UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NEW ENGLAND REGION
FIVE POST OFFICE SQUARE, SUITE 100, BOSTON, MA 02109

September 15, 2020

Bruce Thompson
de maximis, inc.
200 Day Hill Road, Suite 200
Windsor, CT 06095

Re: Approval of de maximis inc. report titled *Remedial Design Work Plan – Remedial Design Work Plan – Appendix C Holding Basin Containment Pre-Design Investigation Work Plan* (the "HB PDIWP"), dated September 2020.

Nuclear Metals, Inc. Superfund Site

Dear Mr. Thompson:

EPA, in consultation with the Massachusetts Department of Environmental Protection, has completed its review of the HB PDIWP, dated September 2020. The HB PDIWP was revised in response to EPA comments dated July 2, 2020. The HB PDIWP is subject to the terms and conditions specified in the Consent Decree (CD) for Remedial Design / Remedial Action (RD/RA) for the Nuclear Metals, Inc. Site, which has an effective Date of December 6, 2019.

EPA has reviewed the revisions to the HB PDIWP and finds that they are acceptable. Therefore, EPA approves the HB PDIWP.

If there is any conflict between the Performance Standards as stated in the Work Plan and the Performance Standards as stated in the CD and statement of work (SOW), the CD and SOW shall control.

Please do not hesitate to contact me at (617) 918-1339 or at smith.christopher@epa.gov should you have any questions in this regard.

Sincerely,

Christopher Smith
Project Manager

NUCLEAR METALS, INC. SUPERFUND SITE

CONCORD, MASSACHUSETTS

Remedial Design Work Plan - Appendix C

Holding Basin Containment

Pre-Design Investigation Work Plan

Prepared for:

de maximis, inc.
200 Day Hill Road, Suite 200
Windsor, CT 06095

Prepared by:

HALEY ALDRICH

465 Medford Street
Suite 2200
Boston, MA 02129

September 2020

Contents

Tables

Figures

Attachments

1 Introduction

On October 17, 2019, the United States Environmental Protection Agency (USEPA) lodged a Consent Decree (CD) with the United States District Court for the District of Massachusetts Eastern Division in connection with Civil Action No. 1:19-cv-12097-RGS. The CD was entered by the Court on December 6, 2019. The CD and the Statement of Work (SOW) provided as Appendix B to the CD describe the Remedial Design/Remedial Action (RD/RA) activities to be performed for the Nuclear Metals, Inc. (NMI) Superfund Site (Site) in Concord, Massachusetts. The RD/RA activities are to be undertaken by the Settling Defendants (SDs) to the CD, with funding contributions from the Settling Federal Agencies (SFAs).

To efficiently implement the remedy, the work will be divided into five RA projects. RA Projects 1) – 4) below are outlined in Section 1.4 of the SOW. The need for RA Project 5) was identified during the Groundwater NTCRA. The five RA projects are:

1) excavation and off-site disposal of contaminated sediments, underground drain lines and debris, and non-Holding Basin (HB) soils, or “Site-wide Soils and Sediments”;
2) Insitu Soil Stabilization (ISS) of depleted uranium (DU) in HB soils and of DU and natural uranium in overburden and bedrock groundwater or “ISS”;
3) containment of HB stabilized soils with a low-permeability vertical wall and horizontal sub-grade cover or “HB Containment”;
4) hydraulic containment and ex-situ treatment of volatile organic compounds (VOCs) and 1,4-dioxane in groundwater; and,
5) 1,4-dioxane and VOCs in bedrock groundwater.

1.1 Remedial Design Work Plan Overview

Section 3.1 of the SOW requires submittal of a *Remedial Design Work Plan* (RDWP) to summarize pertinent Site information, identify and describe the scopes and procedures for various pre-design investigations, describe the anticipated RD process, and discuss the RD-related deliverables and schedule.

The Record of Decision (ROD) summarizes the chemicals of concern (COCs) as the following:

- Natural uranium;
- Depleted uranium (DU);
- Polycyclic aromatic hydrocarbons (PAHs);
- Polychlorinated biphenyls (PCBs);
- Volatile organic compounds (VOCs); and
- Semi-volatile organic compounds (SVOCs).

As required by Section 3.3(a) of the SOW, Pre-Design Investigation Work Plans (PDI WPs) have been prepared for the three remedial components (Site-wide Soils and Sediments, ISS, and HB Containment). Hydraulic containment and ex-situ treatment of VOCs and 1,4-dioxane in groundwater as required by the Groundwater NTCRA is operating and does not require further PDI work to complete. However, the extent of 1,4-dioxane and VOCs in groundwater in the area upgradient from the extraction well needs further delineation. Separate PDI WPs were prepared for each remedial component, and are attached to the RDWP as follows:

- Site-wide Soils and Sediment PDI WP (Appendix A)
- ISS PDI WP (Appendix B)
- HB Containment PDI WP (Appendix C)
- 1,4-dioxane and VOCs in Groundwater (Appendix D)

Section 3.4(a) of the SOW requires performance of Treatability Studies (TS) to support the ISS component of the remedy. Separate studies are needed to evaluate and select treatment materials/reagents for high concentration DU within the HB, low concentration DU outside the HB, and isotopically natural U in bedrock, respectively. In addition to reagent selection, each media will require evaluation to determine the best means to apply the selected reagent. The overall Treatability Study Work Plan (TSWP) is attached as Appendix E.

The RDWP will also include the following “Supporting Deliverables”:

- To continue the Post-Removal Site Control (PRSC) requirements established pursuant to the Building NTCRA, a “Site Maintenance and Inspection Plan” (SMIP) is provided as Appendix F.
- Health and Safety Plan (HASP) – Appendix G
- Emergency Response Plan (ERP) – Appendix H
- Sampling and Analysis Plan: Field Sampling Plan (FSP) – Appendix I
- Sampling and Analysis Plan: Quality Assurance Project Plan (QAPP) – Appendix J
- Site Wide Monitoring Plan (SWMP) – Appendix K
- Community Relations Support Plan (CRSP) – Appendix L

1.2 Purpose

The purpose of the Pre-Design Investigation (PDI) is to address data gaps by conducting additional field investigations. The data gaps to be addressed in this PDI include geotechnical information at the HB which will be used to design the HB containment wall.

1.3 Objective and Scope

The ROD identified in-situ stabilization and subsequent containment of material located within the Holding Basin as the selected remedy for threat source materials within the Holding Basin. The ROD specifies that the remedy involves containment of the stabilized soils with a low-permeability vertical wall and horizontal cover to isolate the stabilized soil and limit mobility of containments through groundwater.

The Holding Basin containment wall will be designed to prevent groundwater from flowing out of the basin for up to 1,000 years to the extent reasonably achievable, and in any case for at least 200 years, as required by 10 CFR Part 40, Appendix A, Criterion 6(1). The containment wall will extend into glacial till or bedrock to a depth to be determined during our hydrogeologic study and will likely consist of concrete with Xypex additive to reduce the permeability as required to satisfy the design criteria. The wall will be constructed using hydromill equipment capable of advancing through overburden and into bedrock. A low permeability cover will also be constructed to cap the Holding Basin.

The key aspects of demonstrating compliance with the ARAR include:

- Designing the cutoff wall to withstand earthquakes, and
- Designing the cutoff wall to retard groundwater flow into and out of the Holding Basin footprint.

An overview of the PDIs that will be implemented for these areas is provided below and summarized in Table 1.

PDI HB-1: Bedrock and Soil Characterization for Containment Wall Design

The purpose of this PDI is to collect subsurface information needed to design the HB containment wall. Figure 1 shows the proposed explorations planned around the HB. The containment wall is planned to be keyed into glacial till or bedrock. Figure 2 shows the plan view and Geologic section through the HB. A principal data gap that this PDI plans to address is information on the geotechnical and hydrogeologic properties of the overburden and bedrock aquifers. This information will be used to design the containment wall thickness and depth. Information on the physical properties of the bedrock is needed to evaluate constructability factors for hydromilling to install the containment wall.

The proposed containment wall runs through the former tank house. While the above-ground portion of the tank house has been demolished, the below-grade foundations and slabs are still in place, as shown on Figure 3. The limits of the below-grade structures as they are understood from historic drawings need to be confirmed for the containment wall design. This PDI will also include an evaluation to identify any potential utilities or structures which may penetrate the below-grade portion of the former tank house.

This PDI includes a subsurface exploration program and a geophysical analysis of the boreholes to determine bedrock fracture zones. Information on fracture zones will be used in the subsequent installation of observation wells and Continuous multi-level tubes (CMTs). A series of hydrogeologic tests will be performed on the newly installed wells to characterize groundwater flow within the proposed containment wall alignment. We do not expect that the final alignment of the wall will incorporate all saturated soils where depleted uranium is present, otherwise it would need to extend to encompass essentially the full extent of the groundwater depleted uranium plume. Depleted uranium in soil and groundwater outside the wall alignment will be treated with ISS.

Soil and bedrock samples will be collected and analyzed for physical and geotechnical properties, and groundwater samples will be collected and analyzed for chemical quality. Drilling and sampling methods are further detailed in the Drilling and Sampling Implementation Plan in Attachment 6.

PDI HB-2: Seismic Evaluation and Data Collection for Containment Wall Design

Based on 10 CFR Part 100, the closure remedy will be designed to withstand the Safe Shutdown Earthquake (SSE), including an assessment of the potential for surface deformation and faulting, liquefaction potential, and stability of the adjacent slope extending downward to the bog. The purpose of this PDI is to collect information on seismic conditions to support the design requirements of 10 CFR Part 100 as well as 10 CFR Part 40.

This PDI includes drilling a series of boreholes, performing crosshole seismic testing at two boreholes at a time in accordance with ASTM D4428M-14, and a subsequent seismic analysis. U.S. Geological Survey data will be used to determine bedrock ground motions for a 2,475-year return period earthquake.

Using the ground motion parameters of the bedrock and the shear wave measurements from the crosshole geophysics, a kinematic analysis of the proposed containment wall will be completed. The goal of this analysis is to determine the seismically-induced loads that the containment wall will need to withstand. This information will be used evaluate the need for reinforcing the containment wall to prevent cracking during the design seismic event. In addition, seismic design information obtained during this effort will be used to evaluate liquefaction potential of soils at the HB and perform pseudo-static slope stability analyses for the slope adjacent to the HB extending downward to the bog.

PDI HB-3: Bench Scale Testing of Containment Wall Mix Designs

The purpose of this PDI is to evaluate potential containment wall mix designs. Hydraulic conductivity is a critical aspect of the containment wall design, and information is needed on the ranges of hydraulic conductivities achievable using slurry wall construction methods with different mix designs. The mix designs will also be used to verify that the design will prevent groundwater flow over the time frame stipulated in 10 CFR Part 40.

This PDI includes preparation of bench scale samples using different mix designs, and a series of tests to evaluate the physical properties of the samples, including permeability and unconfined strength, and density.

PDI HB-4: Characterization of Soils for Cover Design and Slope Stability

The purpose of this PDI is to investigate the geotechnical properties of sloped areas of the site. Existing slopes in some areas of the site pose risk for slope failure or limit access for equipment during investigatory activities and future remedial activities, including around the HB, the Cooling Pond (including the gabion wall at the northern end), and the Sphagnum Bog. Maintaining stable slopes with adequate safety factors is critical for executing the PDIs outlined in this Work Plan and implementing the selected remedial actions outlined in the ROD. Information on the slopes at the HB is also required for the design of the HB cap. Work performed for this PDI will also obtain subsurface information to be used for HB cover design. Details of the proposed drilling methods is included in the Implementation Plan for the collection of samples for the ISS Bench Scale testing. The borings for the cap design purposes will be drilled as part of the same mobilization for the borings to collect representative samples for the Bench Scale testing that Geosyntec is conducting for the In-situ Soil Stabilization (ISS) design.

This PDI includes test borings within the HB for cover design, shallow hand probes at sloped areas of the site, and shallow hand probes and field vane shear testing at the Sphagnum Bog. Figure 4 shows the areas of the site requiring investigation and analysis related to slope stability. In addition, the data collected from the subsurface explorations will be used to perform slope stability analyses for the HB, the Cooling Pond and associated gabion wall, and the Sphagnum Bog.

PDI HB-5: Seepage Analysis for Containment Wall Design

The purpose of this PDI is to evaluate the seepage potential within the overburden and bedrock aquifers. The analysis and results from this PDI will inform the design of the hydraulic and physical properties of the proposed containment wall. The containment wall will be keyed into glacial till or bedrock, and the data collected in this PDI will be used to design the depth, thickness, and hydraulic conductivity of the wall.

This PDI will use hydrogeologic information collected from PDI HB-1 to develop a seepage model using SEEP/w software.

Table 1 – Summary of PDI Objectives and Scope for Holding Basin Containment

SITE AREA	PDI OBJECTIVES	PDI INVESTIGATION	PDI SCOPE
Investigation of Holding Basin Footprint and Containment Wall Alignment	Collect geotechnical, seismic, and hydrogeologic data necessary to design a containment wall that prevents DU from migrating downgradient and meets ARAR	**PDI HB-1**	• Six borings along the alignment of the cutoff wall into bedrock to evaluate soil density and bedrock characteristics by conducting SPTs throughout the overburden of each of these borings, and coring bedrock for laboratory testing to aid in the design of the containment wall and construction methods. Two of the cross-hole geophysical borings will also have SPTs through the overburden and rock core collected. • Borehole geophysics to evaluate water bearing zones and bedrock fracture orientation within the six borings and two of the geophysical cross-hole borings. • CMTs will be installed in six of the bedrock borings to gain multi-level piezometric head and GW quality information to support hydraulic design of the containment wall and evaluating ARARs. • Observation wells (OWs) will be installed within 3 bedrock boreholes located adjacent to the deep CMTs to allow for slug testing and short duration pumping to observe response in CMTs and other OWs. • Geotechnical Laboratory testing: up to 15 grain size tests on overburden soils, up to 15 compression strength tests on rock core, and up to 8 Cerchar Abrasivity tests on rock core. • Conduct research on pump house foundation and utility alignments into pump house, and conduct test pits to confirm utilities and structures (i.e. pump house slabs) that need to be removed for wall construction.

SITE AREA	PDI OBJECTIVES	PDI INVESTIGATION	PDI SCOPE
Holding Basin	Seismic Evaluation for Holding Basin Wall Design	**PDI HB-2**	• Drill six bedrock boreholes for cross-hole geophysics, forming two sets of 3-hole arrays for the geophysics. • Field shear wave measurements using cross-hole geophysical methods to characterize soil and bedrock to support the probabilistic seismic analysis to meet seismic design ARARs. • Conduct seismic analysis, determine design loads for containment wall in accordance with ASCE-7 design standards, and perform structural design of wall to resist design earthquake.
Holding Basin	Bench Scale Testing of Slurry and Wall Mix Designs	**PDI HB-3**	• Testing up to five containment wall mix designs for compressive strength and hydraulic conductivity.to identify a design that will meet the ARAR. Conduct a preliminary evaluation of pH impacts to surrounding groundwater. • Test bentonite slurry mixed with on-site municipal water source for swell index and fluid loss to evaluate potential bentonite products to be used for temporary support of excavated panels during barrier wall construction.
Holding Basin Cover and Side Slopes of Cooling Pond and Bog Area	Cover Design and Slope Stability Analysis	**PDI HB-4**	• Up to four borings into Holding Basin to collect geotechnical data necessary for cover system design. • Hand Probes to determine organics thickness within bog, and soft sediment thickness of sediments in Cooling Pond. • Hand Probes along slopes adjacent to the Holding Basin and Cooling Pond to evaluate near surface soil conditions, • Field vane shear measurements will be conducted on organics located within the bog. • Two test pits behind the gabion wall south of the Cooling Pond to evaluate the wall cross-section. • Plumbness survey of the gabion wall face at up to two transects. • Slope Stability analysis for proposed finished grades of Holding Basin Cap and adjacent side slopes, and side slopes adjacent to bog and Cooling Pond.
Seepage Analysis for Holding Basin Containment Wall Design	Seepage Analysis to evaluate hydraulic properties of wall and depth of wall	**PDI HB-5**	• Setup SEEP/w model with overburden and bedrock aquifer geometry with hydraulic conductivity values from Geosyntec calibrated groundwater flow model and CMTs and OWs tested in PDI HB-1. • Conduct parametric seepage modelling on wall depth and wall hydraulic conductivity to evaluate design parameters of containment wall

1.4 Document Organization

Section 2 provides performance standards which are used to help identify the PDI methodology (Section 3). Within Section 3, the investigation approach and data quality objectives (DQOs) are provided for each PDI. These sections refer to the FSP (Appendix I of the RDWP) for investigation methods, and to the QAPP (Appendix J of the RDWP) for analytical methods. Section 4 provides the PDI schedule, Section 5 defines contingent investigation activities, and Section 6 summarizes the reporting that will be completed to report on the PDI results.

2 Performance Standards

The ROD provided Remedial Action Objectives (RAOs), which are medium-specific goals that define the objective of remedial actions to protect human health and the environment. RAOs specify the COCs, potential exposure routes and receptors and provide a general description of what the cleanup will accomplish. The RAOs that are relevant for the Holding Basin Containment remedial design are:

1. Prevent direct human exposure by a future resident (by dermal contact, ingestion, inhalation, or ionizing radiation) to soils or sediments with contaminants (DU, PCBs, PAHs, and other inorganics) that exceed risk-based standards.
2. Prevent migration of DU/uranium from soils in the HB that would result in groundwater concentrations exceeding ARARs;
3. Limit migration of VOCs, SVOCs, uranium (depleted and/or naturally occurring), PAHs, and other inorganics in groundwater within the contaminant plumes at concentrations that would exceed ARARs or risk-based standards.

Achieving these RAOs in the Holding Basin containment will be guided by the following design parameters, standards and regulations:

- Hydraulic conductivity of the containment wall
- Depth and thickness of the containment wall
- Geochemistry of the containment wall mix design
- Compressive strength of the containment wall
- NRC 10 CFR 20: Standards for Protection Against Radiation
- NRC 10 CFR 40: Domestic Licensing of Source Material
- NRC 10 CFR 73: Physical Protection of Plants and Materials
- NRC 10 CRF 100: Reactor Site Criteria
- ASCE-7 Design Standards
- NRC Regulatory Guide 1.208: A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion
- NRC Regulatory Guide 1.216: Containment Structural Integrity Evaluation

3 Investigation Methodology

This section describes the investigation approach and data quality objectives (DQOs) for each of the PDIs. DQOs are qualitative and quantitative statements derived from the outputs of each step of the investigative process. The DQO process is a series of planning steps based on the scientific method that is designed to ensure that the type, quantity and quality of environmental data used in decision making applicable to the remedial design are appropriate for the intended application.

The seven (7) steps of the DQO process include:

- Stating the problem
- Identifying the decision
- Identifying inputs to the decision
- Defining the boundaries of the study
- Developing a decision rule
- Specifying limits on decision errors
- Optimizing the design for obtaining data

The sampling design and rationale for each of the PDIs are also provided within the discussion of the investigation approach and DQOs.

3.1 PDI HB-1

Investigation Design

The objective of PDI HB-1 is to collect geotechnical and hydrogeologic data at the HB. The data collected in this PDI will support the design of the containment wall. This PDI includes test borings, a geophysical survey, installation of groundwater wells, hydrogeologic and geotechnical testing, and an investigation into the foundations and subsurface structures of the former tank house, which is located within the proposed alignment of the containment wall. The Implementation Plan contained in Attachment 6 includes additional detail on the drilling, sampling, CMT and observation well installation and testing.

Borings will be located within the vicinity of the proposed containment wall alignment and will be terminated 20 to 50 ft into bedrock to gather data within the potential range of anticipated wall depths. Monitoring well and CMT well screens will be installed based on subsurface geology and the results of the geophysical survey. Field investigation and analytical methods referenced in Table 3.1-1 are provided in the FSP and QAPP, respectively.

Historic drawings from the former tank house indicate that the foundation on a portion of the structure extends approximately 19 ft below the slab. This PDI includes two test pits which are intended to confirm the limits of the deeper foundation and evaluate if utilities or other structures are present which would affect the construction of the containment wall.

DQOs

The DQOs for this PDI are as follows:

- Six borings will be installed along the alignment of the cutoff wall, including up to 3 borings with up to 50 ft of rock coring and up to 3 borings with 20 ft of rock coring to characterize subsurface soil and bedrock conditions. Standard Penetration Tests (SPTs) will be performed continuously through the overburden. These six boreholes will be instrumented with CMTs to monitor heads and water quality at different depths within the bedrock.

- A total of six separate boreholes will be drilled for conducting cross-hole seismic testing under PDI-2. Of these six boreholes, two will be drilled using drive and wash methods through the overburden to conduct SPTs. Sonic drilling methods will be employed for drilling through the bedrock and for completion of the other four cross-hole boreholes. Additional borings may be necessary if Rock Quality Designation and depth to rock are highly variable.

- Borehole geophysics will be completed to identify water bearing zones and characterize the nature, extent, and orientation of the bedrock fractures prior to installing the CMTs. Borehole geophysics will be performed on the open bedrock, using a suite of standard borehole geophysics tools, the most valuable of which are the heat-pulse flow meter and the acoustic televiewer. These tools will allow us to identify hydraulically dominant fracture zones in the bedrock and determine where CMT ports should be installed.
- Each of the six boreholes will be completed with a CMT to allow piezometric head and groundwater quality observations from up to 5 separate and isolated zones of the bedrock and overburden within one borehole.
- Three borings will be drilled adjacent to the three deeper CMTs to allow for the installation of an observation well in each of these completed boreholes. These observation wells will be used to pump from during short duration to measure the response in the adjacent multichannel CMTs.
- Two rounds of groundwater sampling and analysis will be completed from the CMTs and observation wells
- Pulse interference testing between CMT ports may be able to show connections between fracture zones. A pulse interference test is based on placing a hydraulic slug (pneumatic or otherwise) in one fracture zone and observing the pulse in nearby wells. This sort of testing is inexpensive but can yield high quality information about fracture connectivity, though this is only possible with high density data.
- Unconfined compression strength tests and Cerchar Abrasivity tests will be performed on selected rock core samples to assess rock properties for hydromill tool selection.

3.2 PDI HB-2

Investigation Design

This PDI includes a cross-hole geophysical analysis and a seismic analysis to support the containment wall design. This analysis will be performed using shear wave velocities from field shear wave measurements made using cross-hole seismic methods in two, three-hole arrays.

DQOs

The DQOs for this PDI are as follows:

- Field Shear Wave Measurements will be made to obtain information required to develop response spectra for seismic design analyses for the containment wall and the adjacent slopes extending downward to the bog and cooling pond. These data will be used to assess potential damage to the cutoff wall and adjacent slope stability during the design earthquake. Geophysical Applications, Inc. will be subcontracted to conduct cross-borehole geophysics for this work. Cascade drilling will drill the boreholes for installing the geophysical instrumentation.

- Site-specific response spectra will be developed through overburden using bedrock accelerations for the design earthquake (2,475-year return period) determined using U.S. Geological Survey seismic hazard deaggregations.
- Geotechnical Laboratory Soil and Rock Testing will be completed on up to 15 grain size analyses on selected soil samples obtained from the borings. In addition, up to 15 unconfined compression strength tests and up to 8 Cerchar Abrasivity tests will be performed on selected rock core samples to assess rock characteristics for hydromilling during containment wall installation.

3.3 PDI HB-3

Investigation Design

The purpose of this PDI is to evaluate the properties of various proposed mix designs for the slurry to be used for temporary support of the excavation and the mix design for the concrete backfill to construct the containment wall. Mix designs will be evaluated by performing bench scale testing. Admixtures to the concrete, including Xypex to reduce permeability, will be included in the mix designs. Laboratory permeability testing (ASTM D5084) and unconfined strength tests (ASTM D-1633) will be performed to evaluate sample performance for conformance with design requirements. The bentonite slurry testing will initially include testing an on-site water source for select parameters to confirm appropriate hydration of bentonite can be achieved.

DQOs

The DQOs for this PDI are as follows:

- If on-site water is not consistent with typical ranges acceptable for use of bentonite products, swell index testing and fluid loss testing of the bentonite slurry mix will be conducted.
- Containment Wall mix designs (up to 5) will be developed and tested to evaluate the hydraulic conductivity and compressive strength of wall backfill achievable using slurry wall construction methods. Admixtures to the Portland cement, including Xypex (to reduce permeability), will be included in the mix designs as needed. Mix designs will also be evaluated for stability in the geochemical environment in which the wall will exist.

3.4 PDI HB-4

Investigation Design

The purpose of this PDI is to investigate the geotechnical properties of soils in the Holding Basing, and at selected sloped areas of the site. Existing slopes in some areas of the site pose risk for slope failure or limit access for equipment during investigatory activities and future remedial activities, including around the HB, the Cooling Pond (including the gabion wall at the northern end), and the Sphagnum Bog. Locations of the proposed test borings and shallow hand probes are based on the slopes that may pose risk and areas associated with proposed remedial excavations which may require support of excavation during soil and sediment removal actions.

DQOs

The DQOs for this PDI are as follows:

- Up to four test borings will be completed within the footprint of the Holding Basin to characterize the soil types and thicknesses above and below the groundwater. Drilling and sampling details for these borings are included in the Implementation Plan prepared by Geosyntec for the ISS sample collection. This Implementation Plan was developed by Geosyntec primarily for collection of soils for the ISS bench testing. The subgrade soil will be subject to additional loading because of the proposed cover system within the Holding Basin footprint. Both borings are planned to extend 10 feet into natural soil encountered beneath the basin. Grain size distribution and hydrometer tests will be completed on up to 8 soil samples.

- Conducting hand probes within the bog and along the Cooling Pond and Holding Basin slopes. Performing field vane shear tests within the bog to the extent possible. This information will be used to evaluate the shear strength of the dike soils and peat in connection with slope stability analyses for the slopes surrounding the Holding Basin. The peat may be too fibrous to perform a field vane test; therefore, the thickness of the peat will be determined and published strength data on peat will be used for the analyses. Specific details on sediment sampling and testing is included in Appendix A, Attachment 6 in the Implementation Plan for Soil and Sediment Sampling.

3.5 PDI HB-5

Investigation Design

This PDI involves a seepage analysis to hydrogeologically characterize seepage potential within the overburden and bedrock aquifers. The analysis and results from this PDI will support the design of the hydraulic and physical properties of the proposed HB wall, including depth and thickness.

DQOs

The DQOs for this PDI are as follows:

- Once a network of CMTs have been installed, and the borehole geophysical data have been interpreted, the hydraulic conductivity and aquifer geometry will be incorporated into the finite element seepage model, SEEP/W to evaluate the containment wall alternate designs. The wall depth and hydraulic conductivity of the wall will be varied to determine the required hydraulic conductivity of the wall to meet the design objectives. It is expected that the SEEP/W analysis will include containment wall hydraulic conductivity varied from 1×10^{-6} cm/sec to as low as 1×10^{-8} cm/sec. The bench scale testing will then be run to evaluate the mix designs that meet the required hydraulic conductivity identified in the SEEP/W modelling.

- The results of the modelling will provide the basis of design for the depth and hydraulic properties of the containment wall to meet the ARARs. The ISS and cap will also be part of the design to meet the ARARs.

4 Investigation Schedule

Refer to RA schedule in RDRA document. The investigation will commence after EPA's approval of the PDI Work Plan.

5 Additional or Contingent Activities

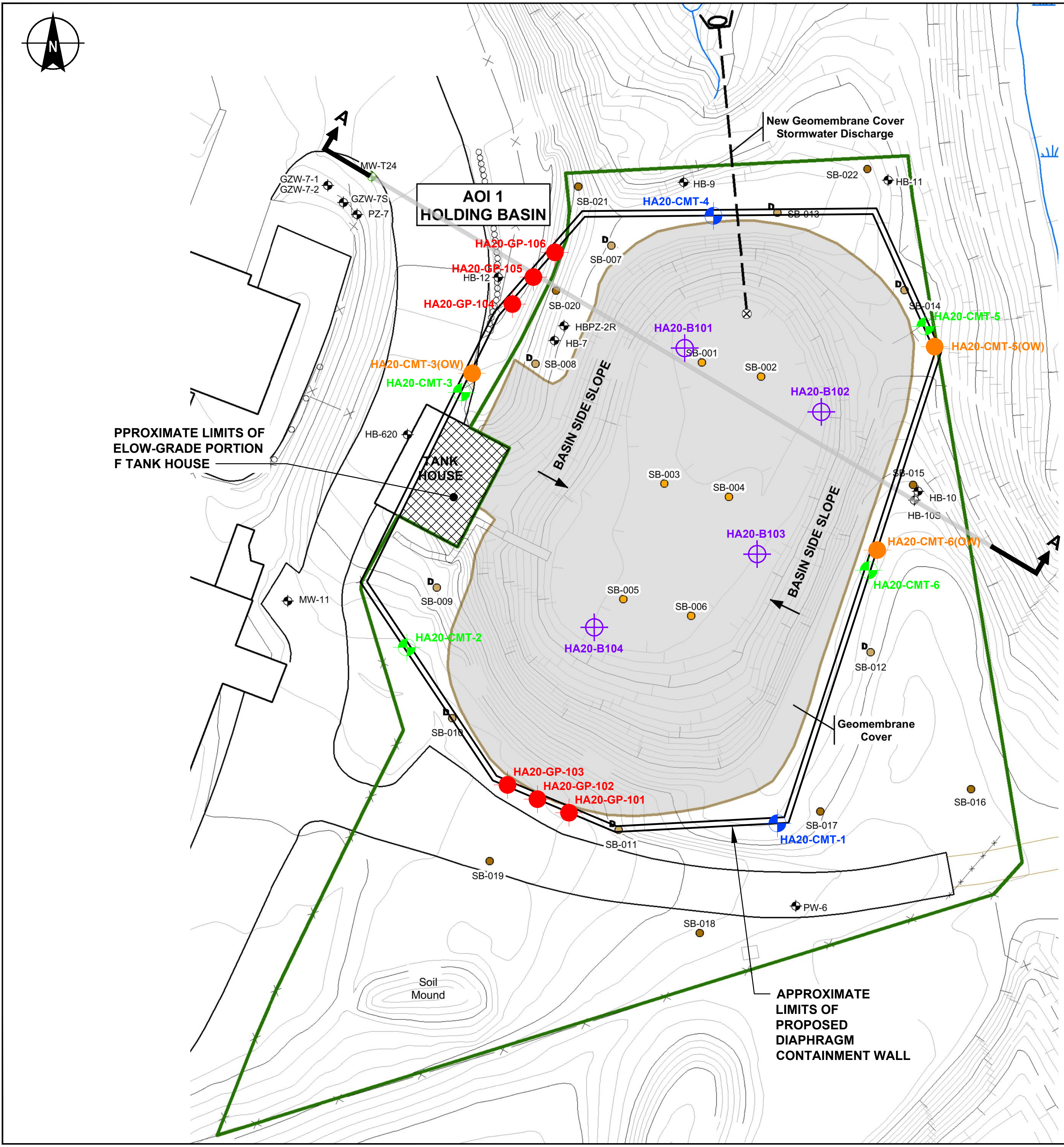
Additional explorations may be added during the subsurface investigations if conditions are highly variable at the proposed boring locations.

Additional analysis of the containment wall design will be conducted following completion of these PDIs. Based on the results of these PDIs, the depth, thickness, and hydraulic conductivity of the containment wall will be determined. The means of constructing the wall to achieve these design parameters will be discussed with our Contractor teaming partners, Trevilcos and Hayward Baker. Specifically, means of constructing the panel joints of the containment wall will be reviewed with these Contractors.

Additionally, information obtained from the ISS PDIs will need to be considered in the containment wall design and construction procedures. It is possible that the containment wall construction with concrete may impact the groundwater pH and alkalinity. These changes could impact the ability of the ISS reagents to sequester the uranium inside the containment wall. These considerations may result in the need for additional PDIs to be completed.

6 Reporting

Results and outcomes from these PDIs will be reported in the upcoming Remedial Design reports, including the PDI Evaluation Report, and the 30% RD report.



LEGEND

HA20-CMT-1 ⊕	PROPOSED HB-1 BORING (20 FT. INTO BEDROCK) - 3 CHANNEL CMT
HA20-CMT-2 ⊕	PROPOSED HB-1 BORING (50 FT. INTO BEDROCK) - 3 CHANNEL CMT
HA20-CMT-3(OW) ●	PROPOSED 2-IN. OBSERVATION WELL
HA20-B101 ⊕	PROPOSED HB-4 BORING (10 FT. INTO NATURAL MATERIAL)
HA20-GP-101 ●	PROPOSED HB-2 GEOPHYSICS BOREHOLE (20 FT. INTO BEDROCK)
●	DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (SUB-BASIN)
●	DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (BASIN PERIMETER)
D●	DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (BASIN PERIMETER, TO BEDROCK)
⊕	DESIGNATION AND APPROXIMATE LOCATION OF EXISTING WELL
⊕	DESIGNATION AND APPROXIMATE LOCATION OF RI PROPOSED WELL
▭	APPROXIMATE LIMIT OF AOI 1 OUTLINE

NOTES

1. BASE PLAN TAKEN FROM REMEDIAL INVESTIGATION/ FEASIBILITY STUDY FIELD SAMPLING PLAN PREPARED BY MACTEC, INC. DATED 29 SEPTEMBER 2004.
2. CROSS SECTION TAKEN FROM FIGURE 3.4.2 OF REMEDIAL INVESTIGATION REPORT PREPARED BY GEOSYNTEC, DATED APRIL 2014.

0 40 80
SCALE IN FEET

HALEY
ALDRICH

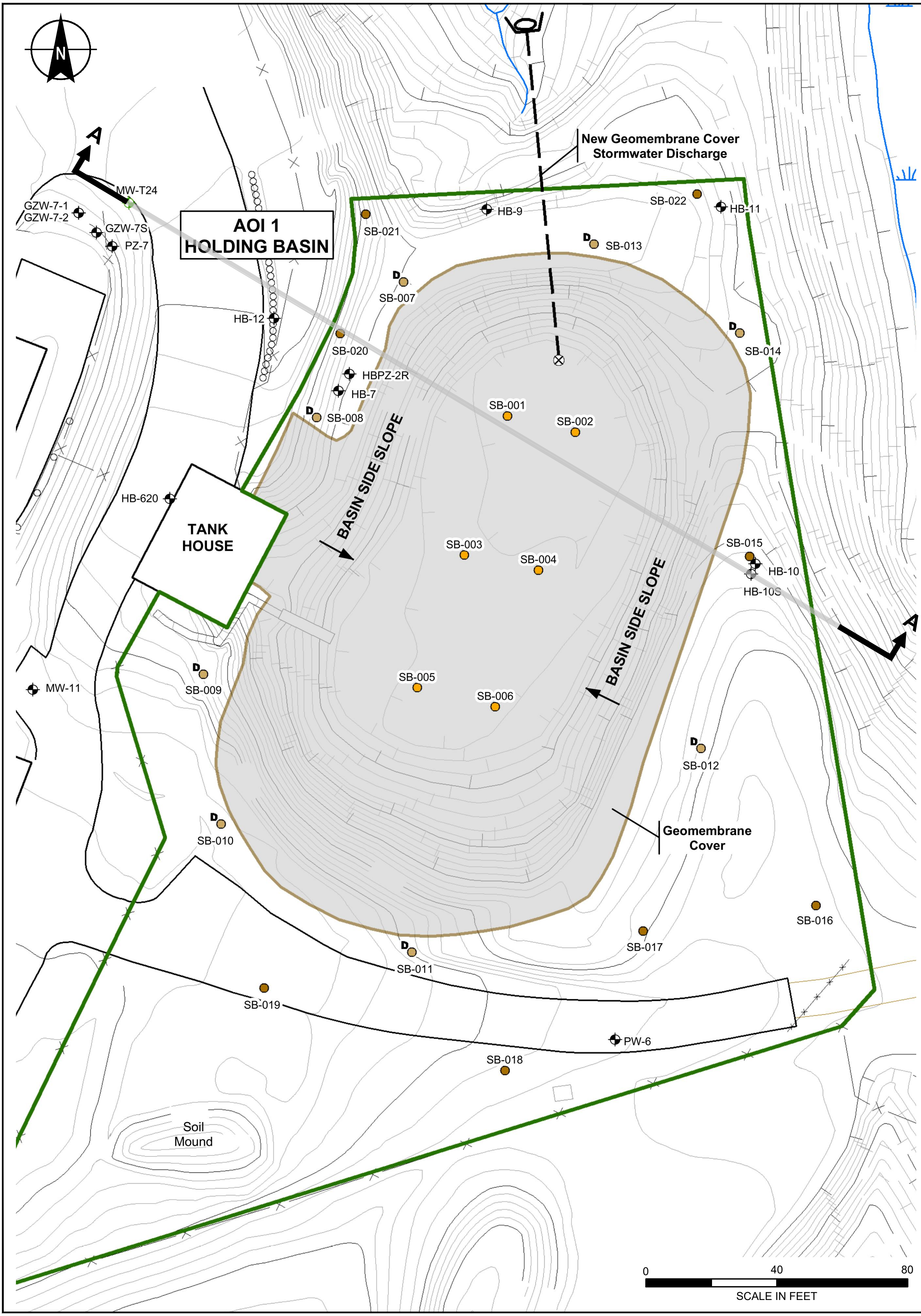
NUCLEAR METALS, INC.
2229 MAIN STREET
CONCORD, MASSACHUSETTS

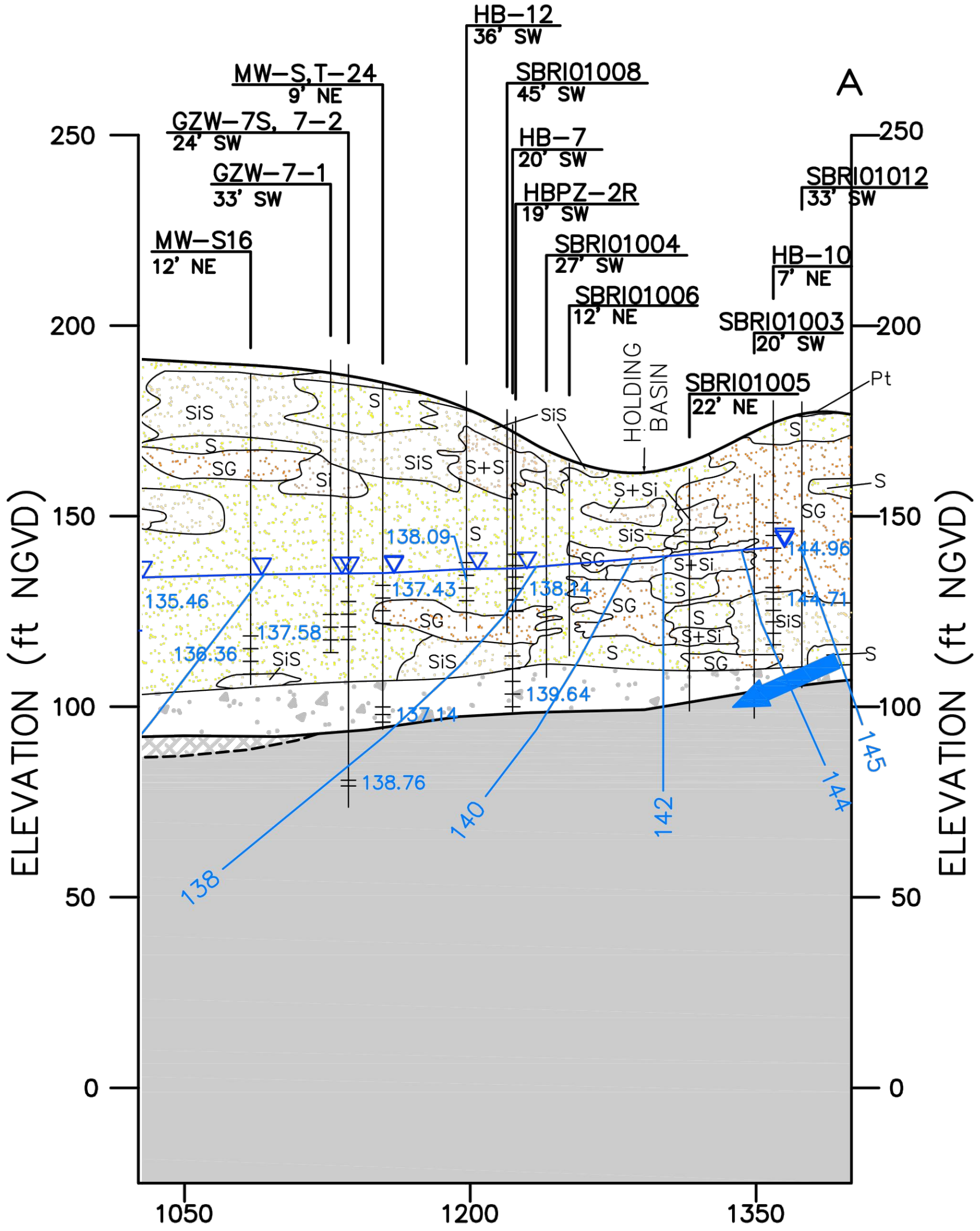
PROPOSED SUBSURFACE EXPLORATION LOCATION PLAN - PDI HB-1

SCALE: AS SHOWN
SEPTEMBER 2020

FIGURE 1

Saved by: DTE Printed: 3/5/2020 10:03 AM Sheet: B001
J:\GRAPHICS\131884\131884-004-B007.DWG





SECTION A-A

HORIZ. 0 100 200

VERT. 0 50 100

SCALE IN FEET

LEGEND

●	DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (SUB-BASIN)
●	DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (BASIN PERIMETER)
D●	DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (BASIN PERIMETER, TO BEDROCK)
⊕	DESIGNATION AND APPROXIMATE LOCATION OF EXISTING WELL
⊕	DESIGNATION AND APPROXIMATE LOCATION OF RI PROPOSED WELL
🟩	APPROXIMATE LIMIT OF AOI 1 OUTLINE

NOTES

1. BASE PLAN TAKEN FROM REMEDIAL INVESTIGATION/ FEASIBILITY STUDY FIELD SAMPLING PLAN PREPARED BY MACTEC, INC. DATED 29 SEPTEMBER 2004.
2. CROSS SECTION TAKEN FROM FIGURE 3.4.2 OF REMEDIAL INVESTIGATION REPORT PREPARED BY GEOSYNTEC, DATED APRIL 2014.

HALEY ALDRICH

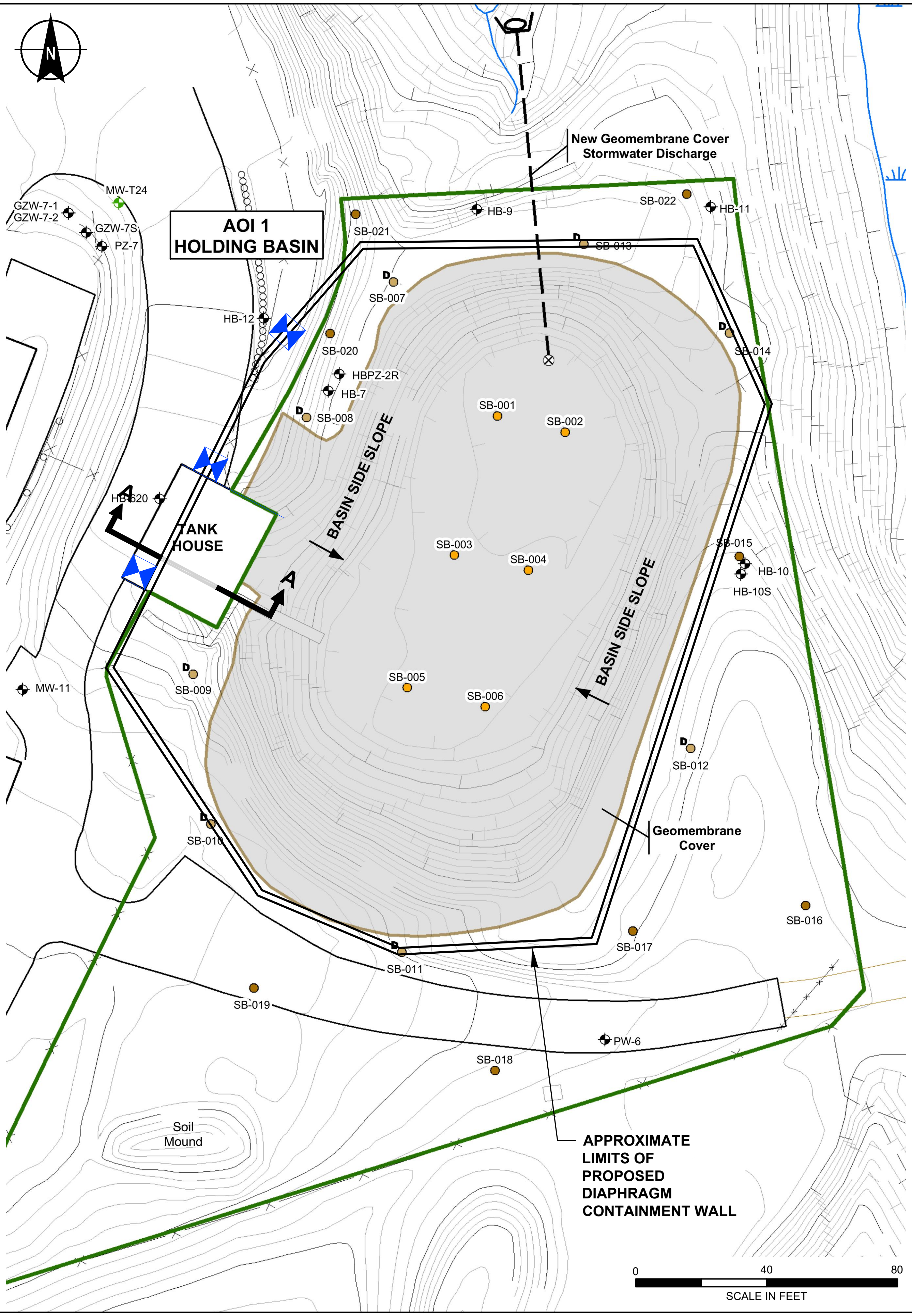
NUCLEAR METALS, INC.
2229 MAIN STREET
CONCORD, MASSACHUSETTS

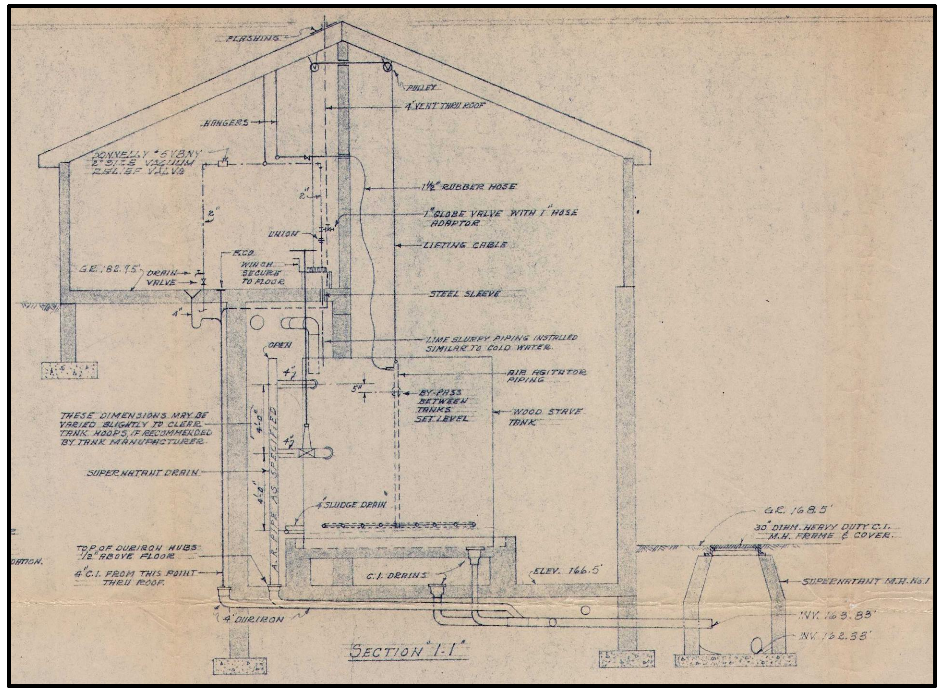
HOLDING BASIN CROSS SECTION

SCALE: AS SHOWN
SEPTEMBER 2020

FIGURE 2

Saved by: DTE Printed: 3/5/2020 10:03 AM Sheet: B001
J:\GRAPHICS\131884\131884-004-B001.DWG





SECTION A-A

0 10 20

APPROXIMATE SCALE IN FEET

LEGEND

⧗	APPROXIMATE LIMIT OF PROPOSED TEST PIT
●	DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (SUB-BASIN)
●	DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (BASIN PERIMETER)
D●	DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (BASIN PERIMETER, TO BEDROCK)
⊕	DESIGNATION AND APPROXIMATE LOCATION OF EXISTING WELL
⊕	DESIGNATION AND APPROXIMATE LOCATION OF RI PROPOSED WELL
🟩	APPROXIMATE LIMIT OF AOI 1 OUTLINE

NOTES

1. BASE PLAN TAKEN FROM REMEDIAL INVESTIGATION/ FEASIBILITY STUDY FIELD SAMPLING PLAN PREPARED BY MACTEC, INC. DATED 29 SEPTEMBER 2004.
2. CROSS SECTION FROM DRAWING TITLED WASTE TREATMENT FOR NUCLEAR METALS INC. PREPARED BY J.Q. ADAMS DATED DECEMBER 1957.

HALEY ALDRICH

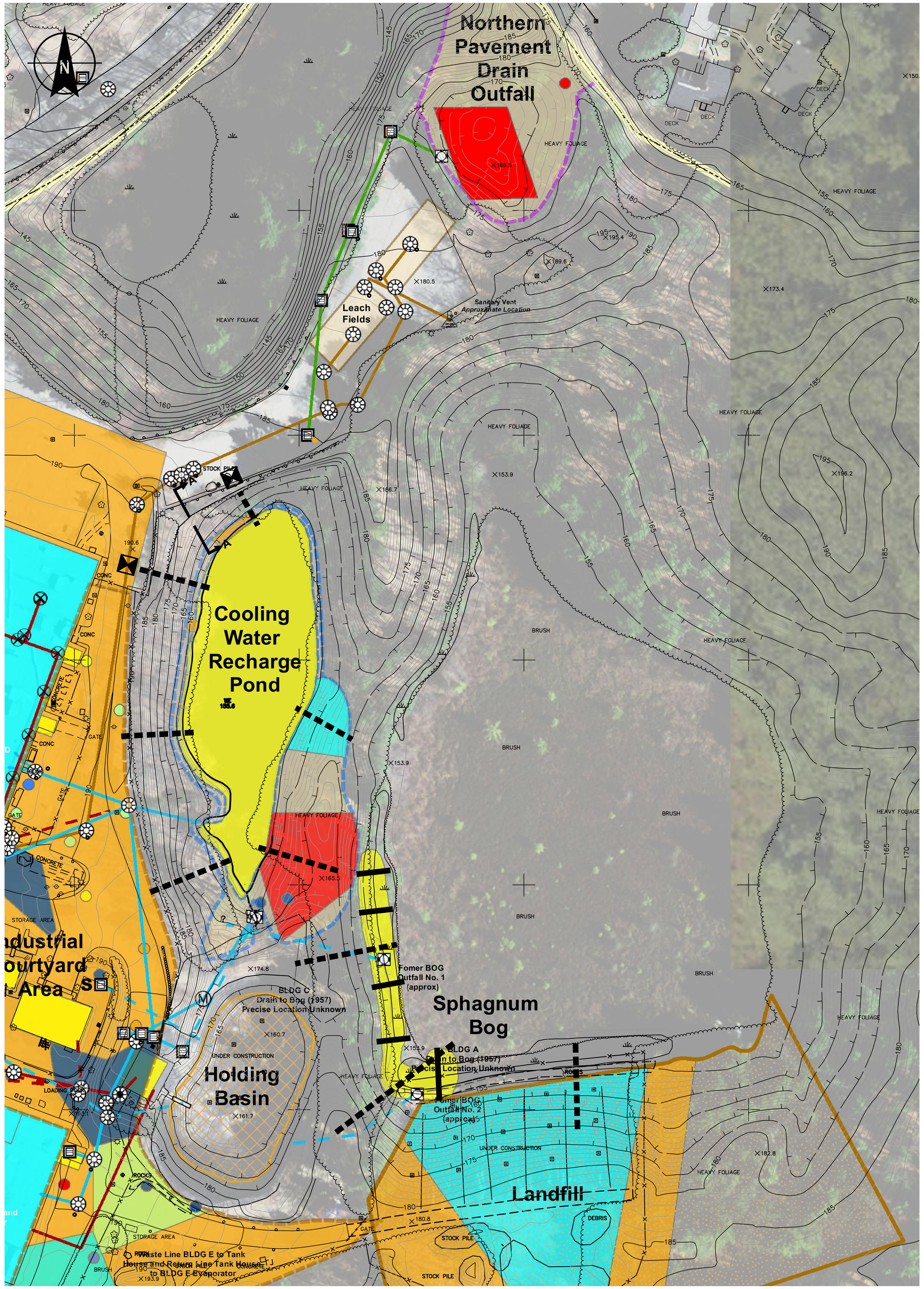
NUCLEAR METALS, INC.
2229 MAIN STREET
CONCORD, MASSACHUSETTS

HISTORIC TANK HOUSE PLAN

SCALE: AS SHOWN
SEPTEMBER 2020

FIGURE 3

Printed: 3/4/2020 2:58 PM Sheet: B002
Saved by: DTE
J:\GRAPHICS\131884\131884-004-B002.DWG



LEGEND

- ⊟ Catch Basin
- ⊘ Gas Gate
- S⊟ Sealed Catch Basin
- Vent
- ⊛ Diverter
- Ⓜ Drain Manhole
- Electric Manhole
- ⊗ Floor Drain
- Hydrant
- Manhole
- ⊠ Outfall
- Valve

- Acid or Active Waste Water Drain
- Former Acid Drain
- Natural Gas
- Cooling Water
- Potable Water Supply/Fire
- Former Fire
- Sanitary
- Parking Drain
- Lines Drain to Cooling Water Pond
- Former Storm Drain
- Unknown
- Site Boundary (Approx.)
- ☐ USTs
- ☐ Septic System

Excavation Depth (ft) **

- 🟥● 1.00
- 🟧● 1.01 - 2.00
- 🟨● 2.01 - 3.00
- 🟩● 3.01 - 4.00
- 🟦● 4.01 - 6.00
- 🟦● 6.01 - 8.00
- 🟦● 8.01 - 10.00
- T.B.D. by remedy selection
- Remove all metal & soil to PRGs

AreaName

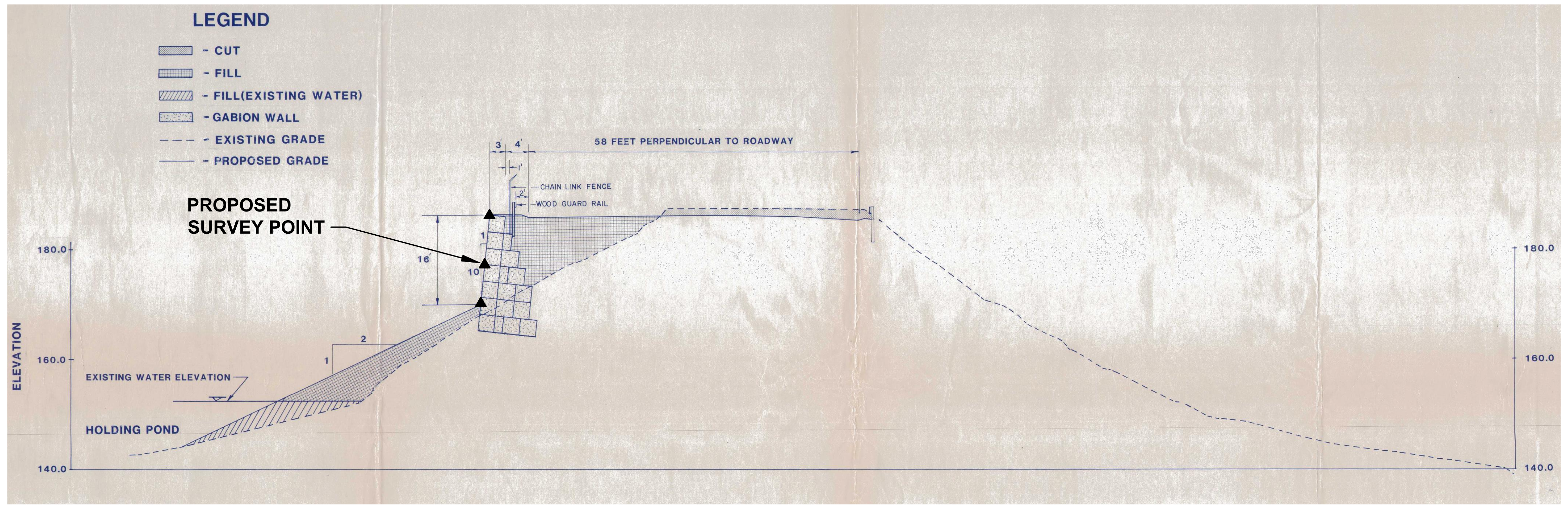
- Cooling Water Recharge Pond
- Industrial Courtyard Area
- Sweepings Area
- Northern Pavement Drain Outfall
- Trailer

NOTES:

**Single PRG exceedance points (not to scale) will be excavated in an initial 2.5 foot radius, followed by confirmation sampling, and additional excavation/sampling until PRGs are met.

All underground lines within the Industrial Coutyard Area extending to the Cooling Water Recharge Pond, the Holding Pond, and the Sphaghnum Bog will be excavated in an initial 2.5 foot radius, followed by confirmation sampling, and additional excavation/sampling until PRGs are met.

All building slabs will be removed together with all soils greater than PRGs. For cost estimating, 2.5 feet of soil will be removed, except buildings C, D, and E where 5 feet will be removed.



SECTION A-A

0 20 40 60 80

APPROXIMATE SCALE IN FEET

LEGEND

- ⊠ PROPOSED TEST PIT ALONG GABION WALL
- TRANSECTS FOR PROPOSED SHALLOW PROBES (3 PER TRANSECT)
- TRANSECTS FOR PROPOSED PROBES AND FIELD VANE SHEAR TESTING

NOTES

1. EXISTING BASEMAP REFERENCES AUTOCAD FILE "CONCORD.DWG", FROM GEOSYNTEC, DATED 2005.

0 50 100 150 200

SCALE IN FEET

HALEY ALDRICH

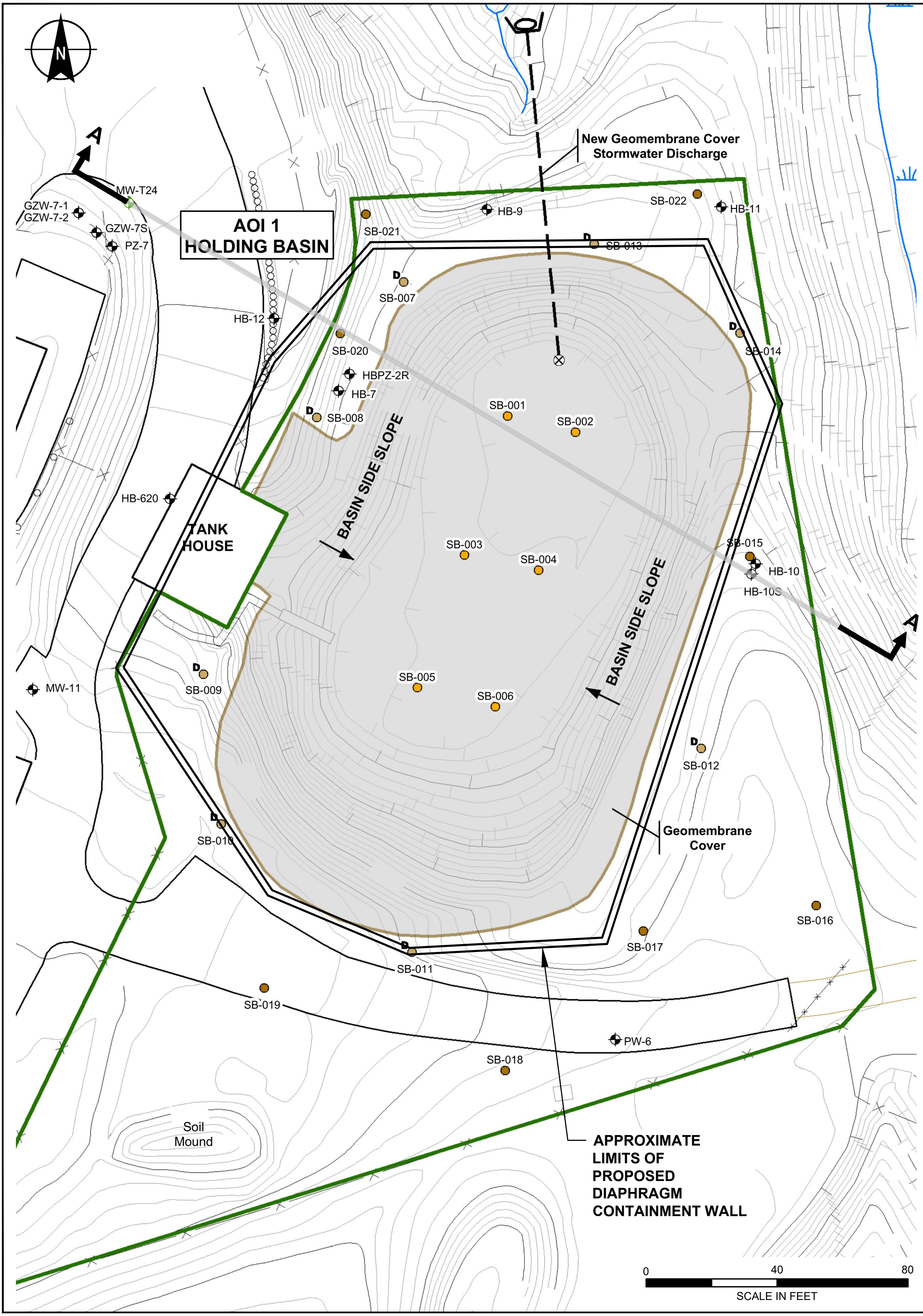
NUCLEAR METALS, INC.
2229 MAIN STREET
CONCORD, MASSACHUSETTS

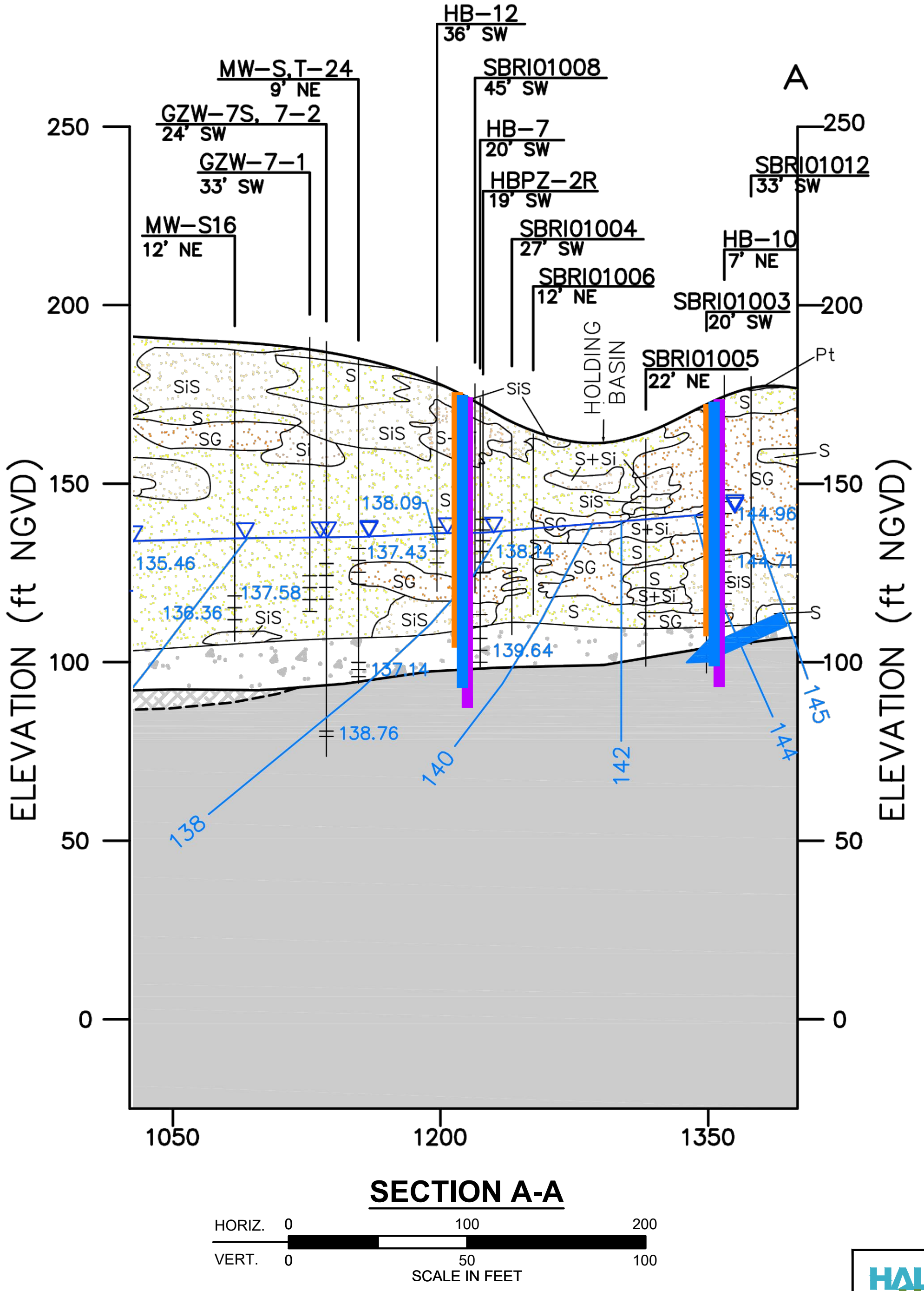
PROPOSED SLOPE STABILITY INVESTIGATION PLAN

SCALE: AS SHOWN
SEPTEMBER 2020

FIGURE 4

Saved by: DTE Printed: 3/4/2020 3:02 PM Sheet: D004
J:\GRAPHICS\131884\131884-003-D005.DWG





SECTION A-A

PLAN LEGEND

- 🟠 DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (SUB-BASIN)
- ● DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (BASIN PERIMETER)
- D● DESIGNATION AND APPROXIMATE LOCATION OF SOIL BORING (BASIN PERIMETER, TO BEDROCK)
- ◆ DESIGNATION AND APPROXIMATE LOCATION OF EXISTING WELL
- ◆ DESIGNATION AND APPROXIMATE LOCATION OF RI PROPOSED WELL
- 🟩 APPROXIMATE LIMIT OF AOI 1 OUTLINE

SECTION LEGEND

- 🟧 PROPOSED CONTAINMENT WALL ALIGNMENT 1
5 FT INTO TILL
- 🟦 PROPOSED CONTAINMENT WALL ALIGNMENT 2
5 FT INTO BEDROCK
- 🟪 PROPOSED CONTAINMENT WALL ALIGNMENT 3
10 TO 25 FT INTO BEDROCK

NOTES

1. BASE PLAN TAKEN FROM REMEDIAL INVESTIGATION/ FEASIBILITY STUDY FIELD SAMPLING PLAN PREPARED BY MACTEC, INC. DATED 29 SEPTEMBER 2004.
2. CROSS SECTION TAKEN FROM FIGURE 3.4.2 OF REMEDIAL INVESTIGATION REPORT PREPARED BY GEOSYNTEC, DATED APRIL 2014.

HALEY
ALDRICH

NUCLEAR METALS, INC.
2229 MAIN STREET
CONCORD, MASSACHUSETTS

PROPOSED CONTAINMENT
WALL ALIGNMENT -
PDI HB-5

SCALE: AS SHOWN
SEPTEMBER 2020

FIGURE 5

Saved by: DTE
J:\GRAPHICS\131884\131884-004-B006.DWG
Printed: 3/4/2020 3:04 PM
Sheet: B006

ATTACHMENT 1 - PDI HB-1: BEDROCK AND SOIL CHARACTERIZATION FOR CONTAINMENT WALL DESIGN

Project	Nuclear Metal Superfund Site, Concord, MA	Date	4 September 2020
Client	Remedial Design Work Plan	Page	1 of 7

1 INTRODUCTION

The Pre-Design Investigation (PDI) activity for the holding basin (HB) will investigate the hydrogeologic and geotechnical subsurface conditions of the overburden soils and bedrock within the limits of the proposed low-permeability vertical wall and the cap area within the footprint of the HB. The results of PDI HB-1 will be used to support the design of the containment wall structure surrounding the HB and determine the methods to be used to construct the containment wall. In addition, the type of cap and future loading due to the construction of the cap on the underlying soils will be evaluated in this PDI.

The HB wall will be designed to prevent groundwater from flowing out of the basin for a minimum of 200 years, and to the extent reasonably achievable, for 1,000 years. It is expected that the containment wall will be constructed using clam shell and hydromill equipment using slurry wall construction methods. The containment wall is expected to extend vertically to be keyed into glacial till or bedrock. A low permeability cover will also be constructed to cap the HB to minimize infiltration of precipitation and runoff.

2 OBJECTIVES

The objectives for performing the work described in this PDI are as follows:

- Characterize the groundwater flow within the overburden and fractured bedrock within the proposed containment wall area.

- Characterize the geotechnical parameters of the overburden and bedrock by collecting soil and rock samples for grain size distribution testing of the soil, and abrasivity testing of the rock.

- Determine the geophysical properties of the bedrock and identify the location and orientation of water bearing zones and fractures within the bedrock.

- Determine the depth and extent of the glacial till stratum, the depth to bedrock within the proposed HB containment wall and measure the hydraulic conductivity of each discrete zone of overburden soils and bedrock.

- Collect groundwater quality data within each discrete zone including the overburden soils and bedrock within the HB containment wall area.

- Evaluate the presence of subsurface structures associated with the pump house which would need to be removed during construction of the HB containment wall.

The results of this PDI will inform the design of a containment wall, including the depth that the wall must extend (into till or bedrock) and whether to key the wall into glacial till or bedrock based on subsurface conditions. The results will also be used to determine details on wall thickness and the methods to be used to construct the wall and to provide the data to conduct the seepage analysis described in PDI HB-5.

3 SCOPE OF WORK

The scope of work for this PDI will include a minimum of six test borings, installation of Continuous Multi-level Tubes (CMT) within these six completed boreholes, installation of three observation wells, drilling six boreholes for cross-hole seismic testing, and the completion of a series of laboratory tests to evaluate soil and bedrock conditions. The locations of the proposed explorations are shown on Figure 1, and Table C-1 provides a summary of the estimated depth and type of well installation proposed for each location. Additional test borings may be recommended if evaluation of soil density, depth to bedrock, and Rock Quality Designation (RQD) obtained from the initial borings indicate these properties are highly variable along the alignment of the proposed HB containment wall.

Borings will be advanced using drive and wash methods in the overburden, and sonic drilling methods to advance boreholes from 20 to 50 ft into bedrock. Observation wells will be installed in 3 boreholes and CMT wells will be installed in 6 boreholes. Down-hole geophysical analysis will be completed in up to 8 boreholes prior to installing the CMTs, and prior to completing the cross-hole seismic boreholes.

Field tests will be performed to evaluate hydrogeologic properties and will include pulse testing, short duration pumping tests, and slug tests on completed observation wells and CMTs. Laboratory tests will include unconfined compression strength tests and Cerchar abrasivity tests on bedrock cores, and grain size distribution on overburden soils.

