SSD condition, immerse in water for 30 min, and then resume the process of surface-drying.

***Note 4:*** A moving stream of air may be used to assist in the drying operation, but take care to avoid evaporation of water from aggregate pores.

**SSD Sample**

4. Determine the SSD mass of the sample, and record this and all subsequent masses to the nearest 0.1 g or 0.1 percent of the sample mass, whichever is greater. Designate this mass as "B."

5. Immediately place the SSD test sample in the sample container and weigh it in water maintained at 23.0 ±1.7°C (73.4 ±3°F). Shake the container to release entrapped air before recording the weight. Re-inspect the immersion tank to ensure the water level is at the overflow outlet height. Designate this submerged weight as "C."

***Note 5:*** The container should be immersed to a depth sufficient to cover both it and the test sample during mass determination. The wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.

**Submerged sample in container**

16 6. Remove the sample from the basket. Ensure that all material has been removed and place in a container of known mass.

17 7. Dry the test sample to constant mass in accordance with the FOP for AASHTO T 255/T 265 (Aggregate section) and cool in air at room temperature for 1 to 3 hours. Designate this mass as "A."

## Calculations

Perform calculations and determine values using the appropriate formula below.

Bulk specific gravity ($G_{sb}$)

$$G_{sb} = \frac{A}{B - C} \quad (18)$$

Bulk specific gravity, SSD ($G_{sb}$ SSD)

$$G_{sb}SSD = \frac{B}{B - C} \quad (19)$$

Apparent specific gravity ($G_{sa}$)

$$G_{sa} = \frac{A}{A - C} \quad (20)$$

Absorption

$$\text{Absorption} = \frac{B - A}{A} \times 100 \quad (21)$$

Where:

A = oven dry mass, g

B = SSD mass, g

C = weight in water, g

**Sample Calculations**

| Sample | A | B | C | B - C | A - C | B - A |
|---|---|---|---|---|---|---|
| 1 | 2030.9 | 2044.9 | 1304.3 | 740.6 | 726.6 | 14.0 |
| 2 | 1820.0 | 1832.5 | 1168.1 | 664.4 | 651.9 | 12.5 |
| 3 | 2035.2 | 2049.4 | 1303.9 | 745.5 | 731.3 | 14.2 |

| Sample | $G_{sb}$ | $G_{sb}$ SSD | $G_{sa}$ | Absorption |
|---|---|---|---|---|
| 1 | 2.742 | 2.761 | 2.795 | 0.7 |
| 2 | 2.739 | 2.758 | 2.792 | 0.7 |
| 3 | 2.730 | 2.749 | 2.783 | 0.7 |

These calculations demonstrate the relationship between $G_{sb}$, $G_{sb}$ SSD, and $G_{sa}$. $G_{sb}$ is always lowest, since the volume includes voids permeable to water. $G_{sb}$ SSD is always intermediate. $G_{sa}$ is always highest, since the volume does not include voids permeable to water. When running this test, check to make sure the values calculated make sense in relation to one another.

22

## Report

- Results on forms approved by the agency
- Sample ID
- Specific gravities to the nearest 0.001
- Absorption to the nearest 0.1 percent

23

## Tips!

- Shake the container and sample when weighing in water to release entrapped air.
- Compare $G_{sb}$, $G_{sb}$ SSD, and $G_{sa}$ to see if they make sense.

## REVIEW QUESTIONS

1. What size sample is required for aggregate with a nominal maximum size of 25 mm (1 in.)?

2. When is soaking required? For how long must material be soaked?

3. When, in the process, are dry and SSD masses determined?

## PERFORMANCE EXAM CHECKLIST

## SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE FOP FOR AASHTO T 85

Participant Name _____ Exam Date _____

**Record the symbols "P" for passing or "F" for failing on each step of the checklist**.

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 1. Sample obtained by FOP for AASHTO R 90 and reduced by FOP for AASHTO R 76 or from FOP for AASHTO T 99 / T 180? | _____ | _____ |
| 2. Screened on the appropriate size sieve? | _____ | _____ |
| 3. Sample mass appropriate? | _____ | _____ |
| 4. Particle surfaces clean? | _____ | _____ |
| 5. Dried to constant mass 110 ±5°C (230 ±9°F) and cooled to room temperature? | _____ | _____ |
| 6. Re-screen over appropriate sieve? | _____ | _____ |
| 7. Covered with water for 15 to 19 hours? | _____ | _____ |
| 8. Wire basket completely submerged in immersion tank and attached to balance? | _____ | _____ |
| 9. Immersion tank inspected for proper water height? | _____ | _____ |
| 10. Balance tared with basket in tank and temperature checked 23.0 ±1.7°C (73.4 ±3°F)? | _____ | _____ |
| 11. Sample removed from water and rolled in cloth to remove visible films of water? | _____ | _____ |
| 12. Larger particles wiped individually? | _____ | _____ |
| 13. Evaporation avoided? | _____ | _____ |
| 14. Sample mass determined to 0.1 g? | _____ | _____ |
| 15. Sample immediately placed in basket, in immersion tank? | _____ | _____ |
| 16. Entrapped air removed before weighing by shaking basket while immersed? | _____ | _____ |
| 17. Immersion tank inspected for proper water height? | _____ | _____ |
| 18. Immersed sample weight determined to 0.1 g? | _____ | _____ |
| 19. All the sample removed from basket? | _____ | _____ |
| 20. Sample dried to constant mass and cooled to room temperature? | _____ | _____ |

**OVER**

| **Procedure Element** | **Trial 1** | **Trial 2** |
|---|---|---|
| 21. Sample mass determined to 0.1 g? | _____ | _____ |
| 22. Proper formulas used in calculations? | _____ | _____ |

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

_____
_____
_____
_____
_____
_____

Examiner Signature _____WAQTC #:_____

# USE OF AKDOT & PF ATM 212, ITD IT 74, WSDOT T 606, OR WFLHD HUMPHRES CURVES

## Background

01 Coarse-grained granular soils are free-draining and have little or no cohesion. These soils are, therefore, not particularly well suited for the moisture-density relations procedures of AASHTO T 99 or AASHTO T 180. Transportation agencies have developed specialized test methods that are hybrids of those moisture-density procedures and methods that employ compaction under load with vibration. Those methods include:

- AKDOT & PF's ATM 212
- ITD's IT 74
- WSDOT's T 606
- WFLHD's Humphres

## Description of Procedure

04 In these tests, material is compacted in a mold and in a manner similar to those used in a moisture / density relationship, after which the material is further compacted through a combination of applied loads and vibration. A laboratory maximum dry density is determined, as is the percent of material passing a certain sieve such as the 4.75 mm (No. 4). A number of determinations are made for different percentages passing the specified sieve. A graph is developed in which dry density is plotted versus the percentage of material passing that sieve. These tests are conducted in the agency's central lab, and the curve developed is a central lab function.

Construction specifications will call out a percent of maximum dry density required for the granular materials used on the job. These specified values will be based on ATM 212, IT 74, T 606, or Humphres, depending on the agency.

In the field, the dry density of the granular material will be determined in accordance with the FOP for AASHTO 310. The percent of material passing the specified sieve will be determined for a sample

obtained at the site of the density test. The dry density and percent passing values will then be compared with the curve developed in the lab for that particular granular material to determine conformance with the project specifications.

## Maximum Density Chart

07

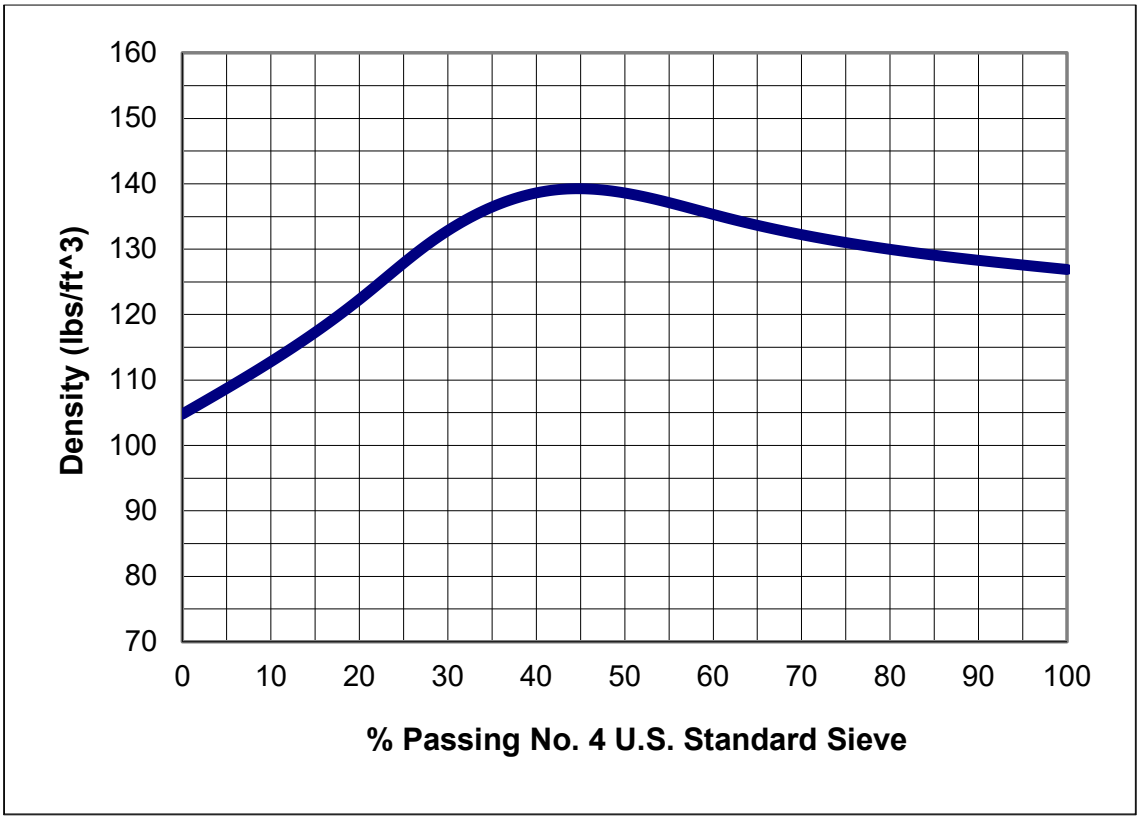
| Density Curves | | | |
|---|---|---|---|
| Pass #4 | Maximum | Pass #4 | Maximum |
| 0.0 | 104.8 | 31.0 | 133.7 |
| 1.0 | 105.6 | 32.0 | 134.5 |
| 2.0 | 106.4 | 33.0 | 135.2 |
| 3.0 | 107.1 | 34.0 | 135.8 |
| 4.0 | 107.9 | 35.0 | 136.4 |
| 5.0 | 108.7 | 36.0 | 137.0 |
| 6.0 | 109.5 | 37.0 | 137.5 |
| 7.0 | 110.3 | 38.0 | 137.9 |
| 8.0 | 111.1 | 39.0 | 138.3 |
| 9.0 | 112.0 | 40.0 | 138.6 |
| 10.0 | 112.8 | 41.0 | 138.9 |
| 11.0 | 113.7 | 42.0 | 139.0 |
| 12.0 | 114.5 | 43.0 | 139.2 |
| 13.0 | 115.4 | 44.0 | 139.2 |
| 14.0 | 116.4 | 45.0 | 139.2 |
| 15.0 | 117.3 | 46.0 | 139.2 |
| 16.0 | 118.2 | 47.0 | 139.1 |
| 17.0 | 119.2 | 48.0 | 139.0 |
| 18.0 | 120.2 | 49.0 | 138.8 |
| 19.0 | 121.3 | 50.0 | 138.6 |
| 20.0 | 122.3 | 51.0 | 138.3 |
| 21.0 | 123.4 | 52.0 | 138.1 |
| 22.0 | 124.5 | 53.0 | 137.8 |
| 23.0 | 125.6 | 54.0 | 137.5 |
| 24.0 | 126.8 | 55.0 | 137.1 |
| 25.0 | 127.9 | 56.0 | 136.8 |
| 26.0 | 129.0 | 57.0 | 136.4 |
| 27.0 | 130.0 | 58.0 | 136.0 |
| 28.0 | 131.0 | 59.0 | 135.7 |
| 29.0 | 132.0 | 60.0 | 135.3 |
| 30.0 | 132.8 | 61.0 | 135.0 |

| Density Curves | | | |
|---|---|---|---|
| Pass #4 | Maximum | Pass #4 | Maximum |
| 62.0 | 134.6 | 82.0 | 129.6 |
| 63.0 | 134.3 | 83.0 | 129.4 |
| 64.0 | 134.0 | 84.0 | 129.3 |
| 65.0 | 133.6 | 85.0 | 129.1 |
| 66.0 | 133.3 | 86.0 | 128.9 |
| 67.0 | 133.1 | 87.0 | 128.8 |
| 68.0 | 132.8 | 88.0 | 128.6 |
| 69.0 | 132.5 | 89.0 | 128.4 |
| 70.0 | 132.2 | 90.0 | 128.3 |
| 71.0 | 132.0 | 91.0 | 128.1 |
| 72.0 | 131.7 | 92.0 | 128.0 |
| 73.0 | 131.5 | 93.0 | 127.9 |
| 74.0 | 131.2 | 94.0 | 127.7 |
| 75.0 | 131.0 | 95.0 | 127.6 |
| 76.0 | 130.8 | 96.0 | 127.4 |
| 77.0 | 130.6 | 97.0 | 127.3 |
| 78.0 | 130.4 | 98.0 | 127.2 |
| 79.0 | 130.2 | 99.0 | 127.0 |
| 80.0 | 130.0 | 100.0 | 126.9 |
| 81.0 | 129.8 | | |

| Control Points for Density Curves | | |
|---|---|---|
| Pass #4 | Maximum | Loose |
| 0.0 | 104.8 | 87.6 |
| 20.5 | 122.8 | 99.6 |
| 27.4 | 130.4 | 103.8 |
| 42.5 | 139.1 | 105.4 |
| 61.1 | 134.9 | 96.7 |
| 100.0 | 126.9 | 81.9 |

**Maximum Density Curve**

08




**Example:**
A compaction test was taken and a sample was removed from the test site per the FOP for AASHTO T 310. The sample was graded over a 4.75 mm (No. 4) sieve. The following results were reported.

09

| | |
|---|---|
| Dry density from FOP for AASHTO T 310 = | 136.0 lb/ft$^3$ |
| Percent passing 4.75 mm (No. 4) sieve = | 49% |
| Maximum density = | 138.8 lb/ft$^3$ |

10

$$Percent\ compaction = \frac{136.0\ lb/ft^3}{138.8\ lb/ft^3} \times 100 = 98\%$$

11

# IN-PLACE DENSITY AND MOISTURE CONTENT OF SOIL AND SOIL-AGGREGATE BY NUCLEAR METHODS (SHALLOW DEPTH)

## FOP FOR AASHTO T 310

01

02

03

04

**Checking deflection**

05

**Caution!**

06

07

08

**Gauge, transport case and instruction manual**

### Significance

The final in-place density of roadway embankment and base is critical to the quality and longevity of a highway project. Low-density material will lead to excessive deflection under load or permanent deformation, or both.

This procedure provides a rapid, nondestructive technique for determining the in-place wet density and moisture content of soil, aggregate, and soil-aggregate mixes. The non-destructive nature of the test allows repetitive measurements to be made at a single test location between roller passes. The procedure is normally suitable from test depths of 50 mm (2 in.) to 300 mm (12 in.).

### Scope

This procedure covers the determination of density, moisture content, and relative compaction of soil, aggregate, and soil-aggregate mixes in accordance with AASHTO T 310-19. This field operating procedure is derived from AASHTO T 310. The nuclear moisture-density gauge is used in the direct transmission mode.

### Apparatus

- Nuclear density gauge with the factory matched standard reference block.
- Drive pin, guide / scraper plate, and hammer for testing in direct transmission mode.
- Transport case for properly shipping and housing the gauge and tools.
- Instruction manual for the specific make and model of gauge.
- Radioactive materials information and calibration packet containing:
  - Daily Standard Count Log

**Nuclear gauge**

09

10

- Factory and Laboratory Calibration Data Sheet
- Leak Test Certificate
- Shippers Declaration for Dangerous Goods
- Procedure Memo for Storing, Transporting and Handling Nuclear Testing Equipment
- Other radioactive materials documentation as required by local regulatory requirements

- Sealable containers and utensils for moisture content determinations.

## Radiation Safety

11

- This method does not purport to address all of the safety problems associated with its use. The gauge utilizes radioactive materials that may be hazardous to the health of the user unless proper precautions are taken. Users of this gauge must become familiar with the applicable safety procedures and governmental regulations. All operators will be trained in radiation safety prior to operating nuclear density gauges. Some agencies require the use of personal monitoring devices such as a thermoluminescent dosimeter or film badge. Effective instructions together with routine safety procedures such as source leak tests, recording and evaluation of personal monitoring device data, etc., are a recommended part of the operation and storage of this gauge.

## Calibration

13

Calibrate the nuclear gauge as required by the agency. This calibration may be performed by the agency using manufacturer's recommended procedures or by other facilities approved by the agency. Verify or re-establish calibration curves, tables, or equivalent coefficients every 12 months.

## Standardization

14

1. Turn the gauge on and allow it to stabilize (approximately 10 to 20 minutes) prior to standardization. Leave the power on during the day's testing.
2. Standardize the nuclear gauge at the construction site at the start of each day's work and as often as deemed necessary by the operator or agency. Daily variations in standard count shall not exceed the daily variations established by the manufacturer of the gauge.

   If the daily variations are exceeded after repeating the standardization procedure, the gauge should be repaired and/or recalibrated.
3. Record the standard count for both density and moisture in the Daily Standard Count Log. The exact procedure for standard count is listed in the manufacturer's Operator's Manual.

***Note 1:*** New standard counts may be necessary more than once a day. See agency requirements.

## Overview

15

There are two methods for determining in-place determination of soil / soil aggregate:

- Method A: Single Direction
- Method B: Two Directions

## Procedure

16

1. Select a test location(s) randomly and in accordance with agency requirements. Test sites should be relatively smooth and flat and meet the following conditions:
   a) At least 10 m (30 ft.) away from other sources of radioactivity
   b) At least 3 m (10 ft.) away from large objects
   c) The test site should be at least 150 mm (6 in.) away from any vertical projection, unless the gauge is corrected for trench wall effect.
2. Remove all loose and disturbed material and remove additional material as necessary to expose the top of the material to be tested.

17

**Prepared area**

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19

**Filling surface voids**

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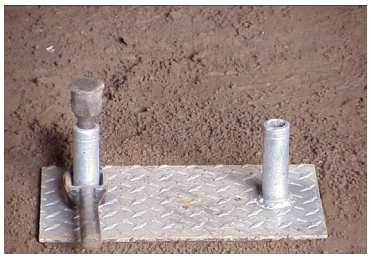


21

**Guide plate and drive pin**

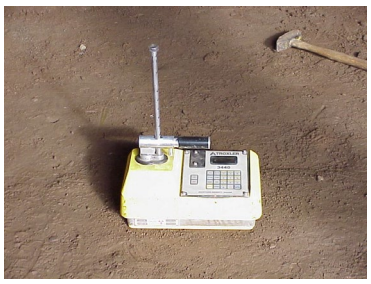
3. Prepare a flat area sufficient in size to accommodate the gauge. Plane the area to a smooth condition so as to obtain maximum contact between gauge and the material being tested. For Method B, the flat area must be sufficient to permit rotating the gauge 90 or 180 degrees about the source rod.
4. Fill in surface voids beneath the gauge with fines of the material being tested passing the 4.75 mm (No. 4) sieve or finer. Smooth the surface with the guide plate or other suitable tool. The depth of the filler should not exceed approximately 3 mm (1/8 in.).
5. Make a hole perpendicular to the prepared surface using the guide plate and drive pin. The hole shall be at least 50 mm (2 in.) deeper than the desired probe depth and shall be aligned so that insertion of the probe will not cause the gauge to tilt from the plane of the prepared area. Remove the drive pin by pulling straight up and twisting the extraction tool.
6. Place the gauge on the prepared surface so the source rod can enter the hole without disturbing loose material.
7. Insert the probe in the hole and lower the source rod to the desired test depth using the handle and trigger mechanism.
8. Seat the gauge firmly by partially rotating it back and forth about the source rod. Ensure the gauge is seated flush against the surface by pressing down on the gauge corners and making sure that the gauge does not rock.
9. Pull gently on the gauge to bring the side of the source rod nearest to the scaler / detector firmly against the side of the hole.

10. Perform one of the following as required by agency:

23

a. **Method A Single Direction**: Take a test consisting of the average of two one-minute readings, and record both density and moisture data. The two wet density readings should be within 32 kg/m$^3$ (2.0 lb/ft$^3$) of each other. The average of the two wet densities and moisture contents will be used to compute dry density.

b. **Method B Two Direction:** Take a one-minute reading and record both density and moisture data. Rotate the gauge 90 or 180 degrees, pivoting it around the source rod. Reseat the gauge by pulling gently on the gauge to bring the side of the source rod nearest to the scaler / detector firmly against the side of the hole and take a one-minute reading. (In trench locations, rotate the gauge 180 degrees for the second test.) Some agencies require multiple one-minute readings in both directions. Analyze the density and moisture data. A valid test consists of wet density readings in both gauge positions that are within 50 kg/m$^3$ (3.0 lb/ft$^3$). If the tests do not agree within this limit, move to a new location. The average of the wet density and moisture contents will be used to compute dry density.



22

**Taking a reading**

24

25

**Representative sample site**

11. If required by the agency, obtain a representative sample of the material, 4 kg (9 lb) minimum, from directly beneath the gauge full depth of material tested. This sample will be used to verify moisture content and / or identify the correct density standard. Immediately seal the material to prevent loss of moisture.

    The material tested by direct transmission can be approximated by a cylinder of soil approximately 300 mm (12 in.) in diameter directly beneath the centerline of the radioactive source and detector. The height of the cylinder will be approximately the depth of the measurement. When organic material or large

aggregate is removed during this operation, disregard the test information and move to a new test site.

12. To verify the moisture content from the nuclear gauge, determine the moisture content with a representative portion of the material using the FOP for AASHTO T 255/ T 265 or other agency approved methods. If the moisture content from the nuclear gauge is within ±1 percent the nuclear gauge readings can be accepted. Moisture content verification is gauge and material specific. Retain the remainder of the sample at its original moisture content for a one-point compaction test under the FOP for AASHTO T 272, or for gradation, if required.

***Note 2:*** Example: A gauge reading of 16.8 percent moisture and oven dry or 17.7 percent are within the ±1 percent requirement. Moisture correlation curves will be developed according to agency guidelines. These curves should be reviewed and possibly redeveloped every 90 days because of moisture source decay.

13. Determine the dry density by one of the following methods:

    a. From nuclear gauge readings, compute by subtracting the mass (weight) of the water ($kg/m^3$ or $lb/ft^3$) from the wet density ($kg/m^3$ or $lb/ft^3$); or compute using the percent moisture by dividing wet density from the nuclear gauge by 1 plus the moisture content expressed as a decimal.

    b. When verification is required and the nuclear gauge readings cannot be accepted, the moisture content is determined by the FOP for AASHTO T 255/T 265 or other agency approved methods. Compute dry density by dividing wet density from the nuclear gauge by 1 plus the moisture content expressed as a decimal.

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## Percent Compaction

- Percent compaction is determined by comparing the in-place dry density as determined by this procedure to the appropriate agency density standard. For soil or soil-aggregate mixes, these are moisture-density curves developed using the FOP for AASHTO T 99 / T 180. When using maximum dry densities developed by the FOP for AASHTO T 99 / T 180 or FOP for AASHTO T 272, it may be necessary to use the Annex in the FOP for AASHTO T 99/T 180 to determine corrected maximum dry density and optimum moisture content.

  For coarse granular materials, the density standard may be density-gradation curves developed using a vibratory method such as AKDOT&PF's ATM 212, ITD's T 74, WSDOT's TM 606, or WFLHD's Humphres.

  See appropriate agency policies for use of density standards.

