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RECEIVED  
JUN 26 2015  
DIV. OF OIL, GAS & MINING

June 26, 2015

C0250005, Incoming ✓  
#4814

DENVER  
LAS VEGAS  
LOS ANGELES  
LOS CABOS  
ORANGE COUNTY  
PHOENIX  
RENO  
SALT LAKE CITY  
TUCSON

Daron R. Haddock  
Coal Program Manager  
Utah Division of Oil, Gas & Mining  
1594 West North Temple  
Salt Lake City, Utah 84116

Re: Final Approval Underground Mining Amendment, Alton Coal Development, LLC, Coal Hollow Mine, Permit No. C/025/0005, Task ID 4814

Dear Associate Director Dean:

On behalf of Alton Coal Development, LLC ("ACD"), attached please find the updated Swell Factor Report requested pursuant to your June 19, 2015 letter. This Report was revised by GEM Engineering, Inc. per the request of the Division.

If you have any questions, please call me.

Very truly yours,

Snell & Wilmer



Denise A. Dragoo

DAD:mkm

Enclosures

cc: Dana Dean  
Steve Alder, Esq.

**Gem ENGINEERING, INC.**

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Phone (435) 867-6478 ♦ Fax (435) 867-4372  
[www.gemengineeringinc.com](http://www.gemengineeringinc.com)

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June 26, 2015

**Alton Coal Development**  
463 North 100 West  
Cedar City, UT 84721

RECEIVED

JUN 26 2015

DIV. OF OIL, GAS & MINING

**Attention: Andrew Christensen**

**Subject:** Response to Letter from the State of Utah - DOGM - Dated May 11, 2015  
Tropic Shale and Alluvium - Shrinkage and Expansion Factors  
Coal Hollow Project  
Cedar City, Utah

At your request, we are providing the this report in response the subject letter from the state of Utah. Our responses are in the same order in which the they were stated in the letter. A copy of letter from the state of Utah is attached. Rather than pulling excerpts from the ASTM Standard we have attached the entire standard as to not be misunderstood. These standards were followed during the performance of our work. It should also be understood the we AASHTO accredited and as such are routinely check for accuracy and completeness.

1. ASTM D4840 sampling and testing methods were utilized during the performance of this investigation for the obtaining of samples and transport to our laboratory . Chain of custody from were not required since the samples never left our control.
2. Please find attached a copy of that standard along with ASTM D1557 and ASTM D698 section 12 is included in that standard. Attached are the proctor curves for the modified proctors that were preformed. Upon review Method D was not utilized for this analysis it was a transitional error. The attached GEM Engineering reports include relevant details are on the actual reports.
3. Attached also are the grain size and atterberg limits which were preformed for the purpose of classifying the materials utilizing ASTM C136, C117 and D4318.

LIMITATIONS

These services have been performed according to generally accepted engineering practices that exist at this time. No warranty, expressed or implied, is provided.

If you should have any questions concerning this letter or require any additional services, please contact us at your convenience.

We appreciate the opportunity to be of continued service to you. Let us know if you have any questions concerning the data contained within this report.

Sincerely,



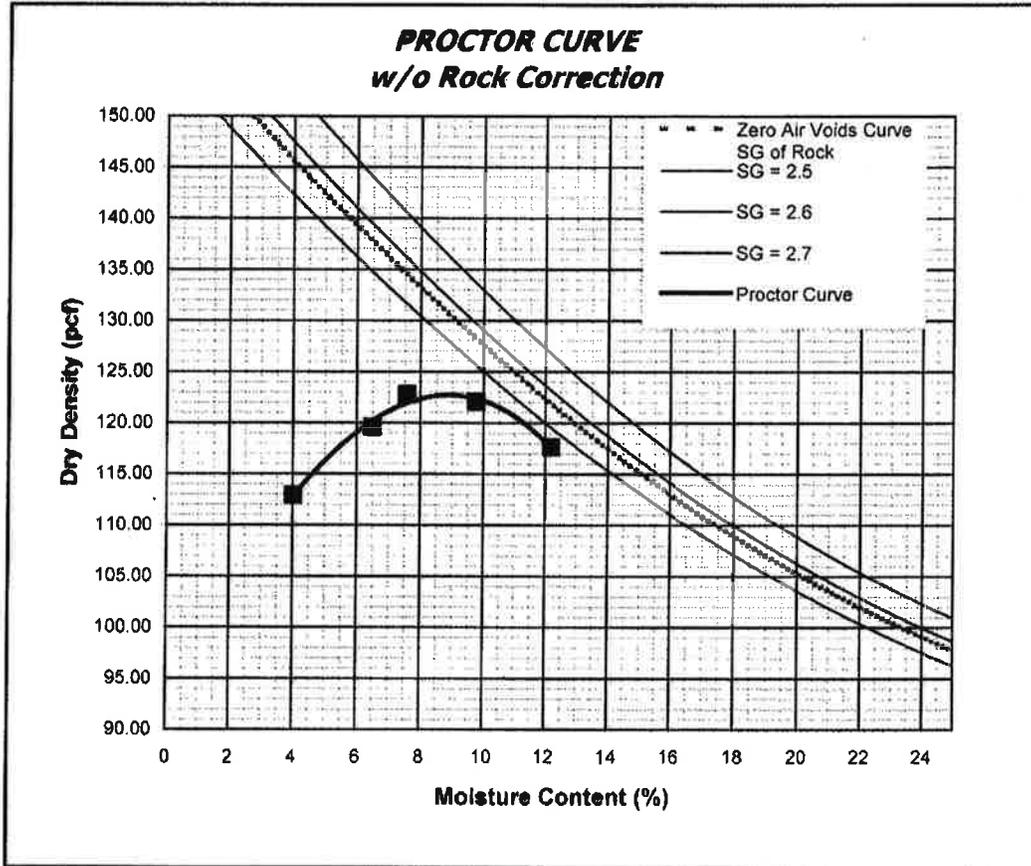
Joel A. Myers, P.E.  
President of GEM Engineering, Inc.



ENC: Proctor Record, Sieve Analysis, Atterberg Limits Results and Standards ASTM D4840, ASTM D1557, ASTM D698, ASTM C136, ASTM C117, ASTM D4318 and Letter from the State of Utah dated May 11, 2015.

# Modified Proctor - Moisture Density Relationship

Client:	Alton Coal Development	Date Sampled:	12/30/2014
Project Name:	Alton Coal Mine	Sample Depth:	
Sample Location:	On site stock pile	Test Method:	ASTM D 1557 AASHTO T-180
Soil Description:	Alluvium		



Preliminary Density\*    122.5 pcf  
 Preliminary Moisture\*    9.0%

Maximum Dry Density (pcf)	Optimum Moisture
<b>126.5</b>	<b>8.0%</b>

\*This sample has 12.47% rock. Therefore, in order to obtain the Maximum Dry Density and the Optimum Moisture values, the preliminary density and moisture are modified by a correction factor.

**REMARKS:** \_\_\_\_\_  
 \_\_\_\_\_

**GEM ENGINEERING, INC.**  
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Reviewed by: \_\_\_\_\_ *[Signature]*

# Sieve Analysis of Fine and Coarse Aggregates

(Test Methods: ASTM C136, C117, AASHTO T27, T11)

<b>Client:</b>	Alton Coal Development
<b>Project Name:</b>	Alton Coal Mine
<b>Sample Location:</b>	On site stock pile
<b>Sample Depth:</b>	0
<b>Sample Depth:</b>	0
<b>Date Sampled:</b>	12/30/14

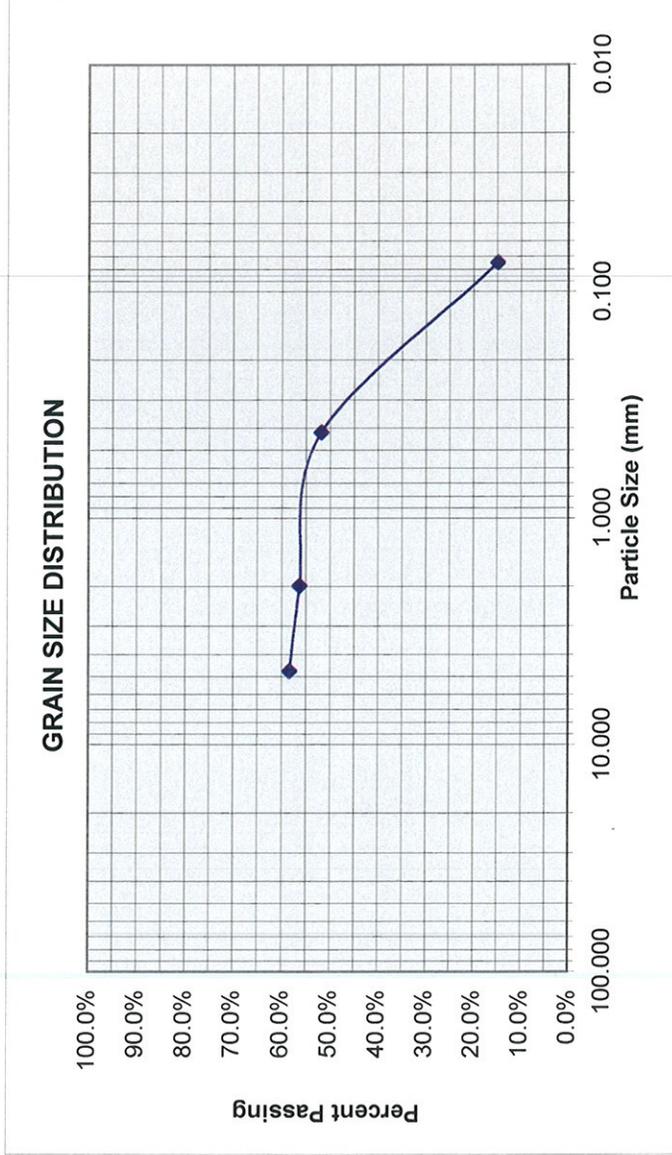
**Soil Classification:** SM

**Average Liquid Limit:** NP

**Plastic Limit:** NP

**Plasticity Index:** NP

Sieve size	Percent (%) Passing
No. 4	58.4%
No. 10	56.4%
No. 40	51.9%
No. 200	15.0%



**REMARKS:**

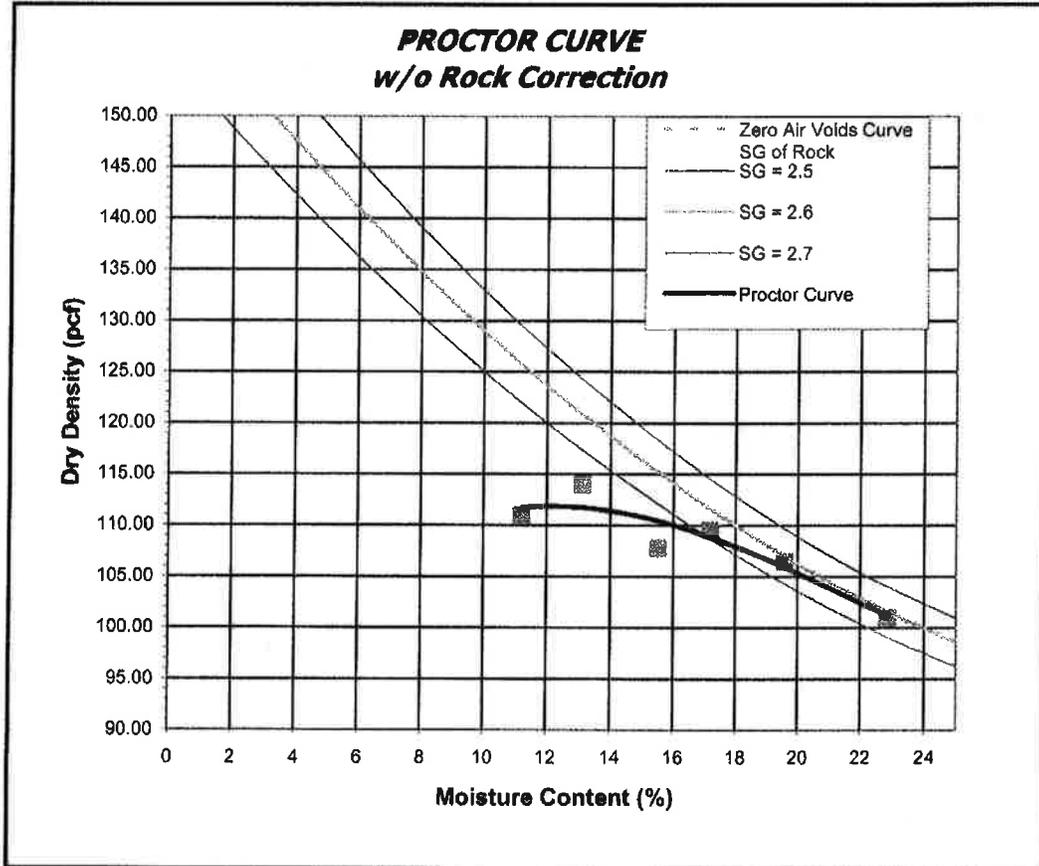
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 Phone (435) 867-6478 ♦ Fax (435) 867-4372  
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Reviewed by:

# Modified Proctor - Moisture Density Relationship

Client:	Alton Coal Development	Date Sampled:	12/30/2014
Project Name:	Alton Coal Mine	Sample Depth:	
Sample Location:	On site stock pile	Test Method:	ASTM D 1557 AASHTO T-180
Soil Description:	Tropic		



Preliminary Density\* 112.0 pcf  
 Preliminary Moisture\* 12.0%

Maximum Dry Density (pcf)	Optimum Moisture
112.0	12.0%

REMARKS: \_\_\_\_\_  
 \_\_\_\_\_

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Reviewed by: \_\_\_\_\_

# Sieve Analysis of Fine and Coarse Aggregates

(Test Methods: ASTM C-136, C-117, AASHTO T27, T11)

Client:	Alton Coal Development		
Project Name:	Alton Coal Mine		
Sample Location:	On site stock pile		Sample Depth: 0
Sample Depth:	0	Date Sampled:	12/30/14

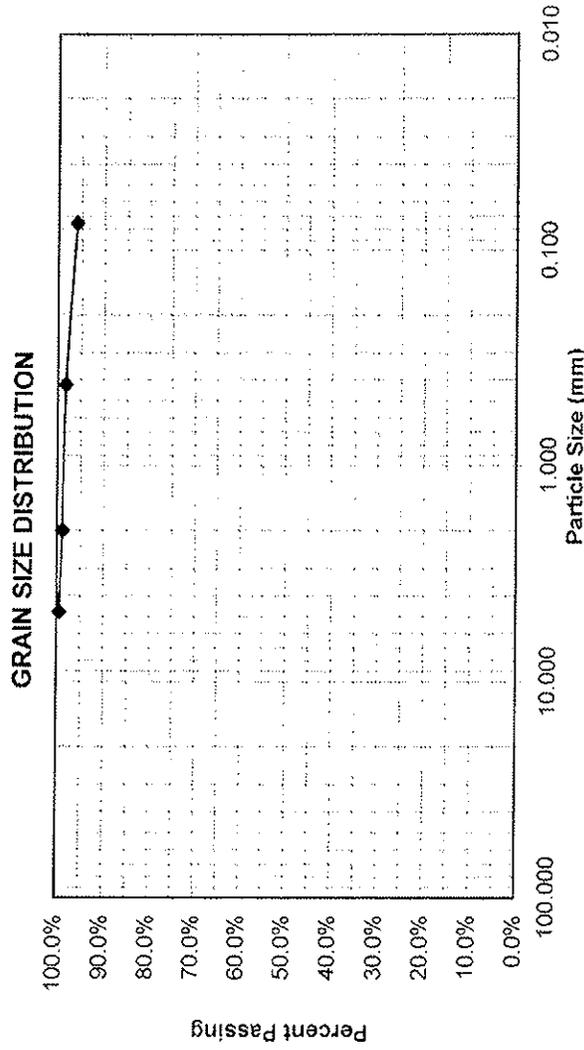
Soil Classification: **CH**

Average Liquid Limit: **112**

Plastic Limit: **29**

Plasticity Index: **83**

Sieve size	Percent (%) Passing
No. 4	99.5%
No. 10	98.9%
No. 40	98.3%
No. 200	96.0%



REMARKS:

**GEM ENGINEERING, INC.**

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Reviewed by:



## Standard Guide for Sample Chain-of-Custody Procedures<sup>1</sup>

This standard is issued under the fixed designation D4840; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This guide contains a comprehensive discussion of potential requirements for a sample chain-of-custody program and describes the procedures involved in sample chain-of-custody. The purpose of these procedures is to provide accountability for and documentation of sample integrity from the time samples are collected until sample disposal.

1.2 These procedures are intended to document sample possession during each stage of a sample's life cycle, that is, during collection, shipment, storage, and the process of analysis.

1.3 Sample chain-of-custody is just one aspect of the larger issue of data defensibility (see 3.2.2 and Appendix X1).

1.4 A sufficient chain-of-custody process, that is, one that provides sufficient evidence of sample integrity in a legal or regulatory setting, is situationally dependent. The procedures presented in this guide are generally considered sufficient to assure legal defensibility of sample integrity. In a given situation, less stringent measures may be adequate. It is the responsibility of the users of this guide to determine their exact needs. Legal counsel may be needed to make this determination.

1.5 Because there is no definitive program that guarantees legal defensibility of data integrity in any given situation, this guide provides a description and discussion of a comprehensive list of possible elements of a chain-of-custody program, all of which have been employed in actual programs but are given as options for the development of a specific chain-of-custody program. In addition, within particular chain-of-custody elements, this guide proscribes certain activities to assure that if these options are chosen, they will be implemented properly.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

<sup>1</sup> This guide is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.02 on Quality Systems, Specification, and Statistics.

Current edition approved Feb. 1, 2010. Published March 2010. Originally approved in 1988. Last previous edition approved in 2004 as D4840 – 99 (2004). DOI: 10.1520/D4840-99R10.