Two rounds of groundwater sampling will be completed from the newly installed locations and will be analyzed for the target chemicals of concern listed in the site Record of Decision (ROD) in order to characterize groundwater quality within the discrete geologic zones below the proposed HB containment wall area.

The scope of work in this PDI also includes an evaluation on existing subsurface structures at the pump house, including foundations and utilities, which would have to be removed to construct the HB containment wall.

4 PROCEDURES

4.1 <u>Borings</u>

To evaluate subsurface geologic and geotechnical conditions, a minimum of six borings will be advanced 20 to 50 ft into bedrock. Boreholes will be advanced using drive and wash methods in the overburden and sonic drill methods in bedrock of each borehole. Overburden soil will be logged continuously in a 4-inch or 6-inch borehole, and standard penetration testing (SPT) will be performed using split spoons to make a qualitative assessment of soil density. Overburden samples will be collected for grain size distribution testing. Sonic drilling will be performed with a PQ diameter wireline barrel, which yields 3.3-inch diameter bedrock cores. Bedrock will be cored to evaluate rock characteristics and measure RQD for every core-run, which will be at 5 ft. intervals. Bedrock will be cored up to 20 ft in three of the borings and up to 50 ft in four of the borings. Two of the six cross-hole seismic boreholes will also be advanced in the same methods as described above. The other four cross-hole borings will be advanced to the prescribed depths using sonic drilling methods. Rock cores will be preserved for geotechnical testing. Locations of the proposed borings are shown on Figure 1.

The following ASTM Standards are attached in Section 1 for the completion of the test borings:

- ASTM D1586 for Standard Penetration Testing (SPT) of the soils;
- ASTM D2488 for the visual description methods for describing the soils;
- ASTM D2113 for rock coring methods; and
- ASTM D6032 for rock quality designation (RQD) measurement methods.

4.2 Installation of Observation Wells

Observation wells will be installed in 3 completed boreholes, each located adjacent to the three deeper CMT instrumented boreholes. Observation wells will be used to monitor the response from hydrogeologic field tests such as slug testing and short duration pump tests. Wells will be constructed with 2” machine-slotted PVC screen and 2” PVC riser pipe. The location of the well screen, screen slot size, and filter pack will be determined based on field conditions.

Following the installation, observation wells will be developed in accordance with NMI-GW-002 Monitoring Well Development Operating procedure included in the Field Sampling Plan (FSP).

4.3 Geophysical Survey

A geophysical survey will be conducted in up to 8 completed boreholes. The geophysical survey consists of lowering a series of downhole tools to the bottom of the exploration which measure the characteristics of the borehole.

The proposed geophysical survey will characterize the depths and orientations of bedrock fractures. The proposed log suite will include a fluid temperature (FTemp), fluid resistivity (FRes), three-arm mechanical caliper, optical televiewer, acoustic televiewer, and heat-pulse flowmeter.

The fluid-property logs will be recorded by sensors (Mt. Sopris model 2FSB-1000) mounted on the bottom of a caliper probe (Mt. Sopris model 2CAA-1000), during the first logging run down each borehole. Fluid properties will be recorded while lowering the probe at a cable speed of 5 feet per minute; the caliper log will be recorded at a speed of 12 feet per minute.

Optical televiewer imaging will be performed using an Advanced Logic Technology (ALT) model OBI40 MkIV optical televiewer probe. This device provides a full-color digital image of the borehole's interior, oriented with respect to both vertical and magnetic north. The OBI40 image will be recorded using a vertical sampling interval of 0.007 feet, with one pixel for each degree of arc around the borehole's interior. The images from the optical televiewer show geologic elements that exhibit contrasting colors (e.g. bedding bands of light or dark-colored minerals, or iron-oxide staining at hydraulically-active bedrock fractures).

Acoustic televiewer imaging will be performed using an ALT model ABI40 acoustic televiewer probe. This device images a bedrock borehole's interior via ultrasound pulses. ABI40 images will be interpreted to measure the dip angle and down-dip azimuth of both tight and physically-open planar features (bedding, joints, and fractures) encountered by each bedrock borehole.

Flowmeter testing will be performed using a Mount Sopris model HPF-2293 heat-pulse flowmeter probe. This device heats a small volume of water that serves as a tracer pulse. The length of time needed for the warm water to pass a thermistor mounted above or below the heating element, allows calculation of the flow rate in gallons per minute (gpm). Flowmeter measurements will be performed during ambient (non-pumping) conditions to identify transmissive fractures encountered by the bedrock boring that exhibit differing hydraulic head. The measurements will be repeated under pumping conditions to identify fractures that contribute to groundwater recharge in each borehole. Flowmeter testing will be performed at depths near hydraulically-active fractures, which will be determined based on results of the fluid-property, caliper, and acoustic televiewer logs.

The data collected from the survey will be used to identify the location of hydraulically dominant fracture zones, and define the nature, extent, and orientation of fractures. This data will be used to determine the intervals to screen observation wells and CMT intervals in each borehole. Previously collected data indicates that preferential pathways in the bedrock could be southwest and northeast based on a fracture set collected from MW-B03.

4.4 Installation of Continuous Multi-level Tubes

Solinst Continuous Multi-level Tube wells will be installed in six of the boreholes following completion and interpretation of the geophysical survey described above. Each CMT well will be installed with 3 to 7 ports. Locations of the ports in the bedrock will be based on the results of the geophysical survey such that the ports will be installed within the hydraulically active fracture sets. In addition, some ports may be placed in the overburden based on geologic conditions. Dual CMT ports may be installed at some locations, where one port is used to monitor water level and the other is equipped with dedicated tubing for groundwater sampling within the same geologic unit. CMT wells are constructed using a stainless-steel mesh surrounding the opening port, secured with clamps and backfilled with a sand pack. CMT well installation will be performed by a Trained CMT Contractor as certified by the manufacturer. The driller that is expected to complete the work is Cascade and they are certified CMT installers.

Each CMT port will be developed prior to sampling using a peristaltic pump, a mini inertial pump, or similar. The purpose of developing the CMT wells is to establish a hydraulic connection with the formation as there is no conventional well screen.

Copies of CMT specifications are included in Section 1 Attached.

4.5 Hydrogeologic Testing and Analysis

A series of tests are planned to estimate the hydraulic conductivity (k) of each hydrogeologic unit within the area of the proposed HB containment wall. Pneumatic slug tests will be performed at each CMT well port and observation well installed in this PDI. Additionally, 1 to 2 short-duration pumping tests will be performed at the 2” diameter observation wells. The water level response in surrounding wells and CMT ports will be monitored during the pumping test. This data will be used to calculate the k value of each hydrogeologic unit. Coupled with the chemical testing data, and evaluation of the potential contaminant pathways can be made and compiled to determine the appropriate depth the HB containment wall should penetrate to mitigate the potential migration pathways of contaminants of concern.

4.6 Geotechnical Laboratory Testing

Geotechnical laboratory testing will include up to 15 grain size tests of overburden soil samples, 15 compression strength tests on rock cores, and up to 8 Cerchar abrasivity tests on rock cores. Testing will be performed in accordance with the following ASTM International Standards:

- ASTM D6913/D6913M-17: Standard Test Methods for Particle Size Distribution (Gradation) of Soils Using Sieve Analysis

- ASTM D7928-17 Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis
- ASTM D7012-14e1: Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures
- ASTM D7625-10: Standard Test Method for Laboratory Determination of Abrasiveness of Rock using the CERCHAR Method.

Copies of these standards are included in Section 1 attached.

4.7 Groundwater Sampling

Two rounds of groundwater sampling will be completed following the installation of the observation wells and CMT wells. Up to 18 samples may be collected from the site during each round.

Sampling will be performed using low-flow methodology as outlined in the EPA Low-Stress (Low-Flow) Standard Operating Procedure EQASOP-GW4. A copy of the NMI-GW-010 is included in the FSP.

Field instruments will be inspected and calibrated at the beginning of each day and checked during field activities to verify performance. Instrument specific calibration procedures will be performed in accordance with the instrument manufacturer's requirements.

During low-flow purging, a multi-parameter meter will be used to measure pH, specific conductivity, turbidity, dissolved oxygen, oxidation reduction potential (ORP) and temperature. Readings will be collected at 5-minute intervals and recorded on field logs. Once parameters are stable, the samples will be collected into laboratory provided glassware.

Samples will be submitted to a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory for analysis of the chemicals of concern outlined in Table L-1 of the ROD, listed below.

- 1,1-Dichloroethane
- Tetrachloroethene
- Trichloroethene
- Vinyl chloride
- 1,4-Dioxane
- bis(2-Ethylexyl)phthalate

- Arsenic
- Barium
- Chromium
- Cobalt
- Copper
- Iron
- Manganese

- Molybdenum
- Thorium
- Depleted Uranium
- Natural Uranium
- Nitrate
- Nitrite

Additional samples will be submitted for quality control, as summarized in the QAPP in Appendix J of the RDWP. Quality control samples will be analyzed for all parameters analyzed during that sampling event.

4.8 Pump House Subsurface Structures Evaluation

The existing pump house is located along the alignment of the proposed HB containment wall, and accordingly, associated subsurface structures and utilities may have to be removed prior to construction of the HB containment wall. Figure 2 shows the plan and profile view of the HB and the historic drawing of the Pump House.

In order to assess the presence of subsurface structures and utilities, this scope includes a review of available information, including drawings, to determine pump house foundation details (including type and approximate depths), and identify potential utility alignments associated with the pump house. Additionally, a minimum of 2 test pits may be excavated to confirm the presence of subsurface utilities or observe foundations at the pump house.

4.9 IDW Management

Investigation-derived waste (IDW) generated during the work described herein will include soil cuttings from subsurface explorations and groundwater from low-flow sampling. Excess soil will be placed in drums and hauled for off-site disposal. Excess groundwater will be containerized, and treated on-site to the extent possible, or transported off-site for disposal.

5 REPORTING

The status of this PDI, and potentially results, will be provided to EPA during routine project meetings and status reports. Results and the outcome of the PDI will be incorporated into a separate PDI Status Report and the 30% RD report.

ATTACHMENTS

Table C-1 – Summary of Subsurface Explorations for PDI HB-1
Section 1 – CMT Specifications and ASTM Standards

TABLE C-1 - SUMMARY OF SUBSURFACE EXPLORATIONS FOR PDI HB-1
Nuclear Metals, Inc.
2229 Main Street
Concord, Massachusetts

Summary of Proposed Borings & Wells						
Boring	**Est. GS Elevation (NGVD)**	**Boring Depth (ft)**	**Well Installation**	**Well Type/Screen Strata**	**Est. Top of Screen Elevation (NGVD)**	**Groundwater Analytes**
HA20-CMT-1	175	90	HA20-CMT-1S	CMT Well - Overburden, Sand/Gravel	160	1,4 Dioxane Throrium Depleted Uranium Natural Uranium Nitrate Nitrite
			HA20-CMT-1I	CMT Well - Overburden, Till	110	
			HA20-CMT-1D	CMT Well - Bedrock	90	
HA20-CMT-2	185	135	HA20-CMT-2S	CMT Well - Overburden, Sand/Gravel	165	
			HA20-CMT-2I	CMT Well - Overburden, Till	110	
			HA20-CMT-2D$_1$	CMT Well - Weathered or Shallow Bedrock	100	
			HA20-CMT-2D$_2$	CMT Well - Intermediate Bedrock	80	
			HA20-CMT-2D$_3$	CMT Well - Deep Bedrock	60	
HA20-CMT-3	180	130	HA20-CMT-3S	CMT Well - Overburden, Sand/Gravel	160	
			HA20-CMT-3I	CMT Well - Overburden, Till	110	
			HA20-CMT-3D$_1$	CMT Well - Weathered or Shallow Bedrock	100	
			HA20-CMT-3D$_2$	CMT Well - Intermediate Bedrock	80	
			HA20-CMT-3D$_3$	CMT Well - Deep Bedrock	60	
HA20-CMT-4	166	90	HA20-CMT-4S	CMT Well - Overburden, Sand/Gravel	140	
			HA20-CMT-4I	CMT Well - Overburden, Till	110	
			HA20-CMT-4D	CMT Well - Bedrock	90	
HA20-CMT-5	169	115	HA20-CMT-5S	CMT Well - Overburden, Sand/Gravel	150	
			HA20-CMT-5I	CMT Well - Overburden, Till	110	
			HA20-CMT-5D$_1$	CMT Well - Weathered or Shallow Bedrock	100	
			HA20-CMT-5D$_2$	CMT Well - Intermediate Bedrock	80	
			HA20-CMT-5D$_3$	CMT Well - Deep Bedrock	60	
HA20-CMT-6	171	120	HA20-CMT-6S	CMT Well - Overburden, Sand/Gravel	140	
			HA20-CMT-6I	CMT Well - Overburden, Till	110	
			HA20-CMT-6D$_1$	CMT Well - Weathered or Shallow Bedrock	100	
			HA20-CMT-6D$_2$	CMT Well - Intermediate Bedrock	80	
			HA20-CMT-6D$_3$	CMT Well - Deep Bedrock	60	
HA20-CMT-3(OW)	180	130	HA20-CMT-3(OW)	2" Observation Well - Till	110	
HA20-CMT-5(OW)	169	115	HA20-CMT-5(OW)	2" Observation Well - Shallow Bedrock	95	
HA20-CMT-6(OW)	171	120	HA20-CMT-6(OW)	2" Observation Well - Deep Bedrock	80	
HA20-GP-101	175	130	-	3" Schedule 40 PVC Riser	-	-
HA20-GP-102	175	130	-	3" Schedule 40 PVC Riser	-	-
HA20-GP-103	175	130	-	3" Schedule 40 PVC Riser	-	-
HA20-GP-104	177	130	-	3" Schedule 40 PVC Riser	-	-
HA20-GP-105	176	130	-	3" Schedule 40 PVC Riser	-	-
HA20-GP-106	175	130	-	3" Schedule 40 PVC Riser	-	-
HA20-B101	161	30	-	-	-	-
HA20-B102	161	30	-	-	-	-
HA20-B103	161	30	-	-	-	-
HA20-B104	161	30	-	-	-	-

NOTES:
- Screen intervals subject to change based on geologic conditions and results of geophysical surveys.

Section 1
PDI HB-1 Standards & Specifications

Solinst®

CMT Multilevel System

Model 403 Data Sheet

CMT Multilevel System*

Get Quote | More Info

Model 403

This multilevel system is reliable, easy to install and inexpensive. It provides site assessors with a better understanding of three-dimensional groundwater flow and the distribution of contaminants in the subsurface. Remediation strategies can then be targeted more precisely, focusing efforts in the most effective manner.

The CMT Multilevel System makes the accurate monitoring of contaminant plumes much more affordable. It provides detailed vertical as well as horizontal data. Monitoring zones are set where needed and the single tube design allows reliable seals between zones.

Two systems are available. The 1.7" (43 mm) OD polyethylene tubing, segmented into seven channels, allows groundwater monitoring at up to 7 depth-discrete zones. The 3-Channel System uses the same material and construction, but it is only 1.1" (28 mm) in diameter. This narrow tube was developed for smaller diameter installations, especially direct push where the annulus for seal placement is narrow.

Advantages of the CMT Multilevel System

- Low cost and easy to install and use
- No joints - one smooth surface for easy, effective sealing
- Up to 7 depth-discrete zones in a single tube
- Locate ports and seals exactly where desired
- Installs quickly in large direct push casing and boreholes
- One 7-Channel CMT System can be completed by two people in under 3 hours, 3-Channel even faster
- Borehole not left open to allow cross contamination
- Isolated zones ensured using sand and bentonite layers or 3-Channel Cartridges - reliable and inexpensive
- Minimizes the risk of producing new contaminant pathways

Advantages of Multilevel Systems

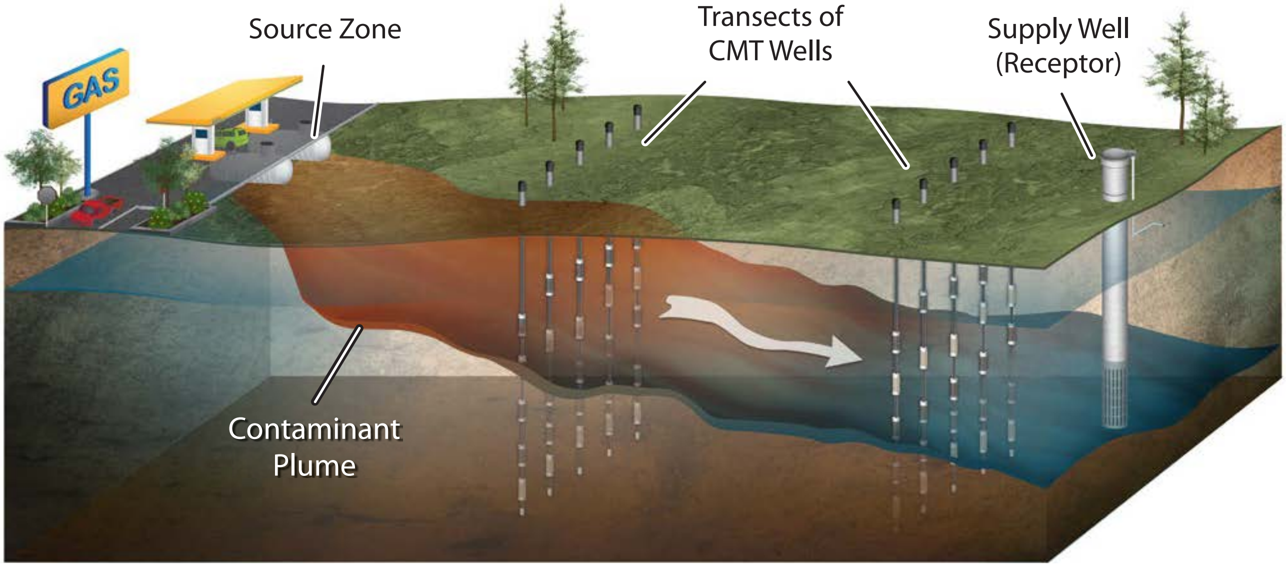
- Provide the most accurate 3-D assessment of a site
- Vital to understanding vertical contaminant distribution
- Allow documentation of changes in the concentration and delineation of contaminant plumes
- Low cost compared to multiple individual wells
- Minimize site disturbance

Research has shown that contaminant plumes are often thin and highly stratified. It has also been documented that traditional monitoring wells, with long screened intervals blend the groundwater over the entire length of the screen**. This can mask the true contaminant concentrations and distribution. Multilevel wells with short screened intervals overcome this problem. This high-resolution data gives unprecedented definition of the subsurface contamination, resulting in more effective and less expensive remediation. Water quality data from short-screened wells yield high quality, defensible data.

® Solinst and CMT are registered trademarks of Solinst Canada Ltd.
**Patents #6,865,933, #2,260,587*

***Elci et al (2001). Implications of observed and simulated ambient flow in monitoring well. Ground Water 39, no. 6: 853-862*

CMT Multilevel System



CMT Transects for Mass Flux Assessment

Multilevel Monitoring is Essential

Multilevels provide the most reliable, detailed data for accurate 3-D site assessment. Important advantages include:

Eliminates contaminant mixing in long screened wells – which averages out heads and contaminants, masks narrow zones of contamination and vertical variations, underestimates the extent and concentration levels due to dilution. Multilevels monitor discrete intervals.

Prevents biases due to ambient flow – cross communication of contaminants can occur when different zones in a borehole are not isolated. Properly sealed multilevels avoid ambient flow within a well.

Provides data for Mass Flux Calculations – Calculating the contaminant concentration and flow rate helps determine the maximum contaminant concentration and risk to receptors. A transect of multilevels across the groundwater flow path provides data for mass flux calculations.

Allows optimized remediation design – Using data from multilevels to accurately define the thickness, concentration variations and extent of a plume.

Saves Cost – through reduced permitting and drilling costs; and because narrow tubes allow smaller purge volumes, reduced disposal costs, efficient low flow sampling and rapid response to pressure changes, all reduce field time.

Typical 3-Channel CMT Installation in Overburden with Bentonite and Sand Cartridges

Typical 3 or 7-Channel CMT Installation using Layers of Bentonite and Sand Backfilled from Surface

Multichannel Tubing

A multilevel well that uses a continuous length of multichannel tubing has the advantage over other multilevels in that there are no joints. This significantly reduces the time and cost of installing wells and at the same time increases the reliability of the system. The CMT is very simple and convenient to use, as it gives full flexibility as to where monitoring zones are located.

The number and location of ports may be determined in advance, or after drilling the borehole. A Port Cutting Guide is used to create a port in a given channel, at the specified depth to be monitored. A plug is positioned and sealed in the channel just below the port opening and a stainless steel screen is fixed in place over the port to prevent fines from entering. Each channel is also sealed at the bottom of the tubing to avoid cross communication between monitoring zones.

Mechanical Plugs Seal Channels Securely

3-Channel Sand and Bentonite Cartridges

For direct push installation of the 3-Channel System, the annulus available is often too small to accurately place sand and bentonite layers. Therefore, bentonite cartridges have been developed to give reliable seals between zones, and accompanying sand cartridges to complete the installation.

These cartridges are approximately 2.4" (61 mm) in diameter and will fit inside various direct push drill rods. Ideally, the borehole diameter these bentonite cartridges are used in should not exceed a nominal 3.5" (90 mm), to ensure proper expansion and sealing.

3-channel CMT Sand and Bentonite Cartridges

One CMT System - Two Sizes

Features	7 Channel	3 channel
Tubing diameter	1.7" (43 mm)	1.1" (28 mm)
Monitoring zones	up to 7	up to 3
Channel diameter	6-Pie: 0.4" (10 mm) 1-Hex: 3/8" (9.5 mm)	3-Hex: 3/8" (9.5 mm)
Channel volume	40 mL/ft. 30 mL/ft. (center)	30 mL/ft.
Installation options	Sand & bentonite backfill Natural formation collapse	Bentonite & sand cartridges Sand & bentonite backfill Natural formation collapse
Coil lengths (Coil 4 ft. dia.)	100 ft. (30 m), 200 ft (60 m) & 300 ft. (90 m)	100 ft. (30 m), 200 ft. (60 m) & 500 ft. (150 m)
Centralizer sizes (other sizes optional)	4.4" standard (112 mm)	3.3" standard (84 mm)
Borehole diameter recommended for backfill installations	4" (100 mm) and larger	3.5" (89 mm) and larger
Borehole diameter for installations with seal and sand cartridges	N/A	2.8" - 3.5" (71 mm - 89 mm)

Monitoring CMT Multilevel Wells

Water levels and samples can be accurately obtained using the following quality Solinst instruments:

Water Levels: The narrow, laser marked, coaxial cable Model 102 Water Level Meter and 102M Mini Water Level Meter with a 0.157" (4 mm) diameter P4 Probe can be used to monitor water levels in any CMT channel. It is narrow enough to be used along side a pump in the same channel.

Samples: Sampling can be performed using the Solinst Peristaltic Pump, which has a suction lift limit of approximately 25 ft (7.5 m). The Mini Inertial Pump can be used with inexpensive polyethylene tubing to depths of 50 ft (15 m), or using PTFE tubing to depths of 150 ft (45 m).

The Micro Double Valve Pump (DVP) is ideal for low flow VOC sampling in narrow applications. The Micro DVP is made of flexible PTFE or polyethylene tubing which is 3/8" (9.5 mm) in diameter. A manifold at the surface has a quick-connect fitting for attachment to the Solinst Electronic Control Unit and a bypass for easy sample collection. Operation is easy, as the Electronic Control Unit has built in pre-sets. A multi-purge manifold is also available for the Micro DVP, for depths up to 240 ft (73 m).

Vapor Samples: A special Vapor Wellhead Assembly can be used to obtain depth discrete vapor samples.

Model 102 Water Level Meter

Model 410 Peristaltic Pump

Mini Inertial Pump 1/4" (6 mm)

Model 464 Electronic Control Unit

Model 408M DVP 3/8" (9.5 mm)

Model 403 Vapor Wellhead

CMT Field Applications

- Identify vertical as well as horizontal contaminant distribution with transect monitoring
- Ideal for shallow wells in high water table environments
- Multilevel water sampling and level monitoring in unconsolidated soils or bedrock
- Dewatering impact assessments at construction & mining sites
- Mass transport calculations and mass flux estimation
- Monitoring of natural attenuation or remediation processes, and documentation of its effectiveness
- VOC, MTBE and Perchlorate monitoring at NAPL sites
- Determination of the best location for reactive barrier walls, the Waterloo Emitter and other remediation methodologies
- Vapor monitoring with special wellhead seals
- Helps optimize design and performance assessment of remedial options

Nineteen 7-Channel CMT Systems were installed inside a manufacturing facility to characterize and monitor a plume beneath the building that is migrating off site. Systems were installed using sonic drilling to 30 m depths. Challenging geology made drilling and installation tricky, however, all Systems were installed in two weeks.

CMT Systems were installed at the bottom of a bay to measure submarine groundwater discharge. Eight 7-Channel CMT Systems were installed, with custom modifications to suit the open water application. Watertight wellheads had to be custom built to allow for sampling from the surface of the bay using a peristaltic pump.

CMT Training Programs

Solinst offers CMT courses that provide both instruction and hands-on training for CMT construction and installation. Contractors who attend and complete the course are "Trained CMT Contractors" and can be listed on the Solinst website at: **www.solinst.com/Prod/403/training.html**

As well as the Environmental Drilling Contractors who are training to become "Trained CMT Contractors", attendees often include regulators, consultants, and Solinst Distributors and their clients. In some states, these training courses qualify for continuing education credits.

Courses are offered at various environmental conferences throughout the year, such as those put on by the NGWA, Battelle and others. For larger groups Solinst can set up a training session at the group's own facility.

Please contact Solinst should you wish to attend or set up a training session.

CMT Installation and training as part of a "Multilevel Course" given by the University of Cranfield at Silsoe, U.K., in conjunction with Waterra (UK), British Geological Survey & Norwest Holst.

Instructing drilling contractors and consultants on CMT installation techniques at Battelle Bio-Symposium, Baltimore, Maryland.

The first CMT contractor training course, conducted at the NGWA Expo in Las Vegas, December 2004. Contractors are being instructed on proper port construction.

Outdoor installation/ demonstration at premises of Parrat-Wolff, Environmental and Geotechnical Drilling Services, Syracuse, New York.

CMT Specifications & Considerations

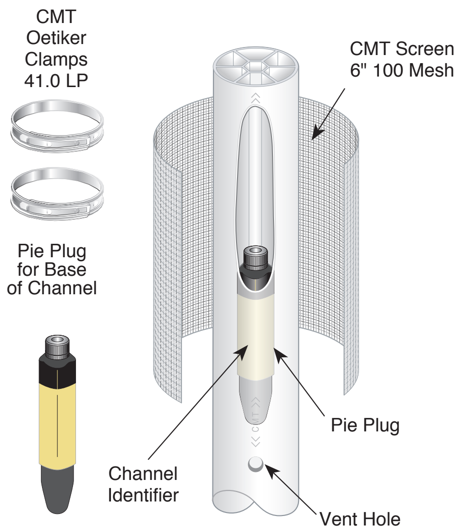
Model 403

CMT Specifications

CMT Multilevel Continuous Multichannel Tubing	 **7-Channel**	 **3-Channel**
Material	*MDPE	*MDPE
Tubing outside diameter	1.7" (43 mm)	1.1" (28 mm)
Channel diameter	6 - Outer pie channels: nominal 0.4" (10 mm) 1 - Center hex channel: nominal 3/8" (9.5 mm)	3 - Hex channels: nominal 3/8" (9.5 mm)
Channel volume	40 mL/ft 30 mL/ft (center)	30 mL/ft
Installation options**	Sand & bentonite backfill Natural formation collapse	Bentonite & sand cartridges Sand & bentonite backfill Natural formation collapse
Coil lengths*** (Coil 4 ft dia.)	100 ft (30 m), 200 ft (60 m) & 300 ft (90 m)	100 ft (30 m), 200 ft (60 m), & 500 ft (150 m)
Tubing temperature during installation	–15ºC to +35ºC ****	
Port plug temperature during installation	+15ºC to +35ºC	
Pressure differential (water levels)	12.5 inch-pounds torqued port plugs are designed to hold 20 psi (50 ft) of head differential.	

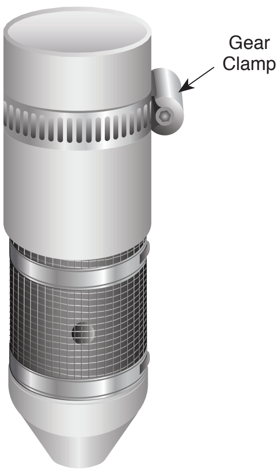
Notes	
	* Tubing is MDPE; proprietary mix of HDPE and LDPE products.
	** Avoid using 'single lifts' of grout, greater than 50 ft in the unsaturated zone.
	*** Each CMT coil measures 1 to 2 ft longer than stated.
	**** If air temperature is above +35ºC, use cold water to cool down the tubing at the port before installing the port plug.

7-Channel Standard Port Assembly (106278)



Note: Port plugs are tightened to a torque of 12.5 inch-pounds. Plugs in the base, or bottom, of the CMT should be torqued sequentially and incrementally to ensure even expansion.

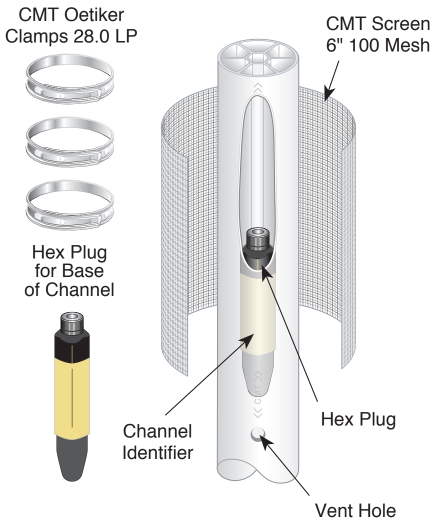
Guide Point with Port Assembly (105856)



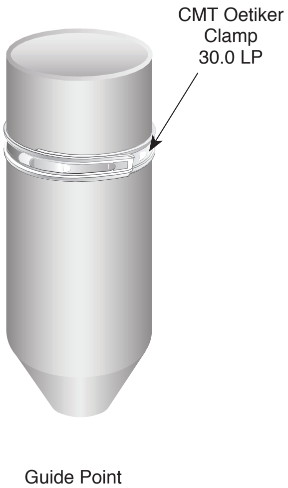
Guide Point Port Assembly

Note: Gear clamp is tightened to a torque of 12.5 inch-pounds, so guide point can support up to 20 lbs of additional weight (optional).

3-Channel Standard Port Assembly (107237)



3-Channel Guide Point (107178)



Note: Port plugs are tightened to a torque of 12.5 inch-pounds.

Hand Tools for CMT System Assembly

Constructing Dual CMT Ports

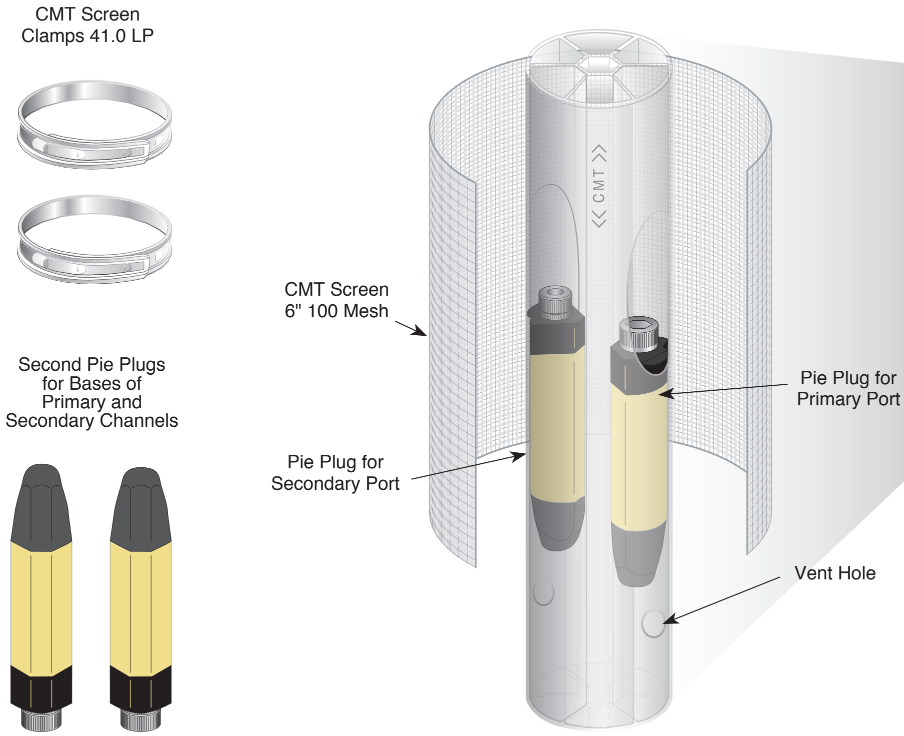
Model 403 7-Channel

If you are monitoring five zones or less, using a 7-Channel CMT Multilevel System, you can take advantage of all seven channels by duplicating channels/ports to the same depth. You can measure water levels in one channel, and have the other channel available for sampling at the same depth.

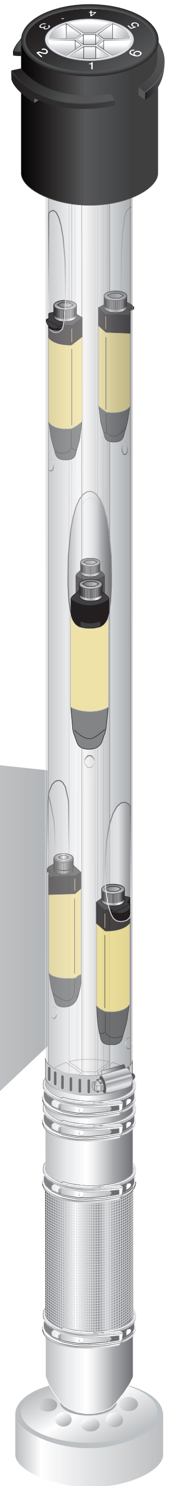
Typically, the four primary ports would be Channels 7, 6, 5, and 4. The three duplicated (or secondary) ports would be constructed in the outer channels 3, 2, 1. To maintain the structural integrity of the CMT, it is recommended to construct the dual ports in opposite channels, i.e. Channel 4 would pair with Channel 1. Channel 7, the central hex-shaped channel, would not be duplicated.

Constructing two monitoring ports at the same depth can be achieved by using a 7CH Standard Port Assembly (pt#106278), and an additional 7CH Standard Pie Plug Seal Assembly (pt#106861) that consists of two pie plugs (one to seal the secondary port opening and the other for the base of that channel). The port screen from pt#106278 wraps around both port openings.

See the 7-Channel CMT Multilevel System Assembly Manual for detailed port construction instructions.



7-Channel Standard Port Assembly (106278) with Additional 7-Channel Standard Pie Plug Seal Assembly (106861) for Duplicating Port



Example of 7-Channel CMT System with Three Ports Duplicated

Printed in Canada
March 28, 2016

Trained CMT Contractors

Trained CMT Contractors have completed the technical training required
by Solinst to ensure the proper assembly of CMT Multilevel Systems.

Company	Trained CMT Contractors	Date Trained	City	State
Advanced Geoenvironmental Inc.	Richard Marty	13 Dec 2004	Stockton	CA
Aardvark Drilling Inc.	Matthew England	25 Oct 2007	Guelph	ON
	Darren Juneau		Guelph	ON
Advanced Drilling, Inc.	Scott Alberalla	10 Mar 2014	Pittstown	NJ
	Brian Wagner		Pittstown	NJ
Advisian	Greg Haryett	19 May 2016	Edmonton	AB
	Kaitlin Kawalilak		Edmonton	AB
	Stuart Gray		Edmonton	AB
	Neil Krystopowicz		Edmonton	AB
	Daniel Lint		Edmonton	AB
	Chisenga Mulenga		Edmonton	AB
	Bailey Nicholson	5 Oct 2018	Calgary	AB
	Megan Cawthorpe		Calgary	AB
	Matthew Eubank		Calgary	AB
	Marissa Hayward		Calgary	AB
Alpine Remediation	Matt Steere	2 Jun 2015	Golden	CO
	Andy Steere		Golden	CO
Cascade Drilling	Jerry Ray	13 Dec 2004	Huntsville	AL
	Clayton Dillard	11 Mar 2005	Mesa	AZ
	Rick Mallett		Peoria	AZ
	Matt Rayson		Peoria	AZ
	John Sanchez		Peoria	AZ
	Perry Hormann	18 Nov 2005	Phoenix	AZ
	Johnathan Gray	11 Mar 2005	Santa Fe Springs	CA
	Jose Munguia		Santa Fe Springs	CA
	Alexandro Patricio	22 Mar 2006	Santa Fe Springs	CA
	Ray Reece		Santa Fe Springs	CA
	Denzil Roberts	11 Mar 2005	Santa Fe Springs	CA
	Steve Vasquez		Santa Fe Springs	CA
	Greg Zekoff		Santa Fe Springs	CA
	Jeff Thornhill	31 Jun 2008	Yuba City	CA
	Chyenne Zimmerman		Yuba City	CA
	Randy Conrad	22 Mar 2006	Ft. Lauderdale	FL
	Raymond Dayton, Sr.	11 Mar 2005	Ocala	FL
	John Klaver		Ocala	FL
	Neil Gamache		Ocala	FL
	Mark McLean	22 Mar 2006	Pensicola	FL
	Thomas Whiddon	18 Dec 2005	Pensicola	FL
	Jason Greer	13 Dec 2004	Indianapolis	IN
	Mike Hansen	21 Dec 2009	Walnut	IL
	Chris Barden	18 Nov 2005	Fenton	MI
	Don Bond		Fenton	MI
	James Vanconant	11 Mar 2005	Fenton	MI
	Rick Poysa	21 Dec 2009	Bemidji	MN
	Bill Beuning		Bemidji	MN
	Kevin Smith		Big Lake	MN
	Jason Koering		Fort Ripley	MN
	Dale Duscher		Little Falls	MN
	Mark Schulz		Little Falls	MN

Company	Trained CMT Contractors	Date Trained	City	State
Cascade Drilling (cont'd)	Ronald Walkoviak	21 Dec 2009	Little Falls	MN
	Chad Johnson		Little Falls	MN
	John Posterick		Little Falls	MN
	Scott Thalacker		Little Falls	MN
	Mark Biermaier		Little Falls	MN
	Lawrence Erdman		Little Falls	MN
	Randy Ochs		Little Falls	MN
	Michael Mueller		Little Falls	MN
	Jeff Jehn		Little Falls	MN
	Jason Drabek		Little Falls	MN
	James Kleinschmidt		Little Falls	MN
	Leonard Jay Rager		Little Falls	MN
	Dennis SchweisThal		Little Falls	MN
	Erik Rekowski		Little Falls	MN
	Gary Burgarot		Little Falls	MN
	Mike Czech		Little Falls	MN
	James Doucette		Little Falls	MN
	Matt Osterberg		Little Falls	MN
	Todd Schmalfeldt	21 Dec 2009	Marathon	MN
	Kevin Finicum		Williams	MN
	Bill Armstrong	18 Nov 2005	Windsor	NJ
	Richie Guerra		Windsor	NJ
	Ron Guerra		Windsor	NJ
	Michael Bentley		Marietta	OH
	Fred Hafner		Marietta	OH
	Mark Knolle	13 Dec 2004	Marietta	OH
	Karl Savinkoff	11 Mar 2005	Marietta	OH
	Jim McCombs		Marietta	OH
	James Waddell	22 Mar 2006	Marietta	OH
	Efelito Rauch	18 Nov 2005	Portland	OR
	Michael Coleman	11 Mar 2005	New Ellenton	SC
	Jose Asua	22 Mar 2006	Memphis	TN
	Kent Adamson		Salt Lake City	UT
	Clyde Moore		Seattle	WA
	Ryan Larsen	21 Dec 2009	Plover	WI
	Alvin Anderson		Mason	WI
	Timothy Mattmiller		Schofield	WI
	Gary Jones		Tomahawk	WI
	Derrik Sandberg	13 Dec 2004	Incline Village	NV
Delta Well & Pump Company	Tom King	26 Aug 2008	Ronkonkoma	NY
	Conrad Strebel		Ronkonkoma	NY
	Pat Dorney		Ronkonkoma	NY
Direct Environmental Drilling Inc.	Andrew Armstrong	25 Oct 2007	London	ON
E C T Manufacturing, Inc.	Tim Ravert	19 Dec 2019	Hamilton	NJ
	Scott Lenglet		Hamilton	NJ
E & G Drilling Services	Edward Loosa	13 May 2009	Ludington	MI
	Robert Gerbers		Ludington	MI
Eichelbergers Inc.	Chris Brenneman	26 Feb 2007	Mechanicsburg	PA
	Will Deininger		Mechanicsburg	PA
Fisher Environmental Ltd.	Marius Voinea	25 Oct 2007	Markham	ON
GeoEnviroTech	Juan D. Negron	13 Dec 2004	Guaynabo	PR
H20 Well Service	Jim Johnston		Hayden	ID

Trained CMT Contractors

Company	Trained CMT Contractors	Date Trained	City	State
HCI Drilling	David Lagoski	17 Aug 2016	Lubbock	TX
	Kenny Cooper		Lubbock	TX
Impact Environmental	Joseph Boyle	18 Nov 2005	Lyndhurst	NJ
Layne Christensen Company	Mike Magnin	16 Dec 2006	Indianapolis	IN
Leidos Engineering EE&S	Bill Lillich	26 Feb 2007	Harrisburg	PA
London Soil Test Ltd.	Don McRae	25 Oct 2007	London	ON
Major Drilling Environmental LLC.	James Blackwood	13 Dec 2004	Huntsville	AL
	Ricky Davis		Huntsville	AL
	Don Larson		Huntsville	AL
Matrix Solutions Inc.	Amit Sharma	14 Aug 2014	Calgary	AB
	Brett O'Donnell		Calgary	AB
	Charla Philippon		Calgary	AB
	Kim Taschuk		Calgary	AB
Mud Bay Drilling Co. Ltd.	Gordon Gibbons	18 Nov 2005	Surrey	BC
	Dale Van Dam	3 Nov 2011	Surrey	BC
	Johnny Barone		Surrey	BC
	Kelly Rosehill		Surrey	BC
	Ryan Fales		Surrey	BC
	Kevin Riplinger	9 Jun 2012	Surrey	BC
	Jeff Froland		Surrey	BC
	Antin Achtymichuk		Surrey	BC
	Nick Rennie		Surrey	BC
	Shawn Ashley		Surrey	BC
M&W Drilling	Jay Hocutt	18 Oct 2008	Knoxville	TN
	Ray Huston		Knoxville	TN
	Anthony Foster		Knoxville	TN
	Garry Akins		Knoxville	TN
	David Duncan		Knoxville	TN
National Exploration Wells Pumps	Tim Cechini	16 Dec 2006	Montclair	CA
	Ignacio Gutierrez		Montclair	CA
	Jorge Gutierrez		Montclair	CA
	Christopher Neal		Montclair	CA
	Jeff O'Connor		Montclair	CA
	Javier Rios		Montclair	CA
	Samuel Rivera		Montclair	CA
	Bill Stuckey		Montclair	CA
	Bob Nix Jr.		Montclair	CA
	Chris Tatum		Richmond	CA
Orbit Garant Drilling, Inc	Evan Williams	19 Mar 2019	Sharon	ON
	Tim Coffey		Sharon	ON
	Ilshat Galiulin		Sharon	ON
Paddock Drilling	Andrew Clark	23 Sept 2009	Saskatoon	SK
	Brian Wolaniuk		Saskatoon	SK
Paradyme Drilling & Env. Serv.	Gary Stone	13 Dec 2004	Brentwood	CA
Parratt-Wolff Inc.	Robert Stevens	5 May 2005	Hillsborough	NC
	Michael Ellingworth		Syracuse	NY
	William Morrow		Syracuse	NY
	Joel Parratt		Syracuse	NY
	Jolaan Price		Syracuse	NY
PGL	Cory Nelson	9 Jun 2012	Vancouver	BC
	Zayed Mohamed		Vancouver	BC

Trained CMT Contractors

Company	Trained CMT Contractors	Date Trained	City	State
Reed Engineering Group	Derrin Williams	11 Jan 2018	Dallas	TX
	Terry Barritt		Dallas	TX
SGS North America Inc.	Nicholas Fallucca	18 Oct 2019	West Creek	NJ
	Keith Butcher		West Creek	NJ
	Phil Gfroehrer		West Creek	NJ
SLR Consulting (Canada) Ltd.	Nicholas Frey	3 Dec 2019	Guelph	ON
	Albanie Douglas		Guelph	ON
SNC Lavalin	Ron Salomonson	16 May 2016	Calgary	AB
	John Jackson		Calgary	AB
	Vladimir Danov		Calgary	AB
	Jessica Perras		Calgary	AB
	Greg Potter		Calgary	AB
	Emily McMaster		Calgary	AB
	June Lu		Calgary	AB
	Scott Poirier		Calgary	AB
	Tim Niskala		Calgary	AB
Sonic Soil Sampling (Ontario) Inc.	Alan Archibald	25 Oct 2007	Concord	ON
Stantec	Scott Brinton	12 Jun 2018	Denver	CO
	Rick Reinke		Denver	CO
	Paul Kos		Denver	CO
Summit Drilling	Dermot Dillon	13 Dec 2004	Bridgewater	NJ
Terra Sonic	Mike Casey	13 Dec 2004	Woodacre	CA
Underground Sonic Drilling	Ryan Bailey	25 Oct 2007	Wasaga Beach	ON
Uniwide Drilling Co. Ltd.	Rick Friedel	14 Mar 2011	Burnaby	BC
Vertex Professional Services Ltd.	Josh Malkin	26 Nov 2019	Sherwood Park	AB
	Terry Husselby		Sherwood Park	AB
	Brian Prodahl		Sherwood Park	AB
	Laura Kluczny		Sherwood Park	AB
	Vladislav Roujanski		Sherwood Park	AB
	Ashley Craig		Sherwood Park	AB
Yellow Jacket Drilling Services, LLC	Marion Phillips	21 Jul 2017	Phoenix	AZ
	Joseph Valentine		Phoenix	AZ
Zebra Environmental Services	Michael Early	13 Dec 2004	Tampa	FL
	William McAllister		Albany	NY
	Paul L. Fleischmann		Lynnbrook	NY

Trained CMT Contractors

INTERNATIONAL

Company	Trained CMT Contractors	Date Trained	Location	Country
Boart Longyear	Sebastien Guenin	31 Jun 2008	Toulon	France
British Geological Survey	Dr. Rachel Dearden	28 Jan 2011	Nottingham	UK
Geo-Engineering	Roland Tóth	26 Feb 2007	Budapest	Hungary
GeoSonic Drilling Ltd.	Andy Condron	7 May 2014	Alloa	UK
	John Wood		Alloa	UK
	Neil Grew		Alloa	UK
	Mark Henderson		Alloa	UK
	Jamie Johns		Alloa	UK
GeoGreen21	Chanhui Park	11 Oct 2018	Seoul	Korea
	Jong Hwa Yi		Seoul	Korea
	Sung Hyun Kim		Seoul	Korea
	Si Eun Song		Seoul	Korea
	Hyung Pyo Kwon		Seoul	Korea
	Tae Yeong Kim		Seoul	Korea
	Byung Yong Yoon		Seoul	Korea
	Hyun Seok Ahn		Seoul	Korea
	Joon NamGung		Seoul	Korea
	Ho June Jang		Seoul	Korea
Geotron UK Ltd.	Dennis van Enk	7 May 2014	Mossley	UK
TOR Drilling	Charlie Lock	3 Jan 2017	Glastonbury	UK
	Jonathan Moore		Glastonbury	UK
	Dan Iles		Glastonbury	UK
	Anthony Duckett		Glastonbury	UK
	Steve Sutton		Glastonbury	UK
	Mark McKinney		Glastonbury	UK
	Nic Raynek		Glastonbury	UK
	Jonathan Whittle		Glastonbury	UK
	Marcus Puddy		Glastonbury	UK
	Paul Whittle		Glastonbury	UK
	Paul Golledge		Glastonbury	UK
	Kevin Lavender		Glastonbury	UK
	Simon Williams		Glastonbury	UK
	Aaron Reeves		Glastonbury	UK
	Jonny Whittle		Glastonbury	UK

Printed in Canada
January 2, 2020

Designation: D6913/D6913M – 17

Standard Test Methods for
Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis[1]

This standard is issued under the fixed designation D6913/D6913M; 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 (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Although this test method has been used for many years, there are vast testing variations due to soil types and conditions. The test is more complicated and complex than would be expected. Multiple procedures are being presented along with new terminology. Although these procedures are not new, they will now be defined and explained. Some examples of these new terms are composite sieving, designated separating sieve and subspecimen. This test method outlines the majority of conditions and procedures but does not cover every conceivable variation or contingency. The table of contents in the Scope section is added to enable the user to easily find a specific topic or requirement. Only sections/subsections with titles are presented. Therefore, numbered subsections will not be continuous in some cases, as indicated in the Scope section.

1. Scope

1.1 Soils consist of particles with various shapes and sizes. This test method is used to separate particles into size ranges and to determine quantitatively the mass of particles in each range. These data are combined to determine the particle-size distribution (gradation). This test method uses a square opening sieve criterion in determining the gradation of soil between the 3-in. (75-mm) and No. 200 (75-µm) sieves.

1.2 The terms, soils and material, are used interchangeably throughout the standard.

1.3 In cases where the gradation of particles larger than 3 in. (75 mm) sieve is needed, Test Method D5519 may be used.

1.4 In cases where the gradation of particles smaller than No. 200 (75-µm) sieve is needed, Test Method D7928 may be used.

1.5 Typically, if the maximum particle size is equal to or less than 4.75 mm (No. 4 sieve), then single-set sieving is applicable. Furthermore, if the maximum particle size is greater than 4.75 mm (No. 4 sieve) and equal to or less than 9.5 mm (⅜-in sieve), then either single-set sieving or composite sieving is applicable. Finally, if the maximum particle size is equal to or greater than 19.0 mm (¾-in sieve), composite sieving is applicable. For special conditions see 10.3.

1.6 Two test methods are provided in this standard. The methods differ in the significant digits recorded and the size of the specimen (mass) required. The method to be used may be specified by the requesting authority; otherwise Method A shall be performed.

1.6.1 *Method A*—The percentage (by mass) passing each sieve size is recorded to the nearest 1 %. This method must be used when performing composite sieving. For cases of disputes, Method A is the referee method.

1.6.2 *Method B*—The percentage (by mass) passing each sieve size is recorded to the nearest 0.1 %. This method is only applicable for single sieve-set sieving and when the maximum particle size is equal to or less than the No. 4 (4.75-mm) sieve.

1.7 This test method does not cover, in any detail, procurement of the sample. It is assumed that the sample is obtained using appropriate methods and is representative.

1.8 *Sample Processing*—Three procedures (moist, air dry, and oven dry) are provided to process the sample to obtain a specimen. The procedure selected will depend on the type of sample, the maximum particle-size in the sample, the range of particle sizes, the initial conditions of the material, the plasticity of the material, the efficiency, and the need for other testing on the sample. The procedure may be specified by the requesting authority; otherwise the guidance given in Section 10 shall be followed.

1.9 This test method typically requires two or three days to complete, depending on the type and size of the sample and soil type.

---

[1] This test method 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 April 15, 2017. Published May 2017. Originally approved in 2004. Last previous edition approved in 2009 as D6913 – 04(2009)$^{\varepsilon 1}$. DOI: 10.1520/D6913-17.

1.10 This test method is ***not*** applicable for the following soils:

1.10.1 Soils containing fibrous peat that will change in particle size during the drying, washing, or sieving procedure.

1.10.2 Soils containing extraneous matter, such as organic solvents, oil, asphalt, wood fragments, or similar items. Such extraneous matter can affect the washing and sieving procedures.

1.10.3 Materials that contain cementitious components, such as cement, fly ash, lime, or other stabilization admixtures.

1.11 This test method may not produce consistent test results within and between laboratories for the following soils and the precision statement does not apply to them.

1.11.1 Friable soils in which the sieving processes change the gradation of the soil. Typical examples of these soils are some residual soils, most weathered shales and some weakly cemented soils such as hardpan, caliche or coquina.

1.11.2 Soils that will not readily disperse such as glauconitic clays or some dried plastic clays.

1.11.3 To test these soils, this test method must be adapted, or altered, and these alterations documented. Depending on the design considerations, a specialized gradation-testing program could be performed. The alterations could require the washing and sieving procedures to be standardized such that each specimen would be processed in a similar manner.

1.12 Some materials that are not soils, but are made up of particles may be tested using this method. However, the applicable sections above should be used in applying this standard.

1.13 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

1.13.1 The procedures used to specify how data are collected/recorded and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of these test methods to consider significant digits used in analysis methods for engineering design.

1.14 *Units*—The dimensional values stated in either SI units or inch-pound units are to be regarded as standard, such as 200-mm or 8-in. diameter sieve. Except, the sieve designations are typically identified using the "alternative" system in accordance with Practice E11, such as 3 in. and No. 200, instead of the "standard" system of 75 mm and 75 µm, respectively. Only the SI units are used for mass determinations, calculations, and reported results. However, the use of balances or scales recording pounds of mass (lbm) shall not be regarded as nonconformance with this standard.

1.15 A summary of the symbols used in this test method is given in Annex A1.

1.16 *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.*

1.17 *Table of Contents*—All tables and figures appear at the end of this standard.

Section

ANNEXES

1.18 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
C702 Practice for Reducing Samples of Aggregate to Testing Size
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))
D1140 Test Methods for Determining the Amount of Material Finer than 75-µm (No. 200) Sieve in Soils by Washing
D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220/D4220M Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D5519 Test Methods for Particle Size Analysis of Natural and Man-Made Riprap Materials
D6026 Practice for Using Significant Digits in Geotechnical Data
D7928 Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *General:*

3.1.1 An overview of terms used in the sieving processes is presented in Fig. 1(a) using a tabular format and in Fig. 1(b) using a flowchart format. In addition, Fig. 1(a) includes symbols used in the sieving processes.

3.1.2 There are two types of definitions in the following sections. There are definitions that are general (see 3.2) and others that are specific to this standard (see 3.3). To locate a definition, it may be necessary to review both sections. The definitions are in alphabetical order.

3.2 *Definitions:*

3.2.1 For definitions of general terms used in this test method, refer to Terminology D653.

3.2.2 *composite sieving, v—in sieving*, the process of separating a large specimen on a designated separating sieve to obtain coarser and finer particle-size portions. The coarser portion is sieved using the coarser sieve set. The finer portion is subsampled to obtain a subspecimen of manageable size (mass) and this subspecimen is sieved using the finer sieve set. The results of both sieve sets (coarser and finer) are combined mathematically to determine the gradation of the large specimen.

3.2.2.1 *Discussion*—In some cases the subspecimen may require another separation; that is, using a 2nd designated separating sieve and resulting in a 2nd coarser portion and 2nd subspecimen obtained from the 2nd finer portion.

3.2.3 *cumulative material retained (cumulative retained material or cumulative mass retained), n—in sieving*, the mass of material retained on an individual sieve plus the masses of material retained on all the coarser sieves in a given stack/set of sieves.

3.2.4 *cumulative percent retained, n—in sieving*, the ratio of cumulative material retained on a given sieve to the mass of the specimen, expressed in percent.

3.2.5 *designated separating sieve, n—in composite sieving*, the sieve selected to separate the specimen into coarser and finer portions for composite sieving.

3.2.5.1 *Discussion*—The designated separating sieve size is a standard sieve size typically ranging from the ¾-in. (19.0-mm) sieve to the No. 10 (2.00-mm) sieve. There can be two designated separating sieves used in composite sieving, that is the 1st subspecimen can be separated on a 2nd designated separating sieve to obtain a 2nd coarser portion and a 2nd subspecimen obtained from the 2nd finer portion.

3.2.6 *fractional cumulative material retained, n—in composite sieving*, when sieving a subspecimen, the mass of material retained on an individual sieve plus the masses of material retained on all the coarser sieves in a given sieve set.

---

[2] 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.

Terms [A]	Modifying Adjectives & Symbols
A – Single Sieve-Set Sieving	
specimen	moist (S,M_m), dry or oven-dried (S,M_d), air-dried (S,M_{ad}), washed (S_wM_d)
sieve set	
cumulative material or mass retained on *Nth* sieve	CMR_N
cumulative percent retained on *Nth* sieve	CPR_N
percent passing the *Nth* sieve [B]	PP_N
percent retained on *Nth* sieve [C]	PR_N
B – Composite Sieving: Single Separation, Only One Designated Separating Sieve Used	
specimen	Same as above.
designated separating sieve	
coarser portion	moist (CP,M_m), dry or oven-dried (CP,M_d), air-dried (CP,M_{ad}), washed ($CPwM_d$)
coarser sieve set	
cumulative material or mass retained on *Nth* sieve	CP,CMR_N
cumulative percent retained on *Nth* sieve	CP,CPR_N
percent passing the *Nth* sieve [B]	CP,PP_N
composite sieving correction factor	$CSCF$
finer portion	moist (FP,M_m), dry (FP,M_m), air-dried (FP,M_{ad})
subspecimen	moist ($SubS,M_m$), dry or oven-dried ($SubS,M_d$), air-dried ($SubS,M_{ad}$), washed ($SubS_w,M_d$)
finer sieve set	
fractional cumulative mass retained on *Nth* sieve	$SubS,FCMR_N$
fractional cumulative percent retained on *Nth* sieve	$SubS,FCPR_N$
fractional percent passing the *Nth* sieve	$SubS,FPP_N$
fractional percent retained the first sieve	$SubS,FPR_{first}$
finer portion percent passing the *Nth* sieve	FP,PP_N
percent passing the *Nth* sieve [D]	$SubS,PP_N$
C – Composite Sieving: Double Separation, 1st & 2nd Designated Separating Sieves Used	
specimen	Same as above.
1st designated separating sieve	
1st coarser portion	Same as above.
Same as above, except the prefix 1st is added to all terms	$1^{st}CP,CMR_N$, $1^{st}CP,CPR_N$, $1^{st}CP,PP_N$, $1^{st}CP,PP_N$, $1^{st}CSCF$
1st finer portion	Same as above.
1st subspecimen (used to produce 2nd subspecimen and 2nd coarser portion for sieving)	moist ($1^{st}SubS,M_m$), dry ($1^{st}SubS,M_d$), air-dried ($1^{st}SubS,M_{ad}$)
2nd designated separating sieve	
2nd coarser portion	dry or oven-dried ($2^{nd}CP,M_d$), washed ($2^{nd}CP_w,M_d$)
2nd finer portion	dry or oven-dried ($2^{nd}FP,M_d$)
2nd coarser sieve set	
1st fractional cum. mass retained on *Nth* sieve	$2^{nd}CP,FCMR_N$
1st fractional cum. percent retained on *Nth* sieve	$2^{nd}CP,,FCPR_N$
1st fractional percent passing the *Nth* sieve	$2^{nd}CP,FPP_N$
1st fractional percent retained on first sieve	$2^{nd}CP,FPR_{first}$
percent passing the *Nth* sieve [C]	$2^{nd}CP,PP_N$
finer portion percent passing the *Nth* sieve	FP,PP_N
2nd composite sieving correction factor	$2^{nd}CSCF$
1st finer portion composite sieving correction factor	$1^{st}FP, CSCF$
2nd subspecimen (selected from 2nd finer portion)	moist ($2^{nd}SubS,M_m$), dry ($2^{nd}SubS,M_d$), air-dried ($2^{nd}SubS,M_{ad}$)
finer sieve set	
2nd fractional cum. mass retained on *Nth* sieve	$2^{nd}SubS,FCMR_N$
2nd fractional cum. percent retained on *Nth* sieve	$2^{nd}SubS,FCPR_N$
2nd fractional percent passing the *Nth* sieve	$2^{nd}SubS,FPP_N$
2nd fractional percent retained on the first sieve	$2^{nd}SubS,FPR_{first}$
1st finer portion percent passing the *Nth* sieve	$1^{st}FP,PP_N$
percent passing the *Nth* sieve [D]	$2^{nd}SubS,PP_N$

Notes: [A] The term mass is omitted, since all non-percent terms are in mass (g). Some terms, such as material retained, percent retained (except as required) and fractional material are omitted since only the "cumulative" methodology is presented herein.

[B] Equals 100 minus cumulative percent retained. [C] Only required in precision determination.

[D] Function of the appropriate fractional percent passing and *CSCF*.

FIG. 1 (a) Typical Terminology and Symbols Used in Sieving Processes

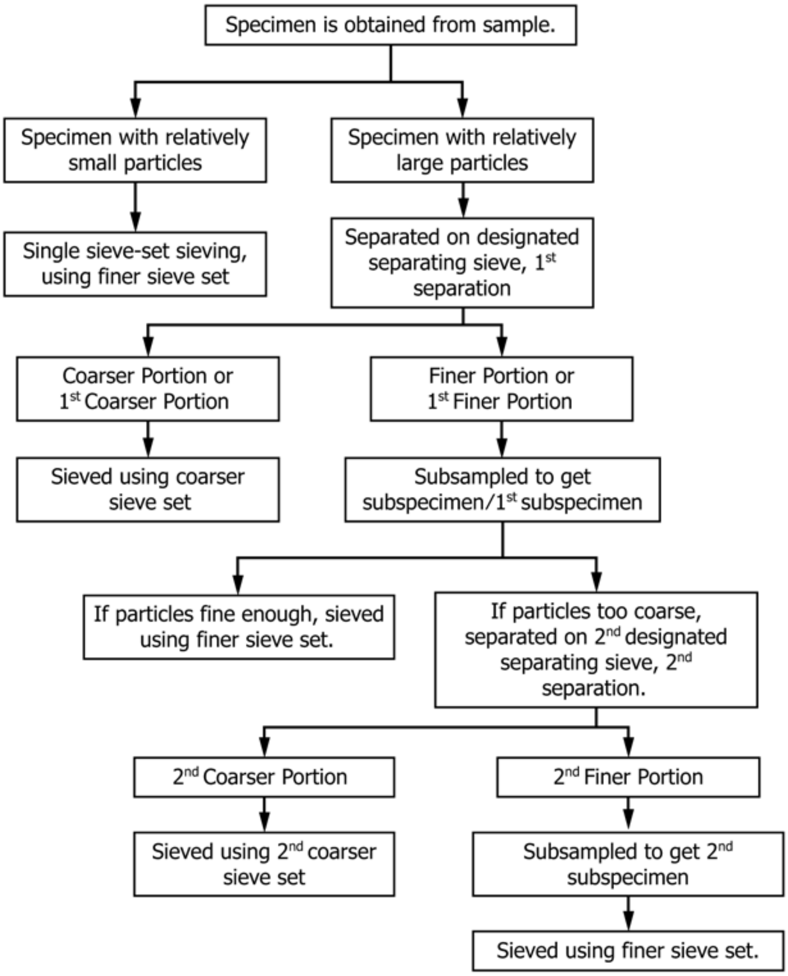


FIG. 1 (b) Terminology Flowchart for Sieving Processes *(continued)*

3.2.7 *fractional cumulative percent retained, n—in composite sieving*, the ratio of fractional cumulative material retained on a given sieve to the mass of the subspecimen, expressed in percent.

3.2.8 *fractional material retained, n—in composite sieving*, when sieving a subspecimen, the mass of material retained on an individual sieve.

3.2.9 *fractional percent passing, n—in composite sieving*, the portion of material by mass in the subspecimen(s) passing a given sieve expressed in percent.

3.2.9.1 *Discussion*—When two subspecimens are used, there will be a 1^{st} and 2^{nd} fractional percent passing.

3.2.10 *fractional percent retained, n—in composite sieving*, the ratio of fractional material retained on a given sieve to the mass of the subspecimen, expressed in percent.

3.2.11 *gradation, n—in soil*, the proportion by mass of various particle sizes.

3.2.11.1 *Discussion*—This proportion is usually presented in tabular format (sieve size and percent passing) or graphical format (percent passing versus logarithm of the sieve size in mm). The graphical format is referred to as particle-size distribution or gradation curve.

3.2.12 *maximum particle size, n—in sieving*, the smallest sieve size from the standard sieve set on which less than one percent of the sample would be retained.

3.2.12.1 *Discussion*—For practical purposes, estimate the maximum particle size as equal to the smallest sieve size from the standard sieve set in which it appears that all the material being tested would pass through that sieve. The maximum particle size is needed to determine the required mass of the specimen and subspecimen.

3.2.13 *maximum sieve size, n—in sieving*, the smallest sieve size that is larger than any particle in the specimen or subspecimen.

3.2.14 *minimum sieve size, n—in sieving*, the smallest sieve size in a sieve set used in sieving the specimen or subspecimen.

3.2.14.1 *Discussion*—This size is either the size of the designated separating sieve (1^{st} or 2^{nd}) or the No. 200 (75-µm) sieve.

3.2.15 *percent passing, n—in sieving*, the portion of material by mass in the specimen passing a given sieve expressed in percent.

3.2.15.1 *Discussion*—This value is equal to the cumulative material retained in a given sieve set divided by the mass of the specimen, subtracting that ratio from one, and then multiplying by 100. For composite sieving, it would be the fractional percent passing multiplied by the composite sieving correction factor (*CSCF*).

3.2.16 *particle size distribution, n*—see *gradation*.

3.2.17 *percent retained, n—in sieving*, the ratio of the material retained on a given sieve to the mass of the specimen, expressed in percent.

3.2.18 *saturated surface-dry condition, n—in coarse-grained soils*, a state in which the soil particles are basically saturated with water, but there are not visible films of water.

3.2.19 *sieve set, n—in sieving*, a set of standard sized sieves. For single sieve-set sieving, the sieve set will range from the maximum sieve size to the No. 200 (75-µm) sieve. For composite sieving, there will be a coarser sieve set and a finer sieve set. Together, these sets will range from the maximum sieve size to the No. 200 (75-µm) sieve. The designated separating sieve will be used as the minimum size in the coarser set and the maximum size in the finer set.

3.2.20 *sieve size, n—in sieving*, the size of the opening in the wire cloth of a given sieve in mm or µm.

3.2.21 *single sieve-set sieving, v—in sieving*, the process in which only one set of sieves is needed to determine the gradation of the specimen from the maximum particle size to the No. 200 (75-µm) sieve.

3.2.21.1 *Discussion*—Typically, this applies to specimens having a maximum particle size of 9.5 mm (⅜ in.) or less when using Method A or a maximum particle size of 4.75 mm (No. 4 sieve) or less when using Method B and the distribution of particles less than the No. 200 (75-µm) sieve is not needed.

3.2.22 *splitting, v—in sampling or subsampling*, the process of stockpile sampling, quartering material, or passing material through a splitter or riffle box to obtain a representative portion of that material for testing; that is, a specimen or subspecimen.

3.2.22.1 *Discussion*—A description of stockpile sampling, and quartering and splitting material is given in Annex A2, A2.1.1 through A2.1.3.

3.2.23 *standard shaking period, n—in sieving*, a time period ranging from 10 to 20 minutes that a mechanical sieve shaker operates during the sieving process and which has been verified to satisfy the requirements for sieving thoroughness.

3.2.24 *standard sieve set, n—in sieving soils*, the group of fourteen specific sieve sizes required to determine the gradation of soils between and including the 3-in. (75-mm) and No. 200 (75-µm) sieves, as listed in Table 1.

3.2.24.1 *Discussion*—Most of these sieve sizes are different than those used in aggregate testing for concrete (Test Method C136), especially for sieves finer than the No. 4 (4.75 mm).

3.2.25 *subspecimen, n—in composite sieving*, a representative portion of the material passing the designated separating sieve; that is, the finer portion.

3.2.25.1 *Discussion*—When composite sieving requires multiple designated separating sieves, there will be more than one subspecimen. The 1st subspecimen (that is, the subspecimen from the finer portion) would be separated into a 2nd coarser portion and a 2nd finer portion that would be subsampled to obtain the 2nd subspecimen.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *coarser portion, n—in composite sieving*, the portion of the specimen retained on the designated separating sieve.

3.3.1.1 *Discussion*—When two designated separating sieves are used, there will be a 1st and 2nd coarser portion.

3.3.2 *coarser sieve set, n—in composite sieving*, the sieve set that ranges from the maximum sieve size to the designated separating sieve size.

3.3.2.1 *Discussion*—When two designated separating sieves are used, the 1st coarser sieve set ranges from the maximum sieve size to the 1st designated separating sieve size. The 2nd coarser sieve set would range from the 1st designated separating sieve size to the 2nd designated separating sieve size.

3.3.3 *composite sieving correction factor (CSCF), n—in composite sieving*, a factor used to convert the fractional percent passing determined from sieving the subspecimen to the percent passing for the specimen. The *CSCF* is equal to the percent passing the designated separating sieve size in the coarser portion sieve set (that is, the last sieve in the coarser portion set). This value shall be calculated to one more digit than required (0.1 %) to reduce rounding errors.

3.3.3.1 *Discussion*—When two designated separating sieves are used, there will be a 1st and 2nd*CSCF*.

3.3.4 *finer portion, n—in composite sieving*, the portion of the specimen passing the designated separating sieve.

3.3.4.1 *Discussion*—When two designated separating sieves are used, the 1st subspecimen obtained from the 1st finer portion will be separated into a 2nd coarser portion and 2nd finer portion, from which the 2nd subspecimen is obtained.

TABLE 1 Standard Sieve Set[A]

Sieve Designation in Accordance with E11			
Alternative	Standard	Alternative	Standard
Lid		No. 10	2.00 mm
3 in.	75 mm	No. 20	850 µm
2 in.	50 mm	No. 40	425 µm
1-½ in.	37.5 mm	No. 60	250 µm
1 in.	25.0 mm	No. 100	150 µm
¾ in.	19.0 mm	No. 140	106 µm
⅜ in.	9.5 mm	No. 200	75 µm
No. 4	4.75 mm	Pan	

[A] A lid is typically not used or needed when using rectangular coarser sieves having dimensions greater than 200 mm or 8 in.

3.3.5 *finer sieve set, n—in composite sieving*, the sieve set that ranges from the last designated separating sieve size to the No. 200 (75-µm) sieve.

3.3.5.1 *Discussion*—When composite sieving requires a 2nd subspecimen, the finer sieve sets ranges from the 2nd separating sieve size to the No. 200 (75-µm) sieve.

3.3.6 *insignificant sieve, n—in precision of test results*, any sieve which has 1 % or less cumulative material retained during the sieve analysis.

3.3.7 *separating, v—in composite sieving*, the process of dividing a specimen or subspecimen into two portions, the coarser (retained) and finer (passing) portions, using a designated separating sieve.

3.3.7.1 *Discussion*—When composite sieving requires two designated sieves, there will be a 1st and 2nd coarser portion, finer portion and subspecimen.

3.3.8 *significant sieve, n—in precision of test results*, any sieve which has more than 1 % of cumulative material retained during the sieve analysis.

4. Summary of Test Method

4.1 This test method is used to determine the particle-size distribution (gradation) of a soil sample. A representative specimen must be obtained from the sample by one of three procedures (moist, air-dried or oven-dried). For specimens containing relatively small particles, the specimen is sieved in its entirety, using single sieve-set sieving. However, the specimen may contain a wide range of particle sizes and may require separating the soil into two, or three size ranges for more efficient sieving, using one or two designated separating sieve(s). This process is termed composite sieving. For a single separation (two portions), the coarser portion is sieved in its entirety, while the finer portion is split into a smaller subspecimen for sieving. These results are mathematically combined. For specimens containing very large particles, the specimen may require two separations; that is, three portions (1st and 2nd coarser portions and 2nd finer portion), see Fig. 1(a) and Fig. 1(b). Prior to sieving, as applicable, the material will be washed to remove fine particles and oven dried. The material to be sieved will be placed on the coarsest sieve size of each sieve set and mechanically shaken. The mass of particles retained on each sieve will be determined. The results will produce a tabulation of sieve sizes versus percent passing that can be graphically presented as a gradation curve (a plot of the percent passing versus the log of the particle size in mm.).