## Calculation

**Calculate the dry density as follows:**

28

$$\rho_d = \left(\frac{\rho_w}{w + 100}\right) \times 100 \quad or \quad \rho_d = \left(\frac{\rho_w}{\frac{w}{100} + 1}\right)$$

where

$\rho_d$ = Dry density, kg/m$^3$ (lb/ft$^3$)

$\rho_w$ = Wet density, kg/m$^3$ (lb/ft$^3$)

w = Moisture content from the FOPs for AASHTO T 255 / T 265, as a percentage

**Calculate percent compaction as follows:** 29

$$\%\ Compaction = \frac{\rho_d}{Agency\ density\ standard} \times 100$$

where:

$\rho_d$ = Dry density, kg/m$^3$ (lb/ft$^3$)

Agency density standard = Corrected maximum dry density from the FOP from T 99/T 180 Annex

## Example:

32

Wet Density readings from gauge: 1948 kg/m$^3$ (121.6 lb/ft$^3$)
1977 kg/m$^3$ (123.4 lb/ft$^3$)

Avg.: 1963 kg/m$^3$ (122.5 lb/ft$^3$)

**Moisture readings from gauge: 14.2% and 15.4% = Avg. 14.8%**

Moisture content from the FOP's for AASHTO T 255 / T 265: 15.9%

*Moisture content is greater than 1 percent different so the gauge moisture cannot be used.*

33

**Calculate the dry density as follows:**

$$\rho_d = \left(\frac{1963\,kg/m^3\ or\ 122.5\ lb/ft^3}{15.9 + 100}\right) \times 100\ or\ \ \rho_d = \left(\frac{1963\,kg/m^3\ or\ 122.5\ lb/ft^3}{\frac{15.9}{100} + 1}\right)$$

$$= 1694\ kg/m^3\ or\ 105.7\ lb/ft^3$$

where:

$\rho_w$ = 1963 kg/m$^3$ or 122.5 lb/ft$^3$

w = 15.9%

**Calculate percent compaction as follows:** 34

$$\%\ Compaction = \frac{105.7\ lb/ft^3}{111.3\ lb/ft^3} \times 100 = 95\%$$

where:

Agency density standard = 111.3 lb/ft$^3$

35

## Report

- Results on forms approved by the agency
- Sample ID
- Location of test, elevation of surface, and thickness of layer tested
- Visual description of material tested
- Make, model and serial number of the nuclear moisture-density gauge
- Wet density to the nearest 0.1 lb/ft$^3$
- Moisture content as a percent, by mass, of dry soil mass to the nearest 0.1 percent
- Dry density to the nearest 0.1 lb/ft$^3$
- Density standard to the nearest 0.1 lb/ft$^3$
- Percent compaction to the nearest 1 percent
- Name and signature of operator

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**Tips!**

- Check to make sure that: 37
  - base of gauge is clean prior to testing.
  - shutter block and assembly are free of debris and operating correctly.
  - source rod tip does not have a buildup of material on end.
  - gauge is reading the proper position of the source rod when it is indexed, and that it has been seated correctly. 39
  - the hole into which the source is lowered is at least 50 mm (2 in.) deeper than the indexed position of the source rod.
  - surface is flat and the gauge does not rock.
  - surface has been properly prepared using filler material.
- Make sure battery is charged before starting work

## REVIEW QUESTIONS

1. Describe the calibration and standardization process.

2. What precautions must be taken in selecting a test location?

3. Describe the procedure leading up to the taking of test measurements.

4. What is the difference between Method A and Method B?

5. What is the purpose of determining moisture content by other means than the nuclear gauge?

## PERFORMANCE EXAM CHECKLIST

## IN-PLACE DENSITY AND MOISTURE CONTENT OF SOIL AND SOIL-AGGREGATE BY NUCLEAR METHODS (SHALLOW DEPTH) FOP FOR AASHTO T 310

Participant Name _____ Exam Date _____

**Record the symbols "P" for passing or "F" for failing on each step of the checklist**.

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 1. Gauge turned on 10 to 20 minutes before use? | _____ | _____ |
| 2. Calibration verified? | _____ | _____ |
| 3. Standard count taken and recorded in accordance with manufacturer's instructions? | _____ | _____ |
| 4. Test location selected appropriately 10 m (30 ft.) from other radioactive sources, 3 m (10 ft.) from large objects, 150 mm (6 in.) away from vertical projections? | _____ | _____ |
| 5. Loose, disturbed material removed? | _____ | _____ |
| 6. Flat, smooth area prepared? | _____ | _____ |
| 7. Surface voids filled with native fines (-No. 4) to 3 mm (1/8 in.) maximum thickness? | _____ | _____ |
| 8. Hole driven 50 mm (2 in.) deeper than probe depth? | _____ | _____ |
| 9. Gauge placed, probe placed, and source rod lowered without disturbing loose material? | _____ | _____ |
| 10. Method A: | | |
| a. Gauge firmly seated, and gently pulled back so that the source rod is against the side of the hole toward the scaler / detectors? | _____ | _____ |
| b. Two, one-minute reading taken; wet density within 32 kg/m$^3$ (2.0 lb/ft$^3$)? | _____ | _____ |
| c. Density and moisture data averaged? | _____ | _____ |
| 11. Method B: | | |
| a. Gauge firmly seated, and gently pulled back so that the source rod is against the side of the hole toward the scaler / detectors? | _____ | _____ |
| b. A minimum of a one-minute reading taken; density and moisture data recorded? | _____ | _____ |
| c. Gauge turned 90° or 180° (180° in trench)? | _____ | _____ |

**OVER**

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| d. Gauge firmly seated, and gently pulled back so that the source rod is against the side of the hole toward the scaler / detectors? | _____ | _____ |
| e. A minimum of a one-minute reading taken; density and moisture data recorded? | _____ | _____ |
| f. Wet densities within 50 kg/m$^3$ (3.0 lb/ft$^3$ )? | _____ | _____ |
| g. Density and moisture data averaged? | _____ | _____ |
| 12. Representative sample (4 kg or 9 lb) obtained from test location? | _____ | _____ |
| 13. Sample sealed immediately to prevent moisture loss? | _____ | _____ |
| 14. Moisture content correctly determined using other means than the nuclear density gauge reading? | _____ | _____ |
| 15. Dry Density calculated using proper moisture content? | _____ | _____ |
| 16. Percent compaction calculated correctly? | _____ | _____ |

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

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Examiner Signature _____WAQTC #:_____

# THEORETICAL MAXIMUM SPECIFIC GRAVITY ($G_{mm}$) AND DENSITY OF ASPHALT MIXTURES FOP FOR AASHTO T 209

## Significance

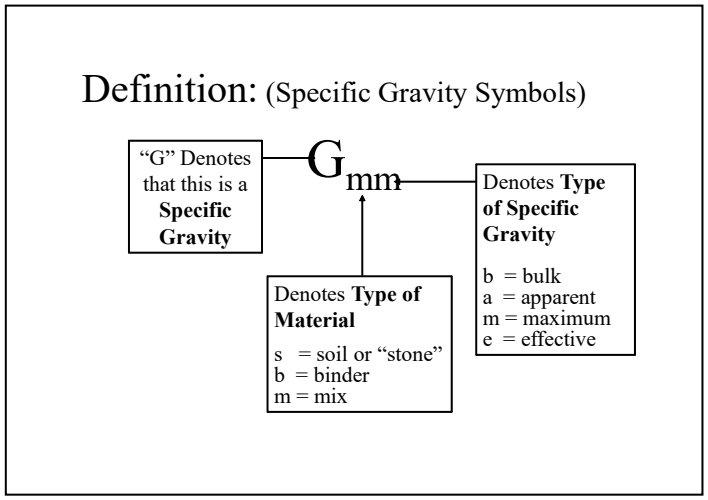
01 Maximum specific gravity ($G_{mm}$) is the ratio of the mass of a given volume of cooled asphalt mixture at 25°C (77°F) to the mass of an equal volume of water at the same temperature. The procedure is often called the Rice test after its developer, James Rice.

02 $G_{mm}$ is used in conjunction with bulk specific gravity to determine in-place density or percent air voids or both in compacted asphalt mixture. Percentage of air voids, $V_a$, is significant because durability characteristics of asphalt mixture are influenced by the amount of voids in the compacted material.

## Scope

03 This procedure covers the determination of the maximum specific gravity ($G_{mm}$) of uncompacted asphalt mixture in accordance with AASHTO T 209-19. Two methods using different containers – bowl and pycnometer / volumetric flask – are covered.

Specimens prepared in the laboratory shall be cured according to the agency standards.




04

05 **Apparatus**

**Metal container/ Volumetric Flask**

- 06 Balance or scale: 10,000 g capacity, readable to 0.1 g
- Container: A glass, metal, or plastic bowl, pycnometer or volumetric flask between 2000 and 10,000 mL as required by the minimum sample size requirements in Table 1 and capable of withstanding a partial vacuum
- Pycnometer / volumetric flask cover: A glass plate or a metal or plastic cover with a vented opening
- 07 Vacuum lid: A transparent lid with a suitable vacuum connection. The vacuum opening to be covered with a fine wire mesh

**Vacuum pump**

- Vacuum pump or water aspirator: Capable of evacuating air from the container to a residual pressure of 4.0 kPa (30 mm Hg)
- Residual pressure manometer or vacuum gauge: Traceable to NIST and capable of measuring residual pressure down to 4.0 kPa (30 mm Hg) or less
- Manometer or vacuum gauge: Capable of measuring the vacuum being applied at the source of the vacuum
- Water bath: A constant-temperature water bath (optional)
- Thermometers: Standardized liquid-in-glass, or electronic digital total immersion type, accurate to 0.5°C (1°F)
- Bleeder valve to adjust vacuum
- Automatic vacuum control unit (optional)
- Timer

08 **Standardization of Pycnometer or Volumetric Flask**

Use a pycnometer / volumetric flask that is standardized to accurately determine the mass of water, at 25 ±0.5°C (77 ±1°F), in the pycnometer / volumetric flask. The pycnometer / volumetric flask

shall be standardized periodically in conformance with procedures established by the agency.

09

## Test Sample Preparation

1. Obtain samples in accordance with the FOP for AASHTO R 97 and reduce according to AASHTO R 47.
2. Test sample size shall conform to the requirements of Table 1. Samples larger than the capacity of the container may be tested in two or more increments. Results will be combined and averaged. If the increments have a specific gravity difference greater than 0.014, the test must be re-run.

**Table 1**
**Test Sample Size for $G_{mm}$**

| Nominal Maximum Aggregate Size* mm (in.) | Minimum Mass g |
|---|---|
| 37.5 or greater (1 ½) | 4000 |
| 19 to 25 (3/4 to 1) | 2500 |
| 12.5 or smaller (1/2) | 1500 |

*Nominal maximum size: One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained.

3.

10

**Separating particles**

12

**Placing sample in flask**

11

**Determining mass**

13

14

## Procedure – General

Two procedures – bowl and pycnometer / volumetric flask – are covered. The first 11 steps are the same for both.

1. Separate the particles of the sample, taking care not to fracture the mineral particles, so that the particles of the fine aggregate portion are not larger than 6.3 mm (1/4 in.). If the mixture is not sufficiently soft to be separated manually, place it in a large flat pan and warm in an oven only until it is pliable enough for separation.
2. Cool the sample to room temperature.
3. Determine and record the mass of the dry container to the nearest 0.1 g.

15 4. Place the sample in the container.

5. Determine and record the mass of the container and sample to the nearest 0.1 g.

6. Determine and record the mass of the sample by subtracting the mass determined in Step 3 from the mass determined in Step 5. Designate this mass as "A."

**Manually agitating container**

16

7. Add sufficient water at approximately 25°C (77°F) to cover the sample by about 25 mm (1 in).

***Note 1:*** The release of entrapped air may be facilitated by the addition of a wetting agent. Check with the agency to see if this is permitted and, if it is, for a recommended agent.

8. Place the lid on the container and attach the vacuum line. To ensure a proper seal between the container and the lid, wet the O-ring or use a petroleum gel.

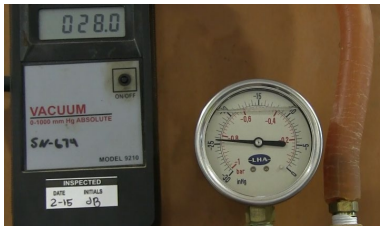
**Mechanically agitating container**

17

9. Remove entrapped air by subjecting the contents to a partial vacuum of 3.7 ±0.3 kPa (27.5 ±2.5 mm Hg) residual pressure for 15 ±2 minutes.

18

10. Agitate the container and contents, either continuously by mechanical device or manually by vigorous shaking, at 2-minute intervals. This agitation facilitates the removal of air.




**Manometer**

19

11. Release the vacuum. Increase the pressure to atmospheric pressure in 10 to 15 seconds if the vacuum release is not automated. Turn off the vacuum pump and remove the lid. When performing the pycnometer / volumetric flask method, complete steps 12B through 16B within 10 ±1 minute.

## Procedure – Bowl

20

12A. Fill the water bath to overflow level with water at 25 ±1°C (77 ±2°F) and allow the water to stabilize.

13A. Zero or tare the balance with the immersion apparatus attached, ensuring that the device is not touching the sides or the bottom of the water bath.

14A Suspend and immerse the bowl and contents in water at 25 ±1°C (77 ±2°F) for 10 ±1

minute. The holder shall be immersed sufficiently to cover both it and the bowl.

15A. Determine and record the submerged weight of the bowl and contents to the nearest 0.1 g.

16A. Refill the water bath to overflow level.

17A. Empty and re-submerge the bowl following step 12A to determine the submerged weight of the bowl to the nearest 0.1 g.

18A. Determine and record the submerged weight of the sample the nearest 0.1 g by subtracting the submerged weight of the bowl from the submerged weight determined in Step 15A. Designate this submerged weight as "C."

## Procedure – Pycnometer or Volumetric Flask

12B. Immediately fill the pycnometer / volumetric flask with water.

13B. Stabilize the temperature of the pycnometer / volumetric flask and contents so that final temperature is within 25 ±1°C (77 ±2°F).

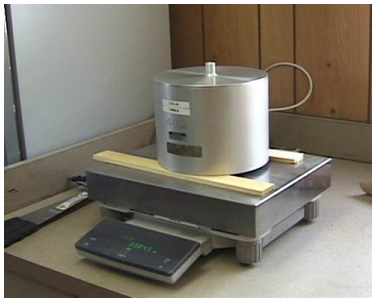
14B. Finish filling the pycnometer / volumetric flask with water that is 25 ±1°C (77 ±2°F), place the metal or plastic cover or a glass plate on the pycnometer / volumetric flask, and eliminate all air.

**Determining temperature**

***Note 2:*** When using a metal pycnometer and cover, place the cover on the pycnometer and push down slowly, forcing excess water out of the hole in the center of the cover. Use care when filling the pycnometer to avoid reintroducing air into the water.

15B. Towel dry the outside of the pycnometer / volumetric flask and cover.

16B. Determine and record the mass of the pycnometer / volumetric flask, cover, de-aired water, and sample to the nearest 0.1 g. within 10 ±1 minute of completion of Step 11. Designate this mass as "E."



**Determining mass**

28 **Procedure – Mixtures Containing Uncoated Porous Aggregate**

If the pores of the aggregates are not thoroughly sealed by a bituminous film, they may become saturated with water during the vacuuming procedure, resulting in an error in maximum density.

To determine if this has occurred, complete the general procedure and then:

29

1. Carefully drain water from sample through a towel held over the top of the container to prevent loss of material.
2. Spread sample in a flat shallow pan and place before an electric fan to remove surface moisture.
3. Determine the mass of the sample when the surface moisture appears to be gone.
4. Continue drying and determine the mass of the sample at 15-minute intervals until less than a 0.5 g loss is found between determinations.
5. Record the mass as the saturated surface dry mass to the nearest 0.1 g. Designate this mass as "$A_{SSD}$."
6. Calculate, as indicated below, $G_{mm}$ using "A" and "$A_{SSD}$," and compare the two values.

## Calculation

Calculate the $G_{mm}$ to three decimal places as follows.

**Bowl Procedure** 30

$$G_{mm} = \frac{A}{A - C} \qquad or \qquad G_{mm} = \frac{A}{A_{SSD} - C}$$

(for mixes containing uncoated aggregate materials)

where:

A = mass of dry sample in air, g

$A_{SSD}$ = Mass of saturated surface dry sample in air, g

C = submerged weight of sample in water, g

**Example**

A = 1432.7 g

$A_{SSD}$ = 1434.2 g

C = 848.6 g

$$G_{mm} = \frac{1432.7\ g}{1432.7\ g - 848.6\ g} = 2.453 \qquad or \qquad G_{mm} = \frac{1432.7\ g}{1434.2\ g - 848.6\ g} = 2.447$$

**Pycnometer / Volumetric Flask Procedure** 31

$$G_{mm} = \frac{A}{A + D - E} \qquad or \qquad G_{mm} = \frac{A}{A_{SSD} + D - E}$$

(for mixtures containing uncoated materials)

where:

A = Mass of dry sample in air, g

$A_{SSD}$ = Mass of saturated surface dry sample in air, g

D = Mass of pycnometer / volumetric flask filled with water at 25°C (77°F), g, determined during the Standardization of Pycnometer / Volumetric Flask procedure

E = Mass of pycnometer / volumetric flask filled with water and test sample at test temperature, g

**Example (in which two increments of a large sample are averaged):**

| Increment 1 | Increment 2 |
|---|---|
| A = 2200.3 g | A = 1960.2 g |
| D = 7502.5 g | D = 7525.5 g |
| E = 8812.0 g | E = 8690.8 g |
| Temperature = 26.2°C | Temperature = 25.0°C |

32

$$G_{mm_1} = \frac{2200.3\ g}{2200.3\ g + 7502.5\ g - 8812.0\ g} = 2.470$$

$$G_{mm_2} = \frac{1960.2\ g}{1960.2\ g + 7525.5\ g - 8690.8\ g} = 2.466$$

Allowable variation is: 0.014

2.470 - 2.466 = 0.004, which is < 0.014, so they can be averaged.

Average:

2.470 + 2.466 = 4.936 4.936 ÷ 2 = **2.468**

## Theoretical Maximum Density

33

To calculate the theoretical maximum density at 25°C (77°F) use one of the following formulas. The density of water at 25°C (77°F) is 997.1 in Metric units or 62.245 in English units.

Theoretical maximum density $kg/m^3 = G_{mm} \times 997.1\ kg/m^3$

$2.468 \times 997.1\ kg/m^3 = 2461\ kg/m^3$

Or:

Theoretical maximum density $lb/ft^3 = G_{mm} \times 62.245\ lb/ft^3$

$2.468 \times 62.245\ lb/ft^3 = 153.6\ lb/ft^3$

34

## Report

- Results on forms approved by the agency
- Sample ID
- $G_{mm}$ to the nearest 0.001
- Theoretical maximum density to the nearest 1 $kg/m^3$ (0.1 $lb/ft^3$)

## Tips!

35

- Use a standardized pycnometer or volumetric flask with known mass when filled, if using pycnometer or volumetric procedure.
- Check for absorption in uncoated aggregate.

## REVIEW QUESTIONS

1. A mix with the nominal maximum aggregate size of 25 mm (1 in.) should use what size sample?

2. At what temperature should the sample be for testing?

3. Removing entrapped air from the contents of the flask by a partial vacuum is done for how long?

4. How and why is the flask agitated?

# BULK SPECIFIC GRAVITY ($G_{mb}$) OF COMPACTED ASPHALT MIXTURES USING SATURATED SURFACE-DRY SPECIMENS FOP FOR AASHTO T 166

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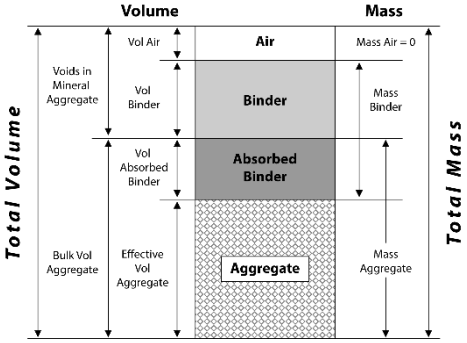
02

**Asphalt mixture core**




03

04

**Asphalt mixture phase diagram**

## Significance

Compacted asphalt mixtures include voids that may contain gas, such as air, or liquid, such as water. The voids may be permeable; that is, they connect to the surface and can fill with water. They may also be impermeable and, thus, filled only with air.

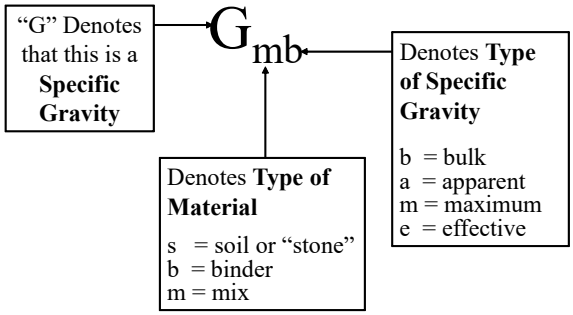
Because voids exist and contain air or water, the overall, or bulk, density of the compacted mix is less than the density of a theoretical mix of aggregate and binder having no voids. Thus, bulk density and associated bulk specific gravity are indications of void and air content – both of which impact various properties of bituminous roadways.

Bulk specific gravity is the ratio of the mass of a given volume of dry, compacted mix at 25°C (77°F) in air to the mass of an equal volume of water at the same temperature. The weight of the sample in water is subtracted from the mass of a saturated surface-dry (SSD) sample in air in order to determine the mass of the water displaced by the specimen. The measurement of void volume, which includes permeable internal and surface pores occupied by water, is useful for mix quality control because it takes into consideration the volume of voids permeable to water within the specimen.

## Scope

05 This procedure covers the determination of bulk specific gravity ($G_{mb}$) of compacted asphalt mixtures using three methods – A, B, and C – in accordance with AASHTO T 166-16. This FOP is for use on specimens not having open or interconnecting voids or not absorbing more than 2.00 percent water by volume, or both. When specimens have open or interconnecting voids and/or absorbing more than 2.00 percent water by volume AASHTO T 275 or AASHTO T 331 should be performed.

## Definition: (Specific Gravity Symbols)




06

### Overview

07

- Method A: Suspension
- Method B: Volumeter
- Method C: Rapid test for A or B

### Test Specimens

08

Test specimens may be either laboratory-molded or from asphalt mixture pavement. For specimens it is recommended that the diameter be equal to four times the maximum size of the aggregate and the thickness be at least one and one half times the maximum size of the aggregate.

Test specimens from asphalt mixture pavement will be sampled according to AASHTO R 67.

### Terminology

09

*Constant Mass:* The state at which a mass does not change more than a given percent, after additional drying for a defined time interval, at a required temperature.

**Suspension apparatus**

## Apparatus – Method A (Suspension)

- Balance or scale: 5 kg capacity, readable to 0.1 g, and fitted with a suitable suspension apparatus and holder to permit weighing the specimen while suspended in water, conforming to AASHTO M 231.

10

- Suspension apparatus: Wire of the smallest practical size and constructed to permit the container to be fully immersed.

11

- Water bath: For immersing the specimen in water while suspended under the balance or scale, and equipped with an overflow outlet for maintaining a constant water level.
- Towel: Damp cloth towel used for surface drying specimens.
- Oven: Capable of maintaining a temperature of 110 ±5°C (230 ±9°F) for drying the specimens to a constant mass.
- Pan: Pan or other suitable container of known mass, large enough to hold a sample for drying in oven.
- Thermometer: Having a range of 19 to 27°C (66 to 80°F), graduated in 0.1°C (0.2°F) subdivisions.
- Vacuum device: refer to AASHTO R 79 (optional)

12

## Procedure – Method A (Suspension)

Recently molded laboratory samples that have not been exposed to moisture do not need drying.

1. Dry the specimen to constant mass, if required.

13

   a. Oven method

      i. Initially dry overnight at 52 ±3°C (125 ±5°F).

      ii. Determine and record the mass of the specimen ($M_p$).

      iii. Return the specimen to the oven for at least 2 hours.

iv. Determine and record the mass of the specimen ($M_n$).

v. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$), divide by the previous mass determination ($M_p$), and multiply by 100.

vi. Continue drying until there is no more than 0.05 percent change in specimen mass after 2-hour drying intervals (constant mass).

vii. Constant mass has been achieved; sample is defined as dry.

***Note 1***: To expedite the procedure, steps 1 and 2 may be performed last. To further expedite the process, see Method C.

14 b. Vacuum dry method

i. Perform vacuum drying procedure according to AASHTO R 79.

ii. Determine and record the mass of the specimen ($M_p$).

iii. Perform a second vacuum drying procedure.

iv. Determine and record the mass of the specimen ($M_n$).

v. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$), divide by the previous mass determination ($M_p$), and multiply by 100.

vi. Continue drying until there is no more than 0.05 percent change in specimen mass (constant mass).

vii. Constant mass has been achieved; sample is defined as dry.

15 2. Cool the specimen in air to 25 ±5°C (77 ±9°F), and determine and record the dry mass to the nearest 0.1 g. Designate this mass as "A."

**Submerged specimen**

16

17

3. Fill the water bath to overflow level with water at 25 ±1°C (77 ±1.8°F) and allow the water to stabilize.
4. Zero or tare the balance with the immersion apparatus attached, ensuring that the device is not touching the sides or the bottom of the water bath.
5. Immerse the specimen shaking to remove the air bubbles. Place the specimen on its side in the suspension apparatus. Leave it immersed for 4 ±1 minutes.
6. Determine and record the submerged weight to the nearest 0.1 g. Designate this submerged weight as "C."
7. Remove the sample from the water and quickly surface dry with a damp cloth towel within 5 seconds.
8. Zero or tare the balance.
9. Immediately determine and record the mass of the saturated surface-dry (SSD) specimen to nearest 0.1 g. Designate this mass as "B." Any water that seeps from the specimen during the mass determination is considered part of the saturated specimen. Do not to exceed 15 seconds performing Steps 7 through 9.