### 2. Referenced Documents

#### 2.1 ASTM Standards:<sup>2</sup>

D1129 Terminology Relating to Water

D3325 Practice for Preservation of Waterborne Oil Samples

D3370 Practices for Sampling Water from Closed Conduits

D3694 Practices for Preparation of Sample Containers and for Preservation of Organic Constituents

D3856 Guide for Management Systems in Laboratories Engaged in Analysis of Water

D4210 Practice for Intralaboratory Quality Control Procedures and a Discussion on Reporting Low-Level Data (Withdrawn 2002)<sup>3</sup>

D4841 Practice for Estimation of Holding Time for Water Samples Containing Organic and Inorganic Constituents

#### 2.2 U.S. EPA Standard:

U.S. EPA Good Automated Laboratory Practices<sup>4</sup>

### 3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminology D1129.

#### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *custody*—physical possession or control. A sample is under custody if it is in possession or under control so as to prevent tampering or alteration of its characteristics.

3.2.2 *data defensibility*—a process that provides sufficient assurance, both legal and technical, that assertions made about a sample and its measurable characteristics can be supported to an acceptable level of certainty. See Appendix X1 for a discussion of the elements of a data defensibility process.

3.2.3 *sample*—a portion of an environmental or source matrix that is collected and used to determine the characteristics of that matrix.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> The last approved version of this historical standard is referenced on www.astm.org.

<sup>4</sup> Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.



3.2.4 *sample chain-of-custody*—a process whereby a sample is maintained under physical possession or control during its entire life cycle, that is, from collection to disposal.

3.2.5 *sample chain-of-custody record*— documentation providing evidence that physical possession or control was maintained during sample chain-of-custody.

#### 4. Summary of Guide

4.1 This guide addresses chain-of-custody procedures as they relate to field practices, shipping methods, and laboratory handling of samples.

#### 5. Significance and Use

5.1 Chain-of-custody procedures are a necessary element in a program to assure one's ability to support data and conclusions adequately in a legal or regulatory situation, but custody documentation alone is not sufficient. A complete data defensibility scheme should be followed.

5.2 In applying the sample chain-of-custody procedures in this guide, it is assumed that all of the other elements of data defensibility have been applied, if applicable.

#### 6. Procedure

6.1 *Facility Chain-of-Custody Standard Operating Procedure*—Each organization should have a chain-of-custody procedure document. This document should spell out in detail the specific procedures utilized at this facility to achieve sample chain-of-custody. It should contain copies of all the forms used in the chain-of-custody process and detailed instructions for their use. It should be kept current and revisions tracked. This guide may serve as a template for the chain-of-custody procedure document.

##### 6.2 *Sample Collection Phase:*

6.2.1 *Custody Assignment*—A single field sampling person should be assigned responsibility for custody of samples. An alternate custodian should also be assigned to cover the prime custodian's absence. As few people as possible should handle samples. The assigned field sampler should be personally responsible for the care and custody of the samples collected until they are properly transferred. While samples are in their custody, field personnel should be able to testify that no one was able to tamper with the samples without their knowledge.

##### 6.2.2 *Documentation/Field Custody Forms:*

6.2.2.1 Standard forms should be designed and available for recording custody information related to field sample handling. The forms may be designed to handle one sample or multiple samples. A single sample form may allow room for laboratory chain-of-custody.

6.2.2.2 In any sampling effort, there is field information related to sample collection and field measurements that are recorded. This information is not specifically part of chain-of-custody, but part of the larger aspect of data defensibility. This information may be recorded on chain-of-custody forms or other forms specific for the purpose. Record keeping may be simplified if separate forms are used.

6.2.2.3 It may be useful to print field forms on polyethylene or other plastic coated paper to keep them from being affected

by water or chemicals. An indelible ink, paint, or crayon should be used to enter information on the forms.

6.2.2.4 Spaces for the following information should be on the form:

- (a) Sample identifying name.
- (b) Sampling location ID, sampling point ID, date, and sampling time interval.
- (c) Signatures of sampling personnel and signatures of all personnel handling and receiving the samples.
- (d) Project identification code (if applicable).
- (e) Preservation (to alert lab personnel): amount and type.
- (f) Number of containers (where field sub-sampling occurs). Indicate number of replicates if there are multiple containers of the same sample.
- (g) Field notes.
- (h) Analyses desired (may be required in some situations).
- (i) Sample type: grab, composite, etc.

Example forms are shown in Appendix X2.

6.2.2.5 Freight bills, post office receipts, and bills of lading should be retained as part of the permanent custody documentation.

##### 6.2.3 *Sample Labeling:*

6.2.3.1 Sample labels may be in the form of adhesive labels or tags, or both. Tags have the advantage of being removable to become part of the record keeping process, although their inadvertent loss or inappropriate removal may leave the sample without documentation. Labels should be made of waterproof paper and indelible ink should be used to make entries. Alternatively, sample information may be written directly on the sample container, as long as the writing can be done indelibly. Containers should be free from other labels and other writing to prevent any confusion. If both tags and labels are used, care should be taken to ensure that the information on both is identical.

6.2.3.2 Labels or tags should be filled out just before or immediately after sample collection. Labels should contain spaces for the following information:

- (a) Project identification code (if applicable).
- (b) Sample identifying name (exactly as it appears on the chain-of-custody record).
- (c) Sampling location ID, sampling point ID, and sampling time interval.
- (d) Safety considerations (if applicable).
- (e) Analysis schedule or schedule code (if applicable).
- (f) Company or agency name.

An example label is shown in Appendix X2.

##### 6.2.4 *Sample Sealing:*

6.2.4.1 Sample custody seals of waterproof adhesive paper may be used to detect unauthorized tampering with samples prior to receipt by the lab. When seals are used, they shall be applied so that it is necessary to break them in order to open the sample container.

6.2.4.2 Electrical (vinyl) tape may be used to prevent bottle closures from loosening in transit. Tape should be applied before any custody seals are applied.

NOTE 1—Electrical tape should not be used to seal vials used for volatile organic analyses due to the potential for sample contamination.

##### 6.2.5 *Field Transfer of Custody and Shipment:*

6.2.5.1 Package samples properly for shipment and transport them to the laboratory for analysis. Special care should be taken when packaging in glass. It is important that all laws and regulations related to the transport of materials have been adequately addressed before shipping samples.

6.2.5.2 When employing a common carrier, the use of padlocks or custody seals on shipping containers should be considered. If padlocks are employed, the keys shall be shipped separately from the samples. Alternatively, padlocks may be sent unfastened to the field and the keys can be retained by the laboratory sample custodian (see 6.3.2.1). A separate custody record should accompany each shipment. Enter the method of shipment, courier name(s), and other pertinent information in the “remarks” section on the custody record.

6.2.5.3 If sent by mail, register the package with return receipt requested.

6.2.5.4 When transferring the possession of samples, the individuals relinquishing and the individuals receiving the samples should sign, date, and note the time on the custody record. Document any opening and closing of the sample containers on the custody record. Provisions should be made for receipt of samples at nonstandard hours, such as nights and weekends by nonlaboratory personnel. Shipping documents, with noted time of receipt and receipt by whom, should be made part of the custody record.

### 6.3 *Laboratory Handling and Analysis Phase:*

#### 6.3.1 *Documentation—Laboratory Custody Forms:*

6.3.1.1 The sample chain-of-custody record in the laboratory is traditionally maintained on paper forms. Based on the data defensibility needs of the organization, it may be possible to maintain the laboratory record in an electronic format. Various computer systems, such as a laboratory information management systems (LIMS) or other electronic data management systems, may meet the data integrity needs. It is the responsibility of each organization to assure that an electronic record system meets these needs. Users of such systems are encouraged to assure compliance of their electronic data system with the U.S. EPA Good Automated Laboratory Practices. All references to laboratory custody record forms in this guide should be understood to refer to either paper or electronic documents.

6.3.1.2 Design a form for the recording of chain-of-custody information related to sample possession in the laboratory. If samples are to be split and distributed to multiple analysts, multiple forms will be needed to accompany the sample splits. Transfer sample identification information to the forms accompanying the splits exactly as it appears on the primary receipt laboratory chain-of-custody form. If an LIMS label is used for the sample splits, a duplicate should be placed on the chain-of-custody form that accompanies them. Example forms are shown in Appendix X2.

#### 6.3.2 *Laboratory Sample Receipt and Handling:*

6.3.2.1 In the laboratory, assign a sample custodian(s) to receive the samples. It is preferable to assign one person the primary responsibility to receive samples as the sample custodian for the laboratory. A second person should serve only as an alternate.

6.3.2.2 Upon receipt of a sample, the custodian should inspect the condition of the sample and the custody sample seal, if used. If sample seals are used, record condition on chain-of-custody record. Reconcile the information on the sample label against that on the chain-of-custody record. The temperature of the samples should be recorded on the chain-of-custody record. If samples are not delivered in a cooler, indicate on record. If pH adjustment to preserve the sample was done in the field, the pH of the samples should be checked and recorded on the chain-of-custody record.

6.3.2.3 If a sample container is leaking, note it on the custody record. The custodian, along with the supervisor responsible for the analytical work, should decide whether the leaky sample is valid. If seals are used, the custodian should examine whether the sample seal is intact or broken, since a broken seal may mean sample tampering and may make analytical results inadmissible as evidence in court. Any discrepancies between the information on the sample label and seal and the information on the chain-of-custody record should be resolved before the sample is assigned for analysis. This effort might require communication with the sample collector. Record the results of any such investigation.

6.3.2.4 After processing the sample, (splitting, logging, preserving) record all sample splits on the laboratory chain-of-custody form. When the sample is logged, the sample identifying information should be transcribed exactly as it appears on the field chain-of-custody form. If custody transfer to analytical staff will not occur immediately or if sample processing is delayed, the samples should be transferred to the custody lockup (see 6.3.3). Record all transfers to and from a lockup on the chain-of-custody form. The custody form should remain with the sample.

#### 6.3.3 *Laboratory Security:*

6.3.3.1 In some situations, legally defensible custody in the laboratory has been achieved without regulating possession within the laboratory but rather by assuring controlled and restricted access to the laboratory facility through keying, guarding access points, and other measures. Sufficiency of security measures for legal defensibility can only be assessed on a case by case basis and should involve legal counsel.

6.3.3.2 Within the laboratory, a secure, locked location (a refrigerator or freezer), if appropriate, should be available. Multiple locations may be necessary to provide access to analysts after they receive their portions of the sample.

6.3.3.3 Limit the number of keys to locked locations and maintain control over them. Limiting keys to laboratory supervisors or providing multiple lockups assigned to specific analysts are appropriate options. Limiting access to samples provides greater security against accidental mishandling of samples.

6.3.3.4 As an alternative to secure lockups, tamperproof seals may also be used in the laboratory. Note any application of seals and their removal on the chain-of-custody forms.

#### 6.3.4 *Analyst Sample Receipt and Handling:*

6.3.4.1 When analytical staff take possession of their samples or sample aliquots, they should acknowledge receipt on the primary laboratory chain-of-custody form.



6.3.4.2 When an analyst takes possession of a sample split, he or she should also receive the accompanying chain-of-custody form. At that time, the analyst should inspect the condition of the sample and the sample seal, if used, and reconcile the information on the sample label against that on the chain-of-custody form.

6.3.4.3 While a sample is in their custody, analysts should be able to testify that no one tampered with the sample without their knowledge. If the sample, a portion of the sample, or processed sample such as a digestate will be held for an extended period of time, the analyst should store it in a security lockup and record all such transfers on the chain-of-custody form.

6.3.4.4 At such time as there is no further need for the sample, it should be disposed of properly and the disposal recorded. If the sample or processed sample is to be retained, it may be transferred to appropriate personnel. This transfer should be recorded on both the analyst custody form and the primary laboratory custody form. The primary custody form then accompanies the sample until its disposal.

#### 6.3.5 *Interlaboratory Transfer:*

6.3.5.1 On some occasions, another laboratory will be performing analytical work that is not directly a part of the project plan, that is, data from this laboratory is not planned to be part of the data defensibility scheme. An example might be when a facility discharge is being monitored and the facility

laboratory wishes a split of the sample. Under these circumstances, the chain-of-custody record remains with the owner. Prepare a receipt (an example receipt is shown in Appendix X2) for these samples and mark to indicate with whom the samples are being split. The person relinquishing the samples to the other laboratory should request the signature of a representative of the appropriate party acknowledging receipt of the samples. If a representative is unavailable or refuses to sign, note this in the “received by” section. Complete this form and give a copy to the owner, operator, or agent in charge. The original is retained by the project supervisor. When appropriate, as in the case where the representative is unavailable, the custody record should contain a statement that the sample splits were delivered to the designated location at a designated time.

6.3.5.2 On some occasions, the sample may have to be split with another laboratory in order to obtain all of the necessary analytical information required in the study plan. In this case, identical chain-of-custody procedures should be employed at the alternate laboratory. Transfer of custody of the split should be handled in like fashion to that used to an intralaboratory transfer (see 6.3.4).

## 7. Keywords

7.1 chain of custody; custody; data defensibility; validation

## APPENDIXES

### (Nonmandatory Information)

#### X1. DISCUSSION OF THE ELEMENTS OF DATA DEFENSIBILITY

X1.1 Data defensibility can be thought of as “proof” that a sample represents the material from which it was taken; that the sample integrity was maintained; that the measurements made on the sample produced valid results; and, that the documentation of the “proof” (custody records, data sheets, etc.) is a factual record. Data defensibility involves the following:

X1.1.1 The use of proper procedures (for sample collection, preservation, analysis, etc.),

X1.1.2 Protection of samples from inappropriate alteration (from tampering, loss, mishandling, etc.), that is, chain-of-custody,

X1.1.3 The use of proper record collection, record handling, and record security procedures, and

X1.1.4 Accurate documentation of all sample related information.

X1.2 There are six principal elements of data defensibility besides chain-of-custody. For a discussion of many of these elements, see Data Validation in Guide D3856.

X1.2.1 *Project Setup and Preparation*—The production of data on environmental and source samples for the purpose of drawing valid conclusions requires good experimental design.

Aspects of the project from sample collection to data interpretation shall be designed from a valid model.

X1.2.2 *Measurement Methods*—Measurements, both field determinations and lab analyses, shall be made using validated techniques with known levels of uncertainty. Use of methods such as those produced by ASTM Committee D19 can provide assurance that the procedures used will produce useful information.

X1.2.3 *Sample Collection Methods*—Sample results can only be as good as the sample analyzed. It is vital that the sample analyzed be representative of the designated variables in the environmental matrix of concern. It should not be inferred that the experimental design is appropriate or representative for any other environmental variables than those designated in the experimental design. Containers shall be made of appropriate materials and properly cleaned. See Practices D3370, specific test methods, and other practices related to sampling procedures for more information.

X1.2.4 *Sample Processing and Handling Methods*—During the course of a sample’s life cycle, a variety of sample processing techniques shall be employed, such as sample splitting and preservation. Valid procedures shall be employed

to maintain sample integrity. See Practices D4841, D3694, D3325, and specific test methods for more information.

**X1.2.5 Data Recording, Archiving, and Retrieval Methods**—Information collected and observations made shall be correctly, legibly, and safely recorded. After a project is completed and information recorded, it is important that this record be safe from tampering and can be reliably retrieved.

**X1.2.6 Quality Control and Quality Assurance Procedures**—During stages of information generation, processes shall be maintained in a state of statistical control so that data uncertainties can be quantified. In addition, there shall be an “external” audit procedure to assure that the quality control procedures are effective. See Guide D3856, Practice D4210, and specific test methods for more information.

**X2. EXAMPLE FORMS**

X2.1 See sample forms in Figs. X2.1-X2.5.

COMPANY/OWNER _____	
ADDRESS _____	
AGENCY/CONTRACTOR _____	
TAKING SAMPLE _____	
PHONE NUMBER _____	
HAZARD WARNING	<input type="checkbox"/> SKIN <input type="checkbox"/> EYES
	<input type="checkbox"/> POSSIBLE CARCINOGEN <input type="checkbox"/> FLAMMABLE
HAZARD REMARKS _____	

(front side of tag)

PROJECT CODE		STATION NO.		MO/DAY/YR.		TIME		DESIGNATE		
								COMP	GRAB	
STATION LOCATION				SAMPLERS SIGNATURE						
TAG NO.	REMARKS								PRESERVATION YES ___ NO ___	
LAB SAMPLE NO.										

(back side of tag)

**FIG. X2.1 Example of Sample Identification Tag**





Side 1

**FIELD SAMPLE COLLECTION CHAIN-OF-CUSTODY FORM**

**A. Field Record**

Field Sample Identification: \_\_\_\_\_ No. Containers: \_\_\_\_\_ Project No.: \_\_\_\_\_ Sampling Location: \_\_\_\_\_  
Collected By: \_\_\_\_\_ Witness: \_\_\_\_\_ Date(s): \_\_\_\_\_ Time(s): \_\_\_\_\_  
Preservation: \_\_\_\_\_ Tins: \_\_\_\_\_

**B. Transfer Record**

Relinquished By	Received By	Date	Time	Sample Condition/Observations

**LABORATORY SAMPLE RECEIPT CHAIN-OF-CUSTODY FORM**

**A. Logging:** Lab Sample I.D.: \_\_\_\_\_ By: \_\_\_\_\_ Date: \_\_\_\_\_ Time: \_\_\_\_\_

**B. Transfer Record:** (within sample receipt area)

Action	Delivered To	By	Date	Time	Cooler Access By

- Permitted Actions:
1. Sample/subsample to locked cooler
  2. Sample/subsample from locked cooler
  3. Person to person custody transfer of samples/subsamples
  4. Dispose of sample/subsample

**C. Subsampling:** by \_\_\_\_\_ Date: \_\_\_\_\_ Time: \_\_\_\_\_

**D. Transfer to Analytical Lab**

Aliquot	Analysis	Preservation	Container
0**			
1			
2			
3			
4			
5			
6			

Delivered By	Received By	Date	Time

\*\*For use when field sample is not subsampled

**NOTE: ALL NAMES ON THIS FORM MUST BE ENTERED AS ORIGINAL SIGNATURES**

**NOTE: DELIVER A PHOTOCOPY OF THIS FORM (2 SIDED) WITH EACH ALIQUOT.**

**FIG. X2.4 Example Field, Laboratory Receipt, and Laboratory Sample Chain-of-Custody Record (Two-Sided)**



Side 2

**LABORATORY ANALYTICAL AREA CHAIN-OF-CUSTODY FORM**

**NOTE: ALL NAMES ON THIS FORM MUST BE ENTERED AS ORIGINAL SIGNATURES**

**A. Condition At Receipt:** \_\_\_\_\_  
\_\_\_\_\_

Place computer label here

**B. Handling/Transfer Record**

Action	Delivered To	Delivered By	Date	Time	Cooler Access By

Additional Notes: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Potential Actions:**

- |  |  |
|--|--|
| 1. Sample/subsamples to locked cooler                      | 5. Re-analysis of aliquot.                                 |
| 2. Sample/subsamples from locked cooler (indicate purpose) | 6. Person-to-person custody transfer of samples/subsamples |
| 3. Sample alterations (specify)                            | 7. Disposal of sample/subsamples                           |
| 4. Subsampling of aliquot.                                 |  |

**FIG. X2.5 Side Two of Custody Record**

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Designation: D 1557 – 02<sup>ε1</sup>

## Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft<sup>3</sup> (2,700 kN-m/m<sup>3</sup>))<sup>1</sup>

This standard is issued under the fixed designation D 1557; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

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<sup>ε1</sup> NOTE—Paragraph 10.4.3 was corrected editorially in November 2003.