4.2 Flowcharts outlining the requirements of the various sieving processes covered above are presented below in four figures, Fig. 2 through Fig. 4(b).

5. Significance and Use

5.1 The gradation of the soil is used for classification in accordance with Practice D2487.

5.2 The gradation (particle-size distribution) curve is used to calculate the coefficient of uniformity and the coefficient of curvature.

5.3 Selection and acceptance of fill materials are often based on gradation. For example, highway embankments, backfills, and earthen dams may have gradation requirements.

5.4 The gradation of the soil often controls the design and quality control of drainage filters, and groundwater drainage.

5.5 Selection of options for dynamic compaction and grouting is related to gradation of the soil.

5.6 The gradation of a soil is an indicator of engineering properties. Hydraulic conductivity, compressibility, and shear strength are related to the gradation of the soil. However, engineering behavior is dependent upon many factors (such as effective stress, stress history, mineral type, structure, plasticity, and geologic origins) and cannot be based solely upon gradation.

NOTE 1—The quality of the result produced by these test methods 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 D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of these test methods are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Sieves*—Each sieve shall conform to the requirements of Specification E11. Generally, these sieve frames are circular and 200 mm or 8 in. in diameter, and either full (50 mm or 2 in.) or half height (25 mm or 1 in.). The sieve height generally depends upon the number of sieves typically required in the sieve set, the particle sizes being sieved, and the size and type of the sieve shaker. Particles having dimensions exceeding or relatively close to the sieve heights cannot be sieved in the sieve stack, but individually. Therefore, in a stack of sieves, the ratio of sieve height or spacing between rectangular sieves to sieve cloth opening shall exceed 2. Larger frames that conform to Specification E11 are acceptable but require special considerations for reinforcement.

6.1.1 *Standard Sieve Set*—This set consists of all the sieve sizes listed in Table 1. Additional sieves sizes may be added if requested or needed to reduce sieve overloading. In addition, some larger sieve sizes may be omitted during the sieve analysis depending on the maximum particle size; however, at least one sieve in the sieving process shall have 100 percent passing.

6.1.2 *Washing Sieve, No. 200 (75-µm)*—A No. 200 (75-µm) sieve with a minimum height above the screen of 50 mm or 2 in. to prevent loss of retained material while washing. Stainless steel sieve cloth is preferred because it is more durable, and less prone to damage or wear. The sieve may be reinforced with a larger mesh underneath the 75-µm cloth. The reinforcement wire cloth (backing) should not have a mesh coarser than the No. 20 (850-µm) wire cloth. The reinforcement wire cloth should be bonded to the sieve frame along with the No. 200 (75-µm) wire cloth, not bonded to the sieve frame below where the No. 200 (75-µm) wire cloth was attached. In addition, it is good practice to use a flattened backing cloth (rolled or calendered backing cloth), so it is less abrasive to the No. 200 (75-µm) wire cloth.

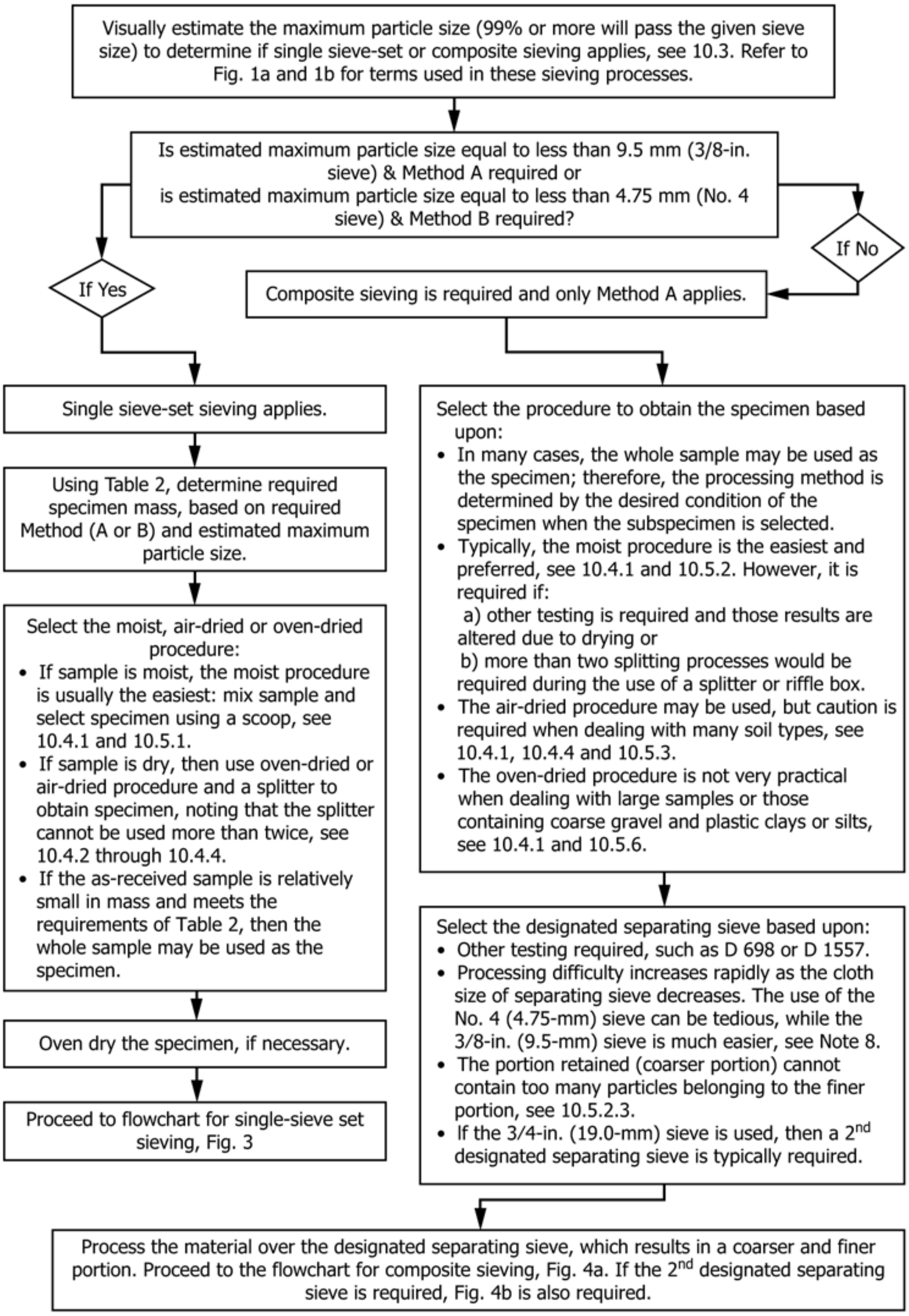
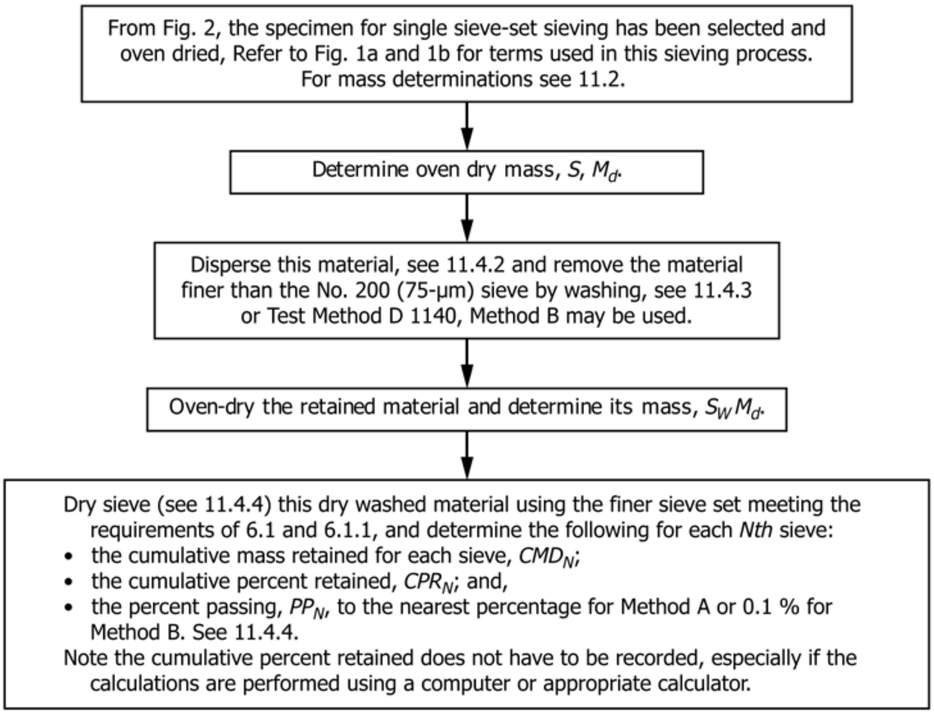


FIG. 2 Decision Flowchart for Sieving Processes

6.1.3 *Designated Separating Sieve*—A sieve used to separate the specimen into two portions (coarser and finer portion) in composite sieving. The designated separating sieve shall conform to Specification E11. It may be necessary to have various sizes of sieves to use as designated separating sieves. Normally, these are not the same sieves that are used in the stack of sieves (sieve set) placed in the sieve shaker. Typically, the 1st designated separating sieve is rectangular and quite large, while the 2nd designated separating sieve is either 200-mm or 8-in. in diameter.

6.2 *Washing Sink with Spray Nozzle*—A sink having a spray nozzle attached to a flexible line to facilitate the washing and material transferring processes without spillage. In addition, the spray nozzle shall be such that the rate of water flow can be easily controlled. The temperature of the water shall be



From Fig. 2, the specimen for single sieve-set sieving has been selected and oven dried, Refer to Fig. 1a and 1b for terms used in this sieving process. For mass determinations see 11.2.

Determine oven dry mass, S, M_d.

Disperse this material, see 11.4.2 and remove the material finer than the No. 200 (75-µm) sieve by washing, see 11.4.3 or Test Method D 1140, Method B may be used.

Oven-dry the retained material and determine its mass, $S_W M_d$.

Dry sieve (see 11.4.4) this dry washed material using the finer sieve set meeting the requirements of 6.1 and 6.1.1, and determine the following for each *Nth* sieve:

- the cumulative mass retained for each sieve, CMD_N;
- the cumulative percent retained, CPR_N; and,
- the percent passing, PP_N, to the nearest percentage for Method A or 0.1 % for Method B. See 11.4.4.

Note the cumulative percent retained does not have to be recorded, especially if the calculations are performed using a computer or appropriate calculator.

FIG. 3 Flowchart for Single Sieve-Set Sieving

relatively close to room temperature to prevent changing the dimensions of the sieve cloth and health and safety concerns.

6.3 *Mechanical Sieve Shaker*—A device that holds a stack of sieves while imparting sufficient motion to the sieves to meet the sieving thoroughness requirements covered in 8.2. The "Standard Shaking Period" must be from 10 to 20 minutes. The shaker shall have a timing device or a timing device shall be used in conjunction with the shaker.

NOTE 2—Shakers imparting a motion that causes the particles on the sieves to bounce and turn so that all particles have ample opportunity in various orientations to the sieve openings will typically meet this sieving thoroughness requirement. A sieve shaker that has a smooth horizontal and/or vertical gyratory/orbital motion will typically ***not*** meet this sieving thoroughness requirement, since the particles will not be bouncing and turning.

6.4 *Balances*—For single sieve-set sieving, one balance will be used. For composite sieving, more than one balance may be necessary. Balances must conform to the requirements of Specification D4753; that is, having a readability (with no estimation) to determine the mass of the specimen or subspecimen to a minimum of three significant digits for Method A or a minimum four significant digits for Method B. The mass of the specimen can be determined in parts (multiple mass determinations). The balance used to determine the cumulative material retained or the fractional cumulative material retained on any given sieve has to have a readability equal to or better than that used to determine the mass of the specimen/subspecimen.

NOTE 3—Preferably the balance should have a taring capability so that the mass of material can be directly determined without subtracting the mass of the container. This feature is immensely useful during the sieving process to determine the mass of the cumulative material retained or when making multiple mass determinations to determine specimen's mass.

6.5 *Drying Oven*—Thermostatically controlled oven, capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber. These requirements typically require the use of a forced-draft oven.

6.6 *Sieving Containers*—The containers used to: *(a)* contain the sieving specimen or material which will be sieved, such as coarser portion; *(b)* remove the retained material from the sieve(s); *(c)* collect and transfer that material; and, *(d)* contain the cumulative material retained.

6.6.1 *Specimen Containers*—Smooth walled containers, without tight corners to trap material, made of material resistant to corrosion and change in mass upon repeated heating, cooling, specimen soaking, and cleaning. The containers should be large enough to enable soaking of the specimen. The container should facilitate the transfer of the specimen from the container to the washing sieve (No. 200 (75 µm) or designated separating sieve) and back by a rinsing/washing operation, and allow for decanting the clear wash water from the container.

6.6.2 *Collection/Transfer Container*—This container is used to collect the material retained on a given sieve and to transfer it to the container holding the cumulative retained material during the sieving process. The container must be larger in diameter than the sieve. A smoothsurface 230-mm (9-in.) pie pan may be used along with a 25-mm (1-in.) paintbrush to assist in transferring all the material. The color of this container shall enhance the observation that all material has been transferred.

6.6.3 *Cumulative Mass Container*—This container shall be large enough to receive the retained material contained in the collection/transfer device without any loss. The mass should be

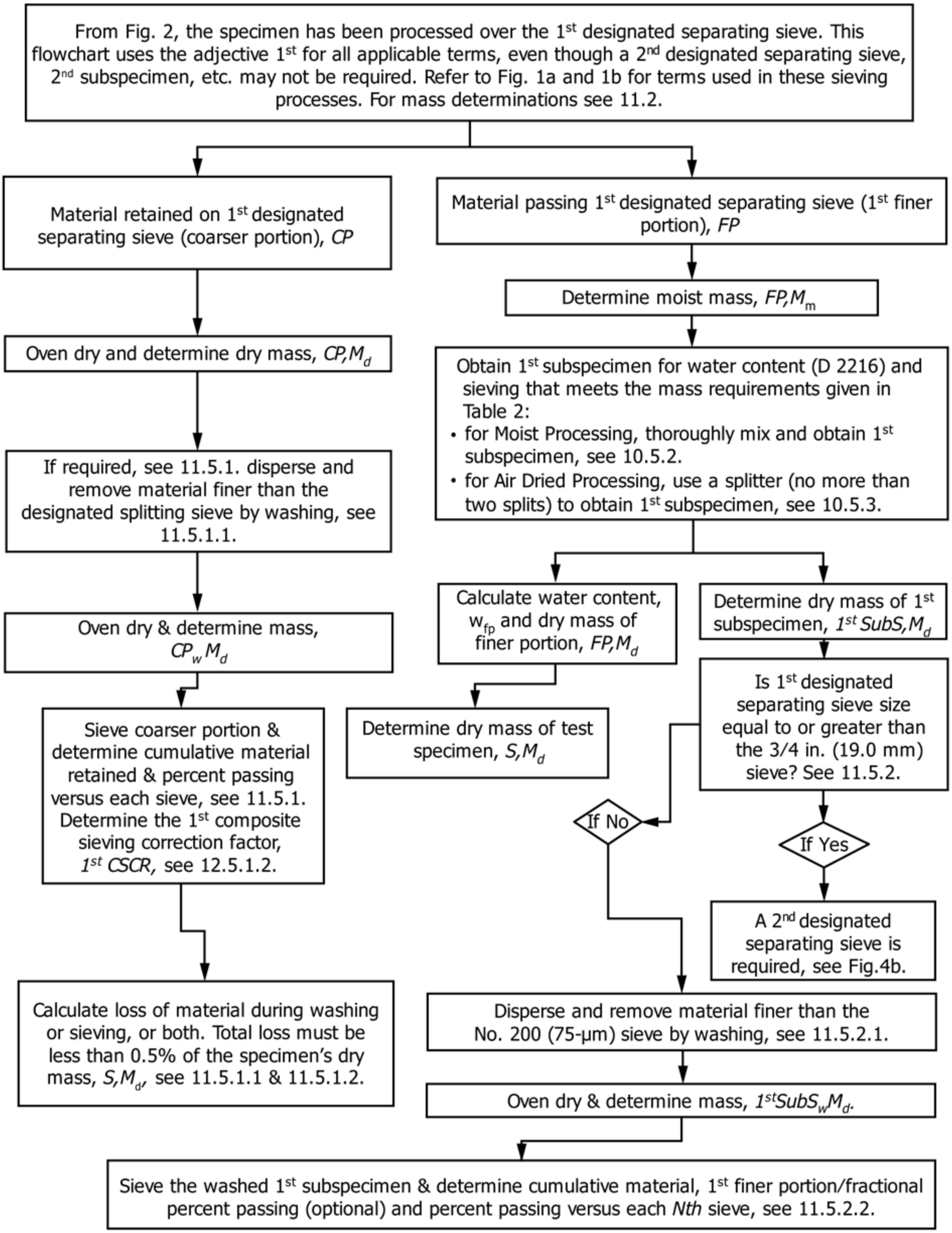
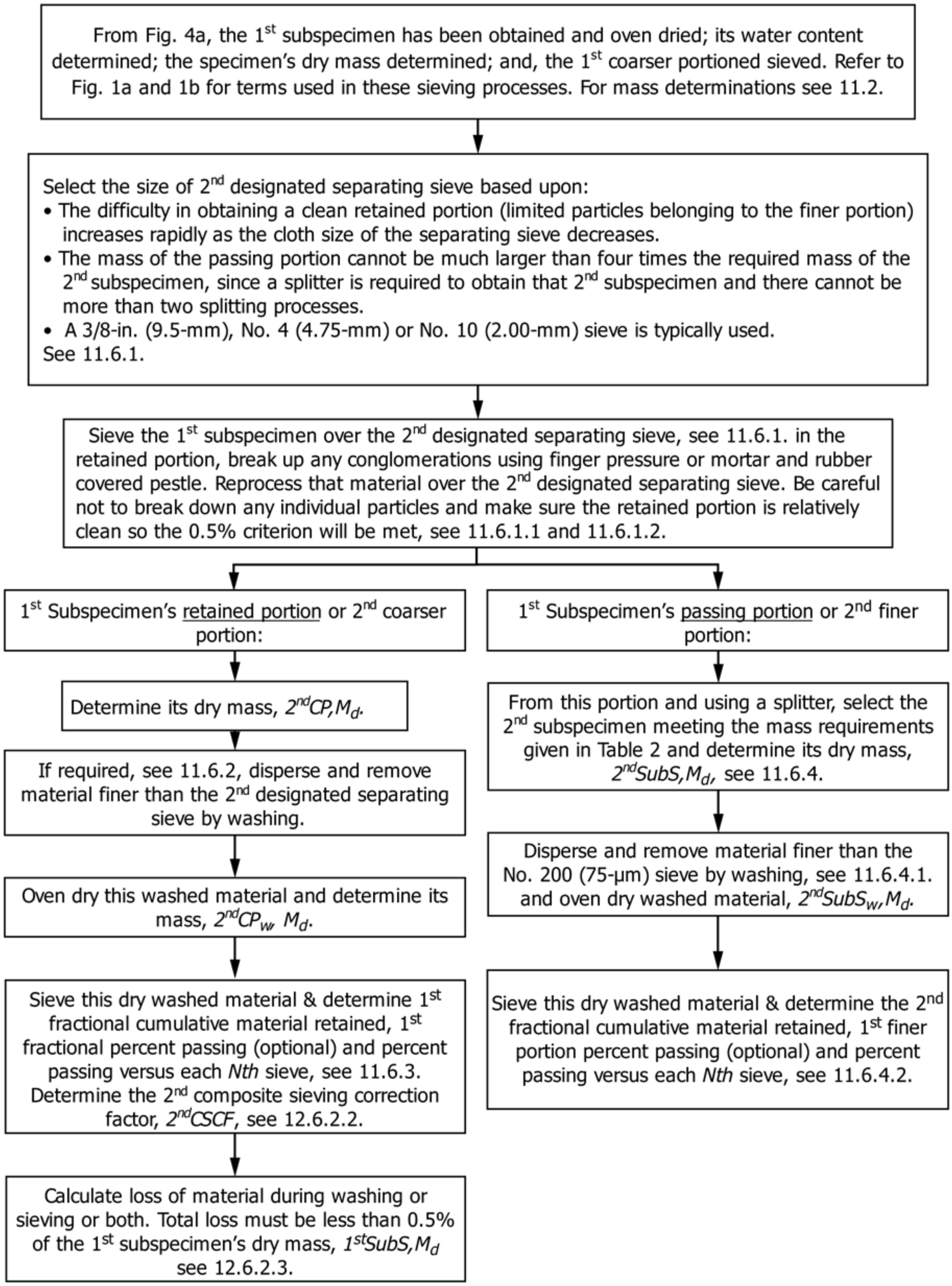


FIG. 4 (a) Flowchart for Composite Sieving—Single Separation



From Fig. 4a, the 1st subspecimen has been obtained and oven dried; its water content determined; the specimen's dry mass determined; and, the 1st coarser portioned sieved. Refer to Fig. 1a and 1b for terms used in these sieving processes. For mass determinations see 11.2.

Select the size of 2nd designated separating sieve based upon:

- The difficulty in obtaining a clean retained portion (limited particles belonging to the finer portion) increases rapidly as the cloth size of the separating sieve decreases.
- The mass of the passing portion cannot be much larger than four times the required mass of the 2nd subspecimen, since a splitter is required to obtain that 2nd subspecimen and there cannot be more than two splitting processes.
- A 3/8-in. (9.5-mm), No. 4 (4.75-mm) or No. 10 (2.00-mm) sieve is typically used.

See 11.6.1.

Sieve the 1st subspecimen over the 2nd designated separating sieve, see 11.6.1. in the retained portion, break up any conglomerations using finger pressure or mortar and rubber covered pestle. Reprocess that material over the 2nd designated separating sieve. Be careful not to break down any individual particles and make sure the retained portion is relatively clean so the 0.5% criterion will be met, see 11.6.1.1 and 11.6.1.2.

1st Subspecimen's retained portion or 2nd coarser portion:

Determine its dry mass, $2^{nd}CP, M_d$.

If required, see 11.6.2, disperse and remove material finer than the 2nd designated separating sieve by washing.

Oven dry this washed material and determine its mass, $2^{nd}CP_w, M_d$.

Sieve this dry washed material & determine 1st fractional cumulative material retained, 1st fractional percent passing (optional) and percent passing versus each *Nth* sieve, see 11.6.3. Determine the 2nd composite sieving correction factor, $2^{nd}CSCF$, see 12.6.2.2.

Calculate loss of material during washing or sieving or both. Total loss must be less than 0.5% of the 1st subspecimen's dry mass, $1^{st}SubS, M_d$ see 12.6.2.3.

1st Subspecimen's passing portion or 2nd finer portion:

From this portion and using a splitter, select the 2nd subspecimen meeting the mass requirements given in Table 2 and determine its dry mass, $2^{nd}SubS, M_d$, see 11.6.4.

Disperse and remove material finer than the No. 200 (75-µm) sieve by washing, see 11.6.4.1. and oven dry washed material, $2^{nd}SubS_w, M_d$.

Sieve this dry washed material & determine the 2nd fractional cumulative material retained, 1st finer portion percent passing (optional) and percent passing versus each *Nth* sieve, see 11.6.4.2.

FIG. 4 (b) Flowchart for Composite Sieving—Double Separation *(continued)* less than the taring capacity of the balance so that the cumulative mass retained can be determined directly (see Note 3). In most cases, the specimen/subspecimen container can be used. This test method assumes that the mass of the cumulative retained material is determined directly. This approach is easier than determining the mass of retained material on each sieve.

6.7 *Sieve Brushes*—Brushes to assist in the removal of the material retained on the smaller (≤200-mm or 8-in.) diameter and finer sieve sizes (≤¾-in. (19.0-mm)). The brushes shall have the following characteristics:

6.7.1 The bristles shall be firmly attached to the brush handle so that the bristles do not become part of the retained material.

6.7.2 The bristles shall be firm and small enough to readily remove the particles entangled in the sieve openings, but made of a material that will not damage the wire cloth or wear rapidly. Wire bristles, even brass, shall ***not*** be used on wire cloth size finer than No. 20 (850–µm).

6.7.3 The bristles shall be capable of contacting the boundary between the wire cloth and sieve's frame.

6.7.4 The brush's handle shall be such that one's hand can easily control the brushing motion and pressure. An example being, the handle is above the bristles (like a paintbrush) or inclined (30- to 45-degree angle) to the bristle's head (like a vegetable brush or bent toothbrush).

6.7.5 The bristles have to be small in diameter and soft when brushing wire cloth size equal to or less than the No. 100 (150-µm) mesh. Small diameter, soft bristles will remove the particles without any re-alignment of the wire cloth.

6.7.6 Brushes meeting these requirements are relatively small round or rectangular stiff paintbrushes with shortened bristles, soft to hard toothbrushes with bent handles, and vegetable brushes with shortened bristles.

6.8 *Miscellaneous Items*—Miscellaneous items such as wash bottle, spatula, and stirring rod may be useful.

6.9 *Splitter or Riffle Box (optional, but may be needed during composite sieving)*—A device to obtain a representative smaller portion (specimen) from a larger portion (sample). This device has an even number of equal width chutes, but not less than eight, which discharge alternately to each side of the splitter. For dry material having particles coarser than the ⅜-in. (9.5-mm) sieve size, the minimum width of the chutes shall be approximately 1-½ times the largest particle in material being split, but not less than 12.5 mm or ½ in. For dry material finer than or equal to the ⅜-in. (9.5-mm) sieve size, the minimum chute width shall be approximately 1-½ times the largest particle in the material, but not less than approximately 3 mm or ⅛ in. The splitter shall be equipped with two or more receptacles to hold the two halves of the material following splitting. It shall also be equipped with a hopper/feed chute (preferably lever activated or having a cut-off gate) and a straight-edged pan or dustpan that has a width equal to or slightly less than the over-all width of the assembly of chutes, by which the dry material may be fed at a controlled rate to the chutes. The splitter and accessory equipment shall be so designed that the material will flow smoothly without restriction or loss of material.

NOTE 4—Some splitters are designed such that the width of the chutes can be adjusted.

6.10 *Quartering Accessories (optional)*—A hard, clean, level surface, or durable nonporous fabric or plastic sheet approximately 2 by 2.5 m or 6 by 8 ft; a straight-edged scoop, shovel, or trowel; and a broom or brush.

6.11 *Mortar and Rubber-Covered Pestle (optional)*—Apparatus for breaking up aggregations of air-dried or oven-dried soil particles without breaking up any individual particles.

6.12 *Low Temperature Drying Oven (optional)*—Thermostatically controlled oven, capable of maintaining a uniform temperature not to exceed 60°C throughout the drying chamber, for use in air-dried processing.

6.13 *Ultrasonic Water Bath (optional)*—The ultrasonic water bath must be large enough to hold a beaker or flask containing the material to be dispersed prior to washing. The water level in the bath should be equal or higher than the water level in the specimen container.

6.14 *Dispersion Shaker (optional)*—A platform, wrist action or similar type shaker having a gyratory, orbital, reciprocating, or similar motion to assist in the dispersion process by continuously agitating the soaking soil.

7. Reagents

7.1 *Sodium Hexametaphosphate*—Also referred to as sodium metaphosphate, is the dispersion agent used to disperse some fine-grained soils after oven drying and prior to washing. Fine-grained soils requiring the use of a dispersant are those that do not readily slake in water, such as some fat clays and most tropical soils.

7.1.1 For materials needing a chemical dispersant, the dispersant can be added either directly to the soaking material (dry addition) or by adding a dispersant solution to the material, plus water as necessary.

7.1.1.1 *Dry Addition*—Add about 4 grams of sodium hexametaphosphate for each 100 mL of water that has been added to the soaking material and stir to distribute the dispersant throughout the material.

7.1.1.2 *Solution*—Make a solution by using 40 g of sodium hexametaphosphate and 1,000 g distilled, deionized, or demineralized water. Add the solution to the material, plus water if needed and stir to distribute the dispersant throughout the material. The solution must be less than one week old and thoroughly mixed or shaken prior to use. The date of preparation must be indicated on the bottle or in a log.

NOTE 5—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action.

8. Preparation of Apparatus

8.1 *Verification of Sieves*—Prior to ***initial use***, evaluate each sieve for general condition of the wire cloth as specified in Test Method One of Specification E11. That method provides the following evaluation instructions, "view the sieve cloth against a uniformly illuminated background. If apparent deviations, for example, weaving defects, creases, wrinkles, and foreign matter in the cloth, are found, the wire cloth (sieve) is unacceptable." This evaluation shall be documented. Unacceptable sieves shall be replaced and discarded or returned to the manufacturer for repair (wire cloth).

8.1.1 *Verification Interval*—The same evaluation shall be performed and documented at 6-month intervals on all sieves that are placed in continuous service. However, for sieves that have a limited usage of less than about 1,000 sieve analyses per 6-month interval, then this interval may be increased to 12 months. Sieves that contain excessive soil particles (about 10 % of the sieve openings contain particles) shall be thoroughly cleaned. An ultrasonic water bath may be used to clean the finer sieve sizes, while a stiffer brush or pointed tool can be used to clean the coarser sieves.

8.1.2 During each sieving process, the sieves finer than and including the No. 100 (150-µm) sieve shall be checked for damaged cloth, such as tearing at the frame contact. This check can be done while the retained material is being removed from the sieve during the sieving process. This check does not need to be documented.

8.2 *Verification of Mechanical Sieve Shaker and Standard Shaking Period*—Prior to ***initial use***, the mechanical sieve shaker shall be checked for sieving thoroughness using applicable sieve sets (typically used coarser and finer) and representative material. In addition, the standard shaking period shall be determined for each applicable sieve set. For each size sieve set, follow the guidance given for single sieve-set sieving (see 11.4). Use enough material (specimen) of known mass (g or kg) such that each sieve in the set, except one or two, will have some retained material but no sieve will be overloaded. Shake the sieve set for ten minutes with the mechanical shaker. Upon completion of mechanical shaking, start with the largest sieve size and place the snug-fitting lid on top of the sieve and the pan underneath it. Shake each sieve by hand, for about one minute using the hand shaking procedure (see 8.2.3). For each sieve, determine the mass of material retained on the sieve and in the pan, to the nearest 0.01 g or one part in 1,000, whichever is largest. The ratio of the material mass in the pan to the specimen's mass multiplied by 100 for each sieve shall be less than 0.5 % (see Note 6). If all ratios are less than 0.5 %, the sieve shaker with a 10-minute shaking period is adequate and shall be used as the standard shaking period for that sieve set. If any ratio is equal to or exceeds 0.5 %, repeat the process using a 15-minute shaking period. If this shaking period meets the above criterion, then it shall be used as the standard shaking period for that sieve set, unless a shorted shaking period, like 12 minutes is verified as adequate. If the 15-minute shaking period fails, then try the maximum allowable shaking period of 20 minutes. If the 20-minute shaking period fails, then the mechanical sieve shaker shall be considered inadequate for sieving. It shall either be repaired or discarded. After repair, repeat the instructions given above to determine the standard shaking period.

8.2.1 *Large Mechanical Sieve Shaker*—If a larger mechanical sieve shaker is used to shake large diameter (greater than 200 mm or 8 in.) or rectangular sieve sets and hand shaking is not practicable, then transfer the retained material in appropriate increments to a 200- mm or 8-in. diameter sieve of equal sieve designation, with lid and pan, and shake for one minute. Follow the instructions given above to determine the standard shaking period for each sieve set.

8.2.2 *Verification Interval*—The same verification shall be performed and documented at 12-month intervals for each sieve shaker placed in continuous service. However, for sieve shakers that have a limited usage of less than about 1,000 sieve analyses per 12-month interval, then this interval may be increased to 24 months. Not all sieve set sizes (coarser and finer) have to be re-verified unless the standard shaking time changes for the sieve set being verified. The finer sieve set or the set having the longest standard shaking period shall be used for re-verification.

NOTE 6—For example, after hand shaking the No. 4 (4.75 mm) sieve, the amount of material retained in the pan is 0.20 g. If the specimen mass is 100.00 g, then the ratio is 0.2% = ((0.20/100.00)*100). In this example, if the amount in the pan had been greater than 0.50 g, the ratio would exceed 0.5 % and the verification process would be repeated with a longer time interval.

8.2.3 *Hand Sieve Shaking Procedure*—For 200-mm or 8-in. diameter sieves, hold the individual sieve, with lid and pan, in a slightly inclined (about 15°) position in one hand. Strike the side of the sieve sharply with the heel of the other hand using an upward motion and at a rate of about 150 times per minute, turn the sieve about one sixth of a revolution at intervals of about 25 strokes. Continue for about one minute.

8.2.3.1 For larger diameter or rectangular sieves, transfer the retained material to 200-mm or 8-in. diameter sieves, in appropriate portions to prevent overloading (see 11.3), and follow the above instructions for each portion.

9. Sampling

9.1 *General*—This test method does not cover, in any detail, procurement of the sample. It is assumed that the sample is obtained using appropriate methods and is representative. However, the testing agency shall preserve all samples in accordance with Practice D4220/D4220M, Group B; except if the as-received sample does not meet those requirements. In that case, the water content of the material does not have to be maintained. The mass of the sample shall meet or exceed the mass requirements for the specimen, as given in Table 2 (see 10.2).

9.2 *Sample Sources*—The sample for a sieve analysis can be from a variety of sources and contain a wide range of particle sizes. Typically, samples for sieve analysis are obtained in the following forms: bulk samples (large bag or bucket samples), small bag or jar samples, tube samples, or specimens from other tests (such as strength, consolidation or hydraulic conductivity). In some cases, (for example, compaction testing) prior testing may cause a reduction of particle sizes. For these cases, the sieve analysis may be required on the initial specimen, or the degraded specimen or both. An overview of how specimens may be selected for various sample types is given below; whereas details for obtaining specimens from samples are in Section 10.

9.2.1 *Bulk Samples*—Generally, bulk samples are obtained because multiple tests are needed or large particles are present, or both. In addition, the bulk sample will usually become the

TABLE 2 Minimum Mass Requirement for Specimen

Maximum Particle Size of Material (99 % or more passes)		Minimum Dry Mass of Specimen, g or kg^A	
Alternative Sieve Designation	Maximum Particle Size, mm	Method A Results Reported to Nearest 1 %	Method B Results Reported to Nearest 0.1 %
No. 40	0.425	50 g	75 g
No. 10	2.00	50 g	100 g
No. 4	4.75	75 g	200 g^B
⅜ in.	9.5	165 g^C	^{D}
¾ in.	19.0	1.3 kg^C	^{D}
1 in.	25.4	3 kg^C	^{D}
1-½ in.	38.1	10 kg^C	^{D}
2 in.	50.8	25 kg^C	^{D}
3 in.	76.2	70 kg^E	^{D}

[A] Specimen masses should not significantly exceed (by more than about 50 %) the presented values because excessively large specimens may result in sieve overloading, (see 11.3) and increase the difficulty of specimen processing.

[B] The same as "C," except multiplied by 10.

[C] These values are based on the mass of an individual spherical shaped particle, at the given sieve, multiplied by 100 then 1.2 (factor to account uncertainty) and finally rounded to a convenient number.

[D] Specimens of this size require composite sieving. The sample sizes required for reporting results to 0.1 % are not practical and the possible errors associated with composite sieving causes this sensitivity to be unrealistic for specimens with these larger size particles.

[E] Same as "C," except 1.2 factor is omitted.

specimen and composite sieving will be required. If other testing is needed, these tests should be coordinated with the sieve analysis so that all specimens are obtained efficiently and representatively using moist (preferred) or air-dried procedure. For example, Test Method D698 or D1557 is frequently requested on bulk samples in addition to the sieve analysis. For this test, it is probably most efficient to process the as-received sample, now a specimen, over the designated separating sieve having either the ¾-in. (19.0-mm), ⅜-in. (9.5-mm) or No. 4 (4.75- mm) sieve and obtain the sieve specimens (coarser and finer portions) during this processing. Although oversize particles (coarser portion) are not used in testing with D698 or D1557, the composite sieve analysis should be calculated to represent both the bulk sample and the compaction material (two gradations). Flowcharts presenting an overview of this procedure are presented in Fig. 2 through Fig. 4(b).

9.2.2 *Jar and Small Bag Samples*—Depending on the sample's gradation, it may be necessary to use the entire sample for the specimen. Observe and estimate the maximum particle size. If the amount of material in the sample is less than the minimum mass required (as given in Table 2), note that the specimen is undersized. If the amount (by mass) of sample is much more (by about 50 %) than needed, the sample can be reduced using moist (preferred) or oven-dried procedure. If there is other testing to be obtained from the sample, it may be better to perform the other testing, such as water content and specific gravity and then sieve the used material. Note on the data sheet if prior testing has been performed on the specimen. This approach cannot be used for tests that might alter the gradation of the soil, such as Atterberg Limits.

9.2.3 *Intact Tube Samples*—To obtain a sieve analysis specimen from an intact tube sample, extrude either the entire sample, or a portion. Observe and estimate the maximum particle size. Use moist procedure (see 10.4.1) to obtain the necessary specimen.

9.2.4 *Samples from Prior Testing*—Frequently, after strength, hydraulic conductivity, consolidation or other testing has been completed, that specimen or a portion of it (from water content) is used for a sieve analysis specimen. The entire specimen can be used or split using the most appropriate procedure for specimen selection (moist or oven dried). If the specimen mass is less than required according to Table 2, note that the specimen is undersized on the data sheet. There may be conditions when it is undesirable to test the entire specimen due to the nonhomogeneity of the specimen. If there are layers in the specimen, it may be necessary and more useful to determine the gradation of individual layers.

10. Specimen

10.1 *General*—This section is separated into four parts. The mass requirement for the specimen is given in the first part (*Minimum Mass Requirement*). In the second part on *Selection of Sieving Procedure*, the determination of which sieving procedure applies, single sieve-set or composite sieving, is explained. In the third part on *Specimen Procurement*, an overview of the three applicable procedures (moist, air dried and oven dried) for use in obtaining a specimen from the sample and processing it for sieving is given. Following this overview is a discussion about special considerations relating to soils that readily segregate. In the fourth part on *Specimen Procurement and Processing Requirements*, details are given on how the above moist, air-dried and oven-dried procedures are to be applied to obtain a specimen(s) and prepare it for single sieve-set or composite sieving.

10.2 *Minimum Mass Requirement*—The minimum dry mass needed for a sieve analysis specimen is based on the maximum particle size in the sample and the test method (Method A or B) used to record the data. Based on the estimated maximum particle size, use Table 2 to determine the minimum mass of the specimen in g or kg.

10.3 *Selection of Sieving Procedure*—As shown in Fig. 2, the first decision step in this test method is to estimate the maximum particle size contained in the sample and then determine, based on the assigned Method (A or B), if the single sieve-set sieving or composite sieving procedure is to be used.

10.3.1 *Single Sieve-Set Sieving*—For Method A, this procedure applies to samples having a maximum particle size equal to or less than 9.5 mm (3⁄8-in. sieve). For Method B, this procedure applies to samples having a maximum particle size equal to or less than 4.75 mm (No. 4 sieve). However, if the material is ***not*** relatively well graded, then these acceptable maximum particle sizes may be smaller. If Method B is assigned and the sample has a maximum particle size larger than 4.75 mm, then this non-conformance should be noted on the data sheet and if necessary, inform the requesting authority. In addition, switch to Method A and if necessary, composite sieving.

10.3.1.1 Single sieve-set sieving ***could*** apply to samples having a maximum particle size up to 19.0 mm (3⁄4-in. sieve) or possibly the 25.4 mm (1-in. sieve); providing Method A applies and the mass of the specimen meets the requirements presented in Table 2. In addition, it depends on the gradation of the sample, the size (diameter) of sieves being used, and if the tester wants to sieve the specimen in portions.

10.3.2 *Composite Sieving*—This procedure applies to samples having a maximum particle size equal to or greater than 19.0 mm (3⁄4-in. sieve), unless 10.3.1.1 applies.

10.4 *Specimen Procurement*—This test method presents three procedures to obtain a representative specimen from the sample (moist, air-dried and oven-dried). In these procedures, the terms moist, air-dried or oven-dried refer to the condition of the material or sample as it is being processed to obtain the specimen. Additional guidance for splitting material to obtain a representative portion (specimen) using a splitter, quartering or moist stockpile sampling (Practice C702, Methods A, B and C, respectively) is given in Annex A2.

10.4.1 *Moist Procedure*—The sample is processed and split using moist stockpile sampling or quartering, if needed, in a moist, as-received state to obtain a representative specimen, unless the material is excessively wet or dry. This procedure is the preferred method for soils that readily segregate in a dry state such as coarse-grained soils with or without fines, or fine-grained soils containing coarse-grained particles, see 10.4.4. In addition, it is the preferred method for any sample containing soil whose properties are altered due to drying, and testing to determine those properties is necessary. These soil types may include most organic soils; many highly plastic fine-grained soils; tropical soils; and soils containing halloysite. Examples of such testing may include compaction, Atterberg Limits, specific gravity, and gradation by sedimentation. For samples requiring composite sieving, the sample typically becomes the specimen and requires additional processing as covered in 10.5.2.

10.4.2 *Air-Dried Procedure*—The sample is air dried, and then processed and split, if needed, using only a splitter to obtain the required specimen. The specimen is oven dried, washed, re-dried and then sieved. For samples requiring composite sieving, the sample typically becomes the specimen and requires additional processing as covered in 10.5.5.

10.4.3 *Oven-Dried Procedure*—The sample is oven dried, and then processed and split using only a splitter, if needed, to obtain the required specimen. The specimen is washed, re-dried, and then sieved. For samples, especially large ones requiring composite sieving and other testing, this procedure is typically not practical and shall not be used for soil types mentioned in 10.4.1.

10.4.4 *Discussion on Segregating Soils*—There are some special considerations relating to soils that readily segregate (such as gravels and sands, with or without fines). Experience gained from the ASTM Reference Soils and Testing Program and obtained at AASHTO Materials Reference Laboratory (AMRL) has clearly demonstrated the following conclusions. When dealing with soils that readily segregate and are in an air-dried or oven-dried state, the splitting processes (Practice C702, Method A) cannot be used more than a few times to obtain a representative specimen. The resulting specimen will have less fine sand and finer particles than the sample. This standard specifies when using a splitter, there cannot be more than two splitting operations (splits) to obtain the specimen. This number is based on judgment. There will be cases when more or less splits would be appropriate; however, use extreme caution in selecting more than two splits. For referee testing two splits cannot be exceeded. The method to obtain representative specimens from these soils requires that the soils be in a moist state. The water content should optimize bulking or be slightly wetter than the saturated surface-dry condition. This water content is to the point that the surface of the soil should look slightly wet but there are no signs of free water exiting the soil. This will reduce the potential for particle segregation and loss. The sample can be mixed and readily scooped/shoveled to obtain representative portions of the material (Practice C702, Method C, see A2.1.3). This procedure is especially useful if the maximum particle size is less than about 19.0 mm (3⁄4-in. sieve).

10.5 *Specimen Procurement and Processing Requirements:*

10.5.1 *Moist Procedure, Single Sieve Set Sieving*—If single sieve-set sieving applies, as determined in 10.3, then either select the whole sample or split the sample after it is mixed in the as-received condition, unless it is too dry or wet for processing to obtain a representative specimen, see 10.5.1.2.

10.5.1.1 If the sample contains standing water or is very wet; then it may be dried back to a moist state, as defined in 10.4.1, 10.4.4, or A2.1.3, by air-drying or oven-drying (60°C). If oven drying is used, the sample is placed in a low temperature, drying oven (not to exceed 60°C) and mixed frequently to avoid excessive drying of any portion of the sample. If the sample is too dry; then water can be added (preferably by spraying) while the sample is being mixed to a moist state.

10.5.1.2 After mixing, obtain a representative specimen having the required mass (Table 2) by taking one or more scoops from the sample. The number of scoops shall increase as the mass of the specimen increases and come from various locations, and each scoop shall have about an equal mass, see A2.1.3. Place all the material in the scoop into the specimen container of known mass (g or kg). In this process, do not attempt to obtain an exact mass or increase the specimen size by adding very small amounts of material. For relatively well-graded coarse-grained soils, especially relatively clean ones containing gravel and coarse sand; do not add material by shaking it off the edge of the scoop. All of these processes could result in altering the gradation of the specimen. Oven dry the specimen (110 ± 5°C), see Notes 7 and 8. Record the identification of the specimen container and the mass (g or kg) of the container on the data sheet. Proceed to Section 11 on *Procedure (Sieving)*.

NOTE 7—For non-referee testing, it is acceptable practice to determine the oven-dried mass of a specimen or subspecimen, based on its moist mass and water content determined to the nearest 1 % for Method A or 0.1 % for Method B.

NOTE 8—This procedure for selecting material from a sample is basically the same as that presented in Practice C702, Method C—Miniature Stockpile Sampling (Damp Fine Aggregate Only) and summarized in A2.1.3.

10.5.2 *Moist Procedure, Composite Sieving*—For composite sieving, typically the whole sample becomes the specimen. If splitting is needed, obtain a representative portion by either the moist stockpile sampling procedure, as described in 10.5.1.2 or quartering (see A2.1.2). For an overview of the composite sieving method, refer to Fig. 2 through Fig. 4(b). In composite sieving, the following information must be obtained:

(a) The oven-dried mass of the coarser portion retained on designated separating sieve, CP,M_d in g or kg,

(b) The moist mass of the finer portion passing the designated separating sieve, FP,M_m in g or kg,

(c) The water content of a subspecimen obtained from the finer portion, w_{fp} in %,

(d) The calculated oven-dry mass of the finer portion, FP,M_d in g or kg, and

(e) The oven-dry mass of the subspecimen obtained from the finer portion for sieving over the finer sieve set, $SubS,M_d$ in g or kg.

10.5.2.1 If necessary, adjust the moisture condition of the material by drying or adding water as described in 10.5.1.1.

10.5.2.2 Select a designated separating sieve following the guidance given in 9.2.1 on *Bulk Samples* and Note 9. Process the specimen over this sieve. Manually or mechanically shake, or wiggle the finer portion through the sieve and collect both the coarser and finer portions. Remove any large conglomerations from the designated separating sieve and break them into individual particles or into conglomerations that are smaller than the openings in the designated separating sieve. Return the soil to the designated separating sieve and continue processing. Do not apply pressure that could damage the sieve. If fines are adhering to the coarser particles, scrape or brush these larger particles and dislodge the fines. If the fines are adhering into large clumps, use knives or spatulas to cut the clumps into chucks that will pass the designated separating sieve.

NOTE 9—Smaller cloth size of the designated separating sieve increases the difficulty in processing the material and having a limited amount of the fines adhering to the retained particles. In addition, selection of the designated separating sieve size may be based on ease of separating the specimen, additional testing to be performed, or convenience. For very plastic, clayey materials, it is easier to select a larger designated separating sieve. For materials that need compaction testing using either D698 or D1557, it is easiest to use the sieve (either No. 4 (4.75 µm), ⅜ in. (9.5 mm) or ¾ in. (19.0 mm)) necessary for the compaction method. Some laboratories are equipped with two sets of mechanical sieve shakers depending on size range, and, hence, the selection would be based on the equipment. There can be more than one designated separating sieve used in composite sieving, because the first subspecimen can be split again to obtain a second subspecimen.

10.5.2.3 *Coarse Portion Acceptable Loss (CP_L)*—It is usually not possible to remove all the fines (particles that would pass the designated separating sieve) adhering to the retained coarser particles. For the finer portion to be representative, the amount adhering to the retained coarser particles has to be less than 0.5 % of the dry mass of the specimen (S,M_d), see Note 9. If it appears that the material adhering to the retained portion will exceed the 0.5 % criterion, then the retained portion must be washed using a minimum amount of water and the washings added to the portion passing the designated separating sieve. The actual value will be determined at the end of the test.

10.5.2.4 Place the coarser portion in a suitable container of known mass (g or kg) and oven dry it (110 ± 5°C). Record the container identification and mass on the data sheet. If the water content of the coarser portion is needed (for example, to report the as received condition), determine it in accordance with Test Method D2216. Record the oven dry mass of the coarser portion, CP,M_d in g or kg.

10.5.2.5 Determine and record the moist mass (g or kg) of finer portion, using a balance meeting the requirements given in 6.4 and 11.2. Depending on the size of this portion, this mass determination can be done in increments as the material is being processed or after it has been processed. Record this moist mass as FP,M_m in g or kg.

10.5.2.6 Mix the moist finer fraction and obtain a representative subspecimen for both a water content determination and sieving using the moist stockpile sampling procedure, see 10.5.1.2. The finer portion subspecimen shall have a mass meeting the requirements given in Table 2. Record the container identification, mass of the container, and mass of the container plus moist material representing the finer portion subspecimen. The balance used shall meet or exceed the requirements of Test Method D2216 for water contents determined to the nearest 1 % or better.

10.5.2.7 Oven-dry the subspecimen in the oven at 110 ± 5°C. Calculate and record the water content, w_{fp}. Determine and record the dry mass of the subspecimen as $SubS,M_d$ in g or kg. If this subspecimen requires a second separation, (see Fig. 4(a) and Fig. 4(b)—composite sieving with double separation) processing the second subspecimen will be performed later (see 11.6).

10.5.2.8 Determine the dry mass of the specimen (coarser portion plus finer portion) in g or kg, see 12.4, and proceed to Section 11 on *Procedure (Sieving)*.

10.5.3 *Air Dried Procedure, General*—This method requires the use of a splitter to obtain a specimen from a sample that has been air-dried, unless the whole sample is tested. Therefore, this procedure can only be used for smaller samples in which no more than two splitting processes will be necessary, see 10.4.4. Typically, this procedure would only be used for soils coming from an arid region in which the soil will become air-dried and when other testing requires an air-dried condition.

10.5.3.1 Depending on the size of the sample, place the material either on a tray(s)/pan(s), smooth tarp/plastic sheet/ etc. or sealed-smooth floor (prevent loss of fines) and air-dry. Alternatively, an oven not exceeding 60°C may be used. Upon the completion of air-drying; place the material into either a container or pile. During this process, break apart any noticeable aggregations of soil particles. This can be done by hand or using a mortar and rubber-covered pestle or similar method that does not break the individual particles.

10.5.4 *Air Dried Procedure, Single Sieve-Set Sieving*—If this applies, as covered in 10.3; then either test the whole sample, noting its mass cannot be too large (Table 2) or after mixing, obtain a representative specimen having the required mass (Table 2) using a splitter and noting the above requirements and those in Annex A2, Sample to Specimen Reduction Methods, A2.1 and A2.1.1.

10.5.4.1 Place the specimen in a container of known mass (g or kg) and oven-dry the material at 110 ± 5°C. Record the identification of the specimen container, and mass of the container on the data sheet. Determine and record the dry mass of the specimen as S,M_d in g or kg. For non-referee testing, this dry mass may be based on an auxiliary water content of similar air-dried material (see Note 7).

10.5.4.2 Proceed to Section 11 on *Procedure (Sieving)*.

10.5.5 *Air Dried Procedure, Composite Sieving*—If composite sieving applies, as determined in 10.3, follow the moist procedure, as outlined in 10.5.2 through 10.5.2.8 to obtain the specimen and process it for composite sieving, except for the following:

(a) The sample is air-dried prior to any processing, see 10.5.4.1.

(b) The moist masses become air-dried masses.

(c) The water content of the coarser portion is not applicable.

(d) To obtain the subspecimen from the finer portion, the applicable guidance given in 10.5.3 shall be followed instead of that given in 10.5.2.6.

10.5.5.1 Proceed to Section 11 on *Procedure Sieving*).

10.5.6 *Oven-Dried Procedure, General*—This method requires the use of a splitter to obtain a specimen from a sample that has been oven-dried, unless the whole sample is tested. Therefore, this procedure can only be used for smaller samples in which no more than two splitting processes will be necessary, see 10.4.2 and 10.4.4. This procedure shall only be used when other testing is not necessary or needed, see 1.8 and 10.4.1. See 10.5.2 for comments on composite sieving.

10.5.6.1 Place the sample on a tray(s)/pan(s) and oven dry at 110 ± 5°C overnight or until thoroughly dry, see Test Method D2216. Upon the completion of drying; place the material into either a container or pile. During this process, break apart any noticeable aggregations of soil particles. This can be done by hand or using a mortar and rubber-covered pestle or similar method that does not break the individual particles.

10.5.7 *Oven Dried Procedure, Single Sieve-Set Sieving*—If this applies, as covered in 10.3; then either test the whole sample, noting its mass cannot be too large (Table 2) or after mixing, obtain a representative specimen having the required mass (Table 2) using a splitter and noting the above requirements and those in Annex A2, Sample to Specimen Reduction Methods, A2.1 and A2.1.1. Record the identification of the specimen container, and mass (g or kg) of the container on the data sheet. Determine and record the dry mass of the specimen as S,M_d in g or kg.

10.5.7.1 Proceed to Section 11 on *Procedure (Sieving)*.

10.5.8 *Oven Dried Procedure, Composite Sieving*—If composite sieving applies, as determined in 10.3, procure the specimen following the applicable guidance given in 10.5.4 through 10.5.4.2. Double check that the specimen's mass and its container has been determined and recorded. Select a designated separating sieve following the guidance given in 9.2.1 and Note 9. Process the specimen over this sieve following the applicable guidance given in 10.5.2.2 and 10.5.2.3.

10.5.8.1 Record the oven-dry mass of the coarser portion, CP,M_d in g or kg.

10.5.8.2 Mix the finer portion and obtain a representative subspecimen having the required mass (Table 2) using a splitter, see requirements given in 10.4.4. Record the container identification, mass of the container, and mass of the container plus dry material representing the finer-portion subspecimen. Calculate and record the dry mass of the subspecimen, $SubS,M_d$ in g or kg.

10.5.8.3 Proceed to Section 11 on *Procedure (Sieving)*.

11. Procedure (Sieving)

11.1 *General*—There are several different ways to determine the percent passing, since there are several different approaches to determine the amount of material retained on each sieve in a given sieve set. As previously stated, the procedure presented in this test method is to determine and record the mass of the cumulative material retained upon any given sieve within any given sieve set, since it is the easiest approach to present. However, this does not mean that other approaches are in nonconformance with this test method. One alternate approach would be to determine the amount of material retained on each sieve within a given sieve set, and then adjust the method of calculation to determine the percent passing.

11.1.1 The sieving process is usually accomplished using a mechanical sieve shaker (see 6.3); however, hand shaking is permissible, especially for the coarser sieves (larger than about the ¾-in. (19.0-mm). For referee testing, a mechanical sieve shaker shall be used for the portion passing the ¾-in. (19.0-mm) sieve.

11.1.2 The proper gradation of a specimen cannot be obtained if one or more sieves are overloaded during the sieving process, see 11.3 on *Sieve Overloading*.

11.2 *Mass Measurements*—The following details supplement the requirements presented in 6.4 on *Balances*. Determine the mass of the specimens to a minimum of three significant digits for Method A or a minimum of four significant digits for Method B. For subspecimens, only Method A applies. Determine the mass (g or kg) of the cumulative material retained using a balance having the same readability or better as was used to determine the mass of the specimen or subspecimen, see Note 3. This balance does not have to be the same one used to determine the mass of the specimen.

11.3 *Sieve Overloading*—The overloading of a sieve occurs when too many particles are retained on a sieve such that all particles do not have an opportunity to reach a sieve opening a number of times during sieve shaking. To prevent sieve overloading, the quantity of material retained on an individual sieve must be less than or equal to that specified in Table 3.

11.3.1 To avoid overloading, it is often necessary to divide large specimens or subspecimens into several portions. Each portion would be sieved and the amount retained on each sieve would be recorded. Then, the masses retained on a given sieve from all the sieved portions would be added as explained in 11.4.5.2.

11.3.2 If overloading has occurred, the specimen or subspecimen must be re-sieved in several portions or using sieves having a larger area.

11.4 *Single Sieve-Set Sieving*—A summary of terms used in single sieve-set sieving is presented in Fig. 1(a) and Fig. 1(b) while Fig. 3 presents a flowchart of this sieving process.

11.4.1 *Specimen Mass*—Check that the following had been determined and recorded in accordance with Section 10; the dry mass of the specimen, the identification of the specimen container and the procedure used to obtain that specimen (moist, air-dried or oven-dried). Record this mass as S,M_d in g or kg.

11.4.2 *Specimen Dispersion*—Prior to washing the specimen on the No. 200 (75-µm) washing sieve, the specimen shall be dispersed by one of the following procedures. However, in no case shall a mechanical mixer (with metal blade) be used to disperse the soil, since such mixers have a tendency to degrade (breakdown) coarse-grained particles. Wrist action shakers or similar agitating devices are acceptable, see 6.14.

11.4.2.1 *Soaking without a Dispersant*—Cover the specimen (soil) with tap water and allow it to soak for at least 5 minutes. Longer soaking periods are typically needed as the amount of fines or the plasticity of the fines or both increases. During this soaking period, the soil and water can be agitated using a stirring rod, spatula, dispersion shaker or similar device to facilitate the dispersion process or to check that the soil is dispersed. If clumps of particles or clods are detected, then this method of dispersion is not effective (see Note 10) and proceed to 11.4.2.2. A dispersion shaker shall not be used for relatively clean coarse-grained soils (such as: GP, SP, GP-GM, SP-SM, SP-SC).

NOTE 10—It is not easy to evaluate effective dispersion. Use visual or manual means or both to detect clumps of particles that would indicate incomplete or ineffective dispersion.

11.4.2.2 *Soaking with a Dispersant*—In accordance with Section 7, add the sodium hexametaphosphate either directly (dry addition) or in solution. Follow the instructions in 11.4.2.1. If this method of dispersion is not effective, the ultrasonic water bath could be used or additional time allowed for dispersion.

11.4.2.3 *Using an Ultrasonic Water Bath*—This procedure may be used for soils that are difficult to disperse. Place the specimen and container in the ultrasonic water bath following the guidance given in 6.13. The water in the specimen container should contain dispersant. If the size of the specimen container is not appropriate to fit into the ultrasonic water bath, then transfer the specimen to a suitable one, noting that the specimen can be dispersed in portions.

11.4.3 *Washing Specimen*—At the end of the soaking-dispersion period, the fines (minus No. 200 (75-µm) sieve material) are removed by washing using this procedure or by following the applicable portions of Method B given in Test Method D1140. The apparatus used shall meet the requirements given in 6.1.2 and 6.2.

TABLE 3 Overloading Limits for Standard Sieve Set

Alternative Sieve Designation	Standard Sieve Designation	Number of Grain Layers on Given Sieve	Maximum Mass Retained on 200-mm (8-in.) Diameter Sieve, g[A]	Maximum Mass Retained on 305-mm (12-in.) Diameter Sieve, g	Maximum Mass Retained on 370- by 580-mm (14.6- by 22.8-in.) Sieve, g
3 in.	75 mm	0.8	2 700	6 100	18 000
2 in.	50 mm	0.9	2 000	4 500	13 000
1-½-in.	37.5 mm	0.9	1 500	3 400	10 000
1 in.	25 mm	1	1 100	2 500	7 000
¾ in.	19.0 mm	1	900	2 000	6 000
⅜ in.	9.5 mm	1.25	550	1 200	3 600
No. 4	4.75 mm	1.5	325	730	2 000
No. 10	2.00 mm	2	180	410	1 000
No. 20	850 µm	3	115	260	800
No. 40	425 µm	4	75	170	500
No. 60	250 µm	5	60	140	400
No. 100	150 µm	6	40	90	300
No. 140	106 µm	6	30	70	200
No. 200	75 µm	6	20	50	100

[A] For sieve sizes other than those listed above, determine the surface area of the sieve(s) cloth being used in m^2 and divide this number by 0.028 m^2 (the approximate surface area of a 200-mm or 8-in. diameter sieve). Then multiply this area ratio by the masses listed in this column to form a column of acceptable masses for the different sieve area of interest. Round these values, so the significant digits are similar to those presented.

11.4.3.1 *General Precautions*—Washing specimens larger than about 200 g should be done in increments. For masses containing particles coarser than No. 4 (4.75-mm) sieve, all of the material should ***not*** be placed directly on the washing sieve (No. 200 or 75-µm), especially for brass cloth. In this case, a coarser size sieve (No. 40 or larger) shall be inserted above the washing sieve. It is necessary to see through this coarser sieve to check if the washing sieve is clogging (often the No. 40 sieve obscures this view and a No. 20 (850 µm) sieve is a better choice).

11.4.3.2 *Transfer Specimen*—Transfer the dispersed specimen, or a portion of the specimen to the washing sieve or the coarser sieve inserted above the washing sieve by pouring or any means that prevents spillage. During this process, stop pouring if any material loss will occur due to clogging of the washing sieve, and unclog the washing sieve, see Note 11. After emptying the dispersed specimen container, wash any remaining material onto the washing sieve or the coarser sieve inserted above it using the spray nozzle, wash bottle, or similar method.

11.4.3.3 *Washing*—Wash the specimen (material) on the washing sieve by means of a stream of water from the spray nozzle. Continually check to see if the washing sieve has clogged (see Note 11). The velocity of the water shall not cause any splashing of the material out of the sieve. The water temperature shall remain close to room temperature (see 6.2). To facilitate the washing process, the retained material may be lightly manipulated by hand while it is against the side of the sieve or above it, taking care not to lose any retained material. A wash shaker may be used to aid in the washing process. No downward pressure should be exerted on the retained material or sieve cloth to avoid forcing particles through the sieve or causing damage to the sieve. When the coarser sieve is being used, remove it from above the washing sieve as soon as the coarser material is washed and transfer it to the specimen container (see 11.4.3.4). Continue washing the specimen on the No. 200 (75-µm) sieve until the wash water is clear.

NOTE 11—If clogging of the washing sieve occurs, lightly hand tap the side or the bottom of the washing sieve until it is unclogged. Another method to unclog the washing sieve is gently spray a small amount of water up through the bottom of the washing sieve, then use the tapping approach to assist in the drainage of wash water.

11.4.3.4 *Transfer Washed Specimen*—Using a washing process, return the portion retained on the washing sieve and coarser sieve, if used, to its original specimen container or new container of known mass in g or kg. This can be done by washing the retained material to one side of the sieve, by tilting the sieve and allowing the wash water to pass through the sieve. Then, slowly wash this material into the container using as little wash water as possible, such that water will not fill and overflow the container. If the container approaches overflowing, stop the transfer process and decant the clear water from the container. Decant as much water from the container as practical without losing any retained material, and dry to a constant mass in an oven at 110 ± 5°C. This drying period will most likely be shorter than the overnight period suggested in D2216, because the retained material does not contained any fines. After oven drying, allow the container to cool, determine and record the dry mass of the washed material, S_wM_d in g or kg.

11.4.4 *Dry Sieving*—Dry sieving is accomplished by sieving the oven-dried washed material over an appropriate sieve set using a mechanical sieve shaker for a standard shaking period (see 8.2) and in such a manner that prevents the overloading of any given sieve (see 11.3). Then, the cumulative material retained for each sieve within a sieve set by mass or cumulative mass retained is determined. Based on these measurements, the percent passing each sieve is determined. The following procedure assumes that a stack of 200-mm or 8-in. diameter sieves is being used. However, the use of other sieve sizes or configurations is not prohibited providing they meet the requirements given in Sections 6, 8, and this section.

11.4.4.1 *Sieve Set*—Assemble an appropriate stack of sieves from the standard set given in Table 1 and meeting the requirements given in 6.1. The largest sieve size shall be such that 100 % of the washed (sieving) material passes through it. Do not omit any standard sieves sizes between the largest sieve size and the No. 200 (75-µm) sieve, but it is permissible to include additional sieves. Assemble the stack of sieves with the largest sieve size at the top. Add the remaining sieves in descending sieve size. Add the pan on the bottom and the lid on the top on the sieve stack, if appropriate. If there are too many sieves to fit into the sieve shaker, it is permissible to separate this set into a coarser subset and a finer subset. It is also permissible to use "half height" sieves, see 6.1. Some sieves are designed to stack on top of each other, and other sieves are inserted like drawers into the shaker. Either type is acceptable.

11.4.4.2 *Mechanical Shaking*—Pour the dried washed material from its container onto the sieve at the top of the sieve stack. Then brush any material remaining in the container onto that sieve. The container should be close to the sieve to prevent spillage and creation of dust. Cover the stack of sieves with the lid, if applicable, and place the sieve set in the sieve shaker. Shake the sieve set for the standard shaking period established in 8.2 (using a timing device) for that sieve shaker and size sieve set. Avoid overloading the sieves, see 11.3. Upon completion of shaking, remove the sieve set for determination of the cumulative material retained for each sieve, as covered below.

11.4.5 *Cumulative Material/Mass Retained* (Hereafter referred to as cumulative mass retained.)

11.4.5.1 *First Sieve*—Remove the lid from the sieve set, verify that no material was retained on the top (largest size) sieve (record 0.0 g or kg in the cumulative mass retained column, CMR_N). If material is retained on the top sieve, determine and record its mass, CMR_N, in accordance with 11.2 in g or kg. Transfer that retained material to the next larger sieve size in the standard sieve set, see Table 1. Add the pan and lid and hand shake that sieve following the procedure given in 8.2.3 on *Hand Sieve Shaking*. Shake until either the entire retained material has passed that sieve or for about one minute. Verify that no material was retained on that sieve by recording 0.0 g or kg as appropriate. Transfer the contents of the pan to the cumulative mass container (see 6.6.3).

11.4.5.2 *Remaining Sieves*—Remove the next sieve and turn the sieve upside down such that the retained material falls onto the collection/transfer device (see 6.6.2) without spillage or creating dust. Any material remaining in the sieve may be gently removed using a sieve brush (see 6.7). Take care to avoid distortion or damage of the sieve cloth (see 6.7.1 through 6.7.6). Next transfer this retained material to the container (see 6.6.3) holding the cumulative mass retained, *CMRN*. Determine, in accordance with 11.2 and record the mass (g or kg) contained in this container, CMR_N. Continue in this manner for the remaining *Nth* sieves and pan.

11.4.5.3 When using the cumulative mass retained method, sieve-overloading problems are not immediately apparent, but they shall be checked for during this process, see 11.3. Conversely, when the data sheet lists the overloading masses and the mass on each sieve is recorded, any problems due to overloading will be immediately noticed. If overloading occurred, re-sieve the material in accordance with the instructions provided in 11.3.1. In the case where the sieving process is done in parts, such as to prevent overloading or overloading has occurred, then there is more than one set of partial cumulative mass retained determinations to be recorded and combined to determine the cumulative mass retained, CMR_N. This will require either special or multiple data sheets.

11.4.5.4 Proceed to Section 12 on *Calculations*.

11.5 *Composite Sieving, Single Separation*—Refer to Fig. 1(a) and Fig. 1(b) for the terms used in composite sieving and Fig. 4(a) for a flowchart of these sieving processes. When composite sieving is necessary, the following items requiring sieving were obtained during the processing of the specimen and identified on the data sheet, as covered in Section 10 on *Specimen*. These items are:

(a) The oven-dried mass of the portion retained on designated separating sieve; that is the coarser portion, CP,M_d in g or kg.

(b) The oven-dried mass of the subspecimen obtained from the finer portion, $SubS,M_d$ in g or kg.

11.5.1 *Coarser Portion*—If the coarser portion is clean (free of material finer than the designated separating sieve) or already washed (see 10.5.2.3), and the testing is not used as referee testing, the coarser portion will not need to be washed. It is permissible to consider the coarser portion to be clean if 0.5 % or less of that finer material (based on specimen's dry mass, S,M_d) would be or are removed from the coarser portion while sieving or washing, or both. Washing is not needed under these conditions. For referee testing, the coarser portion shall be washed.

11.5.1.1 *Dispersing and Washing*—Follow the applicable instructions provided in 11.4.2 to disperse the coarser faction and 11.4.3 to wash the coarser portion after dispersion, while noting the following:

(a) Soaking in water, will usually suffice,

(b) Washing is done on either the designated separating sieve used to separate the specimen into a coarser and finer portion, or another sieve of equal size (designation, see Table 1); and,

(c) During washing or the dispersion process fine particles may be brushed off coarser particles.

11.5.1.2 Return the retained washed portion to the same container and oven dry to a constant mass (110 ± 5°C). Determine and record the dry mass (g or kg) of the washed coarser portion, CP_wM_d, following the instructions provided in 11.2. The calculation of the acceptable percent loss during washing or sieving, or both of the coarser portion is covered in Section 12 on *Calculations*, 12.5.1.3. This calculation is performed after the sieving of the coarser portion. If CF_L is greater than 0.5 %, the sieve analysis is in nonconformance (unless the washings were added to the finer portion) and this factor shall be noted on the data sheet.

11.5.1.3 *Dry Sieving Coarser Portion*—Using this clean or washed coarser portion, follow the applicable instructions given in 11.4.4 (*Dry Sieving*) and 11.4.5 (*Cumulative Mass Retained*), while noting the finest sieve size in the coarser sieve set is the size of the designated separating sieve, ***not*** the No. 200 (75-µm) sieve. Determine and record these values of cumulative mass retained in the coarser sieve set and for each *Nth* sieve as CP,CMR_N in g or kg, Determine and record the mass of material contained in the pan, CP,MR_{pan} in g or kg. The calculation of the acceptable percent loss during washing or sieving, or both of the coarser portion is covered in Section 12 on *Calculations*, 12.5.1.3. If CF_L is greater than 0.5 %, the sieve analysis is in nonconformance and this factor shall be noted on the data sheet.

11.5.2 *Subspecimen from Finer Portion*—If the size of the designated separating sieve is equal to or larger than the ¾-in. (19.0-mm) sieve, then this subspecimen will have to be separated again, or washed and sieved in portions, see 10.3.1.1. If separation over a 2^{nd} designated separation sieve is necessary, then additional processing and sieving is needed, as covered in 11.6.3. If a 2^{nd} separation is ***not*** necessary (see Fig. 4(a)), then this subspecimen can be sieved as described below.

11.5.2.1 *Dispersing and Washing Subspecimen*—Wash the subspecimen following the applicable instructions provided in 11.4.2 to disperse the subspecimen and 11.4.3 to wash the subspecimen after dispersion. After oven drying, allow the container to cool, determine and record the dry mass of the washed material, $SubS_wM_d$ in g or kg.

11.5.2.2 *Dry Sieving Subspecimen*—Using the above dry washed subspecimen, dry sieve this material and determine the cumulative masses retained following the applicable instructions given in 11.4.4 through 11.4.5.3 and noting the following changes:

(a) The coarsest sieve size in the finer sieve set is the size of the designated separating sieve.

(b) For these cumulative mass retained values, they are identified as fractional cumulative mass retained on each *Nth* sieve as $SubS,FCMR_N$ in g or kg.

(c) There should not be any material retained on the coarsest sieve in the finer sieve set. Retained material indicates that the specimen was not split properly or there is a difference in openings in the sieve cloth between the designated separating sieve and the one in the finer sieve set. If the mass of material retained on this sieve, $SubS,MR_{first}$, is equal to or less that 2 % of the subspecimen's mass, $SubS,M_d$, then record the mass in g or kg. There might not be an identifiable space provided on the data sheet for this value, especially in composite sieving with double separations. In that case, record the value in the margin next to the appropriate sieve size.

