Transportation Technician
Qualification Program

IN-PLACE DENSITY
Workbook

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“1998”

Published October 2025

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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 the private sector
- Respond in a unified and consistent manner to identify quality improvement needs and new technologies that impact the products that we provide,
- Provide a forum to promote uniform test standards,
- Provide highly skilled, knowledgeable materials sampling and testing technicians,
- Provide reciprocity opportunities for qualified testing technicians among Accredited Contributing Members.

BACKGROUND

There are two significant driving forces behind the development of the WAQTC qualification program. One, there was a trend toward the use of quality control/quality assurance (QC/QA) specifications which included qualification requirements for contractor's QC personnel. Two, Federal regulation on materials sampling and testing (23 CFR 637, *Quality Assurance Procedures for Construction*, published in June 1995) mandated 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 among participating agencies.
- To create a harmonious working atmosphere between public and private employees based upon trust, open communication, and equivalency 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 among participating agencies and allows qualified testing technicians to cross state lines without needing to be requalified by a different program.

The WAQTC Executive Board

FOREWORD

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

- Aggregate
- Concrete
- Asphalt I
- Asphalt II
- Embankment and Base
- In-place Density
- Embankment and Base/In-place Density
- Self-Consolidating Concrete
- Sampling and Reduction

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:

IN-PLACE DENSITY

Learning Objectives

Understanding:

- Quality Assurance (QA) concepts
- Measurements and calculations
- Highway materials terminology
- Safety issues
- Random sampling techniques
- Basics of compaction and density control
- Demonstrating proficiency in the following test procedures:

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

  FOP for AASHTO T 99/T 180
    Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-in.) Drop;
    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 Soil Moisture-Density Relations (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 in-place density 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

Welcome
Introduction of Instructors
Introduction and Expectations of Participants

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

Review of Quality Assurance Concepts

Background in Measurements and Calculations

Random Sampling

Basics of Compaction and Density Control

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

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

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

Review with Questions and Answers Forum

Afternoon Laboratory Practice

Day Two

Questions from the Previous Day

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

Developing Soil Moisture-Density Relations (Family of Curves)
FOP for AASHTO R 75

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

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

Review with Questions and Answers Forum

Afternoon Laboratory Practice

Day Three

Questions from the Previous Day

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

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

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

Review with Questions and Answers Forum

Afternoon Laboratory Practice

Day Four

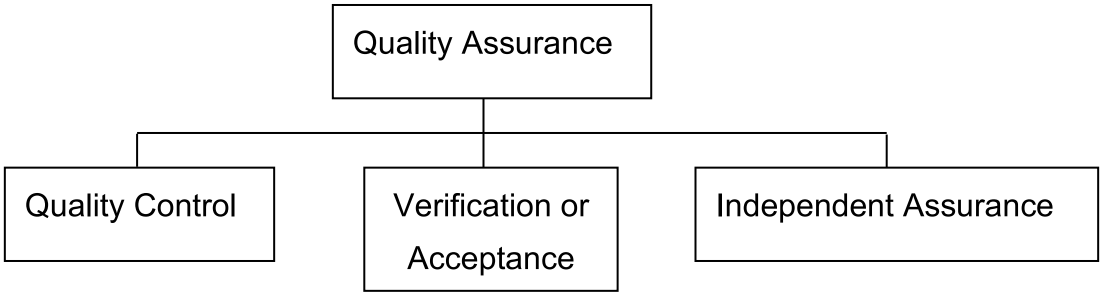
Start of Exams

Evaluation

QUALITY ASSURANCE CONCEPTS 03

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 04
includes the benefit of improvement of overall quality of highway and bridge construction.

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



05

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

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. 06
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 07
by an independent group.

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.

Independent Assurance (IA) are those activities that are an unbiased and independent 08
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.

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.

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.

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).

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

SI units

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 approximate conversions

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.

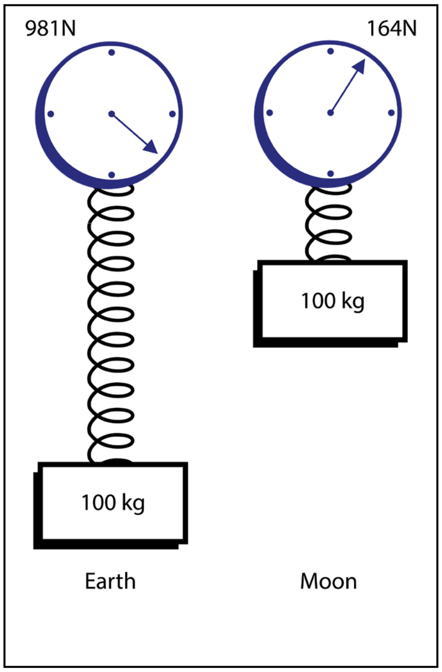
Mass vs. Weight

The terms mass, force, and weight are often
05 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.

$$W = mg$$



Comparison of mass and weight

In SI, the basic unit of mass is the kilogram (kg), the units of acceleration are meters per squared 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:

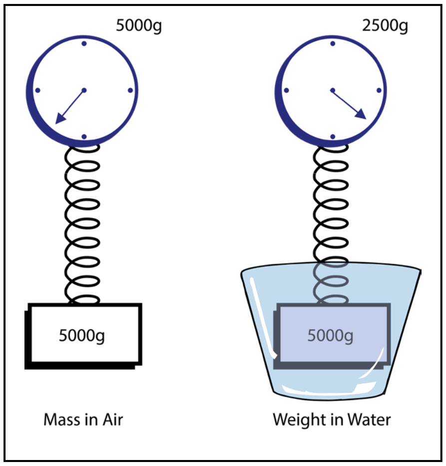
$$W = (84.0\ \text{kg})(9.81\ \text{m/s}^2) = 824\ \text{kg-m/s}^2 = 824\ \text{N}$$

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
07 her mass would remain 185 lb$_m$. Mass does not
depend on location, but weight does.

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.

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
09 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

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
10 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
12 submerged in water.

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
14 Tables 1 and 2.

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

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 is followed by exactly 5, followed by only zeroes, 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.

When rounding numbers that are followed by exactly 5, follow agency guidelines. For the purpose of WAQTC training, if the number being rounded is followed by a 5, the number is increased by 1.

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 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 rounded 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

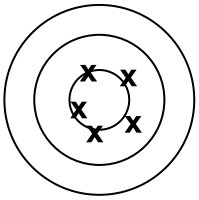
$$Not\colon\ \frac{3.21}{7.94} \times 100 = 40.428 \ldots$$

rounded to 40.0 and reported as 40

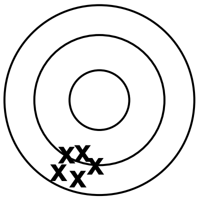
It is extremely important that engineers and technicians understand the rules of rounding and significant digits just as well as they know procedures called for in standard test methods.

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. 20



ACCURATE BUT NOT PRECISE, SCATTERED



PRECISE BUT NOT ACCURATE, BIASED

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

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, leaving only random error for concern.

Tolerance

Dimensions of constructed or manufactured objects, 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 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 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:

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

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

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

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 an asphalt mixture 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 – High quality, thoroughly controlled mix of aggregate and asphalt binder.

- **Hot mix asphalt (HMA)** – Asphalt mixtures of well-graded aggregate and asphalt binder that are mixed and placed at high temperatures.
- **Stone matrix asphalt (SMA) –** A gap-graded hot asphalt mixture that is designed to maximize deformation (rutting) resistance and durability by using a structural basis of stone-on-stone contact.
- **Warm mix asphalt (WMA) –** Asphalt mixtures that, due to a variety of technologies, are mixed and placed at relatively lower temperatures than HMA.

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.

Bleed – Occurs in concrete when coarse aggregate tends to settle down and free water rises to the surface.

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 asphalt mixture (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 criteria – The specified requirement for fractured particles determined by each agency.

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.

Halo – A concentration of mortar that can form at the perimeter of the slump flow patty.

High-range water-reducer (HRWR) – A concrete admixture that can reduce the quantity of mixing water required to produce concrete by more than 12 percent, while maintaining a certain level of consistency in slump.

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

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

HMA continuous mix plant – A manufacturing facility for producing asphalt mixture 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.

J-Ring – a rigid ring made of steel connecting 100 mm (4 in.) vertical smooth bars used in testing the passing ability of SCC.

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.

Passing ability – An indication of the ability of the SCC to flow around and between reinforcement without blocking.

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.

Recycled (reclaimed) asphalt materials – Recycled asphalt pavement (RAP) and recycled asphalt shingles (RAS) used as a component in asphalt mixtures.

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.)

Sectoring – An alternate method for further reducing quarters of a sample of material.

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.

Slump flow – Assesses the horizontal free flow, filling ability of self-compacting concrete in the absence of obstructions and may give some indication of resistance to segregation. It does not indicate the ability of the SCC to pass between reinforcement without blocking.

Smartly – Quickly and usually done with force.

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.

- **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.

- **G_{mb}** – measured bulk specific gravity (Gravity $_{\text{mix bulk}}$)
  The ratio of the mass, in air, of a volume of compacted asphalt mixture (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.

- **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.

- **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.

- **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.

- **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 and 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.

Static segregation - The tendency for coarse aggregate to separate from the sand-cement mortar in SCC.

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 asphalt mixture 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 – Micrometer (micron), a millionth of a meter. Used as a 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.

Viscosity modifying admixture – chemical additives used in concrete to control flow properties and enhance durability.

Visual stability index (VSI) – The Visual Stability Index (VSI) is used to assess the stability of SCC. The stability (or segregation resistance) of an SCC mixture is the ability of the mixture to remain homogeneous during transport, during placement, and after placement. The VSI determination is useful for quality control and consistency testing.

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, earmuffs
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.

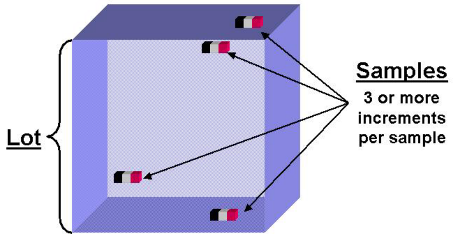
Sampling Concepts

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.

Straight Random Sampling

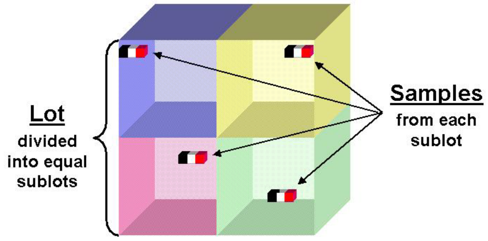
One or more sample locations may be selected, using the entire lot as a single unit



05 **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.

Stratified Random Sampling

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



06 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

08
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

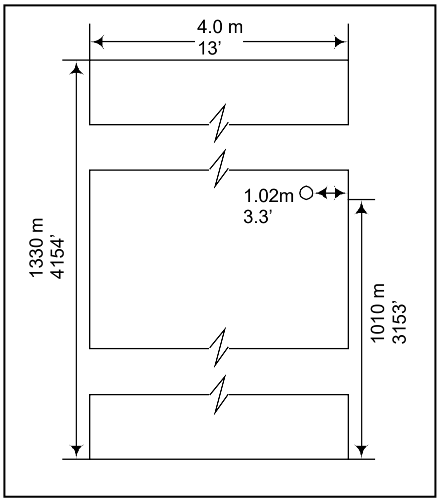
Examples of Straight Random Sampling Procedures Using Random Numbers

10 **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.

11 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.

12 **Sampling from Transport Units:** Based on the agency's specifications – in terms of time, volume, or mass – determine the number of transport 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 transport 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 transport 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
(1000yd^3) and material is being placed 0.15 m
13 (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
14 27.

The first RN would be multiplied by the length to
determine where the sample would be taken along
15 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
16 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.

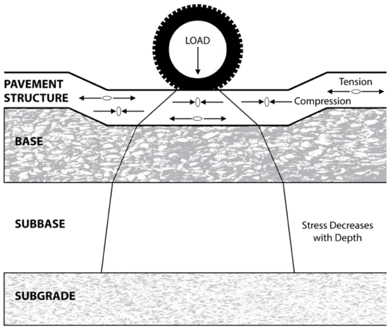
17 **Sampling from a Stockpile:** AASHTO R 90 recommends against sampling from stockpiles. However, some agencies use random procedures in determining sampling locations from a stockpile. Bear in mind that stockpiles are prone to segregation and that a sample obtained from a stockpile may not be representative.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

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

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
19 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

01 Roadways

Roadways are constructed in layers. The first
02 (bottom) layer is the subgrade, or naturally present
material. Next is the subbase, imported material
usually having better structural, drainage, and other
03 properties. Above the subbase is the base, material
of even better structural 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 an economical roadway
structure that supports traffic without undergoing
excessive surface deflection and/or long-term
settlement.

Variations to this layering can occur such as roadways constructed on high quality subgrade so that the subbase layer can be eliminated. Also, there may be “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.

Grading

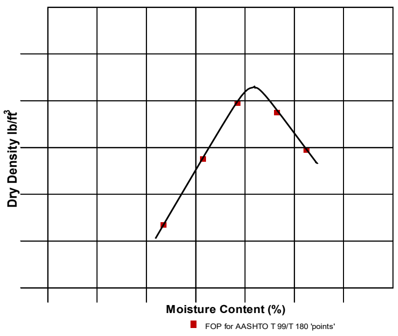
04 Stability and durability of roadways depend on the
final density of each component. Low-density
material will lead to excessive surface deflection
05 under load and/or long-term settlement. However,
compacting material to densities higher than
necessary costs both time and money.

Cracking

The quality of roadways also depends on the quality
of the pavement. In asphalt mixture roadways, the
density of the asphalt mixture plays a significant
06 role in the overall ability to support load and
provide long term service. Asphalt mixture
07 pavement specifications include requirements for
density and percent voids.

Sheepsfoot roller

Proctor molds and hammer



Moisture-density curve

For these reasons, a basic understanding of
compaction theory and a thorough knowledge of
testing methods is necessary. Compaction
08 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 is
often used on asphalt mixtures than soils.

09 Fine-Grained Soils

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
10 and density.

- 11 AASHTO T 99
- AASHTO T 180

In both methods, samples of soil are prepared at
12 several moisture contents and compacted into molds
of specified sizes using manual or mechanical
13 rammers delivering a specified quantity of
compactive energy. Knowing the wet masses of the
compacted samples and the volume of the molds,
wet densities can be determined. Moisture contents
of the compacted samples are determined and used
to obtain dry density values for the same samples.
14 Maximum dry density and optimum moisture
content for the soil are determined by plotting the
relationship between dry density and moisture
content on a moisture-density curve. The peak of
the best fit curve for the data points indicates the
maximum dry density and optimum moisture.

Construction specifications generally require that
15 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
16 AASHTO T 180, depending on the agency. In the
field, in-place dry density and moisture content of
the material will be determined using a nuclear
moisture-density gauge. The in-place values will be

compared to the specifications to determine conformance with the project requirements.

17

Material separated on the 4.75 mm (No. 4) sieve.

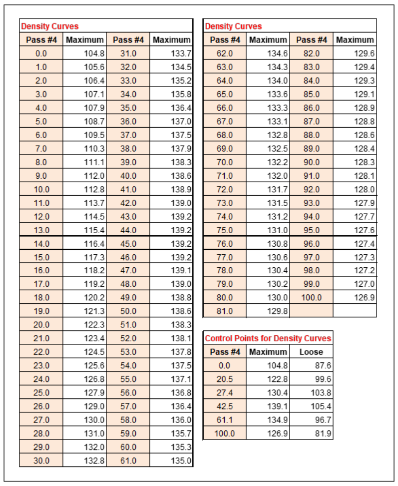
18

Correction for Oversize Material

The FOP for AASHTO T 99/T 180 is conducted on materials passing either 4.75 mm (No. 4) or 19.0 mm (3/4 in.) sieve, depending on the method. If the material includes larger particles, corrections to the maximum dry density determination is required. The corrections are determined using the *Correction of Maximum Dry Density and Optimum Moisture for Oversized Particles* Annex A in the FOP for AASHTO T 99/T 180.

The corrected density is a weighted average of the density of the material passing the specified sieve and the material retained on the sieve. The density of the passing material is determined according to the FOP for AASHTO T 99/T 180. The density of the retained material is based on its bulk specific gravity (G_{sb}), may be assumed according to the FOP for AASHTO T 99/T 180 or determined according to the FOP for AASHTO T 85.

19



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 Dry Density Chart

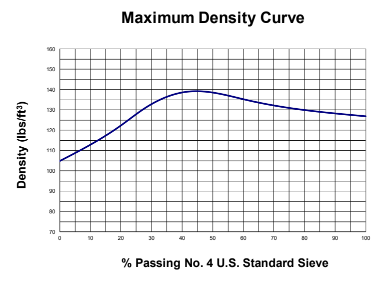
20

Granular Soil and Soil/Aggregates

For coarse-grained granular soil and soil/aggregate having little or no cohesion, compactive effort is the primary concern. Although moisture is not as significant an issue, because materials are free-draining and do not retain water, it does assist in compaction by acting as a lubricant.

Granular, free-draining materials are tested by procedures that combine compaction and vibration. 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



Maximum Dry Density Curve

21

These Agencies worked together to develop WAQTC TM 15, Laboratory Maximum Dry Density of Granular Soils and Soil/Aggregates and

WAQTC TM 17, Determination of Theoretical Maximum Dry Density of Granular Soils and Soil/Aggregates for Use as a Density Standard.

22 In WAQTC TM 15, material is compacted in a
mold with a combination of applied loads and
vibration. A laboratory maximum dry density of
the coarse and fine material is determined. Using
the apparent specific gravity (G_{sa}) and the
23 laboratory maximum dry density, a maximum dry
24 density curve and chart, representing the
25 relationship between the maximum dry density and
material passing the 4.75 mm (No. 4), are
developed for the material.

Backfill compaction

Image courtesy of UDOT

Backfill and Structural Backfill

26 Backfill is replacing material that has been removed
for excavation of pipe, utilities, structures, etc.
Many of these placements are in the Roadway or
27 near the Roadway Section.

Backfill material is placed in lifts (layers) and
compacted with mechanical rollers and tamping
28 devices, each layer must be tested to determine
appropriate compaction and adherence to
specifications.

Testing near structure

Image courtesy of UDOT

29 Proper backfill placement and compaction are important to the stability of a structure, especially those without deep foundations such as pipes, retaining walls and bridges on spread footings.

30 An uncompacted or unevenly compacted backfilled trench in the roadway, such as a pipe crossing, can lead to settlement of the roadway section.

Testing for in-place density and moisture content
according to the FOP for AASHTO T 310 in
31 trenches and near large objects requires extra steps
to correct for 'trench wall effect.' Moisture present
in the walls can be misread by the detector in the
gauge. In locations closer than 600 mm (24 in.) to a
vertical projection, it is necessary to perform a
trench offset correction to adjust the gauge readings.