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### 1. Scope\*

1.1 These test methods cover laboratory compaction methods used to determine the relationship between water content and dry unit weight of soils (compaction curve) compacted in a 4- or 6-in. (101.6 or 152.4 mm) diameter mold with a 10-lbf. (44.5-N) rammer dropped from a height of 18 in. (457 mm) producing a compactive effort of 56,000 ft-lbf/ft<sup>3</sup> (2,700 kN-m/m<sup>3</sup>)

weight may not be well defined, and can be less than obtained using Test Methods D 4253.

1.6 The values in inch-pound units are to be regarded as the standard. The values stated in SI units are provided for information only.

1.6.1 In the engineering profession it is customary practice to use, interchangeably, units representing both mass and force, unless dynamic calculations ( $F = Ma$ ) are involved. This implicitly combines two separate systems of units, that is, the absolute system and the gravimetric system. It is scientifically undesirable to combine the use of two separate systems within a single standard. This test method has been written using inch-pound units (gravimetric system) where the pound (lbf) represents a unit of force. The use of mass (lbm) is for convenience of units and is not intended to convey the use is scientifically correct. Conversions are given in the SI system in accordance with IEEE/ASTM SI 10. The use of balances or scales recording pounds of mass (lbm), or the recording of density in lbm/ft<sup>3</sup> should not be regarded as nonconformance with this standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

### 2.1 ASTM Standards:

- C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate<sup>2</sup>
- C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates<sup>2</sup>
- D 422 Test Method for Particle-Size Analysis of Soils<sup>3</sup>
- D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>3</sup>
- D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft-lbf/ft<sup>3</sup> (600 kN-m/m<sup>3</sup>)]<sup>3</sup>
- D 854 Test Method for Specific Gravity of Soils<sup>3</sup>
- D 2168 Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors<sup>3</sup>
- D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass<sup>3</sup>
- D 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)<sup>3</sup>
- D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)<sup>3</sup>
- D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction<sup>3</sup>
- D 4220 Practices for Preserving and Transporting Soil Samples<sup>3</sup>
- D 4253 Test Methods for Maximum Index Density of Soils Using a Vibratory Table<sup>3</sup>
- D 4718 Practice for Correction of Unit Weight and Water

Content for Soils Containing Oversize Particles<sup>3</sup>

- D 4753 Specification for Evaluating, Selecting and Specifying Balances and Scales For Use in Soil, Rock, and Construction Materials Testing<sup>3</sup>
- D 4914 Test Methods for Density of Soil and Rock in Place by the Sand Replacement Method in a Test Pit<sup>3</sup>
- D 5030 Test Method for Density of Soil and Rock in Place by the Water Replacement Method in a Test Pit<sup>4</sup>
- E 1 Specification for ASTM Thermometers<sup>5</sup>
- E 11 Specification for Wire-Cloth Sieves for Testing Purposes<sup>5</sup>
- E 319 Practice for the Evaluation of Single-Pan Mechanical Balances<sup>5</sup>
- IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System

## 3. Terminology

3.1 *Definitions*—See Terminology D 653 for general definitions.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *modified effort*—the term for the 56 000 ft-lbf/ft<sup>3</sup> (2700 kN-m/m<sup>3</sup>) compactive effort applied by the equipment and methods of this test.

3.2.2 *modified maximum dry unit weight,  $\gamma_{dmax}$*  (lbf/ft<sup>3</sup>(kN/m<sup>3</sup>))—the maximum value defined by the compaction curve for a compaction test using modified effort.

3.2.3 *modified optimum water content,  $w_o$*  (%)—the water content at which the soil can be compacted to the maximum dry unit weight using modified compactive effort.

3.2.4 *oversize fraction (coarse fraction),  $P_c$*  (%)—the portion of total sample not used in performing the compaction test; it may be the portion of total sample retained on the No. 4 (4.75-mm), 3/8-in. (9.5-mm), or 3/4-in. (19.0-mm) sieve.

3.2.5 *test fraction (finer fraction),  $P_F$*  (%)—the portion of the total sample used in performing the compaction test; it may be fraction passing the No. 4 (4.75-mm) sieve in Method A, minus 3/8-in. (9.5-mm) sieve in Method B, or minus 3/4-in. (19.0-mm) sieve in Method C.

## 4. Summary of Test Method

4.1 A soil at a selected water content is placed in five layers into a mold of given dimensions, with each layer compacted by 25 or 56 blows of a 10-lbf (44.5-N) rammer dropped from a distance of 18-in. (457-mm), subjecting the soil to a total compactive effort of about 56 000 ft-lbf/ft<sup>3</sup> (2700 kN-m/m<sup>3</sup>). The resulting dry unit weight is determined. The procedure is repeated for a sufficient number of water contents to establish a relationship between the dry unit weight and the water content for the soil. This data, when plotted, represent a curvilinear relationship known as the compaction curve. The values of optimum water content and modified maximum dry unit weight are determined from the compaction curve.

## 5. Significance and Use

5.1 Soil placed as engineering fill (embankments, foundation pads, road bases) is compacted to a dense state to obtain

<sup>2</sup> Annual Book of ASTM Standards, Vol 04.02.

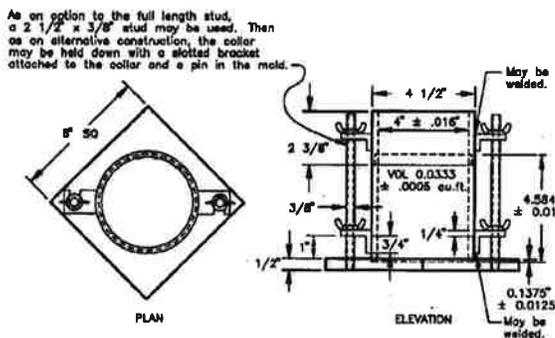
<sup>3</sup> Annual Book of ASTM Standards, Vol 04.08.

<sup>4</sup> Annual Book of ASTM Standards, Vol 04.09.

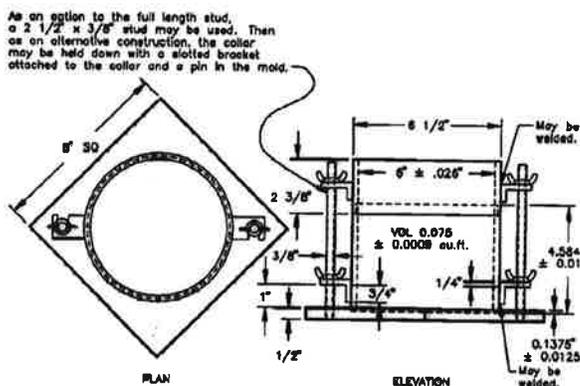
<sup>5</sup> Annual Book of ASTM Standards, Vol 14.02.

satisfactory engineering properties such as, shear strength, compressibility, or permeability. Also, foundation soils are often compacted to improve their engineering properties. Laboratory compaction tests provide the basis for determining the percent compaction and water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved.

5.2 During design of an engineered fill, shear, consolidation, permeability, or other tests require preparation of test specimens by compacting at some water content to some unit weight. It is common practice to first determine the optimum water content ( $w_o$ ) and maximum dry unit weight ( $\gamma_{dmax}$ ) by means of a compaction test. Test specimens are compacted at a selected water content ( $w$ ), either wet or dry of optimum ( $w_o$ ) or at optimum ( $w_o$ ), and at a selected dry unit weight related to a percentage of maximum dry unit weight ( $\gamma_{dmax}$ ). The selection of water content ( $w$ ), either wet or dry of optimum ( $w_o$ ) or at optimum ( $w_o$ ) and the dry unit weight ( $\gamma_{dmax}$



NOTE 1—See Table 2 for metric equivalents.  
FIG. 1 Cylindrical Mold, 4.0-in.



NOTE 1—See Table 2 for metric equivalents.  
FIG. 2 Cylindrical Mold, 6.0-in.

ft<sup>3</sup> (944 ± 14 cm<sup>3</sup>). A mold assembly having the minimum required features is shown in Fig. 1.

6.1.2 *Mold, 6 in.*—A mold having a 6.000 ± 0.026 in. (152.4 ± 0.7 mm) average inside diameter, a height of 4.584 ± 0.018 in. (116.4 ± 0.5 mm), and a volume of 0.075 ± 0.0009 ft<sup>3</sup> (2124 ± 25 cm<sup>3</sup>). A mold assembly having the minimum required features is shown in Fig. 2.

6.2 *Rammer*—A rammer, either manually operated as described further in 6.2.1 or mechanically operated as described in 6.2.2. The rammer shall fall freely through a distance of 18 ± 0.05 in. (457.2 ± 1.3 mm) from the surface of the specimen. The mass of the rammer shall be 10 ± 0.02 lbm (4.54 ± 0.01 kg), except that the mass of the mechanical rammers may be adjusted as described in Test Methods D 2168 (see Note 7). The striking face of the rammer shall be planar and circular, except as noted in 6.2.2.1, with a diameter when new of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). The rammer shall be replaced if the striking face becomes worn or bellied to the extent that the diameter exceeds 2.000 ± 0.01 in. (50.80 ± 0.25 mm).

NOTE 7—It is a common and acceptable practice in the inch-pound system to assume that the mass of the rammer is equal to its mass determined using either a kilogram or pound balance and 1 lbf is equal to 1 lbm or 0.4536 kg or 1 N is equal to 0.2248 lbm or 0.1020 kg.

6.2.1 *Manual Rammer*—The rammer shall be equipped with a guide sleeve that has sufficient clearance that the free

fall of the rammer shaft and head is not restricted. The guide sleeve shall have at least four vent holes at each end (eight holes total) located with centers 3/4 ± 1/16 in. (19.0 ± 1.6 mm) from each end and spaced 90° apart. The minimum diameter of the vent holes shall be 3/8 in. (9.5 mm). Additional holes or slots may be incorporated in the guide sleeve.

6.2.2 *Mechanical Rammer-Circular Face*—The rammer shall operate mechanically in such a manner as to provide uniform and complete coverage of the specimen surface. There shall be 0.10 ± 0.03-in. (2.5 ± 0.8-mm) clearance between the rammer and the inside surface of the mold at its smallest diameter. The mechanical rammer shall meet the calibration requirements of Test Methods D 2168. The mechanical rammer shall be equipped with a positive mechanical means to support the rammer when not in operation.

6.2.2.1 *Mechanical Rammer-Sector Face*—When used with the 6.0-in. (152.4-mm) mold, a sector face rammer may be used in place of the circular face rammer. The specimen contact face shall have the shape of a sector of a circle of radius equal to 2.90 ± 0.02 in. (73.7 ± 0.5 mm). The rammer shall operate in such a manner that the vertex of the sector is positioned at the center of the specimen.

6.3 *Sample Extruder (optional)*—A jack, frame or other device adapted for the purpose of extruding compacted specimens from the mold.

6.4 *Balance*—A class GP5 balance meeting the requirements of Specification D 4753 for a balance of 1-g readability.

6.5 *Drying Oven*—Thermostatically controlled, preferably of a forced-draft type and capable of maintaining a uniform temperature of  $230 \pm 9^\circ\text{F}$  ( $110 \pm 5^\circ\text{C}$ ) throughout the drying chamber.

6.6 *Straightedge*—A stiff metal straightedge of any convenient length but not less than 10 in. (254 mm). The total length of the straightedge shall be machined straight to a tolerance of  $\pm 0.005$  in. ( $\pm 0.1$  mm). The scraping edge shall be beveled if it is thicker than  $\frac{1}{8}$  in. (3 mm).

6.7 *Sieves*— $\frac{3}{4}$  in. (19.0 mm),  $\frac{3}{8}$  in. (9.5 mm), and No. 4 (4.75 mm), conforming to the requirements of Specification E 11.

6.8 *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, spray bottle, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

## 7. Calibration

7.1 Perform calibrations before initial use, after repairs or other occurrences that might affect the test results, at intervals not exceeding 1000 test specimens, or annually, whichever occurs first, for the following apparatus:

7.1.1 *Balance*—Evaluate in accordance with Specification D 4753.

7.1.2 *Molds*—Determine the volume as described in Annex A1.

7.1.3 *Manual Rammer*—Verify the free fall distance, rammer mass, and rammer face in accordance with 6.2. Verify the guide sleeve requirements in accordance with 6.2.1.

7.1.4 *Mechanical Rammer*—Calibrate and adjust the mechanical rammer in accordance with Test Methods D 2168. In addition, the clearance between the rammer and the inside surface of the mold shall be verified in accordance with 6.2.2.

## 8. Test Sample

8.1 The required sample mass for Methods A and B is approximately 35 lbm (16 kg), and for Method C is approximately 65 lbm (29 kg) of dry soil. Therefore, the field sample should have a moist mass of at least 50 lbm (23 kg) and 100 lbm (45 kg), respectively.

8.2 Determine the percentage of material (by mass) retained on the No. 4 (4.75-mm),  $\frac{3}{8}$ -in. (9.5-mm), or  $\frac{3}{4}$ -in. (19.0-mm) sieve as appropriate for choosing Method A, B, or C. Make this determination by separating out a representative portion from the total sample and determining the percentages passing the sieves of interest by Test Methods D 422 or C 136. It is only necessary to calculate percentages for the sieve or sieves for which information is desired.

## 9. Preparation of Apparatus

9.1 Select the proper compaction mold in accordance with the Method (A, B, or C) being used. Determine and record its mass to the nearest gram. Assemble the mold, base and extension collar. Check the alignment of the inner wall of the mold and mold extension collar. Adjust if necessary.

9.2 Check that the rammer assembly is in good working condition and that parts are not loose or worn. Make any

necessary adjustments or repairs. If adjustments or repairs are made, the rammer must be recalibrated.

## 10. Procedure

### 10.1 Soils:

10.1.1 Do not reuse soil that has been previously compacted in the laboratory.

10.1.2 When using this test method for soils containing hydrated halloysite, or where past experience with a particular soil indicates that results will be altered by air drying, use the moist preparation method (see 10.2).

10.1.3 Prepare the soil specimens for testing in accordance with 10.2 (preferred) or with 10.3.

10.2 *Moist Preparation Method (preferred)*—Without previously drying the sample, pass it through a No. 4 (4.75-mm),  $\frac{3}{8}$ -in. (9.5-mm), or  $\frac{3}{4}$ -in. (19.0-mm) sieve, depending on the Method (A, B, or C) being used. Determine the water content of the processed soil.

10.2.1 Prepare at least four (preferably five) specimens having water contents such that they bracket the estimated optimum water content. A specimen having a water content close to optimum should be prepared first by trial additions of water and mixing (see Note 8). Select water contents for the rest of the specimens to provide at least two specimens wet and two specimens dry of optimum, and water contents varying by about 2 %. At least two water contents are necessary on the wet and dry side of optimum to accurately define the dry unit weight compaction curve (see 10.5). Some soils with very high optimum water content or a relatively flat compaction curve may require larger water content increments to obtain a well defined maximum dry unit weight. Water content increments should not exceed 4 %.

Note 8—With practice it is usually possible to visually judge a point near optimum water content. Typically, soil at optimum water content can be squeezed into a lump that sticks together when hand pressure is released, but will break cleanly into two sections when “bent”. At water contents dry of optimum soils tend to crumble; wet of optimum soils tend to stick together in a sticky cohesive mass. Optimum water content is typically slightly less than the plastic limit.

10.2.2 Use approximately 5 lbm (2.3 kg) of the sieved soil for each specimen to be compacted using Method A or B, or 13 lbm (5.9 kg) using Method C. To obtain the specimen water contents selected in 10.2.1, add or remove the required amounts of water as follows: to add water, spray it into the soil during mixing; to remove water, allow the soil to dry in air at ambient temperature or in a drying apparatus such that the temperature of the sample does not exceed  $140^\circ\text{F}$  ( $60^\circ\text{C}$ ). Mix the soil frequently during drying to maintain even water content distribution. Thoroughly mix each specimen to ensure even distribution of water throughout and then place in a separate covered container and allow to stand in accordance with Table 1 prior to compaction. For the purpose of selecting

**TABLE 1 Required Standing Times of Moisturized Specimens**

Classification	Minimum Standing Time, h
GW, GP, SW, SP	no requirement
GM, SM	3
All other soils	16

a standing time, the soil may be classified by Test Method D 2487, Practice D 2488 or data on other samples from the same material source. For referee testing, classification shall be by Test Method D 2487.

10.3 *Dry Preparation Method*—If the sample is too damp to be friable, reduce the water content by air drying until the material is friable. Drying may be in air or by the use of drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). Thoroughly break up the aggregations in such a manner as to avoid breaking individual particles. Pass the material through the appropriate sieve: No. 4 (4.75 mm), 3/8 in. (9.5 mm), or 3/4 in. (19.0–mm). When preparing the material by passing over the 3/4-in. sieve for compaction in the 6 in.-mold, break up aggregations sufficiently to at least pass the 3/8 in. sieve in order to facilitate the distribution of water throughout the soil in later mixing.