## Calculations – Method A (Suspension)

**Constant Mass:** 18

Calculate constant mass using the following formula:

$$\%Change = \frac{M_p - M_n}{M_p} \times 100$$

Where:

$M_p$ = previous mass measurement, g

$M_n$ = new mass measurement, g

**Bulk specific gravity ($G_{mb}$) and percent water absorbed:**

19

$$G_{mb} = \frac{A}{B - C}$$

$$Percent\ Water\ Absorbed\ (by\ volume) = \frac{B - A}{B - C} \times 100$$

where:

$G_{mb}$ = Bulk specific gravity

A = Mass of dry specimen in air, g

B = Mass of SSD specimen in air, g

C = Weight of specimen in water, g

**Example:**

20

$$G_{mb} = \frac{4833.6\ g}{4842.4\ g - 2881.3\ g} = 2.465$$

$$\%\ Water\ Absorbed\ (by\ volume) = \frac{4842.4\ g - 4833.6\ g}{4842.4\ g - 2881.3\ g} \times 100 = 0.45\%$$

## Apparatus – Method B (Volumeter)

21

- Balance or scale: 5 kg capacity, readable to 0.1 g and conforming to AASHTO M 231.
- Water bath: Thermostatically controlled to 25 ±0.5°C (77 ±0.9°F).
- Thermometer: Range of 19 to 27°C (66 to 80°F), and graduated in 0.1°C (0.2°F) subdivisions.
- Volumeter: Calibrated to 1200 mL or appropriate capacity for test sample and having a tapered lid with a capillary bore.

22

- Oven: Capable of maintaining a temperature of 110 ±5°C (230 ±9°F) for drying the specimens to a constant mass.

- Pan: Pan or other suitable container of known mass, large enough to hold a sample for drying in oven.
- Towel: Damp cloth towel used for surface drying specimens.
- Vacuum device: refer to AASHTO R 79 (optional)

23 **Procedure – Method B (Volumeter)**

Recently molded laboratory samples that have not been exposed to moisture do not need drying.

1. Dry the specimen to constant mass, if required.

24 a. Oven method

i. Initially dry overnight at 52 ±3°C (125 ±5°F).

ii. Determine and record the mass of the specimen ($M_p$).

iii. Return the specimen to the oven for at least 2 hours.

iv. Determine and record the mass of the specimen ($M_n$).

v. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$), divide by the previous mass determination ($M_p$), and multiply by 100.

vi. Continue drying until there is no more than 0.05 percent change in specimen mass after 2-hour drying intervals (constant mass).

vii. Constant mass has been achieved; sample is defined as dry.

***Note 1***: To expedite the procedure, steps 1 and 2 may be performed last. To further expedite the process, see Method C.

25 b. Vacuum dry

i. Perform vacuum drying procedure according to AASHTO R 79.

ii. Determine and record the mass of the specimen ($M_p$).

iii. Perform a second vacuum drying procedure.

iv. Determine and record the mass of the specimen ($M_n$).

v. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$), divide by the previous mass determination ($M_p$), and multiply by 100.

vi. Continue drying until there is no more than 0.05 percent change in specimen mass (constant mass).

vii. Constant mass has been achieved; sample is defined as dry.

26 2. Cool the specimen in air to 25 ±5°C (77 ±9°F), and determine and record the dry mass to the nearest 0.1 g. Designate this mass as "A."

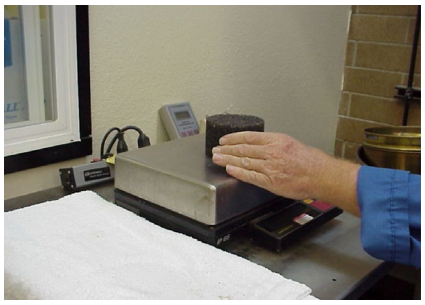
3. Immerse the specimen in the temperature controlled water bath for at least 10 minutes.

4. Fill the volumeter with distilled water at 25 ±1°C (77 ±1.8°F), making sure some water escapes through the capillary bore of the tapered lid.

**Drying surface**

27 5. Wipe the volumeter dry and determine the mass of the volumeter to the nearest 0.1 g. Designate this mass as "D."

6. At the end of the ten minute period, remove the specimen from the water bath and quickly surface dry with a damp towel within 5 seconds.



**Determining mass of SSD specimen**

28 7. Immediately determine and record the mass of the SSD specimen to the nearest 0.1 g. Designate this mass as "B." Any water that seeps from the specimen during the mass determination is considered part of the saturated specimen.

29 8. Place the specimen in the volumeter and let stand 60 seconds.

30 9. Bring the temperature of the water to 25 ±1°C (77 ±1.8°F) and cover the volumeter, making sure some water escapes through the capillary bore of the tapered lid.

31 10. Wipe the volumeter dry.

11. Determine and record the mass of the volumeter and specimen to the nearest 0.1 g. Designate this mass as "E."

***Note 2***: Method B is not acceptable for use with specimens that have more than 6 percent air voids.

## Calculations – Method B (Volumeter) 33

**Constant Mass:**

Calculate constant mass using the following formula:

$$\%Change = \frac{M_p - M_n}{M_p} \times 100$$

Where:

$M_p$ = previous mass measurement

$M_n$ = new mass measurement

**Bulk specific gravity ($G_{mb}$) and percent water absorbed:** 34

$$G_{mb} = \frac{A}{B + D - E}$$

$$Percent\ Water\ Absorbed\ (by\ volume) = \frac{B - A}{B + D - E} \times 100$$

where:

$G_{mb}$ = Bulk specific gravity

A = Mass of dry specimen in air, g

B = Mass of SSD specimen in air, g

D = Mass of volumeter filled with water at 25 ±1°C (77 ±1.8°F), g

E = Mass of volumeter filled with specimen and water, g

**Example:** 35

$$G_{mb} = \frac{4833.6\ g}{4842.4\ g + 2924.4\ g - 5806.0\ g} = 2.465$$

$$\%\ Water\ Absorbed\ (by\ volume) = \frac{4842.4\ g - 4833.6\ g}{4842.4\ g + 2944.4\ g - 5806.0\ g} \times 100 = 0.45\%$$

36 **Apparatus – Method C (Rapid Test for Method A or B)**

See Methods A or B.

***Note 3:*** This procedure can be used for specimens that are not required to be saved and contain substantial amounts of moisture. Cores can be tested the same day as obtained by this method.

**Procedure – Method C (Rapid Test for Method A or B)**

37 1. Start on Step 3 of Method A or B, and complete that procedure, then determine dry mass, "A," as follows.
2. Determine and record mass of a large, flat-bottom container.

38 3. Place the specimen in the container.
4. Place in an oven at a minimum of 105°C (221°F). Do not exceed the Job Mix Formula mixing temperature.
5. Dry until the specimen can be easily separated into fine aggregate particles that are not larger than 6.3 mm (¼ in.).
6. Determine and record the mass of the specimen ($M_p$).
7. Return the specimen to the oven for at least 2 hours.

39 8. Determine and record the mass of the specimen ($M_n$).

9. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$), divide by the previous mass determination ($M_p$), and multiply by 100.
10. Continue drying until there is no more than 0.05 percent change in specimen mass after 2-hour drying intervals (constant mass).
11. Constant mass has been achieved; sample is defined as dry.
12. Cool in air to 25 ±5°C (77 ±9°F).
13. Determine and record the mass of the container and dry specimen to the nearest 0.1 g.
40 14. Determine and record the mass of the dry specimen to the nearest 0.1 g by subtracting the mass of the container from the mass determined in Step 13. Designate this mass as "A."

41

## Calculations – Method C (Rapid Test for Method A or B)

Complete the calculations as outlined in Methods A or B, as appropriate.

42

## Report

- Results on forms approved by the agency
- Sample ID
- $G_{mb}$ to the nearest 0.001
- Absorption to the nearest 0.01 percent
- The method performed

## Tips!

43

- Use method approved by agency.
- Check for open or interconnecting voids and/or absorption over 2.00 percent.
- Check temperature of water in water bath.

## REVIEW QUESTIONS

1. For how long must samples be submerged prior to determining immersed weight for Method A?

2. In determining the SSD mass of a specimen, how must the sample be dried?

3. At what temperature and for how long should core samples be dried?

4. How do methods A and B differ?

# IN-PLACE DENSITY OF ASPHALT MIXTURES BY NUCLEAR METHOD FOP AASHTO T 355

## Significance

01 The final in-place density of roadway pavement is critical to the quality and longevity of a highway
02 project. Low-density material will lead to excessive deflection under load or permanent deformation, or both.

This procedure provides a rapid, nondestructive technique for determining the in-place density of compacted asphalt mixtures. It can be used to establish the proper rolling effort and pattern to achieve the required density. The results of this procedure may also be used as an indicator for in-place properties that could impact overall performance of asphalt mixtures.

The non-destructive nature of the test allows repetitive measurements to be made at a single test location between roller passes.

**Caution!**

## Scope

03 This test method describes a procedure for determining the density of asphalt mixtures by
04 means of a nuclear gauge using the backscatter method in accordance with AASHTO T 355-18. Correlation with densities determined under the FOP for AASHTO T 166 is required by some agencies.

## Apparatus

05
- Nuclear density gauge with the factory matched standard reference block.
- Transport case for properly shipping and housing the gauge and tools.
- Instruction manual for the specific make and model of gauge.
06
- Radioactive materials information and calibration packet containing:
  - Daily standard count log

**Gauge, transport case and instruction manual**

07

**Nuclear gauge**

**Filler on pavement**

08 – Factory and laboratory calibration data sheet

– Leak test certificate

– Shippers' declaration for dangerous goods

– Procedure memo for storing, transporting and handling nuclear testing equipment

– Other radioactive materials documentation as required by local regulatory requirements

## Material

09 • Filler material: Fine-graded sand from the source used to produce the asphalt pavement or other agency approved materials.

## Radiation Safety

10 This method does not purport to address all of the safety problems associated with its use. The

11 gauge utilizes radioactive materials that may be hazardous to the health of the user unless proper precautions are taken. Users of this gauge must become familiar with the applicable safety procedures and governmental regulations. All operators will be trained in radiation safety before operating nuclear density gauges. Some agencies require the use of personal monitoring devices such as a thermoluminescent dosimeter or film badge. Effective instructions, together with routine safety procedures such as source leak tests, recording and evaluation of personal monitoring device data, etc., are a recommended part of the operation and storage of this gauge.

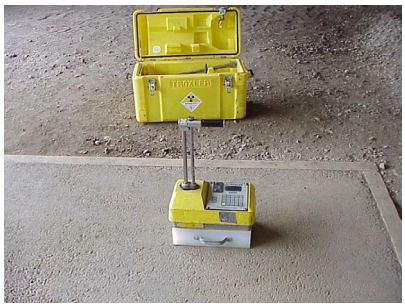
12 ## Calibration

Calibrate the nuclear gauge as required by the agency. This calibration may be performed by the agency using the manufacturer's recommended procedures or by other facilities approved by the agency. Verify or re-establish calibration curves, tables, or equivalent coefficients every 12 months.

## Standardization

1. Turn the gauge on and allow it to stabilize (approximately 10 to 20 minutes) before standardization. Leave the power on during the day's testing.

2. Standardize the nuclear gauge at the construction site at the start of each day's work and as often as deemed necessary by the operator or agency. Daily variations in standard count shall not exceed the daily variations established by the manufacturer of the gauge. If the daily variations are exceeded after repeating the standardization procedure, the gauge should be repaired, recalibrated, or both.



**Stabilizing the Gauge**

3. Record the standard count for both density and moisture in the daily standard count log. The exact procedure for standard count is listed in the manufacturer's Operator's Manual.

***Note 1:*** New standard counts may be necessary more than once a day. See agency requirements.

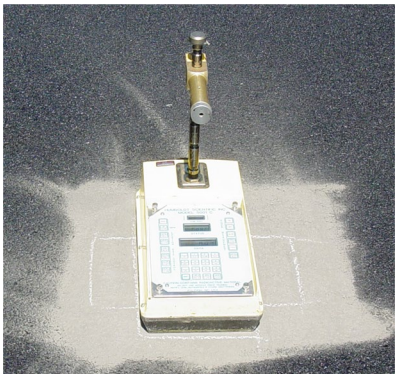
## Test Site Location

1. Select a test location(s) randomly and in accordance with agency requirements. Test sites should be relatively smooth and flat and meet the following conditions:

   a. At least 10 m (30 ft) away from other sources of radioactivity.

   b. At least 3 m (10 ft) away from large objects.

   c. If the gauge will be closer than 600 mm (24 in.) to any vertical mass, or less than 300 mm (12 in.) from a vertical pavement edge, use the gauge manufacturer's correction procedure.



**Nuclear gauge**

## Procedure

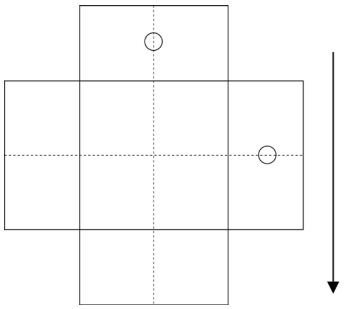
1. Maintain maximum contact between the base of the gauge and the surface of the material under test.

2. Use filler material to fill surface voids. Spread a small amount of filler material over the test site surface and distribute it evenly.

3. Strike off the surface with a straightedge (such as a lathe or flat-bar steel) to remove excess material.
4. If using thin-layer mode, enter the anticipated overlay thickness into the gauge.

***Note 2:*** If core correlation is required, entered thickness, anticipated thickness, and nominal core thickness may be required to match.

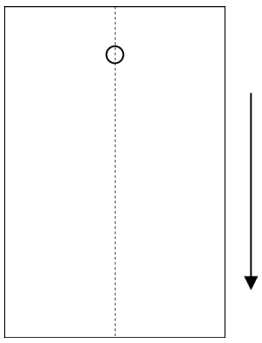
**Method A – Average of two one-minute tests**



**Method A**
**Footprint of the gauge test site**
**Arrow indicates direction of the roller pass**

1. Place the gauge on the test site, perpendicular to the roller passes.
2. Using a crayon (not spray paint), mark the outline or footprint of the gauge.
3. Extend the probe to the backscatter position.
4. Take a one-minute test and record the wet density reading.
5. Rotate the gauge 90 degrees centered over the original footprint. Mark the outline or footprint of the gauge.
6. Take another one-minute test and record the wet density reading.
7. If the difference between the two one-minute tests is greater than 40 kg/m$^3$ (2.5 lb/ft$^3$), retest in both directions. If the difference of the retests is still greater than 40 kg/m$^3$ (2.5 lb/ft$^3$) test at 180 and 270 degrees.
8. The density reported for each test site shall be the average of the two individual one-minute wet density readings.

**Method B – One four-minute test**



**Method B**
**Footprint of the gauge test site**
**Arrow indicates direction of the roller pass**

1. Place the gauge on the test site, parallel to the roller passes.
2. Using a crayon (not spray paint), mark the outline or footprint of the gauge.
3. Extend the probe to the backscatter position.
4. Take one 4-minute test and record the wet density reading.

## Calculation of Results

26

Percent compaction is determined by comparing the in-place wet density as determined by this method to the appropriate agency density standard. See appropriate agency policy for use of density standards.

$$Percent\ compaction = \frac{Corrected\ Reading}{Maximum\ Density} \times 100$$

**Method A Example:** 27

Reading #1: 141.5 lb/ft$^3$

Reading #2: 140.1 lb/ft$^3$ Are the two readings within the tolerance? (YES)

Reading average: 140.8 lb/ft$^3$

Core correction : +2.1 lb/ft$^3$

**Corrected reading**: 142.9 lb/ft$^3$

**Method B Example:** 28

Reading: 140.8 lb/ft$^3$

Core correction: +2.1 lb/ft$^3$

**Corrected reading**: 142.9 lb/ft$^3$

**Example percent compaction:** 29

From the FOP for AASHTO T 209:

$\mathbf{G_{mm}}$ = 2.466

$$Theoretical\ Maximum\ Density = 2.466 \times 62.245 lb/ft^3 = 153.5 lb/ft^3$$

$$Percent\ compaction = \frac{142.9\ lb/ft^3}{153.5\ lb/ft^3} \times 100 = 93.1\%$$

30

## Report

- Results on forms approved by the agency
- Test ID
- Location of test and thickness of layer tested
- Mixture type
- Make, model and serial number of the nuclear moisture-density gauge
- Calculated wet density of each measurement and any adjustment data
- Density standard
- Compaction to the nearest 0.1 percent
- Name and signature of operator

31

## Tips!

– Check to make sure that base of gauge is clean before testing.

– Shutter block and assembly are free of debris and operating correctly.

– Gauge is reading the proper position of the source rod when it is indexed, and that it has been seated correctly.

32

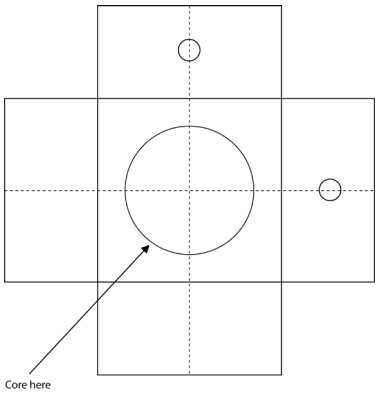
– Surface is flat and the gauge does not rock.

– Surface has been properly prepared using filler material.

– Do not leave the gauge on a hot surface for a long time.

33

33




**Method A**
**Footprint of the gauge test site**
**Core location in the center of the footprint**

## APPENDIX – CORRELATION WITH CORES

(Nonmandatory Information)

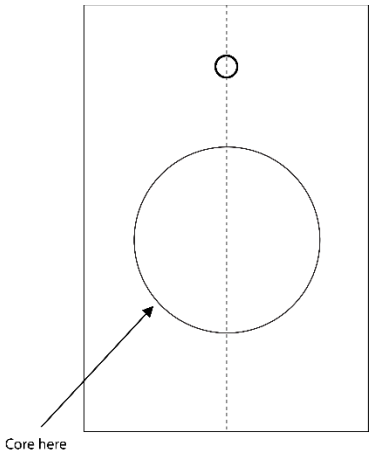
The bulk specific gravity ($G_{mb}$) of the core is a physical measurement of the in-place asphalt mixture and can be compared with the nuclear density gauge readings. Comparing the core value to the corresponding gauge values, a correlation can be established.

The correlation can then be used to adjust the gauge readings to the in-place density of the cores. The core correlation is gauge specific and must be determined without traffic allowed on the pavement between nuclear density gauge readings and obtaining the core. When using multiple nuclear density gauges each gauge should be correlated to the core locations before removal of the core.

When density correlation with the FOP for AASHTO T 166 is required, correlation of the nuclear gauge with pavement cores shall be made on the first day's paving (within 24 hours) or from a test strip constructed before the start of paving. Cores must be taken before traffic is allowed on the pavement.

**Correlation with Cores**

1. Determine the number of cores required for correlation from the agency's specifications. Cores shall be located on the first day's paving or on the test strip. Locate the test sites in accordance with the agency's specifications. Follow the "Procedure" section above to establish test sites and obtain densities using the nuclear gauge.
2. Obtain a pavement core from each of the test sites according to AASHTO R 67. The core should be taken from the center of the nuclear gauge footprint.
3. Determine the density of the cores by the FOP for AASHTO T 166, Bulk Specific Gravity ($G_{mb}$) of Compacted Asphalt Mixtures Using Saturated Surface Dry Specimens.




**Method B**
**Footprint of the gauge test site**
**Core location in the center of the footprint**

34 4. Calculate a correlation factor for the nuclear gauge reading as follows:

35 a. Calculate the difference between the core density and the average nuclear gauge density at each test site to the nearest 1 kg/m$^3$ (0.1 lb/ft$^3$). Calculate the average difference and standard deviation of the differences for the entire data set to the nearest 1 kg/m$^3$ (0.1 lb/ft$^3$).

b. If the standard deviation of the differences is equal to or less than 40 kg/m$^3$ (2.5 lb/ft$^3$), the correlation factor applied to the average nuclear gauge density shall be the average difference calculated above in 4.a.

c. If the standard deviation of the differences is greater than 40 kg/m$^3$ (2.5 lb/ft$^3$), the test site with the greatest variation from the average difference shall be eliminated from the data set and the data set properties and correlation factor recalculated following 4.a and 4.b.

36 d. If the standard deviation of the modified data set still exceeds the maximum specified in 4.b, additional test sites will be eliminated from the data set and the data set properties and correlation factor recalculated following 4.a and 4.b. If the data set consists of less than five test sites, additional test sites shall be established.

***Note A1:*** The exact method used in calculating the nuclear gauge correlation factor shall be defined by agency policy.

***Note A2***: The above correlation procedure must be repeated if there is a new job mix formula. Adjustments to the job mix formula beyond tolerances established in the contract
37 documents will constitute a new job mix formula. A
38 correlation factor established using this procedure is only valid for the particular gauge used in the correlation procedure. If another gauge is brought onto the project, it shall be correlated using the same procedure. Multiple gauges may be correlated from the same series of cores if done at the same time.

39 ***Note A3:*** For the purpose of this procedure, a job mix formula is defined as the percent and grade of paving asphalt used with a specified gradation of aggregate from a designated aggregate source. A new job mix formula may be required whenever compaction of the wearing surface exceeds the agency's specified maximum density or minimum air voids.

## Calculations

### Correlation Factor

40

$$\sqrt{\frac{\sum x^2}{n-1}}$$

Where:

$\sum$ = Sum

x = Difference from the average Difference

n-1 = number of data sets minus 1

## Example

41

| Core # | Core results from T 166: | Average Gauge reading: | Difference: | x | $x^2$ |
|---|---|---|---|---|---|
| 1 | 144.9 lb/ft$^3$ | 142.1 lb/ft$^3$ | 2.8 lb/ft$^3$ | -0.7 | 0.49 |
| 2 | 142.8 lb/ft$^3$ | 140.9 lb/ft$^3$ | 1.9 lb/ft$^3$ | 0.2 | 0.04 |
| 3 | 143.1 lb/ft$^3$ | 140.7 lb/ft$^3$ | 2.4 lb/ft$^3$ | -0.3 | 0.09 |
| 4 | 140.7 lb/ft$^3$ | 138.9 lb/ft$^3$ | 1.8 lb/ft$^3$ | 0.3 | 0.09 |
| 5 | 145.1 lb/ft$^3$ | 143.6 lb/ft$^3$ | 1.5 lb/ft$^3$ | 0.6 | 0.36 |
| 6 | 144.2 lb/ft$^3$ | 142.4 lb/ft$^3$ | 1.8 lb/ft$^3$ | 0.3 | 0.09 |
| 7 | 143.8 lb/ft$^3$ | 141.3 lb/ft$^3$ | 2.5 lb/ft$^3$ | -0.4 | 0.16 |
| 8 | 142.8 lb/ft$^3$ | 139.8lb/ft$^3$ | 3.0 lb/ft$^3$ | 0.9 | 0.81 |
| 9 | 144.8 lb/ft$^3$ | 143.3 lb/ft$^3$ | 1.5 lb/ft$^3$ | -0.6 | 0.36 |
| 10 | 143.0 lb/ft$^3$ | 141.0 lb/ft$^3$ | 2.0 lb/ft$^3$ | -0.1 | 0.01 |

Average Difference: +2.1 lb/ft$^3$ $\Sigma x^2$ = 2.5

**Number of data sets** 42

$$\boldsymbol{n - 1 = 10 - 1 = 9}$$

**Standard deviation**

$$standard\ deviation = \sqrt{\frac{2.5}{9}} = 0.53$$

Where:

Sum of $x^2$ = 2.5

Number of data sets = 9 43

The standard deviation of 0.53 is less than 2.5 therefore no cores are eliminated. The averag difference from all ten cores is used.

## REVIEW QUESTIONS

1. Describe the calibration and standardization process.

2. What precautions must be taken in selecting a test location?

3. How do you determine percent compaction?

4. Describe the procedure for correlating results with pavement cores.

## PERFORMANCE EXAM CHECKLIST

## IN-PLACE DENSITY OF ASPHALT MIXTURES BY NUCLEAR METHOD FOP FOR AASHTO T 355

Participant Name _____ Exam Date _____

**Record the symbols "P" for passing or "F" for failing on each step of the checklist**.

| Procedure Element | Trial 1 | Trial 2 |
|---|---|---|
| 1. Gauge turned on approximately 10 to 20 minutes before use? | _____ | _____ |
| 2. Gauge calibrated, and standard count recorded? | _____ | _____ |
| 3. Test location selected appropriately [600 mm (24 in.) from vertical projections or 10 m (30 ft.) from any other radioactive sources]? | _____ | _____ |
| 4. Filler spread evenly over test site? | _____ | _____ |
| 5. Excess filler material removed by striking off the surface? | _____ | _____ |
| 6. Gauge placed on pavement surface and footprint of gauge marked? | _____ | _____ |
| 7. Probe extended to backscatter position? | _____ | _____ |
| 8. Method A: | | |
| a. One-minute count taken; gauge rotated 90°, reseated, and another one-minute count taken? | _____ | _____ |
| b. Densities averaged? | _____ | _____ |
| c. If difference of the wet densities is greater than 40 kg/m$^3$ (2.5 lb/ft$^3$), retest conducted in both directions? | _____ | _____ |
| 9. Method B: | | |
| a. One four-minute count taken? | _____ | _____ |
| 10. Core correlation applied if required? | _____ | _____ |
| 11. Percent compaction calculated correctly? | _____ | _____ |

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

_____

_____

_____

_____

Examiner Signature _____WAQTC #:_____

## APPENDIX A
## FIELD OPERATING PROCEDURES - SHORT FORM

| Chapter | Section |
|---|---|
| 13 | AASHTO T 255<br>Total Evaporable Moisture Content of Aggregate by Drying; and<br>AASHTO T 265<br>Laboratory Determination of Moisture Content of Soils |
| 14 | AASHTO T 99<br>Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-in.) Drop;<br>AASHTO T 180<br>Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and 457-mm (18-in.) Drop |
| 15 | AASHTO R 75<br>Family of Curves |
| 16 | AASHTO 272<br>One-Point Method for Determining Maximum Dry Density and Optimum Moisture |
| 17 | AASHTO T 85<br>Specific Gravity and Absorption of Coarse Aggregate |
| 18 | Instruction on Use of AKDOT & PF ATM 212, ITD IT 74, WSDOT T 606, or WFLHD Humphres Curves |
| 19 | AASHTO T 310<br>In-Place Density and Moisture Content of Soil and Soil-Aggregate by the Nuclear Method |
| 20 | AASHTO T 209<br>Theoretical Maximum Specific Gravity ($G_{mm}$) and Density of Asphalt Mixtures |
| 21 | AASHTO T 166<br>Bulk Specific Gravity ($G_{mb}$) of Compacted Asphalt Mixtures Using Saturated Surface Dry Specimens |
| 22 | AASHTO T 355<br>In-Place Density of Asphalt Mixtures Using by Nuclear Method |

# TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING FOP FOR AASHTO T 255
# LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS FOP FOR AASHTO T 265

## Scope

This procedure covers the determination of moisture content of aggregate and soil in accordance with AASHTO T 255-00 and AASHTO T 265-15. It may also be used for other construction materials.