(d) If the mass retained on this sieve exceeds 2 %, then the sieve analysis is in nonconformance and this factor noted on the data sheet, but record that value and determine the remaining $SubS,FCMR_N$ values. If this continually occurs, then the testing laboratory shall first review its splitting methodology for errors, and then verify that the sieve cloth of the sieves involved meet the full requirements of Specification E11, or replace those sieves with new ones.

11.5.2.3 Proceed to Section 12 on *Calculations*.

11.6 *Composite Sieving, Double Separation*—The 1st subspecimen will be processed over a 2nd designated separating sieve for composite sieving with double separation. See Fig. 1(a) and Fig. 1(b) for summary and flowchart of terms used and Fig. 4(a) and Fig. 4(b) for a flowchart of these sieving processes.

11.6.1 *Separating 1st Subspecimen*—Select the size of the 2nd designated separating sieve; usually this sieve size is the ⅜-in. (9.5-mm), No. 4 (4.75 mm), or No. 10 (2.00-mm) sieve. When selecting this sieve, remember that as the size of the designated separating sieve decreases, it is more difficult to obtain a representative 2nd subspecimen and meet the 0.5 % criterion on loss of material during washing and sieving of the 2nd coarser portion (see 11.6.2).

11.6.1.1 Sieve the 1st subspecimen over the 2nd designated separating sieve using the mechanical sieve shaker and appropriate standard shaking period and in increments to prevent sieve overloading. Separately collect the retained and passing portions.

11.6.1.2 Closely check the retained material for material finer than the 2nd designated separating sieve, if noted, they can be broken up by hand or by using a mortar and rubber-covered pestle. Re-sieve that material over the 2nd designated separating sieve by hand sieving (see 8.2.3) and add the retained and passing portions to the appropriate container.

11.6.2 *Dispersing and Washing 2nd Coarser Portion*—Recheck the retained material, if the amount of adhering particles appears to exceed 0.5 % of $1^{st}SubS,M_d$ then wash those fines into the container containing the second 2nd finer portion (that is, the material passing the 2nd designated separating sieve) and oven dry (110 ± 5°C) both portions ($2^{nd}CP_wM_d$ and 2nd finer portion). If the amount of finer material appears to be equal or less that this 0.5 % criterion; then determine and record the dry mass, $2^{nd}CP,M_d$ in g or kg and then sieve the 2nd coarser portion using the 2nd coarser sieve set. In addition, if this 2nd coarser portion is washed and it appears the adhering particles will not exceed 0.5 %, then the washings do not have to be added to the 2nd finer portion. For referee testing, the 2nd coarser portion has to be washed following the applicable instructions given in 11.5.1.1, while noting the following.

11.6.2.1 Determine and record the oven-dry mass (g or kg) of the 2nd coarser portion before and after washing as $2^{nd}CP,M_d$ and $2^{nd}CP_wM_d$, respectively.

11.6.2.2 The calculation of acceptable loss on washing criterion of 0.5 % is now based on the mass (g or kg) of the 1st subspecimen, $1^{st}SubS,M_d$. This calculation is covered in Section 12 on *Calculations*, 12.6.2.3.

11.6.3 *Dry Sieving 2nd Coarser Portion*—Using this clean or washed 2nd coarser portion, follow the applicable instructions given in 11.4.4 (*Dry Sieving*) and 11.4.5 (cumulative mass retained), while noting the following.

11.6.3.1 The coarsest and finest sieve sizes in this 2nd coarser sieve set are the size of the 1st and 2nd designated separating sieve, respectively.

11.6.3.2 The mass (g or kg) of material retained on the coarsest sieve shall not exceed 2 % of the dry mass of the 1st subspecimen; see 11.5.2.2, Items c and d.

11.6.3.3 The mass of the material in the pan, plus loss on washing, if applicable, cannot exceed 0.5 % criterion.

11.6.3.4 The calculations related to the 2nd coarser portion are covered in 12.6.2.1 through 12.6.2.5.

11.6.4 *2nd Subspecimen*—Using a splitter (see 6.9 and 10.4.4), split the 2nd finer portion to obtain the 2nd subspecimen having a mass (g or kg) meeting the requirements given in Table 2. Following the instructions provided in 11.2, determine and record the mass of the 2nd subspecimen as $2^{nd}SubS,M_d$ in g or kg.

11.6.4.1 *Dispersing and Washing 2nd Subspecimen*—Wash the 2nd subspecimen following the applicable instructions provided in 11.5.2.1. After oven drying, allow the container to cool, determine and record the dry mass of the washed material, $2^{nd}SubS_wM_d$ in g or kg.

11.6.4.2 *Dry Sieving 2nd Subspecimen*—Using this oven-dried, washed 2nd subspecimen; dry sieve this material and determine the 2nd fractional cumulative masses (g or kg) retained following the applicable instructions given in 11.5.2.2, while noting the following:

(a) The coarsest sieve size in this finer sieve set is the size of the 2nd designated separating sieve.

(b) For these cumulative masses retained values, they are identified as 2nd fractional cumulative mass retained for each *Nth* sieve as $2^{nd}SubS,CMR_N$ in g or kg.

(c) As stated in 11.5.2.2, Item c and d, there should not be any material retained on the coarsest sieve in this finer sieve set and the same 2 % criterion is applicable, except the mass (g or kg) of the 2nd subspecimen ($2^{nd}SubS,M_d$) is used instead of the 1st subspecimen ($1^{st}SubS,M_d = SubS,M_d$).

11.6.4.3 Proceed to Section 12 on *Calculations*, 12.6.3 through 12.6.4.2.

12. Calculations

12.1 *General*—Refer to Fig. 1(a) and Fig. 1(b) for the typical terms used in sieving and data reduction. The cumulative mass retained (*CMR*) or fractional cumulative mass retained (*FCMR*) recorded for each *Nth* sieve, CMR_N or $FCMR_N$, will be used to calculate a percent passing (*PP*) each *Nth* sieve, PP_N. These results will be tabulated and may be presented graphically. Depending on the assigned/selected method, the results are rounded and presented to either the nearest 1 % (Method A) or 0.1 % (Method B), except for composite sieving, when only Method A applies. The graphical presentation is a plot of percent passing versus log of particle size (mm). The individual points should be connected by a smooth curve.

12.1.1 In the calculations presented below the masses can be in either g or kg. All sieving masses are dry (oven), unless noted otherwise.

12.1.2 In performing calculations needing intermediate values, the data sheet does not have to provide spaces for those values. For example, when calculating the percent finer, the needed intermediate calculation of cumulative percent retained does not have to be recorded.

12.1.3 The equations are given for calculation of percent passing. To calculate the percent retained necessary in determining the precision of this test method, see 14.1.2.1.

12.1.4 A summary of the symbols used below, along with their definition is given in the Annex A1 on Symbols.

12.2 *Sieve Overloading*—The details for determining when a sieve(s) is overloaded during the sieving process is given in 11.3. The only calculation involved is to determine the dry mass of material retained on each *Nth* sieve in g and then compare that value with the maximum allowable value given in Table 3. When the *CMR* sieving process is used, the dry mass retained on the *Nth* sieve, MR_N, is as follows:

$$MR_N = CMR_N - CMR_{N-1} \tag{1}$$

where:

MR_N = mass retained on the *Nth* sieve, g,
CMR_{N-1} = cumulative mass retained on the sieve above the *Nth* sieve, g, and
CMR_N = cumulative mass retained on the *Nth* sieve (in this case the sieve being checked for overloading), g.

12.3 *Single Sieve-Set Sieving, Percent Passing*—For single sieve-set sieving (specimens not requiring composite sieving), calculate the percent passing each *Nth* sieve as follows:

$$PP_N = 100\left(1 - CMR_N / S,M_d\right) \tag{2}$$

where:

PP_N = percent passing the *Nth* sieve, %,
CMR_N = cumulative mass retained on the *Nth* sieve; that is, the mass of material retained on the *Nth* sieve and those above it, g or kg, and
S,M_d = dry mass of the specimen, g or kg.

12.4 *Composite Sieving, Mass of Specimen*—Calculate the dry mass of the specimen, S,M_d as follows:

$$S,M_d = CP,M_d + \left(\frac{FP,M_m}{1 + \frac{w_{fp}}{100}}\right) \tag{3}$$

where:

S,M_d = dry mass of the specimen, g or kg,
CP,M_d = dry mass of the coarser portion, g or kg,
FP,M_m = moist or air-dried mass of the finer portion, g or kg, and
w_{fp} = water content of the finer portion, %.

12.5 *Composite Sieving, Single Separation*—The percent passing the coarser portion (*CP*) is calculated using the same approach as for single sieve-set sieving. For the subspecimen obtained from the finer portion; a composite sieving correction factor (*CSCF*) is required to convert the subspecimen's fractional percent passing to the specimen's percent passing, since only a portion of the specimen is sieved. Multiple approaches can be used to make this correction and they are in conformance with this test method, provided the calculated results are the same. In the presentation below, the percent passing values are identified related to the portion being dry sieved, such as CP,PP_N and $SubS,PP_N$; however, this distinction is not necessary on the data sheet. This approach is being done to allow the user to easily distinguish which portion is being calculated to determine the percent passing the specimen.

12.5.1 *Composite Sieving, Coarser Portion (CP):*

12.5.1.1 *CP, Percent Passing*—Calculate the percent passing each *Nth* sieve in the coarser sieve set as follows:

$$CP,PP_N = 100\left(1 - \left(CP,CMR_N / S,M_d\right)\right) \tag{4}$$

where:

CP,PP_N = specimen's percent passing the *Nth* sieve in the coarser sieve set while sieving the coarser portion of the specimen, %, and
CP,CMR_N = coarser portion's cumulative mass retained on the *Nth* sieve in the coarser sieve set, g or kg.

12.5.1.2 *CP, Composite Sieving Correction Factor (CSCF)*—The *CSCF* is equal to the percent passing the designated separating sieve size in the coarser sieve set (that is, the last/bottom sieve in that set). This value, CP,PP_{last}, shall be calculated and recorded to at least one more digit than required (nearest 0.1 %) to reduce rounding errors.

12.5.1.3 *CP, Acceptable Loss During Washing and Sieving*—Calculate the percent loss of the coarser portion during washing or sieving, or both as follows:

$$CP_L = 100\left(\left(\left(CP,M_d - CP_wM_d\right) + CP,MR_{pan}\right) / S,M_d\right) \tag{5}$$

where:

CP_L = percent of the coarser portion lost during washing and dry sieving, %,
CP,M_d = dry mass of the coarser portion, g or kg,
CP_wM_d = dry mass of the coarser portion after washing, g or kg, and
P,MR_{pan} = dry mass retained in the pan after dry sieving the coarser portion, g or kg.

The percent loss is acceptable if the value of CP_L is less than or equal to 0.5 %.

12.5.2 *Composite Sieving, Subspecimen (finer portion):*

12.5.2.1 *Percent Passing, Specimen (combined coarser and finer portions)*—In the approach presented, the fractional percent passing the subspecimen is corrected by the *CSCF* so it represents the percent passing the specimen. Calculate the percent passing each *Nth* sieve in the finer sieve set, $SubS,PP_N$ as follows:

$$\begin{aligned} SubS,PP_N = CSCF \times SubS,FPP_N = CSCF\,\big(1 \\ - \left(SubS,FCMR_N / SubS,M_d\right)\big) \end{aligned} \tag{6}$$

where:

$SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set, %,
$SubS,FPP_N$ = subspecimen's fractional percent passing the *Nth* sieve in the finer sieve set, decimal (*not in %*),

$SubS,FCMR_N$ = subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg, and

$SubS,M_d$ = dry mass of the subspecimen, g or kg.

12.5.2.2 *Subspecimen, Acceptable Fractional Percent Retained*—As covered in 11.5.2.2, there should not be any material retained on the first/top sieve, same size as the designated separating sieve, in the finer sieve set; however, when there is, the fractional percent retained shall not exceed 2 %. Calculate the fractional percent retained on the first sieve as follows:

$$SubS,FCPR_{first} = 100\left(SubS,FCMR_{first}/SubS,M_d\right) \tag{7}$$

where:

$SubS,FCPR_{first}$ = fractional cumulative percent retained on the first sieve (sieve size equal to the designated separating sieve) in the finer sieve set, %, and

$SubS,FCMR_{first}$ = fractional cumulative mass retained on the first sieve in the finer sieve set, g or kg. (This mass is actually the mass retained since there is not any sieve above it.)

12.5.2.3 *Percent Passing, Acceptance Criterion*—If material is retained on the designated separating-sieve size in the fine sieve set, then there will be two percent passing values for the same sieve size. If this occurs, the percent passing value from the coarser sieve set shall be the accepted value in determining the gradation of the specimen.

12.5.3 *Finer Portion, Percent Passing (optional)*—As mentioned in 9.2.1, there are cases where the gradation of the finer portion might be necessary, especially when other testing, such as compaction, are performed. In this case, the fractional percent passing the subspecimen, $SubS,FPP_N$ in %, represents the percent passing the finer portion, FP,PP_N. Calculate those values as follows:

$$FP,PP_N = 100\left(1 - \left(SubS,FCMR_N/SubS,M_d\right)\right) \tag{8}$$

where:

FP,PP_N = finer portion's percent passing the *Nth* sieve, %.

12.6 *Composite Sieving, Double Separation*—The methodology for these calculations is similar to that for calculating composite sieving with single separation, the only basic changes are the addition of new terms, see Fig. 1(a) and Fig. 1(b), and one additional set of calculations relating to the 2nd subspecimen. Therefore, review those figures and the comments presented in 12.5.

12.6.1 *1st Coarser Portion*—The percent passing, *CSCF* and acceptable loss calculations are the same as covered above, see Composite Sieving-Coarser Portion, 12.5.1, except the prefix 1st is added to all terms and symbols.

12.6.2 *1stSubspecimen*—In this case, the subspecimen is not sieved in its entirety, but is separated into a coarser and finer portion (2nd coarser portion and 2nd finer portion). The needed calculations associated with sieving the 2nd coarser portion and associated components are given below.

12.6.2.1 *Percent Passing, 2nd Coarser Portion*—Calculate the percent passing each *Nth* sieve in the 2nd coarser sieve set as follows:

$$2^{nd}CP,PP_N = 1^{st}CSCF \times 2^{nd}CP,\ FPP_N = 1^{st}CSCF\left(1 - \left(2^{nd}CP,CMR_N/SubS,M_d\right)\right) \tag{9}$$

where:

$2^{nd}CP,PP_N$ = specimen's percent passing the *Nth* sieve in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %,

$1^{st}CSCF$ = 1st composite sieving correction factor, which is equal to the percent passing the designated separating sieve size in the 1st coarser sieve set while sieving the coarser portion of the specimen, %,

$2^{nd}CP,\ FPP_N$ = 2nd coarser portion's fractional percent passing the *Nth* sieve in the 2nd coarser sieve set, decimal (*not in %*), and

$2^{nd}CP,CMR_N$ = 2nd coarser portion's fractional cumulative mass retained on *Nth* sieve in the 2nd coarser sieve set, g or kg.

12.6.2.2 *2nd Coarser Portion, Composite Sieving Correction Factor (2ndCSCF)*—The *2ndCSCF* is equal to the percent passing the 2nd designated separating sieve size in the 2nd coarser sieve set (that is, the last/bottom sieve in that set) while sieving the coarser portion of the 1st subspecimen. This value, $2^{nd}CP,PP_{last}$, shall be calculated and recorded to at least one more digit than required (nearest 0.1 %) to reduce rounding errors.

12.6.2.3 *2nd Coarser Portion, Acceptable Loss on Sieving and Washing*—The calculation and acceptance criterion for the 2nd coarser portion are the same as covered above, see 12.5.1.3, except the prefix 2nd is added to the applicable terms and symbols, and the dry mass of the specimen is replaced by the dry mass of the 1st subspecimen, as shown in the following equation:

$$2^{nd}CP_L = 100\left(\left(\left(2^{nd}CP,M,_d - 2^{nd}CP_wM_d\right) + 2^{nd}CP,MR_{pan}\right)/1^{st}SubS,M_d\right) \tag{10}$$

where:

$2^{nd}CP_L$ = percent of the 2nd coarser portion lost during washing and dry sieving, %,

$2^{nd}CP,M,_d$ = dry mass of the 2nd coarser portion, g or kg,

$2^{nd}CP_wM_d$ = dry mass of the 2nd coarser portion after washing, g or kg, and

$2^{nd}CP,MR_{pan}$ = dry mass retained in the pan after dry sieving the coarser portion, g or kg.

12.6.2.4 *2nd Coarser Portion, Acceptable Fractional Percent Retained*—As covered in 11.6.3.2, there should not be any material retained on the first/top sieve, same size as the designated separating sieve, in the 2nd coarser sieve set; however, when there is, the fractional percent retained shall not exceed 2 % of the dry mass of the 1st subspecimen. Calculate the fractional percent retained on the first sieve as follows:

$$2^{nd}CP,FPR_{first} = 100\left(2^{nd}CP,FCMR_{first}/SubS,M_d\right) \tag{11}$$

where:

$2^{nd}CP,FPR_{first}$ = 1st fractional percent retained on the first sieve (sieve size equal to the designated separating sieve) in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %, and

$2^{nd}CP,FCMR_{first}$ = 1st fractional cumulative mass retained on the first sieve in the 2nd coarser sieve set, g or kg. (This mass is actually the mass retained since there is not any sieve above it.)

12.6.2.5 *Percent Passing, Acceptance Criterion*—If material is retained on the designated separating-sieve size in the 2nd coarser sieve set, then there will be two percent passing values for the same sieve size. If this occurs, the percent passing value from the 1st coarser sieve set shall be the accepted value in determining the gradation of the specimen.

12.6.3 *2nd Subspecimen*—The needed calculations associated with sieving the 2nd subspecimen are given below.

12.6.3.1 *Percent Passing, 2nd Subspecimen*—Calculate the percent passing each *Nth* sieve in the finer sieve set as follows:

$$2^{nd}SubS,PP_N = 2^{nd}CSCF \times 2^{nd}SubS,FPP_N = 2^{nd}CSCF\left(1 - \left(2^{nd}SubS,FCMR_N / 2^{nd}SubS,M_d\right)\right) \qquad (12)$$

where:

$2^{nd}SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set while sieving the 2nd subspecimen, %,

$2^{nd}CSCF$ = 2nd composite sieving correction factor, which is equal to the percent passing the 2nd designated separating sieve size in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %,

$2^{nd}SubS,FPP_N$ = 2nd subspecimen's fractional percent passing the *Nth* sieve in the finer sieve set, decimal (not in %),

$2^{nd}SubS,FCMR_N$ = 2nd subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg, and

$2^{nd}SubS,M_d$ = dry mass of the 2nd subspecimen, g or kg.

12.6.3.2 *2nd Subspecimen, Acceptable Fractional Percent Retained*—As covered in 11.6.2.2, there should not be any material retained on the first/top sieve, same size as the designated separating sieve, in the finer sieve set; however, when there is, the fractional percent retained shall not exceed 2 %. Calculate the fractional percent retained on the first sieve as follows:

$$2^{nd}SubS,FPR_{first} = 100\left(2^{nd}SubS,FCMR_{first} / 2^{nd}SubS,M_d\right) \qquad (13)$$

where:

$2^{nd}SubS,FPR_{first}$ = 2nd fractional percent retained on the first sieve (sieve size equal to the 2nd designated separating sieve) in the finer sieve set while sieving the 2nd subspecimen, %, and

$2^{nd}SubS,FCMR_{first}$ = 2nd fractional cumulative mass retained on the first sieve in the finer sieve set while sieving the 2nd subspecimen, g or kg. (This mass is actually the mass retained since there is not any sieve above it.)

12.6.3.3 *Percent Passing, Acceptance Criterion*—If material is retained on the 2nd designated separating-sieve size in the finer sieve set while sieving the 2nd subspecimen, then there will be two percent passing values for the same sieve size. If this occurs, the percent passing value from the coarser sieve set shall be the accepted value in determining the gradation of the specimen.

12.6.4 *1st Finer Portion, Percent Passing (optional)*—As mentioned in 9.2.1, there are cases where the gradation of the specimen's 1st finer portion might be necessary, especially when other testing, such as compaction, are performed. In this case, the fractional percent passing the 2nd coarser portion, $2^{nd}CP,FPP_N$ in %, is representative of the percent passing the 1st finer portion, $1^{st}\,FP,PP_N$, up to the 2nd designated separating sieve size. Calculate those values as follows:

$$1^{st}FP,PP_N = 100\left(1 - \left(2^{nd}CP,FCMR_N / SubS,M_d\right)\right) \qquad (14)$$

where:

$1^{st}FP,PP_N$ = 1st finer portion's percent passing the *Nth* sieve in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %.

While the $1^{st}\,FP,PP_N$ calculations associated with the 2nd finer portion or 2nd subspecimen are given below.

12.6.4.1 *2nd Finer Portion, Composite Sieving Correction Factor (optional)*—When the gradation of the 1st finer portion is needed and the 1st subspecimen is separated, then an additional composite sieving correction factor is necessary to convert the fractional percent passing the 2nd subspecimen to a percent passing which is representative of the 1st finer portion. This *CSCF* is identified as *FP,CSCF* and is equal to either the fractional percent passing the 2nd designated separating sieve size in the 2nd coarser sieve set, or the 1st finer portion's percent passing the last/bottom sieve in the 2nd coarser sieve set, FP,PP_{last}, as calculated above (see 12.6.4) and recorded to at least one more digit than required (nearest 0.1%) to reduce rounding errors.

12.6.4.2 *1st Finer Portion, Percent Passing for 2nd Subspecimen (optional)*—In this case, the 2nd fractional percent passing the finer sieve set, $2^{nd}SubS,FPP_N$ in % has to be corrected by the *FP,CSCF* (see 12.6.4.1) to represent the percent passing the finer portion, $1stFP,PP_N$. Calculate those values as follows:

$$1^{st}FP,PP_N = FP,CSCF\left(1 - \left(2^{nd}SubS,FCMR_N / 2^{nd}SubS,M_d\right)\right) \qquad (15)$$

where:

FP,CSCF = 1st finer portion's composite sieving correction factor, which is equal to the finer portion's percent passing the last/bottom sieve in 2nd coarser sieve set,%.

13. Report: Test Data Sheets(s)/Form(s)

13.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.13. If the test results (gradation) are reported in tabular or graphical format for other than the laboratory's data records, then those values have to be representative of the method used (Method A or B). The percent passing values must be rounded to the appropriate percentage before tabulating or plotting; that is, the nearest 1 % and 0.1 % for Method A and B, respectively. However, the laboratory's test data sheet(s)/form(s) do not have to meet this requirement, if the method used (Method A or B) is clearly identified.

13.2 Record as a minimum the following information (data):

13.2.1 Identification of the material being tested, such as project identification, boring number, sample number, depth, and test number.

13.2.2 Name or initials of person performing the test and date(s).

13.2.3 Visual classification of the soil being tested (estimate group name and symbol in accordance with Practice D2487).

13.2.4 Test method used (Method A, or B).

13.2.5 The procedure used to obtain the specimen(s) from the sample, such as moist, air dried, or oven dried, see 1.8 and Section 10.

13.2.6 If any soil or material was excluded from the specimen, describe the excluded material. If any problems were encountered, describe the problems.

13.2.7 Indicate if composite sieving was used and the size of the designated separating sieve(s). If material is retained on the designated separating sieve size in the finer sieve set, then document that the percent retained (PR) does not exceed the 2 % criterion (see 11.5.2.2, Item c and d; 11.6.3.2 and 11.6.4.2, Item c) on sieving those portion(s)).

13.2.8 Indicate if the ultrasonic bath or shaking apparatus or both were used during the dispersion process.

13.2.9 Any prior testing performed on specimen.

13.2.10 All mass measurements (to the appropriate significant digits or better).

13.2.11 Tabulation of percent passing (PP) for each sieve, preferably to either the nearest 1 % or 0.1 % in accordance with Method A or B, respectively, see 13.1. Note this percentage should have an extra digit associated with designated separating sieve sieves.

13.2.12 *(Optional)*—A graph of the percent passing versus log of particle size in mm.

14. Precision and Bias

14.1 *Precision*—Criteria for judging the acceptability of test results obtained by this test method using single sieve-set sieving on SP soil types are presented in 14.1.3 and 14.1.4. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program. In this program, the Moist Procedure, Method A (except two extra digits were recorded) and Single Sieve-Set Sieving procedures were used. The oven-dry mass of the specimen ranged between 97.56 g and 120.83 g, with an average value of 109.88 g and less than 30 % of the mass of the specimen was retained on any given sieve. In addition, some laboratories performed three replicate tests on the SP soil sample provided (triplicate test laboratories), while other laboratories performed a single test (single test laboratories). However, the data was processed twice to obtain a precision statement for both Method A and B. A description of the soil tested is given in 14.1.5. Testing precision may vary due to the specimen preparation procedure (moist, air-dried or oven-dried), the soil's gradation, and variations in the testing method used (Method A or B). If sample variability is assumed to be negligible, the analyses of the sieve data obtained in this program and others clearly indicate the following regarding sieving precision:

(a) Sieving precision cannot be accurately defined for an insignificant sieve (sieve in which 99 percent or more of the soil passes);

(b) Sieving precision is mainly a function of the amount of soil retained on a given sieve and the acceptable range in the size of the openings of a given sieve cloth;

(c) Sieving precision is also effected by sieve overloading, particle shape, and the slope of the gradation curve; and

(d) These items are interconnected in some manner, which has not been determined.

Additionally, judgement is necessary when applying these precision estimates to another soil.

14.1.1 *Precision Data Analysis*—Typically, precision statements include one or two variables per test, therefore, statements are presented in tabular format. However, in a sieve analysis, there are multiple variables (that is, a result for each sieve size) per test, therefore, it was determined that a non-tabular format would be appropriate.

14.1.1.1 As covered in Practices E177 and E691 and for most test methods, precision statements consist of two main components for each set of test results: Single-Operator Results (Within-Laboratory Repeatability) and Interlaboratory Results (Between-Laboratory Reproducibility). In addition, repeatability and reproducibility are composed of three key variables, the average value, the standard deviation (s) and the acceptable range of two results ($d2s$ or 95 % limit). The $d2s$ or 95 % limit is calculated as $1.960\times\sqrt{2}\times s$, as defined by Practice E177.

14.1.1.2 Based on the above, equations were developed to determine the repeatability and reproducibility standard deviation (s_r and s_R, respectively) as a function of the average percent retained on a given sieve ($avgPR_N$) for each set of test results (Method A and B). All values of $avgPR_N$ were less than 30 %. The equations developed are based on the upper bound (a straight line on which or below which all of the data points fall) of s_r or s_R versus $avgPR_N$ relationship, except if an unusually high outlier was noted. Then, using the appropriate s_r or s_R value, the repeatability limit (r) and reproducibility limit (R) can be determined, that is the acceptable range of two results or the $d2s$ or 95 % limit.

14.1.2 *Calculation of Precision*—To compare two test results using single sieve-set sieving and either Method A or B, use the following sequence to determine either the repeatability and reproducibility limit for each *Nth* sieve size of interest.

14.1.2.1 For both reported test results, determine the percent retained on a given *Nth* sieve (PR_N) which is a significant sieve (that is one in which less than 99 % passes or more than 1 % cumulative mass is retained). This PR_N is equal to the percent passing in the previous sieve (PP_{N-1}) less the percent passing for the given *Nth* sieve (PP_N). In this calculation, use the appropriate rounded PP_N value, for Method A to nearest 1 % and for Method B to nearest 0.1 %. This calculation is shown as follows:

$$PR_N = PP_{N-1} - PP_N \tag{16}$$

where:

PR_N = percent retained on *Nth* sieve, using single sieve-set sieving, %,

PP_{N-1} = percent passing the sieve previous to the *Nth* sieve, for Method A to nearest whole % and Method B to nearest 0.1 %, and

PP_N = percent passing the *Nth* sieve, for Method A to nearest whole % and Method B to nearest 0.1 %.

Then average the two values obtained for each *Nth* sieve size, without rounding, to determine the average percent retained for that *Nth* sieve size, $avgPR_N$. This $avgPR_N$ value shall not exceed 30 %. If it does, the precision shall not be determined for any sieve size within that test result (sieve analysis).

14.1.2.2 Use this $avgPR_N$ value and the appropriate precision equation in 14.1.3 or 14.1.4 to determine the repeatability standard deviation (s_r) or reproducibility standard deviation (s_R). Then, multiply this result by 1.960×√2 (or 2.772) and round the result as appropriate, for Method A to nearest 1 % and Method B to nearest 0.1 %. This value is either the Repeatability Limit (*r*) or the Reproducibility Limit (*R*), depending on the s_r or s_R equation used.

14.1.2.3 Determine the absolute (positive) difference between the two PR_N test values (PR_N) and compare it to the appropriate limit, *r* or *R* to see if that difference is acceptable; that is, PR_N is equal to or less than the appropriate *r* or *R* value. For significant sieves only, repeat this process for each pair of results. If there is a non-acceptable value, then both sets of test results shall be checked for any calculation and rounding errors and all sieves involved shall be checked for apparent deviations, for example, weaving defects, creases, wrinkles, foreign matter in the cloth, as covered in Specification E11, Test Method One. If other comparisons of test results continue to obtain non-acceptable values, then the determination of the size distribution of wire cloth openings shall be determined for all sieves involved, in accordance with Specification E11, Test Method Three. A set of example calculations is given in Appendix X2.

14.1.2.4 *Acceptance Criteria*—Duplicate test results (sieve analyses) are considered valid if no more than one sieve size has a non-acceptable value, as determined in 14.1.2.3. If a nonacceptable value is obtained for more than one sieve size, then one or both of the sets of test results (sieve analyses) are non-acceptable.

14.1.3 *Triplicate Test Precision Data (TTPD)*—The precision equations given below are based upon three replicate tests performed by each triplicate test laboratory on samples of an SP-type soil and upon information provided in 14.1 through 14.1.1.2. These equations are to be applied in accordance with 14.1.2. These equations apply specifically to the soil that was tested in the interlaboratory testing program.

14.1.3.1 *TTPD-Method A Repeatability*—This repeatability standard deviation for a given *Nth* sieve size ($As_{r,N}$) is equal to 0 % for $avgPR_N$ values equal to or less than 2 %. For $avgPR_N$ values greater than 2 %, calculate $As_{r,N}$ in % using the following equation:

$$As_{r,N} = 0.022 \times avgPR_N + 0.21 \tag{17}$$

14.1.3.2 *TTPD-Method A Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($As_{R,N}$ in %) is calculated using the following equation:

$$As_{R,N} = 0.073 \times avgPR_N + 0.43 \tag{18}$$

14.1.3.3 *TTPD-Method B Repeatability*—This repeatability standard deviation for a given *Nth* sieve size ($Bs_{r,N}$) is equal to the larger of 0.02 % or that using the following equation:

$$Bs_{r,N} = 0.0197 \times avgPR_N + 0.0055 \tag{19}$$

14.1.3.4 *TTPD-Method B Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($Bs_{R,N}$) is equal to the larger of 0.28 % or that using the following equation:

$$Bs_{R,N} = 0.0821 \times avgPR_N + 0.0110 \tag{20}$$

14.1.4 *Single Test Precision Data (STPD)*—In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test. This is common practice in the design and construction industry. The equations given below are based upon the first test result from the triplicate test laboratories and the single test result from the other laboratories on samples of an SP-type soil and upon information provided in 14.1 through 14.1.1.2. These equations are to be applied in accordance with 14.1.2. The equations presented apply specifically to the soil that was tested in the interlaboratory testing program.

14.1.4.1 *STPD-Method A Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($As_{R,N}$ in %) is calculated using the following equation:

$$As_{R,N} = 0.038 \times avgPR_N + 0.65 \tag{21}$$

14.1.4.2 *STPD-Method B Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($Bs_{R,N}$) is equal to the larger of 0.382 % or that using the following equation:

$$Bs_{R,N} = 0.0462 \times avgPR_N + 0.357 \tag{22}$$

14.1.5 *Soil Type*—Based on the interlaboratory results, the soil used in the program is described below in accordance with Practice D2487. In addition, the local name of the soil is given: SP—Poorly graded sand, SP, 20 % coarse sand, 48 % medium sand, 30 % fine sand, 2 % fines, yellowish brown. Local name—Frederick sand.

14.1.6 *Discussion on Precision:*

14.1.6.1 The *TTPD* presents a rigorous interpretation of triplicate test data in accordance with Practice E691 from pre-qualified laboratories. *STPD* is derived from test data that would represent common practice.

14.1.6.2 It is quite possible that precision data presented for Method B is not as precise as it should be since a larger specimen should have been tested.

14.1.6.3 The precision data presented cannot be accurately applied to coarse-grained soils containing gravel size particles where more than 1 % gravel is contained in the sample/specimen. This statement is based on the precision data presented in Test Method C136, which demonstrated that the sieving precision decreases substantially when gravel specimens are tested versus sand specimens.

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

15. Keywords

15.1 gradation; grain size; particle size; particle-size distribution; sieve analysis; sieving

ANNEXES

(Mandatory Information)

A1. SYMBOLS

$1^{st}CSCF$ = 1^{st} composite sieving correction factor, which is equal to the percent passing the designated separating sieve size in the 1^{st} coarser sieve set while sieving the coarser portion of the specimen, %

$FP,CSCF$ = 1^{st} finer portion's composite sieving correction factor, which is equal to the finer portion's percent passing the last/bottom sieve in 2^{nd} coarser sieve set, %

$1^{st}FP,PP_N$ = 1^{st} finer portion's percent passing the *Nth* sieve in the 2^{nd} coarser sieve set while sieving the coarser portion of the 1^{st} subspecimen, %

$2^{nd}CP,FCMR_N$ = 2^{nd} coarser portion's fractional cumulative mass retained on *Nth* sieve in the 2^{nd} coarser sieve set, g or kg

$2^{nd}CP,FPP_N$ = 2^{nd} coarser portion's fractional percent passing the *Nth* sieve in the 2^{nd} coarser sieve set, decimal (not in %), or in %

$2^{nd}CP,FPR_{first}$ = 1^{st} fractional percent retained on the first sieve (sieve size equal to the designated separating sieve) in the 2^{nd} coarser sieve set while sieving the coarser portion of the 1^{st} subspecimen, %

$2^{nd}CP,M_d$ = dry mass of the 2^{nd} coarser portion, g or kg

$2^{nd}CP,MR_{pan}$ = dry mass retained in the pan after dry sieving the coarser portion, g or kg

$2^{nd}CP,PP_N$ = specimen's percent passing the *Nth* sieve in the 2^{nd} coarser sieve set while sieving the coarser portion of the 1^{st} subspecimen, %

$2^{nd}CP_L$ = percent of the 2^{nd}coarser portion lost during washing and dry sieving, %

$2^{nd}CP_w,M_d$ = dry mass of the 2^{nd} coarser portion after washing, g or kg

$2^{nd}CSCF$ = 2^{nd} composite sieving correction factor, which is equal to the percent passing the 2^{nd} designated separating sieve size in the 2^{nd} coarser sieve set while sieving the coarser portion of the 1^{st} subspecimen, %

$2^{nd}SubS,FCMR_{first}$ = 2^{nd} fractional cumulative mass retained on the first sieve in the finer sieve set while sieving the 2^{nd} subspecimen, g or kg (This mass is actually the mass retained since there is not any sieve above it.)

$2^{nd}SubS,FCMR_N$ = 2^{nd} subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg

$2^{nd}SubS,FPP_N$ = 2^{nd} subspecimen's fractional percent passing the *Nth*th sieve in the finer sieve set, decimal (not in %) or in %

$2^{nd}SubS,FPR_{first}$ = 2^{nd} fractional percent retained on the first sieve (sieve size equal to the 2^{nd} designated separating sieve) in the finer sieve set while sieving the 2^{nd} subspecimen, %

$2^{nd}SubS,M_d$ = dry mass of the 2^{nd} subspecimen, g or kg

$2^{nd}SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set while sieving the 2^{nd} subspecimen, %

AASHTO = American Association of State Highway and Transportation Officials

AMRL = AASHTO Materials Reference Laboratory

$As_{r,N}$ = Method A repeatability standard deviation for a given *Nth* sieve

$As_{R,N}$ = Method A reproducibility standard deviation for a given *Nth* sieve

$avgPR_N$ = average of two percent retained values on the *Nth* sieve between two laboratories or within laboratory

$Bs_{r,N}$ = Method B repeatability standard deviation for a given *Nth* sieve

$Bs_{R,N}$ = Method B reproducibility standard deviation for a given *Nth* sieve

CMR_N = cumulative mass retained on the th sieve; that is, the mass of material retained on the *Nth* sieve and those above it, g or kg

CMR_{N-1} = cumulative mass retained on the sieve above the *Nth* sieve, g or kg

CP,CMR_N = coarser portion's cumulative mass retained on the *Nth* sieve in the coarser sieve set, g or kg

CP,M_d = dry mass of the coarser portion, g or kg

CP,MR_{pan} = dry mass retained in the pan after dry sieving the coarser portion, g or kg

CP,PP_N = specimen's percent passing the *Nth* sieve in the coarser sieve set while sieving the coarser portion of the specimen, %

CP_L = percent of the coarser portion lost during washing and dry sieving, %
CP_w,M_d = dry mass of the coarser portion after washing, g or kg
$CSCF$ = composite sieving correction factor
$d2s$ = acceptable range of two results (or 95 % limit) calculated as $1.960\times\sqrt{2}\times s$, as defined by Practice E177
FP,M_m = moist or air-dried mass of the finer portion, g or kg
FP,PP_N = finer portion's percent passing the *Nth* sieve, %
MR_N = mass retained on the *Nth* sieve, g or kg
PP = percent passing, %
PP_N = percent passing the *Nth* sieve, %
PR = percent retained, %
s = standard deviation, units of calculation
S,M_d = dry mass of the specimen, g or kg
s_r = repeatability (within laboratory) standard deviation
s_R = reproducibility (between laboratories) standard deviation
$STPD$ = single test precision data
$SubS,FCMR_{first}$ = fractional cumulative mass retained on the first sieve in the 2nd coarser sieve set, g or kg (This mass is actually the mass retained since there is not any sieve above it.)
$SubS,FCMR_{first}$ = fractional cumulative mass retained on the first sieve in the finer sieve set, g or kg (This mass is actually the mass retained since there is not any sieve above it.)
$SubS,FCMR_N$ = subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg
$SubS,FCPR_{first}$ = fractional cumulative percent retained on the first sieve (sieve size equal to the designated separating sieve) in the finer sieve set, %
$SubS,FPP_N$ = subspecimen's fractional percent passing the *Nth* sieve in the finer sieve set, decimal (not in %) or in %
$SubS,M_d$ = dry mass of the subspecimen, g or kg
$SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set, %
$TTPD$ = triplicate test precision data
w_{fp} = water content of the finer portion, %
ΔPP_N = absolute (positive) difference between two PR_N test values (within laboratory or between laboratories)

A2. SAMPLE TO SPECIMEN SPLITTING/REDUCTION METHODS

A2.1 *General*—It is possible that bulk samples, jar samples, or specimens from prior testing may be significantly larger than needed for a sieve analysis. To reduce these samples to an appropriate specimen size, several techniques are applicable. The type and sizes of particles contained within the sample will influence the specimen processing and selection. Practice C702 provides details of mechanical splitting, quartering and miniature stockpile sampling for aggregate. When testing soils, these methods are adapted based on soil type. The goal is to have the specimen accurately represent the sample. Loss of particles (finer sizes) and segregation of particles are the most common problems when obtaining a specimen and most frequently occur during low or no moisture situations. Likewise, it is difficult to obtain a representative specimen if the sample contains excess or free water.

A2.1.1 *Mechanical Splitting*—This method is used only on dry samples that contain little or no fines. If the sample appears to create dust during the splitting, the sample has lost fines and mechanical splitting should be limited. For all soils, the splitting method may be used a maximum of two times, see 10.4.4. The splitter or riffle box shall conform to 6.9. The sample is placed in a feeder pan and distributed evenly throughout the pan. Pour the sample from the pan, into the hopper/feed chute, open the gate, if applicable, and allow the specimen to feed into the two catch pans. This process can be repeated once.

A2.1.2 *Quartering*—This method can be used on moist samples (see Practice C702), however it is often difficult and requires effort to collect all the finer particles. The sample is placed on a clean nonporous smooth surface (floor or sheet) and is thoroughly mixed using shovels, scoops, or spoons as appropriate for the sample size. Then, mound the sample into a cone-type shape by placing each shovelful or scoop on top of the preceding material. Flatten the cone to form a disk. Using a straight edge, or knife, divide the disk into wedge-shaped quarters. Remove two opposing quarters. Remix the remaining two quarters. Repeat this process until the mass of the remaining two quarters is greater than the minimum mass requirement, but less than 1.5 times the minimum mass requirement. If the sample is in a dry state, then this process can be repeated only once.

A2.1.3 *Miniature Stockpile Sampling*—This method is only applicable for moist samples. The sample is placed on a clean nonporous smooth surface and is thoroughly mixed using shovels, scoops or spoons as appropriate for the sample size. Then, mound the sample into a cone-type shape by placing each shovel full or scoop on top of the preceding shovel full or scoop of material. If desired, flatten the cone to form a disk. Using a scoop, obtain material from at least five locations in the pile. Scoop until the mass of the specimen is greater than the minimum mass requirement. Do not attempt to take very small scoops in order to obtain an exact mass because this could skew the particle-size distribution. In some cases, when working with relatively small samples and materials finer than the ⅜-in. (9.5-mm) sieve, a single scoop should be adequate.

A2.2 *Sample Processing Recommendations Based on Soil Type*—Estimate the soil classification using D2488. Then, use the following recommendations in conjunction with those given in Sections 9 and 10.

A2.2.1 *Clean Gravel (GW, GP) and Clean Sand (SW, SP)*—The condition of this sample should be moist or dry (air or oven). Either moist or dry (air or dry) processing can be used, although moist processing is probably easier, especially for sandy soils. The sample will require composite sieving if there are gravel size particles, see 10.3. If sample splitting is necessary to obtain a specimen, the sample can be mechanically split (dry processing), quartered (moist or dry processing), or sampled from a miniature stockpile (moist processing), to obtain a specimen. Refer to 10.4.1 (moist), 10.4.2 (air dried) or 10.4.3 (oven dried) for additional guidance.

A2.2.2 *Gravel with Fines (GM, GC, GC-GM, GW-GM, GW-GC, GP-GM, GP-GC)*—These soil types are the most difficult to obtain a gradation. The difficulty increases with increasing plasticity of the fines. The sample/specimen *will* require composite sieving due to the gravel size particles, see 10.3. Some of the fines may adhere to the gravel particles. Moist processing can be difficult, but with dry processing, it is often impossible or impractical to obtain a representative specimen. If the fine material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. If sample reduction is necessary, the sample can be quartered or sampled from a miniature stockpile to obtain a specimen. Then, it can be processed over the designated separating sieve as described in 10.5.2.

A2.2.3 *Sand with Silt Fines (SW-SM, SP-SM, SM)*—These soils should be processed in a moist state, see 10.5.1. The sample may require composite sieving if there is a wide range of particle sizes. The fines will frequently segregate from the sand and care must be taken to obtain a representative specimen. Moist processing will reduce the probability of segregation of fines. If sample reduction to obtain a specimen is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2

A2.2.4 *Sand with Clay and Silt Fines or Clay Fines (SW-SC, SP-SC, SC, SC-SM) and Clays (CL, CL-ML, CH)*—These soils are processed in a moist state. If the fine material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. Complete drying of these materials usually creates hard lumps that can be difficult to disperse or break apart, see 10.5.2. The sample may require composite sieving if there is gravel size particles, see 10.3. If sample reduction is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2.

A2.2.5 *Silts with Sand or Gravel, or Both (ML, MH)*—These soils are processed in a moist state. If the fine material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. The material may contain large particles and therefore require composite sieving, see 10.3. If sample reduction is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2.

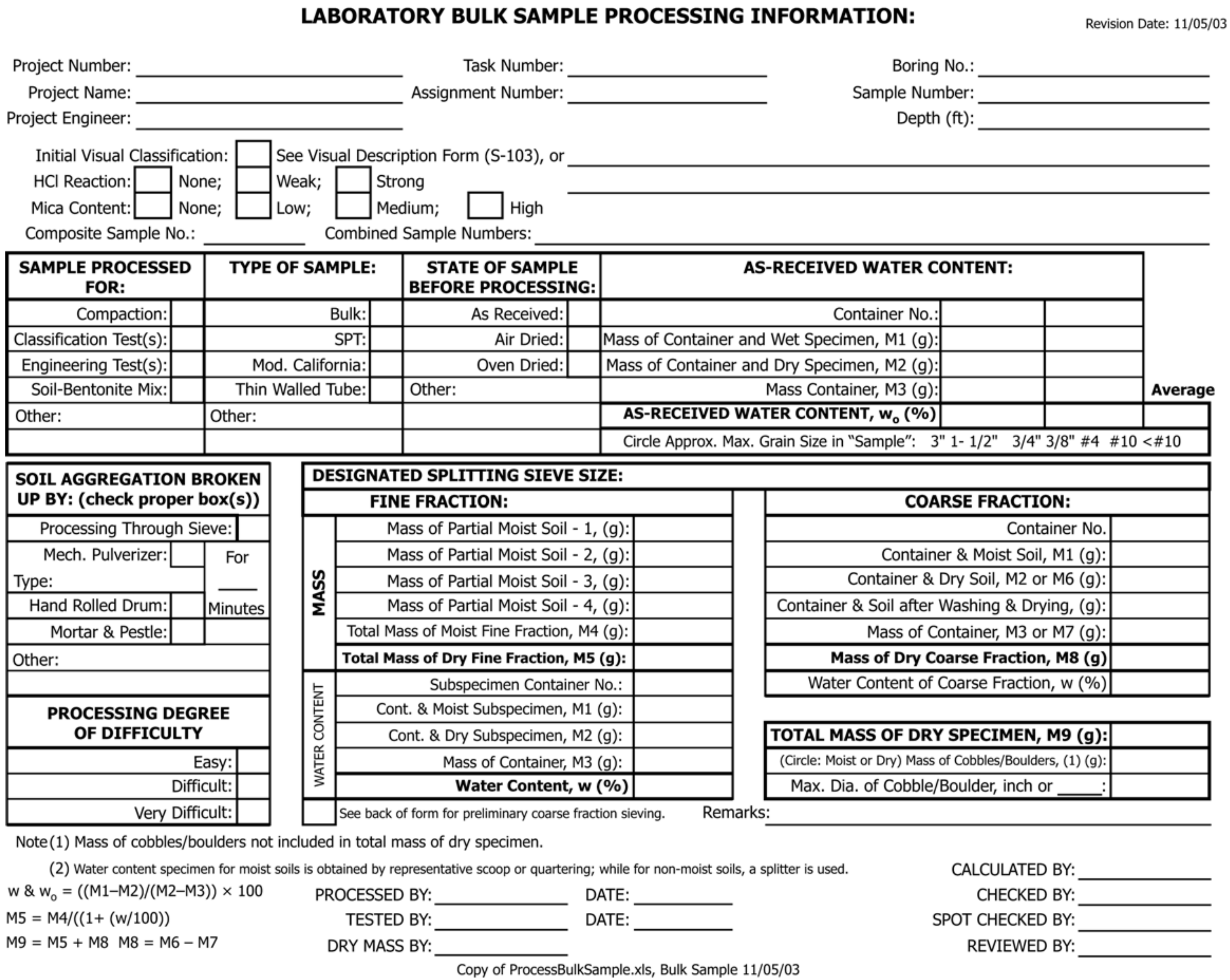
A2.2.6 *Organic Soils with Sand or Gravel, or Both (OL, OH)*—The organic soils are processed moist. If the material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. The material may contain large particles and therefore require composite sieving. Some of the organic material may easily break apart during processing. If sample reduction is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2.

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE TEST DATA SHEETS/FORMS

X1.1 *General*—Two example data sheets are presented. Fig. X1.1 presents a data sheet that may be used in processing bulk samples in which a sieve-analysis specimen, or other testing, or both is needed. Fig. X1.2 presents a data sheet that may be used to record the sieve analysis data.



LABORATORY BULK SAMPLE PROCESSING INFORMATION:

Revision Date: 11/05/03

Project Number: ____________ Task Number: ____________ Boring No.: ____________
Project Name: ____________ Assignment Number: ____________ Sample Number: ____________
Project Engineer: ____________ Depth (ft): ____________

Initial Visual Classification: ☐ See Visual Description Form (S-103), or ____________
HCl Reaction: ☐ None; ☐ Weak; ☐ Strong ____________
Mica Content: ☐ None; ☐ Low; ☐ Medium; ☐ High
Composite Sample No.: ______ Combined Sample Numbers: ____________

SAMPLE PROCESSED FOR:		TYPE OF SAMPLE:		STATE OF SAMPLE BEFORE PROCESSING:		AS-RECEIVED WATER CONTENT:			
Compaction:		Bulk:		As Received:		Container No.:			
Classification Test(s):		SPT:		Air Dried:		Mass of Container and Wet Specimen, M1 (g):			
Engineering Test(s):		Mod. California:		Oven Dried:		Mass of Container and Dry Specimen, M2 (g):			
Soil-Bentonite Mix:		Thin Walled Tube:		Other:		Mass Container, M3 (g):			**Average**
Other:		Other:				**AS-RECEIVED WATER CONTENT, w_o (%)**			
						Circle Approx. Max. Grain Size in "Sample": 3" 1- 1/2" 3/4" 3/8" #4 #10 <#10			

SOIL AGGREGATION BROKEN UP BY: (check proper box(s))		
Processing Through Sieve:		
Mech. Pulverizer:		For ____ Minutes
Type:		
Hand Rolled Drum:		
Mortar & Pestle:		
Other:		
PROCESSING DEGREE OF DIFFICULTY		
Easy:		
Difficult:		
Very Difficult:		

DESIGNATED SPLITTING SIEVE SIZE:

	FINE FRACTION:	
MASS	Mass of Partial Moist Soil - 1, (g):	
	Mass of Partial Moist Soil - 2, (g):	
	Mass of Partial Moist Soil - 3, (g):	
	Mass of Partial Moist Soil - 4, (g):	
	Total Mass of Moist Fine Fraction, M4 (g):	
	Total Mass of Dry Fine Fraction, M5 (g):	
WATER CONTENT	Subspecimen Container No.:	
	Cont. & Moist Subspecimen, M1 (g):	
	Cont. & Dry Subspecimen, M2 (g):	
	Mass of Container, M3 (g):	
	Water Content, w (%)	
☐	See back of form for preliminary coarse fraction sieving.	

COARSE FRACTION:	
Container No.	
Container & Moist Soil, M1 (g):	
Container & Dry Soil, M2 or M6 (g):	
Container & Soil after Washing & Drying, (g):	
Mass of Container, M3 or M7 (g):	
Mass of Dry Coarse Fraction, M8 (g)	
Water Content of Coarse Fraction, w (%)	

TOTAL MASS OF DRY SPECIMEN, M9 (g):	
(Circle: Moist or Dry) Mass of Cobbles/Boulders, (1) (g):	
Max. Dia. of Cobble/Boulder, inch or _____:	

Remarks: ____________

Note (1) Mass of cobbles/boulders not included in total mass of dry specimen.

(2) Water content specimen for moist soils is obtained by representative scoop or quartering; while for non-moist soils, a splitter is used.

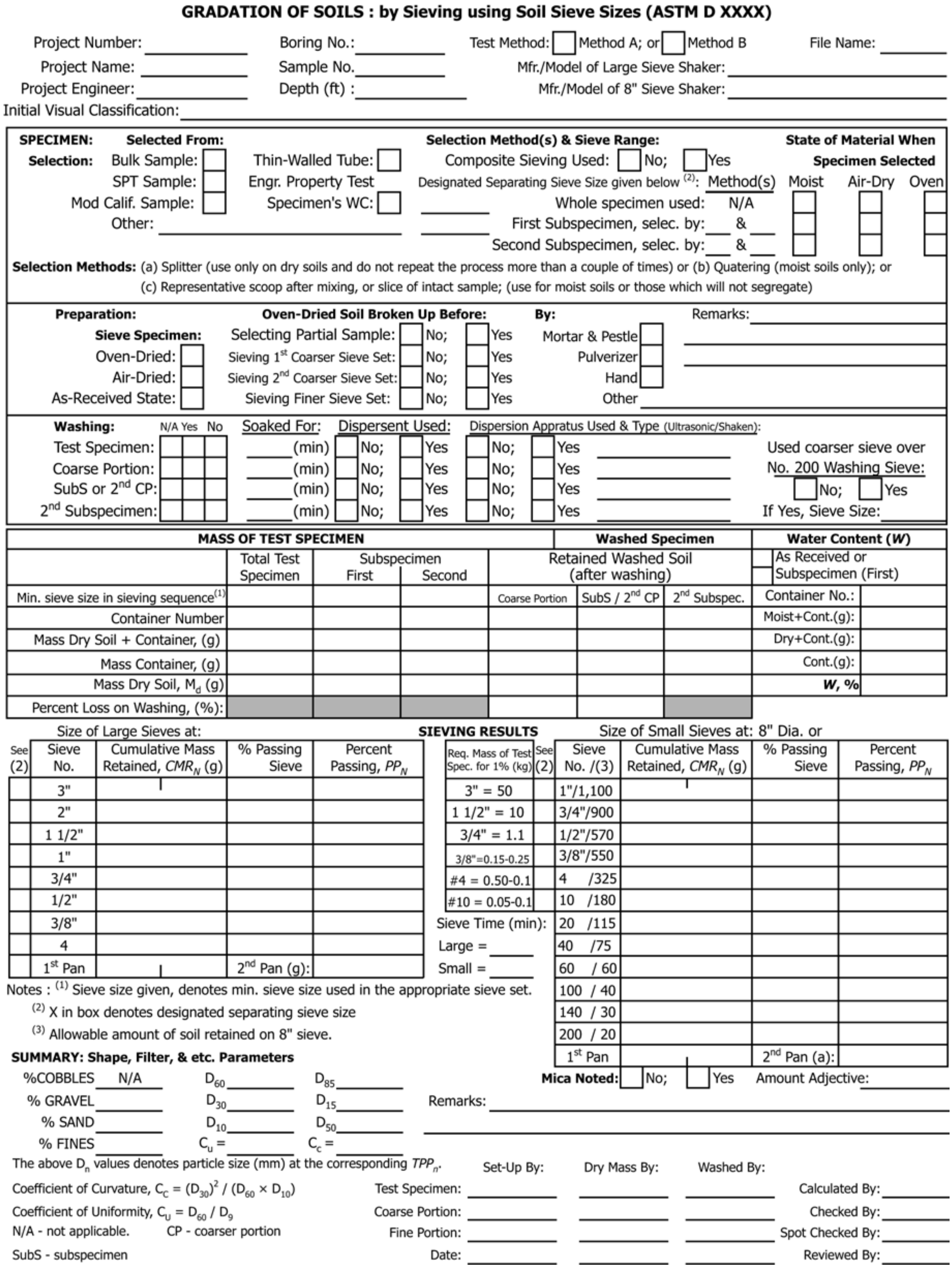
w & w_o = ((M1–M2)/(M2–M3)) × 100
M5 = M4/((1+ (w/100))
M9 = M5 + M8 M8 = M6 – M7

PROCESSED BY: ____________ DATE: ____________
TESTED BY: ____________ DATE: ____________
DRY MASS BY: ____________

CALCULATED BY: ____________
CHECKED BY: ____________
SPOT CHECKED BY: ____________
REVIEWED BY: ____________

Copy of ProcessBulkSample.xls, Bulk Sample 11/05/03

FIG. X1.1 Example Bag Sample Processing Data Sheet



GRADATION OF SOILS : by Sieving using Soil Sieve Sizes (ASTM D XXXX)

Project Number: ____________ Boring No.: __________ Test Method: ☐ Method A; or ☐ Method B File Name: ________
Project Name: ____________ Sample No. __________ Mfr./Model of Large Sieve Shaker: ____________________
Project Engineer: ____________ Depth (ft) : ____________ Mfr./Model of 8" Sieve Shaker: ____________________
Initial Visual Classification: ____

SPECIMEN: Selected From: **Selection Method(s) & Sieve Range:** **State of Material When**
Selection: Bulk Sample: ☐ Thin-Walled Tube: ☐ Composite Sieving Used: ☐ No; ☐ Yes **Specimen Selected**
SPT Sample: ☐ Engr. Property Test Designated Separating Sieve Size given below $^{(2)}$: Method(s) Moist Air-Dry Oven
Mod Calif. Sample: ☐ Specimen's WC: ☐ ________ Whole specimen used: N/A ☐ ☐ ☐
Other: ______________________________ ________ First Subspecimen, selec. by: ___ & ___ ☐ ☐ ☐
Second Subspecimen, selec. by: ___ & ___ ☐ ☐ ☐

Selection Methods: (a) Splitter (use only on dry soils and do not repeat the process more than a couple of times) or (b) Quatering (moist soils only); or (c) Representative scoop after mixing, or slice of intact sample; (use for moist soils or those which will not segregate)

Preparation: **Oven-Dried Soil Broken Up Before:** **By:** Remarks: ____________________
Sieve Specimen: Selecting Partial Sample: ☐ No; ☐ Yes Mortar & Pestle ☐ ____________________
Oven-Dried: ☐ Sieving 1^{st} Coarser Sieve Set: ☐ No; ☐ Yes Pulverizer ☐ ____________________
Air-Dried: ☐ Sieving 2^{nd} Coarser Sieve Set: ☐ No; ☐ Yes Hand ☐
As-Received State: ☐ Sieving Finer Sieve Set: ☐ No; ☐ Yes Other ____________________

Washing:	N/A	Yes	No	Soaked For:	Dispersent Used:		Dispersion Appratus Used & Type (Ultrasonic/Shaken):		
Test Specimen:	☐	☐	☐	_____(min)	☐ No;	☐ Yes	☐ No;	☐ Yes	____________
Coarse Portion:	☐	☐	☐	_____(min)	☐ No;	☐ Yes	☐ No;	☐ Yes	____________
SubS or 2^{nd} CP:	☐	☐	☐	_____(min)	☐ No;	☐ Yes	☐ No;	☐ Yes	____________
2^{nd} Subspecimen:	☐	☐	☐	_____(min)	☐ No;	☐ Yes	☐ No;	☐ Yes	____________

Used coarser sieve over No. 200 Washing Sieve: ☐ No; ☐ Yes
If Yes, Sieve Size: ________

MASS OF TEST SPECIMEN				**Washed Specimen**			**Water Content (*W*)**	
	Total Test Specimen	Subspecimen		Retained Washed Soil (after washing)			☐ As Received or ☐ Subspecimen (First)	
		First	Second					
Min. sieve size in sieving sequence$^{(1)}$				Coarse Portion	SubS / 2^{nd} CP	2^{nd} Subspec.	Container No.:	
Container Number							Moist+Cont.(g):	
Mass Dry Soil + Container, (g)							Dry+Cont.(g):	
Mass Container, (g)							Cont.(g):	
Mass Dry Soil, M_d (g)							***W*, %**	
Percent Loss on Washing, (%):								

SIEVING RESULTS

Size of Large Sieves at:

See (2)	Sieve No.	Cumulative Mass Retained, CMR_N (g)	% Passing Sieve	Percent Passing, PP_N
	3"			
	2"			
	1 1/2"			
	1"			
	3/4"			
	1/2"			
	3/8"			
	4			
	1^{st} Pan		2^{nd} Pan (g):	

Size of Small Sieves at: 8" Dia. or

Req. Mass of Test Spec. for 1% (kg)	See (2)	Sieve No. /(3)	Cumulative Mass Retained, CMR_N (g)	% Passing Sieve	Percent Passing, PP_N
3" = 50		1"/1,100			
1 1/2" = 10		3/4"/900			
3/4" = 1.1		1/2"/570			
3/8"=0.15-0.25		3/8"/550			
#4 = 0.50-0.1		4 /325			
#10 = 0.05-0.1		10 /180			
Sieve Time (min):		20 /115			
Large = _____		40 /75			
Small = _____		60 / 60			
		100 / 40			
		140 / 30			
		200 / 20			
		1^{st} Pan		2^{nd} Pan (a):	

Notes : $^{(1)}$ Sieve size given, denotes min. sieve size used in the appropriate sieve set.
$^{(2)}$ X in box denotes designated separating sieve size
$^{(3)}$ Allowable amount of soil retained on 8" sieve.

Mica Noted: ☐ No; ☐ Yes Amount Adjective: ________

SUMMARY: Shape, Filter, & etc. Parameters

%COBBLES N/A D_{60} ________ D_{85} ________
% GRAVEL ________ D_{30} ________ D_{15} ________
% SAND ________ D_{10} ________ D_{50} ________
% FINES ________ C_u = ________ C_c = ________

Remarks: ____

The above D_n values denotes particle size (mm) at the corresponding TPP_n.
Coefficient of Curvature, $C_C = (D_{30})^2 / (D_{60} \times D_{10})$
Coefficient of Uniformity, $C_U = D_{60} / D_9$
N/A - not applicable. CP - coarser portion
SubS - subspecimen

	Set-Up By:	Dry Mass By:	Washed By:		
Test Specimen:	________	________	________	Calculated By:	________
Coarse Portion:	________	________	________	Checked By:	________
Fine Portion:	________	________	________	Spot Checked By:	________
Date:	________	________	________	Reviewed By:	________

FIG. X1.2 Example Gradation of Soils Data Sheet

X2. PRECISION: EXAMPLE CALCULATIONS

X2.1 *General*—Two sets of example calculations are provided for comparing test results (sieve analyses) obtained within and between laboratories. The first example, Fig. X2.1, presents results for sieve analyses using Method A (data to the nearest whole percentage) and based upon the triplicate test precision data. The second example, Fig. X2.2, presents results for sieve analyses using Method B (data to the nearest 0.1 %) and based upon the triplicate and single test precision data.

Method A - Example Calculations for Within Laboratory Precision (Repeatability)
Based Upon Triplicate Test Precision Data

Equation for Repeatability Standard Deviation: $As_{r,n} = 0.022 \times avgPR_n + 0.21$ or 0 if $avgPR_n$ is equal to or less than 2%

Alternate Sieve Size	Lab 14 Test Results Percent Passing, PP_n Trial Number		Percent Retained, PR_n Trial Number		Average Percent Retained, $avgPR_n$	Method A - Repeatability Standard Deviation, $As_{r,n}$	Repeatability Limit, r (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus r	Acceptability: ΔPR_n =or< r Yes or No
	1	2	1	2						
No.4	100	100	0	0	N/A	N/A	N/A	N/A	N/A	N/A
10	80	81	20	19	19.5	0.639	2	1	–1	Yes
20	59	61	21	20	20.5	0.661	2	1	–1	Yes
40	33	33	26	28	27	0.804	2	2	0	Yes
60	10	11	23	22	22.5	0.705	2	1	–1	Yes
100	4	4	6	7	6.5	0.353	1	1	0	Yes
140	3	3	1	1	1	0	0	0	0	Yes
200	2	2	1	1	1	0	0	0	0	Yes
									Precision Acceptance:	Valid Duplicates

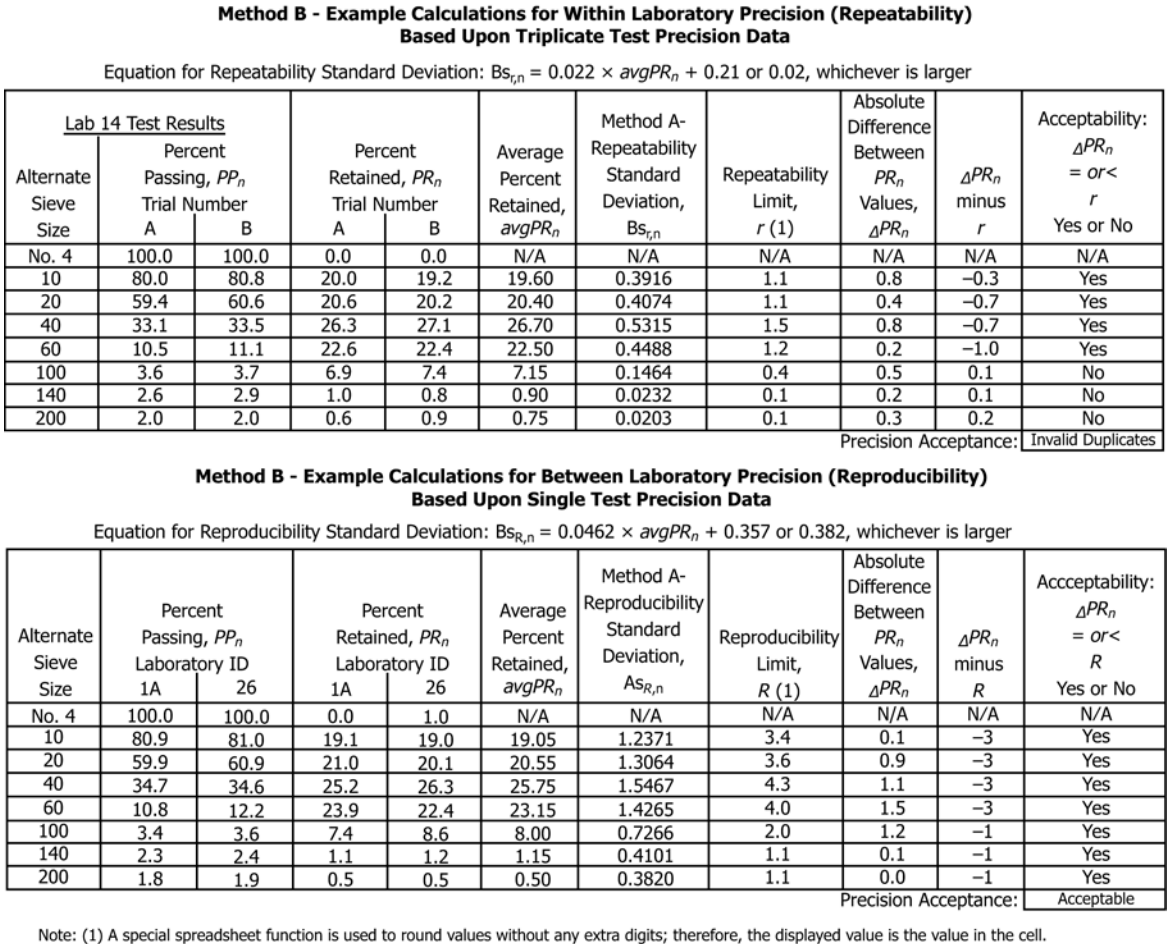
Method A - Example Calculations for Between Laboratory Precision (Reproducibility)
Based Upon Triplicate Test Precision Data

Equation for Reproducibility Standard Deviation: $As_{r,n} = 0.073 \times avgPR_n + 0.43$

Alternate Sieve Size	Percent Passing, PP_n Laboratory ID		Percent Retained, PR_n Laboratory ID		Average Percent Retained, $avgPR_n$	Method A - Reproducibility Standard Deviation, $As_{R,n}$	Reproducibility Limit, R (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus R	Acceptability: ΔPR_n =or< R Yes or No
	1A	23A (2)	1A	23A						
No.4	100	100	0	1	N/A	N/A	N/A	N/A	N/A	N/A
10	81	81	19	19	19	1.817	5	0	–5	Yes
20	60	58	21	23	22	2.036	6	2	–4	Yes
40	35	27	25	31	28	2.474	7	6	–1	Yes
60	11	9	24	18	21	1.963	5	6	1	No
100	3	3	8	6	7	0.941	3	2	–1	Yes
140	2	2	1	1	1	0.503	1	0	–1	Yes
200	2	0	0	2	1	0.503	1	2	1	No
									Precision Acceptance:	Non-acceptable

Note: (1) A special spreadsheet function is used to round values without any extra digits; therefore, the displayed value is the value in the cell.
(2) Some data was adjusted to create non-acceptable data.

FIG. X2.1 Precision Example Calculations: Method A—Triplicate Test Precision Data



Method B - Example Calculations for Within Laboratory Precision (Repeatability)
Based Upon Triplicate Test Precision Data

Equation for Repeatability Standard Deviation: $Bs_{r,n} = 0.022 \times avgPR_n + 0.21$ or 0.02, whichever is larger

Lab 14 Test Results Alternate Sieve Size	Percent Passing, PP_n Trial Number A	Percent Passing, PP_n Trial Number B	Percent Retained, PR_n Trial Number A	Percent Retained, PR_n Trial Number B	Average Percent Retained, $avgPR_n$	Method A-Repeatability Standard Deviation, $Bs_{r,n}$	Repeatability Limit, r (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus r	Acceptability: ΔPR_n = or< r Yes or No
No. 4	100.0	100.0	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A
10	80.0	80.8	20.0	19.2	19.60	0.3916	1.1	0.8	–0.3	Yes
20	59.4	60.6	20.6	20.2	20.40	0.4074	1.1	0.4	–0.7	Yes
40	33.1	33.5	26.3	27.1	26.70	0.5315	1.5	0.8	–0.7	Yes
60	10.5	11.1	22.6	22.4	22.50	0.4488	1.2	0.2	–1.0	Yes
100	3.6	3.7	6.9	7.4	7.15	0.1464	0.4	0.5	0.1	No
140	2.6	2.9	1.0	0.8	0.90	0.0232	0.1	0.2	0.1	No
200	2.0	2.0	0.6	0.9	0.75	0.0203	0.1	0.3	0.2	No
									Precision Acceptance:	Invalid Duplicates

Method B - Example Calculations for Between Laboratory Precision (Reproducibility)
Based Upon Single Test Precision Data

Equation for Reproducibility Standard Deviation: $Bs_{R,n} = 0.0462 \times avgPR_n + 0.357$ or 0.382, whichever is larger

Alternate Sieve Size	Percent Passing, PP_n Laboratory ID 1A	Percent Passing, PP_n Laboratory ID 26	Percent Retained, PR_n Laboratory ID 1A	Percent Retained, PR_n Laboratory ID 26	Average Percent Retained, $avgPR_n$	Method A-Reproducibility Standard Deviation, $As_{R,n}$	Reproducibility Limit, R (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus R	Accceptability: ΔPR_n = or< R Yes or No
No. 4	100.0	100.0	0.0	1.0	N/A	N/A	N/A	N/A	N/A	N/A
10	80.9	81.0	19.1	19.0	19.05	1.2371	3.4	0.1	–3	Yes
20	59.9	60.9	21.0	20.1	20.55	1.3064	3.6	0.9	–3	Yes
40	34.7	34.6	25.2	26.3	25.75	1.5467	4.3	1.1	–3	Yes
60	10.8	12.2	23.9	22.4	23.15	1.4265	4.0	1.5	–3	Yes
100	3.4	3.6	7.4	8.6	8.00	0.7266	2.0	1.2	–1	Yes
140	2.3	2.4	1.1	1.2	1.15	0.4101	1.1	0.1	–1	Yes
200	1.8	1.9	0.5	0.5	0.50	0.3820	1.1	0.0	–1	Yes
									Precision Acceptance:	Acceptable

Note: (1) A special spreadsheet function is used to round values without any extra digits; therefore, the displayed value is the value in the cell.

FIG. X2.2 Precision Example Calculations: Method B—Triplicate and Single Test Precision Data

Designation: D7928 – 17

Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis[1]

This standard is issued under the fixed designation D7928; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the quantitative determination of the distribution of particle sizes of the fine-grained portion of soils. The sedimentation or hydrometer method is used to determine the particle-size distribution (gradation) of the material that is finer than the No. 200 (75-µm) sieve and larger than about 0.2-µm. The test is performed on material passing the No. 10 (2.0-mm) or finer sieve and the results are presented as the mass percent finer versus the log of the particle diameter.

1.2 This method can be used to evaluate the fine-grained fraction of a soil with a wide range of particle sizes by combining the sedimentation results with a sieve analysis resulting in the complete gradation curve. The method can also be used when there are no coarse-grained particles or when the gradation of the coarse-grained material is not required or not needed.