Nuclear moisture-density gauge

In-Place Density

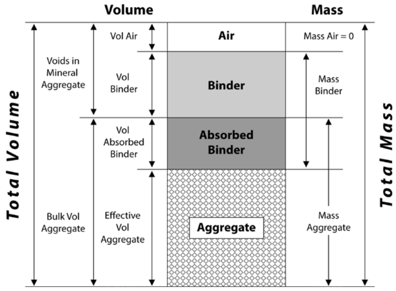
Construction specifications require in-place density 32 to meet a minimum percent of maximum dry density.

For fine-grained soils, the in-place dry density and moisture content of the material is determined 33 according to the FOP for AASHTO T 310 using a 34 nuclear moisture-density gauge. The in-place dry density is compared to the maximum dry density and optimum moisture content obtained according to the FOP for AASHTO T 99/T 180, to determine percent compaction.

For coarse grained granular soil and soil /aggregate, the in-place dry density is determined according to the FOP for AASHTO T 310. The percent of material passing the 4.75 mm (No. 4) sieve is 35 determined on a sample from the density test site according to WAQTC TM 17. Using the percent passing, the maximum dry density is obtained from the maximum dry density chart. The in-place density percent compaction is compared to this maximum dry density to determine percent compaction.

$$\% \, Compaction = \frac{In\ place\ Density}{Maximum\ Density} \times 100$$

Asphalt Mixture Pavement



Asphalt mixture phase diagram

For asphalt mixtures, density depends on 36 compactive effort as well as the mix design. The gradation and particle shape of the aggregate, the 41 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.

Construction specifications will require a certain percentage of maximum voidless density, while maintaining voids within a certain range. A specification of 92 to 96 percent of maximum 37 density and a corresponding void content between 8 and 4 percent is typical. 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, raveling, and freeze-thaw damage. Over-compaction results in high density and low void content which may cause bleeding, rutting, cracking, or premature failure.

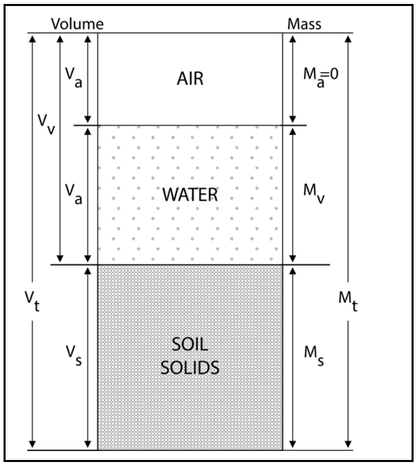
In the field, the in-place density of the compacted asphalt mixture is determined using core samples and/or according to the FOP for AASHTO T 355 using a calibrated nuclear density gauge. The in-place density is compared to the theoretical maximum density obtained from the FOP for AASHTO T 209 to determine the percent air voids and percent compaction to determine conformance with the project specifications.

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 & Base and In-Place Density technicians must obtain samples and perform tests according to proper procedures 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

Significance

01 The amount of water contained in many materials
influences design and construction practices. Road
02 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
03 accordance with AASHTO T 255-25 and
AASHTO T 265-22. It may also be used for other
construction materials.

Apparatus

04 Overview

05 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

- 06 Balance or scale: capacity sufficient for the principal sample mass, readable to 0.1 percent of sample mass or 0.1 g., and meeting the requirements of AASHTO M 231
- 07 Container: clean, dry, and capable of being sealed
- 08 Suitable drying container
  - 09 For soils: container requires close-fitting lid
  - For aggregate: container lid is optional

Containers with lids for drying soils

Forced Air Oven

Infrared Oven

- Microwave safe container with ventilated lid (for drying aggregate only)
- Heat source, thermostatically controlled, capable of maintaining 110 ± 5°C (230 ± 9°F).
- Forced draft oven (preferred)
- Ventilated oven
- Convection oven
- Heat source, uncontrolled, for use when allowed by the agency, which will not alter the material being dried, and when close control of the temperature is not required:
  - Infrared heater/heat lamp, hot plate, fry pan, or any other device/method allowed by the agency
  - Microwave oven (900 watts minimum)
- Utensils such as spoons
- Hot pads or gloves

Sample Preparation

Obtain the sample in accordance with the FOP for AASHTO R 90 in its existing condition. If necessary, reduce the sample to moisture content sample size according to the FOP for AASHTO R 76.

For aggregate, the moisture content sample size is based on Table 1 or other information that may be specified by the agency.

15 **TABLE 1**

Sample Sizes for Moisture Content of Aggregate

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

* 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, the moisture content sample size is based on Table 2 or other information that may be supplied by the agency.

16 **TABLE 2**

Sample Sizes for Moisture Content of Soil

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

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

Procedure

Determine and record the sample masses as follows:

17

- 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.

18

1. Determine and record the mass of the container.
    a. For aggregate: the lid is optional unless drying with a microwave then a ventilated lid is required.
    b. For soils: the container includes the mass of the close-fitting lid.
2. Place the wet sample in the container.
3. Determine and record the total mass of the wet sample and container with lid, when used.
    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.
4. Subtract the container mass determined in Step 1 from the mass of the container and sample determined in Step 3 and record the wet mass of the sample (M_W).

Hotplate

19 20

5. Remove the lid, if used, and place the sample in one of the following drying apparatuses:

21

    a. For aggregate –
        i. Controlled heat source (oven): at 110 ±5°C (230 ±9°F).
        ii. Uncontrolled heat source (Hot plate, infrared heater, or other heat source as

allowed by the agency): 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 with lid, when used. 22
8. Subtract the container mass determined in Step 1 from the mass of the container and sample determined in Step 7 and record the mass of the sample.
9. 23 Return sample and container to the heat source for the additional time interval.
   a. Drying intervals for aggregate –
      i. Controlled heat source (oven): 30 minutes
      ii. Uncontrolled heat source (Hot plate, infrared heater, or other heat source as allowed by the agency): 10 minutes
      iii. Uncontrolled heat source (Microwave oven): 2 minutes

Caution: Some minerals in the sample may cause the aggregate to overheat, crack, and explode; altering the aggregate gradation.

Table 3
Methods of Drying 24

Aggregate		
Heat Source	**Specific Instructions**	**Drying intervals to achieve constant mass (minutes)**
Controlled:		
Forced draft (preferred), ventilated, or convection oven	110 ±5°C (230 ±9°F)	30
Uncontrolled:		
Hot plate, infrared heater, or any other device/method allowed by the agency	Stir frequently	10
Microwave	Heap sample and cover with ventilated lid	2

b. Drying interval for soil – controlled heat source (oven): 1 hour

Table 4
Method of Drying 25

Soil		
Heat Source	**Specific Instructions**	**Drying interval to achieve constant mass**
Controlled: Forced draft (preferred), ventilated, or convection oven	110 ±5°C (230 ±9°F)	1 hour

26 10. Determine mass of sample and container with lid, when used.

11. Subtract the container mass determined in Step 1 from the mass of the container and sample determined in Step 10 and record the mass of the sample.

27 12. Determine percent change by subtracting the new mass determination (M_n) from the previous mass determination (M_p), dividing by

the previous mass determination (M_p), and
28 multiplying 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 and container with lid, when used, to cool. Determine and record the total mass.

16. Subtract the mass of the container determined in Step 1 from the mass of the container and sample determined in Step 15 and record the dry mass of the sample (M_D).

17. Determine and record percent moisture (w) by
29 subtracting the final dry mass determination
30 (M_D) from the initial wet mass determination
(M_W), dividing by the final dry mass
determination (M_D), and multiplying by 100.

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

Constant Mass Example:

Mass of container: 1232.1 g 30
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 sample after second drying cycle: 2634.1 g
Mass, M_n, of 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 sample after third drying cycle: 2633.0 g
Mass, M_n, of sample: 2633.0 g - 1232.1 g = 1400.9 g

$$\% \, Change = \frac{1402.0\ g - 1400.9\ g}{1402.0\ g} \times 100 = 0.08\%$$ 31

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: 27

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

where:

w = moisture content, percent
M_W = wet mass
M_D = dry mass

Example: 32

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

$$w = \frac{1532.6\ g - 1401.4\ g}{1401.4\ g} \times 100 = \frac{131.2\ g}{1401.4\ g} \times 100 = 9.36\% \quad report\ 9.4\%$$

33

Report

- 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

34

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. Sample protected from moisture change?	_____	_____
3. Mass of container determined to 0.1 g?	_____	_____
a. For aggregate: the lid is optional unless drying with a microwave then a ventilated lid is required.		
b. For soils: the container includes the mass of the close-fitting lid.		
4. Sample placed in container, with lid if used, and mass determined to 0.1 g?	_____	_____
5. Wet sample mass recorded to 0.1 g?	_____	_____
6. Sample mass conforms to the required mass?	_____	_____
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, heated for at least 1 hour additional drying time using a controlled heat source?	_____	_____
12. Mass of sample and container, with lid if used, determined?		
13. Constant mass checked at drying intervals. Final interval showing less than 0.10 percent loss?	_____	_____

OVER

14. Sample cooled, dry mass and container, with lid if used, determined and recorded to the nearest 0.1 g? _____ _____
15. Moisture content calculated correctly and recorded to the nearest 0.1 percent? _____ _____

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

Significance

01

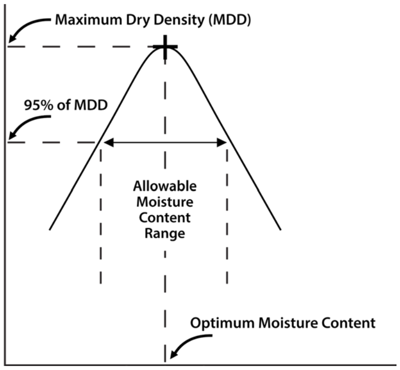
02 The density or degree of compaction, of soil or soil-
aggregate mixtures has a significant influence on
the stability and durability of roadways. Low
density subgrade, subbase, base, or embankment
will lead to excessive deflection under load or long-
term settlement in an amount higher than
03 anticipated,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

Steel roller

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
05 equipment. Equipment includes static and vibratory
06 rollers, smooth and sheepsfoot steel rollers, and
pneumatic tire rollers of varied weights yielding
many different compactive efforts.

Adding water

Density also depends upon moisture content. The
moisture content corresponding to maximum dry
07 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
08 decreases from this optimum value, the dry density
decreases.



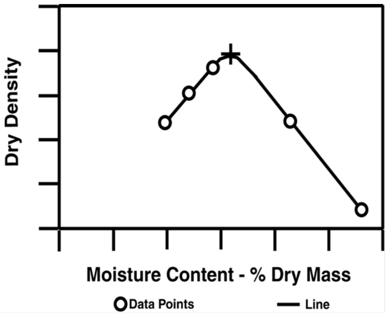
Moisture vs. dry density

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 99-25: Methods A, B, C, and D
- AASHTO T 180-25: Methods A, B, C, and D



Optimum water content

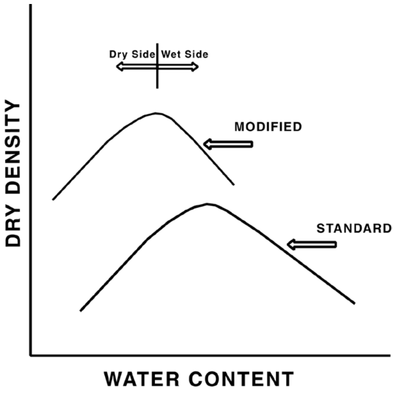
This test method applies to soil mixtures having 40 percent or less retained on the 4.75 mm (No. 4) sieve for methods A or B, or 30 percent or less on 10 the 19 mm (¾ in.) sieve with methods C or D. The retained material is defined as oversize (coarse) 11 material. If no minimum percentage is specified, 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.

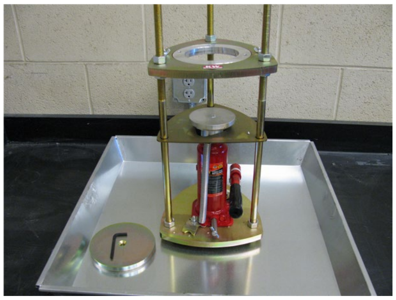
Apparatus

Molds and Rammer

- 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*.

Mechanical Rammer





Sample extruder

- Mold assembly – Mold, base plate, and a detachable collar.

- Rammer – Manually or mechanically operated rammers as detailed in Table 1 or Table 2. A
12 manually operated rammer shall be equipped
with a guide sleeve to control the path and
height of drop. The guide sleeve shall have at
13 least four vent holes no smaller than 9.5 mm
14 (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
15 calibration, see 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
16 (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 oven – 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 ±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 ±2	457 ±2
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 C: 5 (1)	Method B: 7 Method D: 11(1)
Energy, $kN\text{-}m/m^3$	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 ±0.06	18 ±0.06
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 Method C: 12(1) Method D: 25(1)	
Energy, lb-ft/ft^3	12,375	56,250

18

(1) This may not be a large enough sample depending on your nominal maximum size for moisture content samples. 19

Sieve / Mold	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
17 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
20 through the sieve required by the agency. See
21 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.

1. 22 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 at least 12 hrs.
3. 23 24 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.
   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.

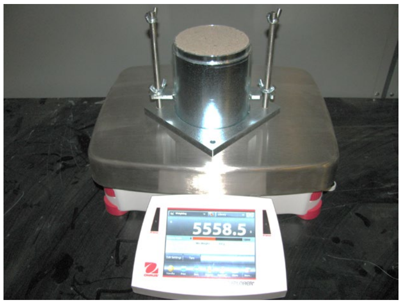
   c. Compact each layer with uniformly distributed blows from the rammer. See Table 1 for mold size, number of layers, number of blows, and rammer specification for the various test methods. Use the method specified by the agency.
   d. Trim down material that has not been compacted and remains adjacent to the walls

of the mold and extends above the compacted surface.

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.

Trimming

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.



Mass of mold and wet soil

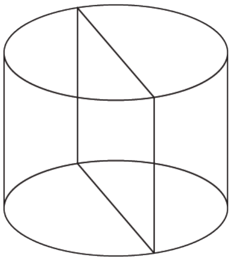
7. Determine the mass of the mold, base plate, and wet soil to the nearest 1 g (0.005 lb).
8. Determine the wet mass of the sample by subtracting the mass in Step 1 from the mass in Step 7.
9. Calculate the wet density (ρ_w), in kg/m^3 (lb/ft^3), by dividing the wet mass by the measured volume (V_m).

Extruding the material

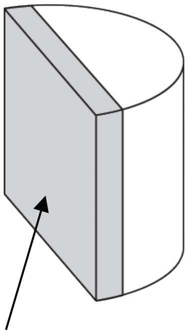
10. Extrude the material from the mold. For soils and soil-aggregate mixtures, slice vertically through the center and remove one of the cut faces for a representative moisture content sample. For granular materials, a vertical face will not exist. Take a representative sample ensuring that all layers are represented. 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 (w) 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

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

Where:

ρ_w = wet density, kg/m^3 (lb/ft^3)

M_w = wet mass

V_m = volume of the mold, Annex B

Dry Density

35

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

Where:

ρ_d = dry density, kg/m^3 (lb/ft^3)
w = moisture content, as a percentage

Example for 4-inch mold, Methods A or C

36

Wet mass, M_w = 1.928 kg (4.250 lb)
Moisture content, w = 11.3%
Measured volume of the mold, V_m = 0.000946 m^3 (0.0334 ft^3)

Wet Density

$$\rho_w = \frac{1.928\ kg}{0.000946\ m^3} = 2038\ kg/m^3 \quad \rho_w = \frac{4.250\ lb}{0.0334\ ft^3} = 127.2\ lb/ft^3$$ 37

Dry Density

38

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

Or

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

Moisture-Density Curve Development

39

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.

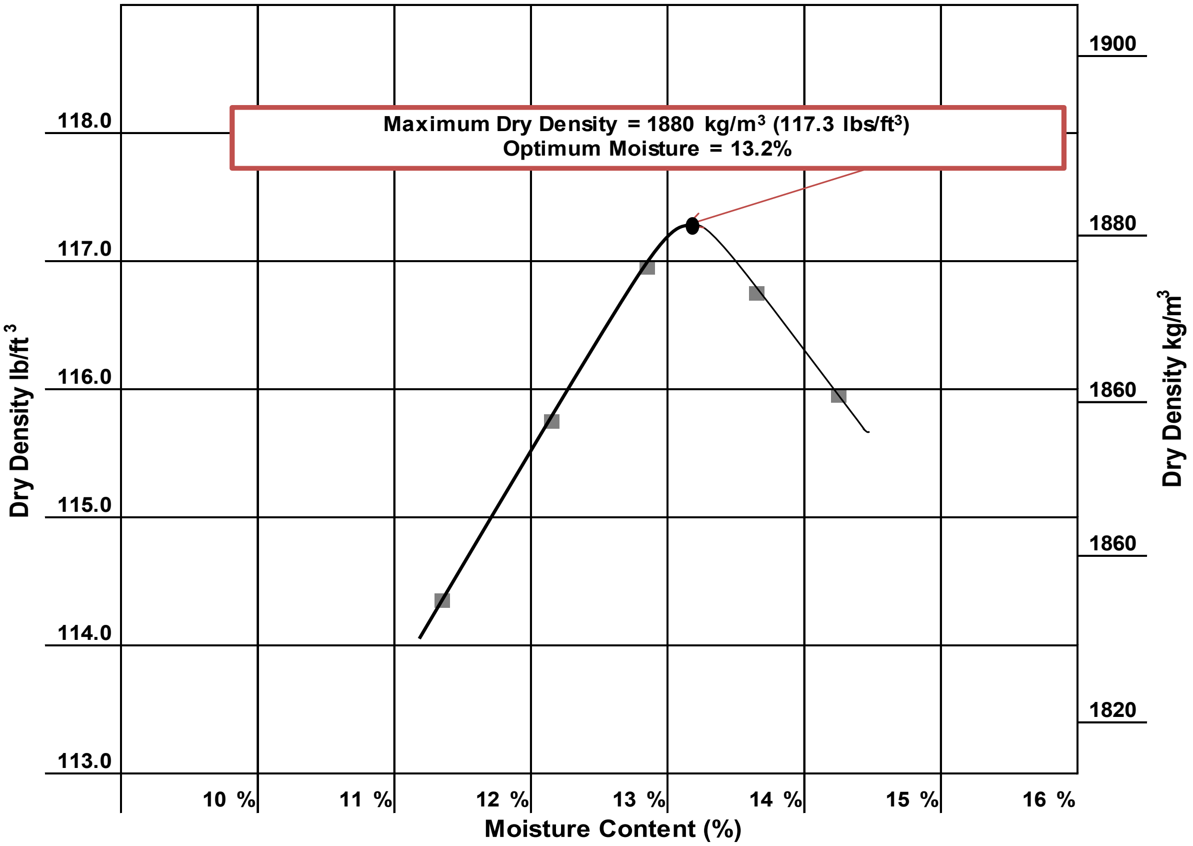
Example

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

- 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

(Mandatory Information)

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. 3

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. 4 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

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. 6

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

Procedure

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.