10.3.1 Prepare at least four (preferably five) specimens in accordance with 10.2.1.

10.3.2 Use approximately 5 lbm (2.3 kg) of the sieved soil for each specimen to be compacted using Procedure A or B, or 13 lbm (5.9 kg) using Method C. Add the required amounts of water to bring the water contents of the specimens to the values selected in 10.3.1. Follow the specimen preparation procedure specified in 10.2.2 for drying the soil or adding water into the soil and curing each test specimen.

10.4 *Compaction*—After curing, if required, each specimen shall be compacted as follows:

10.4.1 Determine and record the mass of the mold or mold and base plate.

10.4.2 Assemble and secure the mold and collar to the base plate. The mold shall rest on a uniform rigid foundation, such as provided by a cylinder or cube of concrete with a mass of not less than 200 lbm (91 kg). Secure the base plate to the rigid foundation. The method of attachment to the rigid foundation shall allow easy removal of the assembled mold, collar and base plate after compaction is completed.

10.4.3 Compact the specimen in five layers. After compaction, each layer should be approximately equal in thickness.

Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a fluffy or loose state, using either the manual compaction rammer or a 2 in. (50.8-mm) diameter cylinder. Following compaction of each of the first four layers, any soil adjacent to the mold walls that has not been compacted or extends above the compacted surface shall be trimmed. The trimmed soil may be included with the additional soil for the next layer. A knife or other suitable device may be used. The total amount of soil used shall be such that the fifth compacted layer slightly extends into the collar, but does not exceed 1/4 in. (6 mm) above the top of the mold. If the fifth layer does extend above the top of the mold by more than 1/4 in. (6 mm), the specimen shall be discarded. The specimen shall be discarded when the last blow on the rammer for the fifth layer results in the bottom of the rammer extending below the top of the compaction mold.

10.4.4 Compact each layer with 25 blows for the 4 in. (101.6 mm) mold or with 56 blows for the 6 in. (152.4 mm) mold.

NOTE 9—When compacting specimens wetter than optimum water content, uneven compacted surfaces can occur and operator judgment is required as to the average height of the specimen.

10.4.5 In operating the manual rammer, take care to avoid lifting the guide sleeve during the rammer upstroke. Hold the guide sleeve steady and within 5° of vertical. Apply the blows at a uniform rate of approximately 25 blows/min and in such a manner as to provide complete, uniform coverage of the specimen surface.

10.4.6 Following compaction of the last layer, remove the collar and base plate from the mold, except as noted in 10.4.7. A knife may be used to trim the soil adjacent to the collar to loosen the soil from the collar before removal to avoid disrupting the soil below the top of the mold.

10.4.7 Carefully trim the compacted specimen even with the top and bottom of the mold by means of the straightedge scraped across the top and bottom of the mold to form a plane surface even with the top and bottom of the mold. Initial trimming of the specimen above the top of the mold with a knife may prevent tearing out soil below the top of the mold. Fill any holes in either surface with unused or trimmed soil from the specimen, press in with the fingers, and again scrape the straightedge across the top and bottom of the mold. Repeat the appropriate preceding operations on the bottom of the specimen when the mold volume was determined without the base plate. For very wet or dry soils, soil or water may be lost if the base plate is removed. For these situations, leave the base plate attached to the mold. When the base plate is left attached, the volume of the mold must be calibrated with the base plate attached to the mold rather than a plastic or glass plate as noted in Annex A1 (A1.4.1).

10.4.8 Determine and record the mass of the specimen and mold to the nearest gram. When the base plate is left attached, determine and record the mass of the specimen, mold and base plate to the nearest gram.

10.4.9 Remove the material from the mold. Obtain a specimen for water content by using either the whole specimen (preferred method) or a representative portion. When the entire

**TABLE 2 Metric Equivalents for Figs. 1 and 2**

in.	mm
0.016	0.41
0.026	0.66
0.032	0.81
0.028	0.71
1/2	12.70
2 1/2	63.50
2 3/4	66.70
4	101.60
4 1/2	114.30
4.584	116.43
4 3/4	120.60
6	152.40
6 1/2	165.10
6 3/4	168.30
6 3/4	171.40
8 1/4	208.60
ft <sup>3</sup>	cm <sup>3</sup>
1/30 (0.0333)	943
0.0005	14
1/13.333 (0.0750)	2,124
0.0011	31

specimen is used, break it up to facilitate drying. Otherwise, obtain a portion by slicing the compacted specimen axially through the center and removing about 500 g of material from the cut faces. Obtain the water content in accordance with Test Method D 2216.

10.5 Following compaction of the last specimen, compare the wet unit weights to ensure that a desired pattern of obtaining data on each side of the optimum water content will be attained for the dry unit weight compaction curve. Plotting the wet unit weight and water content of each compacted specimen can be an aid in making the above evaluation. If the desired pattern is not obtained, additional compacted specimens will be required. Generally, one water content value wet of the water content defining the maximum wet unit weight is sufficient to ensure data on the wet side of optimum water content for the maximum dry unit weight.

**11. Calculation**

11.1 Calculate the dry unit weight and water content of each compacted specimen as explained in 11.3 and 11.4. Plot the values and draw the compaction curve as a smooth curve through the points (see example, Fig. 3). Plot dry unit weight to the nearest 0.1 lb/ft<sup>3</sup> (0.2 kN/m<sup>3</sup>) and water content to the nearest 0.1 %. From the compaction curve, determine the optimum water content and maximum dry unit weight. If more than 5 % by weight of oversize material was removed from the sample, calculate the corrected optimum water content and corrected maximum dry unit weight of the total material using Practice D 4718. This correction may be made to the appropriate field in place density test specimen rather than to the laboratory test specimen.

11.2 Plot the 100 % saturation curve. Values of water content for the condition of 100 % saturation can be calculated as explained in 11.5 (see example, Fig. 3).

NOTE 10—The 100 % saturation curve is an aid in drawing the compaction curve. For soils containing more than approximately 10 % fines at water contents well above optimum, the two curves generally become roughly parallel with the wet side of the compaction curve between 92 % to 95 % saturation. Theoretically, the compaction curve cannot plot to the right of the 100 % saturation curve. If it does, there is an error in specific gravity, in measurements, in calculations, in testing, or in plotting.

NOTE 11—The 100 % saturation curve is sometimes referred to as the zero air voids curve or the complete saturation curve.

11.3 *Water Content, w*—Calculate in accordance with Test Method D 2216.

11.4 *Dry Unit Weights*—Calculate the moist density (Eq 1), the dry density (Eq 2), and then the dry unit weight (Eq 3) as follows:

$$\rho_m = \frac{(M_t - M_{md})}{1000 V} \tag{1}$$

where:

- $\rho_m$  = moist density of compacted specimen, Mg/m<sup>3</sup>,
- $M_t$  = mass of moist specimen and mold, kg,
- $M_{md}$  = mass of compaction mold, kg, and
- $V$  = volume of compaction mold, m<sup>3</sup>(see Annex A1).

$$\rho_d = \frac{\rho_m}{1 + \frac{w}{100}} \tag{2}$$

where:

- $\rho_d$  = dry density of compacted specimen, Mg/m<sup>3</sup>, and

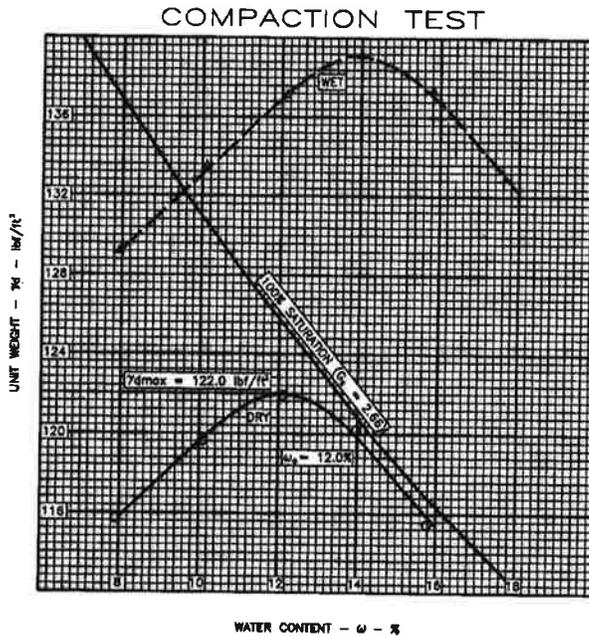


FIG. 3 Example Compaction Curve Plotting

$w$  = water content, % .

$$\gamma_d = 62.43 \rho_d \text{ in lbf/ft}^3 \quad (3)$$

or

$$\gamma_d = 9.807 \rho_d \text{ in kN/m}^3$$

where:

$\gamma_d$  = dry unit weight of compacted specimen.

11.5 To calculate points for plotting the 100 % saturation curve or zero air voids curve select values of dry unit weight, calculate corresponding values of water content corresponding to the condition of 100 % saturation as follows:

$$w_{\text{sat}} = \frac{(\gamma_w)G_s - \gamma_d}{(\gamma_d)(G_s)} \times 100 \quad (4)$$

where:

$w_{\text{sat}}$  = water content for complete saturation, %,

$\gamma_w$  = unit weight of water, 62.32 lbf/ft<sup>3</sup>(9.789 kN/m<sup>3</sup>) at 20°C,

$\gamma_d$  = dry unit weight of soil, lbf/ft (kN/m<sup>3</sup>), and

$G_s$  = specific gravity of soil.

NOTE 12—Specific gravity may be estimated for the test specimen on the basis of test data from other samples of the same soil classification and source. Otherwise, a specific gravity test (Test Method D 854) is necessary.

## 12. Report

12.1 Report the following information:

12.1.1 Method used (A, B, or C).

12.1.2 Preparation method used (moist or dry).

12.1.3 As-received water content, if determined.

12.1.4 Modified optimum water content, to the nearest 0.5 %.

12.1.5 Modified maximum (optimum) dry unit weight, to the nearest 0.5 lbf/ft<sup>3</sup>.

12.1.6 Description of rammer (manual or mechanical).

12.1.7 Soil sieve data when applicable for determination of Method (A, B, or C) used.

12.1.8 Description of material used in test, by Practice D 2488, or classification by Test Method D 2487.

12.1.9 Specific gravity and method of determination.

12.1.10 Origin of material used in test, for example, project, location, depth, and the like.

12.1.11 Compaction curve plot showing compaction points used to establish compaction curve, and 100 % saturation curve, point of maximum dry unit weight and optimum water content.

12.1.12 Oversize correction data if used, including the oversize fraction (coarse fraction),  $P_c$  in %.

## 13. Precision and Bias

13.1 *Precision*—Data are being evaluated to determine the precision of this test method. In addition, pertinent data is being solicited from users of the test method.

13.2 *Bias*—It is not possible to obtain information on bias because there is no other method of determining the values of modified maximum dry unit weight and optimum water content.

## 14. Keywords

14.1 compaction characteristics; density; impact compaction using modified effort; laboratory tests; modified proctor test; moisture-density curves; soil compaction

# ANNEX

## (Mandatory Information)

### A1. VOLUME OF COMPACTION MOLD

#### A1.1 Scope

A1.1.1 This annex describes the method for determining the volume of a compaction mold.

A1.1.2 The volume is determined by a water-filled method and checked by a linear-measurement method.

#### A1.2 Apparatus

A1.2.1 In addition to the apparatus listed in Section 6, the following items are required:

A1.2.1.1 *Vernier or Dial Caliper*, having a measuring range of at least 0 to 6 in. (0 to 150 mm) and readable to at least 0.001 in. (0.02 mm).

A1.2.1.2 *Inside Micrometer*, having a measuring range of at least 2 to 12 in. (50 to 300 mm) and readable to at least 0.001 in. (0.02 mm).

A1.2.1.3 *Plastic or Glass Plates*—Two plastic or glass plates about 8 in.<sup>2</sup> by ¼ in. thick (200 mm<sup>2</sup> by 6 mm).

A1.2.1.4 *Thermometer*—0 to 50°C range, 0.5°C graduations, conforming to the requirements of Specification E 1.

A1.2.1.5 *Stopcock Grease* or similar sealant.

A1.2.1.6 *Miscellaneous equipment*—Bulb syringe, towels, etc.

#### A1.3 Precautions

A1.3.1 Perform this method in an area isolated from drafts or extreme temperature fluctuations.

#### A1.4 Procedure

A1.4.1 *Water-Filling Method*:

A1.4.1.1 Lightly grease the bottom of the compaction mold and place it on one of the plastic or glass plates. Lightly grease the top of the mold. Be careful not to get grease on the inside of the mold. If it is necessary to use the base plate, as noted in 10.4.7, place the greased mold onto the base plate and secure with the locking studs.

A1.4.1.2 Determine the mass of the greased mold and both plastic or glass plates to the nearest 0.01 lbm (1 g) and record. When the base plate is being used in lieu of the bottom plastic

or glass plate determine the mass of the mold, base plate and a single plastic or glass plate to be used on top of the mold to the nearest 0.01 lbm (1 g) and record.

A1.4.1.3 Place the mold and the bottom plate on a firm, level surface and fill the mold with water to slightly above its rim.

A1.4.1.4 Slide the second plate over the top surface of the mold so that the mold remains completely filled with water and air bubbles are not entrapped. Add or remove water as necessary with a bulb syringe.

A1.4.1.5 Completely dry any excess water from the outside of the mold and plates.

A1.4.1.6 Determine the mass of the mold, plates and water and record to the nearest 0.01 lbm (1 g).

A1.4.1.7 Determine the temperature of the water in the mold to the nearest 1°C and record. Determine and record the absolute density of water from Table A1.1.

A1.4.1.8 Calculate the mass of water in the mold by subtracting the mass determined in A1.4.1.2 from the mass determined in A1.4.1.6.

A1.4.1.9 Calculate the volume of water by dividing the mass of water by the density of water and record to the nearest 0.0001 ft<sup>3</sup> (1 cm<sup>3</sup>).

A1.4.1.10 When the base plate is used for the calibration of the mold volume repeat steps A1.4.1.3-A1.4.1.9.

**A1.4.2 Linear Measurement Method:**

A1.4.2.1 Using either the vernier caliper or the inside micrometer, measure the diameter of the mold six times at the

top of the mold and six times at the bottom of the mold spacing each of the six top and bottom measurements equally around the circumference of the mold. Record the values to the nearest 0.001 in. (0.02 mm).

A1.4.2.2 Using the vernier caliper, measure the inside height of the mold by making three measurements equally spaced around the circumference of the mold. Record values to the nearest 0.001 in. (0.02 mm).

A1.4.2.3 Calculate the average top diameter, average bottom diameter and average height.

A1.4.2.4 Calculate the volume of the mold and record to the nearest 0.0001 ft<sup>3</sup> (1 cm<sup>3</sup>) using Eq A1.1 (for inch-pound) or Eq A1.2 (for SI):

$$V = \frac{(\pi)(h)(d_t + d_b)^2}{(16)(1728)} \tag{A1.1}$$

$$V = \frac{(\pi)(h)(d_t + d_b)^2}{(16)(10^3)} \tag{A1.2}$$

where:

- $V$  = volume of mold, ft<sup>3</sup> (cm<sup>3</sup>),
- $h$  = average height, in. (mm),
- $d_t$  = average top diameter, in. (mm),
- $d_b$  = average bottom diameter, in. (mm),
- $\sqrt[3]{1728}$  = constant to convert in<sup>3</sup> to ft<sup>3</sup>, and
- $\sqrt[3]{1000}$  = constant to convert mm<sup>3</sup> to cm<sup>3</sup>.

**A1.5 Comparison of Results**

A1.5.1 The volume obtained by either method should be within the volume tolerance requirements of 6.1.1 and 6.1.2.

A1.5.2 The difference between the two methods should not exceed 0.5 % of the nominal volume of the mold.

A1.5.3 Repeat the determination of volume if these criteria are not met.

A1.5.4 Failure to obtain satisfactory agreement between the two methods, even after several trials, is an indication that the mold is badly deformed and should be replaced.

A1.5.5 Use the volume of the mold determined using the water-filling method as the assigned volume value for calculating the moist and dry density (see 11.4).

**TABLE A1.1 Density of Water<sup>A</sup>**

Temperature, °C (°F)	Density of Water, g/mL or g/cm <sup>3</sup>
18 (64.4)	0.99860
19 (66.2)	0.99841
20 (68.0)	0.99821
21 (69.8)	0.99799
22 (71.6)	0.99777
23 (73.4)	0.99754
24 (75.2)	0.99730
25 (77.0)	0.99705
26 (78.8)	0.99679

<sup>A</sup>Values other than shown may be obtained (5).

**REFERENCES**

- (1) *Earth Manual*, United States Bureau of Reclamation, Part 1, Third Edition, 1998, pp. 255-260.
- (2) *Earth Manual*, United States Bureau of Reclamation, Part 2, Third Edition, 1990.
- (3) Torrey, V.H., and Donaghe, R.T., "Compaction Control of Earth-Rock Mixtures: A New Approach," *Geotechnical Testing Journal*, GTJODJ, Vol 17, No 3, September 1994, pp. 371-386.
- (4) Johnson, A.W., and Sallberg, J.R., *Factors Influencing Compaction Test Results*, Highway Research Board, Bulletin 318, Publication 967, National Academy of Sciences-National Research Council, Washington, DC, 1962, p. 73.
- (5) *CRC Handbook of Chemistry and Physics*, David R. Lide, Editor-in-Chief, 74<sup>th</sup> Edition, 1993-1994

## SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (2000) that may impact the use of this standard.

- |  |   |
|--|---|
| (1) Added Practice D 3740 to Referenced Documents.               | (3) Revised the numbering of existing notes.                                      |
| (2) Added a new note on the use of Practice D 3740 to Section 5. | (4) In Section 6.2 changed the SI tolerance for the height of drop of the rammer. |

*ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent*



Designation: D 698 – 00a<sup>ε1</sup>

## Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft<sup>3</sup>(600 kN-m/m<sup>3</sup>))<sup>1</sup>

This standard is issued under the fixed designation D 698; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappraisal. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reappraisal.

<sup>ε1</sup> Note—Paragraph 10.4.3 was corrected editorially in November 2003.

### 1. Scope\*

1.1 These test methods covers laboratory compaction methods used to determine the relationship between water content and dry unit weight of soils (compaction curve) compacted in a 4 or 6-in. (101.6 or 152.4-mm) diameter mold with a 5.5-lbf (24.4-N) rammer dropped from a height of 12 in. (305 mm) producing a compactive effort of 12,400 ft-lbf/ft<sup>3</sup>(600 kN-m/m<sup>3</sup>).