NOTE 1—The significant digits recorded in this test method preclude obtaining the grain size distribution of materials that do not contain a significant amount of fines. For example, clean sands will not yield detectable amounts of silt and clay sized particles, and therefore should not be tested with this method. The minimum amount of fines in the sedimentation specimen is 15 g.

1.3 When combining the results of the sedimentation and sieve tests, the procedure for obtaining the material for the sedimentation analysis and calculations for combining the results will be provided by the more general test method, such as Test Methods D6913 (Note 2).

NOTE 2—Subcommittee D18.03 is currently developing a new test method "Test Method for Particle-Size Analysis of Soils Combining the Sieve and Sedimentation Techniques."

1.4 The terms "soil" and "material" are used interchangeably throughout the standard.

1.5 The sedimentation analysis is based on the concept that larger particles will fall through a fluid faster than smaller particles. Stokes' Law gives a governing equation used to determine the terminal velocity of a spherical particle falling through a stationary liquid. The terminal velocity is proportional to the square of the particle diameter. Therefore, particles are sorted by size in both time and position when settling in a container of liquid.

1.5.1 Stokes' Law has several assumptions which are: the particles are spherical and smooth; there is no interference between the particles; there is no difference between the current in the middle of the container and the sides; flow is laminar; and the particles have the same density. These assumptions are applied to soil particles of various shapes and sizes.

1.6 A hydrometer is used to measure the fluid density and determine the quantity of particles in suspension at a specific time and position. The density of the soil-water suspension depends upon the concentration and specific gravity of the soil particles and the amount of dispersant added. Each hydrometer measurement at an elapsed time is used to calculate the percentage of particles finer than the diameter given by Stokes' Law. The series of readings provide the distribution of material mass as a function of particle size.

1.7 This test method does not cover procurement of the sample or processing of the sample prior to obtaining the reduced sample in any detail. It is assumed that the sample is obtained using appropriate methods and is representative of site materials or conditions. It is also assumed that the sample has been processed such that the reduced sample accurately reflects the particle-size distribution (gradation) of this finer fraction of the material.

1.8 *Material Processing*—Material is tested in the moist or as-received state unless the material is received in an air-dried state. The moist preparation method shall be used to obtain a sedimentation test specimen from the reduced sample. Air-dried preparation is only allowed when the material is received in the air-dried state. The method to be used may be specified by the requesting authority; however, the moist preparation method shall be used for referee testing.

1.9 This test method is **not** applicable for the following soils:

1.9.1 Soils containing fibrous peat.

---

[1] This test method 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 May 1, 2017. Published May 2017. Originally approved in 2016. Last previous edition approved in 2016 as D7928 – 16$^{\varepsilon 1}$. DOI: 10.1520/D7928-17

1.9.2 Soils containing less than approximately 5 % of fine-grained material (Note 1).

1.9.3 Soils containing extraneous matter, such as organic solvents, oil, asphalt, wood fragments, or similar items (Note 3).

NOTE 3—If extraneous matter, such as wood, can be easily removed by hand, it is permissible to do so. However, there may be cases where the extraneous matter is being evaluated as part of the material and it should not be removed from the material.

1.9.4 Materials that contain cementitious components, such as cement, fly ash, lime, or other stabilization admixtures.

1.10 This test method may not produce consistent test results within and between laboratories for the following soils. To test these soils, this test method must be adapted and these adaptations documented.

1.10.1 Soils that flocculate during sedimentation. Such materials may need to be treated to reduce salinity or alter the pH of the suspension.

1.10.2 Friable soils in which processing changes the gradation of the soil. Typical examples of these soils are some residual soils, most weathered shales, and some weakly cemented soils.

1.10.3 Soils that will not readily disperse, such as glauconitic clays or some dried plastic clays.

1.11 Samples that are not soils, but are made up of particles may be tested using this method. The applicable sections above should be used in applying this standard.

1.12 *Units*—The values stated in SI units are to be regarded as standard. Except the sieve designations, they are identified using the "alternative" system in accordance with Practice E11, such as 3-in. and No. 200, instead of the "standard" of 75-mm and 75-µm, respectively. Reporting of test results in units other than SI shall not be regarded as non-conformance with this test method. The use of balances or scales recording pounds of mass (lbm) shall not be regarded as nonconformance with this standard.

1.13 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

1.13.1 The procedures used to specify how data are collected/recorded and calculated in the standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of these test methods to consider significant digits used in analysis methods for engineering data.

1.14 *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.*

1.15 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1140 Test Methods for Determining the Amount of Material Finer than 75-µm (No. 200) Sieve in Soils by Washing
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220/D4220M Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D6026 Practice for Using Significant Digits in Geotechnical Data
D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E100 Specification for ASTM Hydrometers
E126 Test Method for Inspection, Calibration, and Verification of ASTM Hydrometers

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *reduced sample, n*—the minus ⅜-in. (9.5-mm) sieve or finer material that has been separated from the sample and then worked to reduce the mass while still having sufficient quantity to meet the minimum mass requirements of Table 1.

3.2.2 *sample, n*—material collected without limitation on the total mass or size range of particles meeting the minimum mass requirements provided in Table 1.

3.2.3 *sedimentation sample, n*—the minus No. 10 (2.0-mm) or finer material that is separated from the reduced sample

---

[2] 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.

TABLE 1 Minimum Dry Mass Requirements

Maximum Particle Size of Material (99% or more passing)		Minimum Dry Mass	Comments on separating and splitting requirements for sample reduction
Sieve Designation	Particle Size, mm		
6 in.	152.4	500 kg	Several separations
3 in.	76.2	70 kg	Several separations
1 in.	25.4	3 kg	At least one separation
¾ in.	19.1	1.3 kg	Most likely one separation
⅜ in.	9.5	165 g	Separation for sedimentation analysis
No. 10	2.0	50 g	Splitting only

using the separation sieve from which the sedimentation specimen and water content are obtained.

3.2.4 *sedimentation specimen, n*—the material obtained from the sedimentation sample having a maximum particle-size no greater than the No. 10 (2.0-mm) sieve to be used in the sedimentation test and in sufficient quantity to satisfy the minimum mass requirements of Table 1.

3.2.5 *separation sieve, n*—the No. 10 (2.0-mm) sieve or finer (Note 4) used to separate the reduced sample to obtain the material for the sedimentation sample.

NOTE 4—The methodology for using a sieve finer than the No. 10 (2.0 mm) is not defined in this standard. The methodology used to obtain a representative sample using a sieve finer than the No. 10 (2.0 mm) is not the same as obtaining the representative sample using the No. 10 (2.0 mm) sieve as presented in this standard. Additional effort or steps are necessary to make sure the material passing the finer sieve adequately represents the sample. Such additional effort or steps should be documented if using a sieve finer than the No. 10 (2.0 mm) sieve to obtain the sedimentation specimen.

4. Summary of Test Method

4.1 This test method is used to determine the particle-size distribution (gradation) of material finer than the No. 200 (75-µm) sieve as a percentage of the mass used in the sedimentation test.

4.2 When the source material contains particles larger than the ⅜-in. (9.5-mm) sieve, a reduced sample passing the ⅜-in. (9.5-mm) sieve shall be obtained using techniques presented in Test Methods D6913 or another standard. This reduced sample shall meet the minimum mass requirements in Table 1 for the ⅜-in. (9.5-mm) sieve. The material is processed using the moist (referee) preparation method unless the material is received in the air-dried state.

4.3 The entire reduced sample is separated using the separation sieve. The sedimentation sample is then split to obtain the appropriate mass for the sedimentation test specimen and a water content test specimen.

4.4 The sedimentation test specimen is mixed with a dispersing agent and test water. The slurry is allowed to condition and is then thoroughly mixed and placed in a cylinder with additional test water. Readings are taken with a hydrometer and thermometer over specific time intervals.

4.5 The mass of particles passing specified particle diameters are calculated and recorded. The results produce a tabulation of particle size versus percent passing that can be graphically presented as a gradation curve. The plot is typically expressed as percent passing/finer than the separation sieve size versus the log of the particle size in millimetres.

5. Significance and Use

5.1 Particle-size distribution (gradation) is a descriptive term referring to the proportions by dry mass of a soil distributed over specified particle-size ranges. The gradation curve generated using this method yields the amount of silt and clay size fractions present in the soil based on size definitions, not mineralogy or Atterberg limit data.

5.2 Determination of the clay size fraction, which is material finer than 2 µm, is used in combination with the Plasticity Index (Test Methods D4318) to compute the activity, which provides an indication of the mineralogy of the clay fraction.

5.3 The gradation of the silt and clay size fractions is an important factor in determining the susceptibility of fine-grained soils to frost action.

5.4 The gradation of a soil is an indicator of engineering properties. Hydraulic conductivity, compressibility, and shear strength are related to the gradation of the soil. However, engineering behavior is dependent upon many factors, such as effective stress, mineral type, structure, plasticity, and geological origin, and cannot be based solely upon gradation.

5.5 Some types of soil require special treatment in order to correctly determine the particle sizes. For example, chemical cementing agents can bond clay particles together and should be treated in an effort to remove the cementing agents when possible. Hydrogen peroxide and moderate heat can digest organics. Hydrochloric acid can remove carbonates by washing and Dithionite-Citrate-Bicarbonate extraction can be used to remove iron oxides. Leaching with test water can be used to reduce salt concentration. All of these treatments, however, add significant time and effort when performing the sedimentation test and are allowable but outside the scope of this test method.

5.6 The size limits of the sedimentation test are from about 100 µm to about 1 µm. The length of time required to obtain a stable initial reading on the hydrometer controls the upper range of results, and the test duration controls the lower range.

5.7 The shape and density of the grains are important to the results. Stokes' Law is assumed to be valid for spherical particles even though fine silt- and clay-sized particles are more likely to be plate-shaped and have greater mineral densities than larger particles.

NOTE 5—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 D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Hydrometer*—ASTM hydrometer type 151H or 152H. These hydrometers shall conform to the requirements in Specification E100. See Annex A1.

6.2 *Sedimentation Cylinder*—At least two glass cylinders essentially having a height of about 457 mm, an inside diameter between 55 and 64 mm, and a capacity of 1,000 mL. The cylinders shall have an indication mark at 1,000 ± 5 mL. One cylinder is used for the soil suspension and the other one can be used as the control cylinder or the wash cylinder. The control cylinder shall have the same amount of dispersant as the soil suspension cylinder. See Annex A1.

6.3 *Separation Sieve*—No. 10 (2-mm) or finer sieve used to separate the reduced sample. This sieve is subjected to rough operation and shall not be used for quantitative grain size analysis.

6.4 *Thermometric Device*—A thermometric device capable of measuring the temperature range within which the test is being performed readable to 0.5°C or better and having an accuracy of at least ±0.5°C. The thermometric device must be capable of being immersed in the suspension and reference solutions to a depth ranging between 25 and 80 mm. Full immersion, also known as complete or total immersion thermometers, shall not be used. The thermometric device shall be standardized by comparison to a nationally or internationally traceable thermometric device and shall include at least one temperature reading within the range of testing. The thermometric device shall be standardized at least once every twelve months. The same thermometric device shall be used for all measurements.

6.5 *Timing Device*—A clock, stopwatch, digital timer, or comparable device readable to one second or better.

6.6 *Balance*—Balances shall conform to the requirements of Specification D4753.

6.6.1 To determine the mass of the specimen, the balance shall have readability without estimation of 0.01 g. The capacity of this balance will need to exceed the mass of the container plus soil used to contain the soil suspension after the completion of the sedimentation test. In general, a balance with a minimum capacity of 1,800 g is sufficient.

6.7 *Drying Oven*—Vented, thermostatically controlled oven capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber. These requirements typically require the use of a forced-draft oven.

6.8 *Plate*—A clean, nonporous, smooth, solid surface that is large enough to pile and split about 500 g of material. The surface shall not be made of any type of paper product.

6.9 *Specimen-Mixing Container*—A 250-mL glass beaker or equivalent inert container with enough capacity to hold the specimen, the test water, and dispersant.

6.10 *Temperature Maintaining Device*—Unless otherwise specified by the requesting agency, the standard test temperature shall be in the range of 22 ± 5°C. In addition, the temperature of the soil suspension shall not vary more than ±2°C. Normally, this temperature maintenance is accomplished by performing the test in a room with a relatively constant temperature. If such a room is not available, the cylinders shall be placed in an automatically temperature controlled insulated chamber or water bath that maintains a temperature within the tolerance specified above.

6.11 *Soil Suspension Oven-Drying Container*—A container having smooth walls and capable of holding approximately 1.5-L of the soil suspension. This container shall have a tight fitting lid or fit into a desiccator, to prevent moisture gain during cooling of the oven-dried specimen.

6.12 *Dispersion Apparatus*—Use one of the following devices to disperse the specimen; however for referee testing, the stirring apparatus shall be used.

6.12.1 *Stirring Apparatus (Referee)*—A mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a minimum speed of 10,000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate between 19.0-mm and 37.5-mm above the bottom of the dispersion cup (Note 6).

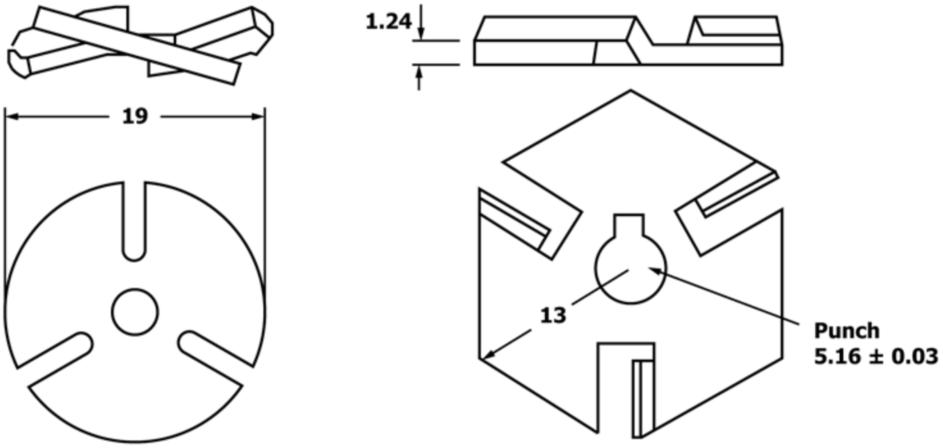
NOTE 6—The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the requirements established by the inch-pound apparatus.

6.12.1.1 *Dispersion Cup*—A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed. The cup shall contain two sets of three long baffle rods and two sets of three short baffle rods rigidly mounted to the interior sides of the cup. This cup is used with the stirring apparatus.

6.12.2 *Air Jet Dispersion Device (Optional)*—A tube type or other comparable device that uses compressed air to disperse the slurry (Note 7). The device requires an air source capable of providing up to 0.0024 m^3/s of air to operate the device, such that pressures of 69 and 172 kPa can be achieved. The device shall be fitted with a pressure gauge on the line between the device and the air source. Water may condense in the lines when not in use and this water must be removed. There are two ways to remove the water: use of a water trap or purging the lines before use. If a water trap is used, it shall be installed on the air line in such a manner to prevent condensed water from entering the slurry. This device shall not be used in referee testing.

NOTE 7—Use of this device or others, causes differing amounts of dispersion and should be used with caution. Information on how to appropriately use this device should be obtained from the manufacturer. 0.0024 m^3/s is equivalent to 5 ft^3/min. The device typically needs at least 0.0009 m^3/s (2 ft^3/min) to operate and therefore, some small air compressors are not capable of supplying sufficient air to operate the device.

6.13 *Agitator (Optional/Referee)*—A hand-held device to mix the soil suspension in the sedimentation cylinder prior to testing, as shown in Fig. 3. The agitator must not have any type of metal, such as a screw head, protruding from the bottom of the disk. To aid in strengthening the connection between the rod and the disk, a smaller disk (about 25 mm or less) having similar thickness and material as the larger disk, may be



Type A

Type B

Dimensional Equivalents^A	
mm	in.
19	0.75
13	0.51
5.16 ± 0.03	0.203 ± 0.001
1.24	0.049 (No. 18 BW Ga.)

Note: All dimensions are shown in millimetres unless otherwise noted.

^{A}The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the technical requirements established by the inch-pound apparatus.

FIG. 1 Detail of Stirring Paddles

inserted on top of and in the center of the larger disk. This device shall be used for referee testing.

6.14 *Agitation of the Soil Slurry*—Any of the following items may be used to break up the soil aggregations as described in 11.1:

6.14.1 *Erlenmeyer Flask*—A glass flask having a capacity between 250-mL and 500-mL.

6.14.2 *Dispersion Shaker*—A platform, wrist action or similar type shaker having a gyratory, orbital, reciprocating, or similar motion to assist in the dispersion process by continuously agitating the soaking soil.

6.14.3 *Ultrasonic Water Bath*—The ultrasonic water bath must be large enough to hold a beaker or flask containing the soil slurry to be agitated for use in the sedimentation test. The water level in the bath should be equal to or higher than the water level in the specimen container.

6.15 *Desiccator (Optional)*—A desiccant containing device of suitable size used to prevent moisture gain during cooling of the oven-dried specimen.

6.16 *Mortar and Rubber-Covered Pestle (Optional)*—Apparatus suitable for breaking up aggregations of air-dried soil particles without breaking individual particles.

6.17 *Miscellaneous Items*—Items such as a wash/rinse bottle (squirt bottle), rubber scraper, spatula, and stirring rod may be useful.

7. Reagents and Materials

7.1 *Sodium Hexametaphosphate* $(NaPO_3)_6$—Also referred to as sodium metaphosphate is the dispersion agent (deflocculant) required to prevent the fine particles in suspension from coalescing or flocculating (Note 8). Consult the Safety Data Sheet (SDS) for specific information regarding this chemical.

7.2 *Isopropyl Alcohol*—Also referred to as isopropanol alcohol or rubbing alcohol is used as a foam inhibitor. Commercially available in concentrations ranging from 70 % to 99 %.

7.3 *Test Water*—Distilled or demineralized water is the only permissible test fluid. The use of tap water is not permitted.

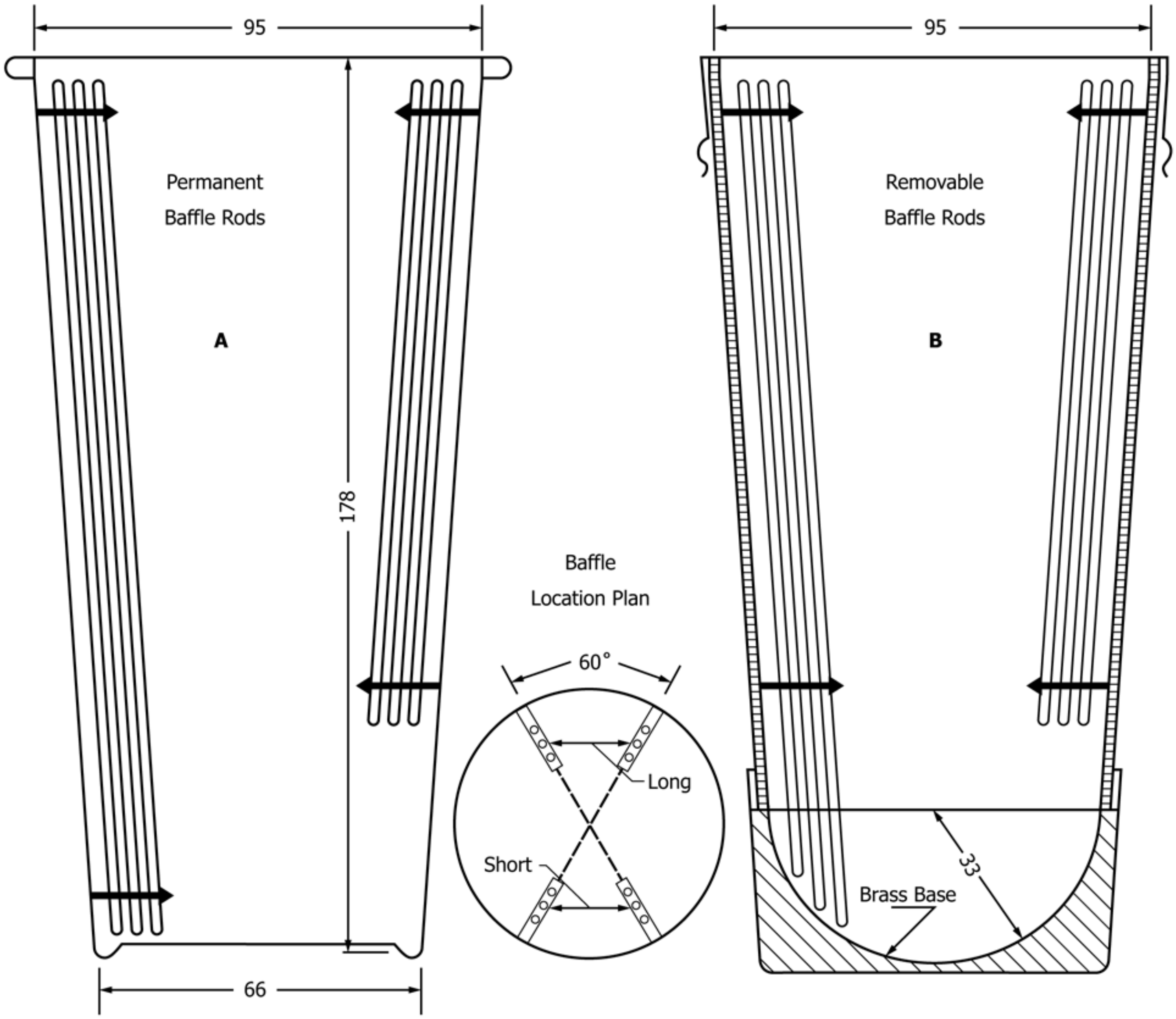
NOTE 8—Fine-grained soils requiring the use of a dispersant are those that do not readily slake in water, such as some highly plastic clays and most tropical soils. Typically, 5 grams per test of dispersant is used to prevent flocculation and is added directly to the soil, such that the concentration will equal 5 g/L in the final soil suspension volume. The chemical formula for the dispersant shown above is approximate.

8. Sampling

8.1 *General*—This test method does not address, in any detail, procurement of the sample. It is assumed the sample is obtained using appropriate methods and is representative of the material under evaluation. However, the testing agency shall preserve all samples in accordance with Practice D4220/D4220M, Group B, except if the as-received sample does not meet those requirements. In which case, the water content of the material does not have to be maintained.

8.2 Where data from this test are to be used for correlation with other laboratory or field test data, use the same material as used for these tests where possible and as much is practical.

8.3 The sample can be from a variety of sources and contain a wide range of particle sizes. Typically, samples for particle-size analysis are obtained from the following sources: large bags or buckets, small bags, jar samples, tube samples, or



Dimensional Equivalents^A	
mm	in.
33	1.30
66	2.60
95	3.75
178	7.01

Note: All dimensions are shown in millimetres unless otherwise noted.

[A] The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the technical requirements established by the inch-pound apparatus.

FIG. 2 Dispersion Cup

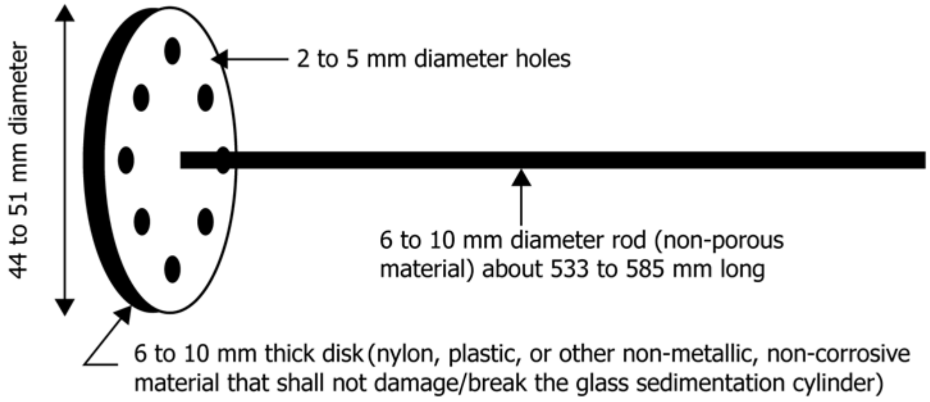
specimens from other tests, such as consolidation, hydraulic conductivity or strength tests. In some cases, such as compaction testing, prior testing may have caused a reduction in particle sizes; therefore, it may be required to obtain a sample of the original material, the degraded sample, or both. Test Methods D6913, Section 9, gives additional information regarding sampling from the different sources.

8.3.1 Preserve the sample at its original moisture condition unless excluded above, and at no time shall the sample be allowed to undergo undesirable temperature changes such as freezing or heating.

8.4 When the sample contains particles larger than the ⅜-in. (9.5-mm) sieve, it shall be processed to obtain the reduced sample. If particle-size separation is necessary, process the sample to meet this requirement using the separation procedures provided in Test Methods D6913.

8.4.1 The reduced sample shall have a maximum particle size that passes through the ⅜-in. (9.5-mm) sieve.

8.4.2 The mass of the reduced sample shall meet or exceed the mass requirements given in Table 1.



Dimensional Equivalents[A]

mm	in.
2 to 5	0.0781 to 0.200
6 to 10	0.250 to 0.375
533 to 585	22 ± 1
44 to 51	1.75 to 2.00

Note: All dimensions are shown in millimetres unless otherwise noted.

[A] The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the technical requirements established by the inch-pound apparatus.

FIG. 3 Detail of Agitator

8.4.3 Preserve the original moisture condition of the reduced sample, and at no time shall the reduced sample be allowed to undergo undesirable temperature changes such as freezing or heating.

9. Preparation of the Test Specimen

9.1 *Specimen Procurement*—This standard presents two preparation methods to obtain the sedimentation specimen from the reduced sample: moist and air-dried. In these preparation methods, moist and air-dried refers to the condition of the material or sample as it is being reduced to an appropriate particle size and mass. The test shall not be performed on oven-dried material. The moist preparation method shall be used for referee testing and for samples not received in the air-dried state. The air-dried method shall only be used on materials received in the air-dried state (Note 9). Since some fine-grained, air-dried soils aggregate, a mortar and rubber covered pestle is used to break up aggregations. Care must be taken to avoid disintegration or reduction of individual particles. Use only enough force as necessary to break up the aggregations without destroying the individual particles. Additional guidance for splitting material to obtain a representative specimen using a splitter, quartering, or moist stockpile sampling is given in Test Methods D6913, Annex A2.

NOTE 9—Air drying causes irreversible changes to the clay particles that cause permanent flocculations and decreases the fine fraction.[3]

9.2 *Moist Preparation (Referee)*—This preparation method shall be used for materials not received in the air-dried state. This method is especially important for any soil whose properties are altered due to drying such as, most organic soils, many highly plastic fine-grained soils, tropical soils and soils containing halloysite. The material is thoroughly mixed to obtain a uniform reduced sample. Intact fine-grained samples should be chopped/reduced into small pieces, less than approximately 13 mm, and mixed to make uniform. Test water can be added to assist in making a uniform sample. There is no need to process the fine-grained materials through a sieve.

9.3 *Air-Dried Preparation*—This preparation method shall only be used if the sample is received in the dried condition. In order to obtain a uniform reduced sample, the sample is blended at room temperature.

9.4 If the reduced sample contains particles which are larger than the No. 10 (2.0-mm) sieve, the material shall be separated using a No. 10 (2.0-mm) or finer sieve. Process the entire reduced sample over the No. 10 (2.0-mm) or finer sieve using a rubber scraper and, if needed, test water to aid in working the material through the sieve. Check that the material retained on the sieve does not contain aggregations of finer particles. Any aggregations should be broken and passed through the sieve. It is not necessary that the separation be totally complete but the material passing the sieve shall be representative. The material passing the separation sieve is termed the sedimentation sample and shall meet the minimum mass requirement of Table 1. Record the separation sieve size that is used to separate the sample.

9.5 Estimate the amount of moist mass needed for the sedimentation test using the equation (Note 10):

$$M_{mest} = H_c \times \left(\frac{100}{\%est}\right) \times \left(1 + \left(\frac{w_{cest}}{100}\right)\right) \tag{1}$$

where:

M_{mest} = estimated moist mass, nearest 1 g,

---

[3] Sridharan, A., Jose, B.T., and Abraham, B.M., Technical Note on "Determination of Clay Size Fraction of Marine Clays," *Geotechnical Testing Journal*, GTJODJ, Vol. 14, No. 1, March 1991, pp. 103-107.

H_c = hydromter capacity, g (either 45 for 151H or 55 for 152H),
$\%est$ = estimated percentage of material passing the No. 200 (75-µm) sieve, nearest 1 %, and
w_{cest} = estimated water content, nearest 1 %.

NOTE 10—The mass of the sedimentation test specimen should be selected based on the amount of material that will be in suspension at the time of the first reading. The capacity of the 152H hydrometer is about 55 g of dry soil and the capacity of the 151H is about 45 g. The wet mass should be adjusted to account for the water content and the fraction of particles larger than the No. 200 (75-µm) sieve. For example, if the water content is estimated at 20 %, using a 151H hydrometer, and an estimated percent passing the No. 200 (75-µm) sieve of 95 %, the estimated moist mass needed is 57 g.

9.6 If the sedimentation sample contains sufficient material, then split or quarter the sedimentation sample into at least two portions: one for the water content determination and one for the sedimentation test. The water content specimen shall contain 50 ± 10 g of material.

9.7 If the sedimentation sample has limited material, reduce the mass to obtain the sedimentation specimen. Do not obtain a water content specimen. Obtain the dry mass, M_d, of the sedimentation specimen at the end of the test as discussed in 11.12 and calculated in 12.1.2.

NOTE 11—If there is enough material after splitting/quartering to obtain the necessary masses for both the sedimentation and water content specimens, the sedimentation sample is considered to have sufficient material. If there is not enough material to obtain both the necessary masses of the specimens, the sedimentation sample is considered to have limited material.

9.8 Record the mass of the moist soil, M_m, used for the sedimentation test to the nearest 0.01 g.

9.9 Place the sedimentation specimen in the specimen-mixing container and record the identification of the specimen-mixing container.

9.10 If sufficient material is available, immediately use the other specimen for determination of the water content in accordance with Test Methods D2216, and record the water content, w_c, to the nearest 0.1 %.

10. Verification/Preparation of Apparatus

10.1 *Hydrometer*—Check and record the dimensions of the 151H or 152H hydrometers as presented in Annex A1 in accordance with the interval listed in the Annex. The hydrometer shall be free of cracks and chips, which can compromise the integrity of the hydrometer. The body and stem of a hydrometer seldom change over time, unless they have been subjected to corrosive materials or have been damaged, that is, chipped or cracked. They only need to be checked before use or after damage has been suspected or seen. Since it is possible for the paper scale inside the hydrometer stem to slide down, the length of the stem above and below the top and bottom graduations, respectively, as well as the hydrometer reading in the test water, shall be checked and documented according to the interval presented in Annex A1 to make sure the scale has remained in its proper place. If the scale has moved, the hydrometer shall be replaced.

10.1.1 *Hydrometer Readings*—Hydrometer readings are taken to the nearest ¼ division (Note 12). Reading the hydrometer can be difficult. A properly placed hydrometer should neither bob nor rotate appreciably when released in the soil suspension. It is important for the stem to be dry and clean when inserting it into the soil suspension. If the stem is wet above the reading point it will add mass to the hydrometer causing the reading to be too low. If the stem is not clean, variations in the meniscus rise will result. In this application, the hydrometers are always read at the top of the meniscus for the reason stated in 10.3.

NOTE 12—Reading the 152H hydrometer to the nearest ¼ division during the first 5 to 8 minutes of the test can be difficult. During that time it is acceptable to read the 152H hydrometer to the nearest ½ division.

10.1.2 To insert the hydrometer correctly do the following: First, make sure the stem is dry. Then, gently hold it by the stem with one or both hands and slowly lower it to the depth at which it just floats. This insertion process should take between 5 to 15 seconds.

10.2 *Temperature-Density Correction*—During a test, the suspension fluid density changes, therefore calculations for the quantity of particles in suspension must account for fluid density changes due to temperature, presence of dispersant and the meniscus rise. The temperature-density correction is shifting the hydrometer scale, which is factory set for distilled water at 20°C. There are two ways to determine this correction: take companion measurements in a control cylinder filled with the reference solution during the testing or generate a reusable, calibration relationship. Both options require the use of a reference solution composed of test water and the same amount of dispersant used in the sedimentation test cylinder. The meniscus correction is automatically accounted for in the temperature-density correction for both options by consistently reading the hydrometer at the top of the meniscus as described in 10.3.

10.2.1 *Reference Solution*—The reference solution shall be prepared with the same amount of dispersant as the soil suspension. Fill a control cylinder to the 1,000 mL mark with a mixture of test water and the same amount of dispersant used in the soil suspension cylinder. The test water and dispersant shall be well mixed such that no visible crystals can be seen and the reference solution shall be agitated to make sure the dispersant is adequately mixed throughout the control cylinder.

10.2.1.1 *Companion Measurements*—Use a control cylinder filled with the reference solution in conjunction with the soil suspension cylinder to obtain the correction. Position the control cylinder in the same temperature controlled location as the test cylinders so that all cylinders are at or near the same temperature. For each hydrometer and temperature reading taken in the soil suspension cylinder, take a corresponding hydrometer reading and temperature reading in the control cylinder. However, it is permissible for one control cylinder hydrometer reading taken at the start of the sedimentation test to be used for the initial series of time readings in the soil suspension up to 30 minutes. It is also permissible for one control cylinder temperature reading taken at the start of the sedimentation test to be used for the initial series of time readings in the soil suspension up to the first 30 minutes if the temperature changes in the soil suspension cylinder vary less than 0.5°C between each temperature reading. Record the elapsed time and the hydrometer and temperature readings of the control cylinder on the data sheet(s) only when measured (Note 13).

NOTE 13—Readings taken in one control cylinder may be used for multiple test cylinders. Therefore, if the hydrometer and temperature readings in the control cylinder are only taken once during the first 30 minutes of the test, only that reading is recorded on each of the data sheet(s) to which it applies. These measured readings are not to be written in for the other times during the first 30 minutes when a measurement was not actually determined.

10.2.2 *Calibration Relationship*—This option generates a general calibration relationship between the hydrometer reading of a control cylinder filled with the reference solution and the temperature, which eliminates the need for companion measurements during the test. A temperature-based general calibration relationship is required and established for each hydrometer. A sedimentation cylinder is filled to the 1,000 mL mark with test water with the same amount of dispersant used in the soil suspension. Be sure the solution is thoroughly mixed and the temperature is allowed to equilibrate. Then insert the hydrometer as described in 10.1.2. Take the reading at the top of the meniscus and record this reading and the temperature of the solution. Rinse the hydrometer well with test water between readings and dry it prior to taking the next reading. Increase/Decrease the temperature of the cylinder, allow it to come to temperature equilibrium and repeat the measurement process. Take at least five different hydrometer and temperature readings within the range of temperatures expected during the sedimentation test. Calculate the constant A or B as discussed below.

10.2.2.1 The 151H hydrometer measures the specific gravity of the fluid relative to distilled water at 20°C. The calibration measurements are used to compute the constant A in the following equation. The standard deviation of the five measurements shall be less than 0.0005. The average value of A is used when computing the temperature-density correction.

$$A = R_{151,t} + (7.784 \times 10^{-6} \times T_t) + (4.959 \times 10^{-6} \times T_t^2) \quad (2)$$

where:

A = average specific gravity shift (151H hydrometer), nearest 0.0001,
$R_{151,t}$ = 151H specific gravity hydrometer at reading, t, in reference solution, readable to 0.00025 or better,
T = temperature at reading, t, readable to 0.5°C or better, and
t = subscript indicating the reading number during calibration.

10.2.2.2 The 152H hydrometer measures the mass of particles (specific gravity of 2.65) in a suspension of distilled water at 20°C. The temperature-density correction provides the offset mass reading for the hydrometer for a specific temperature and dispersant concentration. The calibration measurements are used to compute the constant B in the following equation. The standard deviation of the 5 measurements shall be less than 0.5 g/L. The average value of B is used when computing the temperature-density correction.

$$B = R_{152,t} + (1.248 \times 10^{-2} \times T_t) + (7.950 \times 10^{-3} \times T_t^2) \quad (3)$$

where:

B = average mass reading shift (152H hydrometer), nearest 0.1,
$R_{152,t}$ = mass in reference solution hydrometer at reading, t, readable to 0.25 g/L or better,
T = temperature at reading, t, readable to 0.5°C or better, and
t = subscript indicating the reading number during calibration.

NOTE 14—The equations relating the hydrometer readings to temperature are based on the same water density-temperature expression as used in Test Methods D854. For the 151H specific gravity hydrometer, the constants in the water density-temperature equation from Test Methods D854 are divided by the density of water at 20°C (0.99821 g/mL). For the 152H mass in suspension hydrometer, the constants are multiplied by 1606 setting the scale to read mass of solids in solution for a particle specific gravity of 2.65.

10.3 *Meniscus Correction*—Hydrometers are designed to be read at the fluid surface, however, the fluid is wetting to the glass such that the soil suspension will rise up the hydrometer making a reading at the fluid surface impossible at times. It is common practice to read the hydrometer at the top of the meniscus and it must be taken there even when it is possible to see through the soil suspension. The meniscus rise has a small impact on the effective depth determination since the reading is taken slightly above the surface of the suspension. This rise causes a change to the third significant digit in the computed particle size. The meniscus correction is performed before initial use of the hydrometer and after damage has been suspected or noticed.

10.3.1 The meniscus correction, C_m, as shown in Fig. 4, is determined by inserting the hydrometer with a clean and dry stem and without bobbing into the test water with the proper amount of dispersant. The reading at the top of the meniscus and the reading where the plane of water surface intersects the stem are recorded. The difference between these two readings is the meniscus correction, C_m. In accordance with Test Method E126, the latter reading shall be obtained using the following guidance. Observe a point slightly below the plane of the water surface and raise the line of vision until this surface, seen in an ellipse, becomes a straight line. The point where this line cuts the hydrometer scale is the hydrometer reading. Holding a white card behind the cylinder just below the water level will improve the visibility of the surface. The

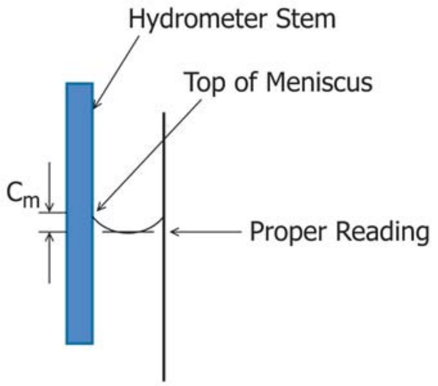


FIG. 4 Meniscus Correction Diagram

hydrometer readings shall be recorded to the nearest ¼ division. The meniscus correction is a positive number for either hydrometer used.

10.4 *Effective Depth*—The effective depth, also referred to as "true depth," is used in the calculation of the particle fall distance for each reading. The effective depth is defined as the center of (volume) buoyancy of the hydrometer to the surface of the soil suspension. The equation to calculate the effective depth when the hydrometer is inserted and removed between readings requires certain dimensional measurements in order to do the calculation. Refer to Fig. 5.

10.4.1 Determine and record the volume of the hydrometer bulb, V_{hb}, to the nearest 1 cm^3 using the procedure given in Annex A1.3.4. The bulb includes everything from the bottom tip up to the base of the stem.

10.4.2 Determine and mark the center of (volume) buoyancy, c_b, using the procedure given in A1.3.5.

10.4.3 Measure the distance between the center of (volume) buoyancy, c_b, and the maximum hydrometer reading H_{r2}, as well as the minimum hydrometer reading, H_{r1}. Record both values to the nearest 0.1 cm. Refer to Fig. 5.

10.4.4 Measure and record the inside cross-sectional area of the sedimentation cylinder, A_c, to the nearest 0.1 cm^2 using the procedure given in A1.4.2.1.

10.5 *Sedimentation Cylinder*—Check and record the dimensions of the sedimentation cylinders as presented in Annex A1 in accordance with the interval presented in Annex A1.

10.6 *Sieves*—See Practice E11 for the verification requirements of the sieves used in this test method.

10.7 *Miscellaneous*—The ancillary equipment used in conjunction with these test methods shall be calibrated/verified/checked according the intervals listed in Practice D3740 and performed in accordance with their applicable standards.

11. Procedure

11.1 Add 5.0 ± 0.1 g of sodium hexametaphosphate to the sedimentation specimen in the specimen-mixing container obtained in 9.9 or dissolve this amount of dispersant in 100 mL of test water and add it to the sedimentation specimen. Record to the nearest 0.01 g the actual amount of dispersant, M_{disp}, placed in the container or dissolved in the test water. If added directly to the sedimentation specimen, add at least 100 mL of test water to the specimen and dispersant to form a slurry of milkshake consistency. The amount of test water to be added during this step should be sufficient enough only to facilitate the process of breaking apart the soil aggregations. Mix the contents with a spatula or similar device until all of the soil aggregations are broken-up (Note 15).

NOTE 15—If hand mixing is not efficient, use a 250 to 500 mL Erlenmeyer flask along with either a wrist or orbital dispersion (mechanical) shaker to vigorously agitate the soil slurry in a minimum of 150 mL of test water for a few hours or until all the soil aggregations are broken-up. Be aware the dispersion cup has a capacity of about 400 mL and the stirring apparatus is only efficient in dispersing soil aggregations that will pass between the baffle rods. An ultrasonic water bath, along with the flask, may also be used to agitate the slurry.

11.2 Prior to the overnight conditioning period, disperse the slurry using either the stirring apparatus or an air jet device.

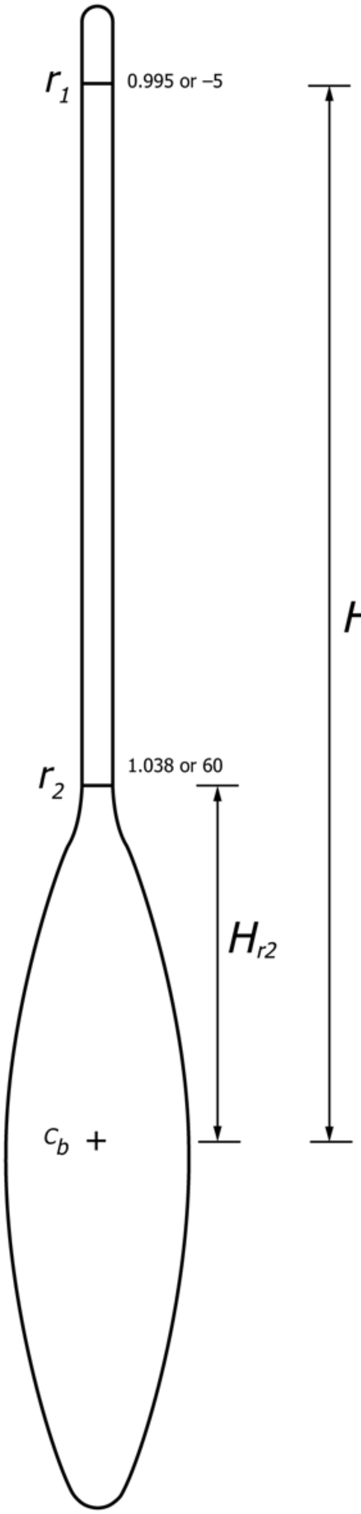


FIG. 5 Effective Depth Dimensional Measurements

11.2.1 If using the stirring apparatus, transfer the slurry to the dispersion cup. Use a wash/rinse bottle filled with test water to aid in the transfer and make sure all of the slurry has been transferred to the dispersion cup. Add additional test water as necessary such that the cup is half full, then use the stirring apparatus to blend the soil for about 1 minute.

11.2.1.1 Transfer all the dispersed slurry into the sedimentation cylinder. Use the wash/rinse bottle filled with test water as needed to make sure all of the slurry is transferred to the cylinder. Add test water to the sedimentation cylinder to bring the bottom of the meniscus of the slurry to the 1,000 mL ± 1 mm mark. Proceed to 11.3.

11.2.2 If using the tube type air jet device, transfer the slurry to the sedimentation cylinder. Use a wash/rinse bottle filled with test water to aid in the transfer and make sure all of the slurry has been transferred to the cylinder. Add additional test water as necessary to bring the volume to no more than 250 mL in the sedimentation cylinder.

11.2.2.1 Before placing the device into the cylinder, slowly allow air to flow until the gauge reads 7 kPa. This initial pressure is needed to prevent the slurry from entering the air jets when the device is inserted into the cylinder and to remove any water that has condensed in the lines. Then, slowly lower the device into the slurry. Make sure the rubber stopper is securely in place at the top of the cylinder to prevent the slurry from being ejected from the cylinder.

11.2.2.2 For clayey soils increase the pressure to 172 kPa and for sandy soils increase the pressure to 69 kPa. Once the pressure is reached, disperse the slurry for five minutes. At the end of five minutes, reduce the pressure to 7 kPa and lift the air jets out of the slurry and wash any slurry remaining on the device back into the cylinder. Once the device is washed off, turn off the air flow to the device and add test water to the sedimentation cylinder to bring the bottom of the meniscus of the slurry to the 1,000 mL ± 1 mm mark. Proceed to 11.3.

11.3 Mix the slurry using the agitator (referee) or the tipping method (Note 16). The agitator device is the preferred/referee method for mixing. Check for the presence of foam on top of the slurry after mixing. If a significant amount of foam is present, it may be necessary to reduce the foam using isopropyl alcohol just prior to the start of testing (See 11.7.1).

11.3.1 To use the agitator, insert the paddle to the lower ¼ of the cylinder. Stroke the agitator at a rate of about one cycle per second over a distance of several centimeters to dislodge any material stuck to the bottom of the cylinder. After the material is dislodged, the agitator should be rapidly moved downwards until the paddle almost comes into contact with the bottom of the cylinder and then upwards with a slower motion. The downward stroke should take about one to two seconds while the upward stroke should take about two to three seconds. As this process is repeated, the elevation of the starting position of the agitation cycle is raised until the bottom of the agitator is significantly above the mid-height of the soil suspension. Keep the paddle submerged at all times during mixing. Mix for about one minute or until the suspension appears uniform.

11.3.2 To use the tipping method, first place a rubber stopper in the open end of the cylinder or use the palm of the hand to cover the opening. Then turn the cylinder upside down and back for a period of one minute to complete the agitation of the slurry (Note 17). Using the cylinder tipping method is not very efficient and tipping for more than one minute will typically be required when testing highly plastic clays. This method of agitation may leave some soil aggregations. Use of the agitator is greatly encouraged.

NOTE 16—When using the tipping method, there will likely be some soil particles remaining on the rubber stopper or hand and on the sides of the sedimentation cylinder above the 1,000 mL mark. Be careful not to lose much material by scraping the material adhering to the rubber stopper or hand off onto the rim of the cylinder. Do not rinse these particles back into the cylinder. The minor loss of mass (~0.02 g or less, if care is taken) is less critical with respect to the calculations than the addition of water (~5 mL) to the cylinder.

NOTE 17—The number of turns during this minute should be approximately 60 counting the turn upside down and back as two turns. Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorously shaking of the cylinder while it is inverted.

11.4 If using a companion measurement to obtain the temperature-density correction, prepare the reference solution in a control cylinder by dissolving the same amount (5.0 ± 0.1 g) of sodium hexametaphosphate as used in the soil suspension cylinder in test water. Add test water to the sedimentation cylinder to bring the bottom of the meniscus of the solution to the 1,000 mL ± 1 mm mark.

11.5 Cover the cylinder(s) to prevent evaporation and allow the cylinder(s) to sit overnight either in a temperature controlled insulated chamber or water bath or in an area of relatively constant temperature. This conditioning period allows the temperature to equilibrate and for the specimen to deflocculate (Note 18). The soil slurry is now referred to as a soil suspension since the specimen is basically ready for testing.

11.6 At the end of the conditioning period, check the suspension for indications of flocculation (Note 19). If the suspension has indications of flocculation, then the test is invalid and the suspension should be discarded since it has been contaminated with dispersant. A new specimen would need to be treated to prevent flocculation. Such treatment is beyond the scope of this test method.

NOTE 18—Strong interparticle bonding can occur in suspension having high salt concentrations. The dispersant will not be effective in breaking these bonds. In such circumstances the salt should be leached from the soil before proceeding with the sedimentation test. This leaching results in a considerable increase in effort and difficulty to process the material and is not discussed in this standard.

NOTE 19—Flocculation of clay particles can be difficult to detect. Minor flocculation will shift the particle-size distribution (gradation) towards a finer fraction. Moderate flocculation will cause a plateau in the curve as the sedimentation process stops. Major flocculation will completely halt sedimentation at an early stage. Only major flocculation is visually detectable showing a lack of material collected at the bottom of the cylinder, a surface layer of clear fluid, or horizontal cracks in the suspension.

11.7 Once the suspension has temperature equilibrated and deflocculated, the suspension shall once again be mixed to create a uniform suspension. Repeat the mixing procedure as described in 11.3. Upon completion of agitation, make sure the cylinder is on a stable surface and in a location where it will not be subjected to any jarring or disturbance and immediately start the timer as directed in either 11.7.2 or 11.7.3. If using a temperature controlled water bath, immediately place the cylinder back into the water bath after agitation.

11.7.1 If significant foam develops on top of the suspension after mixing, immediately add up to three drops of isopropyl alcohol to the suspension to reduce or eliminate the foam.

11.7.2 If using the agitator, start the timer when the paddle of the agitator breaks the surface of the soil suspension. After removing the agitator allow the "free" liquid on it to drain back into the sedimentation cylinder.

11.7.3 If using the tilting method, start the timer after completion of the last inversion.

11.8 Hydrometer readings shall be taken at elapsed times of approximately, 1, 2, 4, 15, 30, 60, 240, and 1440 minutes. Additional readings can be taken to better define the particle-size distribution (gradation) relationship.

11.8.1 About 15 to 20 seconds before a reading is required, gently place the hydrometer into the sedimentation cylinder to a depth approximately equal to the level at which it will float as described in 10.1.2. At the prescribed elapsed times and when the hydrometer is stable, read and record the hydrometer reading, r_m, to the nearest ¼ division, and record the elapsed time, t_m.

11.8.2 When removing the hydrometer from the suspension, the removal process should take about 5 to 10 seconds and be with a steady motion. Generally there will be a drop of suspension at the tip of the hydrometer. Touch the tip to the inside lip of the cylinder and allow the drop to flow back into the cylinder.

11.8.3 With a spinning motion, place the hydrometer into a wash cylinder filled with test water to clean off the hydrometer (Note 20). Once the hydrometer is clean, remove and dry it off prior to the next reading or the reading in the control cylinder if using companion measurements.

NOTE 20—While it is ideal to rinse the hydrometer off in a wash cylinder that can be easily cleaned, it is permissible to rinse the hydrometer in another suitable container filled with test water providing there is ample room for the hydrometer to spin.

11.9 Immediately after taking a hydrometer reading, gently insert the thermometric device into the soil suspension and record the temperature, T_m, to the nearest 0.5°C or better. Do not allow the thermometric device to create disturbance in the suspension. After removing the thermometric device, cover the cylinder to prevent evaporation when the time between the readings exceeds five minutes.

11.9.1 The temperature reading taken at the start of the sedimentation test may be used for the initial series of time readings up to 30 minutes. The temperature does not need to be measured more frequently than 30 minutes and shall be recorded at the elapsed times of actual measurements.

11.10 When using a companion measurement to determine the temperature-density correction, the hydrometer, $r_{d,m}$, and temperature, T_m, readings of the control cylinder shall be measured and recorded in accordance with 10.2.1.1.

11.11 If the dry mass, M_d, of the sedimentation specimen has been or will be determined from a companion specimen, the soil suspension is now ready to be washed over the No. 200 (75-µm) sieve.

11.11.1 Pour the soil suspension over the No. 200 (75-µm) sieve. Take care in transferring the soil suspension from the cylinder to the wash sieve so as not to lose material. Make sure there is no remaining material in the cylinder and that the wash water is running clear before transferring the material retained on the sieve into the oven drying container. Record the identification of the container and proceed to 11.13.

11.12 If the dry mass, M_d, of the sedimentation specimen was not determined using the water content taken in 9.10, then the dry mass is obtained from the soil suspension used for the sedimentation test.

11.12.1 After the last hydrometer reading is obtained, transfer all of the soil suspension to the oven drying container as described in 6.11. To facilitate the complete removal of all of the suspension, agitate the cylinder to distribute the soil as described in 11.3 (Note 21). Pour the agitated suspension into the container and record the identification of the container. If using the container as the tare to calculate the dry mass, also record the mass of the container prior to adding the suspension to the nearest 0.01 g. Use a wash/rinse bottle to aid in transferring the slurry.

NOTE 21—It is not necessary to duplicate the exact requirements of 11.3 in order to sufficiently distribute the soil. Use only as many turns (tipping method) or strokes (agitator method) as needed to dislodge the material from the bottom of the cylinder. The purpose of this agitation is to reduce the amount of additional water needed to remove all of the suspension from the cylinder. Additional test water may be added to thoroughly clean the cylinder and remove all of the suspension.

11.12.2 Dry the suspension to a constant mass in the drying oven at 110 ± 5°C. Usually constant mass is achieved after 24 hours when forced-draft type ovens are used. If there is any uncertainty if the specimen has thoroughly dried, it is necessary to perform the constant mass test after an additional six hours in the drying oven, to verify it has indeed completely dried before proceeding (Note 22).

NOTE 22—Determining the dry mass after the test adds additional time and consideration. Because the oven must remove large amounts of water, the drying time takes longer and the constant mass check interval is extended. The large surface area of the specimen in the container allows the material to potentially absorb more moisture from the air as it cools.

11.12.3 Remove the container from the drying oven and allow it to cool in a desiccator or a tightly covered/sealed container. After the container has cooled, determine and record the dry mass of the soil plus dispersant, M_{dd}, to the nearest 0.01 g.

11.12.4 After recording the dry mass of soil plus dispersant, M_{dd}, cover the specimen with tap water and allow the specimen to soak. During soaking, gently stir the specimen to facilitate the separation of particles. Pour the soaked material over the No. 200 (75- µm) sieve. Take care in transferring the soil suspension from the container to the wash sieve so as not to lose material. Make sure there is no remaining material in the container and that the wash water is running clear before transferring the material retained on the sieve into the oven drying container. Record the identification of the container if a different container is used and proceed to 11.13.

NOTE 23—Test Methods D1140 provides information on the washing technique to use.

11.13 Dry the retained material to a constant mass in the drying oven at 110 ± 5°C. Usually constant mass is achieved overnight (~12-16 hours) when forced-draft type ovens are used. If there is any uncertainty if the specimen has thoroughly dried, perform the constant mass test after an additional two hours in the drying oven, to verify it has indeed completely dried before proceeding.

11.14 Remove the container from the drying oven and allow it to cool in a desiccator or cover the container with a tight fitting lid. After the container has cooled, determine and record the dry mass of the soil retained on the No. 200 (75-µm) sieve, M_{dr}, to the nearest 0.01g. During the washing process, the dispersant has been removed and the resulting dry mass will only include the particles retained on the sieve.

12. Calculations

12.1 Calculate the dry mass, M_d, of the sedimentation specimen using either of the following methods.

12.1.1 *Dry Mass Using Moist Mass and Water Content*—Using the water content, w_c, of the companion specimen determined in 9.6 and the initial moist mass, M_m, of the sedimentation specimen, calculate the dry mass of the sedimentation specimen based as follows:

$$M_d = \frac{M_m}{1 + \left(\frac{w_c}{100}\right)} \qquad (4)$$

where:

M_d = mass of dry soil, nearest 0.01 g,
M_m = mass of moist soil, nearest 0.01 g, and
w_c = water content, nearest 0.1 %.

12.1.2 *Dry Mass Using The Sedimentation Specimen*—Calculate the dry mass, M_d, of the sedimentation specimen based on the oven-dried material as obtained in 11.12 using the following equation:

$$M_d = M_{dd} - M_{disp} \qquad (5)$$

where:

M_d = mass of dry soil, nearest 0.01 g,
M_{dd} = mass of dry soil plus dispersant, nearest 0.01 g, and
M_{disp} = mass of dispersant, nearest 0.01 g.

12.2 *Temperature-Density Correction: Calibration Relationships*—When using the calibration relationship to determine the hydrometer offset reading, $r_{rd,m}$, calculate the corrected hydrometer reading using the equation below that corresponds to the hydrometer used during the test.

12.2.1 For the 151H hydrometer, compute the offset reading for each sedimentation test reading using the following equation:

$$r_{d,m} = A - 7.784 \times 10^{-6} \times T_m - 4.959 \times 10^{-6} \times T_m^2 \qquad (6)$$

where:

$r_{d,m}$ = 151H specific gravity hydrometer offset at reading, *m*, nearest 0.0001 (dimensionless),
A = average specific gravity shift (151H hydrometer), nearest 0.0001 (dimensionless),
T = temperature at reading, *m*, readable to 0.5°C or better, and
m = subscript indicating the reading number during the sedimentation test.

12.2.2 For the 152H hydrometer, compute the offset reading value for each sedimentation test reading using the following equation:

$$r_{d,m} = B - 1.248 \times 10^{-2} \times T_m - 7.950 \times 10^{-3} \times T_m^2 \qquad (7)$$

where:

$r_{d,m}$ = 152H g/L hydrometer offset at reading, *m*, nearest 0.1 g/L,
B = average mass shift (152H hydrometer), nearest 0.1 g/L,
T = temperature at reading, *m*, readable to 0.5°C or better, and
m = subscript indicating the reading number during the sedimentation test.

12.3 *Temperature-Density Correction: Companion Measurement*—When using the companion measurement to obtain the temperature-density correction, use the recorded hydrometer offset reading taken in the control cylinder, $r_{d,m}$, that corresponds to the hydrometer used during the test.

12.4 *Mass Percent Finer*—For each hydrometer reading taken in the soil suspension, compute the mass of material still in suspension as a percentage of the sedimentation specimen using the appropriate equation for the type of hydrometer used during the test.

12.4.1 For each 151H hydrometer reading, calculate and record the mass percent finer using the following equation:

$$N_m = \left(\frac{G_s}{G_s - 1}\right)\left(\frac{V_{sp}}{M_d}\right)\rho_c\left(r_m - r_{d,m}\right) \times 100 \qquad (8)$$

where:

N_m = mass percent finer material at reading *m*, nearest 1 %,
V_{sp} = volume of suspension, nearest 0.1 cm^3,
ρ_c = mass density of water at the temperature of manufacturer calibrated, g/cm^3 (Note 24),
M_d = dry soil mass of the sedimentation specimen, nearest 0.01 g,
G_s = specific gravity of soil, nearest three significant digits, (dimensionless),
r_m = hydrometer reading in suspension at reading *m*, readable to 0.00025 (dimensionless),
$r_{d,m}$ = hydrometer offset reading from reference solution at same temperature as reading *m*, nearest 0.0001 (dimensionless), and
m = subscript indicating the reading number during the sedimentation test.

NOTE 24—The mass density of water at the time of calibration is dependent upon the temperature at time of calibration. H151 and H152 hydrometers are calibrated to 20°C, which gives a mass density of 0.98821 g/cm^3.

12.4.2 *Mass Percent Finer*—For each 152H hydrometer reading, calculate and record the mass percent finer using the following equation:

$$N_m = 0.6226 \times \left(\frac{G_s}{G_s - 1}\right) \times \left(\frac{V_{sp}}{M_d}\right)\left(r_m - r_{d,m}\right) \times \left(\frac{100}{1000}\right) \qquad (9)$$

where:

0.6226 = correction factor to adjust for particle specific gravity,

r_m = hydrometer reading in suspension at reading m, readable to 0.25 g/L, and

$r_{d,m}$ = hydrometer offset reading from reference solution at same temperature as reading m, nearest 0.1 g/L.

12.5 *Effective Depth*—This value is used in the calculation of the particle fall distance for each hydrometer reading. The following equation is used to calculate the travel distance of the particles when the hydrometer is inserted immediately before a reading and is removed until the next reading.

$$H_m = H_{r2} + \left(\frac{(H_{r1} - H_{r2})}{(r_2 - r_1)} \times (r_2 - r_m + C_m)\right) - \left(\frac{V_{hb}}{2A_c}\right) \tag{10}$$

where:

H_m = distance particles fall at reading m when the hydrometer is inserted only for an individual reading, 2 significant digits, cm,

V_{hb} = volume of the hydrometer bulb up to the base of the stem, nearest 1 cm^3,

A_c = cross-sectional area of the sedimentation cylinder, nearest 0.1 cm^2,

H_r = distance between the center of (volume) buoyancy and the minimum (H_{r2}) and maximum (H_{r1}) hydrometer readings nearest 0.1 cm,

r_m = hydrometer reading in suspension at reading m, 151H: readable to 0.00025 (dimensionless) 152H: readable to 0.25 g/L,

C_m = meniscus correction: 151H nearest 0.25 division (dimensionless) 152H: nearest 0.25 g/L,

r = the minimum (r_2) and maximum (r_1) hydrometer reading (dimensionless or g/L), and

m = subscript indicating the reading number during the sedimentation test.

12.6 *Maximum Particle Diameter in Suspension*—For each hydrometer reading, calculate and record the particle diameter of the soil using the following equation:

$$D_m = \left(\sqrt{\frac{18\mu}{\rho_w g(G_s - 1)} \cdot \frac{H_m}{t_m}}\right) \times 10 \tag{11}$$

where:

D_m = particle diameter, two significant digits, mm,

μ = viscosity of water at 20°C, 0.0100 g/cm-s,

ρ_w = mass density of water at 20°C, 0.99821 g/cm^3,

g = acceleration dues to gravity, 980.7 cm/s^2,

G_s = specific gravity of soil, three significant digits (dimensionless),

t_m = elapsed (fall) time, two significant digits, s,

H_m = particle fall distance, two significant digits, cm, and

m = subscript indicating the reading number during the sedimentation test.

12.7 *Percent Passing the No. 200 (75-µm)*—Calculate the percent passing the No. 200 (75-µm) sieve using the following equation:

$$P_p = 100\left(1 - \frac{M_{dr}}{M_d}\right) \tag{12}$$

where:

P_p = percent passing the No. 200 (75-µm) sieve, nearest 0.1 %,

M_d = initial dry mass of the sedimentation specimen without dispersant, nearest 0.01 g, and

M_{dr} = dry mass retained on the No. 200 (75-µm) sieve, nearest 0.01 g.

13. Report: Test Data Sheet(s)/Form(s)

13.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.13 and in Practice D6026.

13.2 Record as a minimum the following general information (data):

13.2.1 Identification of the material being tested, such as the project identification, boring number, sample number, and depth.

13.2.2 Test number, if any, testing dates and the initials of the person(s) who performed the test.

13.2.3 The sample preparation method used: moist or air-dried

13.2.4 The specific gravity of the sedimentation specimen and indicate if the value is assumed or measured.

13.2.5 The following apparatus identification used during the test:

13.2.5.1 Hydrometer type (151H or 152H) and identification number.

13.2.5.2 Sedimentation cylinder identification number.

13.2.5.3 Thermometric device identification number.

13.2.5.4 Balance identification number.

13.2.5.5 Oven identification number.

13.2.5.6 Wet washing sieve identification number.

13.2.6 Description and classification of the soil in accordance with Practice D2488 or when Atterberg limit data are available, Practice D2487.

13.2.7 Describe any material that was excluded from the specimen.

13.2.8 Describe any problems that were encountered.

13.2.9 Indicate any prior testing performed on the specimen.

13.3 Record as a minimum the following test specimen data:

13.3.1 The size of the separation sieve used.

13.3.2 The estimated percentage passing the No. 200 (75-µm) sieve, moist mass, and water content calculated or used in 9.5.

13.3.3 The water content of the material passing the No. 10 (2.0 mm) or finer sieve, if determined.

13.3.4 Moist mass of the sedimentation specimen.

13.3.5 Dry mass of the sedimentation specimen and indicate how obtained: using companion water content or direct measurement after testing.

13.3.6 Amount of dispersant used in the test.

13.3.7 The dry mass of the specimen plus dispersant, if applicable.

13.3.8 The percent passing the No. 200 (75-µm) sieve.

13.3.9 The start time and date of the test.

13.3.10 Indicate if a foam inhibitor was used.

13.3.11 The maximum particle diameter of the material for each hydrometer reading.

13.3.12 The mass percent finer for each hydrometer reading.

13.3.13 The hydrometer, temperature, elapsed time, offset, and effective depth readings from the sedimentation test.

13.3.14 Tabulation of the mass percent finer including the particle diameter in mm.

13.3.15 A graph of the percent passing versus the log of particle size in mm.

NOTE 25—Appendix X1 shows an example data sheet and an example of the graphical display of the results of the test.

14. Precision and Bias

14.1 *Precision*—Test data on precision is not presented due to the nature of the soil materials tested by this test method. An ISR round-robin testing program was conducted; however, the data has not yet been compiled. Subcommittee D18.03 is in the process of determining how to report the data from the ISR round-robin testing.

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

15. Keywords

15.1 clay; grain-size; hydrometer analysis; particle-size distribution (gradation); sedimentation; sieve analysis; silt

ANNEX

A1. CHECK OF HYDROMETER AND SEDIMENTATION CYLINDER

(Mandatory Information)

A1.1 *General*—There are many factors controlling the overall accuracy of sedimentation (hydrometer) test results. This section covers how the equipment constants used in calculating the sedimentation (hydrometer) test results are determined or checked. The equipment tolerances for the hydrometer and sedimentation cylinder are presented below.

A1.2 *Hydrometer Standard Dimensions* —The 152H and 151H hydrometers have specified dimensions in accordance with Specification E100, as shown in Fig. A1.1, and the hydrometer constants or equipment accuracy checks are listed with the accepted tolerances and summarized below.

A1.2.1 The distance from the key reference point on the nominal scale to the top or bottom of the hydrometer bulb H_t and H_b in mm. The key reference point on the nominal scale for 152H hydrometers is 0.0 g/L and 1.000 specific gravity for a 151H hydrometer.

A1.2.1.1 $H_t = 103 – 130$ mm, with an average of 116.5 mm.

A1.2.1.2 $H_b = 244 – 246$ mm.

A1.2.2 The overall length of the hydrometer bulb, H_{Lb} in mm.

A1.2.2.1 $H_{Lb} = 115 – 142$ mm, with an average of 128.5 mm.

A1.2.3 The distance from the top or bottom of the hydrometer's bulb to the maximum diameter of the bulb, H_{ct} or H_{cb} in mm (Note A1.1).

NOTE A1.1—It is possible for the maximum diameter and the center of (volume) buoyancy to have different locations on the bulb. When calculating effective depth, the location of the center of (volume) buoyancy should be used to calculate H_{r1} and H_{r2}, not the location of the maximum diameter.

A1.2.3.1 H_{ct} or $H_{cb} = 58 – 71$ mm, with an average of 64.5 mm assuming the volume of the bulb is symmetrical.

A1.2.4 The distance from the key reference point on the nominal scale to the center of the bulb's volume, H_{Lc} in mm.

A1.2.4.1 $H_{Lc} = 174 – 188$ mm, with an average of 181 mm.

A1.2.5 The length of the quoted nominal scale as stated in Specification E100, H_s in mm.

A1.2.5.1 $H_s = 82 – 84$ mm, with an average of 83 mm.

A1.2.6 The distance between scale divisions, ΔH_s in mm/division (Note A1.2).

A1.2.6.1 ΔH_s for 152H: Quoted scale of 0 – 50 g/L or 50 divisions, $\Delta H_s = 1.66 \pm 0.02$ mm. Full (actual) scale is -5 – 60 g/L.

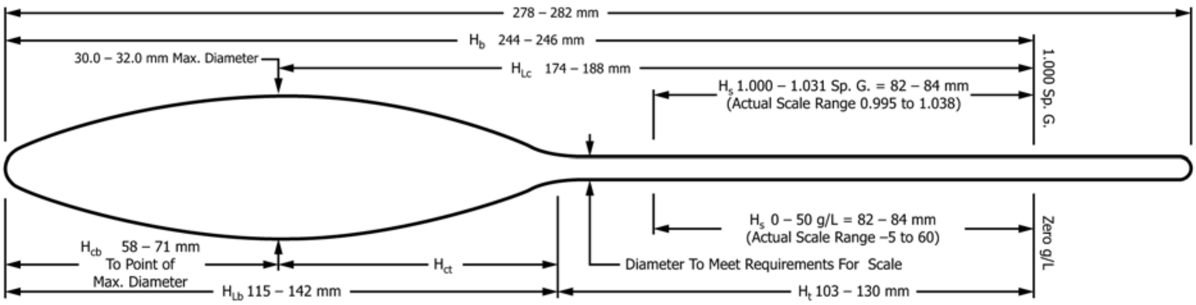


FIG. A1.1 Soil Hydrometer (151H or 152H)

A1.2.6.2 151H: Quoted scale of 1.000 – 1.031 specific gravity or 31 divisions, ΔH_s = 2.68 ± 0.03 mm. Full (actual) scale is 0.995 – 1.038 specific gravity.

A1.2.7 The submerged volume of the hydrometer bulb, V_{hb} in mL or cm^3.

A1.2.7.1 V_{hb} is not a constant and shall be measured for each hydrometer.

A1.2.8 The accuracy of the scale key reference point(s) on the hydrometer scale.

A1.2.8.1 The scale key reference point for the 152H hydrometer is 0.0 ± 1 g/L and 1.000± 0.001 specific gravity for the 151H hydrometer read at the bottom of the meniscus.

A1.2.9 The length of the stem above and below the scale in mm.

A1.2.9.1 Stem shall be uniform and extend at least 15 mm above the top of the graduation and remain cylindrical for at least 3 mm below the lowest graduation.

NOTE A1.2—It is assumed that ΔH_s is uniform over the length of the scale; however, this assumption is not true in accordance with Test Method E126. The equation in Test Method E126 works fine for the 151H hydrometers, but not for the 152H hydrometers since they start at zero. Based on the Test Method E126 equation, the difference in ΔH_s at the top and bottom of the 151H scale is about 6 %.

A1.3 *Checking the Dimensions*—The dimensions provided in A1.2.1 through A1.2.8 shall be checked and documented prior to use. The dimensions provided in A1.2.9 shall be checked and documented once every 12 months. If any of the standard dimensions do not fall within the allowable ranges, the hydrometer shall not be used.

A1.3.1 *Distance/Length*—The length dimensions shall be made and recorded to the nearest 0.5 mm. They can be made using either, and given in order of preference: a height gauge (digimatic, dial, or vernier), calipers (digimatic, dial, or vernier), or a ruler and square (the square is used to transcribe the measurement from the hydrometer to the ruler). The line of contact between the hydrometer stem and bulb can be established and marked using one of two methods. The first choice is to measure the diameter of the stem with calipers, increasing this measurement by about 1 mm and marking the spot where the calipers encounter the bulb. The other method is to visually determine this line of contact and mark it. The visual determination may be assisted by feeling the contact point with fingers. Marking can be accomplished by placing lengthwise a thin strip of label paper/marking tape across the line of contact and then marking it with a pencil.

A1.3.2 *Scale Length*—The quoted scale length shall be measured and recorded to the nearest 0.5 mm using either calipers or a machinist ruler. The distance between scale divisions is simply that length divided by the number of divisions and recorded to the nearest 0.01 mm/div. The error stated in Note A1.1 is ignored.

A1.3.3 *Scale Key Reference Points*—The 152H hydrometer should read 0.0 ± 1 g/L and 1.000 ± 0.001 specific gravity for the 151H hydrometer at the bottom of the meniscus when placed in distilled water that is free of gas bubbles at the calibration temperature of the hydrometers. At temperatures other than the calibration temperature of the hydrometer, the required reading shall be adjusted by the ratio of the density of water at the calibration temperature to the density of water at the check temperature. The check temperature shall be measured to the nearest 0.5°C and the density value associated with that temperature obtained from Table A1.1. If the hydrometer does not read within the allowable range, it shall not be used.