## Overview

Moisture content is determined by comparing the wet mass of a sample and the mass of the sample after drying to constant mass. The term constant mass is used to define when a sample is dry.

*Constant mass* – the state at which a mass does not change more than a given percent, after additional drying for a defined time interval, at a required temperature.

## Apparatus

- Balance or scale: capacity sufficient for the principle sample mass, accurate to 0.1 percent of sample mass or readable to 0.1 g, and meeting the requirements of AASHTO M 231
- Containers, clean, dry and capable of being sealed
- Suitable drying containers
- Microwave safe container with ventilated lid
- Heat source, controlled:
  - Forced draft oven
  - Ventilated oven
  - Convection oven
- Heat source, uncontrolled:
  - Infrared heater/heat lamp, hot plate, fry pan, or any other device/method that will dry the sample without altering the material being dried
  - Microwave oven (900 watts minimum)
- Utensils such as spoons
- Hot pads or gloves

## Sample Preparation

In accordance with the FOP for AASHTO R 90 obtain a representative sample in its existing condition.

For aggregates the representative sample size is based on Table 1 or other information that may be specified by the agency.

**TABLE 1**
**Sample Sizes for Moisture Content of Aggregate**

| Nominal Maximum Size* mm (in.) | Minimum Sample Mass g (lb) |
|---|---|
| 4.75 (No. 4) | 500 (1.1) |
| 9.5 (3/8) | 1500 (3.3) |
| 12.5 (1/2) | 2000 (4) |
| 19.0 (3/4) | 3000 (7) |
| 25.0 (1) | 4000 (9) |
| 37.5 (1 1/2) | 6000 (13) |
| 50 (2) | 8000 (18) |
| 63 (2 1/2) | 10,000 (22) |
| 75 (3) | 13,000 (29) |
| 90 (3 1/2) | 16,000 (35) |
| 100 (4) | 25,000 (55) |
| 150 (6) | 50,000 (110) |

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum.

For soils the representative sample size is based on Table 2 or other information that may be specified by the agency.

**TABLE 2**
**Sample Sizes for Moisture Content of Soil**

| Maximum Particle Size mm (in.) | Minimum Sample Mass g |
|---|---|
| 0.425 (No. 40) | 10 |
| 4.75 (No. 4) | 100 |
| 12.5 (1/2) | 300 |
| 25.0 (1) | 500 |
| 50 (2) | 1000 |

Immediately seal or cover samples to prevent any change in moisture content or follow the steps in "Procedure."

## Procedure

Determine and record the sample mass as follows:

- For aggregate, determine and record all masses to the nearest 0.1 percent of the sample mass or to the nearest 0.1 g.
- For soil, determine and record all masses to the nearest 0.1 g.

When determining the mass of hot samples or containers or both, place and tare a buffer between the sample container and the balance. This will eliminate damage to or interference with the operation of the balance or scale.

1. Determine and record the mass of the container (and lid for microwave drying).
2. Place the wet sample in the container.
   a. For oven(s), hot plates, infrared heaters, etc.: Spread the sample in the container.
   b. For microwave oven: Heap sample in the container; cover with ventilated lid.
3. Determine and record the total mass of the container and wet sample.
4. Determine and record the wet mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 3.
5. Place the sample in one of the following drying apparatus:
   a. For aggregate –
      i. Controlled heat source (oven): at 110 ±5°C (230 ±9°F).
      ii. Uncontrolled heat source (Hot plate, infrared heater, etc.): Stir frequently to avoid localized overheating.
   b. For soil – controlled heat source (oven): at 110 ±5°C (230 ±9°F).

***Note 1:*** Soils containing gypsum or significant amounts of organic material require special drying. For reliable moisture contents dry these soils at 60°C (140°F). For more information see AASHTO T 265, Note 2.

6. Dry until sample appears moisture free.
7. Determine mass of sample and container.
8. Determine and record the mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 7.
9. Return sample and container to the heat source for additional drying.
   a. For aggregate –
      i. Controlled heat source (oven): 30 minutes
      ii. Uncontrolled heat source (Hot plate, infrared heater, etc.): 10 minutes
      iii. Uncontrolled heat source (Microwave oven): 2 minutes

**Caution:** Some minerals in the sample may cause the aggregate to overheat, altering the aggregate gradation.

   b. For soil – controlled heat source (oven): 1 hour

10. Determine mass of sample and container.
11. Determine and record the mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 10.
12. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$) divide by the previous mass determination ($M_p$) multiply by 100.
13. Continue drying, performing steps 9 through 12, until there is less than a 0.10 percent change after additional drying time.
14. Constant mass has been achieved; sample is defined as dry.
15. Allow the sample to cool. Immediately determine and record the total mass of the container and dry sample.
16. Determine and record the dry mass of the sample by subtracting the mass of the container determined in Step 1 from the mass of the container and sample determined in Step 15.
17. Determine and record percent moisture (w) by subtracting the final dry mass determination ($M_D$) from the initial wet mass determination ($M_W$) divide by the final dry mass determination ($M_D$) multiply by 100.

**Table 3**
**Methods of Drying**

| **Aggregate** | | |
|---|---|---|
| **Heat Source** | **Specific Instructions** | **Drying intervals to achieve constant mass (minutes)** |
| **Controlled:**<br>Forced draft (preferred), ventilated, or convection oven | 110 ±5°C (230 ±9°F) | 30 |
| **Uncontrolled:** | | |
| Hot plate, infrared heater, etc. | Stir frequently | 10 |
| Microwave | Heap sample and cover with ventilated lid | 2 |
| **Soil** | | |
| **Heat Source** | **Specific Instructions** | **Drying increments (minutes)** |
| **Controlled:**<br>Forced draft (preferred), ventilated, or convection oven | 110 ±5°C (230 ±9°F) | 1 hour |

## Calculation

**Constant Mass**:

Calculate constant mass using the following formula:

$$\%\ Change = \frac{M_p - M_n}{M_p} \times 100$$

Where:

$M_p$ = previous mass measurement

$M_n$ = new mass measurement

**Example:**

| | |
|---|---|
| Mass of container: | 1232.1 g |
| Mass of container and sample after first drying cycle: | 2637.2 g |
| Mass, $M_p$, of possibly dry sample: | 2637.2 g - 1232.1 g = 1405.1 g |
| Mass of container and dry sample after second drying cycle: | 2634.1 g |
| Mass, $M_n$, of dry sample: | 2634.1 g - 1232.1 g = 1402.0 g |

$$\%\ Change = \frac{1405.1\ g - 1402.0\ g}{1405.1\ g} \times 100 = 0.22\%$$

*0.22 percent is not less than 0.10 percent, so continue drying*

Mass of container and dry sample after third drying cycle: 2633.0 g

Mass, $M_n$, of dry sample: 2633.0 g - 1232.1 g = 1400.9 g

$$\%\ Change = \frac{1402.0\ g - 1400.9\ g}{1402.0\ g} \times 100 = 0.08\%$$

*0.08 percent is less than 0.10 percent, so constant mass has been reached.*

## Moisture Content:

Calculate the moisture content, as a percent, using the following formula:

$$w = \frac{M_W - M_D}{M_D} \times 100$$

Where:

w = moisture content, percent

$M_W$ = wet mass

$M_D$ = dry mass

Example:

| | |
|---|---|
| Mass of container: | 1232.1 g |
| Mass of container and wet sample: | 2764.7 g |
| Mass, $M_W$, of wet sample: | 2764.7 g - 1232.1 g = 1532.6 g |
| Mass of container and dry sample (COOLED): | 2633.5 g |
| Mass, $M_D$, of dry sample: | 2633.5 g - 1232.1 g = 1401.4 g |

$$w = \frac{1532.6\ g - 1401.4\ g}{1401.4\ g} \times 100 = \frac{131.2 g}{1401.4\ g} \times 100 = 9.36\% \quad report\ 9.4\%$$

## Report

- Results on forms approved by the agency
- Sample ID
- $M_W$, wet mass
- $M_D$, dry mass
- w, moisture content to the nearest 0.1 percent

# MOISTURE-DENSITY RELATIONS OF SOILS: USING A 2.5 kg (5.5 lb) RAMMER AND A 305 mm (12 in.) DROP FOP FOR AASHTO T 99 USING A 4.54 kg (10 lb) RAMMER AND A 457 mm (18 in.) DROP FOP FOR AASHTO T 180

## Scope

This procedure covers the determination of the moisture-density relations of soils and soil-aggregate mixtures in accordance with two similar test methods:

- AASHTO T 99-19: Methods A, B, C, and D
- AASHTO T 180-19: Methods A, B, C, and D

This test method applies to soil mixtures having 40 percent or less retained on the 4.75 mm (No. 4) sieve for methods A or B, or, 30 percent or less retained on the 19 mm (¾ in.) with methods C or D. The retained material is defined as oversize (coarse) material. If no minimum percentage is specified, 5 percent will be used. Samples that contain oversize (coarse) material that meet percent retained criteria should be corrected by using *Annex A, Correction of Maximum Dry Density and Optimum Moisture for Oversized Particles*. Samples of soil or soil-aggregate mixture are prepared at several moisture contents and compacted into molds of specified size, using manual or mechanical rammers that deliver a specified quantity of compactive energy. The moist masses of the compacted samples are multiplied by the appropriate factor to determine wet density values. Moisture contents of the compacted samples are determined and used to obtain the dry density values of the same samples. Maximum dry density and optimum moisture content for the soil or soil-aggregate mixture is determined by plotting the relationship between dry density and moisture content.

## Apparatus

- Mold – Cylindrical mold made of metal with the dimensions shown in Table 1 or Table 2. If permitted by the agency, the mold may be of the "split" type, consisting of two half-round sections, which can be securely locked in place to form a cylinder. Determine the mold volume according to *Annex B, Standardization of the Mold.*
- Mold assembly – Mold, base plate, and a detachable collar.
- Rammer – Manually or mechanically operated rammers as detailed in Table 1 or Table 2. A manually operated rammer shall be equipped with a guide sleeve to control the path and height of drop. The guide sleeve shall have at least four vent holes no smaller than 9.5 mm (3/8 in.) in diameter, spaced approximately 90 degrees apart and approximately 19 mm (3/4 in.) from each end. A mechanically operated rammer will uniformly distribute blows over the sample and will be calibrated with several soil types, and be adjusted, if necessary, to give the same moisture-density results as with the manually operated rammer. For additional information concerning calibration, see the FOP for AASHTO T 99 and T 180.

- Sample extruder – A jack, lever frame, or other device for extruding compacted specimens from the mold quickly and with little disturbance.

- Balance(s) or scale(s) of the capacity and sensitivity required for the procedure used by the agency.

  A balance or scale with a capacity of 11.5 kg (25 lb) and a sensitivity of 1 g for obtaining the sample, meeting the requirements of AASHTO M 231, Class G 5.

  A balance or scale with a capacity of 2 kg and a sensitivity of 0.1 g is used for moisture content determinations done under both procedures, meeting the requirements of AASHTO M 231, Class G 2.

- Drying apparatus – A thermostatically controlled drying oven, capable of maintaining a temperature of 110 ±5°C (230 ±9°F) for drying moisture content samples in accordance with the FOP for AASHTO T 255/T 265.

- Straightedge – A steel straightedge at least 250 mm (10 in.) long, with one beveled edge and at least one surface plane within 0.1 percent of its length, used for final trimming.

- Sieve(s) – 4.75 mm (No. 4) and/or 19.0 mm (3/4 in.), meeting the requirements of FOP for AASHTO T 27/T 11.

- Mixing tools – Miscellaneous tools such as a mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device, for mixing the sample with water.

- Containers with close-fitting lids to prevent gain or loss of moisture in the sample.

**Table 1**
**Comparison of Apparatus, Sample, and Procedure – Metric**

| | T 99 | T 180 |
|---|---|---|
| Mold Volume, $m^3$ | Methods A, C: 0.000943 ±0.000014 | Methods A, C: 0.000943 ±0.000014 |
| | Methods B, D: 0.002124 ±0.000025 | Methods B, D: 0.002124 ±0.000025 |
| Mold Diameter, mm | Methods A, C: 101.60 ±0.40 | Methods A, C: 101.60 ±0.4 |
| | Methods B, D: 152.40 ±0.70 | Methods B, D: 152.40 ±0.70 |
| Mold Height, mm | 116.40 ±0.50 | 116.40 ±0.50 |
| Detachable Collar Height, mm | 50.80 ±0.64 | 50.80 ±0.64 |
| Rammer Diameter, mm | 50.80 ±0.25 | 50.80 ±0.25 |
| Rammer Mass, kg | 2.495 ±0.009 | 4.536 ±0.009 |
| Rammer Drop, mm | 305 | 457 |
| Layers | 3 | 5 |
| Blows per Layer | Methods A, C: 25 | Methods A, C: 25 |
| | Methods B, D: 56 | Methods B, D: 56 |
| Material Size, mm | Methods A, B: 4.75 minus | Methods A, B: 4.75 minus |
| | Methods C, D: 19.0 minus | Methods C, D: 19.0 minus |
| Test Sample Size, kg | Method A: 3 Method B: 7<br>Method C: 5 (1) Method D: 11(1) | |
| Energy, kN-m/$m^3$ | 592 | 2,693 |

(1) This may not be a large enough sample depending on your nominal maximum size for moisture content samples.

**Table 2**
**Comparison of Apparatus, Sample, and Procedure – English**

| | T 99 | T 180 |
|---|---|---|
| Mold Volume, $ft^3$ | Methods A, C: 0.0333 ±0.0005 | Methods A, C: 0.0333 ±0.0005 |
| | Methods B, D: 0.07500 ±0.0009 | Methods B, D: 0.07500 ±0.0009 |
| Mold Diameter, in. | Methods A, C: 4.000 ±0.016 | Methods A, C: 4.000 ±0.016 |
| | Methods B, D: 6.000 ±0.026 | Methods B, D: 6.000 ±0.026 |
| Mold Height, in. | 4.584 ±0.018 | 4.584 ±0.018 |
| Detachable Collar Height, in. | 2.000 ±0.025 | 2.000 ±0.025 |
| Rammer Diameter, in. | 2.000 ±0.025 | 2.000 ±0.025 |
| Rammer Mass, lb | 5.5 ±0.02 | 10 ±0.02 |
| Rammer Drop, in. | 12 | 18 |
| Layers | 3 | 5 |
| Blows per Layer | Methods A, C: 25 | Methods A, C: 25 |
| | Methods B, D: 56 | Methods B, D: 56 |
| Material Size, in. | Methods A, B: No. 4 minus | Methods A, B: No.4 minus |
| | Methods C, D: 3/4 minus | Methods C, D: 3/4 minus |
| Test Sample Size, lb | Method A: 7 Method B: 16<br>Method C: 12(1) Method D: 25(1) | |
| Energy, lb-ft/$ft^3$ | 12,375 | 56,250 |

(1) This may not be a large enough sample depending on your nominal maximum size for moisture content samples.

## Sample

If the sample is damp, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus maintained at a temperature not exceeding 60°C (140°F). Thoroughly break up aggregations in a manner that avoids reducing the natural size of individual particles.

Obtain a representative test sample of the mass required by the agency by passing the material through the sieve required by the agency. See Table 1 or Table 2 for test sample mass and material size requirements.

In instances where the material is prone to degradation, i.e., granular material, a compaction sample with differing moisture contents should be prepared for each point.

If the sample is plastic (clay types), it should stand for a minimum of 12 hours after the addition of water to allow the moisture to be absorbed. In this case, several samples at different moisture contents should be prepared, put in sealed containers and tested the next day.

***Note 1:*** Both T 99 and T 180 have four methods (A, B, C, D) that require different masses and employ different sieves.

## Procedure

During compaction, rest the mold firmly on a dense, uniform, rigid, and stable foundation or base. This base shall remain stationary during the compaction process.

1. Determine the mass of the clean, dry mold. Include the base plate, but exclude the extension collar. Record the mass to the nearest 1 g (0.005 lb).

2. Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately 4 to 8 percentage points below optimum moisture content. For many materials, this condition can be identified by forming a cast by hand.

   a. Prepare individual samples of plastic or degradable material, increasing moisture contents 1 to 2 percent for each point.

   b. Allow samples of plastic soil to stand for 12 hrs.

3. Form a specimen by compacting the prepared soil in the mold assembly in approximately equal layers. For each layer:

   a. Spread the loose material uniformly in the mold.

   ***Note 2:*** It is recommended to cover the remaining material with a non-absorbent sheet or damp cloth to minimize loss of moisture.

   b. Lightly tamp the loose material with the manual rammer or other similar device, this establishes a firm surface.

c. Compact each layer with uniformly distributed blows from the rammer. See Table 1 for mold size, number of layers, number of blows, and rammer specification for the various test methods. Use the method specified by the agency.

d. Trim down material that has not been compacted and remains adjacent to the walls of the mold and extends above the compacted surface.

4. Remove the extension collar. Avoid shearing off the sample below the top of the mold. The material compacted in the mold should not be over 6 mm (¼ in.) above the top of the mold once the collar has been removed.

5. Trim the compacted soil even with the top of the mold with the beveled side of the straightedge.

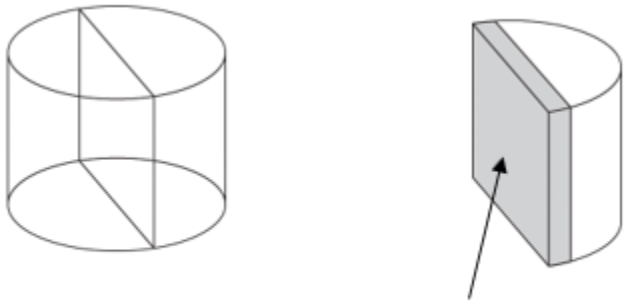
6. Clean soil from exterior of the mold and base plate.

7. Determine and record the mass of the mold, base plate, and wet soil to the nearest 1 g (0.005 lb) or better.

8. Determine and record the wet mass ($M_w$) of the sample by subtracting the mass in Step 1 from the mass in Step 7.

9. Calculate the wet density, in kg/m$^3$ (lb/ft$^3$), by dividing the wet mass by the measured volume ($V_m$).

10. Extrude the material from the mold. For soils and soil-aggregate mixtures, slice vertically through the center and take a representative moisture content sample from one of the cut faces, ensuring that all layers are represented. For granular materials, a vertical face will not exist. Take a representative sample. This sample must meet the sample size requirements of the test method used to determine moisture content.



**Extruded material** **Representative moisture content sample**

***Note 3:*** When developing a curve for free-draining soils such as uniform sands and gravels, where seepage occurs at the bottom of the mold and base plate, taking a representative moisture content from the mixing bowl may be preferred in order to determine the amount of moisture available for compaction.

11. Determine and record the moisture content of the sample in accordance with the FOP for AASHTO T 255 / T 265.

12. If the material is degradable or plastic, return to Step 3 using a prepared individual sample. If not, continue with Steps 13 through 15.

13. Thoroughly break up the remaining portion of the molded specimen until it will again pass through the sieve, as judged by eye, and add to the remaining portion of the sample being tested.

14. Add sufficient water to increase the moisture content of the remaining soil by 1 to 2 percentage points and repeat steps 3 through 11.

15. Continue determinations until there is either a decrease or no change in the wet mass. There will be a minimum of three points on the dry side of the curve and two points on the wet side. For non-cohesive, drainable soils, one point on the wet side is sufficient.

## Calculations

**Wet Density**

$$D_w = \frac{M_w}{V_m}$$

Where:

$D_w$ = wet density, kg/m$^3$ (lb/ft$^3$)

$M_w$ = wet mass

$V_m$ = volume of the mold, Annex B

**Dry Density**

$$D_d = \left(\frac{D_w}{w + 100}\right) \times 100 \quad or \quad D_d = \frac{D_w}{\left(\frac{w}{100}\right) + 1}$$

Where:

$D_d$ = dry density, kg/m$^3$ (lb/ft$^3$)

w = moisture content, as a percentage

**Example for 4-inch mold, Methods A or C**

Wet mass, $M_w$ = 1.928 kg (4.25 lb)

Moisture content, w = 11.3%

Measured volume of the mold, $V_m$ = 0.000946 m$^3$ (0.0334 ft$^3$)

**Wet Density**

$$D_w = \frac{1.928\ kg}{0.000946\ m^3} = 2038\ kg/m^3 \quad D_w = \frac{4.25\ lb}{0.0334\ ft^3} = 127.2\ lb/ft^3$$

**Dry Density**

$$D_d = \left(\frac{2038\ kg/m^3}{11.3 + 100}\right) \times 100 = 1831\ \ kg/m^3 \quad D_d = \left(\frac{127.2\ \ lb/ft^3}{11.3 + 100}\right) \times 100 = 114.3\ lb/ft^3$$

Or

$$D_d = \left(\frac{2038\ kg/m^3}{\frac{11.3}{100} + 1}\right) = 1831\ kg/m^3 \quad D_d = \left(\frac{127.2\ \ lb/ft^3}{\frac{11.3}{100} + 1}\right) = 114.3\ lb/ft^3$$

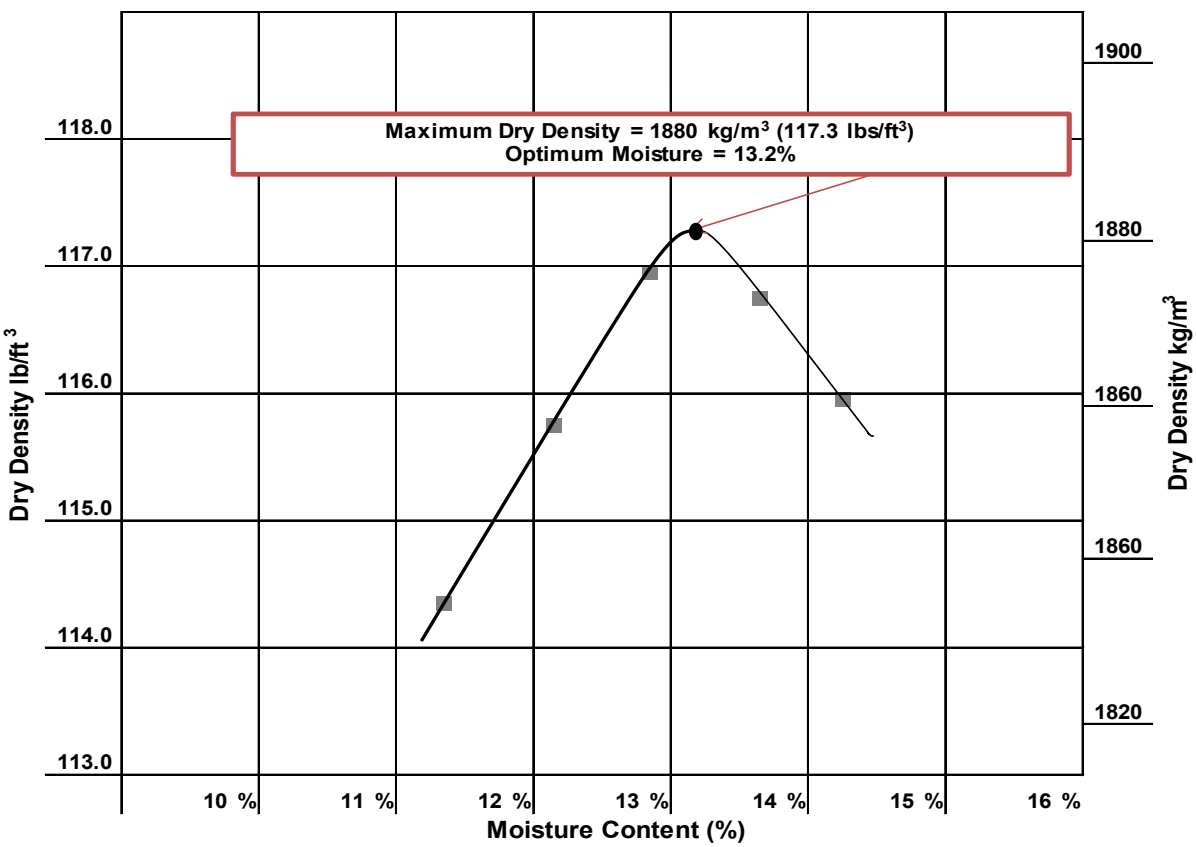
## Moisture-Density Curve Development

When dry density is plotted on the vertical axis versus moisture content on the horizontal axis and the points are connected with a smooth line, a moisture-density curve is developed. The coordinates of the peak of the curve are the maximum dry density, or just "maximum density," and the "optimum moisture content" of the soil.