NOTE 1—The equipment and procedures are similar as those proposed by R. R. Proctor (*Engineering News Record*—September 7, 1933) with this one major exception: his rammer blows were applied as “12 inch firm strokes” instead of free fall, producing variable compactive effort depending on the operator, but probably in the range 15,000 to 25,000 ft-lbf/ft<sup>3</sup> (700 to 1,200 kN-m/m<sup>3</sup>). The standard effort test (see 3.2.2) is sometimes referred to as the Proctor Test.

NOTE 2—Soils and soil-aggregate mixtures should be regarded as natural occurring fine- or coarse-grained soils or composites or mixtures of natural soils, or mixtures of natural and processed soils or aggregates such as silt, gravel, or crushed rock.

1.2 These test methods apply only to soils (materials) that have 30 % or less by mass of particles retained on the ¾-inch (19.0-mm) sieve.

NOTE 3—For relationships between unit weights and water contents of soils with 30 % or less by mass of material retained on the ¾-in. (19.0-mm) sieve to unit weights and water contents of the fraction passing ¾-in. (19.0-mm) sieve, see Practice D 4718.

1.3 Three alternative methods are provided. The method used shall be as indicated in the specification for the material being tested. If no method is specified, the choice should be based on the material gradation.

#### 1.3.1 Method A:

1.3.1.1 *Mold*—4-in. (101.6-mm) diameter.

1.3.1.2 *Material*—Passing No. 4 (4.75-mm) sieve.

1.3.1.3 *Layers*—Three.

1.3.1.4 *Blows per layer*—25.

1.3.1.5 *Use*—May be used if 20 % or less by mass of the material is retained on the No. 4 (4.75-mm) sieve.

1.3.1.6 *Other Use*—If this method is not specified, materials that meet these gradation requirements may be tested using Methods B or C.

#### 1.3.2 Method B:

1.3.2.1 *Mold*—4-in. (101.6-mm) diameter.

1.3.2.2 *Material*—Passing ⅜-in. (9.5-mm) sieve.

1.3.2.3 *Layers*—Three.

1.3.2.4 *Blows per layer*—25.

1.3.2.5 *Use*—Shall be used if more than 20 % by mass of the material is retained on the No. 4 (4.75-mm) sieve and 20 % or less by mass of the material is retained on the ⅜-in. (9.5-mm) sieve.

1.3.2.6 *Other Use*—If this method is not specified, materials that meet these gradation requirements may be tested using Method C.

#### 1.3.3 Method C:

1.3.3.1 *Mold*—6-in. (152.4-mm) diameter.

1.3.3.2 *Material*—Passing ¾-inch (19.0-mm) sieve.

1.3.3.3 *Layers*—Three.

1.3.3.4 *Blows per layer*—56.

1.3.3.5 *Use*—Shall be used if more than 20 % by mass of the material is retained on the ⅜-in. (9.5-mm) sieve and less than 30 % by mass of the material is retained on the ¾-in. (19.0-mm) sieve.

1.3.4 The 6-in. (152.4-mm) diameter mold shall not be used with Method A or B.

NOTE 4—Results have been found to vary slightly when a material is tested at the same compactive effort in different size molds.

1.4 If the test specimen contains more than 5 % by mass of oversize fraction (coarse fraction) and the material will not be included in the test, corrections must be made to the unit mass and water content of the specimen or to the appropriate field in place density test specimen using Practice D 4718.

1.5 This test method will generally produce a well defined maximum dry unit weight for non-free draining soils. If this test method is used for free draining soils the maximum unit

<sup>1</sup> This standard is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved June 10, 2000. Published September 2000. Originally published as D 698 – 42T. Last previous edition D 698 – 00.

\*A Summary of Changes section appears at the end of this standard.

weight may not be well defined, and can be less than obtained using Test Methods **D 4253**.

1.6 The values in inch-pound units are to be regarded as the standard. The values stated in SI units are provided for information only.

1.6.1 In the engineering profession it is customary practice to use, interchangeably, units representing both mass and force, unless dynamic calculations ( $F = Ma$ ) are involved. This implicitly combines two separate systems of units, that is, the absolute system and the gravimetric system. It is scientifically undesirable to combine the use of two separate systems within a single standard. This test method has been written using inch-pound units (gravimetric system) where the pound (lbf) represents a unit of force. The use of mass (lbm) is for convenience of units and is not intended to convey the use is scientifically correct. Conversions are given in the SI system in accordance with IEEE/ASTM SI 10. The use of balances or scales recording pounds of mass (lbm), or the recording of density in  $\text{lbm/ft}^3$  should not be regarded as nonconformance with this standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

### 2.1 ASTM Standards:

- C 127** Test Method for Specific Gravity and Absorption of Coarse Aggregate<sup>2</sup>
- C 136** Method for Sieve Analysis of Fine and Coarse Aggregate<sup>2</sup>
- D 422** Test Method for Particle Size Analysis of Soils<sup>3</sup>
- D 653** Terminology Relating to Soil, Rock, and Contained Fluids<sup>3</sup>
- D 854** Test Methods for Specific Gravity of Soil Solids by Water Pycnometer<sup>3</sup>
- D 1557** Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Efforts (56,000 ft-lbf/ft<sup>3</sup> (2,700 kN-m/m<sup>3</sup>)) Drop<sup>3</sup>
- D 2168** Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors<sup>3</sup>
- D 2216** Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass<sup>3</sup>
- D 2487** Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)<sup>3</sup>
- D 2488** Practice for Description and Identification of Soils (Visual-Manual Procedure)<sup>3</sup>
- D 3740** Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction<sup>3</sup>
- D 4220** Practices for Preserving and Transporting Soil Samples<sup>3</sup>
- D 4253** Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table<sup>3</sup>

- D 4718** Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles<sup>3</sup>
- D 4753** Specification for Evaluating, Selecting and Specifying Balances and Scales For Use in Soil, Rock, and Construction Materials Testing<sup>3</sup>
- D 4914** Test Methods for Density of Soil and Rock in Place by the Sand Replacement Method in a Test Pit<sup>3</sup>
- D 5030** Test Method for Density of Soil and Rock in Place by the Water Replacement Method in a Test Pit<sup>3</sup>
- D 6026** Practice for Using Significant Digits in Geotechnical Data<sup>4</sup>
- E 1** Specification for ASTM Thermometers<sup>5</sup>
- E 11** Specification for Wire-Cloth Sieves for Testing Purposes<sup>6</sup>
- E 177** Practice for Use of the Terms Precision and Bias in ASTM Test Methods<sup>7</sup>
- E 319** Practice for the Evaluation of Single-Pan Mechanical Balances<sup>6</sup>
- E 691** Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method<sup>6</sup>
- IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): the Modern Metric System<sup>8</sup>

## 3. Terminology

3.1 *Definitions:* See Terminology **D 653** for general definitions.

### 3.2 Description of Terms Specific to This Standard:

3.2.1 *oversize fraction (coarse fraction),  $P_c$  in %*—the portion of total sample not used in performing the compaction test; it may be the portion of total sample retained on the No. 4 (4.75-mm),  $\frac{3}{8}$ -in. (9.5-mm), or  $\frac{3}{4}$ -in. (19.0-mm) sieve.

3.2.2 *standard effort*—the term for the 12,400 ft-lbf/ft<sup>3</sup> (600 kN-m/m<sup>3</sup>) compactive effort applied by the equipment and methods of this test.

3.2.3 *standard maximum dry unit weight,  $\gamma_{dmax}$  in lbf/ft<sup>3</sup> (kN/m<sup>3</sup>)*—the maximum value defined by the compaction curve for a compaction test using standard effort.

3.2.4 *standard optimum water content,  $w$ , in %*—the water content at which a soil can be compacted to the maximum dry unit weight using standard compactive effort.

3.2.5 *test fraction (finer fraction),  $P_F$  in %*—the portion of the total sample used in performing the compaction test; it is the fraction passing the No. 4 (4.75-mm) sieve in Method A, minus  $\frac{3}{8}$ -in. (9.5-mm) sieve in Method B, or minus  $\frac{3}{4}$ -in. (19.0-mm) sieve in Method C.

## 4. Summary of Test Method

4.1 A soil at a selected water content is placed in three layers into a mold of given dimensions, with each layer compacted by 25 or 56 blows of a 5.5-lbf (24.4-N) rammer dropped from a distance of 12-in. (305-mm), subjecting the soil to a total compactive effort of about 12,400 ft-lbf/ft<sup>3</sup> (600 kN-m/m<sup>3</sup>). The resulting dry unit weight is determined. The

<sup>4</sup> Annual Book of ASTM Standards, Vol 04.09.

<sup>5</sup> Annual Book of ASTM Standards, Vol 14.03.

<sup>6</sup> Annual Book of ASTM Standards, Vol 14.02.

<sup>7</sup> Annual Book of ASTM Standards, Vol 15.09.

<sup>8</sup> Annual Book of ASTM Standards, Vol 14.04.

<sup>2</sup> Annual Book of ASTM Standards, Vol 04.02.

<sup>3</sup> Annual Book of ASTM Standards, Vol 04.08.

procedure is repeated for a sufficient number of water contents to establish a relationship between the dry unit weight and the water content for the soil. This data, when plotted, represents a curvilinear relationship known as the compaction curve. The values of optimum water content and standard maximum dry unit weight are determined from the compaction curve.

## 5. Significance and Use

5.1 Soil placed as engineering fill (embankments, foundation pads, road bases) is compacted to a dense state to obtain satisfactory engineering properties such as, shear strength, compressibility, or permeability. Also, foundation soils are often compacted to improve their engineering properties. Laboratory compaction tests provide the basis for determining the percent compaction and water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved.

5.2 During design of an engineered fill, shear, consolidation, permeability, or other tests require preparation of test specimens by compacting at some water content to some unit weight. It is common practice to first determine the optimum water content ( $w_o$ ) and maximum dry unit weight ( $\gamma_{dmax}$ ) by means of a compaction test. Test specimens are compacted at a selected water content ( $w$ ), either wet or dry of optimum ( $w_o$ ) or at optimum ( $w_o$ ), and at a selected dry unit weight related to a percentage of maximum dry unit weight ( $\gamma_{dmax}$ ). The selection of water content ( $w$ ), either wet or dry of optimum ( $w_o$ ) or at optimum ( $w_o$ ), and the dry unit weight ( $\gamma_{dmax}$ ) may be based on past experience, or a range of values may be investigated to determine the necessary percent of compaction.

5.3 Experience indicates that the methods outlined in 5.2 or the construction control aspects discussed in 5.1 are extremely difficult to implement or yield erroneous results when dealing with certain soils. 5.3.1-5.3.3 describe typical problem soils, the problems encountered when dealing with such soils and possible solutions for these problems.

5.3.1 *Oversize Fraction*—Soils containing more than 30 % oversize fraction (material retained on the 3/4-in. (19-mm) sieve) are a problem. For such soils, there is no ASTM test method to control their compaction and very few laboratories are equipped to determine the laboratory maximum unit weight (density) of such soils (USDI Bureau of Reclamation, Denver, CO and U.S. Army Corps of Engineers, Vicksburg, MS). Although Test Methods D 4914 and D 5030 determine the “field” dry unit weight of such soils, they are difficult and expensive to perform.

5.3.1.1 One method to design and control the compaction of such soils is to use a test fill to determine the required degree of compaction and the method to obtain that compaction, followed by use of a method specification to control the compaction. Components of a method specification typically contain the type and size of compaction equipment to be used, the lift thickness, and the number of passes.

NOTE 5—Success in executing the compaction control of an earthwork project, especially when a method specification is used, is highly dependent upon the quality and experience of the “contractor” and “inspector.”

5.3.1.2 Another method is to apply the use of density correction factors developed by the USDI Bureau of Reclamation (1,2)<sup>9</sup> and U.S. Corps of Engineers (3). These correction factors may be applied for soils containing up to about 50 to 70 % oversize fraction. Each agency uses a different term for these density correction factors. The USDI Bureau of Reclamation uses  $D$  ratio (or  $D$  – VALUE), while the U.S. Corps of Engineers uses Density Interference Coefficient ( $I_c$ ).

5.3.1.3 The use of the replacement technique (Test Method D 698–78, Method D), in which the oversize fraction is replaced with a finer fraction, is inappropriate to determine the maximum dry unit weight,  $\gamma_{dmax}$ , of soils containing oversize fractions (3).

5.3.2 *Degradation*—Soils containing particles that degrade during compaction are a problem, especially when more degradation occurs during laboratory compaction than field compaction, as is typical. Degradation typically occurs during the compaction of a granular-residual soil or aggregate. When degradation occurs, the maximum dry-unit weight increases (4) so that the laboratory maximum value is not representative of field conditions. Often, in these cases, the maximum dry unit weight is impossible to achieve in the field.

5.3.2.1 Again, for soils subject to degradation, the use of test fills and method specifications may help. Use of replacement techniques is not correct.

5.3.3 *Gap Graded*—Gap-graded soils (soils containing many large particles with limited small particles) are a problem because the compacted soil will have larger voids than usual. To handle these large voids, standard test methods (laboratory or field) typically have to be modified using engineering judgement.

NOTE 6—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing/sampling/inspection, and the like. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

## 6. Apparatus

6.1 *Mold Assembly* —The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and dimensions indicated in 6.1.1 or 6.1.2 and Fig. 1 and Fig. 2. See also Table 1. The walls of the mold may be solid, split, or tapered. The “split” type may consist of two half-round sections, or a section of pipe split along one element, which can be securely locked together to form a cylinder meeting the requirements of this section. The “tapered” type shall an internal diameter taper that is uniform and not more than 0.200 in./ft (16.7- mm/m) of mold height. Each mold shall have a base plate and an extension collar assembly, both made of rigid metal and constructed so they can be securely attached and easily detached from the mold. The extension collar assembly shall have a height extending above the top of the mold of at

<sup>9</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.

As an option to the full length stud, a 2 1/2" x 3/8" stud may be used. Then as an alternative construction, the collar may be held down with a slotted bracket attached to the collar and a pin in the mold.

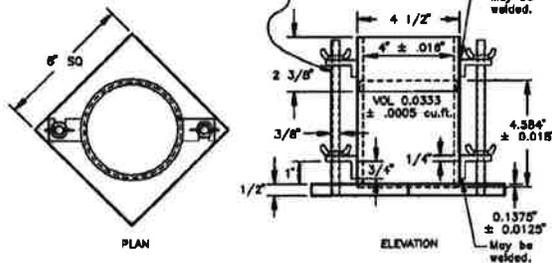


FIG. 1 4.0-in. Cylindrical Mold

As an option to the full length stud, a 2 1/2" x 3/8" stud may be used. Then as an alternative construction, the collar may be held down with a slotted bracket attached to the collar and a pin in the mold.

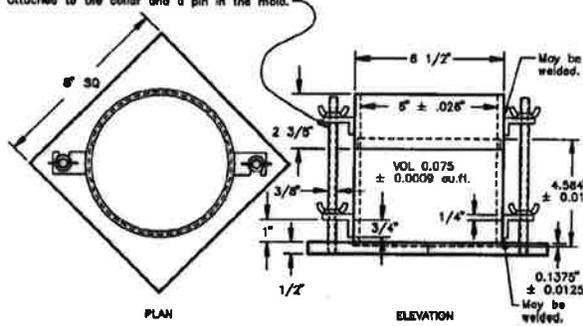


FIG. 2 6.0-in. Cylindrical Mold

TABLE 1 Metric Equivalents for Figs. 1 and 2

in.	mm
0.016	0.41
0.026	0.66
0.032	0.81
0.028	0.71
1/2	12.70
2 1/2	63.50
2 5/8	66.70
4	101.60
4 1/2	114.30
4.584	116.43
4 3/4	120.60
6	152.40
6 1/2	165.10
6 5/8	168.30
6 3/4	171.40
8 1/4	209.60
ft <sup>3</sup>	cm <sup>3</sup>
1/30 (0.0333)	943
0.0005	14
(0.0750)	2,124
0.0011	31

least 2.0 in. (50.8-mm) which may include an upper section that flares out to form a funnel provided there is at least a 0.75 in. (19.0-mm) straight cylindrical section beneath it. The extension collar shall align with the inside of the mold. The

bottom of the base plate and bottom of the centrally recessed area that accepts the cylindrical mold shall be planar.

6.1.1 *Mold, 4 in.*—A mold having a  $4.000 \pm 0.016$ -in. (101.6  $\pm$  0.4-mm) average inside diameter, a height of  $4.584 \pm 0.018$  in. (116.4  $\pm$  0.5 mm) and a volume of  $0.0333 \pm 0.0005$  ft<sup>3</sup> (944  $\pm$  14 cm<sup>3</sup>). A mold assembly having the minimum required features is shown in Fig. 1.

6.1.2 *Mold, 6 in.*—A mold having a  $6.000 \pm 0.026$ -in. (152.4  $\pm$  0.7-mm) average inside diameter, a height of  $4.584 \pm 0.018$  in. (116.4  $\pm$  0.5 mm), and a volume of  $0.075 \pm 0.0009$  ft<sup>3</sup> (2124  $\pm$  25 cm<sup>3</sup>). A mold assembly having the minimum required features is shown in Fig. 2.

6.2 *Rammer*—A rammer, either manually operated as described further in 6.2.1 or mechanically operated as described in 6.2.2. The rammer shall fall freely through a distance of  $12 \pm 0.05$  in. (304.8  $\pm$  1.3 mm) from the surface of the specimen. The mass of the rammer shall be  $5.5 \pm 0.02$  lbm (2.5  $\pm$  0.01 kg), except that the mass of the mechanical rammers may be adjusted as described in Test Methods D 2168; see Note 7. The striking face of the rammer shall be planar and circular, except as noted in 6.2.2.1, with a diameter when new of  $2.000 \pm 0.005$  in. (50.80  $\pm$  0.13 mm). The rammer shall be replaced if the striking face becomes worn or bellied to the extent that the diameter exceeds  $2.000 \pm 0.01$  in. (50.80  $\pm$  0.25 mm).