A1.3.4 *Volume*—The volume dimension, V_{hb}, shall be made and recorded to the nearest 1 cm^3 using either the direct or indirect method. The direct method is done by inserting the hydrometer into a graduated cylinder filled with test water having a minimum scale sensitivity of 5 mL per division. Read and record the volume in the cylinder prior to inserting the hydrometer to the nearest 2 mL. Insert the hydrometer into the test water just to the base of the stem then read and record the volume to the nearest 2 mL. The volume of the hydrometer is the difference in the volume readings before and after insertion into the test water. The volume is the average of three determinations that are within 2 mL of each other. The indirect method is done by determining the mass of the hydrometer. The volume can be measured by placing a partially filled beaker of room temperature test water on a balance, zero or tare the balance, and then lowering the hydrometer into the water just to the base of the stem. While holding the hydrometer in place, read and record the mass of displaced water to the nearest 0.1 g. Using an approximate mass density of water equal to unity (1), the volume of the hydrometer bulb in cm^3 will be equal to the mass reading.

A1.3.5 *Center of (Volume) Buoyancy*—Determine the center of (volume) buoyancy using the direct or indirect method described in A1.3.4, except the bulb is inserted until the mass or water level change is half of the volume of the bulb as determined in A1.3.4.

A1.4 *Sedimentation Cylinder Dimensions*—The sedimentation cylinder constants or equipment accuracy checks are listed with the accepted tolerances and summarized below. The cylinder shall be checked and documented prior to use.

A1.4.1 The accuracy of key volume mark is 1,000 ± 5 mL in mL or cm^3.

A1.4.1.1 *Volume*—Verify the 1,000 mL mark is correct by performing the following steps. Place the cylinder on a balance and zero it. Add distilled water free of air bubbles, having a known temperature, T, nearest 1°C, to the cylinder until the balance reads the required mass, M_w. The mass, M_w, in g, equals 1,000 times the density of water, ρ_w, at T taken from Table A1.1. Read the water level at the bottom of the meniscus. The level should be within about 5 mL or ~2 mm of the 1,000 mL mark on the cylinder. If the mark is not correct, remark the cylinder with the correct 1,000 mL line or do not use the cylinder. If the cylinder is remarked, the correct or incorrect line shall be clearly marked as such to prevent misuse of the incorrect line marking. Record the volume to the nearest 0.1 cm^3.

A1.4.2 The inside area, A_c, in cm^2.

A1.4.2.1 *Area*—Determine the inside area of the cylinder, A_c, by using a commercial-grade meter stick or tape measure

TABLE A1.1 Density of Water (ρ_w) Versus Temperature (T)[A]

T (°C)	ρ_w (g/ML)	T (°C)	ρ_w (g/ML)	T (°C)	ρ_w (g/ML)	T (°C)	ρ_w (g/ML)
15.0	0.99910	16.0	0.99895	17.0	0.99878	18.0	0.99860
.1	0.99909	.1	0.99893	.1	0.99876	.1	0.99858
.2	0.99907	.2	0.99891	.2	0.99874	.2	0.99856
.3	0.99906	.3	0.99890	.3	0.99872	.3	0.99854
.4	0.99904	.4	0.99888	.4	0.99871	.4	0.99852
.5	0.99902	.5	0.99886	.5	0.99869	.5	0.99850
.6	0.99901	.6	0.99885	.6	0.99867	.6	0.99848
.7	0.99899	.7	0.99883	.7	0.99865	.7	0.99847
.8	0.99898	.8	0.99881	.8	0.99863	.8	0.99845
.9	0.99896	.9	0.99879	.9	0.99862	.9	0.99843
19.0	0.99841	20.0	0.99821	21.0	0.99799	22.0	0.99777
.1	0.99839	.1	0.99819	.1	0.99797	.1	0.99775
.2	0.99837	.2	0.99816	.2	0.99795	.2	0.99773
.3	0.99835	.3	0.99814	.3	0.99793	.3	0.99770
.4	0.99833	.4	0.99812	.4	0.99791	.4	0.99768
.5	0.99831	.5	0.99810	.5	0.99789	.5	0.99766
.6	0.99829	.6	0.99808	.6	0.99786	.6	0.99764
.7	0.99827	.7	0.99806	.7	0.99784	.7	0.99761
.8	0.99825	.8	0.99804	.8	0.99782	.8	0.99759
.9	0.99823	.9	0.99802	.9	0.99780	.9	0.99756
23.0	0.99754	24.0	0.99730	25.0	0.99705	26.0	0.99679
.1	0.99752	.1	0.99727	.1	0.99702	.1	0.99676
.2	0.99749	.2	0.99725	.2	0.99700	.2	0.99673
.3	0.99747	.3	0.99723	.3	0.99697	.3	0.99671
.4	0.99745	.4	0.99720	.4	0.99694	.4	0.99668
.5	0.99742	.5	0.99717	.5	0.99692	.5	0.99665
.6	0.99740	.6	0.99715	.6	0.99689	.6	0.99663
.7	0.99737	.7	0.99712	.7	0.99687	.7	0.99660
.8	0.99735	.8	0.99710	.8	0.99684	.8	0.99657
.9	0.99732	.9	0.99707	.9	0.99681	.9	0.99654
27.0	0.99652	28.0	0.99624	29.0	0.99595	30.0	0.99565
.1	0.99649	.1	0.99621	.1	0.99592	.1	0.99562
.2	0.99646	.2	0.99618	.2	0.99589	.2	0.99559
.3	0.99643	.3	0.99615	.3	0.99586	.3	0.99556
.4	0.99641	.4	0.99612	.4	0.99583	.4	0.99553
.5	0.99638	.5	0.99609	.5	0.99580	.5	0.99550
.6	0.99635	.6	0.99607	.6	0.99577	.6	0.99547
.7	0.99632	.7	0.99604	.7	0.99574	.7	0.99544
.8	0.99629	.8	0.99601	.8	0.99571	.8	0.99541
.9	0.99627	.9	0.99598	.9	0.99568	.9	0.99538

[A] Reference: CRC Handbook of Chemistry and Physics, David R. Lide, Editor-In-Chief, 74th Edition, 1993 – 1994.

reading in cm or mm. Insert the meter stick or tape measure into the cylinder until it touches the inside bottom of the cylinder. Read and record the distance from the inside bottom of the cylinder to the 1,000 mL mark to the nearest 1 mm. Repeat this procedure at two more locations on the inside bottom of the cylinder for a total of three readings. Determine and record the average distance, D_{1000}, to the nearest 1 mm. Calculate and record the area of the cylinder, A_c, ($A_c = 1{,}000 \times (10/D_{1000})$) to the nearest 0.1 cm^2.

NOTE A1.3—For example, if the 1,000 mL mark is determined to be 360 mm from the inside bottom of the cylinder, the inside area is 27.8 cm^2 and the diameter is then 59.5 mm. For a 63.5 mm inside diameter cylinder, the 1,000 mL mark should be approximately 316 mm from the inside bottom.

A1.4.3 The inside area's uniformity above the key volume mark.

A1.4.3.1 *Area Uniformity*—Determine and record the uniformity of the area above the 1,000 mL. Add 150 ± 1 mL or 150 ± 1g × ρ_w at T of bubble free, distilled water to the cylinder filled with 1,000 mL of distilled water. If the water surface raises 150 × (10/A_c) ± 0.25 mm, then the area is considered uniform. If this tolerance isn't met, the cylinder shall not be used.

APPENDIX

X1. EXAMPLE DATA SHEETS, GRAPH, AND EQUIPMENT CHECKS

(Nonmandatory Information)

X1.1 *General*—The data sheets in Fig. X1.1and Fig. X1.2 are provided as examples to assist the user by showing results of the calculations performed. Fig. X1.3 is provided as an example of how the results of Fig. X1.1 can be displayed graphically. Fig. X1.1 data is calculated using the calibration relationship and Fig. X1.2 data is calculated using the companion cylinder. Figs. X1.4-X1.6 are examples of typical checks of the hydrometer and sedimentation cylinder. Fig. X1.7 is an example of the meniscus correction and determination of the A constant for a 151H hydrometer.

HYDROMETER ANALYSIS (ASTM D7928)

DATE 08/15/15	PROJECT NAME: Example	PROJECT NO.: 081515

Boring: 1 Visual Identification:

Sample: 27 Test No.: NA

Depth (ft): 5.0 Prior Testing: ☒ No ☐ Yes: Type:

Balance ID: BA- 001 Thermometer ID: TD- 001 Separation Sieve: ☒ No. 10 or:

Oven ID: OV- 001 Wet Wash Sieve ID: WWSV- 200-1 Specimen Prep Method: ☒ Moist ☐ Air Dried

Estimated Moist Mass	
$W_{cest,}$(%):	12
%est:	90
$M_{mest,}$(g):	56

Mass of Moist Soil, M_m, (g)	59.19
Specimen-mixing Container ID:	KS-1

Dry Mass of Soil from Water Content	
Tare No.:	K33
Wet Soil + tare (g):	33.27
Dry Soil + tare (g):	31.44
Tare Mass (g):	14.21
Water Content (%)	10.6
Dry Mass, $M_{d,}$ (g):	53.51

Dry Mass of Soil Direct Meas.	
Tare No.:	
M_{dd} + tare (g):	
Tare Mass (g):	
M_{dd} (g):	
Dry Mass, $M_{d,}$ (g):	

Dispersion/Mixing

Date Dispersed/Mixed: 08/17/15 Dispersion Device: ☒ cup & mixer ☐ air jet: ☐ 69 kPa ☐ 172 kPa

Mixing Method: ☒ agitator ☐ Tipping: Time:______

Amount of Dispersant, M_{disp} (g): Direct Add. ☒ Dissolved in 100 mL water ☐ Contents mixed using: 5.03

Temperature-Density Correction: ☐ Control Cyl. ☒ Calib. Relationship Foam Inhibitor Used: ☐ Yes ☒ No

Temperature Control: ☒ Room control ☐ Chamber/Water bath Flocculation?: ☐ Yes ☒ No

Hydrometer ID. Type: ☒ 151H ☐ 152H	HY-002
Sedimentation Cylinder No.	1
Starting Date (mm/dd/yr)	8/18/2015
Starting Time (hr:min:sec)	10:18:00

No. 200 Wash Information	
Oven Drying Container ID:	JG-33
Container Mass, (g)	0.00
Dry Mass Retained after Washing + tare, (g):	6.24
Dry Mass Retained after Washing over No. 200 Sieve, M_{dr} (g)	6.24
% Passing the No. 200 Sieve	88.3
Specific Gravity of Soil ☐ Assumed ☒ Measured	2.67

Elapsed Time, T (min)	Hydrometer Reading r_m		Temp (°C)	Offset $r_{d,m}$	Effective Depth, H_m (cm)	D (mm)	Mass Percent (%) Finer, N_m
0	NA		NA	NA	NA	NA	NA
1	15.75	1.01575	22.5	1.0048	12	0.047	33
2	13.75	1.01375	22.5	1.0048	13	0.034	27
5	11.00	1.011	22.5	1.0048	13	0.022	18
8	10.00	1.010	22.5	1.0048	14	0.018	15
15	9.00	1.009	22.0	1.0049	14	0.013	12
30	7.50	1.0075	22.0	1.0049	14	0.0094	8
60	7.00	1.007	22.0	1.0049	15	0.0067	6
240	6.50	1.0065	22.0	1.0049	15	0.0033	5
1440	6.25	1.00625	20.0	1.0054	15	0.0014	3

Meniscus Correction, C_m: 0.0005

A constant: 1.0075

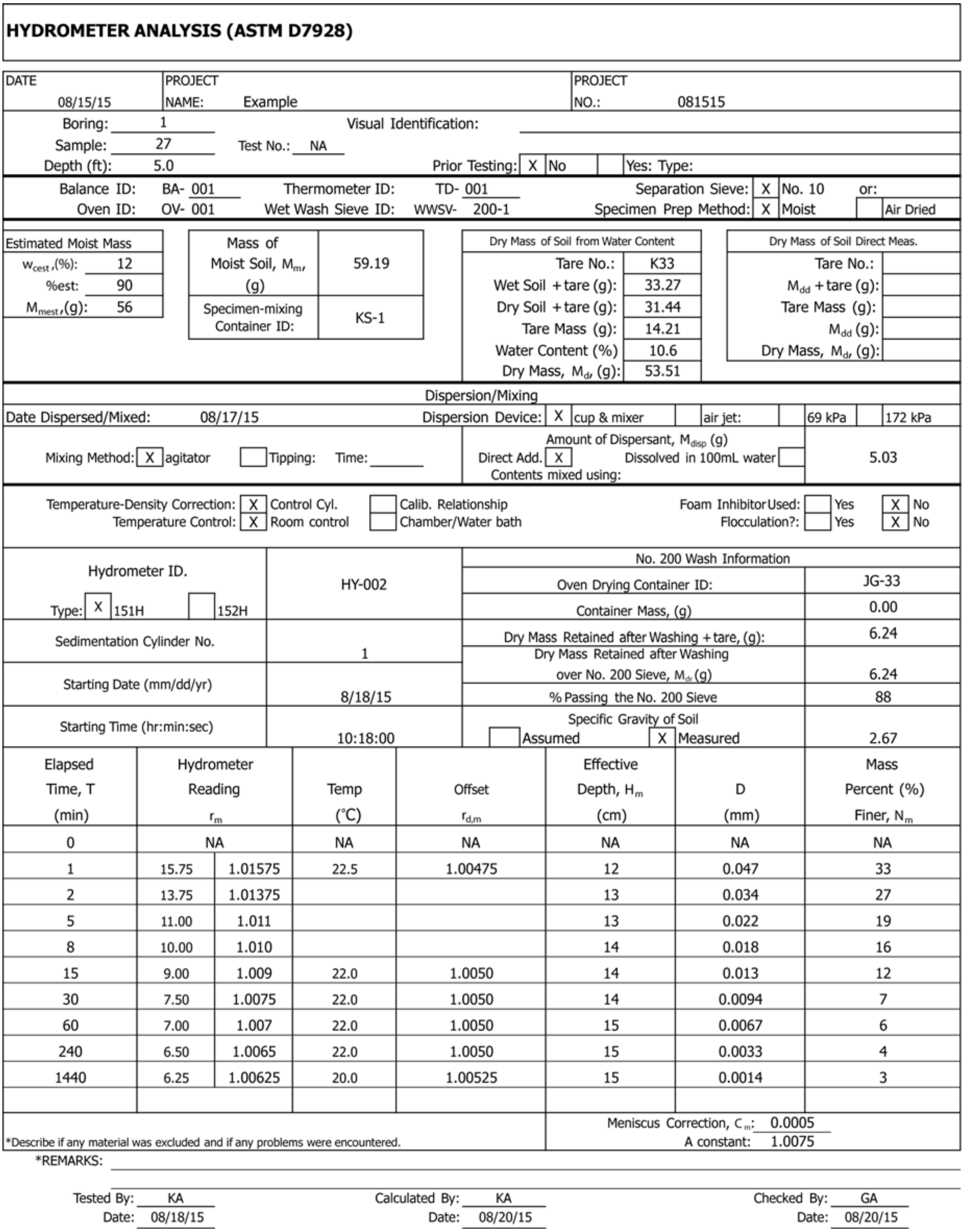
*Describe if any material was excluded and if any problems were encountered.

*REMARKS:

Tested By: KA Calculated By: KA Checked By: GA

Date: 08/18/15 Date: 08/20/15 Date: 08/20/15

FIG. X1.1 Example Data Sheet Using Calibration Relationship



HYDROMETER ANALYSIS (ASTM D7928)

DATE 08/15/15	PROJECT NAME: Example	PROJECT NO.: 081515

Boring: 1 Visual Identification:
Sample: 27 Test No.: NA
Depth (ft): 5.0 Prior Testing: ☒ No ☐ Yes: Type:

Balance ID: BA- 001 Thermometer ID: TD- 001 Separation Sieve: ☒ No. 10 or:
Oven ID: OV- 001 Wet Wash Sieve ID: WWSV- 200-1 Specimen Prep Method: ☒ Moist ☐ Air Dried

Estimated Moist Mass	
w_{cest},(%):	12
%est:	90
M_{mest},(g):	56

Mass of Moist Soil, M_m, (g)	59.19
Specimen-mixing Container ID:	KS-1

Dry Mass of Soil from Water Content	
Tare No.:	K33
Wet Soil + tare (g):	33.27
Dry Soil + tare (g):	31.44
Tare Mass (g):	14.21
Water Content (%)	10.6
Dry Mass, M_d, (g):	53.51

Dry Mass of Soil Direct Meas.	
Tare No.:	
M_{dd} + tare (g):	
Tare Mass (g):	
M_{dd} (g):	
Dry Mass, M_d, (g):	

Dispersion/Mixing

Date Dispersed/Mixed: 08/17/15 Dispersion Device: ☒ cup & mixer ☐ air jet: ☐ 69 kPa ☐ 172 kPa

Mixing Method: ☒ agitator ☐ Tipping: Time: ______

Amount of Dispersant, M_{disp} (g)
Direct Add. ☒ Dissolved in 100mL water ☐
Contents mixed using: 5.03

Temperature-Density Correction: ☒ Control Cyl. ☐ Calib. Relationship Foam Inhibitor Used: ☐ Yes ☒ No
Temperature Control: ☒ Room control ☐ Chamber/Water bath Flocculation?: ☐ Yes ☒ No

Hydrometer ID. Type: ☒ 151H ☐ 152H	HY-002
Sedimentation Cylinder No.	1
Starting Date (mm/dd/yr)	8/18/15
Starting Time (hr:min:sec)	10:18:00

No. 200 Wash Information	
Oven Drying Container ID:	JG-33
Container Mass, (g)	0.00
Dry Mass Retained after Washing + tare, (g):	6.24
Dry Mass Retained after Washing over No. 200 Sieve, M_{dr} (g)	6.24
% Passing the No. 200 Sieve	88
Specific Gravity of Soil ☐ Assumed ☒ Measured	2.67

Elapsed Time, T (min)	Hydrometer Reading r_m		Temp (°C)	Offset $r_{d,m}$	Effective Depth, H_m (cm)	D (mm)	Mass Percent (%) Finer, N_m
0	NA		NA	NA	NA	NA	NA
1	15.75	1.01575	22.5	1.00475	12	0.047	33
2	13.75	1.01375			13	0.034	27
5	11.00	1.011			13	0.022	19
8	10.00	1.010			14	0.018	16
15	9.00	1.009	22.0	1.0050	14	0.013	12
30	7.50	1.0075	22.0	1.0050	14	0.0094	7
60	7.00	1.007	22.0	1.0050	15	0.0067	6
240	6.50	1.0065	22.0	1.0050	15	0.0033	4
1440	6.25	1.00625	20.0	1.00525	15	0.0014	3

Meniscus Correction, C_m: 0.0005
A constant: 1.0075

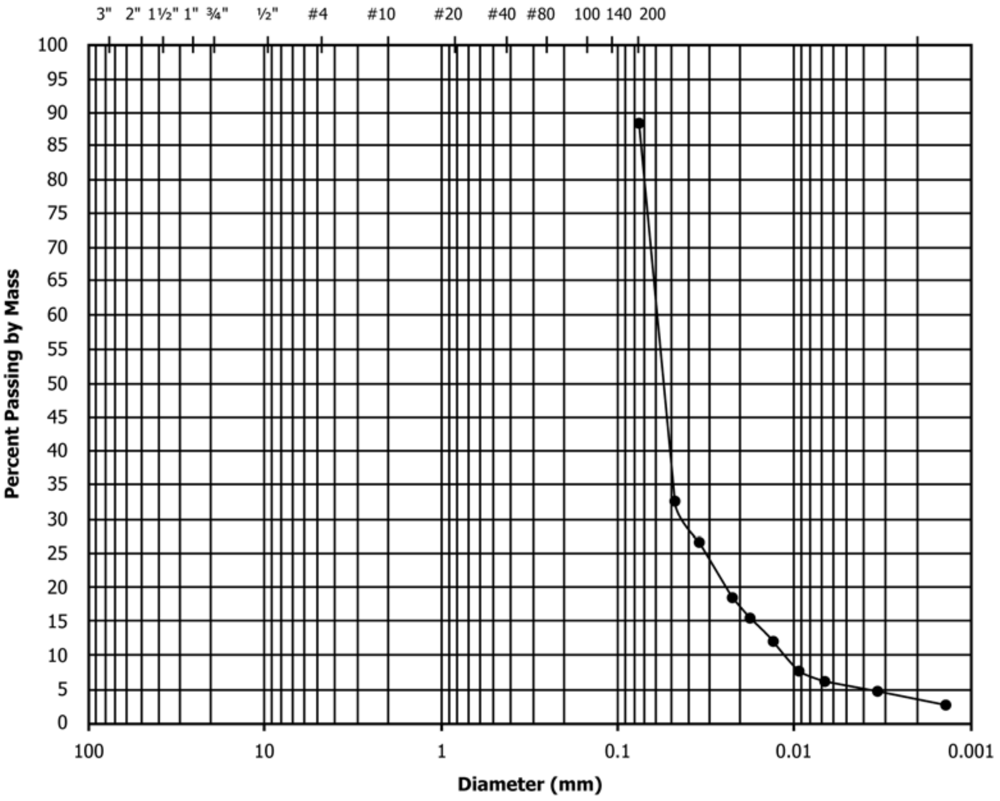
*Describe if any material was excluded and if any problems were encountered.

*REMARKS:

Tested By: KA Date: 08/18/15
Calculated By: KA Date: 08/20/15
Checked By: GA Date: 08/20/15

FIG. X1.2 Example Data Sheet Using Companion Measurement

PARTICLE SIZE DISTRIBUTION
ASTM D7928



Sand (%)	Fines (%)	
11.7	**88.3**	
	Silt	Clay
	85.0	3.3

Project No.: 081515 -- Project Name: Example
Boring: 1
Sample: 27 - Depth: 5 ft.

FIG. X1.3 Typical Graph of Data

Check of Hydrometers

Procedure: D7928

Date: 08/01/15

Date Due*: Before use/After Repair

Location: Soils Lab

Temperature 22 °C = 72 °F

*1 yr due date for items marked with *.

Check/Standard Equipment

Type:	Caliper
Manufacturer:	Pittsburgh
Model Number:	68304
Serial Number:	NA
Instrument Number:	XCD-001
Date Due:	20/03/16

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/16

Type:	Balance
Manufacturer:	Sartorius
Model Number:	3102-1S
Serial Number:	0032950176
Instrument Number:	BA-003
Date Due:	6/8/16

Instrument Identification/Data

Type	Hydrometer
Manufacturer	Chase
Model Number	NA
Serial Number	305055
Instrument Number	HY-002 ☒ 151H ☐ 152H
Previous Verification Date:	New

Check Data

	Instrument	PASS/FAIL	Tolerance (mm)
Top of Scale to Top of Hydrometer Bulb, H_t, (mm):	112.0	PASS	103-130
Top of Scale to Bottom of Hydrometer Bulb, H_b, (mm):	246.0	PASS	244-246
Overall Length of Hydrometer Bulb, H_{Lb} (mm):	134.0	PASS	115-142
Top of Hydrometer Bulb to Maximum Diameter, H_{ct}, (mm):	63.0	PASS	58-71
Bottom of Hydrometer Bulb to Maximum Diameter, H_{cb}, (mm)[1]:	71.0	PASS	58-71
Top of Scale (1.000) to Maximum Diameter, H_{Lc}, (mm):	174.0	PASS	174-188
Nominal Scale Length (1.000-1.031 or 0-50 g/L), (mm):	82.0	PASS	82-84
Distance Between Scale Divisions, Δ H_s, (mm/div):	2.65	PASS	1.64-1.68 2.65-2.71
Submerged Volume of Hydrometer Bulb, V_{hb}, (cm^3)[2]:	54	PASS	NA
Scale Reference Point (Sp.Gr or g/L)[3]:	1.001	PASS	1.001-0.999 1.0-1.0
*Stem extends 15 mm above the top graduation?:	Yes	PASS	Yes
*Stem cylindrical for at least 3 mm below lowest graduation?:	Yes	PASS	Yes
Stem Diameter (mm):	5.2	PASS	NA
Center of (Volume) Buoyancy, C_b, (cm^3):	27.0	PASS	NA
Top of Scale (0.995) to Center of Buoyancy, H_{r1}, (mm):	186.0	PASS	NA
Bottom of Scale (1.038) to Center of Buoyancy, H_{r2}, (mm)[1]:	70.0	PASS	NA

[2] Mass of Displaced Water

1 53.9 g

2 53.9 g

3 53.9 g

Avg. 53.9 g

[3] Temperature (°C): 22.0

Scale Rdg: 1.0001

Adj. Rdg: 1.0005

Equip. Status (Conforms/Nonconforms*): ________

*Who was notified? ________

Action Taken: ________

Checked By: KA

Date: 08/01/15

Input By: KA

Date: 08/01/15

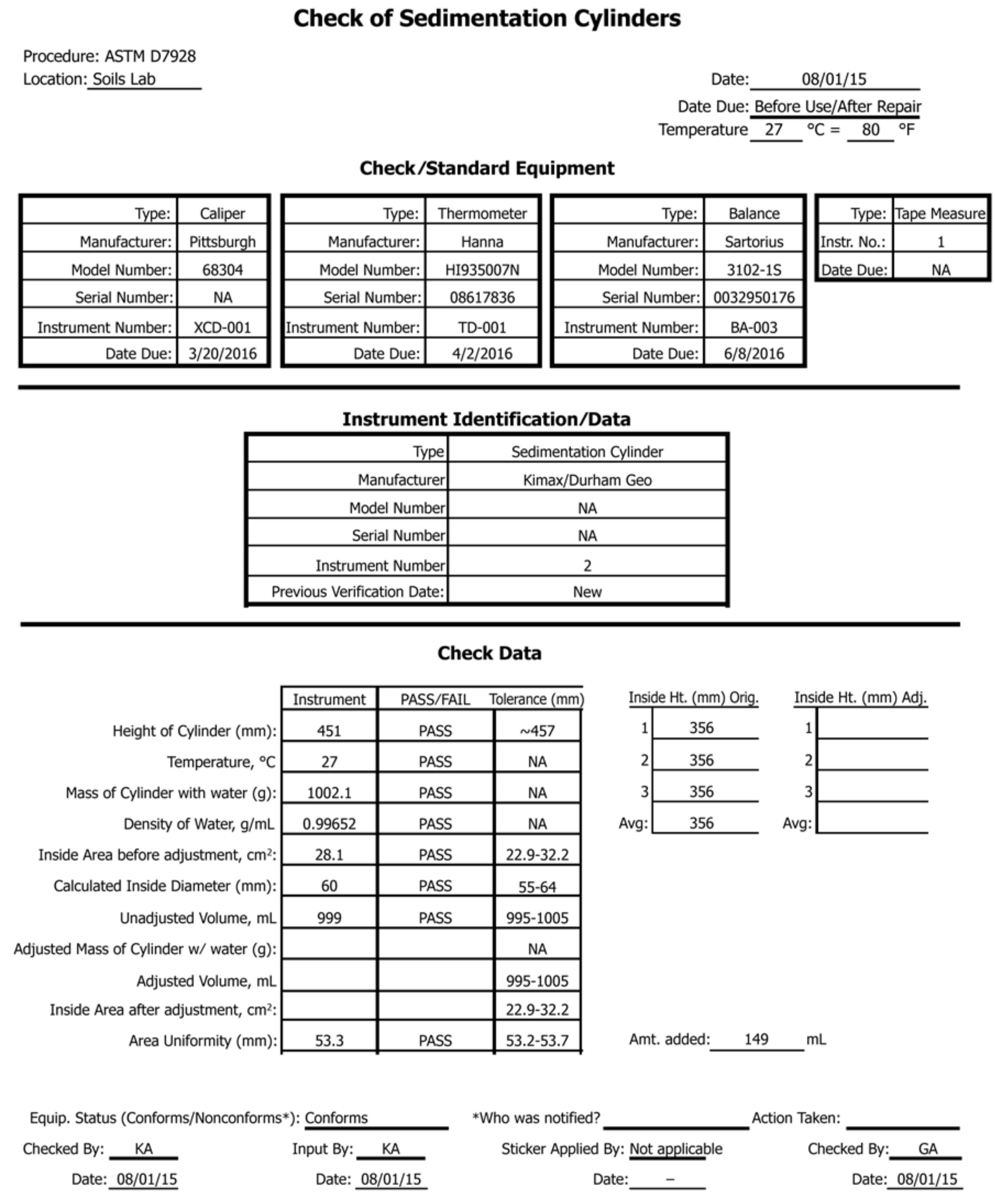
Sticker Applied By: Not Applicable

Date: –

Checked By: GA

Date: 08/01/15

FIG. X1.4 Example Hydrometer Check



Check of Sedimentation Cylinders

Procedure: ASTM D7928
Location: Soils Lab

Date: 08/01/15
Date Due: Before Use/After Repair
Temperature 27 °C = 80 °F

Check/Standard Equipment

Type:	Caliper
Manufacturer:	Pittsburgh
Model Number:	68304
Serial Number:	NA
Instrument Number:	XCD-001
Date Due:	3/20/2016

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/2016

Type:	Balance
Manufacturer:	Sartorius
Model Number:	3102-1S
Serial Number:	0032950176
Instrument Number:	BA-003
Date Due:	6/8/2016

Type:	Tape Measure
Instr. No.:	1
Date Due:	NA

Instrument Identification/Data

Type	Sedimentation Cylinder
Manufacturer	Kimax/Durham Geo
Model Number	NA
Serial Number	NA
Instrument Number	2
Previous Verification Date:	New

Check Data

	Instrument	PASS/FAIL	Tolerance (mm)
Height of Cylinder (mm):	451	PASS	~457
Temperature, °C	27	PASS	NA
Mass of Cylinder with water (g):	1002.1	PASS	NA
Density of Water, g/mL	0.99652	PASS	NA
Inside Area before adjustment, cm^2:	28.1	PASS	22.9-32.2
Calculated Inside Diameter (mm):	60	PASS	55-64
Unadjusted Volume, mL	999	PASS	995-1005
Adjusted Mass of Cylinder w/ water (g):			NA
Adjusted Volume, mL			995-1005
Inside Area after adjustment, cm^2:			22.9-32.2
Area Uniformity (mm):	53.3	PASS	53.2-53.7

	Inside Ht. (mm) Orig.	Inside Ht. (mm) Adj.
1	356	
2	356	
3	356	
Avg:	356	

Amt. added: 149 mL

Equip. Status (Conforms/Nonconforms*): Conforms
*Who was notified?
Action Taken:

Checked By: KA
Date: 08/01/15

Input By: KA
Date: 08/01/15

Sticker Applied By: Not applicable
Date: –

Checked By: GA
Date: 08/01/15

FIG. X1.5 Example Sedimentation Cylinder Check—No Adjustment

Check of Sedimentation Cylinders

Procedure: ASTM D7928
Location: Soils Lab

Date: 08/01/15
Date Due: Before Use/After Repair
Temperature 27 °C = 80 °F

Check/Standard Equipment

Type:	Caliper
Manufacturer:	Pittsburgh
Model Number:	68304
Serial Number:	NA
Instrument Number:	XCD-001
Date Due:	3/20/2016

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/2016

Type:	Balance
Manufacturer:	Sartorius
Model Number:	3102-1S
Serial Number:	0032950176
Instrument Number:	BA-003
Date Due:	6/8/2016

Type:	Tape Measure
Instr. No.:	1
Date Due:	NA

Instrument Identification/Data

Type	Sedimentation Cylinder
Manufacturer	Kimax/Durham Geo
Model Number	NA
Serial Number	NA
Instrument Number	1
Previous Verification Date:	New

Check Data

	Instrument	PASS/FAIL	Tolerance (mm)
Height of Cylinder (mm):	451	PASS	~457
Temperature, °C	27	PASS	NA
Mass of Cylinder with water (g):	987.9	PASS	NA
Density of Water, g/mL	0.99652	PASS	NA
Inside Area before adjustment, cm^2:	29.2	PASS	22.9-32.2
Calculated Inside Diameter (mm):	61	PASS	55-64
Unadjusted Volume, mL	984	FAIL	995-1005
Adjusted Mass of Cylinder w/ water (g):	998.5	PASS	NA
Adjusted Volume, mL	995	PASS	995-1005
Inside Area after adjustment, cm^2:	28.8	PASS	22.9-32.2
Area Uniformity (mm):	52.2	PASS	51.9-52.4

	Inside Ht. (mm) Orig.
1	343
2	343
3	343
Avg:	343

	Inside Ht. (mm) Adj.
1	348
2	347
3	347
Avg:	347

Amt. added: 150 mL

Equip. Status (Conforms/Nonconforms*): Initially: NC After Adj.: C

*Who was notified? Lab Manager

Action Taken: Line remarked.

Checked By: KA
Date: 08/01/15

Input By: KA
Date: 08/01/15

Sticker Applied By: Not applicable
Date: –

Checked By: GA
Date: 08/01/15

FIG. X1.6 Example Sedimentation Cylinder Check—Adjustment

Determination of the Constant A & C_m for Sedimentation Analysis

Procedure: ASTM D7928

Location: Soils Lab

Date: 08/01/15

Temperature 27 °C = 80 °F

Standard Equipment

Type:	Sed. Cylinder
Manufacturer:	Kimax/Durham Geo
Model Number:	NA
Serial Number:	NA
Instrument Number:	1
Date Due:	NA

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/2016

Type:	Hydrometer
Manufacturer:	Chase
Model Number:	151H
Serial Number:	305055
Instrument Number:	HY-002
Date Due:	NA

Data

Amount of Dispersant: 5.0 g

Top of Meniscus Reading: 0.9995

Plane Intersection Reading: 1.0000

Meniscus Correction, C_m: 0.0005

Temperature °C	Hydrometer Reading, $R_{151,t}$	A	
18.4	1.0055	1.0073	
20.3	1.00525	1.0075	
22.8	1.005	1.0078	
23.7	1.00475	1.0077	
27.3	1.00325	1.0072	
	Average:	**1.0075**	
	Std. Dev.:	0.0003	PASS

Verified By: KA
Date: 08/01/15

Input By: KA
Date: 08/01/15

Checked By: GA
Date: 08/01/15

FIG. X1.7 Example of Constant A and Meniscus Correction Determination

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 rights, and the risk of infringement of such rights, are entirely their own responsibility.

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.

Designation: D7012 – 14$^{\varepsilon 1}$

Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures[1]

This standard is issued under the fixed designation D7012; 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 (ε) indicates an editorial change since the last revision or reapproval.

ε^1 NOTE—Editorially corrected legend for Eq 3 in August 2017.

1. Scope

1.1 These four test methods cover the determination of the strength of intact rock core specimens in uniaxial and triaxial compression. Methods A and B determine the triaxial compressive strength at different pressures and Methods C and D determine the unconfined, uniaxial strength.

1.2 Methods A and B can be used to determine the angle of internal friction, angle of shearing resistance, and cohesion intercept.

1.3 Methods B and D specify the apparatus, instrumentation, and procedures for determining the stress-axial strain and the stress-lateral strain curves, as well as Young's modulus, *E*, and Poisson's ratio, υ. These methods make no provision for pore pressure measurements and specimens are undrained (platens are not vented). Thus, the strength values determined are in terms of total stress and are not corrected for pore pressures. These test methods do not include the procedures necessary to obtain a stress-strain curve beyond the ultimate strength.

1.4 Option A allows for testing at different temperatures and can be applied to any of the test methods, if requested.

1.5 This standard replaces and combines the following Standard Test Methods: D2664 Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements; D5407 Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements; D2938 Unconfined Compressive Strength of Intact Rock Core Specimens; and D3148 Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression. The original four standards are now referred to as Methods in this standard.

1.5.1 *Method A:* Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements.

1.5.1.1 Method A is used for obtaining strength determinations. Strain is not typically measured; therefore a stress-strain curve is not produced.

1.5.2 *Method B:* Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements.

1.5.3 *Method C:* Uniaxial Compressive Strength of Intact Rock Core Specimens.

1.5.3.1 Method C is used for obtaining strength determinations. Strain is not typically measured; therefore a stress-strain curve is not produced.

1.5.4 *Method D:* Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression.

1.5.5 *Option A: Temperature Variation*—Applies to any of the methods and allows for testing at temperatures above or below room temperature.

1.6 For an isotropic material in Test Methods B and D, the relation between the shear and bulk moduli and Young's modulus and Poisson's ratio are:

$$G = \frac{E}{2(1+\upsilon)} \tag{1}$$

$$K = \frac{E}{3(1-2\upsilon)} \tag{2}$$

where:

G = shear modulus,
K = bulk modulus,
E = Young's modulus, and
υ = Poisson's ratio.

1.6.1 The engineering applicability of these equations decreases with increasing anisotropy of the rock. It is desirable to conduct tests in the plane of foliation, cleavage or bedding and at right angles to it to determine the degree of anisotropy. It is noted that equations developed for isotropic materials may give

---

[1] These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved May 1, 2014. Published June 2014. Originally approved in 2004. Last previous edition approved in 2013 as D7012 – 13. DOI: 10.1520/D7012-14E01.

*A Summary of Changes section appears at the end of this standard only approximate calculated results if the difference in elastic moduli in two orthogonal directions is greater than 10 % for a given stress level.

NOTE 1—Elastic moduli measured by sonic methods (Test Method D2845) may often be employed as a preliminary measure of anisotropy.

1.7 Test Methods B and D for determining the elastic constants do not apply to rocks that undergo significant inelastic strains during the test, such as potash and salt. The elastic moduli for such rocks should be determined from unload-reload cycles that are not covered by these test methods.

1.8 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.9 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.9.1 The procedures used to specify how data are collected/recorded or calculated, in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analytical methods for engineering design.

1.10 *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.*

1.11 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D2845 Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock (Withdrawn 2017)[3]

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4543 Practices for Preparing Rock Core as Cylindrical Test Specimens and Verifying Conformance to Dimensional and Shape Tolerances (Withdrawn 2017)[3]

D6026 Practice for Using Significant Digits in Geotechnical Data

E4 Practices for Force Verification of Testing Machines

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

2.2 *ASTM Adjunct:*[4]

Triaxial Compression Chamber Drawings (3)

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms in this standard, refer to Terminology D653.

4. Summary of Test Method

4.1 A rock core specimen is cut to length and the ends are machined flat. The specimen is placed in a loading frame and if necessary, placed in a loading chamber and subjected to confining pressure. For a specimen tested at a different temperature, the test specimen is heated or cooled to the desired test temperature prior to the start of the test. The axial load on the specimen is then increased and measured continuously. Deformation measurements are not obtained for Methods A and C, and are measured as a function of load until peak load and failure are obtained for Methods B and D.

5. Significance and Use

5.1 The parameters obtained from Methods A and B are in terms of undrained total stress. However, there are some cases where either the rock type or the loading condition of the problem under consideration will require the effective stress or drained parameters be determined.

5.2 Method C, uniaxial compressive strength of rock is used in many design formulas and is sometimes used as an index property to select the appropriate excavation technique. Deformation and strength of rock are known to be functions of confining pressure. Method A, triaxial compression test, is commonly used to simulate the stress conditions under which most underground rock masses exist. The elastic constants (Methods B and D) are used to calculate the stress and deformation in rock structures.

5.3 The deformation and strength properties of rock cores measured in the laboratory usually do not accurately reflect large-scale *in situ* properties because the latter are strongly influenced by joints, faults, inhomogeneity, weakness planes, and other factors. Therefore, laboratory values for intact specimens must be employed with proper judgment in engineering applications.

NOTE 2—The quality of the result produced by this standard is

---

[2] 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.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Assembly and detail drawings of an apparatus that meets these requirements and which is designed to accommodate 54-mm diameter specimens and operate at a confining fluid pressure of 68.9 MPa are available from ASTM International Headquarters. Order Adjunct No. ADJD7012. Original adjunct produced in 1982.

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 D3740 are generally considered capable of competent and objective testing. Users of this standard are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable results depend on many factors; Practice D3740 provides a means for evaluating some of those factors.

6. Apparatus

6.1 *Compression Apparatus:*

6.1.1 *Methods A to D:*

6.1.1.1 *Loading Device*—The loading device shall be of sufficient capacity to apply load at a rate conforming to the requirements specified in 9.4.1. It shall be verified at suitable time intervals in accordance with the procedures given in Practices E4 and comply with the requirements prescribed in the method. The loading device may be equipped with a displacement transducer that can be used to advance the loading ram at a specified rate.

NOTE 3—For Methods A and B, if the load-measuring device is located outside the confining compression apparatus, calibrations to determine the seal friction need to be made to make sure the loads measured meet the accuracy specified in Practices E4.

6.2 *Confining System:*[4]

6.2.1 *Methods A and B:*

6.2.1.1 *Confining Apparatus*[5]—The confining pressure apparatus shall consist of a chamber in which the test specimen may be subjected to a constant lateral fluid pressure and the required axial load. The apparatus shall have safety valves, suitable entry ports for filling the chamber, and associated hoses, gages, and valves as needed.

6.2.1.2 *Flexible Membrane*—This membrane encloses the rock specimen and extends over the platens to prevent penetration by the confining fluid. A sleeve of natural or synthetic rubber or plastic is satisfactory for room temperature tests; however, metal or high-temperature rubber (viton) jackets are usually necessary for elevated temperature tests. The membrane shall be inert relative to the confining fluid and shall cover small pores in the specimen without rupturing when confining pressure is applied. Plastic or silicone rubber coatings may be applied directly to the specimen provided these materials do not penetrate and strengthen or weaken the specimen. Care must be taken to form an effective seal where the platen and specimen meet. Membranes formed by coatings shall be subject to the same performance requirements as elastic sleeve membranes.

6.2.1.3 *Pressure-Maintaining Device*—A hydraulic pump, pressure intensifier, or other system having sufficient capacity to maintain the desired lateral pressure to within ±1 % throughout the test. The confining pressure shall be measured with a hydraulic pressure gauge or electronic transducer having an accuracy of at least ±1 % of the confining pressure, including errors due to readout equipment, and a resolution of at least 0.5 % of the confining pressure.

6.2.1.4 *Confining-Pressure Fluids*—Hydraulic fluids compatible with the pressure-maintaining device and flexible membranes shall be used. For tests using Option A, the fluid must remain stable at the temperature and pressure levels designated for the test.

6.2.2 *Option A:*

6.2.2.1 *Temperature Enclosure*—The temperature enclosure shall be either an internal system that fits inside the loading apparatus or the confining pressure apparatus, an external system enclosing the entire confining pressure apparatus, or an external system encompassing the complete test apparatus. For high or low temperatures, a system of heaters or coolers, respectively, insulation, and temperature-measuring devices are normally necessary to maintain the specified temperature. Temperature shall be measured at three locations, with one sensor near the top, one at mid-height, and one near the bottom of the specimen. The "average" specimen temperature, based on the mid-height sensor, shall be maintained to within ±1°C of the specified test temperature. The maximum temperature difference between the mid-height sensor and either end sensor shall not exceed 3°C.

NOTE 4—An alternative to measuring the temperature at three locations along the specimen during the test is to determine the temperature distribution in a specimen that has temperature sensors located in drill holes at a minimum of six positions: along both the centerline and specimen periphery at mid-height and each end of the specimen. The specimen may originate from the same batch as the test specimens and conform to the same dimensional tolerances and to the same degree of intactness. The temperature controller set point may be adjusted to obtain steady-state temperatures in the specimen that meet the temperature requirements at each test temperature. The centerline temperature at mid-height may be within ±1°C of the specified test temperature and all other specimen temperatures may not deviate from this temperature by more than 3°C. The relationship between controller set point and specimen temperature can be used to determine the specimen temperature during testing provided that the output of the temperature feedback sensor or other fixed-location temperature sensor in the triaxial apparatus is maintained constant within ±1°C of the specified test temperature. The relationship between temperature controller set point and steady-state specimen temperature may be verified periodically. The specimen is used solely to determine the temperature distribution in a specimen in the triaxial apparatus. It is not to be used to determine compressive strength or elastic constants.

6.2.2.2 *Temperature Measuring Device*—Special limits-of-error thermocouples or platinum resistance thermometers (RTDs) having accuracies of at least ±1°C with a resolution of 0.1°C shall be used.

6.2.3 *Bearing Surfaces:*

6.2.3.1 *Methods A to D:*

(1) Platens—Two steel platens are used to transmit the axial load to the ends of the specimen. They shall be made of tool-hardened steel to a minimum Rockwell Hardness of 58 on the "C" scale. One of the platens shall be spherically seated and the other shall be a plain rigid platen. The bearing faces shall not depart from a plane by more than 0.015 mm when the platens are new and shall be maintained within a permissible variation of 0.025 mm. The diameter of the spherical seat shall be at least as large as that of the test specimen, but shall not exceed twice the diameter of the test specimen. The center of the sphere in the spherical seat shall coincide with that of the bearing face of the specimen. The spherical seat shall be

---

[5] Assembly and detail drawings of an apparatus that meets these requirements and which is designed to accommodate 21/8-in. (53.975-mm) diameter specimens and operate at a confining fluid pressure of 68.9 MPa are available from ASTM International Headquarters. Order Adjunct No. ADJD7012. Original adjunct produced in 1982.

properly lubricated to allow free movement. The movable portion of the platen shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated and tilted through small angles in any direction. If a spherical seat is not used, the bearing surfaces shall be parallel to 0.0005 mm/mm of platen diameter. The platen diameter shall be at least as great as that of the specimen and have a thickness-to-diameter ratio of at least 1:2.

6.3 *Deformation Devices:*

6.3.1 *Methods B and D:*

6.3.1.1 *Strain/Deformation Measuring Devices*—Deformations or strains may be determined from data obtained by electrical resistance strain gages, compressometers, linear variable differential transformers (LVDTs), or other suitable means. The strain/deformation measuring system shall measure the strain with a resolution of at least 25×10^{-6} strain and an accuracy within 2 % of the value of readings above 250×10^{-6} strain and accuracy and resolution within 5×10^{-6} for readings lower than 250×10^{-6} strain, including errors introduced by excitation and readout equipment. The system shall be free from non-characterized long-term instability (drift) that results in an apparent strain of 10^{-8}/s or greater.

NOTE 5—The user is cautioned about the influence of pressure and temperature on the output of strain and deformation sensors located within the confining pressure apparatus.

6.3.1.2 *Determination of Axial Strain*—The design of the measuring device shall be such that the average of at least two axial strain measurements can be determined. Measuring positions shall be equally spaced around the circumference of the specimen, close to midheight. The gauge length over which the axial strains are determined shall be at least ten grain diameters in magnitude.

6.3.1.3 *Determination of Lateral Strain*—The lateral deformations or strains may be measured by any of the methods mentioned in 6.3.1.1. Either circumferential or diametric deformations or strains may be measured. A single transducer that wraps around the specimen can be used to measure the change in circumference. At least two diametric deformation sensors shall be used if diametric deformations are measured. These sensors shall be equally spaced around the circumference of the specimen close to midheight. The average deformation or strain from the diametric sensors shall be recorded.

NOTE 6—The use of strain gauge adhesives requiring cure temperatures above 65°C is not allowed unless it is known that microfractures do not develop and mineralogical changes do not occur at the cure temperature.

6.4 *Timing Devices*—A clock, stopwatch, digital timer, or alike readable to 1 minute.

7. Safety Precautions

7.1 Danger exists near confining pressure testing equipment because of the high pressures and loads developed within the system. Test systems must be designed and constructed with adequate safety factors, assembled with properly rated fittings, and provided with protective shields to protect people in the area from unexpected system failure. The use of a gas as the confining pressure fluid introduces potential for extreme violence in the event of a system failure.

7.2 Many rock types fail in a violent manner when loaded to failure in compression. A protective shield shall be placed around the uniaxial test specimen to prevent injury from flying rock fragments.

7.3 Elevated temperatures increase the risks of electrical shorts and fire. The flash point of the confining pressure fluid shall be above the operating temperatures during the test.

8. Test Specimens

8.1 *Specimen Selection*—The specimens for each sample shall be selected from cores representing a valid average of the type of rock under consideration. This sample selection can be achieved by visual observations of mineral constituents, grain sizes and shape, partings and defects such as pores and fissures, or by other methods such as ultrasonic velocity measurements. The diameter of rock test specimens shall be at least ten times the diameter of the largest mineral grain. For weak rock types, which behave more like soil, for example, weakly cemented sandstone, the specimen diameter shall be at least six times the maximum particle diameter. The specified minimum specimen diameter of approximately 47-mm satisfy this criterion in the majority of cases. When cores of diameter smaller than the specified minimum must be tested because of the unavailability of larger diameter core, as is often the case in the mining industry, suitable notation of this fact shall be made in the report.

8.1.1 Desirable specimen length to diameter ratios are between 2.0:1 and 2.5:1. Specimen length to diameter ratios of less than 2.0:1 are unacceptable. If it is necessary to test specimens not meeting the length to diameter ratio requirements due to lack of available specimens, the report shall contain a note stating the non-conformance with this standard including a statement explaining that the results may differ from results obtained from a test specimen that meets the requirements. Laboratory specimen length to diameter ratios must be employed with proper judgment in engineering applications.

8.1.2 The number of specimens necessary to obtain a specific level of statistical results may be determined using Test Method E122. However, it may not be economically possible to achieve a specific confidence level and professional judgment may be necessary.

8.2 *Preparation*—Test specimens shall be prepared in accordance with Practice D4543.

8.2.1 Test results for specimens not meeting the requirements of Practice D4543 shall contain a note describing the non-conformance and a statement explaining that the results reported may differ from results obtained from a test specimen that meets the requirements of Practice D4543.

8.3 Moisture condition of the specimen at the time of test can have a significant effect upon the deformation of the rock. Good practice generally dictates that laboratory tests shall be made upon specimens representative of field conditions. Thus, it follows that the field moisture condition of the specimen shall be preserved until the time of test. On the other hand, there may be reasons for testing specimens at other moisture contents, including zero. In any case, the moisture content of the test specimen shall be tailored to the problem at hand and determined according to the procedures given in Method D2216. If moisture condition is to be maintained and the temperature enclosure is not equipped with humidity control, the specimen shall be sealed using a flexible membrane or by applying a plastic or silicone rubber coating to the specimen sides. If the specimen is to be saturated, porous sandstones may present little or no difficulty. For siltstone, saturation may take longer. For tight rocks such as intact granite, saturation by water may be impractical.

9. Procedure

9.1 *Seating:*

9.1.1 *Methods A to D:*

9.1.1.1 The spherical seat shall rotate freely in its socket before each test.

9.1.1.2 The lower platen shall be placed on the base or actuator rod of the loading device. The bearing faces of the upper and lower platens and of the test specimen shall be wiped clean, and the test specimen shall be placed on the lower platen. The upper platen shall be placed on the specimen and aligned properly.

9.2 *Confining Stress:*

9.2.1 *Methods A and B:*

9.2.1.1 The membrane shall be fitted over the specimen and platens to seal the specimen from the confining fluid. The specimen shall be placed in the test chamber, ensuring proper seal with the base, and connection to the confining pressure lines. A small axial load, <1 % of anticipated ultimate strength, may be applied to the confining compression chamber by means of the loading device to properly seat the bearing parts of the apparatus.

9.2.1.2 The chamber shall be filled with confining fluid and the confining stress shall be raised uniformly to the specified level within 5 min. The lateral and axial components of the confining stress shall not be allowed to differ by more than 5 percent of the instantaneous pressure at any time.

9.2.1.3 The predetermined confining pressure shall be maintained approximately throughout the test.

9.2.1.4 To make sure that no confining fluid has penetrated into the specimen, the specimen membrane shall be carefully checked for fissures or punctures and the specimen shall be examined with a hand lens at the completion of each confining test.

9.3 *Option A:*

9.3.1 Install the elevated-temperature enclosure for the apparatus used. The temperature shall be raised at a rate not exceeding 2°C/min until the required temperature is reached (Note 7). The test specimen shall be considered to have reached pressure and temperature equilibrium when all deformation transducer outputs are stable for at least three readings taken at equal intervals over a period of no less than 30 min (3 min for tests performed at room temperature). Stability is defined as a constant reading showing only the effects of normal instrument and heater unit fluctuations. Record the initial deformation readings, which are to be taken as zeroes for the test.

NOTE 7—It has been observed that for some rock types microcracking will occur for heating rates above 1°C/min. The operator is cautioned to select a heating rate such that microcracking does not significantly affect the test result.

9.4 *Applying Load:*

9.4.1 *Methods A to D:*

9.4.1.1 The axial load shall be applied continuously and without shock until the load becomes constant, is reduced, or a predetermined amount of strain is achieved. The load shall be applied in such a manner as to produce either a stress rate between 0.5 and 1.0 MPa/s or a strain rate as constant as feasible throughout the test. The stress rate or strain rate shall not be permitted at any given time to deviate by more than 10 % from that selected. The stress rate or strain rate selected shall be that which will produce failure of a cohort test specimen in compression, in a test time between 2 and 15 min. The selected stress rate or strain rate for a given rock type shall be adhered to for all tests in a given series of investigation (Note 8). Readings of deformation shall be observed and recorded at a minimum of ten load levels that are evenly spaced over the load range. Continuous data recording shall be permitted provided that the recording system meets the precision and accuracy requirements of 12.1.1. The maximum load sustained by the specimen shall be recorded. Load readings in kilonewtons shall be recorded to 2 decimal places. Stress readings in megapascals shall be recorded to 1 decimal place.

NOTE 8—Results of tests by other investigators have shown that strain rates within this range will provide strength values that are reasonably free from rapid loading effects and reproducible within acceptable tolerances. Lower strain rates may be permissible, if required by the investigation. The drift of the strain measuring system (see 6.3) may be constrained more stringently, corresponding to the longer duration of the test.

NOTE 9—Loading a high-strength specimen in load control to failure in a loading frame will often result in violent failure, which will tend to damage the strain/deformation measuring devices and be hazardous to the operator.

10. Calculations

10.1 For Methods C and D, the uniaxial compressive strength σ_u, of the test specimen shall be calculated as follows:

$$\sigma_u = \frac{P}{A} \tag{3}$$

where:

σ_u = uniaxial compressive strength (MPa),
P = failure load (N),
A = cross-sectional area (mm^2),

10.2 For Methods A and B, the triaxial compressive strength, σ, of the test specimen shall be calculated as follows:

$$\sigma = \sigma_1 - \sigma_3 \tag{4}$$

where:

σ = differential failure stress (MPa),
σ_1 = total failure stress (MPa), and
σ_3 = confining stress (MPa).

NOTE 10—Tensile stresses and strains are normally recorded as being positive. A consistent application of a compression-positive sign convention may be employed if desired. The sign convention adopted needs to be stated explicitly in the report. The formulas given are for engineering stresses and strains. True stresses and strains may be used, provided that the specimen diameter at the time of peak load is known.

NOTE 11—If the specimen diameter is not the same as the piston diameter through the triaxial apparatus, a correction may be applied to the measured load to account for the confining pressure acting on the difference in area between the specimen and the loading piston where it passes through the seals into the apparatus. The engineer must be knowledgeable in the differences in confinement test systems such as a Hoek cell, through piston chamber, integral load cell and external load cell.

10.3 *Methods B and D:*

10.3.1 Axial strain, ε_a and lateral strain, ε_l, shall be obtained directly from strain-indicating equipment or shall be calculated from deformation readings, depending on the type of apparatus or instrumentation employed. Strain readings shall be recorded to six decimal places.

10.3.2 Axial strain, ε_a shall be calculated as follows:

$$\varepsilon_a = \frac{\Delta L}{L} \tag{5}$$

where:

ε_a = axial strain (mm),
L = original undeformed axial gauge length (mm), and
ΔL = change in measured axial gauge length (mm).

NOTE 12—If the deformation recorded during the test includes deformation of the apparatus, suitable calibration for apparatus deformation shall be made. This may be accomplished by inserting into the apparatus a steel cylinder having known elastic properties and observing differences in deformation between the assembly and steel cylinder throughout the loading range. The apparatus deformation is then subtracted from the total deformation at each increment of load to arrive at specimen deformation from which the axial strain of the specimen is computed. The accuracy of this correction should be verified by measuring the elastic deformation of a cylinder of material having known elastic properties (other than steel) and comparing the measured and computed deformations.

10.3.3 Lateral strain, ε_1, shall be calculated as follows:

$$\varepsilon_1 = \frac{\Delta D}{D} \tag{6}$$

where:

ε_l = lateral strain (mm),
D = original undeformed diameter (mm), and
ΔD = change in diameter (mm); where positive is an increase in diameter and negative is a decrease in diameter.

NOTE 13—Many circumferential transducers measure change in chord length and not change in arc length (circumference). The geometrically nonlinear relationship between change in chord length and change in diameter must be used to obtain accurate values of lateral strain.

10.3.4 The stress-versus-strain curves shall be plotted for the axial and lateral directions, see Fig. 1. The complete curve gives the best description of the deformation behavior of rocks having nonlinear stress-strain relationships at low- and high-stress levels.

10.3.5 The value of Young's modulus, *E*, shall be calculated using any of several methods employed in engineering practice. The most common methods, described in Fig. 2, are as follows:

10.3.5.1 Tangent modulus at a stress level that is some fixed percentage, usually 50 % of the maximum strength.

10.3.5.2 Average slope of the straight-line portion of the stress-strain curve. The average slope shall be calculated either by dividing the change in stress by the change in strain or by making a linear least squares fit to the stress-strain data in the straight-line portion of the curve.

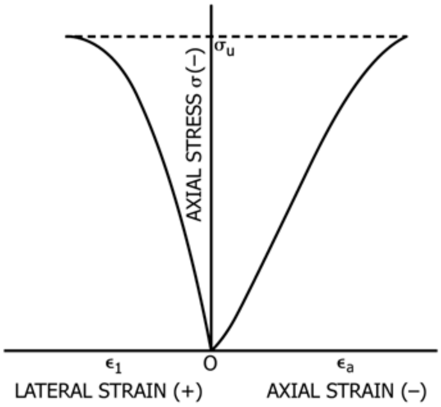


FIG. 1 Format for Graphical Presentation of Data

10.3.5.3 Secant modulus, usually from zero stress to some fixed percentage of maximum strength.

10.3.6 The value of Poisson's ratio, υ, is greatly affected by nonlinearity at low-stress levels in the axial and lateral stress-strain curves. It is desirable that Poisson's ratio shall be calculated from the following equation:

$$\upsilon = -\frac{\text{slope of axial curve}}{\text{slope of lateral curve}} \tag{7}$$

$$= -\frac{E}{\text{slope of lateral curve}}$$

where:

υ = Poisson's ratio
E = Young's modulus

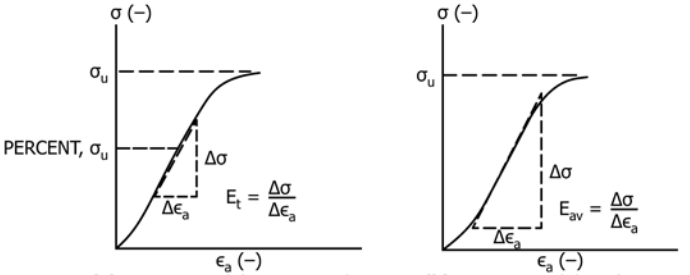
where the slope of the lateral curve is determined in the same manner as was done in 10.3.6 for Young's modulus, *E*.

NOTE 14—The denominator in Eq 7 will usually have a negative value if the sign convention is applied properly.

10.4 *Method A:*

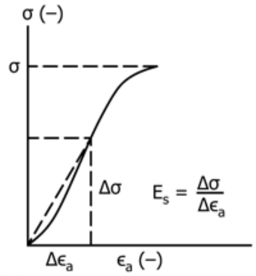
10.4.1 The Mohr stress circles shall be constructed on an arithmetic plot with shear stress as the ordinate and normal stress as the abscissa using the same scale. At least three triaxial compression tests should be conducted, each at a different confining pressure, on the same material to define the envelope to the Mohr stress circles. Because of the heterogeneity of rock and the scatter in results often encountered, good practice requires making at least three tests on essentially identical specimens at each confining pressure or single tests at nine different confining pressures covering the range investigated. Individual stress circles shall be plotted and used in drawing the envelope.

10.4.2 A "best-fit," smooth curve or straight line (Mohr envelope) shall be drawn approximately tangent to the Mohr circles, as shown in Fig. 3. The figure shall also include a brief note indicating whether a pronounced failure plane was or was not developed during the test and the inclination of this plane with reference to the plane of major principal stress. If the envelope is a straight line, the angle the line makes with the horizontal shall be reported as the angle of internal friction, φ, or the slope of the line as tan φ depending upon preference. The intercept of this line at the vertical axis is reported as the



(a) Tangent Modulus Measured at a Fixed Percentage of Ultimate Strength

(b) Average Modulus of Linear Portion of Axial Stress-Strain Curve



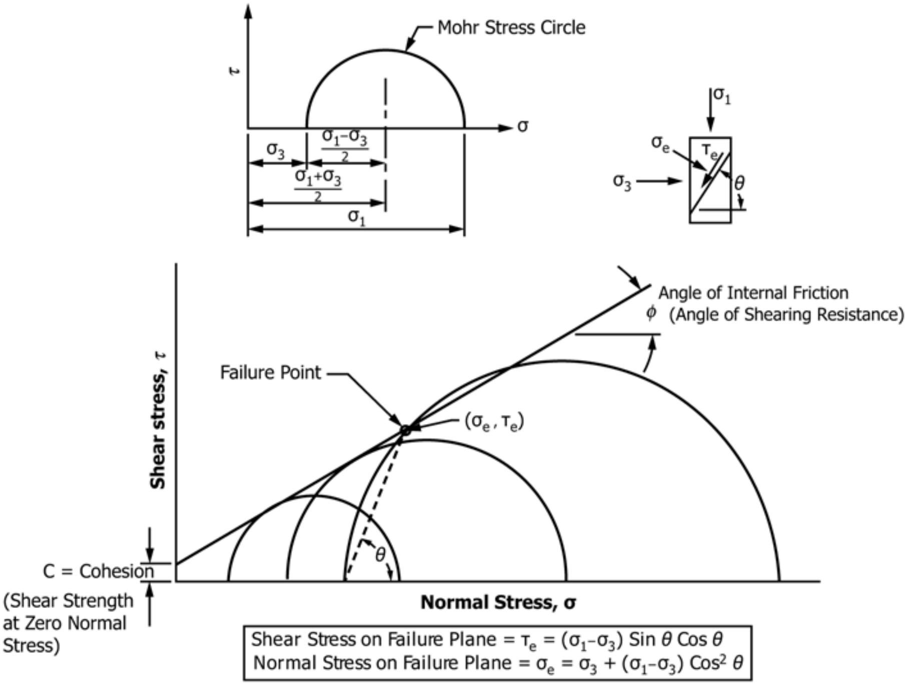
(c) Secant Modulus Measured up to a Fixed Percentage of Ultimate Strength

FIG. 2 Methods for Calculating Young's Modulus from Axial Stress-Axial Strain Curve

apparent cohesion intercept, *c*. If the envelope is not a straight line, values of φ or tan φ shall be determined by constructing a tangent to the Mohr circle for each confining pressure at the point of contact with the envelope and the corresponding cohesion intercept noted.

11. Report: Test Data Sheet(s)/Form(s)

11.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s) as given below, is covered in 1.9 and Practice D6026.



Shear Stress on Failure Plane = $\tau_e = (\sigma_1-\sigma_3)\ \mathrm{Sin}\ \theta\ \mathrm{Cos}\ \theta$

Normal Stress on Failure Plane = $\sigma_e = \sigma_3 + (\sigma_1-\sigma_3)\ \mathrm{Cos}^2\ \theta$

FIG. 3 Typical Mohr Stress Circles

11.2 Record as a minimum the following general information (data):

11.2.1 *Methods A–D:*

11.2.1.1 Source of sample including project name and location. Often the location is specified in terms of the drill hole number, angle and depth of specimen from the collar of the hole,

11.2.1.2 Name or initials of the person(s) who performed the test and the date(s) performed,

11.2.1.3 Lithologic description of the test specimen, formation name, and load direction with respect to lithology,

11.2.1.4 Moisture condition of specimen at the start of shear,

11.2.1.5 Specimen diameter and height, conformance with dimensional requirements,

11.2.1.6 Description of physical appearance of specimen after test, including visible end effects such as cracking, spalling, or shearing at the platen-specimen interfaces,

11.2.1.7 A sketch or photograph of the fractured specimen is recommended,

11.2.1.8 The actual equipment, procedures and the reasons for any variations shall be presented in detail,

11.2.1.9 Temperature at which test was performed if other than room temperature, to the nearest 0.5°C,

11.2.1.10 Any non-conformances with D4543 and the length to diameter ratios, include the explanation statements as describe in 8.1.2 and 8.2.1,

11.2.1.11 Time to failure,

11.2.1.12 Loading, stress, or strain rate as applicable based on method performed.

11.3 Record as a minimum the following test specimen data:

11.3.1 *Methods B and D:*

11.3.1.1 Plot of the stress-versus-strain curves (see Fig. 1),

11.3.1.2 Young's modulus, E, method of determination as given in Fig. 2, and at which stress level or levels determined, and

11.3.1.3 Poisson's ratio, υ, method of determination in 10.3.6, and at what stress level or levels determined.

11.3.1.4 Rate of loading or deformation rate.

11.3.2 *Method A:*

11.3.2.1 Confining stress level at which a triaxial test was performed,

11.3.2.2 Plot of the Mohr stress circles (see Fig. 3), and

11.3.2.3 Triaxial compressive strength as determined in 10.1 to the nearest MPa.

11.3.3 *Method C:*

11.3.3.1 Uniaxial compressive strength as determined in 10.1 to the nearest MPa.

NOTE 15—If failure is ductile, with the load on the specimen still increasing when the test is terminated, the strain at which the compressive strength was calculated may be reported.

TABLE 1 Compressive Strength (MPa) at 0 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	62.0	142.0	217.0
Repeatability	15.8	20.4	15.7
Reproducibility	22.4	38.0	27.7

TABLE 2 Compressive Strength (MPa) at 10 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	127.0	173.0	282.0
Repeatability	5.29	32.2	13.5
Reproducibility	22.5	38.3	25.7

TABLE 3 Compressive Strength (MPa) at 25 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	179.0	206.0	366.0
Repeatability	8.69	43.3	22.5
Reproducibility	34.7	51.8	31.0

TABLE 4 Compressive Strength (MPa) at 40 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	215.0	237.0	N/A
Repeatability	7.95	42.4	N/A
Reproducibility	52.0	73.5	N/A

TABLE 5 Young's Modulus (GPa) at 0 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25 %	50 %	25 %	50%	25 %	50 %
Average Value	12.4	16.7	76.3	74.2	46.9	54.2
Repeatability	3.37	4.15	14.8	10.1	6.12	6.75
Reproducibility	4.17	5.18	17.2	12.3	6.45	7.77

12. Precision and Bias

12.1 The data in Tables 1-5 are the products of the Interlaboratory Testing Program. Table 1 is the product of the work of seven laboratories with five replications. Table 5 is the product of the work of eight laboratories with five replications. Round 1 involved four rock types, but only the data from three were displayed here that were rock types used in all the series of tests. The remaining tables (Tables 6-10) are the products of Round 2 in which six laboratories each tested five specimens of three different rocks, three confining pressures and four replications. Details of the study are referenced in Section 2.2. The tables give the repeatability (within a laboratory) and reproducibility (between laboratories) for the compressive and confined methods and values for Young's Modulus and Poisson's ratio calculated for the intervals from 25 to 50 % and 40 to 60 % of the maximum differential stress at confining

TABLE 6 Young's Modulus (GPa) at 25 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	23.5	22.5	71.1	65.2	60.4	59.8
Repeatability	0.90	1.28	11.4	9.15	2.53	2.49
Reproducibility	3.34	3.47	13.9	11.6	6.80	6.12

TABLE 7 Young's Modulus (GPa) at 40 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	24.2	22.8	70.0	63.4	61.9	60.6
Repeatability	1.09	0.79	9.60	9.57	2.27	2.49
Reproducibility	3.82	3.57	9.69	9.57	5.95	5.34

TABLE 8 Poisson's Ratio at 10 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	0.28	0.34	0.30	0.33	0.26	0.30
Repeatability	0.03	0.04	0.03	0.07	0.03	0.03
Reproducibility	0.05	0.05	0.06	0.09	0.04	0.04

TABLE 9 Poisson's Ratio at 25 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	0.23	0.27	0.31	0.34	0.28	0.33
Repeatability	0.02	0.02	0.05	0.05	0.03	0.03
Reproducibility	0.04	0.04	0.06	0.05	0.04	0.05

TABLE 10 Poisson's Ratio at 40 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	0.20	0.24	0.32	0.34	0.29	0.33
Repeatability	0.01	0.02	0.04	0.05	0.03	0.04
Reproducibility	0.03	0.03	0.04	0.05	0.05	0.06

pressures of 10, 25, and 40 MPa and 25 % and 50 % for the compressive test case. Additional Reference Material found in ASTM Geotechnical Journal.[6,7]

12.1.1 The probability is approximately 95 % that two test results obtained in the same laboratory on the same material will not differ by more than the repeatability limit *r*. Likewise, the probability is approximately 95 % that two test results obtained in different laboratories on the same material will not differ by more than the reproducibility limit *R*. The precision statistics are calculated from:

$$r = 2\left(\sqrt{2}\right)s_r \tag{8}$$

where:

r = repeatability limit, and
s_r = repeatability standard deviation.

$$R = 2\left(\sqrt{2}\right)s_R \tag{9}$$

where:

R = reproducibility limit, and
s_R = reproducibility standard deviation.

12.2 *Bias*—Bias cannot be determined since there is no standard value of each of the elastic constants that can be used to compare with values determined using this test method.

13. Keywords

13.1 bulk modulus; compression testing; compressive strength; confined compression; elastic moduli; loading tests; modulus of elasticity; Mohr stress circle; Poisson's ratio; repeatability; reproducibility; rock; shear modulus; triaxial compression; uniaxial compression; Young's modulus

---

[6] Pincus, H. J., "Interlaboratory Testing Program for Properties: Round One-Longitudinal and Transverse Pulse Velocities, Unconfined Compressive Strength, Uniaxial Modulus, and Splitting Tensile Strength," *ASTM Geotechnical Journal*, Vol 16, No. 1, March 1993, pp. 138–163; and Addendum Vol 17, No. 2, June 1993, and 256–258.

[7] Pincus, H. J., "Interlaboratory Testing Program for Rock Properties: Round Two- Confined Compression: Young's Modulus, Poisson's Ratio, and Ultimate Strength," *ASTM Geotechnical Testing Journal*, Vol 19, No. 3, September 1996, pp. 321–336.

Designation: D7625 – 10

Standard Test Method for Laboratory Determination of Abrasiveness of Rock Using the CERCHAR Method[1]

This standard is issued under the fixed designation D7625; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the abrasiveness of rock by the CERCHAR Abrasiveness Index (CAI) method. The test method consists of measuring the wear on the tip of steel stylus with a cone shape and known Rockwell Hardness, caused by scratching against a freshly broken or saw cut rock surface for a prescribed 10 mm distance using one of the two test apparatus.

1.2 This test method is intended for freshly broken rock surfaces; however, saw cut surfaces are covered for when a satisfactory rock surface cannot be obtained.

1.3 Stylus Rockwell Hardness (HRC) can have a profound effect on the results and the focus of this test method is an HRC value of 55 for every test (**1**,**2**).[2] However, there are situations where stylus with different Rockwell Hardness can be used Therefore, this test method includes discussions on stylus with different Rockwell Hardness.