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

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.

$$\mathrm{P_f} = \frac{100 \times M_{DF}}{M_{DF} + M_{DC}} \qquad \frac{100\ \times 15.4\ lb}{15.4\ lbs + 5.7\ lb} = 73\% \qquad \frac{100\ \times 6.985\ kg}{6.985\ kg + 2.585\ kg} = 73\% \tag{10}$$

And

$$\mathrm{P_c} = \frac{100 \times M_{DC}}{M_{DF} + M_{DC}} \qquad \frac{100\ \times 5.7\ lb}{15.4\ lbs + 5.7\ lb} = 27\% \qquad \frac{100\ \times 2.585\ kg}{6.985\ kg + 2.585\ kg} = 27\% \tag{11}$$

Or for $\mathbf{P_c}$:

$$\mathrm{P_c} = 100 - \mathrm{P_f}$$

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:

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

$$MC_T = \frac{(10.6\% \times 73.0\%) + (2.1\% \times 27.0\%)}{100} = 8.3\%$$ 13

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 (ρ_d) of the total sample (combined fine and oversized particles) as follows:

$$\rho_d = \frac{100\%}{\left[\left(\frac{\mathrm{P_f}}{\boldsymbol{\rho_f}}\right) + \left(\frac{\mathrm{P_c}}{k}\right)\right]}$$

15

Where:

ρ_d = corrected total dry density (combined fine and oversized particles) kg/m^3 (lb/ft ^{3})

$\boldsymbol{\rho_f}$ = dry density of the fine particles kg/m^3 (lb/ft^3), determined in the lab

$\mathrm{P_c}$ = percent of dry oversize particles, of sieve used, by weight.

$\mathrm{P_f}$ = 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 ($\boldsymbol{\rho_f}$):	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

$$\rho_d = \frac{100\%}{\left[\left(\frac{P_f}{\boldsymbol{\rho_f}}\right) + \left(\frac{P_c}{k}\right)\right]}$$

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

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

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

- English:

Maximum laboratory dry density ($\boldsymbol{\rho_f}$):	117.3 lb/ft^3
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

$$\rho_d = \frac{100\%}{\left[\left(\frac{\mathrm{P_f}}{\boldsymbol{\rho_f}}\right) + \left(\frac{\mathrm{P_c}}{k}\right)\right]}$$

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

17

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

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

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

19

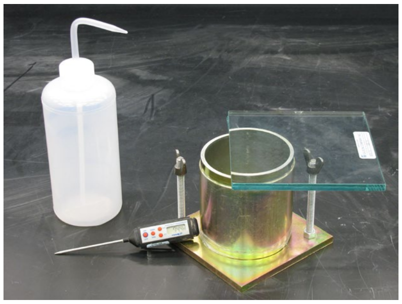
Report

- 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

21

ANNEX B
STANDARDIZATION OF THE MOLD

(Mandatory Information)



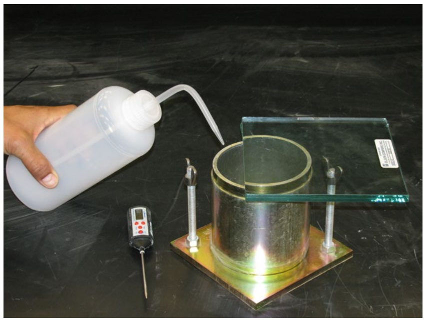
Apparatus

22 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

23

- Mold and base plate
- 24 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)



Filling the mold

Procedure

25 1. Create a watertight seal between the mold and base plate.

26

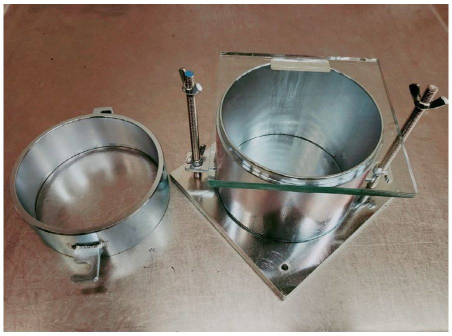
27 2. Determine and record the mass of the dry sealed mold, base plate, and cover plate.

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.

28 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.

29 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.



Dried filled mold

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

31

$$V_m = \frac{M}{\rho_{water}}$$

Where:

V_m = volume of the mold
M = mass of water in the mold
ρ_{water} = density of water at the measured temperature

Example

32

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

DEVELOPING SOIL MOISTURE-DENSITY RELATIONS(FAMILY OF CURVES) FOP FOR AASHTO R 75

01 Significance

Soils sampled from one source will have many
02 different moisture-density curves, but if a group of these curves is plotted together, similarities are usually seen. A group of soil moisture-density relations have 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
04 moisture-density relations using multiple moisture-density curves developed using the same method, A, B, C, or D from the FOP for AASHTO T 99/T 180 in accordance with AASHTO R 75-24.

All curves used in a group 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.

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

Methods of T 99 / T 180

05 Terminology

soil moisture-density relations **—** a group of soil moisture-density relation (commonly known as a family of 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 and optimum moisture content of a group 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
06 required per group.
2. Select the highest and lowest maximum dry densities from those selected to assist in

determining the desired scale of the subsequent graph.

07 3. Plot the maximum density and optimum moisture points of the selected curves on the graph.

08 4. Draw a smooth, "best fit," curved line through
09 the points creating the spine of the soil
moisture-density relations.

5. Remove maximum density and optimum
10 moisture points that were not used to establish
the spine.

11 6. Add the moisture-density curves associated with
the points that were used to establish the spine.
12 It is not necessary to include the portion of the
curves over optimum moisture.

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

16 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 group.

   b. Draw a smooth, "best fit," curved line connecting the 80 percent of optimum moisture points plotted on the curves that parallel the spine.

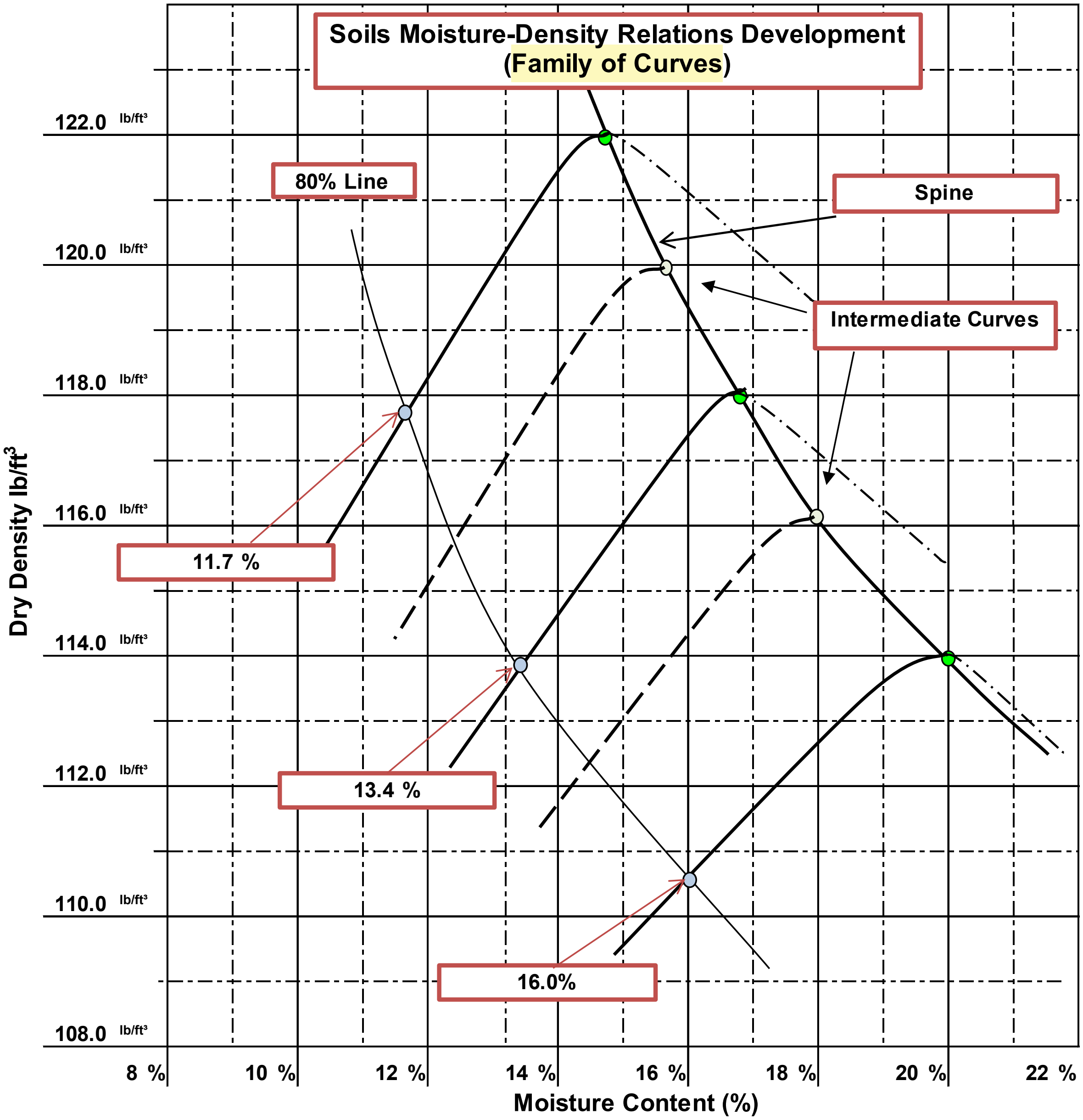
Calculations

Calculate 80 percent of optimum moisture of each curve: 17

Example:

Optimum moisture of the highest density curve = 14.6%

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


Soils Moisture-Density Relations Development
(Family of Curves)
80% Line
Spine
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!

19

- Make sure that the selected moisture-density relations 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?

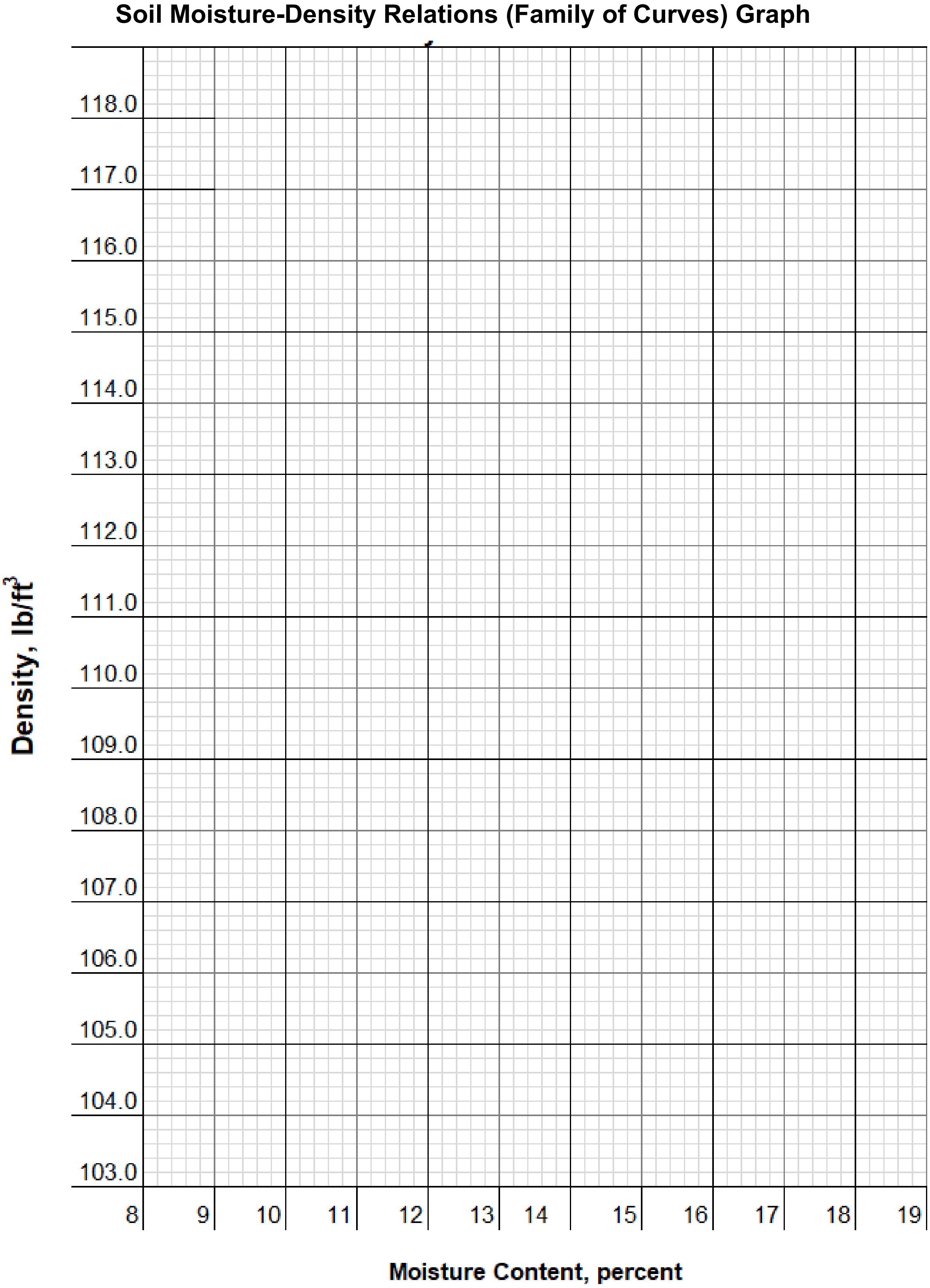
2. What does the 'spine' of the group mean?

3. Describe the limitations of developing moisture-density relations.

STEPS FOR DEVELOPING SOIL MOISTURE-DENSITY RELATIONS (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 group.
    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	111.2	112.4	113.6	114.0	113.5	111.4
T 180 A	10.4	10.9	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


Soil Moisture-Density Relations (Family of Curves) Graph
118.0
117.0
116.0
115.0
114.0
113.0
112.0
111.0
110.0
109.0
108.0
107.0
106.0
105.0
104.0
103.0
Density, lb/ft³
8
9
10
11
12
13
14
15
16
17
18
19
Moisture Content, percent

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 are usually seen. A soil density-relations is a group of soil moisture-density curves 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 soil moisture-density relations group.

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 FOPs 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 soil density-relations group (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 develop the soil density-relations. 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 for the one-point determination.

Apparatus

06 See the FOP for AASHTO T 99/T 180 for full apparatus requirements.

Field Selection of Apparatus – English

	Method used to compact Individual Curve or Group of Curves							
	T 99				T 180			
Method	A	B	C	D	A	B	C	D
Material Size (Passing Sieve)	No. 4	¾ in.	No. 4	¾ in.	No. 4	¾ in.	No. 4	¾ in.
Nominal Mold Diameter	4 in.	6 in.	4 in.	6 in.	4 in.	6 in.	4 in.	6 in.
Nominal Rammer Mass	5.5 lb.				10 lb.			
Rammer Drop	12 in.				18 in.			
Layers	3				5			
Blows per Layer	25	56	25	56	25	56	25	56

Sample

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

07

1. 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).
2. Thoroughly break up aggregations in a manner that avoids reducing the natural size of individual particles.
3. Pass the material through the appropriate sieve.

08

Procedure

Use the method matching the individual curve or soil density-relations group. Refer to Table 1 of the FOP for AASHTO T 99/T 180 for corresponding mold size, number of layers, number of blows, sieve size, and rammer specification for the various test methods.

Dense, uniform, rigid foundation

09

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.

Trim soil

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.

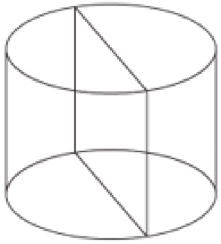
10

5. Trim the compacted soil even with the top of the mold with the beveled side of the straightedge.

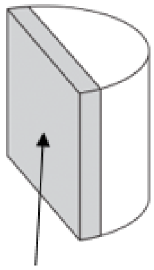
11

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).

Mass of mold and wet sample



Extruded material



Representative moisture Content Sample

8. Determine the wet mass of the sample by subtracting the mass in Step 1 from the mass in Step 7. 12
9. Calculate the wet density (ρ_w) as indicated below under "Calculations."
10. Extrude the material from the mold. For soils 13
    and soil-aggregate mixtures, slice vertically
    through the center and remove one of the cut 14
    faces for a representative moisture content
    sample. For granular materials, a vertical face
    will not exist. Take a representative sample
    ensuring that all layers are represented. This 15
    sample must meet the sample size requirements
    of the test method used to determine moisture 1+
    content.
11. Determine the moisture content (w) of the
    sample in accordance with the FOP for 17
    AASHTO T 255 / T 265.