NOTE 7—It is a common and acceptable practice in the inch-pound system to assume that the mass of the rammer is equal to its mass determined using either a kilogram or pound balance and 1 lbf is equal to 1 lbm or 0.4536 kg, or 1 N is equal to 0.2248 lbm or 0.1020 kg.

6.2.1 *Manual Rammer*—The rammer shall be equipped with a guide sleeve that has sufficient clearance that the free fall of the rammer shaft and head is not restricted. The guide sleeve shall have at least four vent holes at each end (eight holes total) located with centers  $3/4 \pm 1/16$ -in. (19.0  $\pm$  1.6-mm) from each end and spaced 90 degrees apart. The minimum diameter of the vent holes shall be  $3/8$ -in. (9.5-mm). Additional holes or slots may be incorporated in the guide sleeve.

6.2.2 *Mechanical Rammer-Circular Face*—The rammer shall operate mechanically in such a manner as to provide uniform and complete coverage of the specimen surface. There shall be  $0.10 \pm 0.03$ -in. (2.5  $\pm$  0.8-mm) clearance between the rammer and the inside surface of the mold at its smallest diameter. The mechanical rammer shall meet the calibration requirements of Test Methods D 2168. The mechanical rammer shall be equipped with a positive mechanical means to support the rammer when not in operation.

6.2.2.1 *Mechanical Rammer-Sector Face*—When used with the 6-in. (152.4-mm) mold, a sector face rammer may be used in place of the circular face rammer. The specimen contact face shall have the shape of a sector of a circle of radius equal to  $2.90 \pm 0.02$ -in. (73.7  $\pm$  0.5-mm). The rammer shall operate in such a manner that the vertex of the sector is positioned at the center of the specimen.

6.3 *Sample Extruder (optional)*—A jack, frame or other device adapted for the purpose of extruding compacted specimens from the mold.

6.4 *Balance* —A class GP5 balance meeting the requirements of Specification D 4753 for a balance of 1-g readability.

6.5 *Drying Oven* —Thermostatically controlled, preferably of a forced-draft type and capable of maintaining a uniform temperature of 230 ± 9°F (110 ± 5°C) throughout the drying chamber.

6.6 *Straightedge* —A stiff metal straightedge of any convenient length but not less than 10 in. (254 mm). The total length of the straightedge shall be machined straight to a tolerance of ± 0.005 in. (± 0.1mm). The scraping edge shall be beveled if it is thicker than 1/8 in. (3 mm).

6.7 *Sieves* —3/4 in. (19.0 mm), 3/8 in. (9.5 mm), and No. 4 (4.75 mm), conforming to the requirements of Specification E 11.

6.8 *Mixing Tools* —Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

**7. Calibration**

7.1 Perform calibrations before initial use, after repairs or other occurrences that might affect the test results, at intervals not exceeding 1,000 test specimens, or annually, whichever occurs first, for the following apparatus:

7.1.1 *Balance*—Evaluate in accordance with Specification D 4753.

7.1.2 *Molds*—Determine the volume as described in Annex A1.

7.1.3 *Manual Rammer*—Verify the free fall distance, rammer mass, and rammer face in accordance with 6.2. Verify the guide sleeve requirements in accordance with 6.2.1.

7.1.4 *Mechanical Rammer*—Calibrate and adjust the mechanical rammer in accordance with Test Methods D 2168. In addition, the clearance between the rammer and the inside surface of the mold shall be verified in accordance with 6.2.2.

**8. Test Sample**

8.1 The required sample mass for Methods A and B is approximately 35 lbm (16 kg), and for Method C is approximately 65-lbm (29-kg) of dry soil. Therefore, the field sample should have a moist mass of at least 50 lbm (23 kg) and 100 lbm (45 kg), respectively.

8.2 Determine the percentage of material (by mass) retained on the No. 4 (4.75-mm), 3/8-in. (9.5-mm), or 3/4-in. (19.0-mm) sieve as appropriate for choosing Method A, B, or C. Make this determination by separating out a representative portion from the total sample and determining the percentages passing the sieves of interest by Test Methods D 422 or Method C 136. It is only necessary to calculate percentages for the sieve or sieves for which information is desired.

**9. Preparation of Apparatus**

9.1 Select the proper compaction mold in accordance with the Method (A, B, or C) being used. Determine and record its mass to the nearest gram. Assemble the mold, base and extension collar. Check the alignment of the inner wall of the mold and mold extension collar. Adjust if necessary.

9.2 Check that the rammer assembly is in good working condition and that parts are not loose or worn. Make any

necessary adjustments or repairs. If adjustments or repairs are made, the rammer must be recalibrated.

**10. Procedure**

10.1 *Soils:*

10.1.1 Do not reuse soil that has been previously compacted in the laboratory.

10.1.2 When using this test method for soils containing hydrated halloysite, or where past experience with a particular soil indicates that results will be altered by air drying, use the moist preparation method (see 10.2).

10.1.3 Prepare the soil specimens for testing in accordance with 10.2 (preferred) or with 10.3.

10.2 *Moist Preparation Method (preferred)*—Without previously drying the sample, pass it through a No. 4 (4.75-mm), 3/8-in. (9.5-mm), or 3/4-in. (19.0-mm) sieve, depending on the Method (A, B, or C) being used. Determine the water content of the processed soil.

10.2.1 Prepare at least four (preferably five) specimens having water contents such that they bracket the estimated optimum water content. A specimen having a water content close to optimum should be prepared first by trial additions of water and mixing (see Note 8). Select water contents for the rest of the specimens to provide at least two specimens wet and two specimens dry of optimum, and water contents varying by about 2 %. At least two water contents are necessary on the wet and dry side of optimum to accurately define the dry unit weight compaction curve (see 10.5). Some soils with very high optimum water content or a relatively flat compaction curve may require larger water content increments to obtain a well defined maximum dry unit weight. Water content increments should not exceed 4 %.

NOTE 8—With practice it is usually possible to visually judge a point near optimum water content. Typically, soil at optimum water content can be squeezed into a lump that sticks together when hand pressure is released, but will break cleanly into two sections when “bent”. At water contents dry of optimum soils tend to crumble; wet of optimum soils tend to stick together in a sticky cohesive mass. Optimum water content is typically slightly less than the plastic limit.

10.2.2 Use approximately 5-lbm (2.3-kg) of the sieved soil for each specimen to be compacted using Method A or B, or 13-lbm (5.9-kg) using Method C. To obtain the specimen water contents selected in 10.2.1, add or remove the required amounts of water as follows: to add water, spray it into the soil during mixing; to remove water, allow the soil to dry in air at ambient temperature or in a drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). Mix the soil frequently during drying to maintain an even water content distribution. Thoroughly mix each specimen to ensure even distribution of water throughout and then place in a separate covered container and allow to stand in accordance with Table 2 prior to compaction. For the purpose of selecting

**TABLE 2 Required Standing Times of Moisturized Specimens**

Classification	Minimum Standing Time, h
GW, GP, SW, SP	No Requirement
GM, SM	3
All other soils	16

a standing time, the soil may be classified using Test Method D 2487, Practice D 2488 or data on other samples from the same material source. For referee testing, classification shall be by Test Method D 2487.

10.3 *Dry Preparation Method*—If the sample is too damp to be friable, reduce the water content by air drying until the material is friable. Drying may be in air or by the use of drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). Thoroughly break up the aggregations in such a manner as to avoid breaking individual particles. Pass the material through the appropriate sieve: No. 4 (4.75-mm), 3/8-in. (9.5-mm), or 3/4-in. (19.0-mm). When preparing the material by passing over the 3/4-in. sieve for compaction in the 6-in. mold, break up aggregations sufficiently to at least pass the 3/8-in. sieve in order to facilitate the distribution of water throughout the soil in later mixing.

10.3.1 Prepare at least four (preferably five) specimens in accordance with 10.2.1.

10.3.2 Use approximately 5-lbm (2.3-kg) of the sieved soil for each specimen to be compacted using Method A or B, or 13-lbm (5.9-kg) using Method C. Add the required amounts of water to bring the water contents of the specimens to the values selected in 10.3.1. Follow the specimen preparation method specified in 10.2.2 for drying the soil or adding water into the soil and curing each test specimen.

10.4 *Compaction*—After curing, if required, each specimen shall be compacted as follows:

10.4.1 Determine and record the mass of the mold or mold and base plate.

10.4.2 Assemble and secure the mold and collar to the base plate. The mold shall rest on a uniform rigid foundation, such as provided by a cylinder or cube of concrete with a mass of not less than 200-lbm (91-kg). Secure the base plate to the rigid foundation. The method of attachment to the rigid foundation shall allow easy removal of the assembled mold, collar and base plate after compaction is completed.

10.4.3 Compact the specimen in three layers. After compaction, each layer should be approximately equal in thickness. Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a fluffy or loose state, using either the manual compaction rammer or a 2-in. (50.8-mm) diameter cylinder. Following compaction of each of the first two layers, any soil adjacent to the mold walls that has not been compacted or extends above the compacted surface shall be trimmed. The trimmed soil may be included with the additional soil for the next layer. A knife or other suitable device may be used. The total amount of soil used shall be such that the third compacted layer slightly extends into the collar, but does not exceed 1/4-in. (6-mm) above the top of the mold. If the third layer does extend above the top of the mold by more than 1/4-in. (6-mm), the specimen shall be discarded. The specimen shall be discarded when the last blow on the rammer for the third layer results in the bottom of the rammer extending below the top of the compaction mold.

10.4.4 Compact each layer with 25 blows for the 4-in. (101.6-mm) mold or with 56 blows for the 6-in. (152.4-mm) mold.

NOTE 9—When compacting specimens wetter than optimum water content, uneven compacted surfaces can occur and operator judgement is required as to the average height of the specimen.

10.4.5 In operating the manual rammer, take care to avoid lifting the guide sleeve during the rammer upstroke. Hold the guide sleeve steady and within 5° of vertical. Apply the blows at a uniform rate of approximately 25 blows/min and in such a manner as to provide complete, uniform coverage of the specimen surface.

10.4.6 Following compaction of the last layer, remove the collar and base plate from the mold, except as noted in 10.4.7. A knife may be used to trim the soil adjacent to the collar to loosen the soil from the collar before removal to avoid disrupting the soil below the top of the mold.

10.4.7 Carefully trim the compacted specimen even with the top of the mold by means of the straightedge scraped across the top of the mold to form a plane surface even with the top of the mold. Initial trimming of the specimen above the top of the mold with a knife may prevent the soil from tearing below the top of the mold. Fill any holes in the top surface with unused or trimmed soil from the specimen, press in with the fingers, and again scrape the straightedge across the top of the mold. Repeat the appropriate preceding operations on the bottom of the specimen when the mold volume was determined without the base plate. For very wet or dry soils, soil or water may be lost if the base plate is removed. For these situations, leave the base plate attached to the mold. When the base plate is left attached, the volume of the mold must be calibrated with the base plate attached to the mold rather than a plastic or glass plate as noted in Annex A1, A1.4.

10.4.8 Determine and record the mass of the specimen and mold to the nearest gram. When the base plate is left attached, determine and record the mass of the specimen, mold and base plate to the nearest gram.

10.4.9 Remove the material from the mold. Obtain a specimen for water content by using either the whole specimen (preferred method) or a representative portion. When the entire specimen is used, break it up to facilitate drying. Otherwise, obtain a portion by slicing the compacted specimen axially through the center and removing about 500-g of material from the cut faces. Obtain the water content in accordance with Test Method D 2216.

10.5 Following compaction of the last specimen, compare the wet unit weights to ensure that a desired pattern of obtaining data on each side of the optimum water content will be attained for the dry unit weight compaction curve. Plotting the wet unit weight and water content of each compacted specimen can be an aid in making the above evaluation. If the desired pattern is not obtained, additional compacted specimens will be required. Generally, one water content value wet of the water content defining the maximum wet unit weight is sufficient to ensure data on the wet side of optimum water content for the maximum dry unit weight.

## 11. Calculation

11.1 Calculate the dry unit weight and water content of each compacted specimen as explained in 11.3 and 11.4. Plot the values and draw the compaction curve as a smooth curve through the points (see example, Fig. 3). Plot dry unit weight

COMPACTION TEST

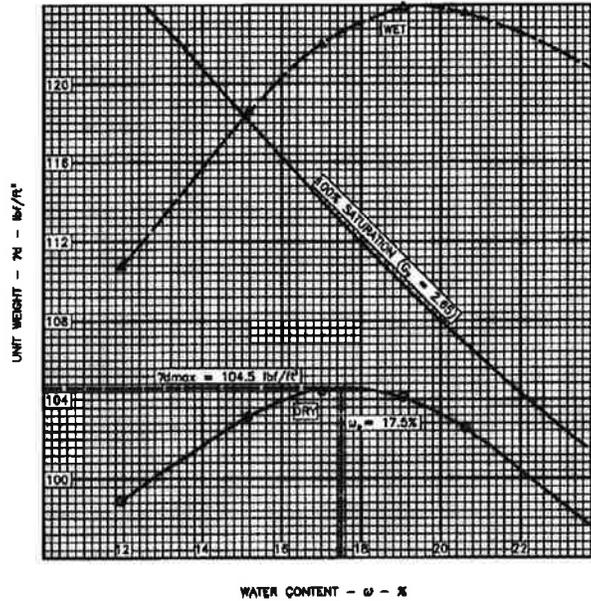


FIG. 3 Example Compaction Curve Plotting

to the nearest 0.1 lb/ft<sup>3</sup> (0.2 kN/m<sup>3</sup>) and water content to the nearest 0.1 %. From the compaction curve, determine the optimum water content and maximum dry unit weight. If more than 5 % by mass of oversize material was removed from the sample, calculate the corrected optimum water content and maximum dry unit weight of the total material using Practice D 4718. This correction may be made to the appropriate field in place density test specimen rather than to the laboratory test specimen.

11.2 Plot the 100 % saturation curve. Values of water content for the condition of 100 % saturation can be calculated as explained in 11.5 (see example, Fig. 3).

NOTE 10—The 100 % saturation curve is an aid in drawing the compaction curve. For soils containing more than approximately 10 % fines at water contents well above optimum, the two curves generally become roughly parallel with the wet side of the compaction curve between 92 % to 95 % saturation. Theoretically, the compaction curve cannot plot to the right of the 100 % saturation curve. If it does, there is an error in specific gravity, in measurements, in calculations, in testing, or in plotting.

NOTE 11—The 100 % saturation curve is sometimes referred to as the zero air voids curve or the complete saturation curve.

11.3 *Water Content, w*—Calculate in accordance with Test Method D 2216.

11.4 *Dry Unit Weights*—Calculate the moist density (Eq 1), the dry density (Eq 2), and then the dry unit weight (Eq 3) as follows:

$$\rho_m = \frac{(M_t - M_{md})}{1000 V} \quad (1)$$

where:

- $\rho_m$  = moist density of compacted specimen, Mg/m<sup>3</sup>,
- $M_t$  = mass of moist specimen and mold, kg,

- $M_{md}$  = mass of compaction mold, kg, and
- $V$  = volume of compaction mold, m<sup>3</sup>(see Annex A1)

$$\rho_d = \frac{\rho_m}{1 + \frac{w}{100}} \quad (2)$$

where:

- $\rho_d$  = dry density of compacted specimen, Mg/m<sup>3</sup>, and
- $w$  = water content, % .

$$\gamma_d = 62.43 \rho_d \text{ in lb/ft}^3 \quad (3)$$

or

$$\gamma_d = 9.807 \rho_d \text{ in kN/m}^3 \quad (4)$$

where:

- $\gamma_d$  = dry unit weight of compacted specimen.

11.5 To calculate points for plotting the 100 % saturation curve or zero air voids curve select values of dry unit weight, calculate corresponding values of water content corresponding to the condition of 100 % saturation as follows:

$$w_{sat} = \frac{(\gamma_w)(G_s) - \gamma_d}{(\gamma_d)(G_s)} \times 100 \quad (5)$$

where:

- $w_{sat}$  = water content for complete saturation, %,
- $\gamma_w$  = unit weight of water, 62.32 lb/ft<sup>3</sup> (9.789 kN/m<sup>3</sup>) at 20°C,
- $\gamma_d$  = dry unit weight of soil, lb/ft<sup>3</sup> (kN/m<sup>3</sup>), and
- $G_s$  = specific gravity of soil.

NOTE 12—Specific gravity may be estimated for the test specimen on the basis of test data from other samples of the same soil classification and source. Otherwise, a specific gravity test (Test Method C 127, Test Method D 854, or both) is necessary.

## 12. Report: Data Sheet(s)/Form(s)

12.1 The data sheet(s)/form(s) shall contain the following information:

- 12.1.1 Method used (A, B, or C).
- 12.1.2 Preparation method used (moist or dry).
- 12.1.3 As received water content if determined.
- 12.1.4 Standard optimum water content, to the nearest 0.1 %.
- 12.1.5 Standard maximum dry unit weight, to the nearest 0.1 lbf/ft<sup>3</sup>.
- 12.1.6 Description of rammer (manual or mechanical).
- 12.1.7 Soil sieve data when applicable for determination of Method (A, B, or C) used.
- 12.1.8 Description of material used in test, by Practice D 2488, or classification by Test Method D 2487.
- 12.1.9 Specific gravity and method of determination.
- 12.1.10 Origin of material used in test, for example, project, location, depth, and the like.
- 12.1.11 Compaction curve plot showing compaction points used to establish compaction curve, and 100 % saturation curve, point of maximum dry unit weight and optimum water content.
- 12.1.12 Oversize correction data if used, including the oversize fraction (coarse fraction), P<sub>c</sub> in %.