1.4 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D5079 Practices for Preserving and Transporting Rock Core Samples
D6026 Practice for Using Significant Digits in Geotechnical Data
E18 Test Methods for Rockwell Hardness of Metallic Materials

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *abrasiveness, n*—the wear or loss of material which the rock produces on contact with another material such as TBM cutter or drill bit.

3.2.2 *Rockwell Hardness Scale (HRC), n*—a hardness scale based on the indentation hardness of a material, which correlates linearly with its tensile strength. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. The results, as a dimensionless number, are noted by HR followed by the designation letter from A-F based upon used scale. For current standard, letter C is used as the scale letter for hard steel.

4. Summary of Test Method

4.1 A steel stylus having a 90E conical tip with its axis perpendicular, and in contact with a rock surface, under a total constant force of 70 N, is scratched in a direction parallel to the rock surface over a distance of 10 mm.

4.2 Basically, the CERCHAR test is a measurement of the relative different hardness of stylus tip and rock specimen surface. The stylus tip is made of steel having a known Rockwell Hardness. Experiments have shown that CAI varies inversely with stylus hardness. Test results with the same steel

---

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved May 15, 2010. Published July 2010. DOI: 10.1520/D7625–10.

[2] The bold numbers in parenthesis refer to a list of references at the end of this standard.

[3] 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.

type stylus but with different hardness need to be normalized to standard stylus hardness (**3**).

4.3 After the test, width of the wear flatness is measured on stylus tip surface in units of 0.1 mm and number of units reported as the CERCHAR Abrasiveness Index, 0.1mm (= 1CAI).

4.4 The scratch distance shall be limited to 10 mm. A CAI of 85 % is achieved after the first 2 mm of the scratch's length, and 15 % of the change in CAI is achieved on the last 8 mm of the testing length. Deviations in CAI due to variations of scratch length shall not be significant when the variation in testing length is kept between ±0.5 mm in length (**1**).

4.5 Five individual CAI tests shall be conducted for each rock specimen to achieve a defined average value (**1**). If there is not any obvious preference, for example, different colors, beddings, foliations on specimen, a set of three parallel tests in one direction, and two more perpendicular to first set shall be done.

5. Significance and Use

5.1 The CERCHAR test and associated CAI were developed at a time of more demand for application of mechanical excavation machines at the Laboratoire du Center d' Études et Recherches des Charbonnages de France (CERCHAR) (**4**). CAI is used to assess the abrasiveness of rock for mechanical excavation. Rock abrasiveness governs the performance of disc cutters, the rate of its replacement and therefore subsequent tunnel costs. Advances in methods of underground excavation, in particular the use of the tunnel boring machine (TBM), necessitates knowledge of rock abrasiveness. Abrasiveness expresses a behavioral characteristic of rock rather than a fundamental physical or mechanical property.

5.2 CAI tests were originally carried out on natural broken surfaces. In heterogeneous rock types such as conglomerates, coarse grained granite or schistose rock, suitable fresh test surfaces are not achieved by mechanical breakage using a hammer. In these cases CAI values for "smooth" surfaces cut with a diamond saw are acceptable for use but shall be normalized by Eq 2 before they can be used (**1**).

5.3 The test velocity for the Original Cerchar apparatus is approximately 10 mm/s and 1 mm/s for the West Cerchar apparatus. The CAI values obtained for both testing velocities (**1**) are estimated to be equal.

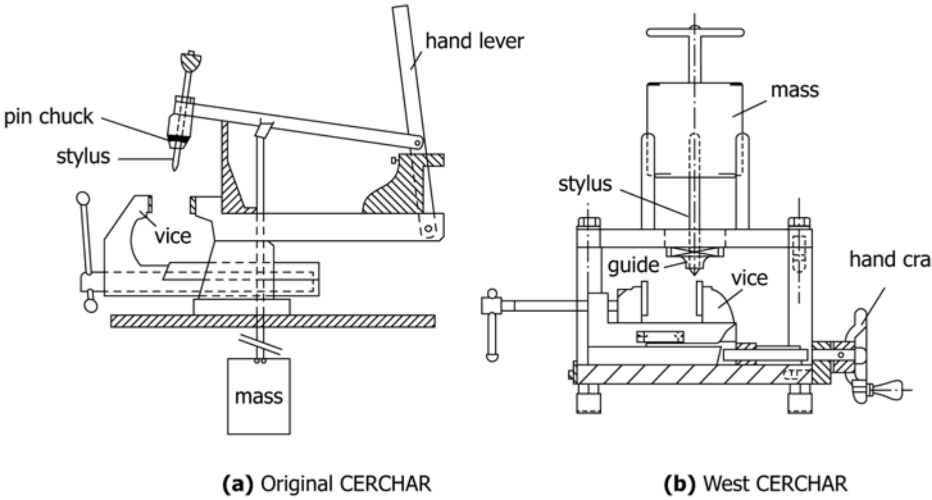
NOTE 1—The quality of the result produced by these practices is dependent upon the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing and sampling. Users of these practices are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *CERCHAR Apparatus*—Two types of Cerchar apparatus (**1**) are in use today (See Fig. 1). Both devices employ a vice to clamp the specimen and a constant force of 70 N acting axially on a stylus tip when place against the test surface. The original apparatus employs a manually operated hand lever to displace the stylus tip on the stationary rock surface held fixed in place by a vice. The West apparatus displaces the vice holding the rock by use of a hand crank and driving screw under a stationary stylus.

6.2 *Stylus*—As mentioned in the Scope, CERCHAR test is a measurement of the relative different hardness between the stylus tip and rock specimen surface. The stylus tip shall be made of steel having a known Rockwell Hardness. Experiments have shown that CAI varies inversely with steel hardness. Test results with the same steel type stylus but with different hardness should be normalized to standard stylus hardness (**3**). The use of stylus hardened to 55 HRC (**1**,**2**), and conforming to Test Methods E18 is advised. The length and diameter of stylus shall be greater than 15 mm and 10 mm respectively, and have a sharpened profile at one end to a conical angle of 90°, and 1 mm in length.

6.3 *Mass*—The static mass for either test apparatus shall be appropriately sized and configured so that the total force of 70



(a) Original CERCHAR **(b)** West CERCHAR

FIG. 1 Illustrations of Two Types of CERCHAR Testing Apparatuses

N, including any other components which would contribute any force to the stylus tip during testing. This force shall act axially on the stylus tip in contact with the specimen surface all the time during the test.

6.4 *Vice*—The vice in Fig. 1a shall be of sufficient rigidity, such that the clamped specimen is immobilized during the test. The vice in Fig. 1b holds the specimen and moves under the stylus by using the hand crank that advances the driving screw. Small wooden wedges may be used to ensure tightness of fit. Also, the vice shall have precise control of movement in two horizontal planes, with accurate positioning and change of position of the specimen with a secure hold.

6.5 *Resting Support*—a mechanism or configuration to hold the mass and stylus in a stationary position above the test surface location while setting up and removing the test specimen. The original Cerchar uses a resting support to place the lever arm on and the West Cerchar apparatus has a set of lock screws to grip onto the static mass.

6.6 *Hand Lever*—The articulated hand lever arm shall be of sufficient stiffness to displace the stylus over the rock surface allowing unrestrained vertical displacement of the stylus under the total force of 70 N (Fig. 1a).

6.7 *Hand Crank*—The hand crank screw-feed attached to the vice and powered manually with a crank displaces the vice holding a specimen under the stationary stylus. The screw-feed thread shall be machined such that displacement of the rock surface occurs at a constant displacement per revolution under the stationary stylus while allowing unrestrained vertical displacement of the stylus under the total force of 70 N (Fig. 1b).

6.8 *Microscope*—A toolmaker's microscope equipped with digital micrometer heads, XY stage and LCD readout are recommended. The microscope shall have a minimum magnification of 30X. The XY stage micrometer heads shall have a minimum range of 50 mm graduated to 0.01 mm and readable to 0.001 mm (**4**). Fig. 2 shows one example of this microscope with a stylus tip positioned under it, during flatness measurements.

6.9 *Grinder*—An apparatus that uses an abrasive stone wheel that is rotated and when place in contact with softer material removes material from that surface without appreciable wear to the stone wheel, or other suitable metal work apparatus, capable of shaping metal pen stock or sharpening the end of the stylus according to desired geometry. Cooling of the surface being ground by some type of fluid may be required in order not to heat up the metal excessively and change the original Rockwell hardness of the metal being used for the stylus.

6.10 *Miscellaneous*—Machinist's blue dye, wood shims, timer.

7. Sampling and Test Specimens

7.1 The specimen shall be selected from the core sample or pieces of in situ rock to represent a true average of the type of rocks to be drilled or bored. This can be achieved on a large scale by viewing rock types encountered at the project and on a smaller scale by visual observations of mineral constituents, grain sizes and shape, partings, and defects such as pores and fissures. Core or irregular shape specimens with a typical diameter or length of approximately 50 mm are recommended.

FIG. 2 Toolmaker's Microscope

7.2 The moisture conditions of the specimen at the time of test can have a significant effect upon the indicated strength of the rock. The field moisture condition for the specimen shall be preserved until the time of test in accordance with Practices D5079. This may be problematic when saw cut or drilled rock surfaces that need a water coolant are used instead of natural rock surfaces.

7.3 Specimens displaying apparent anisotropic features such as bedding or schistosity shall be prepared so that the orientation of the CAI test surface relative to anisotropic features can be determined precisely.

7.4 Specimen test surface shall be either fresh flat natural surface or saw cut one. For saw cut surface, specimen surfaces shall be prepared by cutting the rock sample with a water cooled diamond saw blade to expose fresh specimen surfaces provided the resulting surfaces are reasonably planar.

7.5 The specimen test surface should be of sufficient length such that edge chipping within the 10 mm test path does not occur as the stylus approaches the specimen outer dimension.

7.6 Specimens with either natural or saw cut test surfaces shall be trimmed to fit in the CERCHAR test machine by cutting the rock sample with a water cooled diamond saw blade.

7.7 Before and after photographs shall be taken of tested surfaces.

8. Preparation of Apparatus

8.1 The stylus shall be in good condition and verified under a microscope before use.

8.2 If stylus is not in good condition or previously used, then prior to testing, stylus tip shall be sharpened to the prescribed shape and condition described in 6.2. Special care shall be taken when re-sharpening used styli. High temperatures induced from sharpening too quickly can influence the styli hardness. Therefore application of a water coolant during re-sharpening process is recommended.

8.3 Regularly re-examining of stylus hardness is advised; Rockwell Hardness of stylus shall be 55.

8.4 Rockwell Hardness of stylus shall be verified in accordance with Test Methods E18.

8.5 Prior to testing, coating of each stylus tip with machinist's blue dye makes the wear flat area of the tip more visible under the microscope, and also helps to differentiate ready for test styli from used ones.

9. Procedure

9.1 Orient and securely clamp the test specimen in the vice such that the test surface is horizontal and parallel to the direction of displacement with the stylus. If necessary, use wood or other suitable materials between the vice and specimen surface to assist clamping and orienting the specimen.

9.2 The stylus and associated components are lowered with care to bear on the specimen test surface so that the stylus tip is not damaged before testing.

9.3 The static mass and any associated components are positioned and checked for functionality ensuring there are no frictional impediments to the specified 70 N total force.

9.4 Two scratching velocities are used depending on which device is available. A scratching distance of 10 mm is used for both devices.

9.4.1 The articulated hand lever is pulled over the test surface with a stylus scratching speed (**1**) of approximately 10 mm/s (Fig. 1a).

9.4.2 The hand crank is turned at a rate consistent with the number of threads on the screw-feed for moving the specimen surface under the stylus with a scratching speed of approximately 1 mm/s (Fig. 1b) (**1**).

9.5 Carefully lift the stylus, with it associated components, off the test surface and secure in the at rest position.

9.6 The tested stylus is taken off the apparatus and two perpendicular diameters of the abraded flat area of the stylus are measured under a microscope in 0.1 mm increments and recorded based on the observations and suggested action noted in Fig. 3.

9.7 The test is repeated 5 times, each time with a new/refurbished stylus on a new scratch location of the rock surface (see 4.4 and 4.5).

9.8 Where the results are sensitive to water content, it may be necessary to determine the actual water content of the specimen at the time of testing. Water content may be determined in accordance with Test Methods D2216.

10. Calculation or Interpretation of Results

10.1 The arithmetic average width of the wear flat of the stylus tip d_i (two perpendicular diameters of the abraded flat area for each of five used stylus), measured in units of 0.1 mm is reported as the CAI or CAI_s value, using Eq 1 (**1**):

$$CAI\, or\, CAI_s = \frac{1}{10}\sum_{1}^{10} d_i \tag{1}$$

where:

CAI or CAI_s = CERCHAR index for natural or saw cut surface respectively and d_i is diameter of the abraded flat area measured in units of 0.1 mm.

10.2 If saw cut specimen is tested, then calculated CAI_s of Eq 1, it is advised to be normalized using Eq 2 (**1**):

$$CAI = 0.99CAI_s + 0.48 \tag{2}$$

where:

CAI = CERCHAR index for natural surface, and
CAI_s = CERCHAR index for smooth (saw cut) surface from Eq 1.

10.3 The arithmetic average of CAI for each specimen shall be calculated and reported.

10.4 The CAI classification shall be determined from Table 1 based on the stylus tip Rockwell Hardness.

11. Report

11.1 Report the following information:

11.1.1 Sources of the specimen including project name and location, and if known, storage environment. The location is frequently specified in terms of the borehole number and depth of specimen from collar of hole. Specimens are frequently logged by chainage referenced to a benchmark.

11.1.2 Physical description of the specimen including fresh broken or saw cut rock surface, rock type, location and orientation of apparent weakness planes, bedding planes, and schistosity; large inclusions or in homogeneities, if any.

11.1.3 Sampling and testing dates, and name(s) of testing personnel.

11.1.4 As a minimum, a general indication of the moisture condition of test specimens at the time of testing, such as saturated, as received, laboratory air dry, or oven dry.

11.1.5 Direction of stylus displacement (parallel to or normal to plane of weakness or anisotropy directions, if any).

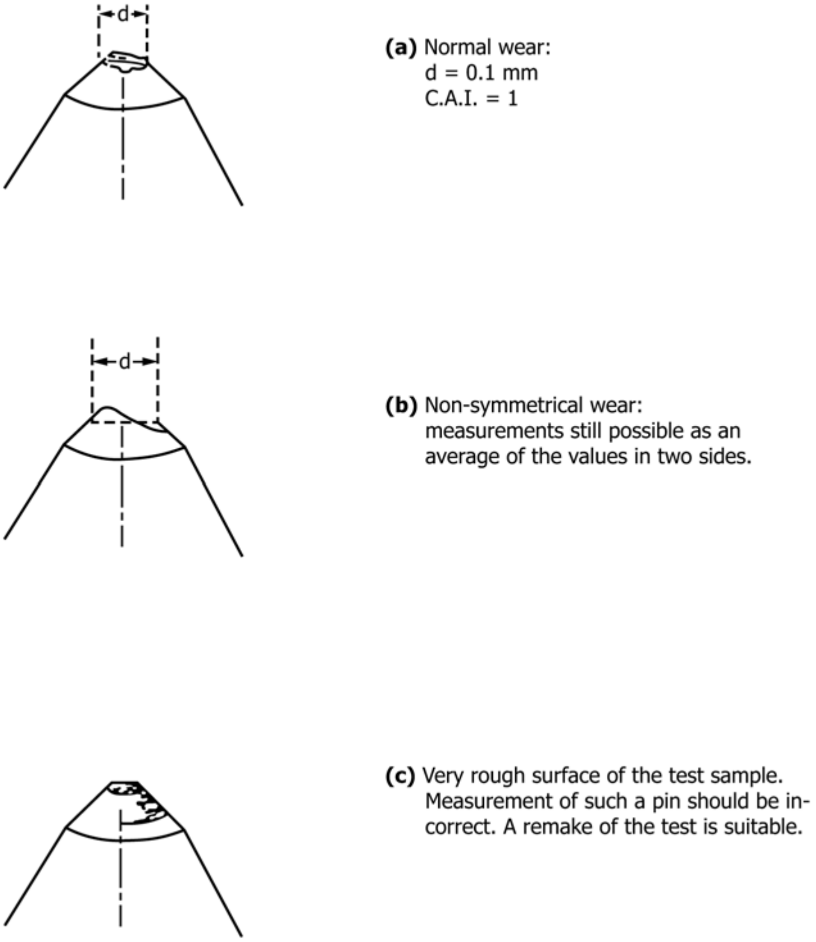
11.1.6 The number of specimens tested.

11.1.7 The stylus Rockwell Hardness, tip shape.

11.1.8 The calculated uncorrected, average, and corrected CAI values.

11.1.9 The CERCHAR apparatus type shall be recorded.

11.1.10 The specimen classification of abrasiveness based on Table 1.



(a) Normal wear:
d = 0.1 mm
C.A.I. = 1

(b) Non-symmetrical wear:
measurements still possible as an average of the values in two sides.

(c) Very rough surface of the test sample.
Measurement of such a pin should be incorrect. A remake of the test is suitable.

FIG. 3 Sketch of Abraded Shape of Extremity of Stylus After Testing Under a Microscope (5)

TABLE 1 Criteria for the CERCHAR Abrasiveness Index

Classification	Average CAI (3) (HRC=55)	Average CAI (2) (HRC=40)
Very low abrasiveness	0.30–0.50	0.32–0.66
Low abrasiveness	0.50–1.00	0.66–1.51
Medium abrasiveness	1.00–2.00	1.51–3.22
High abrasiveness	2.00–4.00	3.22–6.62
Extreme abrasiveness	4.00–6.00	6.62–10.03
Quartzitic	6.0–7.0	N/A

12. Precision and Bias

12.1 *Precision*—Test data on precision is not presented as it is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program.

12.2 The Subcommittee D18.12 is seeking any data from the users of this test method that might be used to make a limited statement on precision. Extensive preliminary data presented by others can be found in Ref. (2).

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

13. Keywords

13.1 abrasiveness; abrasivity; CERCHAR; disk cutter; mechanical excavation; Rockwell Hardness; TBM

REFERENCES

(1) Plinninger, R., Kasling, H., Thuro, K. and Spaun, G., "Testing conditions and geomechanical properties influencing the CERCHAR abrasiveness index (CAI) value," *International Journal of Rock Mechanics and Mining Sciences*, Vol 40, 2003, pp. 259-263.

(2) Michalakopoulos, T.N., Anagnostou, V.G., Bassanou, M.E. and Panagiotou, G.N., " The influence of steel styli hardness on the CERCHAR abrasiveness index value," National Technical University of Athens, Technical Note, 2005, 16p.

(3) Sanford, Julian and Hagan, Paul. "An Assessment of the impact of stylus metallurgy on the CERCHAR Abrasiveness Index value," Coal operators' conference, University of Wollongong, 12-13 Feb. 2009, pp. 347-355.

(4) West, G. " Rock Abrasiveness Testing for Tunnelling," Technical Note, *International Journal of Rock Mechanics and Mining Sciences & Geomechanics*, Vol 26, No 2, 1989, pp. 151-160.

(5) ROCTEST Limited. "The CERCHAR ABRASIVENESS INDEX," Geotechnical and Structural Instrumentation and Techniques, Montreal, Canada, 13 October 1986, 12p.

Designation: D1586/D1586M − 18

Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils[1]

This standard is issued under the fixed designation D1586/D1586M; 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 (ε) indicates an editorial change since the last revision or reapproval.

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

1. Scope*

1.1 This test method describes the procedure, generally known as the Standard Penetration Test (SPT), for driving a split-barrel sampler with a 140 lb [63.5 kg] hammer dropped 30 in. [750 mm] to obtain a soil sample for identification purposes, and measure the resistance of the soil to penetration of the standard 2 in. [50 mm] diameter sampler. The SPT "*N*" value is the number of hammer blows required to drive the sampler over the depth interval of 0.5 to 1.5 ft [0.15 to 0.45 m] of a 1.5 ft [0.45 m] drive interval.

1.2 Test Method D4633 is generally necessary to measure the drill rod energy of a given drop hammer system and using the measured drill rod energy, *N* values can be corrected to a standard energy level. Practice D6066 uses Test Methods D1586 and D4633 and has additional requirements for hammers, hammer energy, and drilling methods to determine energy corrected penetration resistance of loose sands for liquefaction evaluation.

1.3 Practice D3550/D3550M is a similar procedure using a larger diameter split barrel sampler driven with a hammer system that may allow for a different hammer mass. The penetration resistance values from Practice D3550/D3550M do not comply with this standard.

1.4 Test results and identification information are used in subsurface exploration for a wide range of applications such as geotechnical, geologic, geoenvironmental, or geohydrological explorations. When detailed lithology is required for geohydrological investigations, use of continuous sampling methods (D6282/D6282M, D6151/D6151M, D6914/D6914M) are recommended when the incremental SPT *N* value is not needed for design purposes (see 4.1.1).

1.5 Penetration resistance testing is typically performed at 5 ft [1.5 m] depth intervals or when a significant change of materials is observed during drilling, unless otherwise specified.

1.6 This test method is limited to use in nonlithified soils and soils whose maximum particle size is approximately less than one-half of the sampler diameter.

1.7 This test method involves use of rotary drilling equipment (Guide D5783, Practice D6151/D6151M). Other drilling and sampling procedures (Guides D6286 and D6169/D6169M) are available and may be more appropriate. Considerations for hand driving or shallow sampling without boreholes are not addressed. Subsurface investigations should be recorded in accordance with Practice D5434. Samples should be preserved and transported in accordance with Practice D4220/D4220M using Group B. Soil samples should be identified by group name and symbol in accordance with Practice D2488.

1.8 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

1.8.1 The procedures used to specify how data are collected/recorded and calculated in the standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of these test methods to consider significant digits used in analysis methods for engineering data.

1.9 *Units*—The values stated in either inch-pound or SI units [presented in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. Reporting of test results in units other than inch-pound shall not be regarded as

---

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Evaluations.

Current edition approved Dec. 1, 2018. Published December 2018. Originally approved in 1958. Last previous edition approved in 2011 as D1586 – 11. DOI: 10.1520/D1586_D1586M-18.

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

nonconformance with this practice. SI equivalent units shown herein are in general conformance with existing international standards.

1.10 Penetration resistance measurements often will involve safety planning, administration, and documentation. This test method does not purport to address all aspects of exploration and site safety.

1.11 Performance of the test usually involves use of a drill rig; therefore, safety requirements as outlined in applicable safety standards (for example, OSHA regulations,[2] NDA Drilling Safety Guide,[3] drilling safety manuals, and other applicable local agency regulations) must be observed.

1.12 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.13 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[4]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1452/D1452M Practice for Soil Exploration and Sampling by Auger Borings
D1587/D1587M Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)
D2573/D2573M Test Method for Field Vane Shear Test in Saturated Fine-Grained Soils
D3550/D3550M Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220/D4220M Practices for Preserving and Transporting Soil Samples
D4633 Test Method for Energy Measurement for Dynamic Penetrometers
D5088 Practice for Decontamination of Field Equipment Used at Waste Sites
D5092 Practice for Design and Installation of Groundwater Monitoring Wells
D5299 Guide for Decommissioning of Groundwater Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities
D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock
D5778 Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils
D5782 Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5783 Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5784/D5784M Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water Quality Monitoring Devices
D5872/D5872M Guide for Use of Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water Quality Monitoring Devices
D6026 Practice for Using Significant Digits in Geotechnical Data
D6066 Practice for Determining the Normalized Penetration Resistance of Sands for Evaluation of Liquefaction Potential
D6151/D6151M Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling
D6169/D6169M Guide for Selection of Soil and Rock Sampling Devices Used With Drill Rigs for Environmental Investigations
D6282/D6282M Guide for Direct Push Soil Sampling for Environmental Site Characterizations
D6286 Guide for Selection of Drilling Methods for Environmental Site Characterization
D6913/D6913M Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
D6914/D6914M Practice for Sonic Drilling for Site Characterization and the Installation of Subsurface Monitoring Devices

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms in this standard refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *anvil, n—in drilling*, that portion of the drive-weight assembly which the hammer strikes and through which the hammer energy passes into the drill rods.

3.2.2 *cathead, n—in drilling*, the rotating drum or windlass in the rope-cathead lift system around which the operator

---

[2] Available from Occupational Safety and Health Administration (OSHA), 200 Constitution Ave., NW, Washington, DC 20210, http://www.osha.gov.

[3] Available from the National Drilling Association, 3511 Center Rd., Suite 8, Brunswick, OH 44212, http://www.nda4u.com.

[4] 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.

wraps a rope to lift and drop the hammer by successively tightening and loosening the rope turns around the drum.

3.2.3 *drill rods, n—in drilling*, rods used to transmit downward force and torque to the drill bit while drilling a borehole and also connect sampler to the hammer system for testing.

3.2.4 *hammer, n—in drilling*, that portion of the hammer drop system consisting of the 140 ± 2 lbm [63.5 ± 0.5 kg] impact mass which is successively lifted and dropped to provide the impact energy to drill rods that accomplishes the sampling and penetration.

3.2.5 *hammer drop system, n—in drilling*, the equipment that includes the 140 lbm [63.5 kg] hammer, lifting and dropping assembly, and guide tube (if used) which the operator or automatic system accomplishes the lifting and dropping of the hammer to produce the blow.

3.2.6 *hammer fall guide, n—in drilling*, that part of the hammer drop system used to guide the fall of the hammer.

3.2.7 *number of rope turns, n—in drilling*, the total contact angle between the rope and the cathead at the beginning of the operator's rope slackening to drop the hammer, divided by 360° (see Fig. 1).

3.2.8 *sampling rods, n—in drilling*, rods that connect the drive-weight assembly to the sampler. Drill rods are often used for this purpose.

3.2.9 *standard penetration test (SPT), n—in drilling*, a test process in the bottom of a borehole in which a split-barrel sampler (see 5.3) with an outside diameter of 2 in. [50 mm] is driven a prescribed distance of 1.0 ft [0.3 m] after a seating interval of 0.5 ft [0.15 m] using a 140 lbm [63.5 kg] hammer falling 30 in. [750 mm] for each hammer blow to compute the *N*-value.

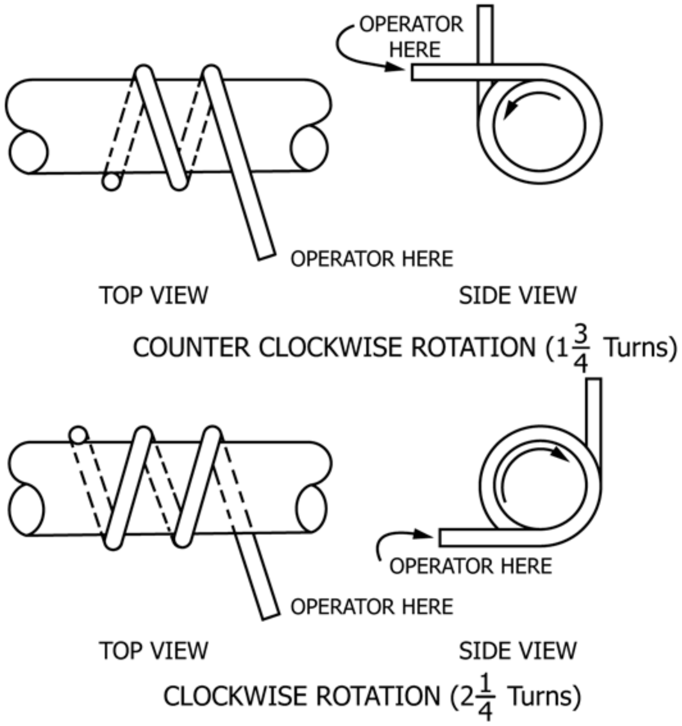


FIG. 1 Definitions of the Number of Rope Turns and the Angle for (*a*) Counterclockwise Rotation and (*b*) Clockwise Rotation of the Cathead

3.2.10 *test interval, n—in drilling*, the depth interval for the SPT test consists of an 0.5 ft [0.15 m] seating interval followed by the 1.0 ft [0.3 m] test interval.

3.3 *Definitions from D6066 Pertinent to This Standard:*

3.3.1 *cleanout depth, n*—depth that the bottom of the cleanout tool (end of drill bit or cutter teeth) reaches before termination of cleanout procedures.

3.3.2 *cleanout interval, n*—interval between successive penetration resistance tests from which material must be removed using conventional drilling methods.

3.3.2.1 *Discussion*—During the clean-out process, the previous penetration test interval (1.5 ft [450 mm]) is drilled through and an additional distance is cleaned past the end depth of the previous test to assure minimal disturbance of the next test interval. The term cleanout interval in this practice refers to the additional distance past the previous test termination depth.

3.4 *Symbols Specific to This Standard:*

3.4.1 *N-value, n*—reported in blows per foot, equals the sum of the number of blows (N) required to drive the sampler over the depth interval of 0.5 to 1.5 ft [0.15 to 0.45 m] below the base of the boring (see 8.3).

3.4.2 N_{60}, *n*—standard penetration resistance adjusted to a 60 % drill rod energy transfer ratio (Test Method D4633, Practice D6066).

3.5 *Symbols Specifc to This Standard and Pertinent to This Standard from Test Method D4633:*

3.5.1 *EFV, n*—the energy transmitted to the drill rod from the hammer during the impact event.

3.5.2 *ETR, n*—ratio (*EFV / PE*) of the measured energy transferred to the drill rods to the theoretical potential energy (PE).

4. Significance and Use

4.1 This test is the most frequently used subsurface exploration drilling test performed worldwide. Numerous international and national standards are available for the SPT which are in general conformance with this standard.[5] The test provides samples for identification purposes and provides a measure of penetration resistance which can be used for geotechnical design purposes. Many local and widely published international correlations which relate blow count, or *N*-value, to the engineering properties of soils are available for geotechnical engineering purposes.

4.1.1 Incremental SPT sampling is not a preferred method of soil sampling for environmental or geohydrological exploration unless the SPT *N*-value is needed for design purposes. Continuous sampling methods such as Direct Push Soil Sampling (Guide D6282/D6282M), or continuous coring using Hollow-Stem Augers (Practice D6151/D6151M) or Sonic

---

[5] "Geotechnical Investigation and testing – Field testing- Part 3: Standard Penetration Test (ISO 22476-3:2004)," EN ISO 22476-3, European Standard, European Committee for Standardization, Brussels Belgium.

Drills (Practice D6914/D6914M) provide the best continuous record of lithology. Continuous sampling can be performed with SPT samplers, but it is slow compared to other methods, and *N* values may unreliable (see 4.6.1). Sampling for detailed lithology can be reduced by using screening tests such as geophysics and Direct Push profiling tests such as Cone Penetrometers (Test Method D5778), Dynamic Cone Penetrometer, or electrical resistivity probe.

4.2 SPT *N* values are affected by many variables allowed in the design and execution of the test (see Appendix X1). Investigations of energy transmission in SPT testing began in the 1970's and showed that differing drop hammer systems provide different energies to the sampler at depth. There are so many different hammer designs that it is important to obtain the energy transfer ratio (ETR) for the hammer system being used according to Test Method D4633. ETR of various hammer systems has shown to vary between 45 to 95 % of maximum Potential Energy (PE). Since the *N*-value is inversely proportional to the energy delivered, resulting *N* values from different systems are far from standard. It is now common practice to correct *N* values to an energy level of 60 % of total (PE), or N_{60} values as presented here and in Practice D6066. In this standard it is not required to report ETR or N_{60} but strongly advised to be noted and reported if available. If ETR of the hammer/anvil/rod system is known, the hammer PE can still vary after calibration, thus it is essential that hammer drop heights/rates be monitored to confirm consistent performance. Report any occurrence of hammer drop heights that do not meet the required value of 30 in. [750 mm] during testing. Using previous ETR data for a hammer system does not assure that it will perform the same on the current project. If onsite ETR is not obtained, be sure to check hammer drop height/rates to assure the hammer is operating the same as when previously checked.

4.2.1 Other mechanical variables and drilling errors can also adversely affect the *N* value as discussed in X1.4. Drilling methods can have a major effect on testing (see 4.5). While the SPT hammer system is standardized knowing ETR, drilling methods are not, and a variety of drilling methods can be used.

4.3 SPT is applicable to a wide range of soils. For nomenclature on soil in terms of *N*-value refer to Appendix X2 for consistency of clays (cohesive soils) and relative density of sands (cohesionless soils) as proposed by Terzaghi and Peck and used commonly in geotechnical practice. SPT drilling can be performed easily using a variety of drilling methods in denser soils but has some difficulty in softer and looser soils. This test method is limited to non-lithified or un-cemented soils and soils whose maximum particle size is approximately one-half of the sampler diameter or smaller. Large particles result in higher blow counts and may make the data unsuitable for empirical correlations with finer soils. For example, chamber tests on clean sands have shown coarse sands have higher blow counts than medium fine sands (see X1.6). In gravelly soils, with less than 20 % gravel, liquefaction investigations may require recording of penetration per blow in an attempt to extrapolate the results to sand blow counts (see X1.7). Soil deposits containing gravels, cobbles, or boulders typically result in penetration refusal, damage to the equipment, and unreliable *N* values if gravel plugs the sampler.

4.3.1 *Sands*—SPT is widely used to determine the engineering properties of drained clean sands during penetration. Obtaining "intact" soil samples of clean sands for laboratory testing is difficult and expensive (see thin walled tube, Practice D1587/D1587M), so engineers use penetration results in sands for predicting engineering properties (Appendix X1). Appendix X2 and X1.6 provides some estimated properties of sands. There are problems with SPT in loose sands below the water table since they are unstable during drilling. Practice D6066 provides restricted drilling methods for SPT in loose sands for evaluating earthquake liquefaction potential. Practice D6066 method relies on mud rotary drilling, casing advancers, and fluid filled hollow-stem augers.

4.3.2 *Clays*—SPT is easy to perform in clays of medium to stiff consistency and higher using a variety of drilling methods. SPT is unreliable in soft to very soft clays because the clay, yields or "fails" under the static weight of the rods alone, or weight of rods and hammer before the test is started. This problem is accentuated by the heavier weights of automatic hammer assemblies (see X1.3.1.4) but can be alleviated with automatic hammers which are designed to float over the anvil (see 5.4.2.1). There is such a large variation in possible *N* values in soft clays it is well accepted that SPT is a poor predictor of the undrained shear strength of clay. It is recommended to evaluate soft clays with more appropriate methods such as CPT (Test Method D5778), vane shear (Test Method D2573/D2573M), and/or Thin-Wall Tube sampling (Practice D1587/D1587M) and laboratory testing.

4.4 *Hammer Drop System*—SPT can be performed with a wide variety of hammer drop systems. Typical hammer systems are listed below in order of preference of use:

(1) Hydraulic automatic chain cam/mechanical grip-release hammers
(2) Mechanical trip donut hammers
(3) Rope and cathead operated safety hammers
(4) Rope and cathead operated donut hammers

4.4.1 Automatic and trip hammers are preferred for consistent energy during the test. Automatic chain cam hammers are also the safest because the hammer is enclosed, and the operators can stand away from the equipment. If the rope and cathead method is used, the enclosed safety hammer is safer than donut hammer because the impact anvil is enclosed. For more information on hammer systems, consult X1.3.

4.5 *Drilling Methods*—The predominant drilling methods used for SPT are open hole fluid rotary drilling (Guide D5783) and hollow-stem auger drilling (Practice D6151/D6151M). Limited research has been done comparing these methods and their effects on SPT *N* values (see X1.5.1.1).

4.5.1 Research shows that open hole bentonite fluid rotary drilling is the most reliable method for most soils below the water table. Hollow-stem augers had problems with saturated loose sands since they must be kept full of fluid. The research also showed that driven casing using water as the drilling fluid, can adversely influence the SPT if the casing is driven close to the test depth interval. Use of casing combined with allowing a fluid imbalance also causes disturbances in sands below the water table. Fluid filled rotary casing advancers (Guide D6286) are included as an allowable drilling method for loose sands in Practice D6066.

4.5.2 SPT is used with other drilling methods including reverse circulation, sonic drilling, and direct push methods practices. There are concerns, undocumented by research, with direct push (Guide D6282/D6282M), sonic drilling (Practice D6914/D6914M), and reverse circulation methods using heavy casing drive hammers (Guide D6286), that the extreme dynamic loading and vibrations could disturb some soils such as sands and soft clays past the seating interval. The professional responsible for the investigation should evaluate SPT under these conditions and if drilling disturbance is suspected, then *N* values can be checked against other drilling methods in section 4.5 or deploy the alternate drilling method through and ahead of the casings.

4.5.3 SPT is also performed at shallow depths above the groundwater table using solid stem flight augers (Practice D1452/D1452M), but below the water table borings may be subject to caving sands. Solid stem borings have been drilled to depths of 100 ft or more in stable material.

4.5.4 SPT is rarely performed in cable tool or air rotary drilling.

4.6 *Planning, Execution, and Layout*—When SPT borings are used, often there are requirements for other companion borings or test holes to be located near or around the SPT boring. In general, borings should be no closer than 10 ft [3 m] at the surface for depths of up to 100 ft [30 m]. A minimum would be as close as 5 ft [2 m], but at this spacing, boreholes may meet if there is significant vertical deviation.

4.6.1 *Test Depth Increments*—Test intervals and locations are normally stipulated by the project engineer or geologist. Typical practice is to test at 5 ft [1.5 m] intervals or less in homogeneous strata. If a different soil type in the substratum is encountered, then a test is conducted as soon as the change is noted. It is recommended to clean out the borehole a minimum cleanout interval of at least 1 ft [0.25 m] past the termination point of the previous test depth between tests to assure test isolation and to check drill hole condition for the next test. Therefore, the closest spacing for typical practice of SPT is 2.5 ft [0.75 m]. The cleanout between test intervals can be adjusted by the user depending on borehole conditions and design data needs such as hard soils or thin strata. The practice of performing continuous SPT for *N*-value determination is not recommended but can be done with careful cleanout before testing. The borehole must be cleaned out between tests (see 6.5). At continuous spacing, with no additional cleanout depth, *N* values may be adversely affected by disturbance of previous sample driving especially in softer soils but the effect his not known. Some practitioners like to overdrive the sampler an additional 0.5 ft [0.15 m] to gain additional soil sample for a total drive interval of 2.0 [0.6 m]. This is acceptable if the *N*-value remains the sum of the 0.5 to 1.0 ft [0.15 to 0.3 m] intervals of the drive interval and reasonable cleanout is performed between tests.

4.7 This test method provides a Class A and B soil samples according to Practice D4220/D4220M which is suitable for soil identification and classification (Practices D2487 and D2488), water content (Test Methods D2216), and specific gravity tests (Test Methods D854). The soil can be reconstituted for some advanced laboratory tests. The small-diameter, thick wall, drive sampler will not obtain a sample suitable for advanced laboratory tests such as those used for strength or compressibility from the core. Consult Guide D6169/D6169M for samplers that provide laboratory grade intact samples.

NOTE 1—The reliability of data and interpretations generated by this practice 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 D3740 generally are considered capable of competent testing. Users of this practice are cautioned that compliance with Practice D3740 does not assure reliable testing. Reliable testing depends on several factors and Practice D3740 provides a means of evaluating some of these factors.

Practice D3740 was developed for agencies engaged in the testing, inspection, or both, of soils and rock. As such, it is not totally applicable to agencies performing this field test. Users of this test method should recognize that the framework of Practice D3740 is appropriate for evaluating the quality of an agency performing this test method. Currently, there is no known qualifying national authority that inspects agencies that perform this test method.

5. Apparatus

5.1 *Drilling Equipment*—Any drilling equipment that provides at the time of sampling a suitable borehole before insertion of the sampler and ensures that the penetration test is performed on intact soil shall be acceptable. A suitable borehole is one in which the drilling indicates stable conditions at the base of the boring (see 6.2). In general the boring should have an diameter of 3 to 6 in. [75 to 150 mm] diameter. Borings greater than 6 in. [150 mm] inside diameter may result in lower blow counts and require a correction factor (see X1.5.4).

5.1.1 *Fluid Rotary Drilling Drill Bits*—Use side discharge or baffled bottom discharge bits to avoid jetting fluid disturbance in the base of the boring. The tricone roller bit baffles produce some downward discharge. If the deposit is fine grained, it is preferred to use a fishtail or drag bit with baffled discharge points to advance the boring. Wash boring chopping bits should not be used near the test zone.

5.1.2 *Hollow-Stem Augers*—The boring can be advanced either using a pilot bit or an interior sampling tube. When drilling below the water table in unstable sands, add water when retrieving the cleanout string and sampler to maintain water at or above the groundwater table depth. Two types of hollow-stem auger systems are used, either center rod or wireline type. The wireline system suffers from several problems when unstable soil such as sand gets inside the augers and the pilot bit will not latch. If the bit does not latch, the sand must be cleared, but often drillers will pull back the outer augers instead of cleaning causing further disturbance. For that reason, rod type systems are preferred in unstable soils.

5.2 *Sampling Rods*—Flush-joint steel drill rod shall be used to connect the split-barrel sampler to the drive-weight assembly. Drill rod mass per foot ranges from 4 lbm/ft [6 kg/m] to 8 lbm/ft [12 kg/m]. See X1.4.3 for effects on energy in drill rods. If drill rods are longer than 100 ft [30 m], an energy correction may be needed to account for energy loss in long drill strings. *N* series drill rods are the maximum size allowed for the test (see Note 2 and X1.4.3).

NOTE 2—In North America, drill rods specifications commonly used are those from the Diamond Drill Core Manufacturers Association.[6] The most common drill rods used are A series rods (A, AW, AWJ) of 1.75 in. [45 mm] outside diameter weighing about 4 lbm/ft [6 kg/m]. For depths greater than 75 ft [20 m] some publications recommend going to stiffer B or N size rod. Some agencies drill solely with N series rod which are about 2.63 in. [67 mm] O.D. and weigh about 8 lb/ft [11 kg/m].

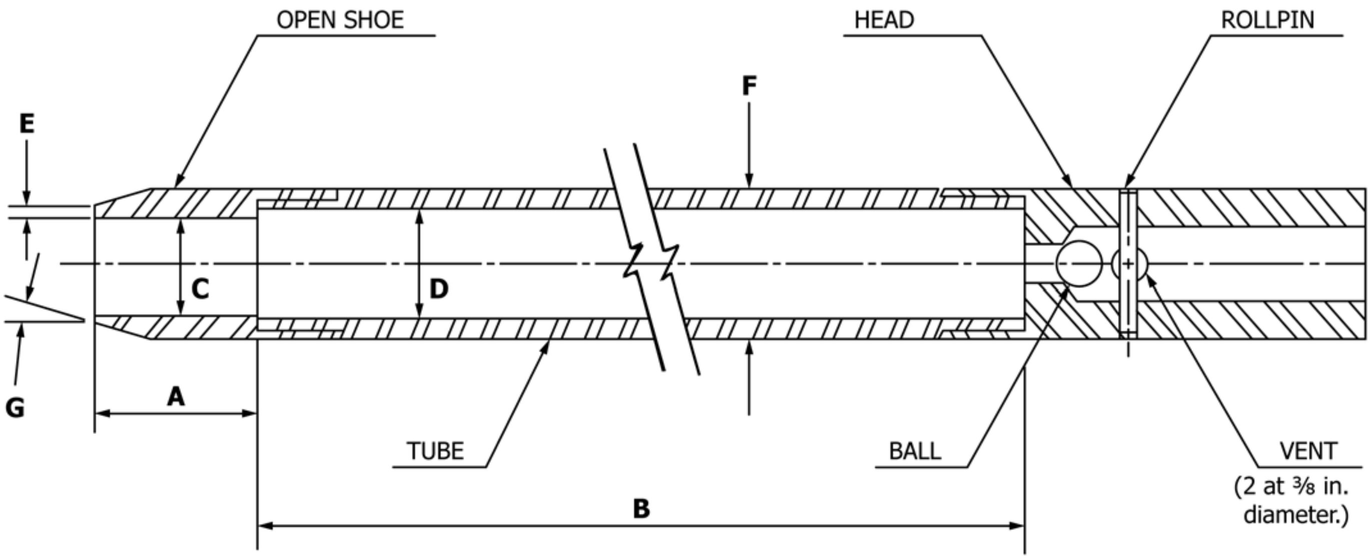
5.3 *Split-Barrel Sampler*—The standard sampler dimensions are shown in Fig. 2. Samplers are made from steel and in most cases are hardened for durability. The split-barrel sampler must be equipped with a ball check and vent. The sampler has an outside diameter of 2.00 in. [51 mm]. The inside diameter of the shoe is 1.375 in. [35 mm]. The inside diameter of the split-barrel (dimension D in Fig. 2) can be either 1.5 in. [38 mm] or 1.375 in. [35 mm]. The upset portion of the split barrel may be equipped with liners making the inside diameter 1.375 in. [35 mm]. The length of the sampler should be at least 2 ft [0.6 m] such that it can accommodate the drive interval of 1.5 ft [0.45 m] plus 0.5 ft [0.15 m] of additional length of material. This split barrel sampler is also in conformance with Practice D3550/D3550M split barrel sampler specifications as shown in Appendix X1, X1.4.2.1, and Fig. X1.6.

5.3.1 *Liners*—Typical practice in the North America has been to use the upset wall sampler. The use of an upset wall improves recovery of the sample but has been shown to reduce friction especially in denser soils. International practice favors the original use of a constant inside diameter sampler. Limited research suggests that N-values may differ as much as 10 to 30 % between a constant inside diameter sampler which provides higher N values than the upset wall sampler and recommends that a correction may be required for soils with blow counts exceeding $N > 10$ (see X1.4.1). For liquefaction evaluations it is common practice to correct upset wall data to constant diameter using the procedures in X1.4.1.1. Report the type of sampler used, e.g., Liner or no Liners. Liners are usually steel, brass, or plastic and may be sectional and supplied with end caps for sealing. Report the type of liner used.

5.3.2 *Drive Shoe*—Drive shoes are made of steel and should be hardened for durability. The drive shoe shown on Fig. 2 is the standard for use in finer soils without gravels. Manufacturers do supply thicker more durable shoes for denser soils and where coarser soils are encountered (see X1.4.4). The thicker shoes are not in conformance with this standard. There is no research on the effect of shoe size/dimensions on N values. If thicker shoes are used, they should be noted.

5.3.3 *Retainers*—Various types of retainers are used for sandy soils which may be difficult to recover. These retainers cause a restriction to sample entrance and may affect the N-value. There is no available research on the effect of use of retainers on blow counts. If retainers are used, they should be reported.

5.3.4 *Sampler Maintenance*—The sampler must be clean at the beginning of each test and should be smooth and free of scars, indentations, and distortions. The driving shoe should be repaired and restored to specifications tolerances or replaced when it becomes dented, cracked, or distorted. Plugging of the vent ports and ball check system of the sampler results in



A = 1.0 to 2.0 in. (25 to 50 mm)
B = 18.0 to 30.0 in. (0.457 to 0.762 m)
C = 1.375± 0.005 in. (34.93 ± 0.13 mm)
D = 1.50 ± 0.05 – 0.00 in. (38.1 ± 1.3 – 0.0 mm)
E = 0.10 ± 0.02 in. (2.54 ± 0.25 mm)
F = 2.00 ± 0.05 – 0.00 in. (50.8 ± 1.3 – 0.0 mm)
G = 16.0° to 23.0°

FIG. 2 Split-Barrel Sampler

---

[6] DCDMA Technical Manual, National Drilling Association, 6089 Frantz Rd. Suite 101, Dublin, Ohio 43017, 1991.

unreliable penetration resistance values. Instances of vent port plugging must be noted on daily data sheets and reported in the boring log.

5.4 *Hammer, Anvil, and Hammer Drop System:*

5.4.1 *Hammer and Anvil*—The hammer shall weigh 140 ± 2 lbm [63.5 kg ± 0.5 kg] and shall be a rigid metallic mass. The hammer shall strike the anvil and make steel on steel contact when it is dropped. The hammer drop system is to be designed to permit a constant and unimpeded vertical hammer fall of 30 in. [750 mm] on the impact anvil which is firmly connected by threaded connection to the top drill rods. The anvil acts as an energy damper, such that the transmitted energy through the drill rods is attenuated; therefore, the larger the anvil the lower the energy transmission. Special precautions should be taken to ensure that the energy of the falling mass is not significantly reduced by friction between the drive weight and guide system. Periodic inspection and maintenance (cleaning and lubrication) should be performed to avoid friction buildup and to check the hammer and assembly mass.

5.4.2 *Hammer Drop Systems*—Any hammer assembly that meets the requirements of 5.4.1 may be used for SPT. Various hammer assemblies as listed here and in section 4.4 may be used in order of preference. At a minimum, report the type and details of the hammer system being used. Many hammer systems have published information on their respective energy transfer or ETR. However, these should not be relied upon as manufacturers can change components during their production life. It is desirable that that actual hammer being used be tested for ETR within some reasonable time frame. If available, report the ETR or onsite measured ETR using Test Method D4633. Report any operational problems when conducting the test that may impact ETR. If using a previously calibrated hammer, check and report that the hammer drops heights and rates still comply with the calibrated condition. The total mass of the hammer assembly bearing on the drill rods can be changed to avoid sinking in soft clays (see X1.3.1.4).

5.4.2.1 *Automatic Hammer*—The typical automatic hammer finding widespread use in drilling today is an enclosed hydraulic motor operated chain cam hammer lifting system (Fig. 3). These hammers are safer and produce very reproducible drop heights or energy. These assemblies are often heavy and may add considerable static pressure to the test zone. Some hammer systems like the Diedrich or eSPT or others[7] are designed to float over the impact anvil. Many of the automatic drop hammer systems are built on the drill and may be safely swung into position for testing but rest on the impact anvil. The drop height of 30 in. [750 mm] assumes the top of the anvil is fully inside the guide tube. If the hammer has an adjustable follower, the operator should avoid exerting extra pressure on the anvil (see X1.3.1.1). A chain cam automatic hammer should be equipped with a view slot on the guide tube to allow drop height checks although some automated systems may not require it. Heavy automatic hammers resting on the sampler may result in unreliable penetration test data in soft and very soft clays (see X1.3.1.4). The speed of a chain cam automatic hammer affects the drop height and consequently the energy transmission, ETR; therefore, the hammers must be routinely checked to be sure they are operating at the correct blow rate and drop height. The automatic hammer system should be adjusted to provide the desired blow rate and energy transmission for the project requirements prior to testing. If ETR data are not known, then adjust and operate the hammer to assure 30 in. [750 mm] drop height. If ETR is known, an automatic hammer may be adjusted to provide drop heights of less than 30 in. [750 mm] if the blow rate needs to be reduced from manufacturers design speed (see X1.3.1.2).

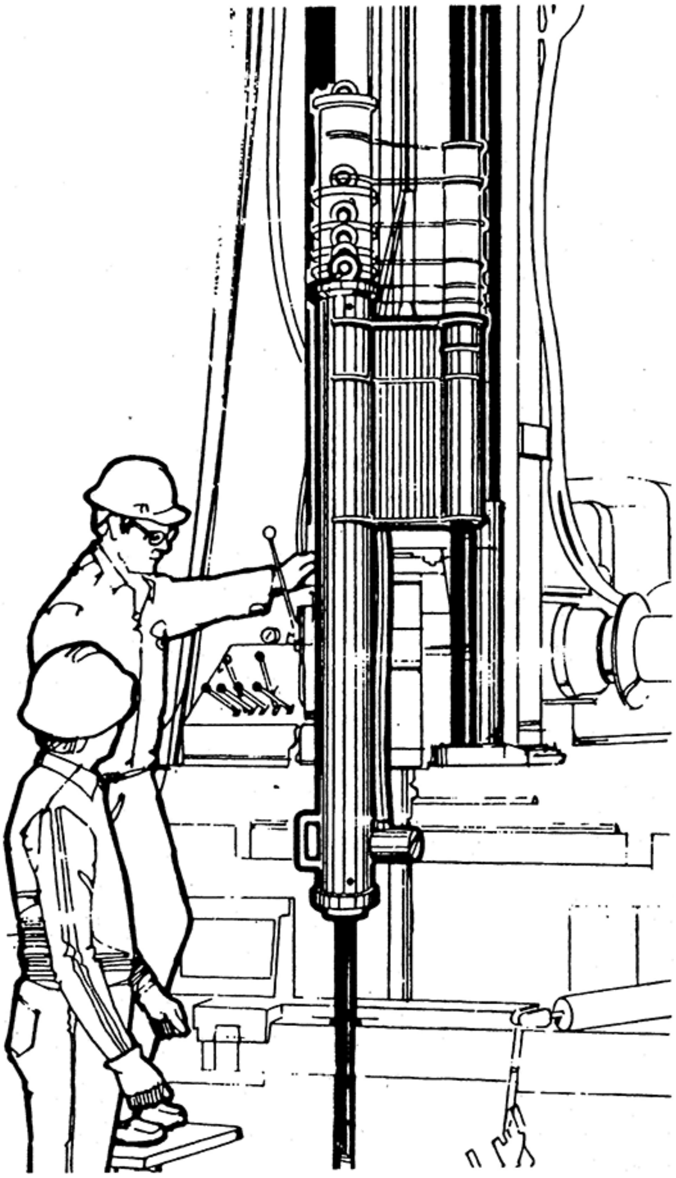


FIG. 3 Typical Hydraulic Automatic Hammer Drop System

5.4.2.2 *Mechanical Trip Donut Hammer Drop System*—These hammer systems use fingers or pawls that grip a donut

---

[7] The Diedrich (www.Diedrichdrill.com), and eSPT (www.marltechnologies.com) hammer systems and laser depth recorder PileTrac (www.piletrac.com) are known to the subcommittee D18.02 at this time with special characteristics cited in the text. If you are aware of alternative suppliers meeting these criteria or other special equipment, please provide this information to the subcommittee D18.02. Other hammer apparatus meeting these features can be added to the standard and will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

hammer and release the hammer at the 30 in. [750 mm] drop height (Fig. 4). The fall guide is a central tube. This hammer is lifted with a rope and cathead but rope turns and cathead speed do not significantly affect drop height. These hammers are often available internationally even where truck mounted drills are not used. They are not as safe as built in automatic hammers and must be hoisted and lowered using a cathead and the hammer anvil impact surface is exposed providing a dangerous pinch point. Some of these hammers have fairly large anvils which provide lower ETR. Safety problems include hoisting, lowering, cathead operation pinch points at the impact surface, and metal fragments which can come off the anvil.

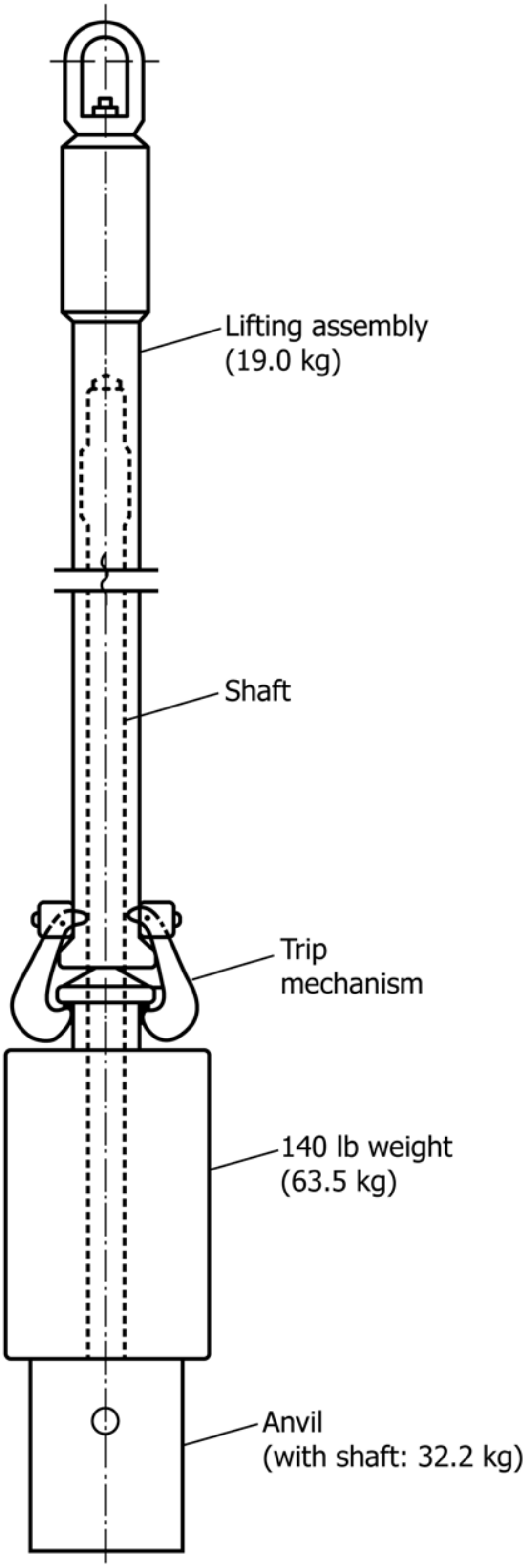


FIG. 4 Mechanical Automatic Trip Drop Donut Hammer System

5.4.2.3 *Rope and Cathead Operated Safety Hammer*—The safety hammer drop system shown on Fig. 5 is a long hammer assembly used on truck mounted drills in North America and was developed to enclose the impact surface for safer operation. This hammer system uses an operator cathead rope drop with two rope turns on the cathead. Since it is dependent on the operator, the energy transmission may vary between operators and single operator precision has a much larger variation than automatic hammers. The geometry is slender, with a small impact anvil, and ETR can be much higher than a donut hammer (see X1.3.3). In order to allow 30 in. [750 mm] drop height without back tapping, the hammer lift height should provide for an additional 3 to 4 in. [75 to 100 mm] of vertical lift. The hammer should have a mark on the fall guide tube, which is generally another section of A rod, so the operator can see the 30 in. [750 mm] drop height. Safety concerns include hoisting, lowering, and cathead operation.

5.4.2.4 *Rope and Cathead Operated Donut Hammer*—The donut hammer is the original design and the dimensions can vary widely (Fig. 5). Some countries have standardized dimensions of the hammer and anvil to maintain consistent energy transmission. This hammer system also uses an operator cathead rope drop with two rope turns on the cathead. Since it is dependent on the operator, the energy transmission may vary between operators and single operator precision has a much larger variation than automatic hammers. Donut hammer with large impact anvils generally have lower energy transmission ratios, ETR (see X1.3.4). Safety concerns include hoisting, lowering, cathead operation, pinch points at the impact surface, and metal fragments off the anvil.

NOTE 3—It is suggested that the hammer fall guide be permanently marked to enable the operator or inspector to judge the hammer drop height.

5.4.2.5 *Spooling Winch Hammer Systems*—This hammer system uses an automated wireline spool behind the mast to lift a safety or donut hammer the prescribed 30 in. [750 mm] drop and then unwind at a computed free fall speed for the hammer system. Several published studies have shown these hammers do not perform well and often restrict the drop speed resulting in very low drill rod energy, ETR and resulting very high blow counts (see X1.3.5). These hammer systems should not be used unless their performance is checked onsite using energy measurements prescribed by Test Method D4633.

5.5 *Accessory Equipment*—Accessories such as labels, sample containers, data sheets, groundwater level, and SPT energy measuring devices shall be provided in accordance with the requirements of the project and other applicable ASTM standards.

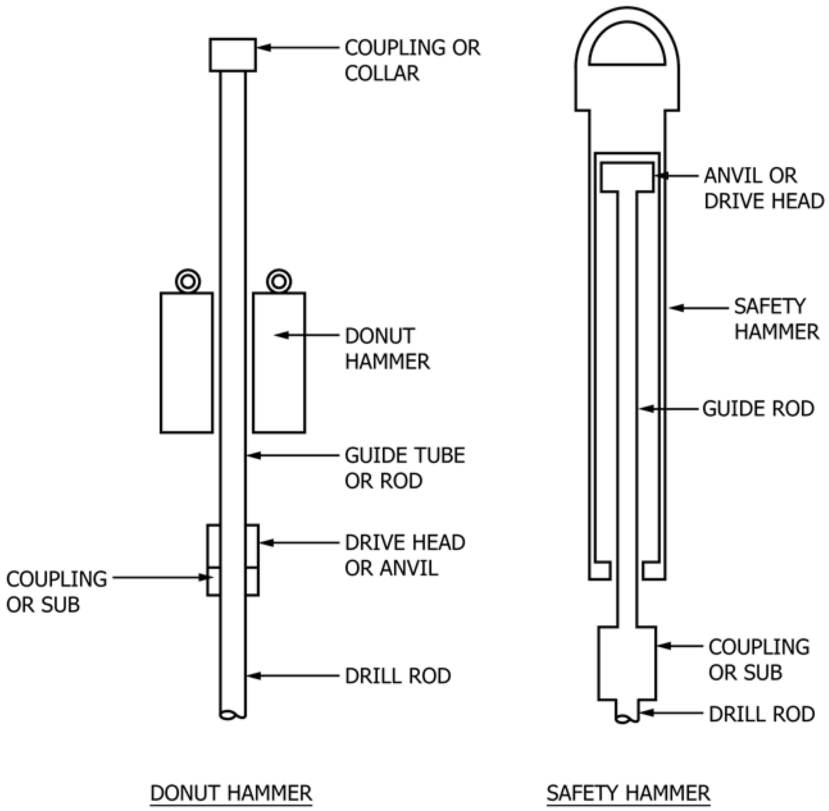


FIG. 5 Schematic Drawing of the Donut Hammer and Safety Hammer (see Note 3)

6. Drilling Procedure

6.1 The borehole shall be advanced incrementally to permit intermittent or continuous sampling. Record the depth of drilling to the nearest 0.1 ft [0.025 m] or better.

6.2 Any drilling procedure that provides a suitably clean and stable borehole before insertion of the sampler and assures that the penetration test is performed on essentially intact soil shall be acceptable. Stable borehole conditions are confirmed for each test by comparing the cleanout depths to sampler depths prior to tests and examining recovered soil cores. Each of the following procedures has proven to be acceptable for some subsurface conditions. The subsurface conditions anticipated should be considered when selecting the drilling method to be used (see 4.5 and 5.1).

6.2.1 *Open-Hole Fluid Rotary Drilling Method (D5783).*

6.2.2 *Hollow-Stem Auger Method (D6151/D6151M).*

6.2.3 *Solid Stem Auger Method (D1452/D1452M)*—Open hole solid stem augers can be used to advance borings as long as the hole remains open, stable, and clean. These open uncased borings are subject to sloughing or caving of cohesionless soils below the water table and may not be suitable for those conditions. In stiff cohesive soils borings can often be extended below the water table. Typical diameter is 4 in. [100 mm].

6.2.4 *Fluid Rotary Casing Advancer (D5872/D5872M)*—Since this drilling method circulates fluids up the exterior annulus of the rotary casing, care must be taken to maintain fluid circulation (Practice D6066).

6.2.5 *Other Drilling Methods,* with concerns listed. It is the responsibility of the user (driller, site geologist/engineer) to examine the test conditions and evaluate if disturbance requires change of drilling method or procedures. Use of fluid rotary or hollow-stem auger drilling is recommended if there are serious concerns and a check boring is required. The other drilling methods have distinct issues with their usage:

6.2.5.1 *Wash Boring Method*—Wash borings are an older drilling method using pumped water to a chopping bit which is raised and lowered impacting the base of the boring and circulating the fluid and cuttings upward. Casing is also used to help keep the boring stabilized. This method has been listed previously in this procedure but is recognized as a jetting method, Section 12 of Guide D6286. Concerns with this method include jetting and impact disturbance in the base of the boring and disturbance caused by casing near the test zone. See X1.5.1.1 for research information on this method.

6.2.5.2 *Sonic Drilling (D6914/D6914M)*—Concerns with this drilling method include the strong vibrations produced which could influence and disturb sandy soils in the test zone. This method does not use drilling fluid and disturbance in sands below the water table can occur if fluid balance is not maintained during removal of the inner barrel. The advantage is the outer casing protect the borehole from caving. There is some preliminary research on effects of sonic drilling on SPT *N*-values which are currently inconclusive (see X1.5.3) pointing to a need to perform site specific checks with conventional drilling methods on effect on *N*-values if required.

6.2.5.3 *Dual-Wall Reverse Circulation*—If used with a casing hammer, this method could disturb sandy soils at the base of the boring. When drilling with air, circulation must be maintained as there is high risk of soil fracturing in the test zone. This method also provides continuous protective casing to stabilize the hole.

6.2.5.4 *Direct Push Casings*—SPT has been routinely used with larger diameter dual tube equipment without problems in many types of soils. The primary concern with this method is the hammer impacts disturbing sandy soils in the test zone below the water table. This affect can be mitigated by using a large diameter dual tube sampler in sampling mode (Guide D6282/D6282M) instead of driving with a center plug point. Fluid should be added in saturated sands during extraction of the inner tube. The outer dual tube stabilizes the boring for testing. There is some preliminary research on effects of Direct Push drilling on SPT *N*-values which are currently inconclusive (see X1.5.3) pointing to a need to perform site specific checks with conventional drilling methods on effect on *N*-values if required.

6.3 All drilling methods, to be successful, require the driller to advance the drill rate slow enough to ensure that the cuttings are removed, and circulation is maintained during the drilling process. If drilled too fast using fluids, the bit or hole may plug, the fluid circulation may be lost, and soil at the base of the boring may be hydraulically fractured. Report any major fluid losses.

6.4 *Drilling Below Groundwater*—The drilling fluid level within the borehole or hollow-stem augers shall be maintained at or above the in situ groundwater level at all times during drilling, removal of drill rods, and sampling. Numerous investigations and published data show adverse effects of allowing fluid levels to drop (see X1.5.1). If the site requires that casing be installed close to the test interval it is advised to keep it as far from the test zone as possible. When drilling in unstable saturated sands, the use of a bypass line is required to add fluid when removing the cleanout string to maintain the fluid balance. If soil heaves into a casing a considerable distance, there could be a large disturbed zone at the base of the boring. If this occurs, it must be reported. If sand is flowing into the casings, more viscous drill fluids may be required.

6.5 Several drilling methods produce unacceptable boreholes. The process of jetting through an open tube sampler and then sampling when the desired depth is reached shall not be permitted. Casing shall not be advanced below the sampling elevation prior to sampling. Advancing a borehole with bottom discharge bits is not permissible. It is not permissible to advance the borehole for subsequent insertion of the sampler solely by means of previous sampling with the SPT sampler.

7. Hammer Operating Procedures

7.1 The lifting and dropping of the 140 lbm [63.5 kg] hammer shall be accomplished using either of the following using automatic or rope and cathead methods. Drill rod energy transfer ETR can be measured according to procedures in Test Method D4633 (see 4.2 and Note 4). For proper performance, the hammer drop height (PE) and blow rate should be continuously monitored during testing and any deviations noted.

7.1.1 *Automatic and Trip Hammers*—By using a trip, automatic, or semi-automatic hammer drop system that lifts the 140 lbm [63.5 kg] hammer and allows it to drop 30 ± 1.0 in. [750 ± 30 mm] with limited frictional resistance. Check the drop height and blow count rate as required based on previous testing (see 5.4.2.1 and X1.3.1).

7.1.2 *Rope and Cathead Method*—By using a cathead to pull a rope attached to the hammer. When the cathead and rope method is used the system and operation shall conform to the following:

7.1.2.1 The cathead shall be essentially free of rust, oil, or grease with a diameter in the range of 6 to 10 in. [150 to 250 mm]. The mast should only have two well lubricated crown sheaves for the rope. A third crown sheave could reduce ETR.

7.1.2.2 The cathead should be operated at a speed of rotation of about 100 RPM.

7.1.2.3 The operator should generally use either 1-¾ or 2-¼ rope turns on the cathead, depending if the rope comes off the top (1-¾ turns for counterclockwise rotation) or the bottom (2-¼ turns for clockwise rotation) of the cathead during the penetration test, as shown in Fig. 1. It is generally accepted that 2-¾ or more rope turns impede the fall of the hammer and should not be permitted. The cathead rope should be relatively dry, clean, and should be replaced when it becomes excessively frayed, oily, or burned.

7.1.2.4 For each hammer blow, a 30 in. [750 mm] lift and drop shall be employed by the operator. The operation of pulling and throwing the rope shall be performed rhythmically without holding the rope at the top of the stroke. If the hammer drop height is not 30 ± 1.0 in. [750 ± 30 mm], then record the actual drop heights used.

NOTE 4—Test Method D4633 provides information on making energy measurement for variable drop heights and Practice D6066 provides information on adjustment of the *N*-value to a constant energy level (60 % of theoretical, N_{60}). Practice D6066 allows the hammer drop height to be adjusted to provide 60 % energy.

8. Sampling and Testing Procedure

8.1 After the borehole has been advanced to the desired sampling elevation and excessive cuttings have been removed, record the cleanout depth to the nearest 0.1 ft [0.025 m], and prepare for the test with the following sequence of operations:

8.1.1 Attach the split-barrel sampler to the sampling rods and lower into the bottom of the borehole. Do not allow the sampler and rods to drop onto the soil to be sampled. Record the sampling start depth to the nearest 0.1 ft [0.025 m] or better. If the sampler penetrates past the cleanout depth record the partial penetration prior to driving.

8.1.2 Attach the anvil and hammer assembly to the top of the drill rods.and rest the dead weight of the sampler, rods, anvil, and hammer on the bottom of the borehole. Compare the sampling start depth to the cleanout depth in 8.1. If excessive cuttings are encountered at the bottom of the borehole, remove the sampler and sampling rods from the borehole and remove the cuttings. See section 8.2.5 if the sampler begins to settle under the weight of rods, or rod and hammer.

8.1.3 Mark the drill rods in three successive 0.5 ft [0.15 m] increments so that the advance of the sampler under the impact of the hammer can be easily observed for each 0.5 ft [0.15 m] increments. If the penetration is known from the hammer system, i.e., Diedrich hammer or recorded using automated methods such as the eSPT system, or laser depth recorder (PileTrac)[7], the rods do not need to be marked, however, the marks can be used as a visual check. Record any hammer drops not meeting project requirements regarding fall heights, changes in hammer speed, or pauses during testing (Note 5).

8.2 Drive the sampler with blows from the 140 lbm [63.5 kg] hammer using procedures in Section 7 and count the number of blows for each 0.5 ft (0.15 m) increment until one of the following occurs:

8.2.1 A total of 50 blows during any one of the three 0.5 ft [0.15 m] increments described in 8.1.3.

8.2.2 A total of 100 blows have been applied.

8.2.3 There is no observed advance of the sampler during the application of 10 successive blows of the hammer. For automated systems an advance of less than 0.1 in. [2 mm] per blow can be considered refusal.

8.2.4 The sampler is advanced the entire 1.5 ft [0.45 m] without the limiting blow counts occurring as described in 8.2.1, 8.2.2, or 8.2.3.

8.2.5 If the sampler sinks under the weight of the hammer, weight of rods, or both, record the length of travel to the nearest 0.1 ft [0.025 m], and drive the sampler through the remainder of the test interval. If the sampler sinks the entire interval, stop the penetration, remove the sampler and sampling rods from the borehole, and advance the borehole through the very soft or very loose materials to the next sampling depth. Record the *N*-value as either weight of hammer, weight of rods, or both.

8.3 Record the number of blows (*N*) required to advance the sampler each 0.5 ft [0.15 m] of penetration or fraction thereof. The first 0.5 ft [0.15 m] is the seating drive. The sum of the number of blows required for the second and third 0.5 ft [0.15 m] of penetration is termed the "standard penetration resistance," or "*N*-value." If the sampler is driven less than 1.5 ft [0.45 m], as permitted in 8.2.1, 8.2.2, or 8.2.3, the number of blows per each complete 0.5 ft [0.15 m] increment and per each partial increment shall be recorded on the boring log. For partial increments, the depth of penetration shall be reported to the nearest 0.1 ft [0.25 m] or better in addition to the number of blows (Note 5).