Calculations

Wet Density 18

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

Where:

ρ_w = wet density, kg/m^3 (lb/ft^3)

M_w = wet mass

V_m = volume of the mold, (FOP for AASHTO T 99/T 180)

Dry Density

$$\rho_d = \left(\frac{\rho_w}{w + 100}\right) \times 100 \quad or \quad \rho_d = \frac{\rho_w}{\left(\frac{w}{100}\right) + 1}$$ 19

Where:

ρ_d = dry density, kg/m^3 (lb/ft^3)

w = moisture content, as a percentage

Example for 4-inch mold, Methods A or C 20

Wet mass, M_w = 2.0055 kg (4.42 lb)

Moisture content, w = 13.5%

Measured volume of the mold, V_m = 0.0009469 m^3 (0.0334 ft^3)

Wet Density

21

$$\rho_w = \frac{2.0055\ kg}{0.0009469\ m^3} = 2118\ kg/m^3 \quad \rho_w = \frac{4.42\ lb}{0.0334\ ft^3} = 132.2\ lb/ft^3$$

Dry Density

22

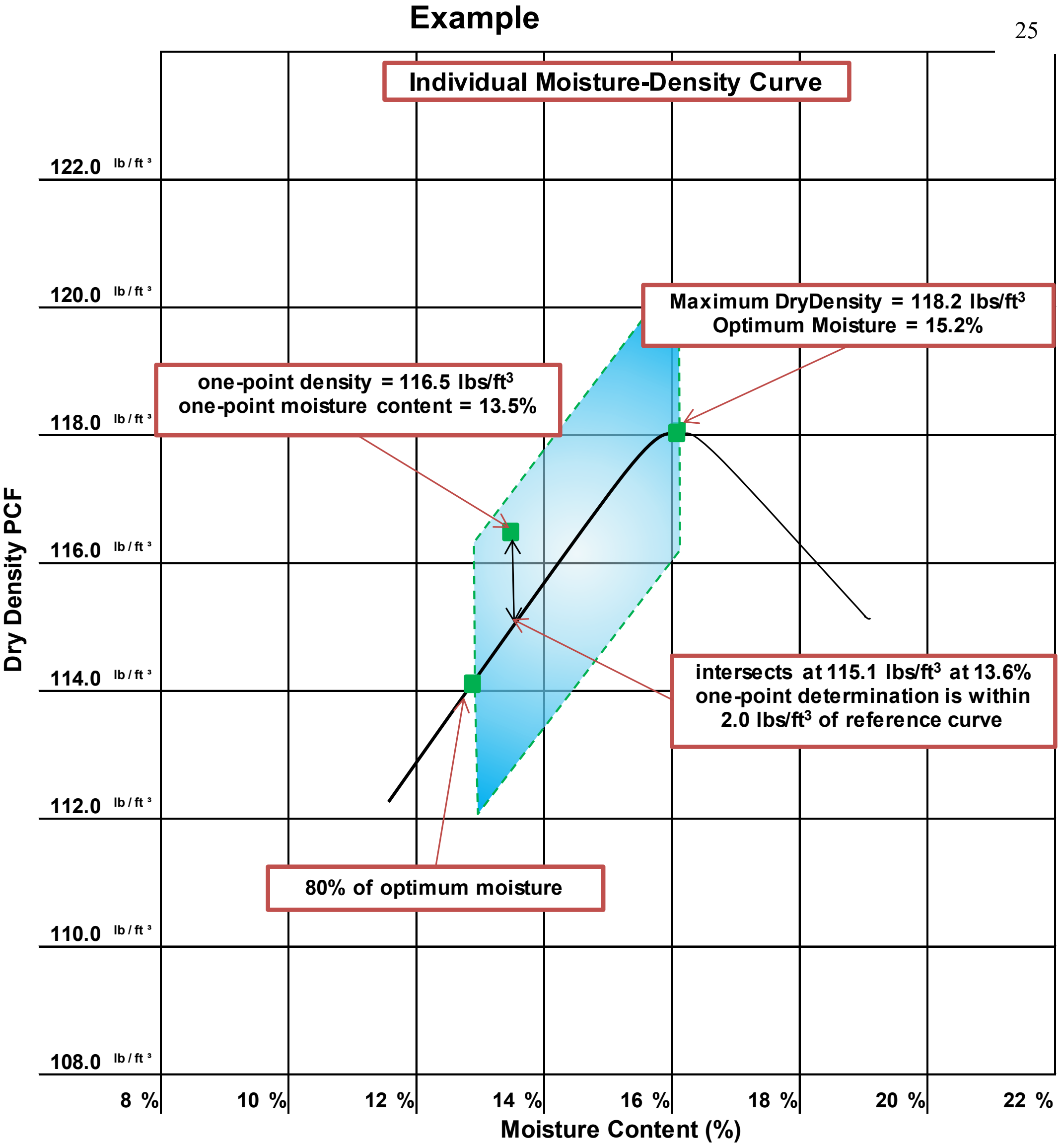
$$\rho_d = \left(\frac{2118\ kg/m^3}{13.5 + 100}\right) \times 100 = 1866\ kg/m^3 \quad \rho_d = \left(\frac{132.2\ lb/ft^3}{13.5 + 100}\right) \times 100 = 116.5\ lb/ft^3$$

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 range of the reference curve.
   a. If the moisture content of the one-point does not fall within the range, adjust the moisture content. 23
   b. Compact another one-point specimen using the moisture adjusted sample.
2. Plot the one-point, dry density on the vertical axis and moisture content on the horizontal axis, on the reference curve graph. 24
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.
4. 26 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 lb/ft^3 of the reference curve at 80 to 100 percent optimum moisture.



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 Soil Moisture-Density Relations

27 1. Plot the one-point, dry density on the vertical axis and moisture content on the horizontal axis, on the reference soil density-relations graph.

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

28 3. If the moisture-density one-point falls within the soil density-relations 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 soil density-relations. Use the maximum dry density and optimum moisture content as defined by the new curve.

    29 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.

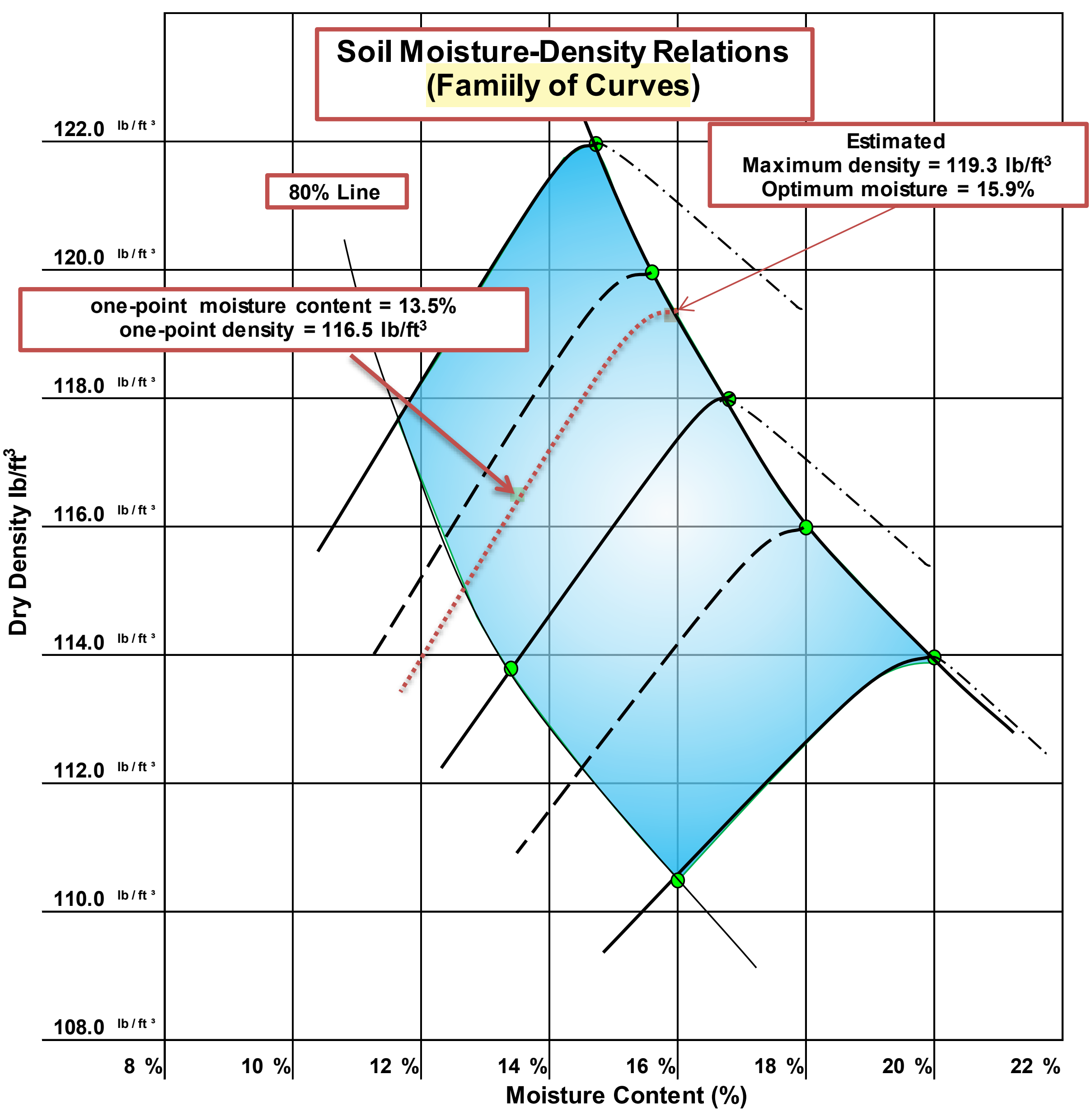
    b. If the one-point plotted within or on the soil density-relations group does not fall in the 80 to 100 percent of optimum moisture content, compact another specimen, using the same material, at an adjusted moisture content that will place the one-point within this range.

30 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 soil density-relations.

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

Example


Soil Moisture-Density Relations (Famiily of Curves)

Estimated
Maximum density = 119.3 lb/ft^3
Optimum moisture = 15.9%

80% Line

one-point moisture content = 13.5%
one-point density = 116.5 lb/ft^3

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 group 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.

32

Report

- 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 Soil Moisture-Density Relations used

33

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 soil moisture-density relations shall be developed 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 soils moisture density relations graph (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 (0.005 lb.)?	_____	_____
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 soils moisture-density relations group 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_____

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 (0.005 lb.)?	_____	_____
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 soils moisture-density relations group 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_____

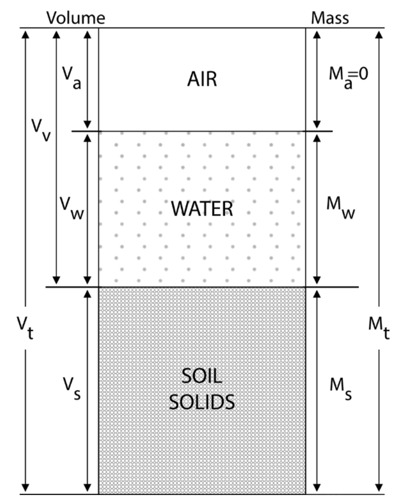
____

____

____

Examiner Signature ________________________________WAQTC #:_____________

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



Phase diagram

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, asphalt mixtures, 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.

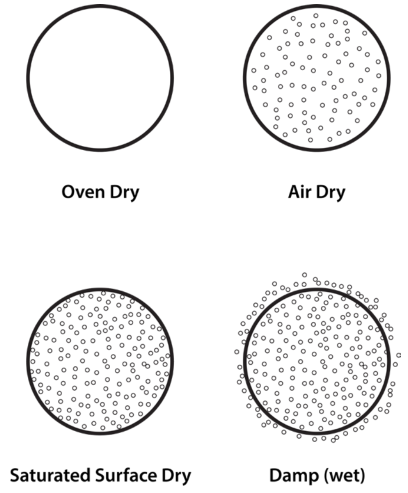
Bulk specific gravity (oven dry), G_{sb}, is used for computations when the aggregate is dry. Bulk specific gravity (saturated surface dry or SSD), G_{sb} SSD, is used if the aggregate is wet. Apparent specific gravity, G_{sa}, is based solely on the solid material making up the constituent particles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

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-hour-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 85-25. Specific
04 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

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

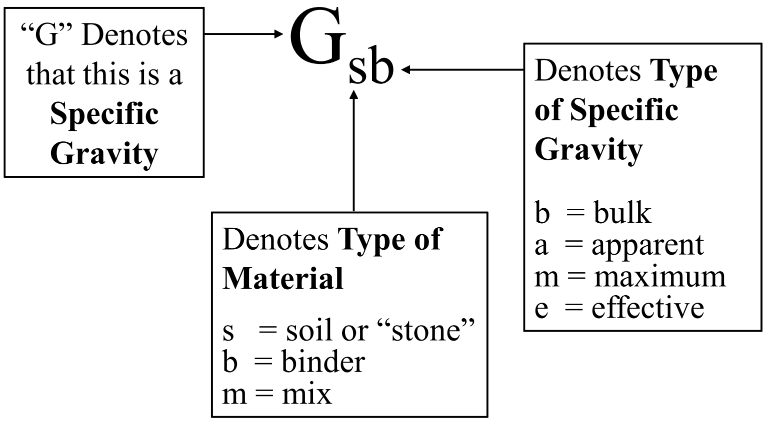
Specific Gravity – the ratio of the mass, in air, of a volume of a material to the mass of the same volume of gas-free distilled water at a stated temperature.

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)



G_{sb}

"G" Denotes that this is a **Specific Gravity**

Denotes **Type of Specific Gravity**

b = bulk
a = apparent
m = maximum
e = effective

Denotes **Type of Material**

s = soil or "stone"
b = binder
m = mix

8

Sample container and scale

Apparatus

- Balance or scale: with a capacity of 5 kg, sensitive to 0.1 g, and meeting the requirements of AASHTO M 231. 09
- 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. 10
- 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 cloth

Sample Preparation

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

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 the sample to remove dust or other coatings from the surface.

12

5. Dry the sample to constant mass according to the FOP for AASHTO T 255/T 265 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).

13

Table 1

Nominal Maximum Size*, mm (in.)	Minimum Mass of 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 sample in water at room temperature for a period of 15 to 19 hours.

14 *Note 3:* When testing coarse aggregate of large nominal maximum size requiring large 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 and basket is fully submerged. Tare the balance with the empty basket attached in the water bath.

SSD Sample

15

3. Remove the 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 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 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 and basket is fully submerged. Designate this submerged weight as "C."

Note 5: The container should be immersed to a depth sufficient to cover both it and the 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 sample to constant mass according to the FOP for AASHTO T 255/T 265 at 110 ±5°C (230 ±9°F) and cool in air at room temperature for 1 to 3 hours.

8. Determine and record the dry mass. Designate this mass as "A."

Calculations

Perform calculations and determine values using the appropriate formula below.

Bulk specific gravity (G_{sb})

$$G_{sb} = \frac{A}{B - C} \tag{18}$$

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

$$G_{sb}SSD = \frac{B}{B - C} \tag{19}$$

Apparent specific gravity (G_{sa})

$$G_{sa} = \frac{A}{A - C} \tag{20}$$

Absorption

$$\text{Absorption} = \frac{B - A}{A} \times 100 \tag{21}$$

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

- 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?

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

FOP FOR AASHTO T 310

Checking deflection

Caution!

Gauge, transport case and instruction manual

01 Significance

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

Performance of this test method in trenches and near structures requires a trench offset correction.

The nondestructive nature of the test allows
04 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 310-22. This procedure provides
05 a rapid, nondestructive technique for determining
06 the in-place wet density and moisture content of
soil, aggregate, and soil-aggregate mixes. 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
07 testing in direct transmission mode.
- Transport case for properly shipping and
08 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
  - 09 Factory and Laboratory Calibration Data Sheet
  - Leak Test Certificate
  - Shippers Declaration for Dangerous Goods
  - 10 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 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 11 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

12 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.

Standardizing the nuclear density gauge

13 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
14 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 density 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.
    d) Correct for trench wall effect according to manufacturer's correction procedures if the test site is closer than 600 mm (24 in.) to vertical projection. See Note 2.

Note 2: To perform moisture and density tests in a trench or against a large solid object, it is necessary to perform a trench moisture correction to adjust the gauge or it may read a falsely high moisture content. Moisture present in the walls can thermalize neutrons which return to the gauge and are read as moisture by the detector in the gauge.

2. Remove all loose and disturbed material and remove additional material as necessary to expose the top of the material to be tested.

Prepared area

17

3. Prepare a flat area sufficient in size to accommodate the gauge. Plane the area to a smooth condition 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.

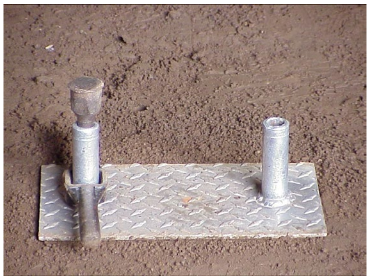
18

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.).

Filling surface voids

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 source rod depth and shall be aligned so that insertion of the source rod 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.

19



Guide plate and drive pin

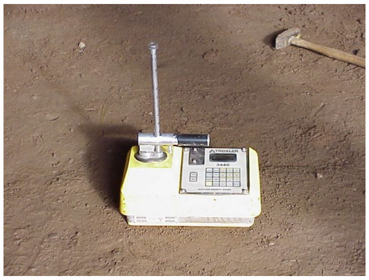
6. Place the gauge on the prepared surface so the source rod can enter the hole without disturbing loose material.
7. Lower the source rod into the hole to the desired test depth using the handle and trigger mechanism.
8. Seat the gauge firmly by partially rotating it back and forth about the source 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. 22 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.



Taking a reading

11. If required by the agency, obtain a representative sample of the material, 4 kg 24 (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

Representative sample site

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
25 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
26 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.

Percent Compaction

29

- 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, WAQTC TM 15, or WFLHD's Humphres.

  See appropriate agency policies for use of density standards.

Calculation

Calculate the dry density as follows:

$$\rho_d = \left(\frac{\rho_w}{w+100}\right) \times 100 \quad or \quad \rho_d = \frac{\rho_w}{\frac{w}{100}+1}$$ 27

Where:

ρ_d = Dry density, kg/m^3 (lb/ft^3)

ρ_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:

ρ_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: 30

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% 31

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: 32

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

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

Given:

ρ_w = 1963 kg/m^3 or 122.5 lb/ft^3
w = 15.9%

Calculate percent compaction as follows: 33

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

Given:

Agency density standard = 111.3 lb/ft^3

Report

34
- 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 35
- 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

Tips!

- Check to make sure that:
  - 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.
  - 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. When is a trench offset correction required?

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

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

6. 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 source rod depth?	_____	_____
9. Gauge 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

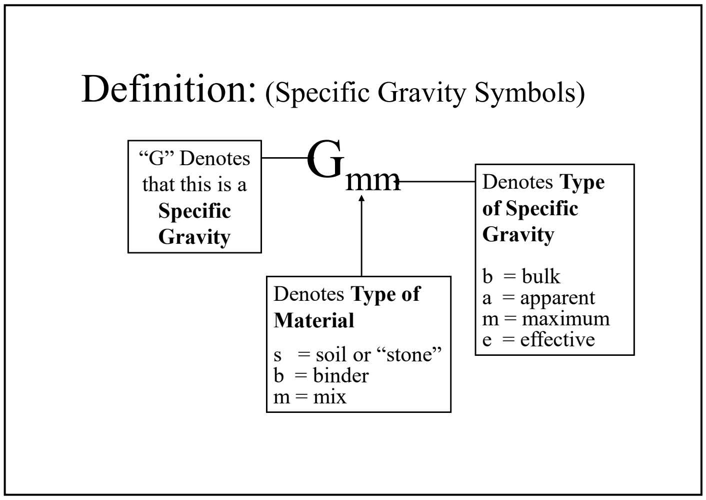
Significance

Maximum specific gravity (G_{mm}) is the ratio of the
01 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.
G_{mm} is used in conjunction with bulk specific gravity
to determine in-place density and percent air voids or
02 both in compacted asphalt mixture. Percentage of air
voids, V_a, is significant because durability
characteristics of asphalt mixture are influenced by
the number of voids in the compacted material.