## 13. Precision and Bias

13.1 *Precision*—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types are given in Table 3 and Table 4. These estimates of precision are based on the results of the interlaboratory program con-

**TABLE 3 Summary of Test Results from Triplicate Test Laboratories (Standard Effort Compaction)**

(1) Number of Triplicate Test Labs	(2) Test Value <sup>A</sup> (Units)	(3) Average Value <sup>B</sup>	(4) Standard Deviation <sup>C</sup>	(5) Acceptable Range of Two Results <sup>D,E</sup>
<i>Soil Type:</i>				
CH CL ML		CH CL ML	CH CL ML	CH CL ML
<i>Single-Operator Results (Within-Laboratory Repeatability):</i>				
11 12 11	γ <sub>d,max</sub> (pcf)	97.2 109.2 106.3	0.5 0.4 0.5	1.3 1.2 1.3
11 12 11	w <sub>opt</sub> (%)	22.8 16.6 17.1	0.2 0.3 0.3	0.7 0.9 0.9
<i>Multilaboratory Results (Between-Laboratory Reproducibility):</i>				
11 12 11	γ <sub>d,max</sub> (pcf)	97.2 109.2 106.3	1.4 0.8 0.6	3.9 2.3 1.6
11 12 11	w <sub>opt</sub> (%)	22.8 16.6 17.1	0.7 0.5 0.5	1.8 1.5 1.3

<sup>A</sup>γ<sub>d,max</sub> (pcf) = standard maximum dry unit weight in lbf/ft<sup>3</sup> and w<sub>opt</sub> (%) = standard optimum water in percent.

<sup>B</sup>The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D 6026, the standard deviation and acceptable range of results can not have more decimal places than the input data.

<sup>C</sup>Standard deviation is calculated in accordance with Practice E 691 and is referred to as the 1 s limit.

<sup>D</sup>Acceptable range of two results is referred to as the d2s limit. It is calculated as 1.960 √2 · 1s, as defined by Practice E 177. The difference between two properly conducted tests should not exceed this limit. The number of significant digits/decimal places presented is equal to that prescribed by this standard or Practice D 6026. In addition, the value presented can have the same number of decimal places as the standard deviation, even if that result has more significant digits than the standard deviation.

<sup>E</sup>Both values of γ<sub>d,max</sub> and w<sub>opt</sub> have to fall within values given for the selected soil type.

ducted by the ASTM Reference Soils and Testing Program<sup>10</sup>. In this program, Method A and the Dry Preparation Method were used. In addition, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single test laboratory). A description of the soils tested is given in 13.1.4. The precision estimates vary with soil type, and may vary with methods used (Method A, B, or C, or wet/dry preparation method). Judgement is required when applying these estimates to another soil, method, or preparation method.

13.1.1 The data in Table 3 are based on three replicate test performed by each triplicate test laboratory on each soil type. The single operator and multilaboratory standard deviation show in Table 3, Column 4 were obtained in accordance with Practice E 691, which recommends each testing laboratory perform a minimum of three replicate test. Results of two properly conducted test performed by the same operator on the same material, using the same equipment, and in the shortest practical period of time should not differ by more than the single-operator d2s shown in Table 3, Column 5. For definition of d2s, see Footnote D in Table 1. Results of two properly conducted test performed by different operators and on different days should not differ by more than the multilaboratory d2s limits shown in Table 3, Column 5.

13.1.2 In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test on each soil type. This is common practice in the design and construction industry. The data for each soil type in Table 4 are based upon the first test result from the triplicate test laboratories and the single test results from the other laboratories. Results of two properly conducted test performed by two different laboratories with different operators using different equipment and on different days should not vary by more than the d2s limits shown in Table 4, Column 5. The results in Table 3 and Table 4 are dissimilar because the data sets are different.

13.1.3 Table 3 presents a rigorous interpretation of triplicate test data in accordance with Practice E 691 from pre-qualified laboratories. Table 4 is derived from test data that represents common practice.

13.1.4 *Soil Types*—Based on the multilaboratory test results the soils used in the program are described below in accordance with Practice D 2487. In addition, the local names of the soils are given.

- CH—Fat clay, CH, 99 % fines, LL=60, PI=39, grayish brown, soil had been air dried and pulverized. Local name—Vicksburg Buckshot Clay
- CL—Lean clay, CL, 89 % fines, LL=33, PI=13, gray, soil had been air dried and pulverized. Local name—Annapolis Clay
- ML—Silt, ML, 99 % fines, LL=27, PI=4, light brown, soil had been air dried and pulverized. Local name—Vicksburg Silt

13.2 *Bias*—There is no accepted reference values for this test method, therefore, bias cannot be determined.

## 14. Keywords

14.1 impact compaction using standard effort; density; moisture-density curves; proctor test; compaction characteristics; soil compaction; laboratory tests

<sup>10</sup> Research Report RR:D18–1008 contains the data and statistical analysis used to establish these precision statements and it is available from ASTM Headquarters.



#### A1.4.2 Linear Measurement Method:

A1.4.2.1 Using either the vernier caliper or the inside micrometer, measure the diameter of the mold 6 times at the top of the mold and 6 times at the bottom of the mold, spacing each of the six top and bottom measurements equally around the circumference of the mold. Record the values to the nearest 0.001-in. (0.02-mm).

A1.4.2.2 Using the vernier caliper, measure the inside height of the mold by making three measurements equally spaced around the circumference of the mold. Record values to the nearest 0.001-in. (0.02-mm).

A1.4.2.3 Calculate the average top diameter, average bottom diameter and average height.

A1.4.2.4 Calculate the volume of the mold and record to the nearest 0.0001 ft<sup>3</sup> (1 cm<sup>3</sup>) as follows:

$$V = \frac{(\pi)(h)(d_t + d_b)^2}{(16)(1728)} \text{ (inch-pound)} \quad (\text{A1.1})$$

$$V = \frac{(\pi)(h)(d_t + d_b)^2}{(16)(1000)} (S) \quad (\text{A1.2})$$

where:

- $V$  = volume of mold, ft<sup>3</sup> (cm<sup>3</sup>),
- $h$  = average height, in. (mm),
- $d_t$  = average top diameter, in. (mm),
- $d_b$  = average bottom diameter, in. (mm),
- $1/1728$  = constant to convert in<sup>3</sup> to ft<sup>3</sup>, and
- $1/1000$  = constant to convert mm<sup>3</sup> to cm<sup>3</sup>.

#### A1.5 Comparison of Results

A1.5.1 The volume obtained by either method should be within the volume tolerance requirements of 6.1.1 and 6.1.2.

A1.5.2 The difference between the two methods should not exceed 0.5 % of the nominal volume of the mold.

A1.5.3 Repeat the determination of volume if these criteria are not met.

A1.5.4 Failure to obtain satisfactory agreement between the two methods, even after several trials, is an indication that the mold is badly deformed and should be replaced.

A1.5.5 Use the volume of the mold determined using the water-filling method as the assigned volume value for calculating the moist and dry density (see 11.4).

### REFERENCES

- (1) *Earth Manual*, Unites States Bureau of Reclamation, Part 1, Third Edition, 1998, pp. 255-260.
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- (3) Torrey, V.H., and Donaghe, R.T., "Compaction Control of Earth-Rock Mixtures: A New Approach," *Geotechnical Testing Journal*, GTJODJ, Vol 17, No. 3, September 1994, pp. 371-386.
- (4) Johnson, A.W., and Sallberg, J.R., *Factors Influencing Compaction Test Results*, Highway Research Board, Bulletin 318, Publication 967, National Academy of Sciences-National Research Council, Washington, DC, 1962, p. 73.
- (5) *CRC Handbook of Chemistry and Physics*, David R. Lide, Editor-in-Chief, 74<sup>th</sup> Edition, 1993-1994.

### SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last published edition (91(Reapproved 1998)) that may impact the use of this standard.

Changes made in the March 2000 revision.

- (1) The Summary of Changes section was added.
- (2) Changed "Method" to "Methods in the title to reflect multiple methods. Replace "Procedure A, B, or C" with "Method A, B, or C", and "procedure(s) with "methods(s)", where applicable. Replaced the terms "by weight" with "by mass", where applicable.
- (3) In 1.6.1, replaced E 380 with IEEE/ASTM SI 10.
- (4) In Section 2, replaced E 380 with IEEE/ASTM SI 10 and added D 4914 and D 5030.
- (5) In the Significance and Use section, added subsection, added subsections 5.3—5.3.3 along with two references. These subsection discuss the problems in applying Test Methods D 1557 when dealing with soils containing oversize fractions, in which degradation occurs, and soils which are gap graded.
- (6) In Table A1.1, the density values were updated to agree

with Test Methods D 854 and in 11.5 unit weight of water values were updated to agree with the density values in Test Methods D 854 at 20°C.

Changes made in the June 2000 revision.

- (1) Under Referenced Documents, added Practices D 3740, D 6026, E 177, and E 691.
- (2) Following the Significance and Use section, a note was added referencing Practice D 3740 in accordance with the policy of D18. Renumbered the remaining notes.
- (3) In 12, changed title and 12.1 to state that this section covers what data needs to be recorded on the data sheets(s)/form(s). In addition, the recording sensitivity for the optimum water content and maximum dry weight was changed from 0.5 to 0.1
- (4) The precision statement in 13.1 was completely revised, and now includes data.
- (5) The bias statement was reworded.

 **D 698 – 00a<sup>ε1</sup>**

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Designation: C 136 – 05

## Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates<sup>1</sup>

This standard is issued under the fixed designation C 136; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense.*

### 1. Scope\*

1.1 This test method covers the determination of the particle size distribution of fine and coarse aggregates by sieving.

1.2 Some specifications for aggregates which reference this method contain grading requirements including both coarse and fine fractions. Instructions are included for sieve analysis of such aggregates.

1.3 The values stated in SI units are to be regarded as the standard. The values in parentheses are provided for information purposes only. Specification E 11 designates the size of sieve frames with inch units as standard, but in this test method the frame size is designated in SI units exactly equivalent to the inch units.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:<sup>2</sup>

- C 117 Test Method for Materials Finer Than 75- $\mu$ m (No. 200) Sieve in Mineral Aggregates by Washing
- C 125 Terminology Relating to Concrete and Concrete Aggregates
- C 637 Specification for Aggregates for Radiation-Shielding Concrete
- C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 702 Practice for Reducing Field Samples of Aggregate to Testing Size
- D 75 Practice for Sampling Aggregates

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

Current edition approved Feb. 1, 2005. Published February 2005. Originally approved in 1938. Last previous edition approved in 2004 as C 136 – 04.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E 11 Specification for Wire-Cloth and Sieves for Testing Purposes

#### 2.2 AASHTO Standard:

AASHTO No. T 27 Sieve Analysis of Fine and Coarse Aggregates<sup>3</sup>

### 3. Terminology

3.1 *Definitions*—For definitions of terms used in this standard, refer to Terminology C 125.

### 4. Summary of Test Method

4.1 A sample of dry aggregate of known mass is separated through a series of sieves of progressively smaller openings for determination of particle size distribution.

### 5. Significance and Use

5.1 This test method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. The data may also be useful in developing relationships concerning porosity and packing.

5.2 Accurate determination of material finer than the 75- $\mu$ m (No. 200) sieve cannot be achieved by use of this method alone. Test Method C 117 for material finer than 75- $\mu$ m sieve by washing should be employed.

5.3 Refer to methods of sampling and testing in Specification C 637 for heavyweight aggregates.

### 6. Apparatus

6.1 *Balances*—Balances or scales used in testing fine and coarse aggregate shall have readability and accuracy as follows:

6.1.1 For fine aggregate, readable to 0.1 g and accurate to 0.1 g or 0.1 % of the test load, whichever is greater, at any point within the range of use.

<sup>3</sup> Available from American Association of State Highway and Transportation Officials, 444 North Capitol St. N.W., Suite 225, Washington, DC 20001.

\*A Summary of Changes section appears at the end of this standard.

6.1.2 For coarse aggregate, or mixtures of fine and coarse aggregate, readable and accurate to 0.5 g or 0.1 % of the test load, whichever is greater, at any point within the range of use.

6.2 *Sieves*—The sieve cloth shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. The sieve cloth and standard sieve frames shall conform to the requirements of Specification E 11. Nonstandard sieve frames shall conform to the requirements of Specification E 11 as applicable.

NOTE 1—It is recommended that sieves mounted in frames larger than standard 203.2-mm (8 in.) diameter be used for testing coarse aggregate to reduce the possibility of overloading the sieves. See 8.3.

6.3 *Mechanical Sieve Shaker*—A mechanical sieving device, if used, shall create motion of the sieves to cause the particles to bounce, tumble, or otherwise turn so as to present different orientations to the sieving surface. The sieving action shall be such that the criterion for adequacy of sieving described in 8.4 is met in a reasonable time period.

NOTE 2—Use of a mechanical sieve shaker is recommended when the size of the sample is 20 kg or greater, and may be used for smaller samples, including fine aggregate. Excessive time (more than approximately 10 min) to achieve adequate sieving may result in degradation of the sample. The same mechanical sieve shaker may not be practical for all sizes of samples, since the large sieving area needed for practical sieving of a large nominal size coarse aggregate very likely could result in loss of a portion of the sample if used for a small sample of coarse aggregate or fine aggregate.

6.4 *Oven*—An oven of appropriate size capable of maintaining a uniform temperature of  $110 \pm 5^\circ\text{C}$  ( $230 \pm 9^\circ\text{F}$ ).

## 7. Sampling

7.1 Sample the aggregate in accordance with Practice D 75. The size of the field sample shall be the quantity shown in Practice D 75 or four times the quantity required in 7.4 and 7.5 (except as modified in 7.6), whichever is greater.

7.2 Thoroughly mix the sample and reduce it to an amount suitable for testing using the applicable procedures described in Practice C 702. The sample for test shall be approximately the quantity desired when dry and shall be the end result of the reduction. Reduction to an exact predetermined quantity shall not be permitted.

NOTE 3—Where sieve analysis, including determination of material finer than the 75- $\mu\text{m}$  sieve, is the only testing proposed, the size of the sample may be reduced in the field to avoid shipping excessive quantities of extra material to the laboratory.

7.3 *Fine Aggregate*—The size of the test sample, after drying, shall be 300 g minimum.

7.4 *Coarse Aggregate*—The size of the test sample of coarse aggregate shall conform with the following:

Nominal Maximum Size, Square Openings, mm (in.)	Test Sample Size, min, kg (lb)
9.5 (3/8)	1 (2)
12.5 (1/2)	2 (4)
19.0 (3/4)	5 (11)
25.0 (1)	10 (22)
37.5 (1 1/2)	15 (33)
50 (2)	20 (44)
63 (2 1/2)	35 (77)
75 (3)	60 (130)
90 (3 1/2)	100 (220)

100 (4)  
125 (5)

150 (330)  
300 (660)

7.5 *Coarse and Fine Aggregate Mixtures*—The size of the test sample of coarse and fine aggregate mixtures shall be the same as for coarse aggregate in 7.4.

7.6 *Samples of Large Size Coarse Aggregate*—The size of sample required for aggregate with 50-mm nominal maximum size or larger is such as to preclude convenient sample reduction and testing as a unit except with large mechanical splitters and sieve shakers. As an option when such equipment is not available, instead of combining and mixing sample increments and then reducing the field sample to testing size, conduct the sieve analysis on a number of approximately equal sample increments such that the total mass tested conforms to the requirement of 7.4.

7.7 In the event that the amount of material finer than the 75- $\mu\text{m}$  (No. 200) sieve is to be determined by Test Method C 117, proceed as follows:

7.7.1 For aggregates with a nominal maximum size of 12.5 mm (1/2 in.) or less, use the same test sample for testing by Test Method C 117 and this method. First test the sample in accordance with Test Method C 117 through the final drying operation, then dry sieve the sample as stipulated in 8.2-8.7 of this method.

7.7.2 For aggregates with a nominal maximum size greater than 12.5 mm (1/2 in.), a single test sample may be used as described in 7.7.1, or separate test samples may be used for Test Method C 117 and this method.

7.7.3 Where the specifications require determination of the total amount of material finer than the 75- $\mu\text{m}$  sieve by washing and dry sieving, use the procedure described in 7.7.1.

## 8. Procedure

8.1 Dry the sample to constant mass at a temperature of  $110 \pm 5^\circ\text{C}$  ( $230 \pm 9^\circ\text{F}$ ).

NOTE 4—For control purposes, particularly, where rapid results are desired, it is generally not necessary to dry coarse aggregate for the sieve analysis test. The results are little affected by the moisture content unless: (1) the nominal maximum size is smaller than about 12.5 mm (1/2 in.); (2) the coarse aggregate contains appreciable material finer than 4.75 mm (No. 4); or (3) the coarse aggregate is highly absorptive (a lightweight aggregate, for example). Also, samples may be dried at the higher temperatures associated with the use of hot plates without affecting results, provided steam escapes without generating pressures sufficient to fracture the particles, and temperatures are not so great as to cause chemical breakdown of the aggregate.

8.2 Select sieves with suitable openings to furnish the information required by the specifications covering the material to be tested. Use additional sieves as desired or necessary to provide other information, such as fineness modulus, or to regulate the amount of material on a sieve. Nest the sieves in order of decreasing size of opening from top to bottom and place the sample on the top sieve. Agitate the sieves by hand or by mechanical apparatus for a sufficient period, established by trial or checked by measurement on the actual test sample, to meet the criterion for adequacy or sieving described in 8.4.

8.3 Limit the quantity of material on a given sieve so that all particles have opportunity to reach sieve openings a number of times during the sieving operation. For sieves with openings

smaller than 4.75-mm (No. 4), the quantity retained on any sieve at the completion of the sieving operation shall not exceed  $7 \text{ kg/m}^2$  of sieving surface area (Note 5). For sieves with openings 4.75 mm (No. 4) and larger, the quantity retained in kg shall not exceed the product of  $2.5 \times$  (sieve opening, mm  $\times$  effective sieving area,  $\text{m}^2$ )

coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100: 150- $\mu\text{m}$  (No. 100), 300- $\mu\text{m}$  (No. 50), 600- $\mu\text{m}$  (No. 30), 1.18-mm (No. 16), 2.36-mm (No. 8), 4.75-mm (No. 4), 9.5-mm ( $\frac{3}{8}$ -in.), 19.0-mm ( $\frac{3}{4}$ -in.), 37.5-mm ( $1\frac{1}{2}$ -in.), and larger, increasing in the ratio of 2 to 1.

### 10. Report

10.1 Depending upon the form of the specifications for use of the material under test, the report shall include the following:

10.1.1 Total percentage of material passing each sieve, or

10.1.2 Total percentage of material retained on each sieve, or

10.1.3 Percentage of material retained between consecutive sieves.

10.2 Report percentages to the nearest whole number, except if the percentage passing the 75- $\mu\text{m}$  (No. 200) sieve is less than 10 %, it shall be reported to the nearest 0.1 %.