**Example**

Given the following dry density and corresponding moisture content values develop a moisture-density relations curve and determine maximum dry density and optimum moisture content.

| Dry Density kg/m³ | Dry Density lb/ft³ | Moisture Content, % |
|---|---|---|
| 1831 | 114.3 | 11.3 |
| 1853 | 115.7 | 12.1 |
| 1873 | 116.9 | 12.8 |
| 1869 | 116.7 | 13.6 |
| 1857 | 115.9 | 14.2 |



In this case, the curve has its peak at:

Maximum dry density = 1880 kg/m$^3$ (117.3 lb/ft$^3$)

Optimum moisture content = 13.2%

Note that both values are approximate, since they are based on sketching the curve to fit the points.

## Report

- Results on forms approved by the agency
- Sample ID
- Maximum dry density to the nearest 1 kg/m$^3$ (0.1 lb/ft$^3$)
- Optimum moisture content to the nearest 0.1 percent

## ANNEX A

## CORRECTION OF MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE FOR OVERSIZED PARTICLES

This section corrects the maximum dry density and moisture content of the material retained on the 4.75 mm (No. 4) sieve, Methods A and B; or the material retained on the 19 mm (¾ in.) sieve, Methods C and D. The maximum dry density, corrected for oversized particles and total moisture content, are compared with the field-dry density and field moisture content.

This correction can be applied to the sample on which the maximum dry density is performed. A correction may not be practical for soils with only a small percentage of oversize material. The agency shall specify a minimum percentage below which the method is not needed. If not specified, this method applies when more than 5 percent by weight of oversize particles is present.

Bulk specific gravity ($G_{sb}$) of the oversized particles is required to determine the corrected maximum dry density. Use the bulk specific gravity as determined using the FOP for AASHTO T 85 in the calculations. For construction activities, an agency established value or specific gravity of 2.600 may be used.

This correction can also be applied to the sample obtained from the field while performing in-place density.

1. Use the sample from this procedure or a sample obtained according to the FOP for AASHTO T 310.

2. Sieve the sample on the 4.75 mm (No. 4) sieve for Methods A and B or the 19 mm (¾ in.) sieve, Methods C and D.

3. Determine the dry mass of the oversized and fine fractions ($M_{DC}$ and $M_{DF}$) by one of the following:

   a. Dry the fractions, fine and oversized, in air or by use of a drying apparatus that is maintained at a temperature not exceeding 60ºC (140ºF).

   b. Calculate the dry masses using the moisture samples.

To determine the dry mass of the fractions using moisture samples.

1. Determine the moist mass of both fractions, fine ($M_{Mf}$) and oversized ($M_{Mc}$):

2. Obtain moisture samples from the fine and oversized material.

3. Determine the moisture content of the fine particles ($MC_f$) and oversized particles ($MC_C$) of the material by FOP for AASHTO T 255/T 265 or agency approved method.

4. Calculate the dry mass of the oversize and fine particles.

$$M_D = \frac{M_m}{1 + \mathrm{MC}}$$

Where:

$M_D$ = mass of dry material (fine or oversize particles)
$M_m$ = mass of moist material (fine or oversize particles)
MC = moisture content of respective fine or oversized, expressed as a decimal

5. Calculate the percentage of the fine ($P_f$) and oversized ($P_c$) particles by dry weight of the total sample as follows: See Note 2.

$$P_f = \frac{100 \times M_{DF}}{M_{DF} + M_{DC}} \qquad \frac{100 \ \times 15.4\ lb}{15.4\ lbs + 5.7\ lb} = 73\% \qquad \frac{100 \ \times 6.985\ kg}{6.985\ kg + 2.585\ kg} = 73\%$$

And

$$P_c = \frac{100 \times M_{DC}}{M_{DF} + M_{DC}} \qquad \frac{100 \ \times 5.7\ lb}{15.4\ lbs + 5.7\ lb} = 27\% \qquad \frac{100 \ \times 2.585 kg}{6.985\ kg + 2.585\ kg} = 27\%$$

Or for $\mathbf{P_c}$:

$$P_c = 100 - P_f$$

Where:

$P_f$ = percent of fine particles, of sieve used, by weight
$P_c$ = percent of oversize particles, of sieve used, by weight
$M_{DF}$ = mass of dry fine particles
$M_{DC}$ = mass of dry oversize particles

## Optimum Moisture Correction Equation

1. Calculate the corrected moisture content as follows:

$$MC_T = \frac{(MC_F \times P_f) + (MC_c \times P_c)}{100} \qquad \frac{(13.2\% \times 73.0\%) + (2.1\% \times 27.0\%)}{100} = 10.2\%$$

$MC_T$ = corrected moisture content of combined fines and oversized particles, expressed as a % moisture
$MC_F$ = moisture content of fine particles, as a % moisture
$MC_C$ = moisture content of oversized particles, as a % moisture

***Note 1:*** Moisture content of oversize material can be assumed to be two (2) percent for most construction applications.

***Note 2:*** In some field applications agencies will allow the percentages of oversize and fine materials to be determined with the materials in the wet state.

## Density Correction Equation

2. Calculate the corrected dry density of the total sample (combined fine and oversized particles) as follows:

$$D_d = \frac{100\%}{\left[\left(\frac{P_f}{D_f}\right) + \left(\frac{P_c}{k}\right)\right]}$$

Where:

$D_d$ = corrected total dry density (combined fine and oversized particles) kg/m$^3$ (lb/ft $^3$)

$D_f$ = dry density of the fine particles kg/m$^3$ (lb/ft$^3$), determined in the lab

$P_c$= percent of dry oversize particles, of sieve used, by weight.

$P_f$ = percent of dry fine particles, of sieve used, by weight.

k = Metric: 1,000 * Bulk Specific Gravity ($G_{sb}$) (oven dry basis) of coarse particles (kg/m$^3$).

k = English: 62.4 * Bulk Specific Gravity ($G_{sb}$) (oven dry basis) of coarse particles (lb/ft$^3$)

***Note 3:*** If the specific gravity is known, then this value will be used in the calculation. For most construction activities the specific gravity for aggregate may be assumed to be 2.600.

## Calculation

**Example**

- Metric:

| | |
|---|---|
| Maximum laboratory dry density ($D_f$): | 1880 kg/m$^3$ |
| Percent coarse particles ($P_c$): | 27% |
| Percent fine particles ($P_f$): | 73% |
| Mass per volume coarse particles (k): | (2.697) (1000) = 2697 kg/m$^3$ |

$$D_d = \frac{100\%}{\left[\left(\frac{P_f}{D_f}\right) + \left(\frac{P_c}{k}\right)\right]}$$

$$D_d = \frac{100\%}{\left[\left(\frac{73\%}{1880\,kg/m^3}\right) + \left(\frac{27\%}{2697\,kg/m^3}\right)\right]}$$

$$D_d = \frac{100\%}{[0.03883\,kg/m^3 + 0.01001\,kg/m^3]}$$

$$D_d = 2047.5\,kg/m^3\ report\ \ 2048\,kg/m^3$$

English:

Maximum laboratory dry density ($D_f$): 117.3 lb/ft$^3$

Percent coarse particles ($P_c$): 27%

Percent fine particles ($P_f$): 73%

Mass per volume of coarse particles (k): (2.697) (62.4) = 168.3 lb/ft$^3$

$$D_d = \frac{100\%}{\left[\left(\frac{P_f}{D_f}\right) + \left(\frac{P_c}{k}\right)\right]}$$

$$D_d = \frac{100\%}{\left[\left(\frac{73\%}{117.3\ lb/ft^3}\right) + \left(\frac{27\%}{168.3\ lb/ft^3}\right)\right]}$$

$$D_d = \frac{100\%}{[0.6223\ \ lb/ft^3 + 0.1604\ \ lb/ft^3]}$$

$$D_d = \frac{100\%}{0.7827\ \ lb/ft^3}$$

$$D_d = 127.76\ \ lb/ft^3 \quad Report\ 127.8\ \ lb/ft^3$$

## Report

- Results on forms approved by the agency
- Sample ID
- Corrected maximum dry density to the nearest 1 kg/m$^3$ (0.1 lb/ft$^3$)
- Corrected optimum moisture to the nearest 0.1 percent

## ANNEX B

## STANDARDIZATION OF THE MOLD

Standardization is a critical step to ensure accurate test results when using this apparatus. Failure to perform the standardization procedure as described herein will produce inaccurate or unreliable test results.

### Apparatus

Mold and base plate

Balance or scale – Accurate to within 45 g (0.1 lb) or 0.3 percent of the test load, whichever is greater, at any point within the range of use.

- Cover plate – A piece of plate glass, at least 6 mm (1⁄4 in.) thick and at least 25 mm (1 in.) larger than the diameter of the mold.

- Thermometers – Standardized liquid-in-glass, or electronic digital total immersion type, accurate to 0.5°C (1°F)

### Procedure

1. Create a watertight seal between the mold and base plate.

2. Determine and record the mass of the dry sealed mold, base plate, and cover plate.

3. Fill the mold with water at a temperature between 16°C and 29°C (60°F and 85°F) and cover with the cover plate in such a way as to eliminate bubbles and excess water.

4. Wipe the outside of the mold, base plate, and cover plate dry, being careful not to lose any water from the mold.

5. Determine and record the mass of the filled mold, base plate, cover plate, and water.

6. Determine and record the mass of the water in the mold by subtracting the mass in Step 2 from the mass in Step 5.

7. Measure the temperature of the water and determine its density from Table B1, interpolating as necessary.

8. Calculate the volume of the mold, $V_m$, by dividing the mass of the water in the mold by the density of the water at the measured temperature.

## Calculations

$$V_m = \frac{M}{D}$$

Where:

$V_m$ = volume of the mold

M = mass of water in the mold

D = density of water at the measured temperature

**Example**

Mass of water in mold= 0.94367 kg (2.0800 lb)

Density of water at 23°C (73.4°F) = 997.54 kg/m$^3$ (62.274 lb/ft$^3$)

$$V_m = \frac{0.94367\ kg}{997.54\ \ kg/m^3} = 0.000946\ m^3 \qquad V_m = \frac{2.0800\ lb}{62.274\ \ lb/ft^3} = 0.0334\ ft^3$$

**Table B1**
**Unit Mass of Water**
**15°C to 30°C**

| °C | (°F) | kg/m$^3$ | (lb/ft$^3$) | °C | (°F) | kg/m$^3$ | (lb/ft$^3$) |
|---|---|---|---|---|---|---|---|
| 15 | (59.0) | 999.10 | (62.372) | 23 | (73.4) | 997.54 | (62.274) |
| 15.6 | (60.0) | 999.01 | (62.366) | 23.9 | (75.0) | 997.32 | (62.261) |
| 16 | (60.8) | 998.94 | (62.361) | 24 | (75.2) | 997.29 | (62.259) |
| 17 | (62.6) | 998.77 | (62.350) | 25 | (77.0) | 997.03 | (62.243) |
| 18 | (64.4) | 998.60 | (62.340) | 26 | (78.8) | 996.77 | (62.227) |
| 18.3 | (65.0) | 998.54 | (62.336) | 26.7 | (80.0) | 996.59 | (62.216) |
| 19 | (66.2) | 998.40 | (62.328) | 27 | (80.6) | 996.50 | (62.209) |
| 20 | (68.0) | 998.20 | (62.315) | 28 | (82.4) | 996.23 | (62.192) |
| 21 | (69.8) | 997.99 | (62.302) | 29 | (84.2) | 995.95 | (62.175) |
| 21.1 | (70.0) | 997.97 | (62.301) | 29.4 | (85.0) | 995.83 | (62.166) |
| 22 | (71.6) | 997.77 | (62.288) | 30 | (86.0) | 995.65 | (62.156) |

## Report

- Mold ID
- Date Standardized
- Temperature of the water
- Volume, $V_m$, of the mold to the nearest 0.000001 m$^3$ (0.0001 ft$^3$)

# DEVELOPING A FAMILY OF CURVES FOP FOR AASHTO R 75

## Scope

This procedure provides a method to develop a family of curves in accordance with AASHTO R 75-16 using multiple moisture density relationships developed using the same method, A, B, C, or D, from the FOP for AASHTO T 99/T 180.

All curves used in a family must be developed using a single Method: A, B, C, or D of a procedure for AASHTO T 99 or T 180. See the FOP for AASHTO T 99/T 180.

## Terminology

***family of curves*** **—** a group of soil moisture-density relationships (curves) determined using AASHTO T 99 or T 180, which reveal certain similarities and trends characteristic of the soil type and source.

***spine*** **—** smooth line extending through the point of maximum density/optimum moisture content of a family of moisture-density curves.

## Procedure

1. Sort the curves by Method (A, B, C, or D of the FOP for T 99/T 180). At least three curves are required to develop a family.
2. Select the highest and lowest maximum dry densities from those selected to assist in determining the desired scale of the subsequent graph.
3. Plot the maximum density and optimum moisture points of the selected curves on the graph.
4. Draw a smooth, "best fit," curved line through the points creating the spine of the family of curves.
5. Remove maximum density and optimum moisture points that were not used to establish the spine.
6. Add the moisture/density curves associated with the points that were used to establish the spine. It is not necessary to include the portion of the curves over optimum moisture.

***Note 1***—Intermediate template curves using slopes similar to those of the original moisture-density curves may be included when maximum density points are more than 2.0 lb/ft$^3$ apart. Template curves are indicated by a dashed line.

7. Plot the 80 percent of optimum moisture range when desired:
   a. Using the optimum moisture of an existing curve, calculate 80 percent of optimum moisture and plot this value on the curve. Repeat for each curve in the family.
   b. Draw a smooth, "best fit," curved line connecting the 80 percent of optimum moisture points plotted on the curves that parallel the spine.

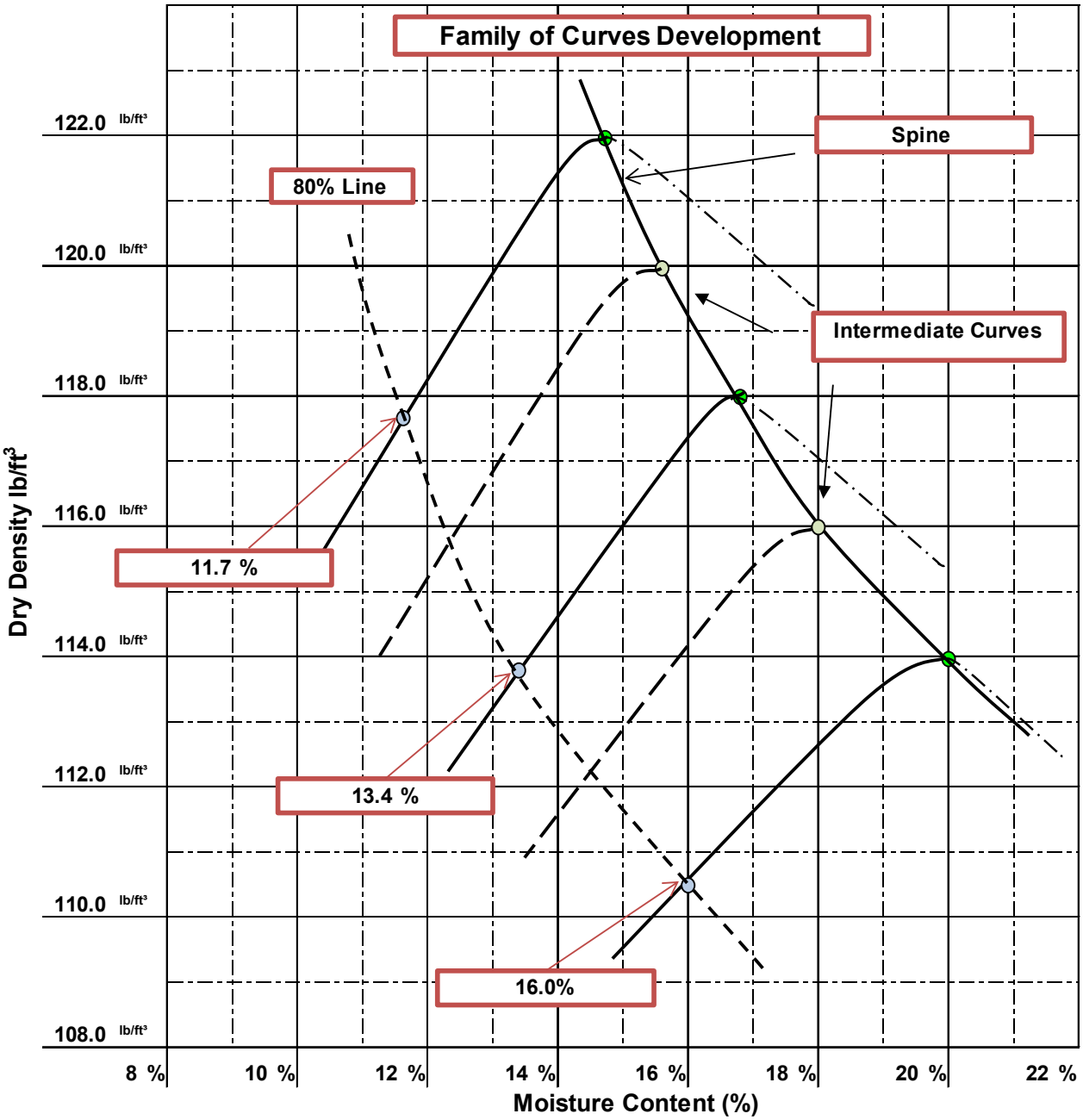
## Calculations

Calculate 80 percent of optimum moisture of each curve:

Example:

Optimum moisture of the highest density curve = 14.6%

$$80\%\ point = \frac{80}{100} \times 14.6\% = 11.7\%$$



# ONE-POINT METHOD FOR DETERMINING MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE
# FOP FOR AASHTO T 272

## Scope

This procedure provides for a rapid determination of the maximum dry density and optimum moisture content of a soil sample, using a one-point determination in accordance with AASHTO T 272-18. This procedure is related to the FOPs for AASHTO T 99/T 180 and R 75.

One-point determinations are made by compacting the soil in a mold of a given size with a specified rammer dropped from a specified height and then compared to an individual moisture/density curve (FOP for AASHTO T 99 or T 180) or a family of curves (FOP for AASHTO R 75). Four alternate methods – A, B, C, and D – are used and correspond to the methods described in the FOP for AASHTO T 99/T 180. The method used in AASHTO T 272 must match the method used for the reference curve or to establish the family of curves. For example, when moisture-density relationships as determined by T 99 - Method C are used to form the family of curves or an individual moisture density curve, then T 99 - Method C must be used to for the one-point determination.

## Apparatus

See the FOP for AASHTO T 99/T 180. Use the method matching the individual curve or Family of Curves. Refer to Table 1 of the FOP for AASHTO T 99 / T 180 for corresponding mold size, number of layers, number of blows, and rammer specification for the various test methods.

## Sample

Sample size determined according to the FOP for AASHTO T 310. In cases where the existing individual curve or family cannot be used a completely new curve will need to be developed and the sample size will be determined by the FOP for AASHTO T 99/T 180.

If the sample is damp, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus maintained at a temperature not exceeding 60°C (140°F). Thoroughly break up aggregations in a manner that avoids reducing the natural size of individual particles.

## Procedure

1. Determine the mass of the clean, dry mold. Include the base plate but exclude the extension collar. Record the mass to the nearest 1 g (0.005 lb).
2. Thoroughly mix the sample with sufficient water to adjust moisture content to 80 to 100 percent of the anticipated optimum moisture.
3. Form a specimen by compacting the prepared soil in the mold (with collar attached) in approximately equal layers. For each layer:
   a. Spread the loose material uniformly in the mold.

***Note 1:*** It is recommended to cover the remaining material with a non-absorbent sheet or damp cloth to minimize loss of moisture.

b. Lightly tamp the loose material with the manual rammer or other similar device, this establishes a firm surface.

c. Compact each layer with uniformly distributed blows from the rammer.

d. Trim down material that has not been compacted and remains adjacent to the walls of the mold and extends above the compacted surface.

4. Remove the extension collar. Avoid shearing off the sample below the top of the mold. The material compacted in the mold should not be over 6 mm (¼ in.) above the top of the mold once the collar has been removed.

5. Trim the compacted soil even with the top of the mold with the beveled side of the straightedge.

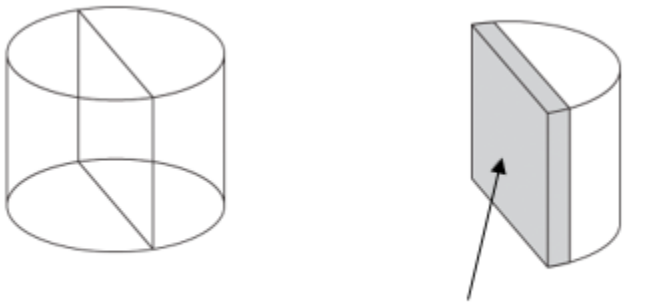
6. Clean soil from exterior of the mold and base plate.

7. Determine the mass of the mold and wet soil to the nearest 1 g (0.005 lb) or better.

8. Determine the wet mass of the sample by subtracting the mass in Step 1 from the mass in Step 7.

9. Calculate the wet density as indicated below under "Calculations."

10. Extrude the material from the mold. For soils and soil-aggregate mixtures, slice vertically through the center and take a representative moisture content sample from one of the cut faces, ensuring that all layers are represented. For granular materials, a vertical face will not exist. Take a representative sample. This sample must meet the sample size requirements of the test method used to determine moisture content.



**Extruded material** **Representative moisture content sample**

11. Determine the moisture content of the sample in accordance with the FOP for AASHTO T 255 / T 265.

## Calculations

1. Calculate the wet density, in kg/m$^3$ (lb/ft$^3$), by dividing the wet mass by the measured volume of the mold (T 19).

   Example – Methods A or C mold:

   Wet mass = 2.0055 kg (4.42 lb)

   Measured volume of the mold = 0.0009469 m$^3$ (0.03344 ft$^3$)

$$Wet\ Density = \frac{2.0055\ kg}{0.0009469\ m^3} = 2118\ kg/m^3$$

$$Wet\ Density = \frac{4.42\ lb}{0.03344\ ft^3} = 132.2\ lb/ft^3$$

2. Calculate the dry density as follows.

$$\rho_d = \left(\frac{\rho_w}{w + 100}\right) \times 100 \quad or \quad \rho_d = \frac{\rho_w}{\left(\frac{w}{100}\right) + 1}$$

   Where:

   $\rho_d$ = Dry density, kg/m$^3$ (lb/ft$^3$)

   $\rho_w$ = Wet density, kg/m$^3$ (lb/ft$^3$)

   w = Moisture content, as a percentage

   Example:

   $\rho_w$ = 2118 kg/m$^3$ (132.2 lb/ft$^3$)

   w = 13.5%

$$\rho_d = \left(\frac{2118\ kg/m^3}{13.5 + 100}\right) \times 100 = 1866\ kg/m^3 \quad \rho_d = \left(\frac{132.2\ lb/ft^3}{13.5 + 100}\right) \times 100 = 116.5\ lb/ft^3$$

or

$$\rho_d = \left(\frac{2118\ kg/m^3}{\frac{13.5}{100} + 1}\right) = 1866\ kg/m^3 \quad \rho_d = \left(\frac{132.2\ lb/ft^3}{\frac{13.5}{100} + 1}\right) = 116.5\ lb/ft^3$$

## Maximum Dry Density and Optimum Moisture Content Determination Using an Individual Moisture / Density Curve

1. The moisture content must be within 80 to 100 percent of optimum moisture of the reference curve. Compact another specimen, using the same material, at an adjusted moisture content if the one-point does not fall in the 80 to 100 percent of optimum moisture range.