Scope

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

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



04

05 Apparatus

- Balance or scale: 10,000 g capacity, readable to 0.1 g, meeting AASHTO M 231, Class G2
- 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 full vacuum applied
- Pycnometer / volumetric flask cover: A glass plate or a metal or plastic cover with a vented opening 06
- 07 Vacuum lid: A transparent lid with a suitable vacuum connection. The 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 3.4 kPa (25 mm Hg)
- Vacuum measurement device: Residual pressure manometer or vacuum gauge capable of measuring residual pressure down to 3.4 kPa (25 mm Hg) or less and readable to at least 0.2 kPa (2 mm Hg)
- Suspension apparatus: Suitable apparatus and holder to permit determining the mass of the sample while suspended below the balance. The wire suspending the holder shall be the smallest practical size to minimize any possible effects of a variable immersed length for Bowl Method.
- Water bath: A constant-temperature water bath (optional for Pycnometer or Volumetric Flask Method)

Note 1: The water bath may be equipped with a circulator and heater or chiller to maintain constant temperatures throughout the bath. If a circulator is used, turn it off before any masses are recorded.

- Thermometer: An immersion thermometer readable to at least 0.5°C (1°F) and with a temperature range of at least 20 to 45°C (68 to 113°F).

- Bleeder valve to adjust vacuum
- Automatic vacuum control unit (optional)
- Timer
- Towel

08 Standardization

Use a container that has been standardized according to the Annex. Record the standardized container mass for use in subsequent calculations.

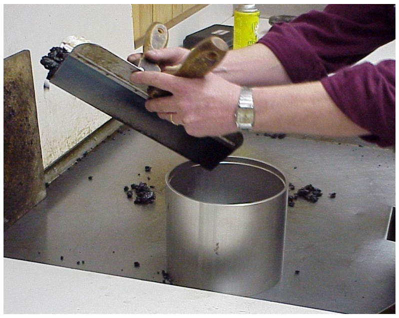
The container shall be standardized periodically in conformance with procedures established by the agency.

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 by calculating the weighted average ($G_{mm\ (avg)}$.). If the increments have a specific gravity difference greater than 0.013, the test must be re-run.
3. Plant-produced samples may be short-term conditioned according to AASHTO R 30 as specified by the agency.

Note 2: Short-term conditioning at the specified temperature is especially important when absorptive aggregates are used. This short-term conditioning will ensure the computation of realistic values for the amount of asphalt absorbed by the aggregate and void properties of the mix. Plant-produced asphalt mixtures should be evaluated to make sure short-term conditioning has taken place during production and delivery.

Separating particles



Placing sample in the flask

Determining mass

Manually agitating container

10

12

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.

Procure – General

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

14

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 (do not exceed Job Mix Formula (JMF) compaction temperature) until it is pliable enough for separation.
2. Cool the sample to room temperature. 13
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 container and sample to the nearest 0.1 g. 15
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.” 16
7. Add sufficient water at approximately 25°C (77°F) to cover the sample by about 25 mm (1 in).

Note 3: 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.

Mechanically agitating container

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.

17 9. Remove entrapped air by subjecting the sample
18 to a partial vacuum of 4.0 ±0.6 kPa
(30 ±5 mm Hg) residual pressure for
15 ±1 minutes.

10. Agitate the container and sample, 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.

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. Immerse the suspension apparatus sufficiently to cover both it and the bowl.

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

Determining temperature

21 15A. Determine and record the submerged weight
23 of the bowl and sample to the nearest 0.1 g.
Designate as "C."

Procedure – Pycnometer or Volumetric Flask

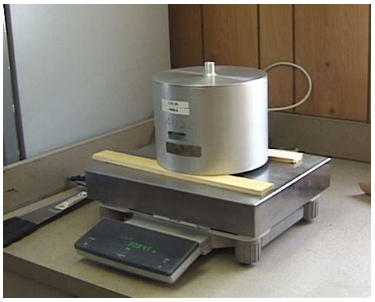
22 Complete steps 12B through 16B within 10 ±1 min.

Eliminating air

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

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

25 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 mass

26 ***Note 4:*** 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
27 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
28 sealed by an asphalt binder film, they may become
saturated with water during the vacuuming
procedure, resulting in an error in G_{mm} and
theoretical 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. 29
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

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

(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

B = standardized submerged weight of the bowl, g (see Annex)

C = submerged weight of sample and bowl in water, g

Example 31

$$G_{mm} = \frac{1432.7\ g}{1432.7\ g + 286.3\ g - 1134.9\ g} = 2.453 \qquad or$$

$$G_{mm} = \frac{1432.7\ g}{1434.2\ g + 286.3\ g - 1134.9\ g} = 2.447$$

Given:

A = 1432.7 g

A_{SSD} = 1434.2 g

B = 286.3 g

C = 1134.9 g

Pycnometer / Volumetric Flask Procedure 32

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

(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 = standardized mass of pycnometer / volumetric flask filled with water at 25°C (77°F), g, (See Annex)

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

Example (two increments of a large sample): 33

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

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

Given:

Increment 1	Increment 2
$A_1 = 2200.3$ g	$A_2 = 1960.2$ g
$D_1 = 7502.5$ g	$D_2 = 7525.5$ g
$E_1 = 8812.0$ g	$E_2 = 8690.8$ g

Variation = 2.470 - 2.466 = 0.004, which is < 0.013

Allowable variation is: 0.013. The values may be used.

Weighted average 34

For large samples tested a portion at a time, calculate the $G_{mm\,(avg)}$ by multiplying the dry mass of each increment by its G_{mm}, add the results together (Σ) and divide by the sum (Σ) of the dry masses.

$$G_{mm(avg)} = \frac{\sum\left(A_x \times G_{mm_x}\right)}{\sum A_x}$$

or

$$G_{mm(avg)} = \frac{\left(A_1 \times G_{mm_1}\right) + \left(A_2 \times G_{mm_2}\right)}{A_1 + A_2}\ etc.$$

Where:

A_x = mass of dry sample increment in air, g

G_{mmx} = theoretical maximum specific gravity of the increment

Example: 35

$$G_{mm(avg)} = \frac{(2200.3\ g \times 2.470) + (1960.2\ g \times 2.466)}{2200.3\ g + 1960.2\ g} = \frac{10{,}268.6}{4160.5\ g} = 2.468$$

Theoretical Maximum Density 36

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 kg/ m^3 in Metric units or 62.245 lb/ft^3 in English units.

Theoretical maximum density kg/m^3 = G_{mm} × 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} × 62.245 lb/ft^3

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

37 Report

- 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! 38

- Use a standardized container.
- Check for absorption in uncoated aggregate.

A1

ANNEX – STANDARDIZATION OF BOWL AND PYCNOMETER OR VOLUMETRIC FLASK

(Mandatory Information)

A2

Bowl – Standardization

1. Fill the water bath to overflow level with 25 ±1°C (77 ±2°F) water and allow the water to stabilize.
2. 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. Immerse the suspension apparatus sufficiently to cover both it and the bowl.
3. Suspend and completely immerse the bowl for 10 ±1 minute.
4. Determine and record the submerged weight of the bowl to the nearest 0.1 g.

A3

5. Refill the water bath to overflow level.
6. Perform Steps 2 through 5 two more times for a total of three determinations.
7. If the range of the three determinations is less than or equal to 0.3 g., average the determinations. Designate as "B."
8. If the range of the three determinations is greater than 0.3 g., take corrective action and perform the standardization procedure again.

A4

Bowl – Check

1. Fill the water bath to overflow level 25 ±1°C (77 ±2°F) water and allow the water to stabilize.
2. 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. Immerse the suspension apparatus sufficiently to cover both it and the bowl.
3. Suspend and completely immerse the bowl for 10 ±1 minute.
4. Determine and record the submerged weight of the bowl to the nearest 0.1 g.

A5

5. If this determination is within 0.3 g of the standardized value, use the standardized value for “B.”
6. If it is not within 0.3 g, take corrective action and perform the standardization procedure again.
7. A6 For labs that check the bowl standardization frequently (such as daily), calculate the moving average and range of the last three mass determinations. Designate the average of the last three masses as “B.”
8. If the moving range exceeds 0.3 g at any time, take corrective action and perform the standardization procedure again.

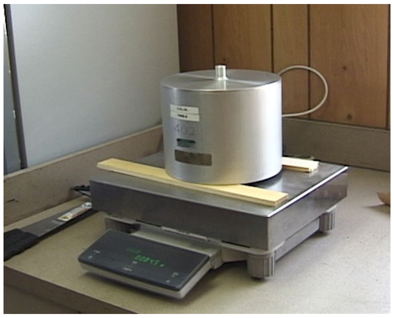
A7 Pycnometer or Volumetric Flask – Standardization

Determining temperature

1. A8 Fill the pycnometer / volumetric flask with water at approximately 25°C (77°F).
2. Place the metal or plastic cover, or a glass plate on the pycnometer / volumetric flask and eliminate all air. (See Note 4.) A9

Remove all the air

3. Stabilize the pycnometer / volumetric flask at 25 ± 1ºC (77 ± 2ºF) for 10 ± 1 min. A10
4. Towel dry the outside of the pycnometer / volumetric flask and cover to the nearest 0.1 g.
5. Determine and record the mass of the pycnometer / volumetric flask, water, and cover or plate.
6. A11 Perform Steps 2 through 5 two more times for a total of three determinations.
7. If the range of the three determinations is less than or equal to 0.3 g, average the three determinations. Designate as “D.” A12
8. If the range of the determinations is greater than 0.3 g, take corrective action and perform the “Pycnometer or Volumetric Flask – Standardization” again.



Determining mass

Pycnometer or Volumetric Flask – Check

A13 1. Fill the pycnometer / volumetric flask with water at approximately 25°C (77°F).
2. Place the metal or plastic cover or a glass plate on the pycnometer / volumetric flask and eliminate all air. (See Note 4.)
3. Stabilize the pycnometer / volumetric flask at 25 ± 1ºC (77 ± 2ºF) for 10 ± 1 min.
4. Towel dry the outside of the pycnometer / volumetric flask and cover.

A14 5. Determine and record the mass of the pycnometer / volumetric flask, water, and cover or plate.
6. If this determination is within 0.3 g of the standardized value, use the standardized value for “D.”
7. If it is not within 0.3 g, perform the standardization procedure again.

REVIEW QUESTIONS

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

2. Describe the standardization procedure for:

   Bowl

   Pycnometer / Volumetric Flask

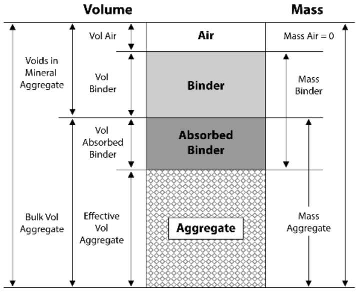
3. At what temperature should the sample be for testing?

4. Removing entrapped air from the container and sample by a partial vacuum is done for how long?

5. How and why is the container and sample agitated?

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

Asphalt mixture core



Asphalt mixture phase diagram

01 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
02 connect to the surface and can fill with water.
They may also be impermeable and, thus, filled
only with air.

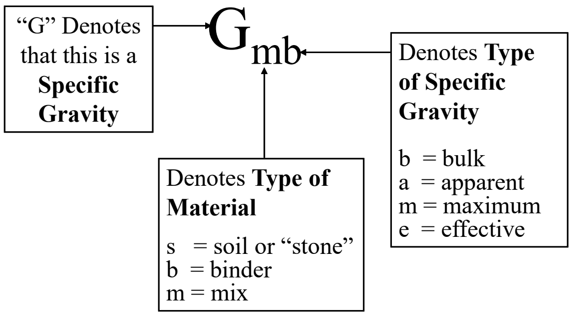
Because voids exist and contain air or water, the overall, or bulk, density of the compacted mix is less than the density of a theoretical mix of aggregate and binder having no voids. Thus, bulk density and associated bulk specific gravity are indications of void and air content – both of which impact 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
04 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

This procedure covers the determination of bulk
03 specific gravity (G_{mb}) of compacted asphalt
05 mixtures using three methods – A, B, and C – in
accordance with AASHTO T 166-24. 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

- Method A: Suspension
- Method B: Volumeter
- 07 Method C: Rapid Test

Test Specimens

Test specimens may be either laboratory-molded or sampled from asphalt mixture pavement. For specimens it is recommended that the diameter be 08 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.

Terminology

Constant mass: The state at which a mass does not 09 change more than a given percent, after additional drying for a defined time interval, at a required temperature.

Apparatus – Method A (Suspension)

Suspension apparatus

- 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.
- Potable water: Water that is suitable for drinking. 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

Note 1: The water bath may be equipped with a circulator and heater or chiller to maintain constant temperatures throughout the bath. If a circulator is used, turn it off before any masses are recorded.

- Towel: Damp cloth towel used for surface drying specimens.
- Oven: Capable of maintaining a temperature of 52 ± 3°C (126 ± 5°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 15 to 45°C (59 to 113°F), graduated in 0.1°C (0.2°F) subdivisions.
- Vacuum device: refer to the FOP for AASHTO R 79 (optional)

12

Procedure – Method A (Suspension)

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

1. Dry the specimen to constant mass, if required.
    a. 13 Oven method
        i. Initially dry overnight at 52 ±3°C (126 ±5°F).

        ii. Determine and record the mass of the specimen. Designate this mass as M_p.
        iii. Return the specimen to the oven for at least 2 hours.
        iv. Determine and record the mass of the specimen. Designate this mass as M_n.
        v. Determine percent change by subtracting the new mass determination, M_n, from the previous mass determination, M_p, dividing by the previous mass determination, M_p, and multiplying 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; specimen is defined as dry.

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

    b. Vacuum dry method according to the FOP for AASHTO R 79.

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 ±2°F) and allow the water to stabilize.
4. Zero or tare the balance with the suspension apparatus attached, ensuring that the suspension apparatus is completely submerged and not touching the sides or the bottom of the water bath.

Submerged specimen

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 min.
6. Determine and record the submerged weight to the nearest 0.1 g. Designate this submerged weight as C.

7. Remove the specimen from the water and quickly surface dry with a damp cloth towel within 5 sec.
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 exceed 15 sec. 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 at 25 ±1°C (77 ±2°F), g

Example:

20

$$G_{mb} = \frac{4833.6\ g}{4842.4\ g - 2881.3\ g} = 2.465$$

$$\%\ Water\ Absorbed\ (by\ volume) = \frac{4842.4\ g - 4833.6\ g}{4842.4\ g - 2881.3\ g} \times 100 = 0.45\%$$

Given:

A = 4833.6 g

B = 4842.4 g

C = 2881.3 g

Apparatus – Method B (Volumeter)

- 21 Balance or scale: 5 kg capacity, readable to 0.1 g and conforming to AASHTO M 231.
- Potable water: Water that is suitable for drinking.
- Water bath: For immersing the specimen in water, capable of maintaining a uniform temperature at 25 ± 1°C (77 ± 2°F). Use potable water to fill the water bath. The water in the 22 bath does not need to maintain a potable condition but must remain clear at all times.
- Thermometer: Range of 15 to 45°C (59 to 113°F) and graduated in 0.1°C (0.2°F) subdivisions.
- Distilled water: Clear, distilled water for filling the volumeter.
- Volumeter: Calibrated to 1200 mL or appropriate capacity for specimen and having a tapered lid with a capillary bore.
- Oven: Capable of maintaining a temperature of 52 ± 3°C (126 ± 5°F) for drying the specimens to a constant mass.
- Pan: Pan or other suitable container of known mass, large enough to hold a specimen for drying in oven.

- Towel: Damp cloth towel used for surface drying specimens.
- Vacuum device: refer to the FOP for AASHTO R 79 (optional)

23 Procedure – Method B (Volumeter)

Method B is not acceptable for use with specimens that have more than 6 percent air voids.

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

24 1. Dry the specimen to constant mass, if required.
    a. Oven method
        i. Initially dry overnight at 52 ±3°C (126 ±5°F).
        ii. Determine and record the mass of the specimen. Designate this mass as M_p.
        iii. Return the specimen to the oven for at least 2 hours.
        iv. Determine and record the mass of the specimen. Designate this mass as M_n.
        v. Determine percent change by subtracting the new mass determination, M_n, from the previous mass determination, M_p, dividing by the previous mass determination, M_p, and multiplying 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; specimen is defined as dry.

***Note* 3**: To expedite the procedure, steps 1 and 2 may be performed last. To further expedite the process, see Method C.

25 b. Vacuum dry according to the FOP for AASHTO R 79.

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.

Surface drying

3. Immerse the specimen in the temperature-controlled water bath at 25 ±1°C (77 ±2°F) for at least 10 minutes.
4. At the end of the ten-minute period, fill the volumeter with distilled water at 25 ±1°C (77 ±2°F), making sure some water escapes through the capillary bore of the tapered lid.
5. Wipe the volumeter dry and determine the mass of the volumeter and water to the nearest 0.1 g. Designate this mass as D.
6. Remove the specimen from the water bath and quickly surface dry with a damp towel within 5 sec.

Determining mass of SSD specimen

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 sec.
9. Bring the temperature of the water to 25 ±1°C (77 ±2°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, water, and specimen to the nearest 0.1 g. Designate this mass as E.

Calculations – Method B (Volumeter) 34

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:

35

$$G_{mb} = \frac{A}{B + D - E}$$

$$Percent\ Water\ Absorbed\ (by\ volume) = \frac{B - A}{B + D - E} \times 100$$

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 ±2°F), g

E = Mass of volumeter filled with specimen and water, g

Example: 36

$$G_{mb} = \frac{4833.6\ g}{4842.4\ g + 2924.4\ g - 5806.0\ g} = 2.465$$

$$\%\ Water\ Absorbed\ (by\ volume) = \frac{4842.4\ g - 4833.6\ g}{4842.4\ g + 2944.4\ g - 5806.0\ g} \times 100 = 0.45\%$$

Given:

A = 4833.6 g

B = 4842.4 g

D = 2924.4 g

E = 5806.0 g

37

Apparatus – Method C (Rapid Test)

- Oven: Capable of maintaining a temperature of 110 ±5°C (230 ±9°F) for drying the specimens to a constant mass.

See Methods A or B.

Note 4: 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)

38

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.

39

4. Place in an oven at 110 ±5°C (230 ±9°F).

5. Dry until the specimen can be easily separated into fine aggregate particles that are not larger than 6.3 mm (¼ in.). 40
6. Determine and record the mass of the specimen. Designate this mass as M_p.
7. Return the specimen to the oven for at least 2 hours.
8. Determine and record the mass of the specimen. Designate this mass as M_n.
9. Determine percent change by subtracting the new mass determination, M_n, from the previous mass determination, M_p, dividing by the previous mass determination, M_p, and multiplying by 100. 41
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; specimen 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.

42

Calculations – Method C (Rapid Test)

Complete the calculations as outlined in Methods A or B, as appropriate.