10.3 Report the fineness modulus, when required, to the nearest 0.01.

### 11. Precision and Bias

11.1 *Precision*—The estimates of precision for this test method are listed in Table 2. The estimates are based on the results from the **AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by Test Method C 136 and AASHTO Test Method T 27**. The data are based on the analyses of the test results from 65 to 233 laboratories that tested 18 pairs of coarse aggregate proficiency test samples and test results from 74 to 222 laboratories that tested 17 pairs of fine aggregate proficiency test samples (Samples No. 21 through 90). The values in the table are given for different ranges of total percentage of aggregate passing a sieve.

11.1.1 The precision values for fine aggregate in Table 2 are based on nominal 500-g test samples. Revision of this test method in 1994 permits the fine aggregate test sample size to be 300 g minimum. Analysis of results of testing of 300-g and 500-g test samples from Aggregate Proficiency Test Samples 99 and 100 (Samples 99 and 100 were essentially identical) produced the precision values in Table 3, which indicate only minor differences due to test sample size.

NOTE 6—The values for fine aggregate in Table 2 will be revised to reflect the 300-g test sample size when a sufficient number of Aggregate

**TABLE 2 Precision**

	Total Percentage of Material Passing		Standard Deviation (1s), % <sup>A</sup>	Acceptable Range of Two Results (d2s), % <sup>A</sup>	
<i>Coarse Aggregate:<sup>B</sup></i>					
Single-operator precision	<100	$\geq 95$	0.32	0.9	
	<95	$\geq 85$	0.81	2.3	
	<85	$\geq 80$	1.34	3.8	
	<80	$\geq 60$	2.25	6.4	
	<60	$\geq 20$	1.32	3.7	
	<20	$\geq 15$	0.96	2.7	
	<15	$\geq 10$	1.00	2.8	
	<10	$\geq 5$	0.75	2.1	
	<5	$\geq 2$	0.53	1.5	
	<2	>0	0.27	0.8	
	Multilaboratory precision	<100	$\geq 95$	0.35	1.0
		<95	$\geq 85$	1.37	3.9
		<85	$\geq 80$	1.92	5.4
<80		$\geq 60$	2.82	8.0	
<60		$\geq 20$	1.97	5.6	
<20		$\geq 15$	1.60	4.5	
<15		$\geq 10$	1.48	4.2	
<10		$\geq 5$	1.22	3.4	
<5		$\geq 2$	1.04	3.0	
<2		>0	0.45	1.3	
<i>Fine Aggregate:</i>					
Single-operator precision		<100	$\geq 95$	0.26	0.7
		<95	$\geq 60$	0.55	1.6
	<60	$\geq 20$	0.83	2.4	
	<20	$\geq 15$	0.54	1.5	
	<15	$\geq 10$	0.36	1.0	
	<10	$\geq 2$	0.37	1.1	
	<2	>0	0.14	0.4	
	Multilaboratory precision	<100	$\geq 95$	0.23	0.6
<95		$\geq 60$	0.77	2.2	
<60		$\geq 20$	1.41	4.0	
<20		$\geq 15$	1.10	3.1	
<15		$\geq 10$	0.73	2.1	
<10		$\geq 2$	0.65	1.8	
<2		>0	0.31	0.9	

<sup>A</sup> These numbers represent, respectively, the (1s) and (d2s) limits described in Practice C 670.

<sup>B</sup> The precision estimates are based on aggregates with nominal maximum size of 19.0 mm ( $\frac{3}{4}$  in.).

Proficiency Tests have been conducted using that sample size to provide reliable data.

11.2 *Bias*—Since there is no accepted reference material suitable for determining the bias in this test method, no statement on bias is made.

### 12. Keywords

12.1 aggregate; coarse aggregate; fine aggregate; gradation; grading; sieve analysis; size analysis


**C 136 – 05**
**TABLE 3 Precision Data for 300-g and 500-g Test Samples**

Test Result	Fine Aggregate Proficiency Sample			Within Laboratory		Between Laboratory	
	Sample Size	Number Labs	Average	1s	d2s	1s	d2s
ASTM C136/AASHTO T27							
Total material passing the No. 4 sieve (%)	500 g	285	99.992	0.027	0.066	0.037	0.104
	300 g	276	99.990	0.021	0.060	0.042	0.117
Total material passing the No. 8 sieve (%)	500 g	281	84.10	0.43	1.21	0.63	1.76
	300 g	274	84.32	0.39	1.09	0.69	1.92
Total material passing the No. 16 sieve (%)	500 g	286	70.11	0.53	1.49	0.75	2.10
	300 g	272	70.00	0.62	1.74	0.76	2.12
Total material passing the No. 30 sieve (%)	500 g	287	48.54	0.75	2.10	1.33	3.73
	300 g	276	48.44	0.87	2.44	1.36	3.79
Total material passing the No. 50 sieve (%)	500 g	286	13.52	0.42	1.17	0.98	2.73
	300 g	275	13.51	0.45	1.25	0.99	2.76
Total material passing the No. 100 sieve (%)	500 g	287	2.55	0.15	0.42	0.37	1.03
	300 g	270	2.52	0.18	0.52	0.32	0.89
Total Material passing the No. 200 sieve (%)	500 g	278	1.32	0.11	0.32	0.31	0.85
	300 g	266	1.30	0.14	0.39	0.31	0.85

**SUMMARY OF CHANGES**

Committee C09 has identified the location of selected changes to this test method since the last issue, C 136 – 04, that may impact the use of this test method. (Approved February 1, 2005)

(1) Added 5.3.

(2) Revised 8.5.

Committee C09 has identified the location of selected changes to this test method since the last issue, C 136 – 01, that may impact the use of this test method. (Approved August 1, 2004)

(1) Revised the last sentence of Footnote B in Table 1.

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*This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.*

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## Standard Test Method for Materials Finer than 75- $\mu$ m (No. 200) Sieve in Mineral Aggregates by Washing<sup>1</sup>

This standard is issued under the fixed designation C 117; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense.*

### 1. Scope

1.1 This test method covers the determination of the amount of material finer than a 75- $\mu$ m (No. 200) sieve in aggregate by washing. Clay particles and other aggregate particles that are dispersed by the wash water, as well as water-soluble materials, will be removed from the aggregate during the test.

1.2 Two procedures are included, one using only water for the washing operation, and the other including a wetting agent to assist the loosening of the material finer than the 75- $\mu$ m (No. 200) sieve from the coarser material. Unless otherwise specified, Procedure A (water only) shall be used.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:<sup>2</sup>

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

C 702 Practice for Reducing Field Samples of Aggregate to Testing Size

D 75 Practice for Sampling Aggregates

E 11 Specification for Wire Cloth and Sieves for Testing Purposes

<sup>1</sup> Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001.

This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

Current edition approved Aug. 1, 2004. Published August 2004. Originally approved in 1935. Last previous edition approved in 2003 as C 117 – 03.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

#### 2.2 AASHTO Standard:

T11 Method of Test for Amount of Material Finer than 0.075-mm Sieve in Aggregate<sup>3</sup>

### 3. Summary of Test Method

3.1 A sample of the aggregate is washed in a prescribed manner, using either plain water or water containing a wetting agent, as specified. The decanted wash water, containing suspended and dissolved material, is passed through a 75- $\mu$ m (No. 200) sieve. The loss in mass resulting from the wash treatment is calculated as mass percent of the original sample and is reported as the percentage of material finer than a 75- $\mu$ m (No. 200) sieve by washing.

### 4. Significance and Use

4.1 Material finer than the 75- $\mu$ m (No. 200) sieve can be separated from larger particles much more efficiently and completely by wet sieving than through the use of dry sieving. Therefore, when accurate determinations of material finer than 75  $\mu$ m in fine or coarse aggregate are desired, this test method is used on the sample prior to dry sieving in accordance with Test Method C 136. The results of this test method are included in the calculation in Test Method C 136, and the total amount of material finer than 75  $\mu$ m by washing, plus that obtained by dry sieving the same sample, is reported with the results of Test Method C 136. Usually, the additional amount of material finer than 75  $\mu$ m obtained in the dry sieving process is a small amount. If it is large, the efficiency of the washing operation should be checked. It could also be an indication of degradation of the aggregate.

4.2 Plain water is adequate to separate the material finer than 75  $\mu$ m from the coarser material with most aggregates. In some cases, the finer material is adhering to the larger particles, such as some clay coatings and coatings on aggregates that have been extracted from bituminous mixtures. In these cases, the fine material will be separated more readily with a wetting agent in the water.

<sup>3</sup> Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001.

**5. Apparatus and Materials**

5.1 *Balance*—A balance or scale readable and accurate to 0.1 g or 0.1 % of the test load, whichever is greater, at any point within the range of use.

5.2 *Sieves*—A nest of two sieves, the lower being a 75- $\mu$ m (No. 200) sieve and the upper a 1.18-mm (No. 16) sieve, both conforming to the requirements of Specification E 11.

5.3 *Container*—A pan or vessel of a size sufficient to contain the sample covered with water and to permit vigorous agitation without loss of any part of the sample or water.

5.4 *Oven*—An oven of sufficient size, capable of maintaining a uniform temperature of  $110 \pm 5$  °C ( $230 \pm 9$  °F).

5.5 *Wetting Agent*—Any dispersing agent, such as liquid dishwashing detergents, that will promote separation of the fine materials.

NOTE 1—The use of a mechanical apparatus to perform the washing operation is not precluded, provided the results are consistent with those obtained using manual operations. The use of some mechanical washing equipment with some samples may cause degradation of the sample.

**6. Sampling**

6.1 Sample the aggregate in accordance with Practice D 75. If the same test sample is to be tested for sieve analysis according to Test Method C 136, comply with the applicable requirements of that test method.

6.2 Thoroughly mix the sample of aggregate to be tested and reduce the quantity to an amount suitable for testing using the applicable methods described in Practice C 702. If the same test sample is to be tested according to Test Method C 136, the minimum mass shall be as described in the applicable sections of that method. Otherwise, the mass of the test sample, after drying, shall conform with the following:



**7. Selection of Procedure**

7.1 Procedure A shall be used, unless otherwise specified by the Specification with which the test results are to be compared, or when directed by the agency for which the work is performed.

**8. Procedure A—Washing with Plain Water**

8.1 Dry the test sample in the oven to constant mass at a temperature of  $110 \pm 5$  °C ( $230 \pm 9$  °F). Determine the mass to the nearest 0.1 % of the mass of the test sample.

8.2 If the applicable specification requires that the amount passing the 75- $\mu$ m (No. 200) sieve shall be determined on a portion of the sample passing a sieve smaller than the nominal maximum size of the aggregate, separate the sample on the designated sieve and determine the mass of the material passing the designated sieve to 0.1 % of the mass of this portion of the test sample. Use this mass as the original dry mass of the test sample in 10.1.

NOTE 2—Some specifications for aggregates with a nominal maximum

size of 50 mm or greater, for example, provide a limit for material passing the 75- $\mu$ m (No. 200) sieve determined on that portion of the sample passing the 25.0-mm sieve. Such procedures are necessary since it is impractical to wash samples of the size required when the same test sample is to be used for sieve analysis by Test Method C 136.

8.3 After drying and determining the mass, place the test sample in the container and add sufficient water to cover it. No detergent, dispersing agent, or other substance shall be added to the water. Agitate the sample with sufficient vigor to result in complete separation of all particles finer than the 75- $\mu$ m (No. 200) sieve from the coarser particles, and to bring the fine material into suspension. Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, arranged with the coarser sieve on top. Take care to avoid, as much as feasible, the decantation of coarser particles of the sample.

8.4 Add a second charge of water to the sample in the container, agitate, and decant as before. Repeat this operation until the wash water is clear.

NOTE 3—If mechanical washing equipment is used, the charging of water, agitating, and decanting may be a continuous operation.

8.5 Return all material retained on the nested sieves by flushing to the washed sample. Dry the washed aggregate in the oven to constant mass at a temperature of  $110 \pm 5$  °C ( $230 \pm 9$  °F) and determine the mass to the nearest 0.1 % of the original mass of the sample.

NOTE 4—Following the washing of the sample and flushing any material retained on the 75- $\mu$ m (No. 200) sieve back into the container, no water should be decanted from the container except through the 75- $\mu$ m sieve, to avoid loss of material. Excess water from flushing should be evaporated from the sample in the drying process.

**9. Procedure B—Washing Using a Wetting Agent**

9.1 Prepare the sample in the same manner as for Procedure A.

9.2 After drying and determining the mass, place the test sample in the container. Add sufficient water to cover the sample, and add wetting agent to the water (Note 5). Agitate the sample with sufficient vigor to result in complete separation of all particles finer than the 75- $\mu$ m (No. 200) sieve from the coarser particles, and to bring the fine material into suspension. Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, arranged with the coarser sieve on top. Take care to avoid, as much as feasible, the decantation of coarser particles of the sample.

NOTE 5—There should be enough wetting agent to produce a small amount of suds when the sample is agitated. The quantity will depend on the hardness of the water and the quality of the detergent. Excessive suds may overflow the sieves and carry some material with them.

9.3 Add a second charge of water (without wetting agent) to the sample in the container, agitate, and decant as before. Repeat this operation until the wash water is clear.

9.4 Complete the test as for Procedure A.

**10. Calculation**

10.1 Calculate the amount of material passing a 75- $\mu$ m (No. 200) sieve by washing as follows:

$$A = [(B - C)/B] \times 100 \tag{1}$$

where:

*A* = percentage of material finer than a 75- $\mu\text{m}$  (No. 200) sieve by washing,

*B* = original dry mass of sample, g, and

*C* = dry mass of sample after washing, g.

## 11. Report

11.1 Report the following information:

11.1.1 Report the percentage of material finer than the 75- $\mu\text{m}$  (No. 200) sieve by washing to the nearest 0.1 %, except if the result is 10 % or more, report the percentage to the nearest whole number.

11.1.2 Include a statement as to which procedure was used.

## 12. Precision and Bias

12.1 *Precision*—The estimates of precision of this test method listed in Table 1 are based on results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by this test method and

AASHTO Method T 11. The significant differences between the methods at the time the data were acquired is that Method T 11 required, while Test Method C 117 prohibited, the use of a wetting agent. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

12.1.1 The precision values for fine aggregate in Table 1 are based on nominal 500-g test samples. Revision of this test method in 1994 permits the fine aggregate test sample size to be 300 g minimum. Analysis of results of testing of 300-g and 500-g test samples from Aggregate Proficiency Test Samples 99 and 100 (Samples 99 and 100 were essentially identical) produced the precision values in Table 2, which indicates only minor differences due to test sample size.

NOTE 6—The values for fine aggregate in Table 1 will be revised to reflect the 300-g test sample size when a sufficient number of Aggregate Proficiency Tests have been conducted using that sample size to provide reliable data.

12.2 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is made.

## 13. Keywords

13.1 aggregate; coarse aggregate; fine aggregate; grading; loss by washing; 75  $\mu\text{m}$  (No. 200) sieve; size analysis



Designation: D 4318 – 00

**Standard Test Methods for  
Liquid Limit, Plastic Limit, and Plasticity Index of Soils<sup>1</sup>**

- D 3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes<sup>4</sup>
- D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction<sup>4</sup>
- D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil, Rock, and Related Construction Materials Testing<sup>4</sup>
- D 6026 Practice for Using Significant Digits in Geotechnical Data<sup>5</sup>
- E 11 Specification for Wire-Cloth Sieves for Testing Purposes<sup>6</sup>
- E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods<sup>6</sup>
- E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method<sup>6</sup>

### 3.1 Definitions:

3.1.1 The definitions of terms in this standard are in accordance with Terminology D 653.

#### 3.2 Description of Terms Specific to This Standard:

3.2.1 *Atterberg Limits*—Originally, six “limits of consistency” of fine-grained soils were defined by Albert Atterberg: the upper limit of viscous flow, the liquid limit, the sticky limit, the cohesion limit, the plastic limit, and the shrinkage limit. In current engineering usage, the term usually refers only to the liquid limit, plastic limit, and in some references, the shrinkage limit.

3.2.2 *consistency*—the relative ease with which a soil can be deformed.

3.2.3 *liquid limit (LL,  $w_L$ )*—the water content, in percent, of a soil at the arbitrarily defined boundary between the semi-liquid and plastic states.

3.2.3.1 *Discussion*—The undrained shear strength of soil at the liquid limit is considered to be approximately 2 kPa (0.28 psi).

3.2.4 *plastic limit (PL,  $w_p$ )*—the water content, in percent, of a soil at the boundary between the plastic and semi-solid states.

3.2.5 *plastic soil*—a soil which has a range of water content over which it exhibits plasticity and which will retain its shape on drying.

3.2.6 *plasticity index (PI)*—the range of water content over which a soil behaves plastically. Numerically, it is the difference between the liquid limit and the plastic limit.

3.2.7 *liquidity index*—the ratio, expressed as a percentage of (1) the water content of a soil minus its plastic limit, to (2) its plasticity index.

3.2.8 *activity number (A)*—the ratio of (1) the plasticity index of a soil to (2) the percent by mass of particles having an equivalent diameter smaller than 2  $\mu\text{m}$ .

4.1 The specimen is processed to remove any material retained on a 425- $\mu\text{m}$  (No. 40) sieve. The liquid limit is

determined by performing trials in which a portion of the specimen is spread in a brass cup, divided in two by a grooving tool, and then allowed to flow together from the shocks caused by repeatedly dropping the cup in a standard mechanical device. The multipoint liquid limit, Method A, requires three or more trials over a range of water contents to be performed and the data from the trials plotted or calculated to make a relationship from which the liquid limit is determined. The one-point liquid limit, Method B, uses the data from two trials at one water content multiplied by a correction factor to determine the liquid limit.

4.2 The plastic limit is determined by alternately pressing together and rolling into a 3.2-mm ( $\frac{1}{8}$ -in.) diameter thread a small portion of plastic soil until its water content is reduced to a point at which the thread crumbles and can no longer be pressed together and re-rolled. The water content of the soil at this point is reported as the plastic limit.

4.3 The plasticity index is calculated as the difference between the liquid limit and the plastic limit.

5.1 These test methods are used as an integral part of several engineering classification systems to characterize the fine-grained fractions of soils (see Practices D 2487 and D 3282) and to specify the fine-grained fraction of construction materials (see Specification D 1241). The liquid limit, p