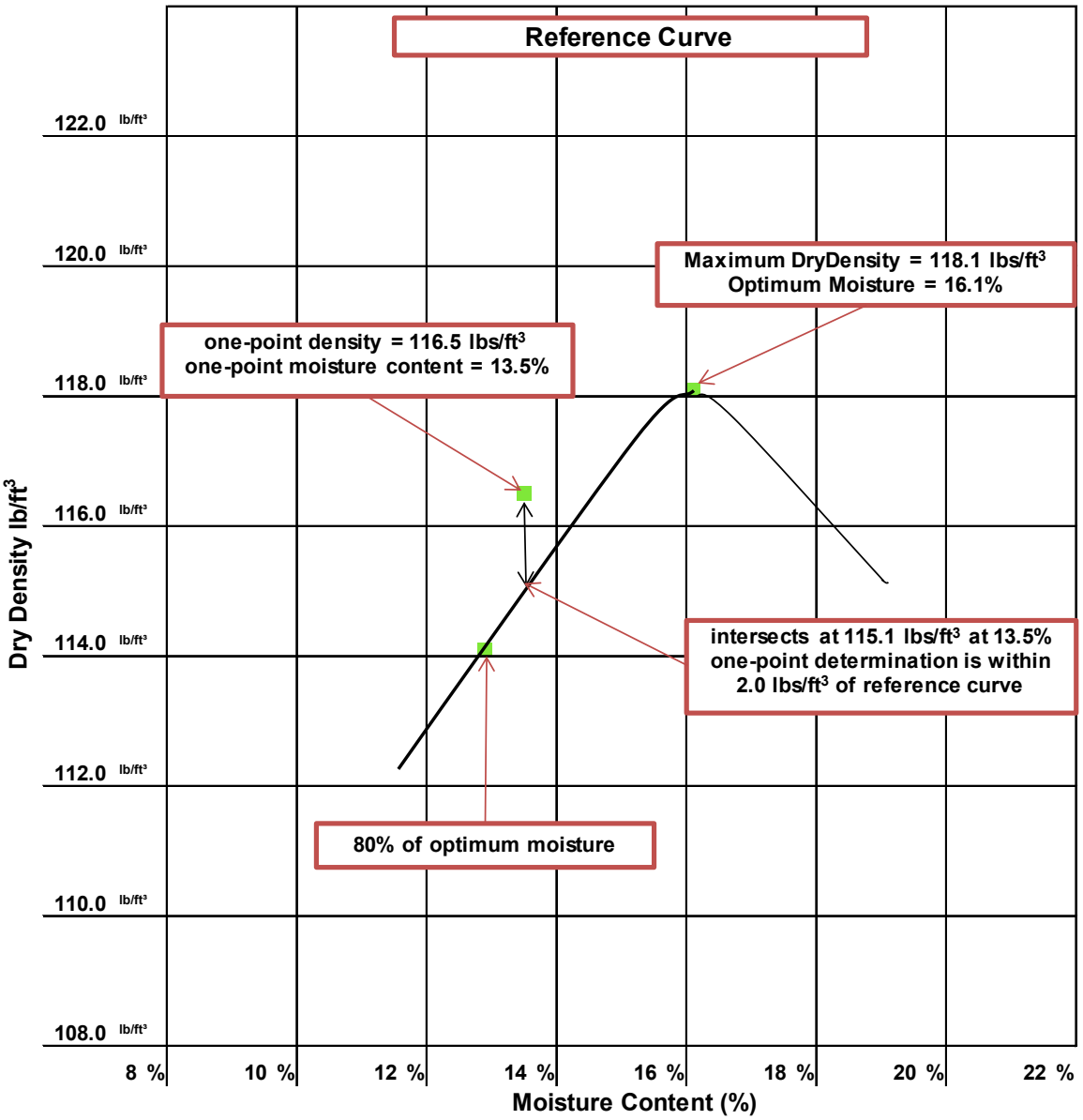
2. Plot the one-point, dry density on the vertical axis and moisture content on the horizontal axis, on the reference curve graph.

3. If the one-point falls on the reference curve or within ±2.0 lbs/ft$^3$, use the maximum dry density and optimum moisture content determined by the curve.

4. Use the FOP for AASHTO T 99/T 180 Annex A to determine corrected maximum dry density and optimum moisture content if oversize particles have been removed.

5. Perform a full moisture-density relationship if the one-point does not fall on or within ±2.0 lbs/ft$^3$ of the reference curve at 80 to 100 percent optimum moisture.

## Example




The results of a one-point determination were 116.5 lb/ft$^3$ at 13.5 percent moisture. The point was plotted on the reference curve graph. The one-point determination is within 2.0 lb/ft$^3$ of the point on the curve that corresponds with the moisture content.

## Maximum Dry Density and Optimum Moisture Content Determination Using a Family of Curves

1. Plot the one-point, dry density on the vertical axis and moisture content on the horizontal axis, on the reference family of curves graph.

2. If the moisture-density one-point falls on one of the curves in the family of curves, use the maximum dry density and optimum moisture content defined by that curve.

3. If the moisture-density one-point falls within the family of curves but not on an existing curve, draw a new curve through the plotted single point, parallel and in character with the nearest existing curve in the family of curves. Use the maximum dry density and optimum moisture content as defined by the new curve.

    a. The one-point must fall either between or on the highest or lowest curves in the family. If it does not, then a full curve must be developed.

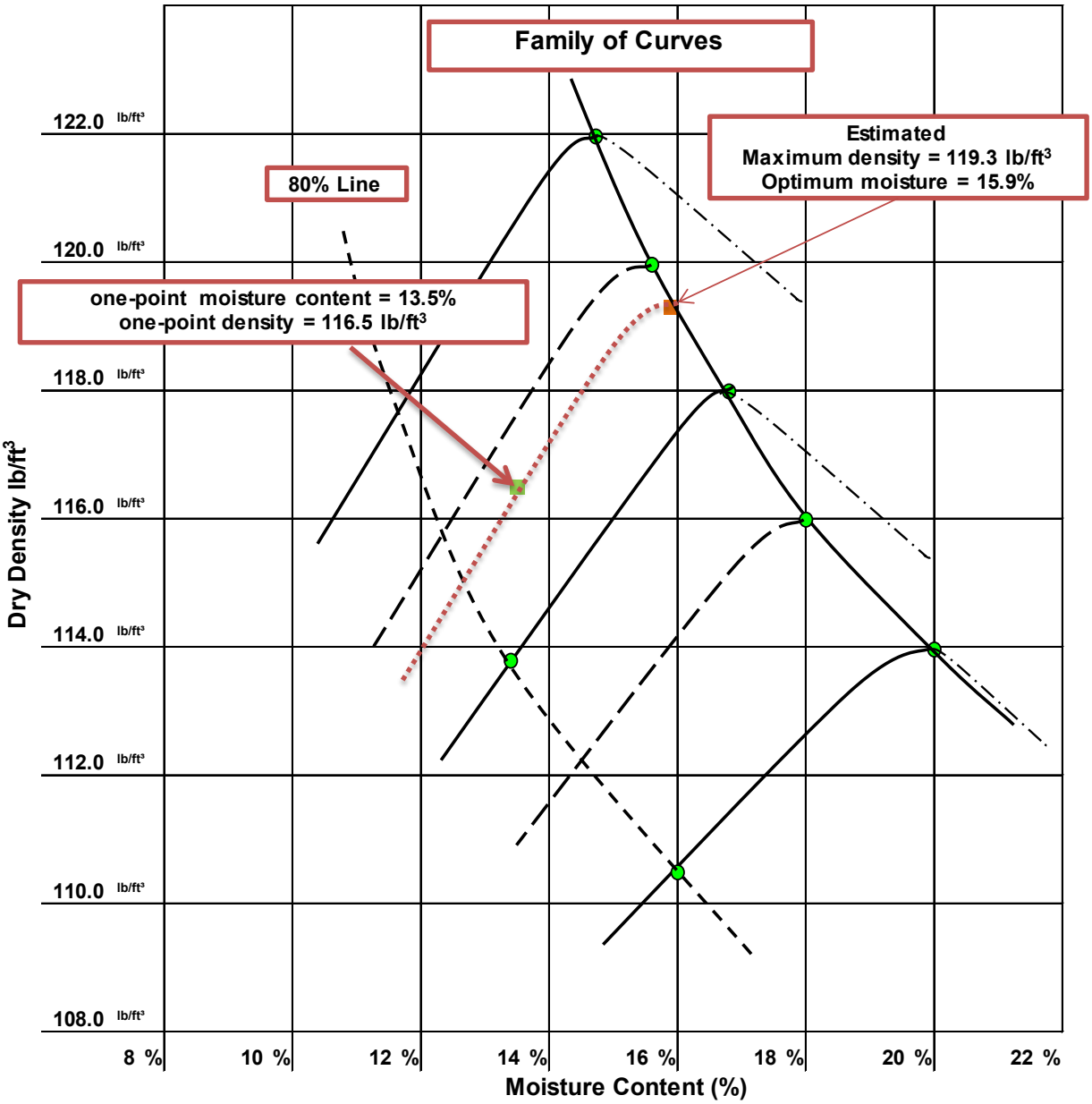
    b. If the one-point plotted within or on the family of curves does not fall in the 80 to 100 percent of optimum moisture content, compact another specimen, using the same material, at an adjusted moisture content that will place the one point within this range.

4. Use the FOP for AASHTO T 99/T 180 Annex A to determine corrected maximum dry density and optimum moisture content if oversize particles have been removed.

5. If the new curve through a one-point is not well defined or is in any way questionable, perform a full moisture-density relationship to correctly define the new curve and verify the applicability of the family of curves.

***Note 2:*** New curves drawn through plotted single point determinations shall not become a permanent part of the family of curves until verified by a full moisture-density procedure following the FOP for AASHTO T 99/T 180.

## Example




The results of a one-point determination were 116.5 lb/ft$^3$ at 13.5 percent moisture. The point was plotted on the reference curve graph. The point was plotted on the appropriate family between two previously developed curves near and intermediate curve.

The "dotted" curve through the moisture-density one-point was sketched between the existing curves. A maximum dry density of 119.3 lb/ft$^3$ and a corresponding optimum moisture content of 15.9 percent were estimated.

## Report

- Results on forms approved by the agency
- Sample ID
- Maximum dry density to the nearest 1 $kg/m^3$ (0.1 $lb/ft^3$)
- Corrected maximum dry density (if applicable)
- Optimum moisture content to the nearest 0.1 percent
- Corrected optimum moisture content (if applicable)
- Reference curve or Family of Curves used

# SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE FOP FOR AASHTO T 85

## Scope

This procedure covers the determination of specific gravity and absorption of coarse aggregate in accordance with AASHTO T 85-14. Specific gravity may be expressed as bulk specific gravity ($G_{sb}$), bulk specific gravity, saturated surface dry ($G_{sb}$ SSD), or apparent specific gravity ($G_{sa}$). $G_{sb}$ and absorption are based on aggregate after soaking in water. This procedure is not intended to be used with lightweight aggregates.

## Terminology

Absorption – the increase in the mass of aggregate due to water being absorbed into the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. The aggregate is considered "dry" when it has been maintained at a temperature of 110 ±5°C (230 ±9°F) for sufficient time to remove all uncombined water.

Saturated Surface Dry (SSD) – condition of an aggregate particle when the permeable voids are filled with water, but no water is present on exposed surfaces.

Specific Gravity – the ratio of the mass, in air, of a volume of a material to the mass of the same volume of gas-free distilled water at a stated temperature.

Apparent Specific Gravity ($G_{sa}$)– the ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of gas-free distilled water at a stated temperature.

Bulk Specific Gravity ($G_{sb}$)– the ratio of the mass, in air, of a volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of gas-free distilled water at a stated temperature.

Bulk Specific Gravity (SSD) ($G_{sb}$ SSD) – the ratio of the mass, in air, of a volume of aggregate, including the mass of water within the voids filled to the extent achieved by submerging in water for 15 to 19 hours (but not including the voids between particles), to the mass of an equal volume of gas-free distilled water at a stated temperature.

## Apparatus

- Balance or scale: with a capacity of 5 kg, sensitive to 1 g. Meeting the requirements of AASHTO M 231.
- Sample container: a wire basket of 3.35 mm (No. 6) or smaller mesh, with a capacity of 4 to 7 L (1 to 2 gal) to contain aggregate with a nominal maximum size of 37.5 mm (1 1/2 in.) or smaller; or a larger basket for larger aggregates, or both.
- Water tank: watertight and large enough to completely immerse aggregate and basket, equipped with an overflow valve to keep water level constant.
- Suspension apparatus: wire used to suspend apparatus shall be of the smallest practical diameter.

- Sieves 4.75 mm (No. 4) or other sizes as needed, meeting the requirements of FOP for AASHTO T 27/T 11.
- Large absorbent towel

## Sample Preparation

1. Obtain the sample in accordance with the FOP for AASHTO R 90 (see Note 1).
2. Mix the sample thoroughly and reduce it to the approximate sample size required by Table 1 in accordance with the FOP for AASHTO R 76.
3. Reject all material passing the appropriate sieve by dry sieving.
4. Thoroughly wash sample to remove dust or other coatings from the surface.
5. Dry the test sample to constant mass at a temperature of 110 ±5°C (230 ±9°F) and cool in air at room temperature for 1 to 3 hours.

***Note 1:*** Where the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement for initial drying to constant mass may be eliminated, and, if the surfaces of the particles in the sample have been kept continuously wet until test, the 15-to-19 hour soaking may also be eliminated.

6. Re-screen the sample over the appropriate sieve. Reject all material passing that sieve.
7. The sample shall meet or exceed the minimum mass given in Table 1.

***Note 2:*** If this procedure is used only to determine the $G_{sb}$ of oversized material for the FOP for AASHTO T 99 / T 180, the material can be rejected over the appropriate sieve. For T 99 / T 180 Methods A and B, use the 4.75 mm (No. 4) sieve; T 99 / T 180 Methods C and D use the 19 mm (3/4 in).

**Table 1**

| Nominal Maximum Size* mm (in.) | Minimum Mass of Test Sample, g (lb) |
|---|---|
| 12.5 (1/2) or less | 2000 (4.4) |
| 19.0 (3/4) | 3000 (6.6) |
| 25.0 (1) | 4000 (8.8) |
| 37.5 (1 1/2) | 5000 (11) |
| 50 (2) | 8000 (18) |
| 63 (2 1/2) | 12,000 (26) |
| 75 (3) | 18,000 (40) |

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

## Procedure

1. Immerse the aggregate in water at room temperature for a period of 15 to 19 hours.

***Note 3:*** When testing coarse aggregate of large nominal maximum size requiring large test samples, it may be more convenient to perform the test on two or more subsamples, and then combine the values obtained.

2. Place the empty basket into the water bath and attach to the balance. Inspect the immersion tank to ensure the water level is at the overflow outlet height. Tare the balance with the empty basket attached in the water bath.

3. Remove the test sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually. If the test sample dries past the SSD condition, immerse in water for 30 min, and then resume the process of surface-drying.

***Note 4:*** A moving stream of air may be used to assist in the drying operation, but take care to avoid evaporation of water from aggregate pores.

4. Determine the SSD mass of the sample, and record this and all subsequent masses to the nearest 0.1 g or 0.1 percent of the sample mass, whichever is greater. Designate this mass as "B."

5. Immediately place the SSD test sample in the sample container and weigh it in water maintained at 23.0 ±1.7°C (73.4 ±3°F). Shake the container to release entrapped air before recording the weight. Re-inspect the immersion tank to insure the water level is at the overflow outlet height. Designate this submerged weight as "C."

***Note 5:*** The container should be immersed to a depth sufficient to cover it and the test sample during mass determination. Wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.

6. Remove the sample from the basket. Ensure all material has been removed. Place in a container of known mass.

7. Dry the test sample to constant mass in accordance with the FOP for AASHTO T 255 / T 265 (Aggregate section) and cool in air at room temperature for 1 to 3 hours. Designate this mass as "A."

## Calculations

Perform calculations and determine values using the appropriate formula below.

Bulk specific gravity ($G_{sb}$)

$$G_{sb} = \frac{A}{B - C}$$

Bulk specific gravity, SSD ($G_{sb}$ SSD)

$$G_{sb}SSD = \frac{B}{B - C}$$

Apparent specific gravity ($G_{sa}$)

$$G_{sa} = \frac{A}{A - C}$$

Absorption

$$\text{Absorption} = \frac{B - A}{A} \times 100$$

Where:

A = oven dry mass, g

B = SSD mass, g

C = weight in water, g

## Sample Calculations

| Sample | A | B | C | B - C | A - C | B - A |
|---|---|---|---|---|---|---|
| 1 | 2030.9 | 2044.9 | 1304.3 | 740.6 | 726.6 | 14.0 |
| 2 | 1820.0 | 1832.5 | 1168.1 | 664.4 | 651.9 | 12.5 |
| 3 | 2035.2 | 2049.4 | 1303.9 | 745.5 | 731.3 | 14.2 |

| Sample | $G_{sb}$ | $G_{sb}$ SSD | $G_{sa}$ | Absorption |
|---|---|---|---|---|
| 1 | 2.742 | 2.761 | 2.795 | 0.7 |
| 2 | 2.739 | 2.758 | 2.792 | 0.7 |
| 3 | 2.730 | 2.749 | 2.783 | 0.7 |

These calculations demonstrate the relationship between $G_{sb}$, $G_{sb}$ SSD, and $G_{sa}$. $G_{sb}$ is always lowest, since the volume includes voids permeable to water. $G_{sb}$ SSD is always intermediate. $G_{sa}$ is always highest, since the volume does not include voids permeable to water. When running this test, check to make sure the values calculated make sense in relation to one another.

## Report

- Results on forms approved by the agency
- Sample ID
- Specific gravity values to the nearest 0.001
- Absorption to the nearest 0.1 percent

## USE OF AKDOT & PF ATM 212, ITD IT 74, WSDOT T 606, OR WFLHD HUMPHRES CURVES

### Background

Coarse-grained granular soils are free-draining and have little or no cohesion. These soils are, therefore, not particularly well suited for the moisture-density relations procedures of AASHTO T 99 or AASHTO T 180. Transportation agencies have developed specialized test methods that are hybrids of those moisture-density procedures and methods that employ compaction under load with vibration. Those methods include:

- AKDOT & PF's ATM 212
- ITD's IT 74
- WSDOT's T 606
- WFLHD's Humphres

### Description of Procedure

In these tests, material is compacted in a mold and in a manner similar to those used in a moisture / density relationship, after which the material is further compacted through a combination of applied loads and vibration. A laboratory maximum dry density is determined, as is the percent of material passing a certain sieve such as the 4.75 mm (No. 4). A number of determinations are made for different percentages passing the specified sieve. A graph is developed in which dry density is plotted versus the percentage of material passing that sieve. These tests are conducted in the agency's central lab, and the curve developed is a central lab function.

Construction specifications will call out a percent of maximum dry density required for the granular materials used on the job. These specified values will be based on ATM 212, IT 74, T 606, or Humphres, depending on the agency.

In the field, the dry density of the granular material will be determined in accordance with the FOP for AASHTO 310. The percent of material passing the specified sieve will be determined for a sample obtained at the site of the density test. The dry density and percent passing values will then be compared with the curve developed in the lab for that particular granular material to determine conformance with the project specifications.

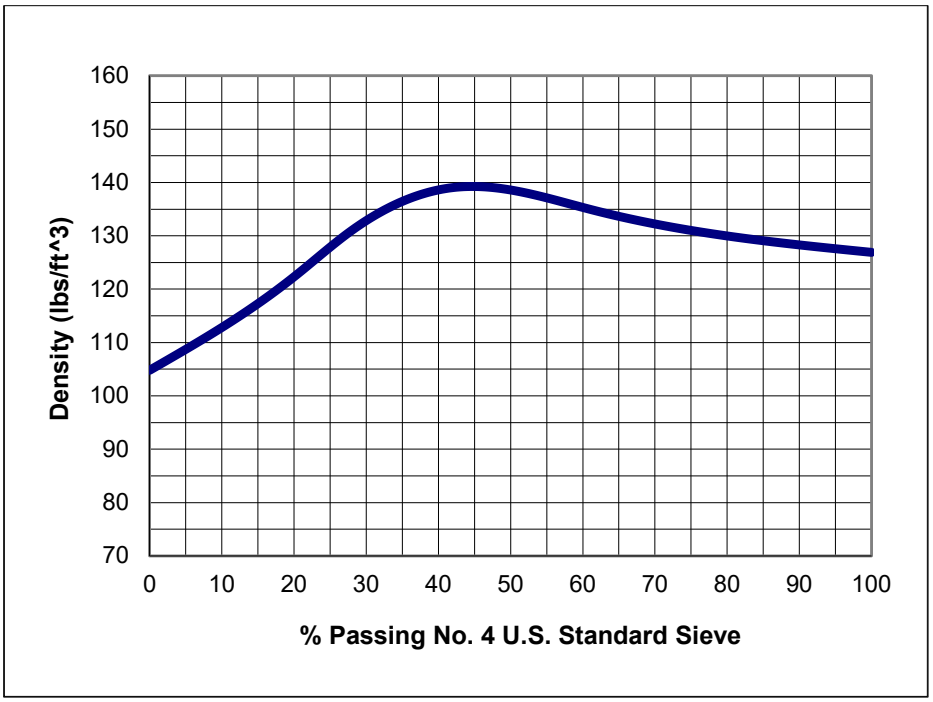
## Maximum Density Chart

| Density Curves | | | |
|---|---|---|---|
| Pass #4 | Maximum | Pass #4 | Maximum |
| 0.0 | 104.8 | 31.0 | 133.7 |
| 1.0 | 105.6 | 32.0 | 134.5 |
| 2.0 | 106.4 | 33.0 | 135.2 |
| 3.0 | 107.1 | 34.0 | 135.8 |
| 4.0 | 107.9 | 35.0 | 136.4 |
| 5.0 | 108.7 | 36.0 | 137.0 |
| 6.0 | 109.5 | 37.0 | 137.5 |
| 7.0 | 110.3 | 38.0 | 137.9 |
| 8.0 | 111.1 | 39.0 | 138.3 |
| 9.0 | 112.0 | 40.0 | 138.6 |
| 10.0 | 112.8 | 41.0 | 138.9 |
| 11.0 | 113.7 | 42.0 | 139.0 |
| 12.0 | 114.5 | 43.0 | 139.2 |
| 13.0 | 115.4 | 44.0 | 139.2 |
| 14.0 | 116.4 | 45.0 | 139.2 |
| 15.0 | 117.3 | 46.0 | 139.2 |
| 16.0 | 118.2 | 47.0 | 139.1 |
| 17.0 | 119.2 | 48.0 | 139.0 |
| 18.0 | 120.2 | 49.0 | 138.8 |
| 19.0 | 121.3 | 50.0 | 138.6 |
| 20.0 | 122.3 | 51.0 | 138.3 |
| 21.0 | 123.4 | 52.0 | 138.1 |
| 22.0 | 124.5 | 53.0 | 137.8 |
| 23.0 | 125.6 | 54.0 | 137.5 |
| 24.0 | 126.8 | 55.0 | 137.1 |
| 25.0 | 127.9 | 56.0 | 136.8 |
| 26.0 | 129.0 | 57.0 | 136.4 |
| 27.0 | 130.0 | 58.0 | 136.0 |
| 28.0 | 131.0 | 59.0 | 135.7 |
| 29.0 | 132.0 | 60.0 | 135.3 |
| 30.0 | 132.8 | 61.0 | 135.0 |

| Density Curves | | | |
|---|---|---|---|
| Pass #4 | Maximum | Pass #4 | Maximum |
| 62.0 | 134.6 | 82.0 | 129.6 |
| 63.0 | 134.3 | 83.0 | 129.4 |
| 64.0 | 134.0 | 84.0 | 129.3 |
| 65.0 | 133.6 | 85.0 | 129.1 |
| 66.0 | 133.3 | 86.0 | 128.9 |
| 67.0 | 133.1 | 87.0 | 128.8 |
| 68.0 | 132.8 | 88.0 | 128.6 |
| 69.0 | 132.5 | 89.0 | 128.4 |
| 70.0 | 132.2 | 90.0 | 128.3 |
| 71.0 | 132.0 | 91.0 | 128.1 |
| 72.0 | 131.7 | 92.0 | 128.0 |
| 73.0 | 131.5 | 93.0 | 127.9 |
| 74.0 | 131.2 | 94.0 | 127.7 |
| 75.0 | 131.0 | 95.0 | 127.6 |
| 76.0 | 130.8 | 96.0 | 127.4 |
| 77.0 | 130.6 | 97.0 | 127.3 |
| 78.0 | 130.4 | 98.0 | 127.2 |
| 79.0 | 130.2 | 99.0 | 127.0 |
| 80.0 | 130.0 | 100.0 | 126.9 |
| 81.0 | 129.8 | | |

| Control Points for Density Curves | | |
|---|---|---|
| Pass #4 | Maximum | Loose |
| 0.0 | 104.8 | 87.6 |
| 20.5 | 122.8 | 99.6 |
| 27.4 | 130.4 | 103.8 |
| 42.5 | 139.1 | 105.4 |
| 61.1 | 134.9 | 96.7 |
| 100.0 | 126.9 | 81.9 |

**Maximum Density Curve**




**Example:**

A compaction test was taken, and a sample was removed from the test site per the FOP for AASHTO T 310. The sample was graded over a 4.75 mm (No. 4) sieve. The following results were reported.

| | |
|---|---|
| Dry density from the FOP for AASHTO T 310 = | 136.0 lb/ft$^3$ |
| Percent passing 4.75 mm (No. 4) sieve = | 49% |
| Maximum density = | 138.8 lb/ft$^3$ |

$$Percent\ compaction = \frac{136.0\ lb/ft^3}{138.8\ lb/ft^3} \times 100 = 98\%$$

# IN-PLACE DENSITY AND MOISTURE CONTENT OF SOIL AND SOIL-AGGREGATE BY NUCLEAR METHODS (SHALLOW DEPTH) FOP FOR AASHTO T 310

## Scope

This procedure covers the determination of density, moisture content, and relative compaction of soil, aggregate, and soil-aggregate mixes in accordance with AASHTO T 310-19. This field operating procedure is derived from AASHTO T 310. The nuclear moisture-density gauge is used in the direct transmission mode.