43

Report

- 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!

44

- 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 completely submerged before 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 METHODS 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

This test method describes a procedure for
03 determining the density of asphalt mixtures by
means of a nuclear gauge using the backscatter
04 method in accordance with AASHTO T 355-22.
Correlation with densities determined under the
FOP for AASHTO T 166 is required by some
agencies.

Gauge, transport case and instruction manual

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 06 model of gauge.
- Radioactive materials information and calibration packet containing:

07

- Daily standard count log
- Factory and laboratory calibration data sheet
- Leak test certificate 08
- 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

Nuclear gauge

Material

- Filler material: Fine-graded sand from the source used to produce the asphalt pavement or other agency approved materials. 09

Filler on pavement

Radiation Safety

10

This method does not purport to address all of
the safety problems associated with its use. The
11 gauge uses 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.

Standardizing the gauge

13 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.

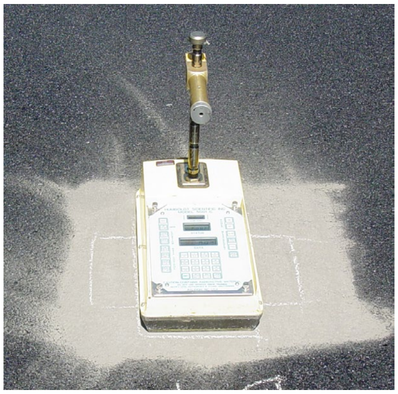
14 3. Record the standard count for both density and moisture in the daily standard count log. The exact procedure for standard count is listed in the manufacturer's Operator's Manual.

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

Test Site Location

15 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



Nuclear gauge

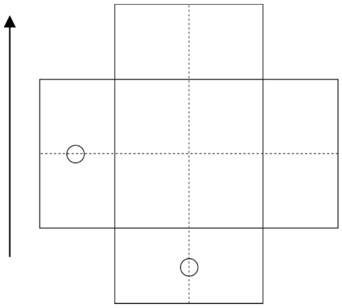
16 1. Maintain maximum contact between the base of the gauge and the surface of the material under test.

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.

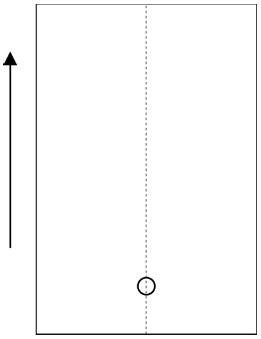
Method A – Average of two one-minute tests



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 source rod 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 source rod 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.

$$\% \, Compaction = \frac{Corrected\ Reading}{Maximum\ Density} \times 100$$

27

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: 28

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:

$$\mathbf{G_{mm}} = 2.466$$

29

$$Theoretical\ Maximum\ Density = 2.466 \times 62.245 lb/ft^3 = 153.5 lb/ft^3$$

$$\% \, Compaction = \frac{142.9 \, lb/ft^3}{153.5 \, lb/ft^3} \times 100 = 93.1\%$$

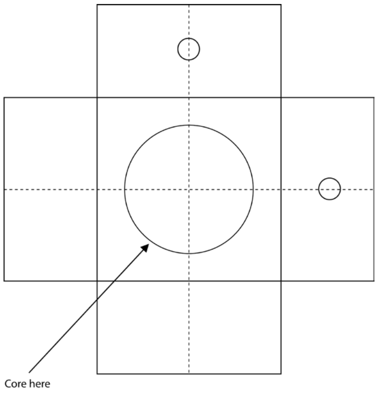
Report

30
- 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.
- – Surface is flat and the gauge does not rock. 32
- – Surface has been properly prepared using filler material.
- – Do not leave the gauge on a hot surface for a long time.



Method A
Footprint of the gauge test site
Core location in the center of the footprint

33
APPENDIX – CORRELATION WITH CORES

(Nonmandatory Information)

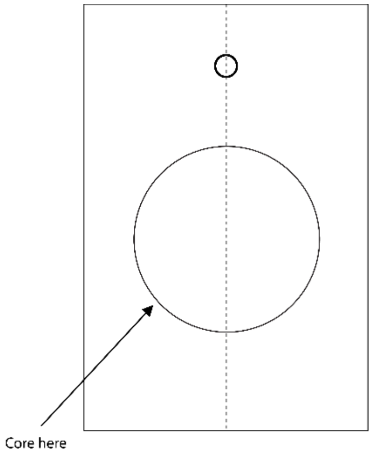
The bulk specific gravity (G_{mb}) of the core is a physical measurement of the in-place asphalt mixture and can be compared with the nuclear density gauge readings. Comparing the core value to the corresponding gauge values, a correlation can be established. 34

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

4. Calculate a correlation factor for the nuclear
35 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
36 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.
37 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
38 documents will constitute a new job mix formula. A
39 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

40

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

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

$$n - 1 = 10 - 1 = 9$$

Standard deviation

$$standard\ deviation = \sqrt{\frac{2.5}{9}} = 0.53$$

Given:

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.

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 METHODS 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. Source rod 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**
12	FOP for AASHTO T 255 Total Evaporable Moisture Content of Aggregate by Drying AASHTO T 265 Laboratory Determination of Moisture Content of Soils
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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 255-25 and AASHTO T 265-22. 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 principal sample mass, readable to 0.1 percent of sample mass or 0.1 g, and meeting the requirements of AASHTO M 231
- Containers: clean, dry, and capable of being sealed
- Suitable drying container
    - For soils: container requires close-fitting lid
    - For aggregate: container lid is optional
- Microwave safe container with ventilated lid (for drying aggregate only)
- Heat source, thermostatically controlled, capable of maintaining 110 ± 5°C (230 ± 9°F).
    - Forced draft oven (preferred)
    - Ventilated oven
    - Convection oven
- Heat source, uncontrolled, for use when allowed by the agency, which will not alter the material being dried, and when close control of the temperature is not required:
    - Infrared heater/heat lamp, hot plate, fry pan, or any other device/method allowed by the agency .
    - Microwave oven (900 watts minimum)
- Utensils such as spoons
- Hot pads or gloves

Sample Preparation

Obtain a representative sample according to the FOP for AASHTO R 90 in its existing condition. If necessary, reduce the sample to moisture content sample size according to the FOP for AASHTO R 76.

For aggregate, the moisture content 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)
150 (6)	50,000 (110)
100 (4)	25,000 (55)
90 (3 1/2)	16,000 (35)
75 (3)	13,000 (29)
63 (2 1/2)	10,000 (22)
50 (2)	8000 (18)
37.5 (1 1/2)	6000 (13)
25.0 (1)	4000 (9)
19.0 (3/4)	3000 (7)
12.5 (1/2)	2000 (4)
9.5 (3/8)	1500 (3.3)
4.75 (No. 4)	500 (1.1)

* 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 moisture content 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**
50 (2)	1000
25.0 (1)	500
12.5 (1/2)	300
4.75 (No. 4)	100
0.425 (No. 40)	10

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

Procedure

Determine and record the sample masses 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 .
   a. For aggregate: the lid is optional unless drying with a microwave then a ventilated lid is required.
   b. For soils: the container includes the mass of the close-fitting lid.
2. Place the wet sample in the container.
3. Determine and record the total mass of the wet sample and container with lid, when used.
   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.
4. Subtract the container mass determined in Step 1 from the mass of the container and sample determined in Step 3 and record the wet mass of the sample (M_W).
5. Remove the lid, if used, and place the sample in one of the following drying apparatuses:
   a. For aggregate –
      i. Controlled heat source (oven): at 110 ±5°C (230 ±9°F).
      ii. Uncontrolled heat source (Hot plate, infrared heater, or other heat source as allowed by the agency): 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 and lid, when used.
8. Subtract the container mass determined in Step 1 from the mass of the container and sample determined in Step 7 and record the mass of the sample.
9. Return sample and container to the heat source for the additional time interval.
   a. Drying intervals for aggregate –
      i. Controlled heat source (oven): 30 minutes
      ii. Uncontrolled heat source (Hot plate, infrared heater, or other heat source as allowed by the agency): 10 minutes
      iii. Uncontrolled heat source (Microwave oven): 2 minutes

Caution: Some minerals in the sample may cause the aggregate to overheat, crack, and explode; altering the aggregate gradation.

Table 3
Methods of Drying

Aggregate		
Heat Source	**Specific Instructions**	**Drying intervals to achieve constant mass (minutes)**
Controlled:		
Forced draft (preferred), ventilated, or convection oven	110 ±5°C (230 ±9°F)	30
Uncontrolled:		
Hot plate, infrared heater, or any other device/method allowed by the agency	Stir frequently	10
Microwave	Heap sample and cover with ventilated lid	2

b. Drying interval for soil – controlled heat source (oven): 1 hour

Table 4
Methods of Drying

Soil		
Heat Source	**Specific Instructions**	**Drying interval to achieve constant mass**
Controlled: Forced draft (preferred), ventilated, or convection oven	110 ±5°C (230 ±9°F)	1 hour

10. Determine mass of sample and container with lid, if used.
11. Subtract the container mass determined in Step 1 from the mass of the container and sample determined in Step 10 and record the mass of the sample.
12. Determine percent change by subtracting the new mass determination (M_n) from the previous mass determination (M_p), dividing by the previous mass determination (M_p), and multiplying 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 and container with lid, when used, to cool. Determine and record the total mass.
16. Subtract the mass of the container determined in Step 1 from the mass of the container and sample determined in Step 15 and record the dry mass of the sample (M_D).
17. Determine and record percent moisture (w) by subtracting the final dry mass determination (M_D) from the initial wet mass determination (M_W), dividing by the final dry mass determination (M_D), and multiplying by 100.

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 sample after second drying cycle:	2634.1 g
Mass, M_n, of 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 sample after third drying cycle: 2633.0 g

Mass, M_n, of 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 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

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

$$w = \frac{1532.6\ g - 1401.4\ g}{1401.4\ g} \times 100 = \frac{131.2g}{1401.4\ g} \times 100 = 9.36\% \quad report\ 9.4\%$$

Report

- 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 99-25: Methods A, B, C, and D
- AASHTO T 180-25: 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.) sieve 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 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 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 ±2	457 ±2
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 C: 5 (1)	Method B: 7 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 ±0.06	18 ±0.06
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 C: 12(1)	Method B: 16 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

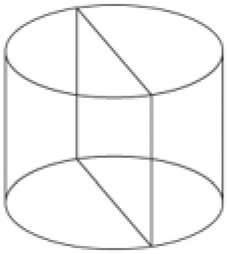
During compaction, rest the mold firmly on a dense, uniform, rigid, and stable foundation, or base. This base shall remain stationary during the compaction process.

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 at least 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.

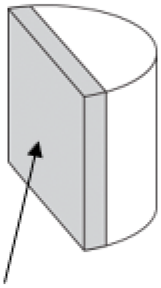
    Note 2: It is recommended to cover the remaining material with a non-absorbent sheet or damp cloth to minimize loss of moisture.

    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).
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 (ρ_w), 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 remove one of the cut faces for a representative moisture content sample. For granular materials, a vertical face will not exist. Take a representative sample ensuring that all layers are represented. 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 (w) 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

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

Where:

ρ_w = wet density, kg/m^3 (lb/ft^3)

M_w = wet mass

V_m = volume of the mold, Annex B

Dry Density

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

Where:

ρ_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 (4.250 lb)
Moisture content, w	=	11.3%
Measured volume of the mold, V_m	=	0.000946 m^3 (0.0334 ft^3)

Wet Density

$$\rho_w = \frac{1.928\ kg}{0.000946\ m^3} = 2038\ kg/m^3 \quad \rho_w = \frac{4.250\ lb}{0.0334\ ft^3} = 127.2\ lb/ft^3$$

Where:

ρ_w = Wet density, kg/m^3 (lb/ft^3)

Dry Density

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

Or

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

ρ_d = Dry density, kg/m^3 (lb/ft^3)

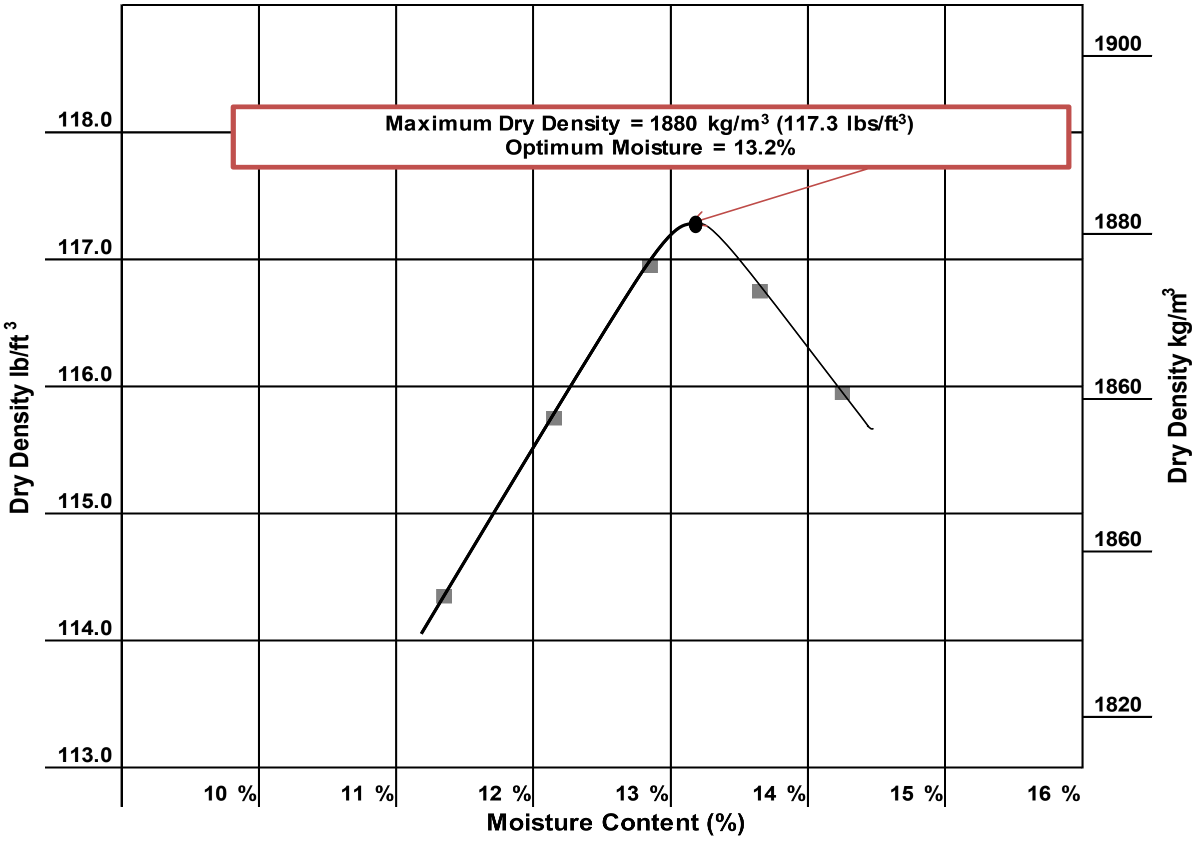
Moisture-Density Curve Development

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		Moisture Content, %
kg/m^3	lb/ft^3	
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

(Mandatory Information)

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.

Procedure

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.

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

And

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

Or for **P_c**:

$$\mathrm{P_c} = 100 - \mathrm{P_f}$$

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:

$$MC_T = \frac{(MC_F \times \mathrm{P_f}) + (MC_c \times \mathrm{P_c})}{100} \qquad \frac{(13.2\% \times 73.0\%) + (2.1\% \times 27.0\%)}{100} = 10.2\%$$

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

$\mathrm{MC_F}$ = moisture content of fine particles, as a % moisture

$\mathrm{MC_C}$ = 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 (ρ_d) of the total sample (combined fine and oversized particles) as follows:

$$\rho_d = \frac{100\%}{\left[\left(\frac{\mathrm{P_f}}{\boldsymbol{\rho_f}}\right) + \left(\frac{\mathrm{P_c}}{k}\right)\right]}$$

Where:

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

$\boldsymbol{\rho_f}$ = dry density of the fine particles kg/m^3 (lb/ft^3), determined in the lab

$\mathrm{P_c}$ = percent of dry oversize particles, of sieve used, by weight.

$\mathrm{P_f}$ = 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 ($\boldsymbol{\rho_f}$):	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

$$\rho_d = \frac{100\%}{\left[\left(\frac{\mathrm{P_f}}{\boldsymbol{\rho_f}}\right) + \left(\frac{\mathrm{P_c}}{k}\right)\right]}$$

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

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

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

English:

Maximum laboratory dry density ($\boldsymbol{\rho_f}$): 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

$$\rho_d = \frac{100\%}{\left[\left(\frac{P_f}{\boldsymbol{\rho_f}}\right) + \left(\frac{P_c}{k}\right)\right]}$$

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

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

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

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

Report

- 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

(Mandatory Information)

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

$$V_m = \frac{M}{\rho_{water}}$$

Where:

V_m = volume of the mold

M = mass of water in the mold

ρ_{water} = density of water at the measured temperature

Example

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

ρ_{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 SOIL MOISTURE-DENSITY RELATIONS (FAMILY OF CURVES) FOP FOR AASHTO R 75

Scope

This procedure provides a method to develop soils density-relations in accordance with AASHTO R 75-24 using multiple moisture-density curves developed using the same method, A, B, C, or D, from the FOP for AASHTO T 99/T 180.

All curves used in a group 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

***soil moisture-density relations* —** a group of soil moisture-density relations (commonly known as a family of 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 and optimum moisture content of a group 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 per group.
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 soil moisture-density relations.
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 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. Intermediate 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 group.
   b. Draw a smooth, "best fit," curved line connecting the 80 percent of optimum moisture points plotted on the curves that parallel the spine.