## Apparatus

- Nuclear density gauge with the factory matched standard reference block.
- Drive pin, guide/scraper plate, and hammer for testing in direct transmission mode.
- Transport case for properly shipping and housing the gauge and tools.
- Instruction manual for the specific make and model of gauge.
- Radioactive materials information and calibration packet containing:
  - Daily Standard Count Log.
  - Factory and Laboratory Calibration Data Sheet.
  - Leak Test Certificate.
  - Shippers Declaration for Dangerous Goods.
  - Procedure Memo for Storing, Transporting and Handling Nuclear Testing Equipment.
  - Other radioactive materials documentation as required by local regulatory requirements.
- Sealable containers and utensils for moisture content determinations.

## Radiation Safety

This method does not purport to address all of the safety problems associated with its use. This test method involves potentially hazardous materials. The gauge utilizes radioactive materials that may be hazardous to the health of the user unless proper precautions are taken. Users of this gauge must become familiar with the applicable safety procedures and governmental regulations. All operators will be trained in radiation safety prior to operating nuclear density gauges. Some agencies require the use of personal monitoring devices such as a thermoluminescent dosimeter or film badge. Effective instructions together with routine safety procedures such as source leak tests, recording and evaluation of personal monitoring device data, etc., are a recommended part of the operation and storage of this gauge.

## Calibration

Calibrate the nuclear gauge as required by the agency. This calibration may be performed by the agency using manufacturer's recommended procedures or by other facilities approved by the agency. Verify or re-establish calibration curves, tables, or equivalent coefficients every 12 months.

## Standardization

1. Turn the gauge on and allow it to stabilize (approximately 10 to 20 minutes) prior to standardization. Leave the power on during the day's testing.
2. Standardize the nuclear gauge at the construction site at the start of each day's work and as often as deemed necessary by the operator or agency. Daily variations in standard count shall not exceed the daily variations established by the manufacturer of the gauge. If the daily variations are exceeded after repeating the standardization procedure, the gauge should be repaired and/or recalibrated.
3. Record the standard count for both density and moisture in the Daily Standard Count Log. The exact procedure for standard count is listed in the manufacturer's Operator's Manual.

***Note 1:*** New standard counts may be necessary more than once a day. See agency requirements.

## Overview

There are two methods for determining in-place density of soil / soil aggregate mixtures. See agency requirements for method selection.

- Method A Single Direction
- Method B Two Direction

## Procedure

1. Select a test location(s) randomly and in accordance with agency requirements. Test sites should be relatively smooth and flat and meet the following conditions:
   a. At least 10 m (30 ft) away from other sources of radioactivity
   b. At least 3 m (10 ft) away from large objects
   c. The test site should be at least 150 mm (6 in.) away from any vertical projection, unless the gauge is corrected for trench wall effect.
2. Remove all loose and disturbed material and remove additional material as necessary to expose the top of the material to be tested.
3. Prepare a flat area sufficient in size to accommodate the gauge. Plane the area to a smooth condition so as to obtain maximum contact between the gauge and the material being tested. For Method B, the flat area must be sufficient to permit rotating the gauge 90 or 180 degrees about the source rod.

4. Fill in surface voids beneath the gauge with fines of the material being tested passing the 4.75 mm (No. 4) sieve or finer. Smooth the surface with the guide plate or other suitable tool. The depth of the filler should not exceed approximately 3 mm (1/8 in.).
5. Make a hole perpendicular to the prepared surface using the guide plate and drive pin. The hole shall be at least 50 mm (2 in.) deeper than the desired probe depth and shall be aligned such that insertion of the probe will not cause the gauge to tilt from the plane of the prepared area. Remove the drive pin by pulling straight up and twisting the extraction tool.
6. Place the gauge on the prepared surface so the source rod can enter the hole without disturbing loose material.
7. Insert the probe in the hole and lower the source rod to the desired test depth using the handle and trigger mechanism.
8. Seat the gauge firmly by partially rotating it back and forth about the source rod. Ensure the gauge is seated flush against the surface by pressing down on the gauge corners and making sure that the gauge does not rock.
9. Pull gently on the gauge to bring the side of the source rod nearest to the scaler / detector firmly against the side of the hole.
10. Perform one of the following methods, per agency requirements:
    a. Method A Single Direction: Take a test consisting of the average of two, one-minute readings, and record both density and moisture data. The two wet density readings should be within 32 kg/m$^3$ (2.0 lb/ft$^3$) of each other. The average of the two wet densities and moisture contents will be used to compute dry density.
    b. Method B Two Direction: Take a one-minute reading and record both density and moisture data. Rotate the gauge 90 or 180 degrees, pivoting it around the source rod. Reseat the gauge by pulling gently on the gauge to bring the side of the source rod nearest to the scaler/detector firmly against the side of the hole and take a one-minute reading. (In trench locations, rotate the gauge 180 degrees for the second test.) Some agencies require multiple one-minute readings in both directions. Analyze the density and moisture data. A valid test consists of wet density readings in both gauge positions that are within 50 kg/m$^3$ (3.0 lb/ft$^3$). If the tests do not agree within this limit, move to a new location. The average of the wet density and moisture contents will be used to compute dry density.
11. If required by the agency, obtain a representative sample of the material, 4 kg (9 lb) minimum, from directly beneath the gauge full depth of material tested. This sample will be used to verify moisture content and / or identify the correct density standard. Immediately seal the material to prevent loss of moisture.

    The material tested by direct transmission can be approximated by a cylinder of soil approximately 300 mm (12 in.) in diameter directly beneath the centerline of the radioactive source and detector. The height of the cylinder will be approximately the

depth of measurement. When organic material or large aggregate is removed during this operation, disregard the test information and move to a new test site.

12. To verify the moisture content from the nuclear gauge, determine the moisture content with a representative portion of the material using the FOP for AASHTO T 255/T 265 or other agency approved methods. If the moisture content from the nuclear gauge is within ±1 percent, the nuclear gauge readings can be accepted. Moisture content verification is gauge and material specific. Retain the remainder of the sample at its original moisture content for a one-point compaction test under the FOP for AASHTO T 272, or for gradation, if required.

***Note 2:*** Example: A gauge reading of 16.8 percent moisture and an oven dry of 17.7 percent are within the ±1 percent requirement. Moisture correlation curves will be developed according to agency guidelines. These curves should be reviewed and possibly redeveloped every 90 days.

13. Determine the dry density by one of the following.

    a. From nuclear gauge readings, compute by subtracting the mass (weight) of the water ($kg/m^3$ or $lb/ft^3$) from the wet density ($kg/m^3$ or $lb/ft^3$) or compute using the percent moisture by dividing wet density from the nuclear gauge by 1 plus the moisture content expressed as a decimal.

    b. When verification is required and the nuclear gauge readings cannot be accepted, the moisture content is determined by the FOP for AASHTO T 255/T 265 or other agency approved methods. Compute dry density by dividing wet density from the nuclear gauge by 1 plus the moisture content expressed as a decimal.

## Percent Compaction

- Percent compaction is determined by comparing the in-place dry density as determined by this procedure to the appropriate agency density standard. For soil or soil-aggregate mixes, these are moisture-density curves developed using the FOP for AASHTO T 99/T 180. When using maximum dry densities from the FOP for AASHTO T 99/T 180 or FOP for AASHTO T 272, it may be necessary to use the Annex in the FOP for T 99/T 180 to determine corrected maximum dry density and optimum moisture content.

  For coarse granular materials, the density standard may be density-gradation curves developed using a vibratory method such as AKDOT&PF's ATM 212, ITD's T 74, WSDOT's TM 606, or WFLHD's Humphres.

See appropriate agency policies for use of density standards.

## Calculation

**Calculate the dry density as follows:**

$$\rho_d = \left(\frac{\rho_w}{w + 100}\right) \times 100 \quad or \quad \rho_d = \left(\frac{\rho_w}{\frac{w}{100} + 1}\right)$$

Where:

$\rho_d$ = Dry density, kg/m$^3$ (lb/ft$^3$)

$\rho_w$ = Wet density, kg/m$^3$ (lb/ft$^3$)

w = Moisture content from the FOP's for AASHTO T 255 / T 265, as a percentage

**Calculate percent compaction as follows:**

$$\%\ Compaction = \frac{\rho_d}{Agency\ density\ standard} \times 100$$

where:

$\rho_d$ = Dry density, kg/m$^3$ (lb/ft$^3$)

Agency density standard = Corrected maximum dry density from the FOP from T 99/T 180 Annex

## Example:

Wet density readings from gauge: 1948 kg/m$^3$ (121.6 lb/ft$^3$)

1977 kg/m$^3$ (123.4 lb/ft$^3$)

Avg: 1963 kg/m$^3$ (122.5 lb/ft$^3$)

**Moisture readings from gauge: 14.2% and 15.4% = Avg 14.8%**

Moisture content from the FOP's for AASHTO T 255/ T 265: 15.9%

*Moisture content is greater than 1 percent different so the gauge moisture cannot be used.*

**Calculate the dry density as follows:**

$$\rho_d = \left(\frac{1963\,kg/m^3\ or\ 122.5\ \ lb/ft^3}{15.9 + 100}\right) \times 100\ or\ \ \rho_d = \left(\frac{1963\,kg/m^3\ or\ \ 122.5\ \ lb/ft^3}{\frac{15.9}{100} + 1}\right)$$

$$= 1694\ \ kg/m^3\ or\ 105.7\ \ lb/ft^3$$

where:

$\rho_w$ = 1963 kg/m$^3$ or 122.5 lb/ft$^3$

w = 15.9%

**Calculate percent compaction as follows:**

$$\%\ Compaction = \frac{105.7\ lb/ft^3}{111.3\ lb/ft^3} \times\ 100 = 95\%$$

where:

Agency density standard = 111.3 lb/ft$^3$

## Report

- Results on forms approved by the agency
- Sample ID
- Location of test, elevation of surface, and thickness of layer tested
- Visual description of material tested
- Make, model and serial number of the nuclear moisture-density gauge
- Wet density to the nearest 0.1 lb/ft$^3$
- Moisture content as a percent, by mass, of dry soil mass to the nearest 0.1 percent
- Dry density to the nearest 0.1 lb/ft$^3$
- Density standard to the nearest 0.1 lb/ft$^3$
- Percent compaction the nearest 1 percent
- Name and signature of operator

# THEORETICAL MAXIMUM SPECIFIC GRAVITY ($G_{mm}$) AND DENSITY OF ASPHALT MIXTURES
# FOP FOR AASHTO T 209

## Scope

This procedure covers the determination of the maximum specific gravity ($G_{mm}$) of uncompacted asphalt mixtures in accordance with AASHTO T 209-19. Two methods using different containers – bowl and pycnometer / volumetric flask– are covered.

Specimens prepared in the laboratory shall be cured according to agency standards.

## Apparatus

- Balance or scale: 10,000 g capacity, readable to 0.1 g
- Container: A glass, metal, or plastic bowl, pycnometer or volumetric flask between 2000 and 10,000 mL as required by the minimum sample size requirements in Table 1 sample and capable of withstanding a partial vacuum
- Pycnometer / volumetric flask cover: A glass plate or a metal or plastic cover with a vented opening
- Vacuum lid: A transparent lid with a suitable vacuum connection, with a vacuum opening to be covered with a fine wire mesh
- Vacuum pump or water aspirator: Capable of evacuating air from the container to a residual pressure of 4.0 kPa (30 mm Hg)
- Residual pressure manometer or vacuum gauge: Traceable to NIST and capable of measuring residual pressure down to 4.0 kPa (30 mm Hg) or less
- Manometer or vacuum gauge: Capable of measuring the vacuum being applied at the source of the vacuum
- Water bath: A constant-temperature water bath (optional)
- Thermometers: Standardized liquid-in-glass, or electronic digital total immersion type, accurate to 0.5°C (1°F)
- Bleeder valve to adjust vacuum
- Automatic vacuum control unit (optional)
- Timer

## Standardization of Pycnometer or Volumetric Flask

Use a pycnometer / volumetric flask that is standardized to accurately determine the mass of water, at 25 ±0.5°C (77 ±1°F), in the pycnometer / volumetric flask. The pycnometer / volumetric flask shall be standardized periodically in conformance with procedures established by the agency.

## Test Sample Preparation

1. Obtain samples in accordance with the FOP for AASHTO R 97 and reduce according to the FOP for AASHTO R 47.
2. Test sample size shall conform to the requirements of Table 1. Samples larger than the capacity of the container may be tested in two or more increments. Results will be combined and averaged. If the increments have a specific gravity difference greater than 0.014, the test must be re-run.

**Table 1**
**Test Sample Size for $G_{mm}$**

| Nominal Maximum* Aggregate Size mm (in.) | Minimum Mass g |
|---|---|
| 37.5 or greater (1½) | 4000 |
| 19 to 25 (3/4 to 1) | 2500 |
| 12.5 or smaller (1/2) | 1500 |

*Nominal maximum size: One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained.

## Procedure – General

Two procedures – bowl and pycnometer / volumetric flask – are covered. The first 11 steps are the same for both.

1. Separate the particles of the sample, taking care not to fracture the mineral particles, so that the particles of the fine aggregate portion are not larger than 6.3 mm (1/4 in.). If the mixture is not sufficiently soft to be separated manually, place it in a large flat pan and warm in an oven only until it is pliable enough for separation.
2. Cool the sample to room temperature.
3. Determine and record the mass of the dry container to the nearest 0.1 g.
4. Place the sample in the container.
5. Determine and record the mass of the dry container and sample to the nearest 0.1 g.
6. Determine and record the mass of the sample by subtracting the mass determined in Step 3 from the mass determined in Step 5. Designate this mass as "A."
7. Add sufficient water at approximately 25° C (77° F) to cover the sample by about 25 mm (1 in.).

***Note 1:*** The release of entrapped air may be facilitated by the addition of a wetting agent. Check with the agency to see if this is permitted and, if it is, for a recommended agent.

8. Place the lid on the container and attach the vacuum line. To ensure a proper seal between the container and the lid, wet the O-ring or use a petroleum gel.
9. Remove entrapped air by subjecting the contents to a partial vacuum of 3.7 ±0.3 kPa (27.5 ±2.5 mm Hg) residual pressure for 15 ±2 minutes.
10. Agitate the container and contents, either continuously by mechanical device or manually by vigorous shaking, at 2-minute intervals. This agitation facilitates the removal of air.
11. Release the vacuum. Increase the pressure to atmospheric pressure in 10 to 15 seconds if the vacuum release is not automated. Turn off the vacuum pump and remove the lid. When performing the pycnometer / volumetric flask method, complete steps 12B through 16B within 10±1 minute.

## Procedure – Bowl

12A. Fill the water bath to overflow level with water at 25 ±1°C (77 ±2°F) and allow the water to stabilize.

13A. Zero or tare the balance with the immersion apparatus attached, ensuring that the device is not touching the sides or the bottom of the water bath.

14A. Suspend and immerse the bowl and contents in water at 25 ±1°C (77 ±2°F) for 10 ±1 minute. The holder shall be immersed sufficiently to cover both it and the bowl.

15A. Determine and record the submerged weight of the bowl and contents to the nearest 0.1 g.

16A. Refill the water bath to overflow level.

17A. Empty and re-submerge the bowl following Step 12A to determine the submerged weight of the bowl to the nearest 0.1 g.

18A. Determine and record the submerged weight of the sample to the nearest 0.1 g by subtracting the submerged weight of the bowl from the submerged weight determined in Step 15A. Designate this submerged weight as “C.”

## Procedure – Pycnometer or Volumetric Flask

12B. Immediately fill the pycnometer / volumetric flask with water without reintroducing air.

13B. Stabilize the temperature of the pycnometer / volumetric flask and contents so that the final temperature is within 25 ±1°C (77 ±2°F).

14B. Finish filling the pycnometer / volumetric flask with water that is 25 ±1°C (77 ±2°F), place the cover or a glass plate on the pycnometer / volumetric flask, and eliminate all air.

***Note 2:*** When using a metal pycnometer and cover, place the cover on the pycnometer and push down slowly, forcing excess water out of the hole in the center of the cover. Use care when filling the pycnometer to avoid reintroducing air into the water.

15B. Towel dry the outside of the pycnometer / volumetric flask and cover.

16B. Determine and record the mass of the pycnometer / volumetric flask, cover, de-aired water, and sample to the nearest 0.1 g. within 10 ±1 minute of completion of Step 11. Designate this mass as "E."

## Procedure – Mixtures Containing Uncoated Porous Aggregate

If the pores of the aggregates are not thoroughly sealed by a bituminous film, they may become saturated with water during the vacuuming procedure, resulting in an error in maximum density. To determine if this has occurred, complete the general procedure and then:

1. Carefully drain water from sample through a towel held over the top of the container to prevent loss of material.
2. Spread sample in a flat shallow pan and place before an electric fan to remove surface moisture.
3. Determine the mass of the sample when the surface moisture appears to be gone.
4. Continue drying and determine the mass of the sample at 15-minute intervals until less than a 0.5 g loss is found between determinations.
5. Record the mass as the saturated surface dry mass to the nearest 0.1 g. Designate this mass as "ASSD."
6. Calculate, as indicated below, $G_{mm}$ using "A" and "ASSD," and compare the two values.

## Calculation

Calculate the $G_{mm}$ to three decimal places as follows:

**Bowl Procedure**

$$G_{mm} = \frac{A}{A - C} \qquad or \qquad G_{mm} = \frac{A}{A_{SSD} - C}$$

(for mixes containing uncoated aggregate materials)

where:

A = mass of dry sample in air, g

$A_{SSD}$ = Mass of saturated surface dry sample in air, g

C = submerged weight of sample in water, g

**Example**:

A = 1432.7 g

$A_{SSD}$ = 1434.2 g

C = 848.6 g

$$G_{mm} = \frac{1432.7\ g}{1432.7\ g - 848.6\ g} = 2.453 \qquad or \qquad G_{mm} = \frac{1432.7\ g}{1434.2\ g - 848.6\ g} = 2.447$$

**Pycnometer / Volumetric Flask Procedure**

$$G_{mm} = \frac{A}{A + D - E} \qquad or \qquad G_{mm} = \frac{A}{A_{SSD} + D - E}$$

(for mixtures containing uncoated materials)

where:

A = Mass of dry sample in air, g

$A_{SSD}$ = Mass of saturated surface-dry sample in air, g

D = Mass of pycnometer / volumetric flask filled with water at 25°C (77°F), g, determined during the Standardization of Pycnometer / Volumetric Flask procedure

E = Mass of pycnometer / volumetric flask filled with water and the test sample at test temperature, g

**Example (in which two increments of a large sample are averaged):**

| Increment 1 | Increment 2 |
|---|---|
| A = 2200.3 g | A = 1960.2 g |
| D = 7502.5 g | D = 7525.5 g |
| E = 8812.0 g | E = 8690.8 g |
| Temperature = 26.2°C | Temperature = 25.0°C |

$$G_{mm_1} = \frac{2200.3\ g}{2200.3\ g + 7502.5\ g - 8812.0\ g} = 2.470$$

$$G_{mm_2} = \frac{1960.2\ g}{1960.2\ g + 7525.5\ g - 8690.8\ g} \times 1.00000 = 2.466$$

Allowable variation is: 0.014

2.470 - 2.466 = 0.004, which is < 0.014, so they can be averaged.

Average:

2.470 + 2.466 = 4.936 4.936 ÷ 2 = **2.468**

## Theoretical Maximum Density

To calculate the theoretical maximum density at 25°C (77°F) use one of the following formulas. The density of water at 25°C (77°F) is 997.1 in Metric units or 62.245 in English units.

Theoretical maximum density kg/m$^3$ = $G_{mm}$ × 997.1 kg/ m$^3$

2.468 × 997.1 kg/ m$^3$ = 2461 kg/ m$^3$

or

Theoretical maximum density lb/ft$^3$ = $G_{mm}$ × 62.245 lb/ft$^3$

2.468 × 62.245 lb/ft$^3$ = 153.6 lb/ft$^3$

## Report

- Results on forms approved by the agency
- Sample ID
- $G_{mm}$ to the nearest 0.001
- Theoretical maximum density to the nearest 1 kg/m$^3$ (0.1 lb/ft$^3$)

# BULK SPECIFIC GRAVITY ($G_{mb}$) OF COMPACTED ASPHALT MIXTURES USING SATURATED SURFACE-DRY SPECIMENS FOP FOR AASHTO T 166

## Scope

This procedure covers the determination of bulk specific gravity ($G_{mb}$) of compacted asphalt mixtures using three methods – A, B, and C – in accordance with AASHTO T 166-16. This FOP is for use on specimens not having open or interconnecting voids or absorbing more than 2.00 percent water by volume, or both. When specimens have open or interconnecting voids or absorbing more than 2.00 percent water by volume, or both, AASHTO T 275 or AASHTO T 331 should be performed.

## Overview

- Method A: Suspension
- Method B: Volumeter
- Method C: Rapid test for A or B

## Test Specimens

Test specimens may be either laboratory-molded or from asphalt mixture pavement. For specimens it is recommended that the diameter be equal to four times the maximum size of the aggregate and the thickness be at least one and one half times the maximum size.

Test specimens from asphalt mixture pavement will be sampled according to AASHTO R 67.

## Terminology

*Constant Mass*: The state at which a mass does not change more than a given percent, after additional drying for a defined time interval, at a required temperature.

## Apparatus - Method A (Suspension)

- Balance or scale: 5 kg capacity, readable to 0.1 g, and fitted with a suitable suspension apparatus and holder to permit weighing the specimen while suspended in water, conforming to AASHTO M 231.
- Suspension apparatus: Wire of the smallest practical size and constructed to permit the container to be fully immersed.
- Water bath: For immersing the specimen in water while suspended under the balance or scale and equipped with an overflow outlet for maintaining a constant water level.
- Towel: Damp cloth towel used for surface drying specimens.
- Oven: Capable of maintaining a temperature of 110 ±5°C (230 ±9°F) for drying the specimens to a constant mass.

- Pan: Pan or other suitable container of known mass, large enough to hold a sample for drying in oven.
- Thermometer: Having a range of 19 to 27°C (66 to 80°F), graduated in 0.1°C (0.2°F) subdivisions.
- Vacuum device: refer to AASHTO R 79 (optional)

## Procedure - Method A (Suspension)

Recently molded laboratory samples that have not been exposed to moisture do not need drying.

1. Dry the specimen to constant mass, if required.
   a. Oven method
      i. Initially dry overnight at 52 ±3°C (125 ±5°F).
      ii. Determine and record the mass of the specimen ($M_p$).
      iii. Return the specimen to the oven for at least 2 hours.
      iv. Determine and record the mass of the specimen ($M_n$).
      v. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$), divide by the previous mass determination ($M_p$), and multiply by 100.
      vi. Continue drying until there is no more than 0.05 percent change in specimen mass after 2-hour drying intervals (constant mass).
      vii. Constant mass has been achieved; sample is defined as dry.

   ***Note 1:*** To expedite the procedure, steps 1 and 2 may be performed last. To further expedite the process, see Method C.

   b. Vacuum dry method
      i. Perform vacuum drying procedure according to AASHTO R 79.
      ii. Determine and record the mass of the specimen ($M_p$).
      iii. Perform a second vacuum drying procedure.
      iv. Determine and record the mass of the specimen ($M_n$).
      v. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$), divide by the previous mass determination ($M_p$), and multiply by 100.
      vi. Continue drying until there is no more than 0.05 percent change in specimen mass (constant mass).
      vii. Constant mass has been achieved; sample is defined as dry.

2. Cool the specimen in air to 25 ±5°C (77 ±9°F), and determine and record the dry mass to the nearest 0.1 g. Designate this mass as "A."
3. Fill the water bath to overflow level with water at 25 ±1°C (77 ±1.8°F) and allow the water to stabilize.
4. Zero or tare the balance with the immersion apparatus attached, ensuring that the device is not touching the sides or the bottom of the water bath.
5. Immerse the specimen shaking to remove the air bubbles. Place the specimen on its side in the suspension apparatus. Leave it immersed for 4 ±1 minutes.
6. Determine and record the submerged weight to the nearest 0.1 g. Designate this submerged weight as "C."
7. Remove the sample from the water and quickly surface dry with a damp cloth towel within 5 seconds.
8. Zero or tare the balance.
9. Immediately determine and record the mass of the saturated surface-dry (SSD) specimen to nearest 0.1 g. Designate this mass as "B." Any water that seeps from the specimen during the mass determination is considered part of the saturated specimen. Do not to exceed 15 seconds performing Steps 7 through 9.