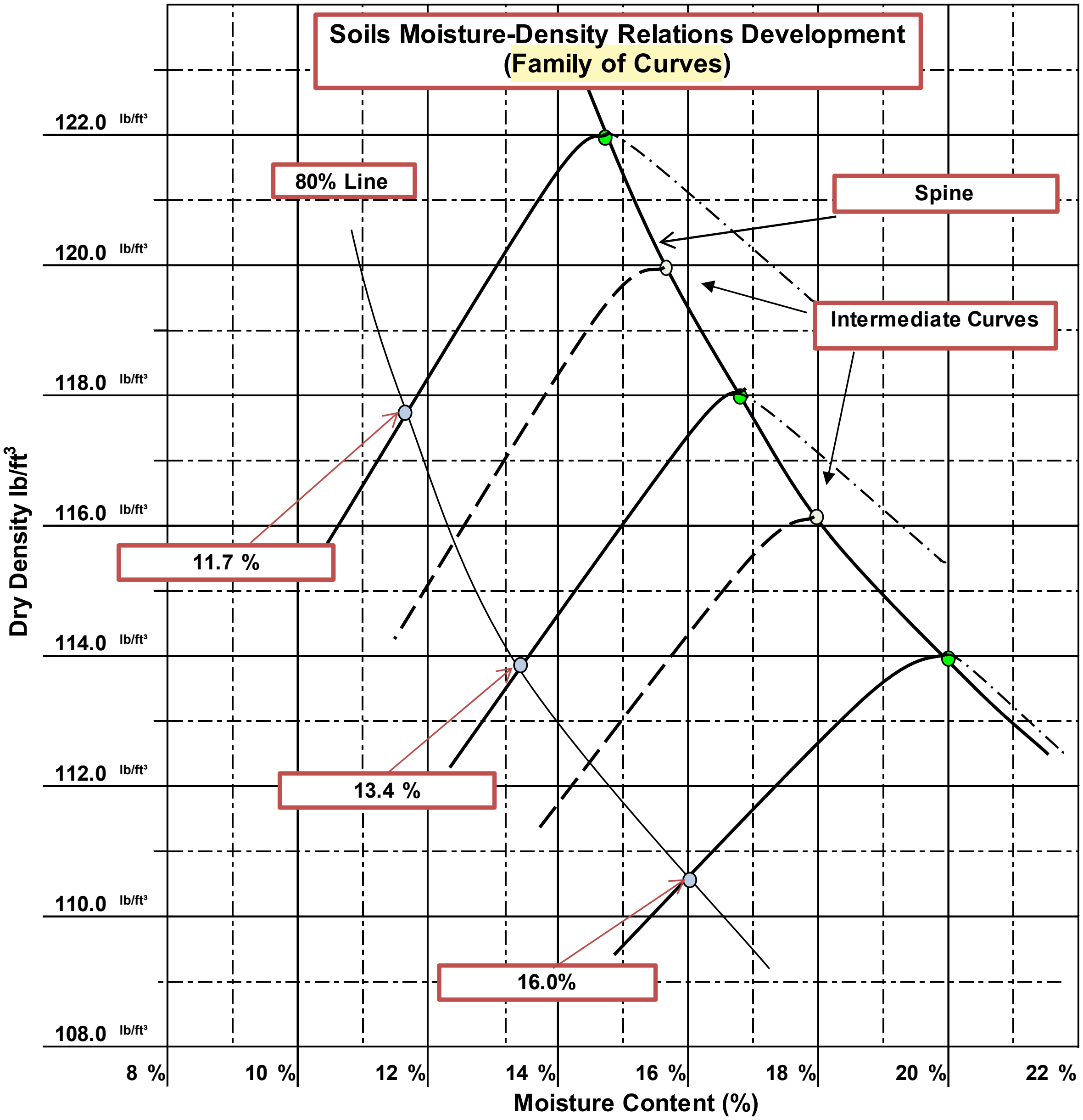
Calculations

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 soil density-relations group (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 develop the soil density-relations. For example, when moisture-density relationships as determined by T 99 – Method C are used to form the soil density-relations group or an individual moisture density curve, then T 99 – Method C must be used for the one-point determination.

Apparatus

See the FOP for AASHTO T 99/T 180 for full apparatus requirements.

Table 1
Field Selection of Apparatus – English

	Method used to compact Individual Curve or Group of Curves							
	T 99				T 180			
Method	A	B	C	D	A	B	C	D
Material Size (Passing Sieve)	No. 4	¾ in.	No. 4	¾ in.	No. 4	¾ in.	No. 4	¾ in.
Nominal Mold Diameter	4 in.	6 in.	4 in.	6 in.	4 in.	6 in.	4 in.	6 in.
Nominal Rammer Mass	5.5 lb.				10 lb.			
Rammer Drop	12 in.				18 in.			
Layers	3				5			
Blows per Layer	25	56	25	56	25	56	25	56

Sample

Sample size determined according to the FOP for AASHTO T 310. In cases where the existing individual curve or soil density-relations group 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.

1. 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).
2. Thoroughly break up aggregations in a manner that avoids reducing the natural size of individual particles.
3. Pass the material through the appropriate sieve.

Procedure

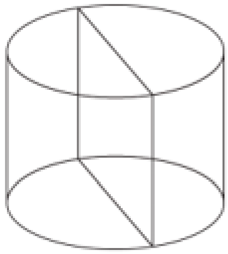
Use the method matching the individual curve or soil density-relations group. Refer to Table 1 of the FOP for AASHTO T 99 / T 180 for corresponding mold size, number of layers, number of blows, sieve size, and rammer specification for the various test methods.

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.

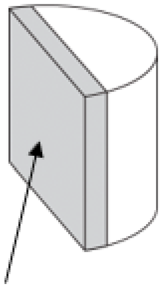
Note 1: It is recommended to cover the remaining material with a non-absorbent sheet or damp cloth to minimize loss of moisture.

    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).
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 (ρ_w) as indicated below under "Calculations."

10. Extrude the material from the mold. For soils and soil-aggregate mixtures, slice vertically through the center and remove one of the cut faces for a representative moisture content sample. For granular materials, a vertical face will not exist. Take a representative sample ensuring that all layers are represented. 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 (w) of the sample in accordance with the FOP for AASHTO T 255 / T 265.

Calculations

Wet Density

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

Where:

ρ_w = wet density, kg/m^3 (lb/ft^3)

M_w = wet mass

V_m = volume of the mold, (FOP for AASHTO T 99/T 180)

Dry Density

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

Where:

ρ_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 = 2.0055 kg (4.42 lb)

Moisture content, w = 13.5%

Measured volume of the mold, V_m = 0.0009469 m^3 (0.0334 ft^3)

Wet Density

$$\rho_w = \frac{2.0055\ kg}{0.0009469\ m^3} = 2118\ kg/m^3 \quad \rho_w = \frac{4.42\ lb}{0.0334\ ft^3} = 132.2\ lb/ft^3$$

Where:

ρ_w = Wet density, kg/m^3 (lb/ft^3)

Dry Density

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

or

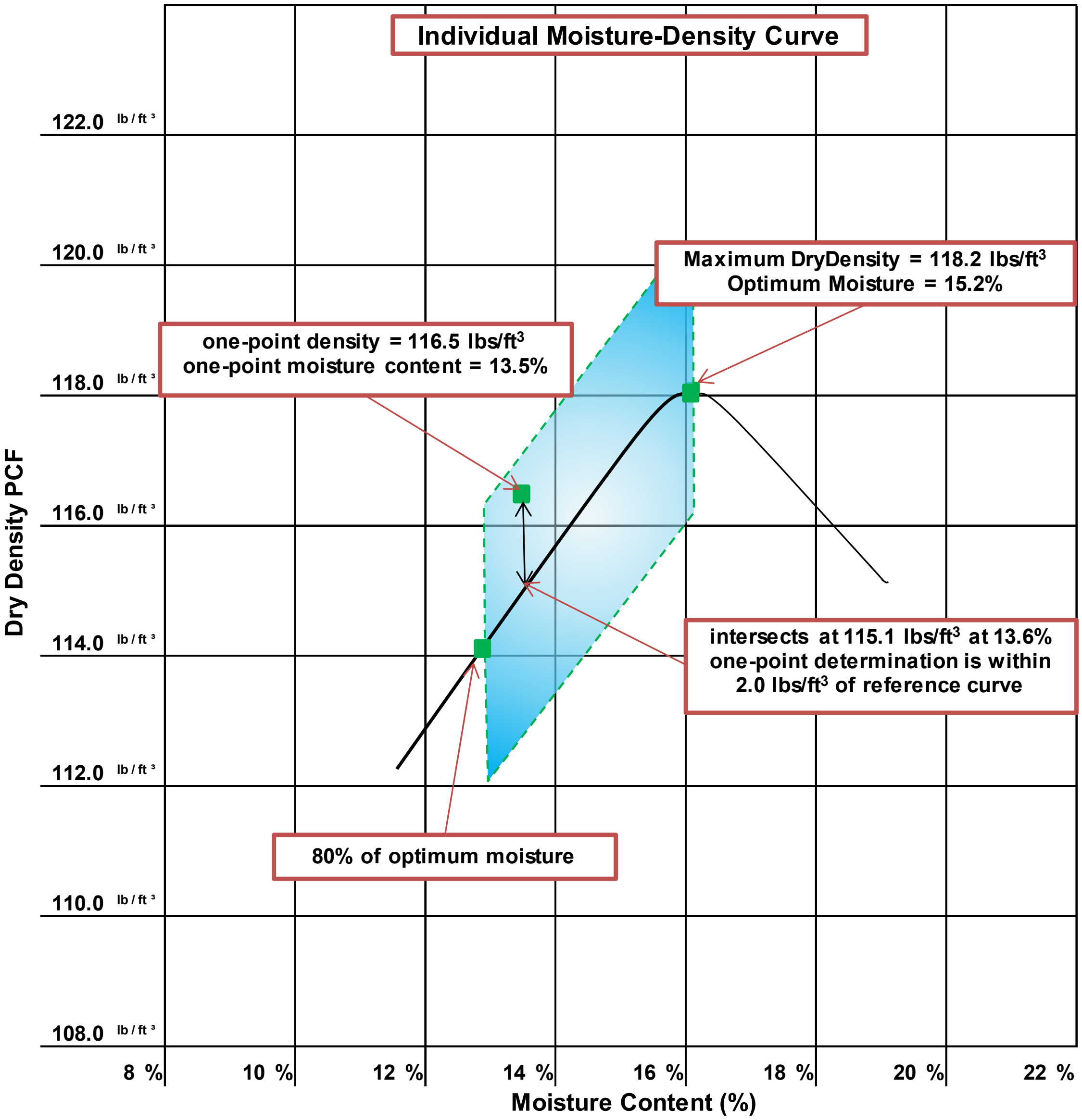
$$\rho_d = \left(\frac{2118\ kg/m^3}{\frac{13.5}{100} + 1}\right) = 1866\ \ kg/m^3 \quad \rho_d = \left(\frac{132.2\ lb/ft^3}{\frac{13.5}{100} + 1}\right) = 116.5\ lb/ft^3$$

ρ_d = Dry density, kg/m^3 (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 range of the reference curve.
    a. If the moisture content of the one-point does not fall within the range, adjust the moisture content.
    b. Compact another one-point specimen using the moisture adjusted sample.
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 Soil Moisture-Density Relations

1. Plot the one-point, dry density on the vertical axis and moisture content on the horizontal axis, on the reference soil density-relations graph.

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

3. If the moisture-density one-point falls within the soil density-relations 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 soil density-relations. 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. If it does not, then a full curve must be developed.

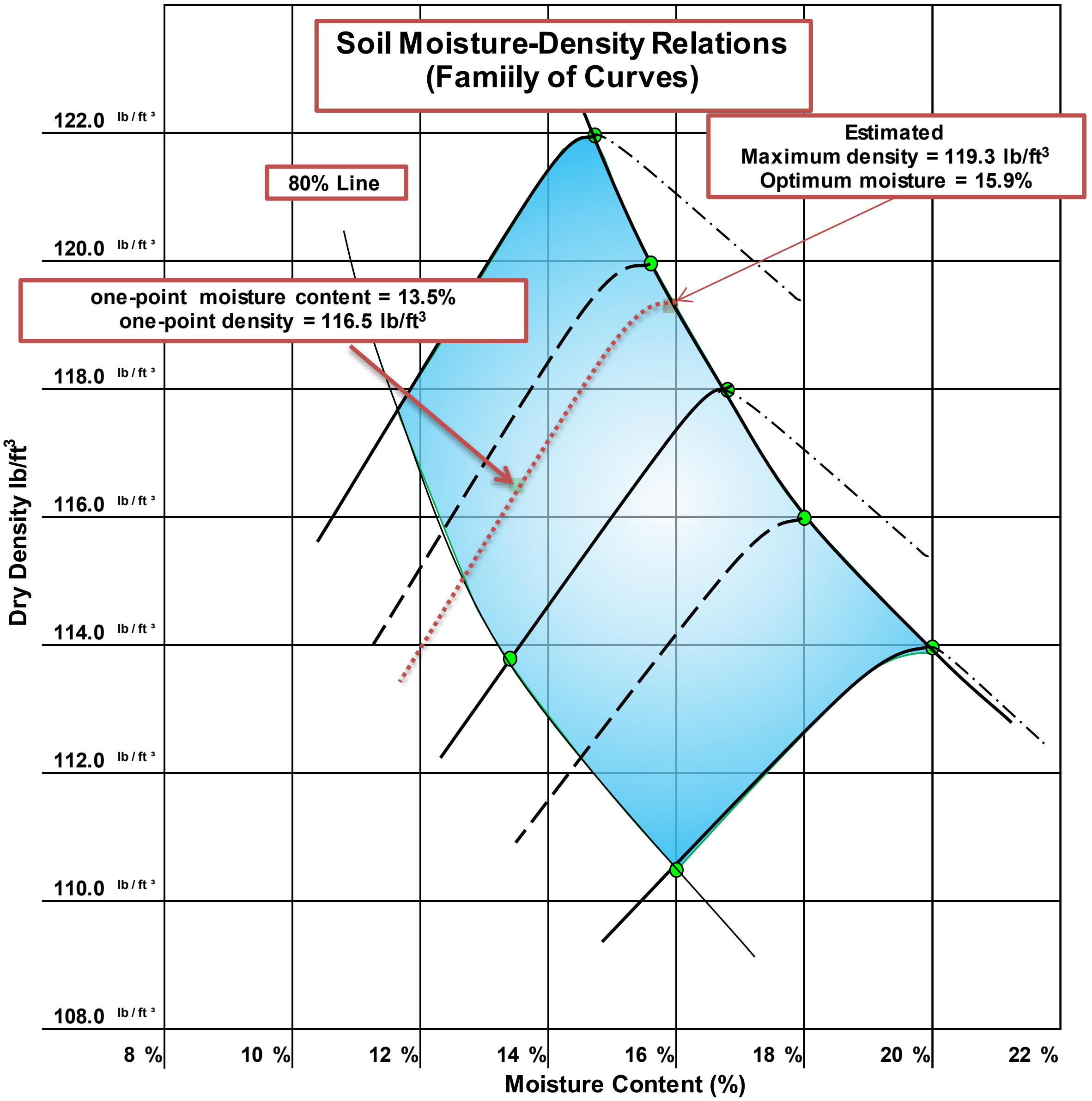
    b. If the one-point plotted within or on the soil density-relations group does not fall in the 80 to 100 percent of optimum moisture content, compact another specimen, using the same material, at an adjusted moisture content that will place the one point within this range.

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 soil density-relations.

Note 2: New curves drawn through plotted single point determinations shall not become a permanent part of the soil density-relations 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 group 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

- 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 Soil Moisture-Density Relations 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 85-25. 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.

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 0.1 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 cloth

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 the sample to remove dust or other coatings from the surface.
5. Dry the sample to constant mass according to the FOP for AASHTO T 255/T 265 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 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 sample 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 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 and basket is fully submerged. Tare the balance with the empty basket attached in the water bath.
3. Remove the 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 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 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 and basket is fully submerged. Designate this submerged weight as “C.”

Note 5: The container should be immersed to a depth sufficient to cover it and the 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 sample to constant mass according to the FOP for AASHTO T 255 / T 265 at 110 ±5°C (230 ±9°F) and cool in air at room temperature for 1 to 3 hours.
8. Determine and record the dry mass. 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

- On forms approved by the agency
- Sample ID
- Specific gravity values to the nearest 0.001
- Absorption to the nearest 0.1 percent

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 310-22. This procedure provides a rapid, nondestructive technique for determining the in-place wet density and moisture content of soil, aggregate, and soil-aggregate mixes. 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.
   d. Correct for trench wall effect according to manufacturer's correction procedures if the test site is closer than 600 mm (24 in.) to vertical projection. See Note 2.

Note 2: To perform moisture and density tests in a trench or against a large solid object, it is necessary to perform a trench offset correction to adjust the gauge, or it may read a falsely high moisture content. Moisture present in the walls can thermalize neutrons which return to the gauge and are read as moisture by the detector in the gauge.

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 source rod depth and shall be aligned such that insertion of the source rod 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. Lower the source rod into the hole 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, WAQTC TM 15, or WFLHD's Humphres.

See appropriate agency policies for use of density standards.

Calculation

Calculate the dry density as follows:

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

Where:

ρ_d = Dry density, kg/m^3 (lb/ft^3)

ρ_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:

ρ_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:

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

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

Given:

ρ_w = 1963 kg/m^3 or 122.5 lb/ft^3

w = 15.9%

Calculate percent compaction as follows:

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

Given:

Agency density standard = 111.3 lb/ft^3

Report

- 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 209-25. 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, meeting AASHTO M 231, Class G2
- 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 full vacuum applied
- 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 3.4 kPa (25 mm Hg)
- Vacuum measurement device: Residual pressure manometer or vacuum gauge, capable of measuring residual pressure down to 3.4 kPa (25 mmHg) or less and readable to at least 0.2 kPa (2 mmHg)
- Suspension apparatus: Suitable apparatus and holder to permit determining the mass of the sample while suspended below the balance. The wire suspending the holder shall be the smallest practical size to minimize any possible effects of a variable immersed length for Bowl Method.
- Water bath: A constant-temperature water bath (optional for Pycnometer or Volumetric Flask Method)

Note 1: The water bath may be equipped with a circulator and heater or chiller to maintain constant temperatures throughout the bath. If a circulator is used, turn it off before any masses are recorded.

- Thermometer: An immersion thermometer readable to at least 0.5°C (1°F) and with a temperature range of at least 20 to 45°C (68 to 113°F).
- Bleeder valve to adjust vacuum
- Automatic vacuum control unit (optional)

- Timer
- Towel

Standardization

Use a container that has been standardized according to the Annex. Record the standardized container mass for use in subsequent calculations.

The container 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 by calculating the weighted average ($G_{mm\ (avg)}$.). If the increments have a specific gravity difference greater than 0.013, the test must be re-run.
3. Plant-produced samples may be short-term conditioned according to AASHTO R 30 as specified by the agency.

Note 2: Short-term conditioning at the specified temperature is especially important when absorptive aggregates are used. This short-term conditioning will ensure the computation of realistic values for the amount of asphalt absorbed by the aggregate and void properties of the mix. Plant-produced asphalt mixtures should be evaluated to make sure short-term conditioning has taken place during production and delivery.

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 (do not exceed Job Mix Formula (JMF) compaction temperature) 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 3: 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 sample to a partial vacuum of 4.0 ±0.6 kPa (30 ±5 mmHg) residual pressure for 15 ±1 minutes.
10. Agitate the container and sample, 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.

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. Immerse the suspension apparatus sufficiently to cover both it and the bowl.

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

15A. Determine and record the submerged weight of the bowl and sample to the nearest 0.1 g. Designate as "C."

Procedure – Pycnometer or Volumetric Flask

Complete steps 12B through 16B within 10 ±1 min.

12B. Immediately fill the pycnometer / volumetric flask with water without reintroducing air.

13B. Stabilize the temperature of the pycnometer / volumetric flask and sample 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 4: 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 an asphalt binder film, they may become saturated with water during the vacuuming procedure, resulting in an error in G_{mm} and theoretical 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 "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

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

(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

B = standardized submerged weight of the bowl, g (see Annex)

C = submerged weight of sample and bowl, g

Example:

$$G_{mm} = \frac{1432.7\ g}{1432.7\ g + 286.3\ g - 1134.9\ g} = 2.453 \quad or$$

$$G_{mm} = \frac{1432.7\ g}{1434.2\ g + 286.3\ g - 1134.9\ g} = 2.447$$

Given:

A = 1432.7 g

A_{SSD} = 1434.2 g

B = 286.3 g

C = 1134.9 g

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 = standardized mass of pycnometer / volumetric flask filled with water at 25°C (77°F), g, (See Annex)

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

Example (two increments of a large sample):

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

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

Given:

Increment 1	Increment 2
A_1 = 2200.3 g	A_2 = 1960.2 g
D_1 = 7502.5 g	D_2 = 7525.5 g
E_1 = 8812.0 g	E_2 = 8690.8 g

Variation = 2.470 - 2.466 = 0.004, which is < 0.013

Allowable variation is: 0.013. The values may be used.

Weighted average

For large samples tested a portion at a time, calculate the $G_{mm\ (avg)}$ by multiplying the dry mass of each increment by its G_{mm}, add the results together (Σ) and divide by the sum (Σ) of the dry masses.

$$G_{mm(avg)} = \frac{\sum\left(A_x \times G_{mm_x}\right)}{\sum A_x}$$

or

$$G_{mm(avg)} = \frac{\left(A_1 \times G_{mm_1}\right) + \left(A_2 \times G_{mm_2}\right)}{A_1 + A_2}\ etc.$$

Where:

A_x = mass of dry sample increment in air, g

G_{mmx} = theoretical maximum specific gravity of the increment

Example:

$$G_{mm(avg)} = \frac{(2200.3\ g \times 2.470) + (1960.2\ g \times 2.466)}{2200.3\ g + 1960.2\ g} = \frac{10{,}268.6}{4160.5\ g} = 2.468$$

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 kg/ m^3 in Metric units or 62.245 lb/ft^3 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

- 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)

ANNEX – STANDARDIZATION OF BOWL AND PYCNOMETER OR VOLUMETRIC FLASK

(Mandatory Information)

Bowl – Standardization

1. Fill the water bath to overflow level with 25 ±1°C (77 ±2°F) water and allow the water to stabilize.
2. 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. Immerse the suspension apparatus sufficiently to cover both it and the bowl.
3. Suspend and completely immerse the bowl for 10 ±1 minute.
4. Determine and record the submerged weight of the bowl to the nearest 0.1 g.
5. Refill the water bath to overflow level.
6. Perform Steps 2 through 5 two more times for a total of three determinations.
7. If the range of the three determinations is less than or equal to 0.3 g., average the determinations. Designate as “B.”
8. If the range of the three determinations is greater than 0.3 g., take corrective action and perform the standardization procedure again.

Bowl – Check

1. Fill the water bath to overflow level 25 ±1°C (77 ±2°F) water and allow the water to stabilize.
2. 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. Immerse the suspension apparatus sufficiently to cover both it and the bowl.
3. Suspend and completely immerse the bowl for 10 ±1 minute.
4. Determine and record the submerged weight of the bowl to the nearest 0.1 g.
5. If this determination is within 0.3 g of the standardized value, use the standardized value for “B.”
6. If it is not within 0.3 g, take corrective action and perform the standardization procedure again.
7. For labs that check the bowl standardization frequently (such as daily), calculate the moving average and range of the last three mass determinations. Designate the average of the last three masses as “B.”
8. If the moving range exceeds 0.3 g at any time, take corrective action and perform the standardization procedure again.

Pycnometer or Volumetric Flask – Standardization

1. Fill the pycnometer / volumetric flask with water at approximately 25°C (77°F).
2. Place the metal or plastic cover, or a glass plate on the pycnometer / volumetric flask and eliminate all air. (See Note 4.)
3. Stabilize the pycnometer / volumetric flask at 25 ± 1ºC (77 ± 2ºF) for 10 ± 1 min.
4. Towel dry the outside of the pycnometer / volumetric flask and cover.
5. Determine and record the mass of the pycnometer / volumetric flask, water, and cover or plate to the nearest 0.1 g.
6. Perform Steps 2 through 5 two more times for a total of three determinations.
7. If the range of the three determinations is less than or equal to 0.3 g, average the three determinations. Designate as "D."
8. If the range of the determinations is greater than 0.3 g., take corrective action and perform the "Pycnometer or Volumetric Flask – Standardization" again.

Pycnometer or Volumetric Flask – Check

1. Fill the pycnometer / volumetric flask with water at approximately 25°C (77°F).
2. Place the metal or plastic cover or a glass plate on the pycnometer / volumetric flask and eliminate all air. (See Note 4.)
3. Stabilize the pycnometer / volumetric flask at 25 ± 1ºC (77 ± 2ºF) for 10 ± 1 min.
4. Towel dry the outside of the pycnometer / volumetric flask and cover.
5. Determine and record the mass of the pycnometer / volumetric flask, water, and cover or plate.
6. If this determination is within 0.3 g of the standardized value, use the standardized value for "D."
7. If it is not within 0.3 g, perform the standardization procedure again.

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 166-25. 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

Test Specimens

Test specimens may be either laboratory-molded or sampled 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.

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.
- Potable water: Water that is suitable for drinking.
- 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. Use potable water to fill the water bath. The water in the bath does not need to maintain a potable condition but must remain clear at all times.

Note 1: The water bath may be equipped with a circulator and heater or chiller to maintain constant temperatures throughout the bath. If a circulator is used, turn it off before any masses are recorded.

- Towel: Damp cloth towel used for surface drying specimens.
- Oven: Capable of maintaining a temperature of 52 ± 3°C (126 ±5°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 15 to 45°C (59 to 113°F) and, graduated in 0.1°C (0.2°F) subdivisions.
- Vacuum device: refer to the FOP for AASHTO R 79 (optional)

Procedure – Method A (Suspension)

Recently molded laboratory specimens 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 (126 ±5°F).
      ii. Determine and record the mass of the specimen. Designate this mass as M_p.
      iii. Return the specimen to the oven for at least 2 hours.
      iv. Determine and record the mass of the specimen. Designate this mass as M_n.
      v. Determine percent change by subtracting the new mass determination, M_n, from the previous mass determination, M_p, dividing by the previous mass determination M_p, and multiplying 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; specimen is defined as dry.

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

   b. Vacuum dry method according to the FOP for AASHTO R 79.

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 the overflow level with water at 25 ±1°C (77 ±2°F) and allow the water to stabilize.
4. Zero or tare the balance with the suspension apparatus attached, ensuring that the suspension apparatus is completely submerged and 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 specimen from the water and quickly surface dry with a damp cloth towel within 5 sec.
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 exceed 15 sec. 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:

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 at 25 ±1°C (77 ±2°F), g

Example:

$$G_{mb} = \frac{4833.6\ g}{4842.4\ g - 2881.3\ g} = 2.465$$

$$\%\ Water\ Absorbed\ (by\ volume) = \frac{4842.4\ g - 4833.6\ g}{4842.4\ g - 2881.3\ g} \times 100 = 0.45\%$$

Given:

A = 4833.6 g

B = 4842.4 g

C = 2881.3 g

Apparatus – Method B (Volumeter)

- Balance or scale: 5 kg capacity, readable to 0.1 g and conforming to AASHTO M 231.
- Potable water: Water that is suitable for drinking.
- Water bath: For immersing the specimen in water, capable of maintaining a uniform temperature at 25 ± 1°C (77 ± 2°F). Use potable water to fill the water bath. The water in the bath does not need to maintain a potable condition but must remain clear at all times.
- Thermometer: Range of 15 to 45°C (59 to 113°F) and graduated in 0.1°C (0.2°F) subdivisions.
- Distilled water: Clear, distilled water for filling the volumeter.
- Volumeter: Calibrated to 1200 mL or appropriate capacity for specimen and having a tapered lid with a capillary bore.
- Oven: Capable of maintaining a temperature of 52 ± 3°C (126 ± 5°F) for drying the specimens to a constant mass.
- Pan: Pan or other suitable container of known mass, large enough to hold a specimen for drying in oven.
- Towel: Damp cloth towel used for surface drying specimens.
- Vacuum device: refer to the FOP for AASHTO R 79 (optional)

Procedure – Method B (Volumeter)

Method B is not acceptable for use with specimens that have more than 6 percent air voids.

Recently molded laboratory specimens 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 (126 ±5°F).
        ii. Determine and record the mass of the specimen. Designate this mass as M_p.
        iii. Return the specimen to the oven for at least 2 hours.
        iv. Determine and record the mass of the specimen. Designate this mass as M_n.
        v. Determine percent change by subtracting the new mass determination, M_n, from the previous mass determination, M_p, dividing by the previous mass determination, M_p, and multiplying 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; specimen is defined as dry.

    Note 3: To expedite the procedure, steps 1 and 2 may be performed last. To further expedite the process, see Method C.

    b. Vacuum dry method according to the FOP for AASHTO R 79.
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 at 25 ±1°C (77 ±2°F) for at least 10 minutes.
4. At the end of the ten-minute period, fill the volumeter with distilled water at 25 ±1°C (77 ±2°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 and water to the nearest 0.1 g. Designate this mass as D.
6. Remove the specimen from the water bath and quickly surface dry with a damp cloth towel within 5 sec.
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 sec.
9. Bring the temperature of the water to 25 ±1°C (77 ±2°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, water, and specimen to the nearest 0.1 g. Designate this mass as E.

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 ±2°F), g

E = Mass of volumeter filled with specimen and water, g

Example:

$$G_{mb} = \frac{4833.6\ g}{4842.4\ g + 2924.4\ g - 5806.0\ g} = 2.465$$

$$\%\ Water\ Absorbed\ (by\ volume) = \frac{4842.4\ g - 4833.6\ g}{4842.4\ g + 2924.4\ g - 5806.0\ g} \times 100 = 0.45\%$$

Given:

A = 4833.6 g
B = 4842.4 g
D = 2924.4 g
E = 5806.0 g

Apparatus – Method C (Rapid Test)

- Oven: Capable of maintaining a temperature of 110 ±5°C (230 ±9°F) for drying the specimens to a constant mass.

See Methods A or B.

Note 4: 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)

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 110 ±5°C (230 ±9°F).
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. Designate this mass as M_p.
7. Return the specimen to the oven for at least 2 hours.
8. Determine and record the mass of the specimen. Designate this mass as M_n.
9. Determine percent change by subtracting the new mass determination, M_n, from the previous mass determination, M_p, dividing by the previous mass determination, M_p, and multiplying 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; specimen 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)

Complete the calculations as outlined in Methods A or B, as appropriate.

Report

- 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 METHODS 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 355-22. 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.

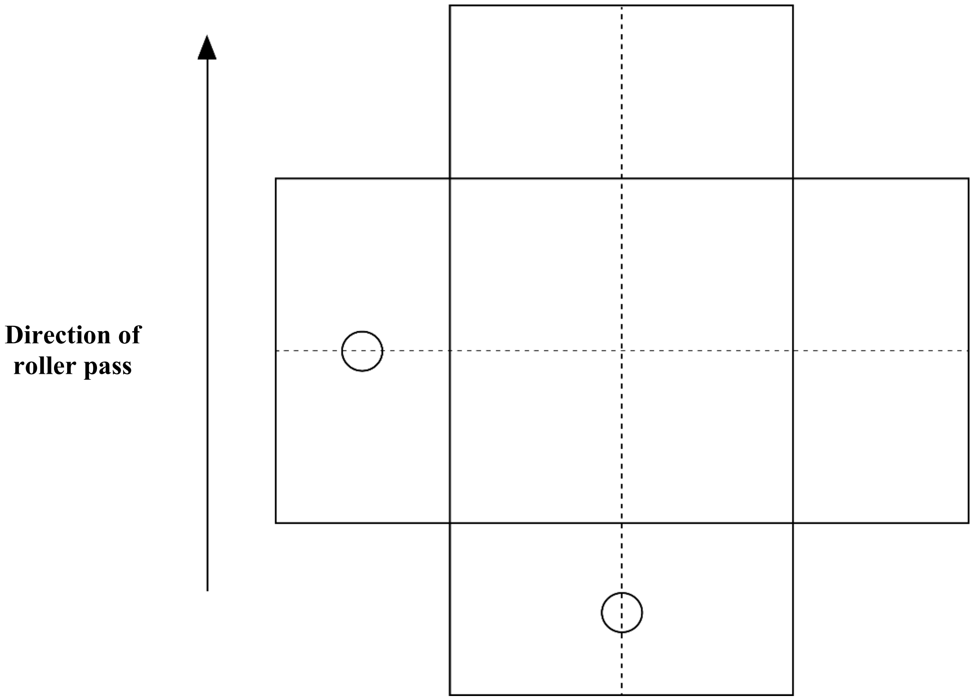
Procedure

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 source rod 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.

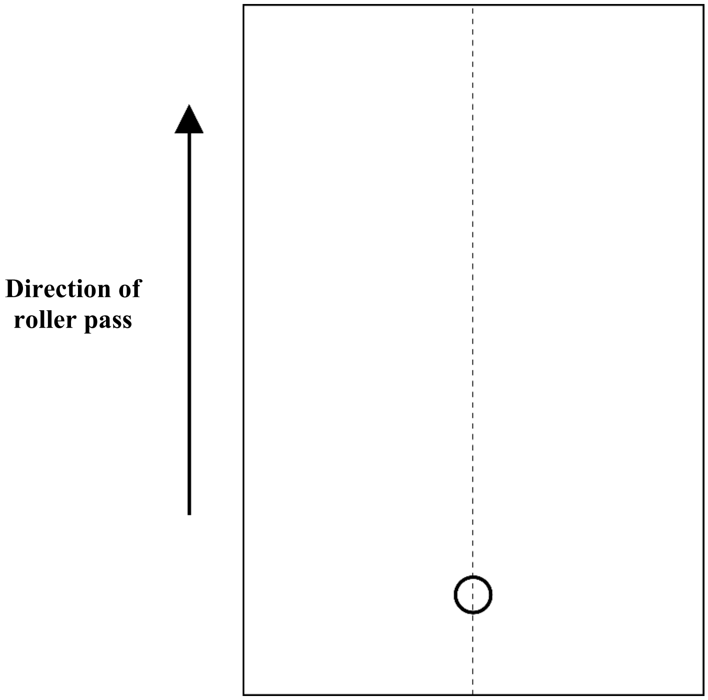


Method A

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 source rod 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.

$$\%\,Compaction = \frac{Corrected\ Reading}{Maximum\ Density} \times 100$$

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:

$$\mathbf{G_{mm}} = 2.466$$

$$Theoretical\ Maximum\ Density = 2.466 \times 62.245 lb/ft^3 = 153.5 lb/ft^3$$

$$\%\,Compaction = \frac{142.9\ lb/ft^3}{153.5\ lb/ft^3} \times 100 = 93.1\%$$

Report

- 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)

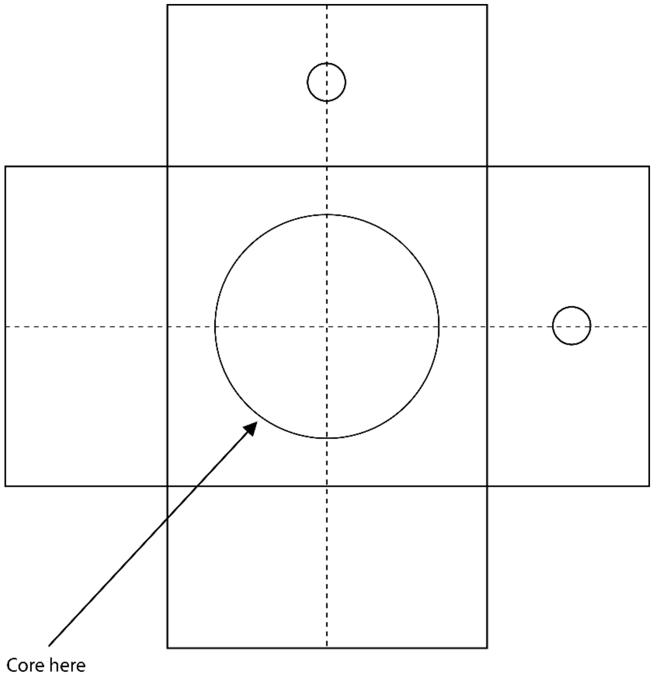
The bulk specific gravity (G_{mb}) of the core is a physical measurement of the in-place asphalt mixture and can be compared with the nuclear density gauge readings. Comparing the core value to the corresponding gauge values, a correlation can be established.

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.

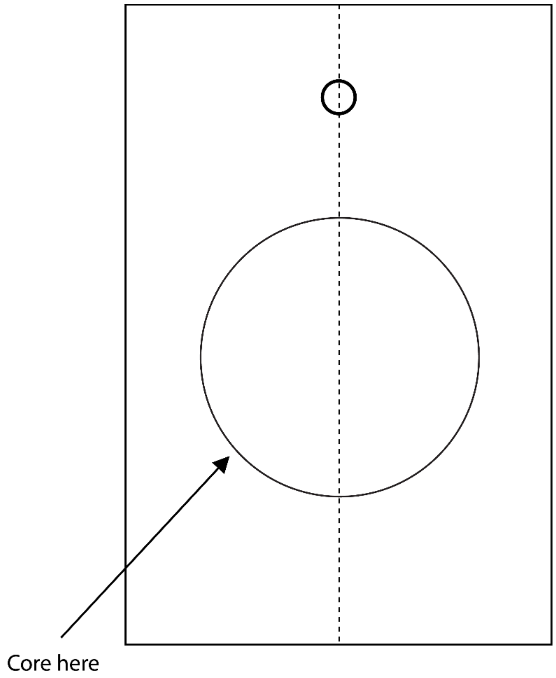
When density correlation with the FOP for AASHTO T 166 is required, correlation of the nuclear gauge with pavement cores shall be made on the first day's paving (within 24 hours) or from a test strip constructed before the start of paving. Cores must be taken before traffic is allowed on the pavement.

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	Σx^2	= 2.5

Number of data sets

$$n - 1 = 10 - 1 = 9$$

Standard deviation

$$standard\ deviation = \sqrt{\frac{2.5}{9}} = 0.53$$

Given:

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.