## Calculations - Method A (Suspension)

**Constant Mass:**

Calculate constant mass using the following formula:

$$\%Change = \frac{M_p - M_n}{M_p} \times 100$$

Where:

$M_p$ = previous mass measurement, g

$M_n$ = new mass measurement, g

**Bulk specific gravity ($G_{mb}$) and percent water absorbed:**

$$G_{mb} = \frac{A}{B - C}$$

$$Percent\ Water\ Absorbed\ (by\ volume) = \frac{B - A}{B - C} \times 100$$

where:

A = Mass of dry specimen in air, g

B = Mass of SSD specimen in air, g

C = Weight of specimen in water at 25 ±1°C (77 ±1.8°F), g

**Example:**

$$G_{mb} = \frac{4833.6\ g}{4842.4\ g - 2881.3\ g} = 2.465$$

$$\%\ Water\ Absorbed\ (by\ volume) = \frac{4842.4\ g - 4833.6\ g}{4842.4\ g - 2881.3\ g} \times 100 = 0.45\%$$

## Apparatus - Method B (Volumeter)

- Balance or scale: 5 kg capacity, readable to 0.1 g and conforming to AASHTO M 231.
- Water bath: Thermostatically controlled to 25 ±0.5°C (77 ±0.9°F).
- Thermometer: Range of 19 to 27°C (66 to 80°F) and graduated in 0.1°C (0.2°F) subdivisions.
- Volumeter: Calibrated to 1200 mL or appropriate capacity for test sample and having a tapered lid with a capillary bore.
- Oven: Capable of maintaining a temperature of 110 ±5°C (230 ±9°F) for drying the specimens to a constant mass.
- Pan: Pan or other suitable container of known mass, large enough to hold a sample for drying in oven.
- Towel: Damp cloth towel used for surface drying specimens.
- Vacuum device: AASHTO R 79 (optional)

## Procedure - Method B (Volumeter)

Recently molded laboratory samples that have not been exposed to moisture do not need drying.

1. Dry the specimen to constant mass, if required.
   a. Oven method:
      i. Initially dry overnight at 52 ±3°C (125 ±5°F).
      ii. Determine and record the mass of the specimen ($M_p$).
      iii. Return the specimen to the oven for at least 2 hours.
      iv. Determine and record the mass of the specimen ($M_n$).
      v. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$), divide by the previous mass determination ($M_p$), and multiply by 100.
      vi. Continue drying until there is no more than 0.05 percent change in specimen mass after 2-hour drying intervals (constant mass).
      vii. Constant mass has been achieved; sample is defined as dry.

   ***Note 1:*** To expedite the procedure, steps 1 and 2 may be performed last. To further expedite the process, see Method C.

   b. Vacuum dry method
      i. Perform vacuum drying procedure according to AASHTO R 79.
      ii. Determine and record the mass of the specimen ($M_p$).

iii. Perform a second vacuum drying procedure.

iv. Determine and record the mass of the specimen ($M_n$).

v. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$), divide by the previous mass determination ($M_p$), and multiply by 100.

vi. Continue drying until there is no more than 0.05 percent change in specimen mass (constant mass).

vii. Constant mass has been achieved; sample is defined as dry.

2. Cool the specimen in air to 25 ±5°C (77 ±9°F), and determine and record the dry mass to the nearest 0.1 g. Designate this mass as "A."
3. Immerse the specimen in the temperature-controlled water bath for at least 10 minutes.
4. Fill the volumeter with distilled water at 25 ±1°C (77 ±1.8°F) making sure some water escapes through the capillary bore of the tapered lid.
5. Wipe the volumeter dry. Determine the mass of the volumeter to the nearest 0.1 g. Designate this mass as "D."
6. At the end of the ten-minute period, remove the specimen from the water bath and quickly surface dry with a damp cloth towel within 5 seconds.
7. Immediately determine and record the mass of the SSD specimen to the nearest 0.1 g. Designate this mass as "B." Any water that seeps from the specimen during the mass determination is considered part of the saturated specimen.
8. Place the specimen in the volumeter and let stand 60 seconds.
9. Bring the temperature of the water to 25 ±1°C (77 ±1.8°F) and cover the volumeter, making sure some water escapes through the capillary bore of the tapered lid.
10. Wipe the volumeter dry.
11. Determine and record the mass of the volumeter and specimen to the nearest 0.1 g. Designate this mass as "E."

***Note 2:*** Method B is not acceptable for use with specimens that have more than 6 percent air voids.

## Calculations - Method B (Volumeter)

**Constant Mass:**

Calculate constant mass using the following formula:

$$\%Change = \frac{M_p - M_n}{M_p} \times 100$$

Where:

$M_p$ = previous mass measurement, g

$M_n$ = new mass measurement, g

**Bulk specific gravity ($G_{mb}$) and percent water absorbed:**

$$G_{mb} = \frac{A}{B + D - E}$$

$$Percent\ Water\ Absorbed\ (by\ volume) = \frac{B - A}{B + D - E} \times 100$$

where:

$G_{mb}$ = Bulk specific gravity

A = Mass of dry specimen in air, g

B = Mass of SSD specimen in air, g

D = Mass of volumeter filled with water at 25 ±1°C (77 ±1.8°F), g

E = Mass of volumeter filled with specimen and water, g

**Example:**

$$G_{mb} = \frac{4833.6\ g}{4842.4\ g + 2924.4\ g - 5806.0\ g} = 2.465$$

$$\%\ Water\ Absorbed\ (by\ volume) = \frac{4842.4\ g - 4833.6\ g}{4842.4\ g + 2924.4\ g - 5806.0\ g} \times 100 = 0.45\%$$

## Method C (Rapid Test for Method A or B)

See Methods A or B.

***Note 3:*** This procedure can be used for specimens that are not required to be saved and contain substantial amounts of moisture. Cores can be tested the same day as obtained by this method.

## Procedure - Method C (Rapid Test for Method A or B)

1. Start on Step 3 of Method A or B, and complete that procedure, then determine dry mass, "A," as follows.
2. Determine and record mass of a large, flat-bottom container.
3. Place the specimen in the container.
4. Place in an oven at a minimum of 105°C (221°F). Do not exceed the Job Mix Formula mixing temperature.
5. Dry until the specimen can be easily separated into fine aggregate particles that are not larger than 6.3 mm (¼ in.).
6. Determine and record the mass of the specimen ($M_p$).
7. Return the specimen to the oven for at least 2 hours.
8. Determine and record the mass of the specimen ($M_n$).
9. Determine percent change by subtracting the new mass determination ($M_n$) from the previous mass determination ($M_p$), divide by the previous mass determination ($M_p$), and multiply by 100.
10. Continue drying until there is no more than 0.05 percent change in specimen mass after 2-hour drying intervals (constant mass).
11. Constant mass has been achieved; sample is defined as dry.
12. Cool in air to 25 ±5°C (77 ±9°F).
13. Determine and record the mass of the container and dry specimen to the nearest 0.1 g.
14. Determine and record the mass of the dry specimen to the nearest 0.1 g by subtracting the mass of the container from the mass determined in Step 13. Designate this mass as "A."

## Calculations - Method C (Rapid Test for Method A or B)

Complete the calculations as outlined in Methods A or B, as appropriate.

## Report

- Results on forms approved by the agency
- Sample ID
- $G_{mb}$ to the nearest 0.001
- Absorption to the nearest 0.01 percent
- Method performed.

# IN-PLACE DENSITY OF ASPHALT MIXTURES BY NUCLEAR METHOD FOP FOR AASHTO T 355

## Scope

This test method describes a procedure for determining the density of asphalt mixtures by means of a nuclear gauge using the backscatter method in accordance with AASHTO T 355-18. Correlation with densities determined under the FOP for AASHTO T 166 is required by some agencies.

## Apparatus

- Nuclear density gauge with the factory-matched standard reference block.
- Transport case for properly shipping and housing the gauge and tools.
- Instruction manual for the specific make and model of gauge.
- Radioactive materials information and calibration packet containing:
  - Daily standard count log
  - Factory and laboratory calibration data sheet
  - Leak test certificate
  - Shippers' declaration for dangerous goods
  - Procedure memo for storing, transporting and handling nuclear testing equipment
  - Other radioactive materials documentation as required by local regulatory requirements

## Material

- Filler material: Fine-graded sand from the source used to produce the asphalt pavement or other agency approved materials.

## Radiation Safety

This method does not purport to address all of the safety problems associated with its use. This test method involves potentially hazardous materials. The gauge utilizes radioactive materials that may be hazardous to the health of the user unless proper precautions are taken. Users of this gauge must become familiar with the applicable safety procedures and governmental regulations. All operators will be trained in radiation safety before operating nuclear density gauges. Some agencies require the use of personal monitoring devices such as a thermoluminescent dosimeter or film badge. Effective instructions, together with routine safety procedures such as source leak tests, recording and evaluation of personal monitoring device data, etc., are a recommended part of the operation and storage of this gauge.

## Calibration

Calibrate the nuclear gauge as required by the agency. This calibration may be performed by the agency using the manufacturer's recommended procedures or by other facilities approved by the agency. Verify or re-establish calibration curves, tables, or equivalent coefficients every 12 months.

## Standardization

1. Turn the gauge on and allow it to stabilize (approximately 10 to 20 minutes) before standardization. Leave the power on during the day's testing.
2. Standardize the nuclear gauge at the construction site at the start of each day's work and as often as deemed necessary by the operator or agency. Daily variations in standard count shall not exceed the daily variations established by the manufacturer of the gauge. If the daily variations are exceeded after repeating the standardization procedure, the gauge should be repaired, recalibrated, or both.
3. Record the standard count for both density and moisture in the daily standard count log. The exact procedure for standard count is listed in the manufacturer's Operator's Manual.

***Note 1:*** New standard counts may be necessary more than once a day. See agency requirements.

## Test Site Location

1. Select a test location(s) randomly and in accordance with agency requirements. Test sites should be relatively smooth and flat and meet the following conditions:
    a. At least 10 m (30 ft.) away from other sources of radioactivity.
    b. At least 3 m (10 ft.) away from large objects.
    c. If the gauge will be closer than 600 mm (24 in.) to any vertical mass, or less than 300 mm (12 in.) from a vertical pavement edge, use the gauge manufacturer's correction procedure.

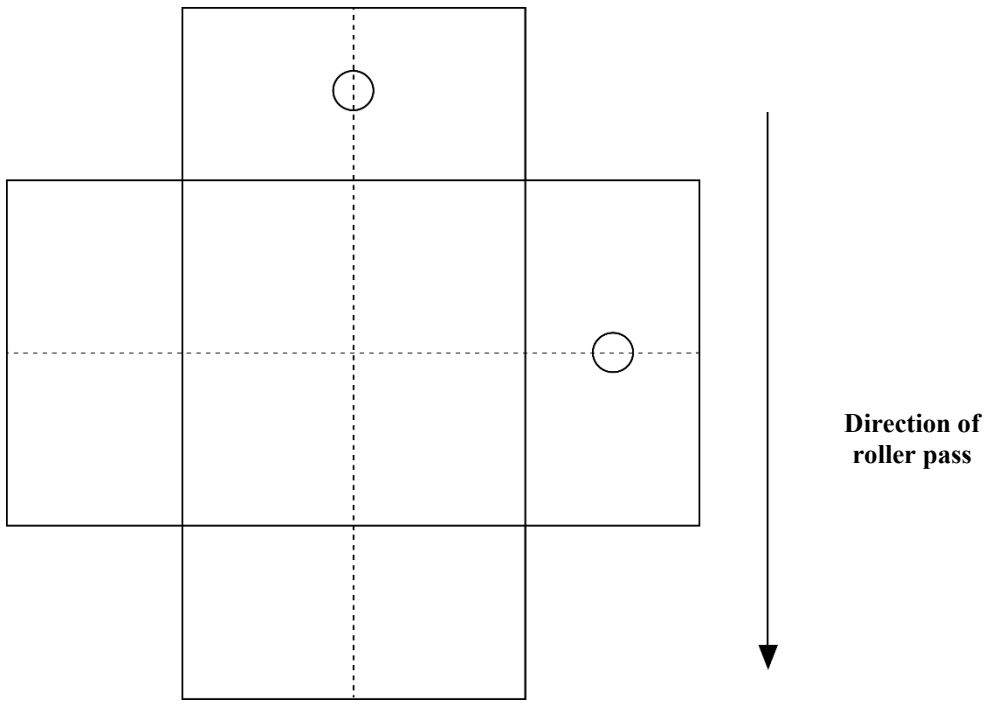
## Procedure

1. Maintain maximum contact between the base of the gauge and the surface of the material under test.
2. Use filler material to fill surface voids.
3. Spread a small amount of filler material over the test site surface and distribute it evenly. Strike off the surface with a straightedge (such as a lathe or flat-bar steel) to remove excess material.
4. If using thin-layer mode, enter the anticipated overlay thickness into the gauge.

***Note 2:*** If core correlation is required, entered thickness, anticipated thickness, and nominal core thickness may be required to match.

**Method A – Average of two one-minute tests**

1. Place the gauge on the test site, perpendicular to the roller passes.
2. Using a crayon (not spray paint), mark the outline or footprint of the gauge.
3. Extend the probe to the backscatter position.
4. Take a one-minute test and record the wet density reading.
5. Rotate the gauge 90 degrees centered over the original footprint. Mark the outline or footprint of the gauge.
6. Take another one-minute test and record the wet density reading.
7. If the difference between the two one-minute tests is greater than 40 kg/m$^3$ (2.5 lb/ft$^3$), retest in both directions. If the difference of the retests is still greater than 40 kg/m$^3$ (2.5 lb/ft$^3$) test at 180 and 270 degrees.
8. The density reported for each test site shall be the average of the two individual one-minute wet density readings.

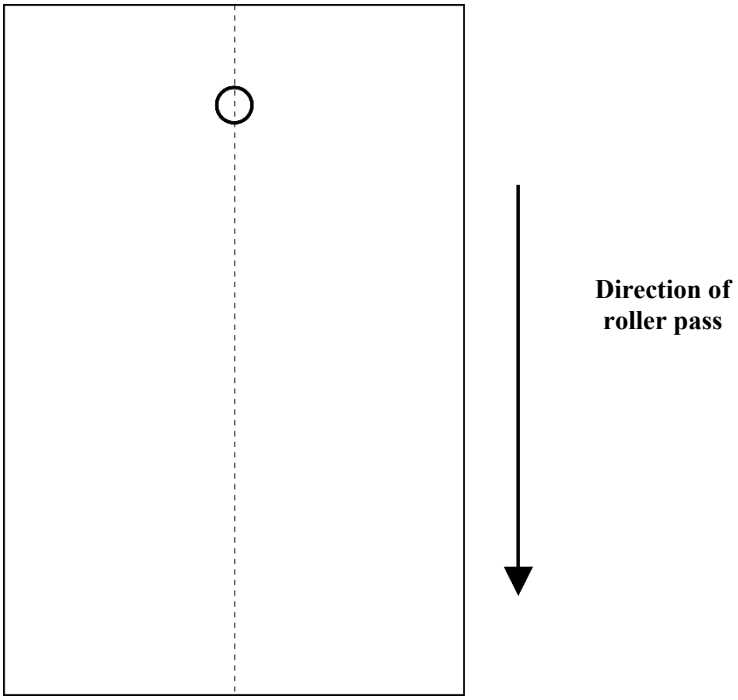



**Method A**

**Footprint of the gauge test site**

**Method B – One four-minute test**

1. Place the gauge on the test site, parallel to the roller passes.
2. Using a crayon (not spray paint), mark the outline or footprint of the gauge.
3. Extend the probe to the backscatter position.
4. Take one 4-minute test and record the wet density reading.




**Method B**

**Footprint of the gauge test site**

## Calculation of Results

Percent compaction is determined by comparing the in-place wet density as determined by this method to the appropriate agency density standard. See appropriate agency policy for use of density standards.

$$Percent\ compaction = \frac{Corrected\ Reading}{Maximum\ Density} \times 100$$

**Method A Example:**

Reading #1: 141.5 lb/ft$^3$

Reading #2: 140.1 lb/ft$^3$ Are the two readings within the tolerance? (YES)

Reading average: 140.8 lb/ft$^3$

Core correction: +2.1 lb/ft$^3$

Corrected reading: 142.9 lb/ft$^3$

**Method B Example:**

Reading: 140.8 lb/ft$^3$

Core correction: +2.1 lb/ft$^3$

Corrected reading 142.9 lb/ft$^3$

**Example percent compaction:**

From the FOP for AASHTO T 209:

$\mathbf{G_{mm}}$ = 2.466

$$Theoretical\ Maximum\ Density = 2.466 \times 62.245 lb/ft^3 = 153.5 lb/ft^3$$

$$Percent\ compaction = \frac{142.9\ lb/ft^3}{153.5\ lb/ft^3} \times 100 = 93.1\%$$

## Report

- Results on forms approved by the agency
- Test ID
- Location of test and thickness of layer tested
- Mixture type
- Make, model and serial number of the nuclear moisture-density gauge
- Calculated wet density of each measurement and any adjustment data
- Density standard
- Compaction to the nearest 0.1 percent
- Name and signature of operator

## APPENDIX – CORRELATION WITH CORES

(Nonmandatory Information)

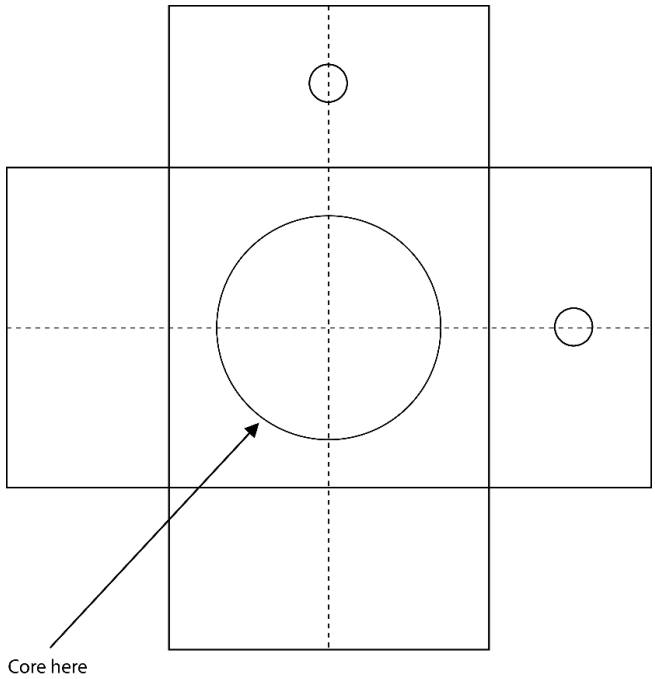
The bulk specific gravity ($G_{mb}$) of the core is a physical measurement of the in-place asphalt mixture and can be compared with the nuclear density gauge readings. Comparing the core value to the corresponding gauge values, a correlation can be established.

The correlation can then be used to adjust the gauge readings to the in-place density of the cores. The core correlation is gauge specific and must be determined without traffic allowed on the pavement between nuclear density gauge readings and obtaining the core. When using multiple nuclear density gauges each gauge should be correlated to the core locations before removal of the core.

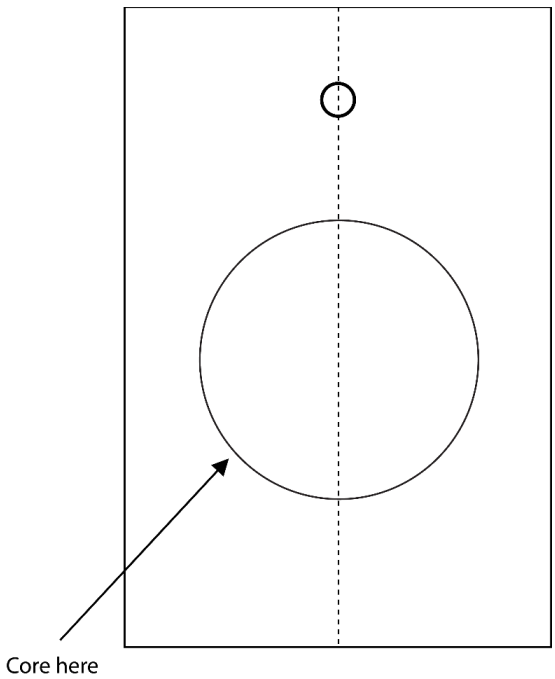
When density correlation with the FOP for AASHTO T 166 is required, correlation of the nuclear gauge with pavement cores shall be made on the first day's paving (within 24 hours) or from a test strip constructed before the start of paving. Cores must be taken before traffic is allowed on the pavement.

### Correlation with Cores

1. Determine the number of cores required for correlation from the agency's specifications. Cores shall be located on the first day's paving or on the test strip. Locate the test sites in accordance with the agency's specifications. Follow the "Procedure" section above to establish test sites and obtain densities using the nuclear gauge.
2. Obtain a pavement core from each of the test sites according to AASHTO R 67. The core should be taken from the center of the nuclear gauge footprint.




**Method A – Footprint of the gauge test site. Core location in the center of the footprint.**




**Method B - Footprint of the gauge test site.**

3. Determine the density of the cores by the FOP for AASHTO T 166, Bulk Specific Gravity of Compacted Asphalt Mixtures Using Saturated Surface Dry Specimens.
4. Calculate a correlation factor for the nuclear gauge reading as follows:
    a. Calculate the difference between the core density and the average nuclear gauge density at each test site to the nearest 1 kg/m$^3$ (0.1 lb/ft$^3$). Calculate the average difference and standard deviation of the differences for the entire data set to the nearest 1 kg/m$^3$ (0.1 lb/ft$^3$).
    b. If the standard deviation of the differences is equal to or less than 40 kg/m$^3$ (2.5 lb/ft$^3$), the correlation factor applied to the average nuclear gauge density shall be the average difference calculated above in 4.a.
    c. If the standard deviation of the differences is greater than 40 kg/m$^3$ (2.5 lb/ft$^3$), the test site with the greatest variation from the average difference shall be eliminated from the data set and the data set properties and correlation factor recalculated following 4.a and 4.b.
    d. If the standard deviation of the modified data set still exceeds the maximum specified in 4.b, additional test sites will be eliminated from the data set and the data set properties and correlation factor recalculated following 4.a and 4.b. If the data set consists of less than five test sites, additional test sites shall be established.

***Note A1:*** The exact method used in calculating the nuclear gauge correlation factor shall be defined by agency policy.

***Note A2:*** The above correlation procedure must be repeated if there is a new job mix formula. Adjustments to the job mix formula beyond tolerances established in the contract documents will constitute a new

job mix formula. A correlation factor established using this procedure is only valid for the particular gauge used in the correlation procedure. If another gauge is brought onto the project, it shall be correlated using the same procedure. Multiple gauges may be correlated from the same series of cores if done at the same time.

***Note A3:*** For the purpose of this procedure, a job mix formula is defined as the percent and grade of paving asphalt used with a specified gradation of aggregate from a designated aggregate source. A new job mix formula may be required whenever compaction of the wearing surface exceeds the agency's specified maximum density or minimum air voids.

## Calculations

### Correlation Factor

$$\sqrt{\frac{\sum x^2}{n-1}}$$

Where:

$\sum$ = Sum

x = Difference from the average Difference

n-1 = number of data sets minus 1

## Example

| Core # | Core results from T 166: | Average Gauge reading | Difference: | x | $x^2$ |
|---|---|---|---|---|---|
| 1 | 144.9 lb/ft$^3$ | 142.1 lb/ft$^3$ | 2.8 lb/ft$^3$ | -0.7 | 0.49 |
| 2 | 142.8 lb/ft$^3$ | 140.9 lb/ft$^3$ | 1.9 lb/ft$^3$ | 0.2 | 0.04 |
| 3 | 143.1 lb/ft$^3$ | 140.7 lb/ft$^3$ | 2.4 lb/ft$^3$ | -0.3 | 0.09 |
| 4 | 140.7 lb/ft$^3$ | 138.9 lb/ft$^3$ | 1.8 lb/ft$^3$ | 0.3 | 0.09 |
| 5 | 145.1 lb/ft$^3$ | 143.6 lb/ft$^3$ | 1.5 lb/ft$^3$ | 0.6 | 0.36 |
| 6 | 144.2 lb/ft$^3$ | 142.4 lb/ft$^3$ | 1.8 lb/ft$^3$ | 0.3 | 0.09 |
| 7 | 143.8 lb/ft$^3$ | 141.3 lb/ft$^3$ | 2.5 lb/ft$^3$ | -0.4 | 0.16 |
| 8 | 142.8 lb/ft$^3$ | 139.8lb/ft$^3$ | 3.0 lb/ft$^3$ | 0.9 | 0.81 |
| 9 | 144.8 lb/ft$^3$ | 143.3 lb/ft$^3$ | 1.5 lb/ft$^3$ | -0.6 | 0.36 |
| 10 | 143.0 lb/ft$^3$ | 141.0 lb/ft$^3$ | 2.0 lb/ft$^3$ | -0.1 | 0.01 |

Average Difference: +2.1 lb/ft$^3$ $\Sigma x^2$ = 2.5

**Number of data sets**

$$\boldsymbol{n - 1 = 10 - 1 = 9}$$

**Standard deviation**

$$standard\ deviation = \sqrt{\frac{2.5}{9}} = 0.53$$

Where:

Sum of $x^2$ = 2.5

Number of data sets = 9

The standard deviation of 0.53 is less than 2.5 therefore no cores are eliminated. The average difference from all ten cores is used.