NOTE 5—Often, liquefaction studies require recording of penetration per blow in gravelly soils as described in X1.7. For those cases, automated recording is desirable because the practice of hand marking the drill rods is hazardous and data recording is cumbersome. For latest automated hammer systems, the penetration per blow can be continuously recorded and the blow counts for each increment computed from the data. An example is the eSPT hammer system that uses terms of n_1, n_2, n_3, to specify the penetration increments and the *N*-value is the sum of n_2 and n_3. Another continuous depth recorder, PileTrac (www.piletrac.com), can also automate collection of penetration per blow data using exterior placed laser distance sensor.

8.4 Retrieve the sampler and open. Record the percent recovery to the nearest 5 % or the length of sample recovered to the nearest 0.1 ft [0.025 m] or better. Classify the soil samples recovered in accordance with Practice D2488, then place one or more representative portions of the sample into sealable moisture-proof containers (ziplock bags or jars) without ramming or distorting any apparent stratification. Seal each container to prevent evaporation of moisture. Affix labels to the containers bearing job designation, boring number, sample depth. . Protect the samples against extreme temperature fluctuation . If there is a soil change within the sampler, use a container for each stratum and note its location in the sampler barrel. Samples should be preserved and transported in accordance with Practice D4220/D4220M using Group B.

8.5 *Borehole Completion and Sealing*—Information on the sealing of boreholes and installations can be found in Guides D5782, D5783, and D5784/D5784M for drilling methods and in Practice D5092, and Guide D5299 for wells. Local regulating agencies or organizations may control both the method and the materials required for borehole sealing. The use of low solids content bentonite slurry should not be used in the unsaturated zones (Practice D5092).

8.6 *Equipment Decontamination*—Often is required to clean the drill rig and equipment prior to and after investigation at a specific site. Practice D5088 should be used if the investigation and sampling equipment require decontamination for environmental investigations.

9. Report: Test Data Sheet(s)/Form(s)

9.1 The methodology used to specify how data are recorded is covered in section 1.8.

9.2 Record as a minimum the following general information (data) Data obtained in each borehole shall be recorded in accordance with the Subsurface Logging Guide D5434 as required by the exploration program. An example of a sample data sheet is included in Appendix X3.

9.3 Drilling information shall be recorded in the field and shall include the following:

9.3.1 Name and location of job,

9.3.2 Names of driller, crew and logger,

9.3.3 Type and make of drilling machine,

9.3.4 Weather conditions,

9.3.5 Date and time of start and finish of borehole,

9.3.6 Boring number and location (station and coordinates, if available and applicable),

9.3.7 Surface elevation, if available,

9.3.8 Method of drilling and advancing and cleaning the borehole,

9.3.9 Method of keeping borehole open, fluid circulation rates and loses,

9.3.10 Depth of water surface to the nearest 0.1 ft [0.025 m] and drilling depth to the nearest 0.1 ft [0.025 m] or better at the time of a noted loss of drilling fluid, and time and date when reading or notation was made,

9.3.11 Location of strata changes, to the nearest 0.5 ft [0.15 m] or better,

9.3.12 Size of casing, depth of cased portion of borehole to the nearest 0.1 ft [0.025 m] or better,

9.3.13 Hammer system used including notes on configuration, blow count rates, and drop heights for driving the sampler. Report drop heights not meeting 30 in. [750 mm] requirements or other factors affecting required drop heights or drop speed during a particular test (ETR),

9.3.14 Sampler length and inside diameter of barrel, no liner, or liner and liner type if used, shoe type, and if a sample basket retainer is used, occurrence of plugged vent ports,

9.3.15 Size, type, and section length of the sampling rods, and

9.3.16 Remarks.

9.4 *Sample Data*—Data obtained for each sample shall be recorded in the field and shall include the following:

9.4.1 Top of cleanout depth to the nearest 0.1 ft [0.025 m] or better, and any occurrence of excessive heave,

9.4.2 Top of sample depth to the nearest 0.1 ft [0.025 m] or better, and, if utilized, the sample number, report any sinking of the sampler under weight of rods, or rods and hammer.

9.4.3 Strata changes within sample,

9.4.4 Sampler penetration and recovery lengths to the nearest 0.1 ft [0.025 m] or better, and

9.4.5 Number of blows per 0.5 ft [0.15 m] or partial increment (see 8.2.1 – 8.2.3).

9.4.6 Report the *N*-value rounded to the nearest whole number.

9.5 *Hammer Energy Data (optional)*—If the energy ratio (ETR) of the hammer system is known from previous measurements, report the data and how and when the data were obtained. Alternately, if an assumed value is used, report the basis for such based on the type of hammer and operation. For any hammer that has had previous past measurement and is currently being used, report the most recent date of measurement. Report hammer drop heights and blow rates to confirm hammer performance. If energy measurements are performed onsite during testing, report the energy data with locations and frequency on drill logs or in the report. Rope and Cathead hammers are operator dependent, so the operator should be identified.

9.5.1 N_{60} values calculated in Practice D6066 may also be reported. However never place N_{60} corrected data solely on the boring log. The log shall contain only the measured N values or both.

9.5.2 Report calculated N_{60} values to the nearest whole number.

9.6 Record as a minimum the following sampling data, regarding significant digits (see 1.8) as follows:

9.6.1 Report SPT N values to the nearest whole number.

9.6.2 Record all drilling and sampling measurements to the nearest 0.1 ft [0.025 m] or better.

9.6.3 *Sampling*—Report depth interval sampled, sample recovery lengths to the nearest 0.1 ft [0.025 m] or better.

9.6.4 *Recovery,* to the nearest five percent.

9.6.5 *In Situ testing*—Report the depths and types of in situ tests performed. For devices which were inserted below the base of the drill hole, report the depths below the base of the hole to the nearest 0.1 ft [0.025 m] or better, and any unusual conditions during testing.

10. Precision and Bias

10.1 *Precision*—Test data on precision is not presented due to the nature of this test method. It is either not feasible or too costly at this time to have ten or more agencies participate in an in situ testing program at a given site.

10.1.1 Subcommittee 18.02 is seeking additional data from the users of this test method to provide a limited statement on precision. Present knowledge indicates the following:

10.1.1.1 Variations in *N*-values of 100 % or more have been observed when using different standard penetration test apparatus and drillers for adjacent boreholes in the same soil formation. Current opinion, based on field experience, indicates that when using the same apparatus and driller, *N*-values in the same soil can be reproduced with a coefficient of variation of about 10 %.

10.1.1.2 The use of faulty equipment, such as an extremely massive or damaged anvil, a rusty cathead, a low speed cathead, an old, oily rope, or massive or poorly lubricated rope sheaves can significantly contribute to differences in *N*-values obtained between operator-drill rig systems.

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

11. Keywords

11.1 blow count; in-situ test; *N*-value; penetration resistance; soil; split-barrel sampling; SPT; standard penetration test

APPENDIXES

(Nonmandatory Information)

X1. SPT GUIDANCE ON METHODS AND EQUIPMENT

X1.1 History

X1.1.1 The International Society for Soil Mechanics and Foundation Engineering published a review of SPT on an international scale in 1988 (**1**).[8] SPT started in the 1920's when pile driving companies started using wash boring methods, standard metal pipe, and different samplers driven by a hammer. ASTM first published a recommended procedure in 1958 and in 1967 a standard was adopted. Additional references (**2, 3**) provide more history. Rodgers reports history of both SPT and Cone Penetration Testing (CPT) (Test Method D5778) in reference (**4**). CPT can be more reliable than SPT because it does not suffer from drilling disturbance problems and mechanical variables in the SPT; however, there is no soil sample.

X1.2 Energy Measurements and Hammer Systems

X1.2.1 In the 1970's Schmertmann and Palacios began testing the SPT energy transmission effects and found some significant problems with the hammer designs, the test equipment, and drilling procedures. Table X1.1 is from a 1978 paper postulating the effects from energy measurements and hammer systems and other test variables on the SPT *N*-value (**5**). This table shows some of the factors which since that time many have been further researched, so these numbers are estimates which have now been refined. Energy measurements were collected using force transducers up until the 1990's (**5, 6, 7**). In 1985 it was decided that SPT data should be corrected for energy to a 60 % level of PE (**8, 9**). Energy measurement methods switched from force transducers to also adding the use of accelerometers for velocity in the Force-Velocity method in Test Method D4633 in 2005 (**10**). Since that time there have been numerous publications on hammer types and energy measurements. It has now become common practice for high level quality assurance projects, to measure the ETR of the particular hammer system and use corrected N_{60} values for design purposes (Practice D6066).

X1.2.2 Refer to Test Method D4633 on how to measure drill rod energy transmission and note that Practice D6066 requires energy measurements for liquefaction evaluations. The requirements for measuring energy depend on the project requirements. Some operators calibrate hammers annually or based on frequency of use. Automatic hammers when operated at a constant speed deliver very consistent energy so calibration frequency can be reduced as long as the operation rate is checked. New automatic hammers are being designed to constantly monitor the drop height (e.g., eSPT system[7]). Projects requiring a high level of quality assurance should use automatic hammers and have them calibrated and documented for a particular test site.

X1.2.3 Rope and cathead operated hammers are also operator dependent and energy can vary widely. Certain drill rigs have features on cathead systems that impede free fall. The drill rig should have preferably only two crown sheaves. Drills with three crown sheaves have been shown to deliver lower energy, and subsequently higher *N* values. Field data have shown large variations in energy from extreme cold to warm weather effects on rope. The condition of the rope will also change the energy.

X1.3 Hammer Systems

NOTE X1.1—Below is a partial summary of some experience regarding the hammer systems listed in the standard.

X1.3.1 *Automatic Hammer Systems:*

X1.3.1.1 The typical hydraulically operated chain cam hammer system is highly reliable for delivering consistent ETR with a standard deviation of only 2 to 3 % during an individual test. A typical range of ETR is from 70 to 95 % of maximum PE. The hammers are blow rate dependent and for more information see (**11**). The original designers set a rate of about 50 blows per minute to throw the hammer slug 30 in. [750 mm] in the air. The 30 in. [750 mm] drop assumes the anvil top is fully inside the guide tube. To maintain the drop height the

TABLE X1.1 Factors Affecting the Variability of the Standard Penetration Test *N* (Schmertmann, 1978 (5)).

NOTE 1—Metric conversions: 1 ft = 0.3048 m; 1 in. = 2.54 cm.

Cause		Estimated % by Which Cause Can Change *N*
Basic	Detailed	
Effective stresses at bottom of borehole (sands)	1. Use drilling mud versus casing and water	+ 100%
	2. Use hollow-stem auger versus casing and water and allow head imbalance	+ 100%
	3. Small-diameter hole (3 in.) versus large diameter (18 in.)	50%
Dynamic energy reaching sampler (All Soils)	4. 2 to 3 turn rope-cathead versus free drop	+ 100%
	5. Large versus small anvil	+ 50%
	6. Length of rods	
	Less than 10 ft	+ 50%
	30 to 80 ft	0%
	more than 100 ft	+ 10%
	7. Variations in height drop	± 10%
	8. A-rods versus NW-rods	± 10%
Sampler design	9. Larger ID for liners, but no liners	– 10% (sands) – 30% (insensitive clays)
Penetration inteval	10. $N_{0\text{ to }12\text{ in.}}$ instead $N_{6\text{ to }18\text{ in.}}$	– 15% (sands) – 30% (insensitive clays)
	11. $N_{12\text{ to }24\text{ in.}}$ versus $N_{6\text{ to }18\text{ in.}}$	+ 15% (sands) + 30% (insensitive clays)

---

[8] The boldface numbers in parentheses refer to the list of references at the end of this standard.

drop system must follow the anvil as penetration occurs. Different approaches have been made to accomplish this. Most hammers float in a carrier and permanently rest on the anvil exerting full mass. The Lift cylinder (Fig. X1.1) can be equipped with a double acting cylinder to maintain contact but in this case additional pressure is added to the rods. For the double acting cylinder, the operator can use a follower control on the cylinder but must be careful not to load the rods in soft material. The hydraulic motor speed can be adjusted with a Flow Control constrictor (see Fig. X1.1). Operators not familiar with the drill may allow the Flow Control (Fig. X1.1) to go off speed so it's important to check the blow rate of automatic hammers. They should always be operated at a constant Throttle Speed (Fig. X1.1) so the hydraulic supply pressure is constant. Once the hammer speed has been set, the hammer performance can be checked periodically by using the View Slot (Fig. X1.1) and the hammer can deliver consistent ETR if blow rate and speed are checked and constant during testing. There are now several different manufacturers of these hammer systems and it is not known how much they vary in performance. New automatic hammer systems are being developed to continuously measure drop heights and penetration data such as the eSPT hammer.[7]

X1.3.1.2 The typical chain cam is operated at high speed of 50 to 55 BPM to achieve the 30 in. [750 mm] drop height using an anvil with a specific length inside the guide tube. These hammers achieve high energy but for those involved with liquefaction investigations (Practice D6066) the speed is faster than recommended 20 to 40 BPM (Seed, et., al. (**8**)). On most liquefaction sites the ETR is measured and the hammer than can be adjusted to give the desired speed or energy. For example, is you wish to slow the hammer to 40 BPM the hammer will not drop 30 inches. To maintain the drop height some have equipped the anvil with a spacer ring, so the anvil is lower inside the guide tube. In other cases, the rate is reduced to the desired speed and the lower ETR is used to correct the data to N_{60}. Another reason for slowing the hammer is to record penetration per blow in gravelly soils (see X1.7).

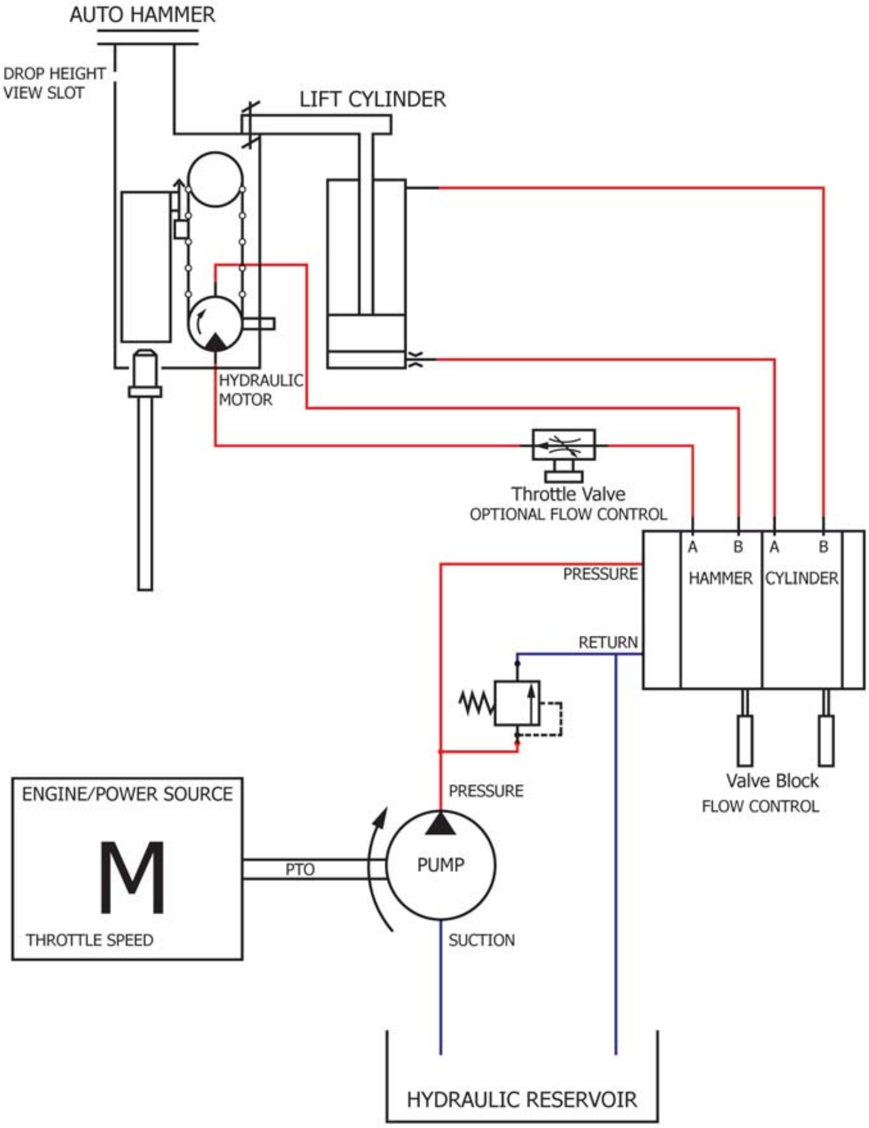


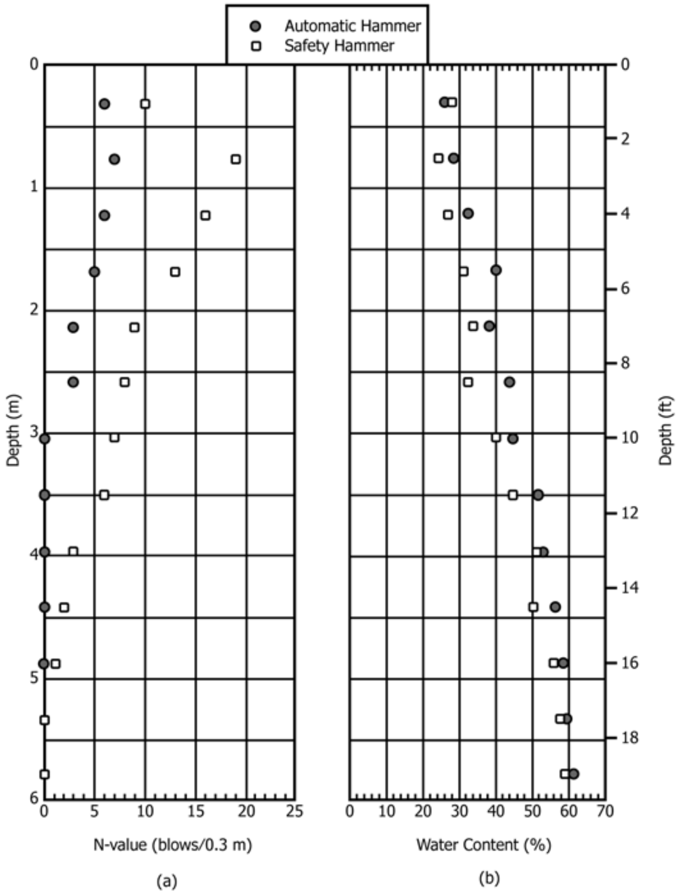
FIG. X1.1 Schematic of Hydraulic Motor Operation of Chain Cam Automatic Hammer System (courtesy MARL Technologies)

X1.3.1.3 A study of 32 automatic hammer systems was summarized by Biringen and Davie in 2008 (**12**) as part of major investigations for nuclear power plants. Their study also looked at previous automatic hammer studies from Utah DOT and Florida DOT. Although the hammer brands and blow rates were not reported, they found average ETR of automatic hammers averaged around 80 % with standard deviations of 6 to 8 %. Based on this and without any energy measurements they recommended a blanket correction factor of 1.24 to correct Nauto to N_{60} with that value being the lower bound standard deviation energy and thus a conservative correction factor. A more recent study of six CME automatic hammers of Alabama DOT resulted in an average ETR of 91 % and ranging from 82 to 96 % when operated near the design speed of 50 bpm (**13**).

X1.3.1.4 The automatic hammer systems impart considerable static mass to the rods and sampler prior to the test causing sinking under the weight of rods and hammer in soft clays. Fig. X1.2 by Luttenegger and Kelley (1997) (**14**) shows dramatically the effect in clays. This affect does not occur in sands or denser materials. They observed that typical safety and donut hammers had masses of 150 to 220 lbm [70 to 100 kg] including the 140 lbm [63.5 kg] hammer mass while auto hammers had masses of 500 to 530 lbm [230 to 240 kg]. As discussed section 4.3.2, the SPT is not reliable in soft clays and this example shows one of the primary reasons. Even a lighter safety hammer will sink through soft clays at depth due to the high rod weight from the longer drill string. For soft clays, alternate tests are recommended. If one must perform a check test of automatic hammers, use the mechanical trip or rope and cathead safety hammer or donut hammers. Their paper also shows a comparison of donut, safety, and automatic hammers at a sand site and show that energy correction worked well at that site and that all hammer systems are acceptable if the energy is known (Fig. X1.3). But for conditions where complete sinking occurs, *N* values are lost. Ideally, the hammer system should exert minimal additional weight on the rods and sampler. Some automatic hammer systems are made to float above the impact anvil using a guide tube and hydraulic lift such as the Diedrich and eSPT hammer systems. Luttengger and Kelly (**14**) did not test the floating Diedrich hammer although they list an assembly mass.

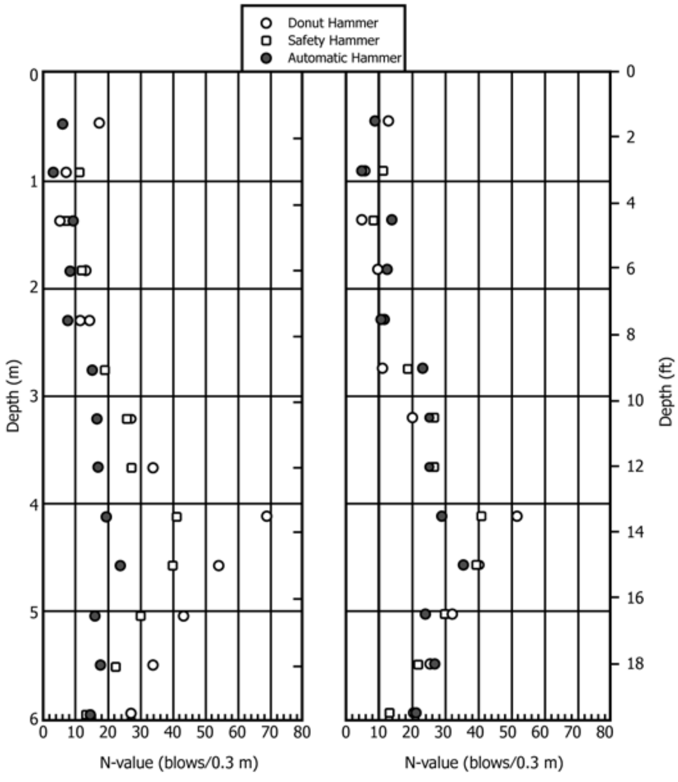
X1.3.2 *Mechanical Trip Hammers:*

X1.3.2.1 Mechanical Trip hammers are available in many countries. These trip hammers were reviewed by H. B. Seed (**8**) and summarized in Table X1.2 during the SPT review for liquefaction studies. Table X1.2 shows an effort to understand



National Geotechnical Experimentation Site, Amherst, Mass.: (a) Uncorrected Blow Count Data; (b) Water Content Data

FIG. X1.2 Illustration of Automatic and Safety Hammer Data in Clays at the NGES Test Site (Luttenegger and Kelly, 1997 (14))



(a) (b)

Plattsburgh, N.Y., Sand Site: (a) Uncorrected Blow Count Data; (b) Corrected (N_{60}) Blow Count Data

FIG. X1.3 Comparison of Automatic, Safety and Donut Hammers at a Sand Site (a) Raw Data, (b) Corrected N_{60} Values (Lutenneger and Kelly, (14))

TABLE X1.2 Summary of Pilcon Mechanical Trip Hammer ETR (Seed, (8))

Study (1)	Hammer (2)	Energy Ratio (%) (3)
Decker, Holtz, and Kovacs (in press)	Pilcon	55
Douglas and Strutznsky (8)	Pilcon	62
Liang (29)	Pilcon-type	58
Overall average		60

the Chinese trip hammers which were similar to British Pilcon hammers. The ETR of these hammers depends on the hammer-anvil impedance ratio which means that larger anvils have lower energy transmission. There are quite few variations in design and some systems even have two impact anvils or built in anvil cushioning. The estimated ETR of the Chinese and British hammers was estimated at 60 % and that is due to the large anvil. Japanese Tombi trip hammers had 78 % energy transmission because the impact anvil is very small.

X1.3.3 *Safety Hammers:*

X1.3.3.1 Safety hammers found common use in North America in the 1970's as an improvement to donut hammers. The long assembly length could be accommodated on truck mounted drills. Kovacs and Salamone (7) measured numerous safety hammer systems and the average energy was 61 % and when efficiently operated run as high as 75 % ETR (15). These hammers have higher standard deviation of ETR during an individual test, i.e., 5 to 10 %. Two rope turns, or wraps should be used on the cathead to operate the hammer. The energy transmission depends on the number of rope turns used on the cathead. Extra rope turns (wraps) can cause large energy transmission losses. Use of a new stiff rope can result in temporary increase of ETR until the rope has been broken in.

X1.3.4 *Donut Hammers:*

X1.3.4.1 The older Donut hammers have shown a wide variation of low energies ranging from 35 to 65 %. Once again, the ETR depends on the hammer anvil impedance ratio. Based on data from Kovacs, Seed estimated an average energy of these hammers at 45 % (8). Due to the large variation in ETR for these hammers it would be unwise to use an assumed value of ETR, so some kind of previous or on-site energy measurements (Test Method D4633) should be required for the hammer prior to its use. Some countries such as Japan use hammers with fixed hammer and anvil dimensions and there are considerable energy data available so that an assumed value could be used on small projects (Kovacs, Seed (7, 8)). As with the safety hammer, two rope turns, or wraps should be used on the cathead to operate the hammer. The energy transmission depends on the number of rope turns used on the cathead. Extra rope turns (wraps) can cause large energy transmission losses. Use of a new stiff rope can result in temporary increase of ETR until the rope has been broken in.

X1.3.5 *Spooling Winch Hammers:*

X1.3.5.1 Published data indicate the spooling mechanism can sometimes impede the free fall of the hammer resulting in very low energy measurements (15). Before using this test at any given site, the ETR must be measured to confirm proper operation. This hammer system should not be used if the ETR has not been checked.

X1.4 Mechanical Variables

X1.4.1 *Sampler Split Barrel – Inside Diameter – Liners and No Liners:*

X1.4.1.1 There is limited research on the effects of the upset wall sampler barrel with and without liners. The available data were summarized by H.B Seed (8) and shown on Fig. X1.4 for liquefaction evaluation. The studies were predominantly done at sand sites. As would be expected, the differences are more pronounced in denser soils where internal friction buildup occurs in a constant wall diameter. Since the bulk of international data are collected with constant wall diameters, it is recommended that, for liquefaction studies, to correct for liners by EERI (16) a shown on Fig. X1.5. For most standard investigations the effect is minor for $N < 20$ and data are lacking for clay soils. Sample recovery is higher with upset wall split barrels due to reduced friction on the soil core.

X1.4.2 *Sampler Design:*

X1.4.2.1 The bulk of the samplers manufactured in North America are made to the Diamond Drill Core Manufacturers Association (DDCMA) specifications shown on Fig. X1.6 (17). These barrels have upset wall design.

X1.4.3 *Drill Rod Type and Rod Length:*

X1.4.3.1 There is no definitive research on the effect of A versus N size drill rods on N values. These sizes of rods should

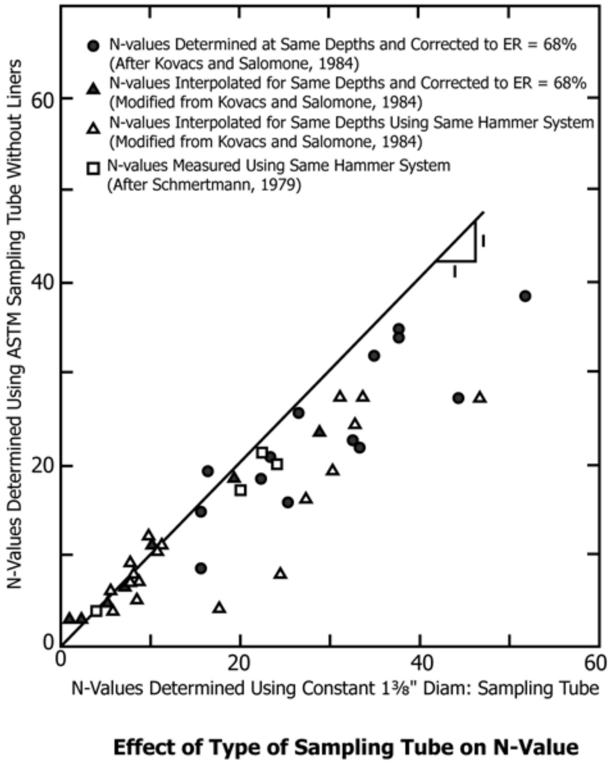


FIG. X1.4 Comparison of Use of SPT Barrel With and Without Liners in Sands (Seed (8))

Standard split spoon without room for liners (the inside diameter is a constant 1⅜ in.). $C_S = 1.0$.

Split-spoon sampler with room for liners but with the liners absent (this increases the inside diameter to 1½ in. behind the driving shoe):

$$C_S = 1.1 \quad \text{for} \quad (N_1)_{60} \leq 10$$

$$C_S = 1 + \frac{(N_1)_{60}}{100} \quad \text{for} \quad 10 \leq (N_1)_{60} \leq 30$$

$$C_S = 1.3 \quad \text{for} \quad (N_1)_{60} \geq 30$$

(from Seed et al. 1984, equation by Seed et al. 2001)

FIG. X1.5 Recommended Liner Correction for SPT in Sands for Liquefaction Evaluation (EERI (15))

transmit energy effectively to the sampler. If anything, the energy reaching the sampler would be less in N rods than smaller diameter A rods because of reflections and dispersion of the stress wave (strain energy) component in the rods with larger joint pins. There is no indication that a loose joint or rod whip and friction on the borehole wall cause significant reductions in energy flowing through the rods, however this can be noted if suspected. For general practice, the differences in drill rods and the losses from length in typical depth ranges up to 100 ft [30 m] are less than 5 % and can be ignored for most production testing. However, for liquefaction evaluations corrections are sometimes used for short length and longer rods as follows irrespective of rod type.

X1.4.3.2 *Short Rod Lengths < 30 ft [10 m]*—Early energy transmission research using the F2 method assumed sampler penetration occurred primarily from the first big incident wave. Schmertmann proposed, in Table X1.1 for depths less than 30 ft [10 m] there could be some reduction in energy to the sampler because of termination of hammer contact by the reflected compression wave and reduction factors were applied for shallow blow counts. These corrections are still found today in some liquefaction guidelines (**16**). However, recently, researchers have argued that no reductions should be applied, and it was found that hammer anvil contact was maintained (**18, 19**). Part of these conclusions are due to the fact new ETR measurements use the FV method and include energy content of the first incident wave and subsequent smaller reflected pulses that occur past the first major stress pulse (see Test Method D4633, Appendix X1 and Odenbrecht et al., (**20**).

X1.4.3.3 *Long Rod Lengths > 100 ft [30 m]*—Besides the short rod corrections for liquefaction studies, there is also concern with energy losses of very long drill rods. Based on some early studies it was recommended that for borings of excess of 100 ft [30 m] one should reduce energy about 1 % for every 10 ft [3 m] (**21**). More recent energy measurements seem to confirm N rods lose energy at a greater rate compared to A rods and in some instances, the loss rate is greater (or efficiency is less) than previously expected (**22, 23**).

X1.4.4 *Drive Shoes:*

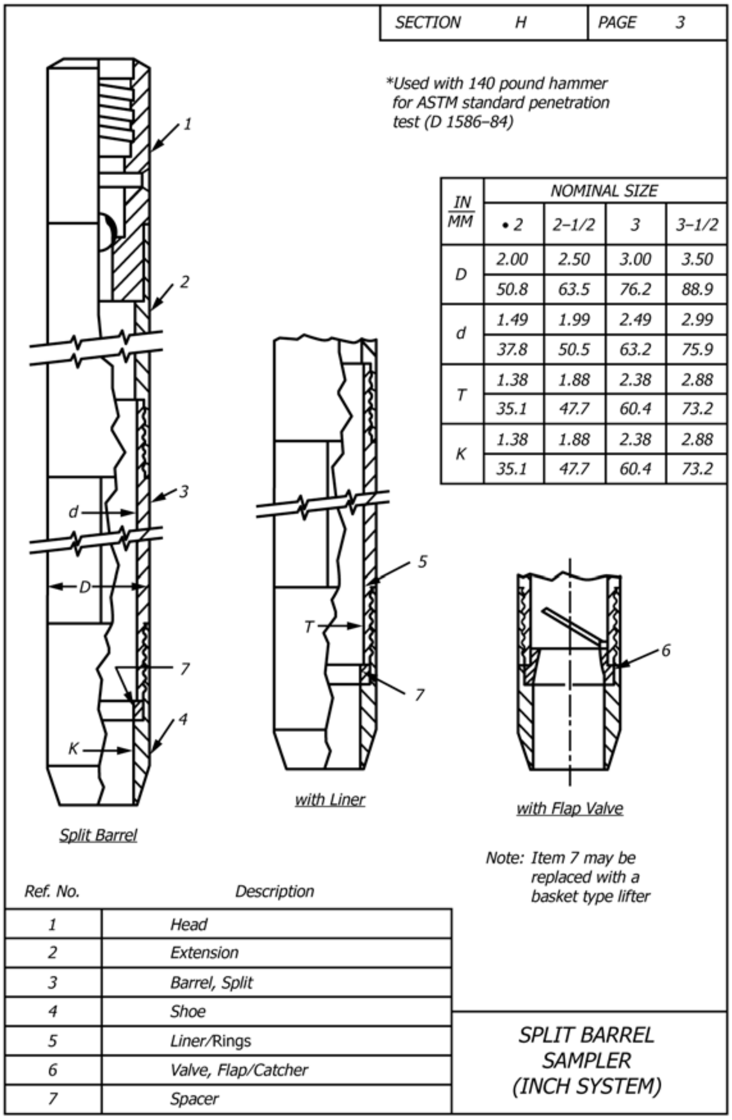
X1.4.4.1 As noted in the standard, manufacturers produce several types of drive shoes used for sampling. Fig. X1.7 shows shoes commonly used and only the sharper shoe to the left is made for sampling fine soils while the thicker, blunter, shoes are used in coarser and denser soils. Thicker shoes are not in conformance with section 5.3. There has been no known controlled study on the effects on *N* values between these different styles of drive shoes.

X1.5 Operational Variables

X1.5.1 *Drilling Methods – Research on SPT and Drilling Methods:*

X1.5.1.1 One of the early reports on drilling methods was Parsons (**24**) where he discovered poor SPT data in sands that were drilled with water below the water table. The results are summarized on Fig. X1.8. Although the drilling methods were not clearly described it was assumed that the low blow counts in sand were caused by the removal of the drill bit and a drop in borehole fluid causing sand to flow into the base of the boring. It is not clear how the casing was used or if they were rotary or wash borings. Check test holes were carefully drilled using auger and drilling mud to clear the test zone which resulted in very high blow counts in the dense sand.

X1.5.1.2 A study of mud rotary, hollow-stem augers, water fluid rotary drilling with driven casing was reported by Whited and Edil in 1986 (**25**). Thirty-six borings in differing geologic conditions in Wisconsin were conducted by transportation drill crews experienced with SPT. Hollow-stem auger borings were advanced with the pilot bit in-place and when below the water table drill fluid (Mud) was injected using a spindle adaptor. The water borings were advanced by driving the casing in 1.5 m increments while cleaning the casing with roller bit and clear water. The conclusions of the study were that the drilling methods had no effect on SPT in clay soils. The driven casing



*Used with 140 pound hammer for ASTM standard penetration test (D 1586–84)

IN MM	NOMINAL SIZE			
	• 2	2–1/2	3	3–1/2
D	2.00	2.50	3.00	3.50
	50.8	63.5	76.2	88.9
d	1.49	1.99	2.49	2.99
	37.8	50.5	63.2	75.9
T	1.38	1.88	2.38	2.88
	35.1	47.7	60.4	73.2
K	1.38	1.88	2.38	2.88
	35.1	47.7	60.4	73.2

Note: Item 7 may be replaced with a basket type lifter

Ref. No.	Description
1	Head
2	Extension
3	Barrel, Split
4	Shoe
5	Liner/Rings
6	Valve, Flap/Catcher
7	Spacer

SPLIT BARREL
SAMPLER
(INCH SYSTEM)

FIG. X1.6 DDCMA Split Barrel Design (17)

borings yielded high blow counts above the water table and lower blow counts below the water table in sands. This is due to suspected densification above the water table in sands and the focusing effect of groundwater seepage force at the base of the casing and sand disturbance by water imbalance by removing cleanout tools. The report does not mention if a bypass line is used to add fluid when drilling below the water table. There was some tendency for hollow-stem auger holes to record lower blow counts in sands below the water table. The important finding in this study is that driven casing should be kept away from the test zone.

X1.5.1.3 A study of mud rotary drilling and hollow-stem auger drilling was performed by Seed et al., (**26**) for purposes of investigating USGS blow count case history liquefaction database. The study focused on sands below the water table and all drilling methods use a fluid bypass to maintain the fluid levels at the top of the boring during removal of the cleanout string. Four different sites were investigated comparing 66 SPT drilled with water (in augers or casing) and 147 SPT drilled with drill mud. The results indicated minimal differences in the two drilling methods. On Fig. X1.9 there was a trend of lower *N*-value with Hollow-stem versus mud rotary borings.

X1.5.1.4 These conclusions by Seed et al., (**26**) were worth quoting; "In either case it is clear that borehole fluid type (drilling mud or water) had no significant effect on penetration resistance so long as good drilling and sampling techniques are used, including prevention of hydraulic inflow at the base of the borehole." The purpose of the study was to prove careful hollow stem augering can be used, but the Fluid Rotary Drilling method using drill mud is considered to be the most reliable method and should be used as the reference test.

X1.5.2 *Hollow-Stem Auger Type and Problems in Sands:*

X1.5.2.1 There are two types of Hollow-stem Augers (Practice D6151/D6151M) the "Inner Rod" type and "Wireline" type. Both systems can be operated with a pilot bit or long inside sampling barrel and removal of these tools causes a suction effect in sands below the water table. In order to

Drive samplers usually employ three types of cutting heads, or shoes, shown here. The sharp tapered heads are intended for soil sampling, while the more blunt tips are designed for greater longevity when sampling granular soils.

FIG. X1.7 SPT Drive Shoes for Fine and Coarse-Grained Soils (Rodgers, 2006 (4))

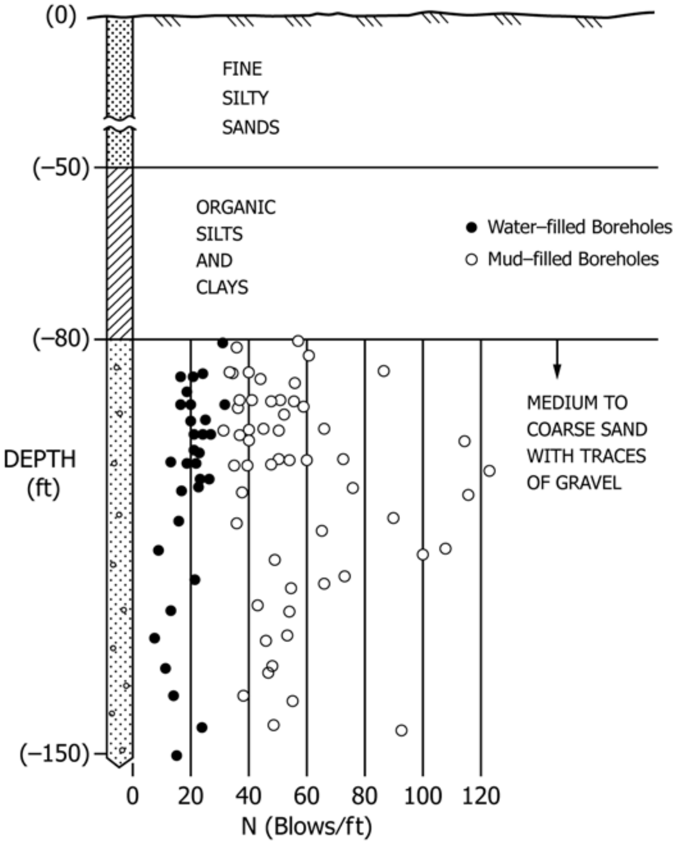


FIG. X1.8 Comparison of SPT Drilled With Water versus Drilling Fluid (Mud) (Parsons (24))

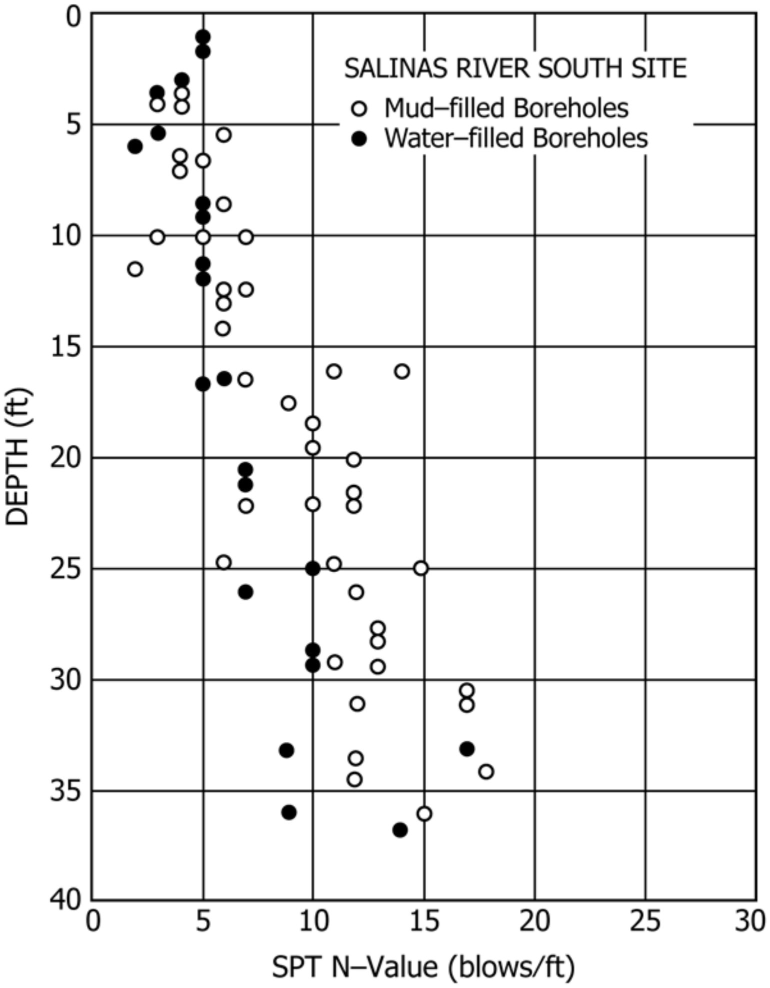
minimize disturbance to the test zone below the water table, the inner tube should be kept full of fluid and the barrel or bit removed slowly to reduce suction effect. The lesser used wireline systems have had many problems with sands below the water table because the bit or barrel is removed rapidly. When this happens and if sand flows into the barrel, it will not be able to re-latch. This may require that the whole auger string be pulled upward to clear the sand inside causing even more suction and disturbance in the bottom of the boring. Hollow-stem augers have also been advanced without an interior pilot bit, however, material may require cleaning if there are soils inside the augers. This can be checked by comparing the bit or barrel depth the SPT sampler depth.

X1.5.3 *Sonic and Direct Push Drilling Methods:*

X1.5.3.1 There is very limited information on comparison of SPT *N*-values from Sonic or Direct Push drilling methods but some studies are underway. One study on Sonic drilling by Wentz et al., (27) shows that there were negligible pore pressure increases in sands as close as 300 mm to casings but comparisons to conventional rotary drilling were inconclusive. A study by Wotherspoon et al., (28) compared numerous Sonic and Direct Push SPT *N*-values to *N* values predicted by CPT methods at a site in Canterbury, N.Z. showed that the drilling methods may be affecting soils with lower *N*-values and that site-specific correlations may be required. This points to a need to check site specific SPT *N*-values from these drilling methods to conventional methods such as the fluid rotary drilling or hollow stem auger drilling.

X1.5.4 *Drill Hole Diameter:*

X1.5.4.1 A Borehole diameter correction was proposed by Skempton (9) for use in liquefaction evaluation. He noted the majority of case history borings were 2.6 to 4 in. [65 to 100 mm] diameter but some borings as large as 8 in. [200 mm] are allowed for SPT. He proposed correction factors of 1.05 and 1.15 for 6 in. [150 mm] and 8 in. [200 mm] diameter borings, respectively. This standard specifies 3 to 6 in. [75 to 150 mm] borehole diameter. He stated that the size effect in clays was



-Data for Salinas River South Site.

FIG. X1.9 Comparison of Mud Rotary versus Hollow-Stem Augers at Salinas Site (Seed et al., (26))

probably negligible but that these correction factors are recommended of liquefaction potential in sands. He noted that there is no research on this topic and it is needed.

X1.6 Notes on Soil Types – Coarse Grained Soils

X1.6.1 *Maximum Particle Size – Research on SPT in Sands:*

X1.6.1.1 The maximum particle size is listed in section 4.3 as ½ the sampler diameter or smaller. Actually, the test is generally applicable to soils containing no gravels, soils with gravels, depending on the percentage will begin to artificially raise the blow count over non-gravel soils, and hence affect geotechnical engineering estimates based on SPT data.

X1.6.1.2 SPT chamber test research has been conducted for clean quartz sands by several agencies and the result were summarized by Jamiolkowski et al., (**29**) in 1988. Numerous field and chamber studies have been performed in an effort to correlate *N* and Relative Density as a function of effective overburden pressure. Actually, the ratio at which particle size begins to elevate blow count at a constant Dr and pressure is approximately 1⁄10 the diameter of the penetrometer or smaller. There were differences in coarse versus fine to medium sands tested by USACE in chambers (**29**). There are also data from field studies with coarser sands. Based on a review of the field and laboratory data, Skempton (**9**) proposed the following modification of Terzaghi's chart in Appendix X2 as follows on Fig. X1.10.

X1.7 Recording Penetration per Blow (PPB) in Gravelly Sands

X1.7.1 As outlined in the EERI publication on soil liquefaction (**16**) the presence of coarse particles in sands can interfere with obtaining usable SPT data for the sand matrix. Some agencies dealing with these soils, record PBB or penetration per 0.1 ft [0.025 m]. The goal is to extrapolate a reliable sand *N*-value as shown on Fig. X1.11(b). This method is only reliable for gravel contents of up to 15 to 20 %. For more information consult the EERI report.

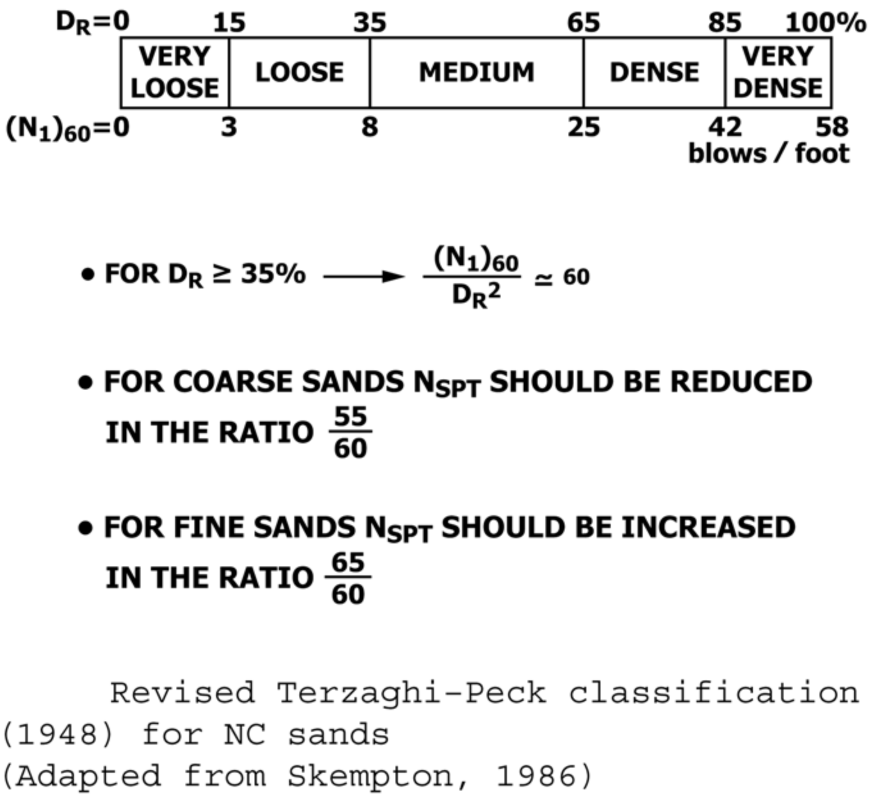
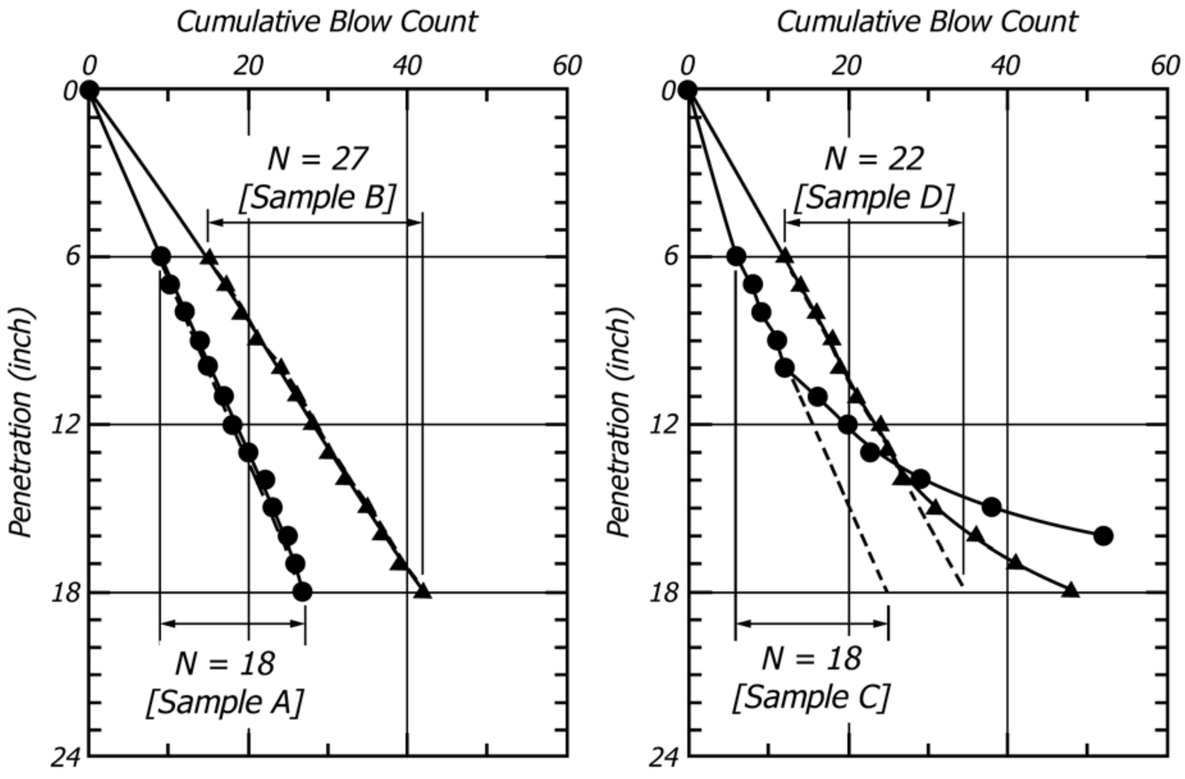


FIG. X1.10 Revised Classification and Estimated Relative Density of Sands Considering Differences Between Coarse and Medium to Fine Sands (Skempton (9))

X1.7.2 Use of automated systems that have laser distance recorders (PileTrac) or system like the new automated eSPT hammers greatly facilitate recording and post processing of data and reduce errors (see 8.3 and Note 5). Recording by hand can be done but requires a third person recorder or hand marking on drill rods which is hazardous. Manual recording must be input into spreadsheets.



Examples of interpreting SPT blow counts on a per-inch basis: (a) smooth driving patterns that do not require corrections to *N* values and (b) strong increases in driving resistance that, along with sample recoveries, suggest that the sampler encountered large particles; this graph also shows the adjusted *N* value, based on extrapolating the pre-obstruction driving rate.

FIG. X1.11 EERI Example of Recording Penetration per Blow in Sands (16).

X2. SOIL CONSISTENCY DECRIPTORS

X2.1 The standard uses consistency descriptors in discussion of drilling and sampling of soils. Fig. X2.1 are two tables extracted from Terzaghi and Peck, *Soil Mechanic in Engineering Practice*, second edition, 1967, Wiley & Sons. These two tables provide SPT *N* values from this standard and the corresponding basic soils consistency descriptors for clays and sands.

Relation of Consistency of Clay, Number of Blows N on Sampling Spoon, and Unconfined Compressive Strength

	q_u in tons/ ft^2					
Consistency	Very Soft	Soft	Medium	Stiff	Very Stiff	Hard
N	< 2	2–4	4–8	8–15	15–30	> 30
q_u	< 0.25	0.25–0.50	0.50–1.00	1.00–2.00	2.00–4.00	> 4.00

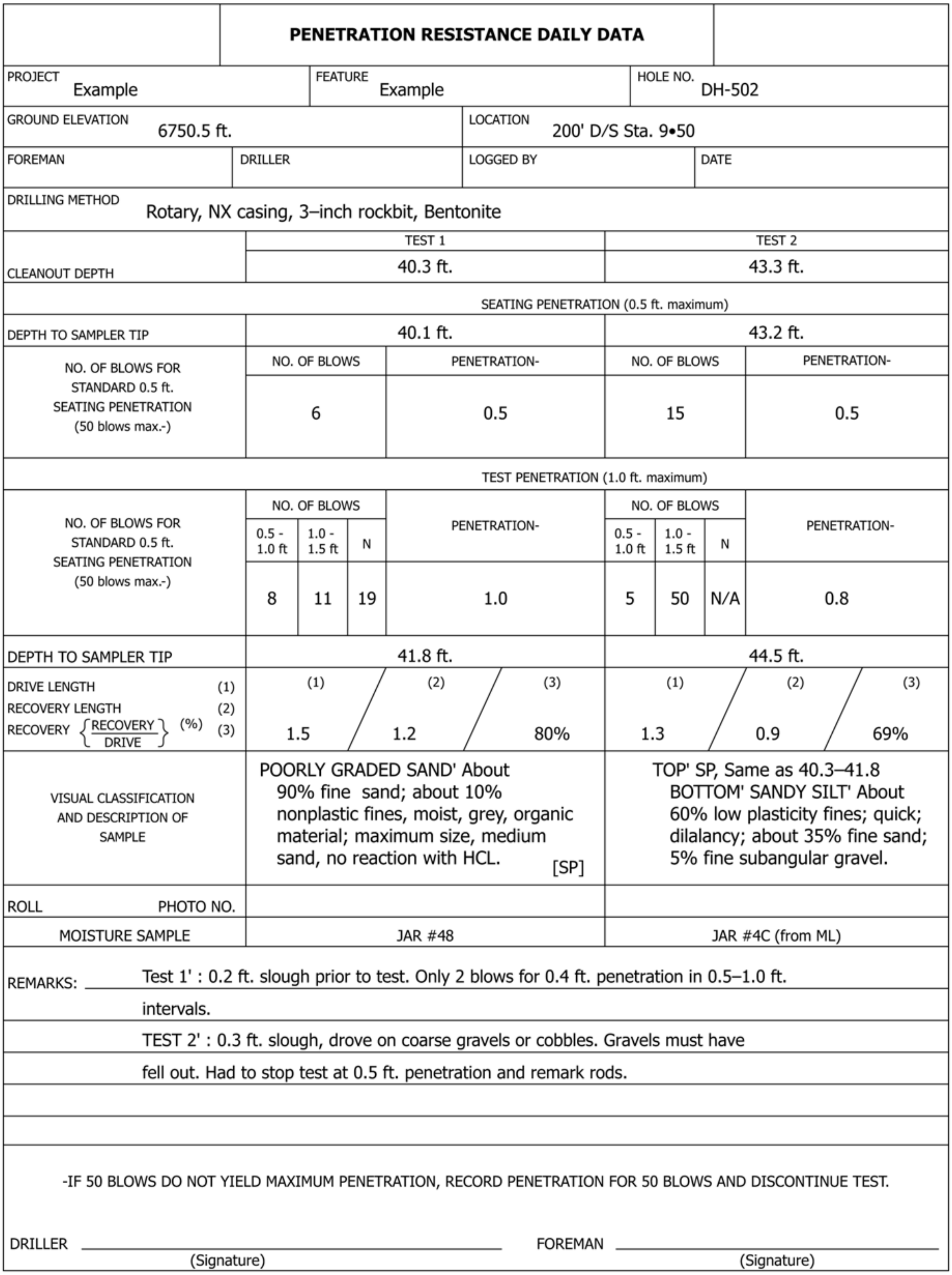
Relative Density of Sands according to Results of Standard Penetration Test

No. of Blows *N*	**Relative Density**
0–4	Very loose
4–10	Loose
10–30	Medium
30–50	Dense
Over 50	Very dense

FIG. X2.1 Terzaghi and Peck Descriptors of Soil from SPT *N* Values

X3. EXAMPLE DATA SHEET

X3.1 See Fig. X3.1.



PENETRATION RESISTANCE DAILY DATA

PROJECT Example	FEATURE Example		HOLE NO. DH-502
GROUND ELEVATION 6750.5 ft.		LOCATION 200' D/S Sta. 9•50	
FOREMAN	DRILLER	LOGGED BY	DATE
DRILLING METHOD Rotary, NX casing, 3–inch rockbit, Bentonite			

	TEST 1				TEST 2			
CLEANOUT DEPTH	40.3 ft.				43.3 ft.			
	SEATING PENETRATION (0.5 ft. maximum)							
DEPTH TO SAMPLER TIP	40.1 ft.				43.2 ft.			
NO. OF BLOWS FOR STANDARD 0.5 ft. SEATING PENETRATION (50 blows max.-)	NO. OF BLOWS			PENETRATION-	NO. OF BLOWS			PENETRATION-
	6			0.5	15			0.5
	TEST PENETRATION (1.0 ft. maximum)							
NO. OF BLOWS FOR STANDARD 0.5 ft. SEATING PENETRATION (50 blows max.-)	NO. OF BLOWS			PENETRATION-	NO. OF BLOWS			PENETRATION-
	0.5 - 1.0 ft	1.0 - 1.5 ft	N		0.5 - 1.0 ft	1.0 - 1.5 ft	N	
	8	11	19	1.0	5	50	N/A	0.8
DEPTH TO SAMPLER TIP	41.8 ft.				44.5 ft.			
DRIVE LENGTH (1) RECOVERY LENGTH (2) RECOVERY $\left\{\frac{\text{RECOVERY}}{\text{DRIVE}}\right\}$ (%) (3)	(1) 1.5	(2) 1.2	(3) 80%		(1) 1.3	(2) 0.9	(3) 69%	
VISUAL CLASSIFICATION AND DESCRIPTION OF SAMPLE	POORLY GRADED SAND' About 90% fine sand; about 10% nonplastic fines, moist, grey, organic material; maximum size, medium sand, no reaction with HCL. [SP]				TOP' SP, Same as 40.3–41.8 BOTTOM' SANDY SILT' About 60% low plasticity fines; quick; dilalancy; about 35% fine sand; 5% fine subangular gravel.			
ROLL PHOTO NO.								
MOISTURE SAMPLE	JAR #48				JAR #4C (from ML)			

REMARKS: Test 1' : 0.2 ft. slough prior to test. Only 2 blows for 0.4 ft. penetration in 0.5–1.0 ft. intervals.

TEST 2' : 0.3 ft. slough, drove on coarse gravels or cobbles. Gravels must have fell out. Had to stop test at 0.5 ft. penetration and remark rods.

-IF 50 BLOWS DO NOT YIELD MAXIMUM PENETRATION, RECORD PENETRATION FOR 50 BLOWS AND DISCONTINUE TEST.

DRILLER ______________________ (Signature)

FOREMAN ______________________ (Signature)

FIG. X3.1 Example Data Sheet

REFERENCES

(1) "Standard Penetration Test (SPT): International Reference Test Procedure," (1988), ISSMFE Technical Committee on Penetration Testing, Penetration Testing 1988, ISOPT-1, DeRuiter (ed.), Balkema, Rotterdam ISBN90 6191 8014.

(2) Hvorslev, M. J., 1949, Subsurface Exploration and Sampling of Soils for Engineering Purposes, report of a research project of the Committee on Sampling and Testing, Soil Mechanics and Foundations Division, American Society of Civil Engineers, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg Mississippi, re-published by Engineering Foundation 1960.

(3) Clayton, C.R.I. 1995. The standard penetration test (SPT): Methods and use. CIRIA Report 143, London.

(4) Rodgers, J. David, "Subsurface Exploration Using the Standard Penetration Test and Cone Penetration Test," (2006), *Environmental & Engineering Geoscience*, Association of Engineering Geologists/ Geological Society of America, Vol XII, No. 2, May, pp. 161-179.

(5) Schmertman, J. H., "Use the SPT to Measure Dynamic Soil Properties? -Yes, But!" Dynamic Geotechnical Testing, ASTM STP 654, American Society for Testing and Materials, 1978, pp. 341-355.

(6) Schmertman, J. H., and Palacios, A., "Energy Dynamics of SPT," *Proceedings of the ASCE Journal of Geotechncial Engineering*, Vol. 105, 1979, pp. 909-926.

(7) Kovacs, W. D., and Salomone, L. A., "Field Evaluation of SPT Energy, Equipment and Methods in Japan Compared with SPT in the United States," *NBSIR-2910*, National Bureua of Standards, U.S. Department of Commerce, August 1984.

(8) Seed, H. B., Tokimatsu, K, Harder, L. F., and Chung, R. M., "Influence of SPT Procedures in Soil Liquefaction Resistance Evaluations," *Journal of Geotechnical Engineering*, Vol 111, No. 12, December 1985.

(9) Skempton, A. W., "Standard Penetration Test Procedures and the Effects in Sands of Overburden Pressure, Relative Density, Particle Size, Aging, and Overconsolidation," *Geotechnique*, 36, No. 3, 1986, pp. 425-447.

(10) Abou-mater, J., and Goble, G. G., "SPT Dynamic Analysis and Measurements," *Journal of Geotechnical and Geoenvironmental Engineering*, Vol 123, No. 10, October 1997, pp. 921-928.

(11) Farrar, J. A, and Chitwood, D., "CME Automatic Hammer Operations Bulletin," Dam Safety Report DSO-99-03, U. S. Bureau of Reclamation, Technical Service Center, PO Box 25007 Denver, Colorado, 80225.

(12) Biringen, E., and Davie, J., "SPT Automatic Hammer Efficiency Revisited," 6th International Conference on Case Histories in Geotechncial Engineering, Arlington VA, August 11-16, 2006.

(13) Honeycutt, J. N., "Local and National Scale Energy Calibration of Standard Penetration Test Hammers," Master's Thesis, Civil Engineering department, Auburn University, Auburn, Alabama, May 6, 2012.

(14) Lutenegger, A. J., and Kelly, S. P., "Influence of Hammer Type on SPT Results," *Journal of Geotechnical and Geoenvironmental Engineering*, American Society of Civil Engineers, Vol X, No, X, September 1997.

(15) Farrar, J. F., "Standard Penetration Test: Driller's / Operator's Guide," Dam Safety Office Report DSO-98-17, U.S. Department of Interior Bureau of Reclamation Dam Safety Office, Technical Service center, Denver, CO. May 1999.

(16) Idriss, I. M., and Boulanger, R. W., "Soil Liquefaction During Earthquakes," Engineering Monograph MNO-12, Earthquake Engineering Institute (EERI), www.eeri.org , Oakland, CA, USA 2008.

(17) *DCDMA Technical Manual*, Drilling Equipment Manufacturers Association, 3008 Millwood Avenue, Columbia, SC, 1991.

(18) Sancio, R. B. and Bray, J. D., "An Assessment of the Effect of Rod Length on SPT Energy Calculations Based on Measured Field Data," *Geotechnical Testing Journal*, Vol 28, No. 1, 2005.

(19) Daniel, C. R., Howie, J. A., Jackson, R. S. and Walker, B. W. (2005), "A Review of Short Rod Correction Factors," *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 131, No. 4, pp. 489-497.

(20) Odebrecht, Edgar, et al. "Energy efficiency for standard penetration tests." *Journal of Geotechnical and Geoenvironmental Engineering*, 131.10 (2005): 1252-1263.

(21) Farrar, J. A, Nickell, J., Allen, M. G., Goble, G. G., and J. Berger, "Energy Loss in Long Rod Penetration Testing – Terminus Dam Investigation," *Geotechnical Earthquake Engineering and Soil Dynamics III*, Geotechnical Special Publication GSP75, American Society of Civile Engineers Reston, VA. (1998).

(22) Johnsen, L. F, and J. J. Jagello, "Discussion of "Energy Efficiency for Standard Penetration Tests" by Edgar Odebrecht, Fernando Schnaid, Marcelo Maia Rocha, and George de Paula Bernardes October 2005, Vol. 131, No. 10, pp. 1252-1263, *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE / April 2007.

(23) C. M. Santana & F. A. B. Danziger B. R. Danziger "The measurement of energy reaching the sampler in SPT," Geotechnical and Geophysical Site Characterization 4 – Coutinho & Mayne (eds) Taylor & Francis Group, London, ISBN 978-0-415-62136-6 (2013).

(24) Parsons, J. D., Discussion of the previous article "Standard Penetration Test: Uses and Abuses," (1966), *Journal of the Soil Mechanics and foundation Engineering Division*, ASCE, Vol. 91, No. SM3, pp. 103-105.

(25) Whited, G. C., and Edil, T. B., (1986) "Influence of Borehole Stabilization Techniques on Standard Penetration Test Results," *Geotechnical Testing Journal*, ASTM, Vol. 9, No. 4, pp. 180-188.

(26) Seed, R. B, Harder, L. F.,Jr., and Youd, T. L., (1988), "Effects of Borehole Fluid on Standard Penetration Tests," *Geotechnical Testing Journal, GTJODJ*, Vol. 11, No. 4, Dec., pp. 248-256.

(27) Wentz, F. J., and S. E. Dickenson, (2013) "Pore Pressure response during high frequency sonic drilling and SPT sampling in liquefiable sand," *Proc 19th NZGS Geotechnical Symposium*, Ed. CY Chin, Queenstown.

(28) Wotherspoon, L. M., Li, Z., Haycock, I. (2015). Assessment of SPT – CPT correlations using Canterbury site investigation database. 12th Australia New Zealand Conference on Geomechanics, Wellington, New Zealand.

(29) Jamiolkowski, M., Ghionna, V.n., Lancellotta, R., and E. Pasqualini, "New Correlations of Penetration Tests for Design Practice," Penetration Testing 1988, ISOPT-1, DeRuiter(ed), Balkema, Rotterdam, 1988. pp. 263-296.

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this test method since the last issue, D1586–11, that may impact the use of this test method. (Approved December 1, 2018.)

(1) A major revision was undertaken in 2018. The standard had significant changes to the significance and use and apparatus sections. The major changes were:
(2) Section 4: The section was revised to include important information regarding SPT energy measurements on the test result. Its use in sand and clays was clarified and in soft clay was use has been shown to be problematic.
(3) Section 4: Sampler with or without liners are allowed and the differences are discussed the Appendix.
(4) Section 4: Recommends the use of automatic or trip hammer system but allows other systems.
(5) Sections 4 and 5: Preferred drilling methods are provided but most all methods are allowed based on approval of the user.
(6) Sections 4 and 5: Preferred hammer systems are also given but any hammer system meeting basic requirements can be used. It is strongly recommended that the user determine or know the energy of the hammer system they use and at a minimum the hammer type must be reported.
(7) General: Appendix X1 has been added to give the user more information on the effects of equipment usage and the various drilling methods.

Designation: D2113 – 14

Standard Practice for
Rock Core Drilling and Sampling of Rock for Site Exploration[1]

This standard is issued under the fixed designation D2113; 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 (ε) indicates an editorial change since the last revision or reapproval.

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

1. Scope*

1.1 This practice covers the guidelines, requirements, and procedures for core drilling, coring, and sampling of rock for the purposes of site exploration. The borehole could be vertical, horizontal, or angled.

1.2 This practice is described in the context of obtaining data for the design, construction, or maintenance of structures, and applies to surface drilling and drilling from adits and exploratory tunnels.

1.3 This practice applies to core drilling in hard and soft rock.

1.4 This practice does not address considerations for core drilling for geo-environmental site characterization and installation of water quality monitoring devices (see Guides D5782 and D5783).

1.5 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.6 This practice does not purport to comprehensively address all of the methods and the issues associated with coring and sampling of rock. Users should seek qualified professionals for decisions as to the proper equipment and methods that would be most successful for their site exploration. Other methods may be available for drilling and sampling of rock, and qualified professionals should have flexibility to exercise judgment as to possible alternatives not covered in this practice. This practice is current at the time of issue, but new alternative methods may become available prior to revisions; therefore, users should consult with manufacturers or producers prior to specifying program requirements.*This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

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.* Also, the user must comply with prevalent regulatory codes, such as OSHA (Occupational Health and Safety Administration) guidelines, while using this practice. For good safety practice, consult applicable OSHA regulations and other safety guides on drilling (**1**).

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D4380 Test Method for Density of Bentonitic Slurries
D4630 Test Method for Determining Transmissivity and Storage Coefficient of Low-Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test
D5079 Practices for Preserving and Transporting Rock Core Samples
D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock
D5782 Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5783 Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration

---

[1] This Practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Evaluations.

Current edition approved Nov. 1, 2014. Published November 2014. Originally approved in 1962. Last previous edition approved in 2008 as D2113 – 08. DOI: 10.1520/D2113-14.

[2] 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.

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

and the Installation of Subsurface Water-Quality Monitoring Devices

D5876 Guide for Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices

D6032 Test Method for Determining Rock Quality Designation (RQD) of Rock Core

D6151 Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling

2.2 *American Petroleum Institute Standard:*[3]

API RP 13B Recommended Practice Standard Procedure for Testing Drilling Fluids

2.3 *NSF Standard:*[4]

NSF/ANSI 60-1988 Drinking Water Treatment Chemicals-Health Effects

3. Terminology

3.1 For common definitions of terms in this standard, refer to Terminology D653.

3.2 *Definitions:*

3.2.1 *blind hole, n*—borehole that yields no fluid recovery of the drilling fluids.

3.2.2 *casing, n*—hollow tubes of steel used to support borehole walls or where fluid losses must be stopped.

3.2.3 *caving hole, n*—borehole whose walls or bottom are unstable and cave or collapse into the drilled borehole.

3.2.4 *core barrel, n*—hollow tube of steel used to collect cores of drilled rock.

3.2.5 *core bit, n*—a drill bit that cuts cylindrical rock samples and consists of one of the following: a drill bit with surface set of diamonds or impregnated diamonds in a tungsten carbide mix of hardened steel, polycrystalline bit, or tungsten carbide (TC) inserts mounted on a cylindrical bit that cuts out cylindrical rock samples.

3.2.6 *drill rig, n*—includes drilling power unit, mast or derrick, circulating pumps, and mounting platform.

3.2.7 *drill rod, n*—hollow steel tubes that are connected to the drill bit or core barrel and to the rotary head of the drilling power unit.

3.2.8 *drill platform, n*—a platform for a drilling rig.

3.2.9 *overshot, n*—a latching mechanism at the end of the hoisting line, specially designed to latch onto or release pilot bit or core barrel assemblies when using *wireline drilling*. **(D5876)**

3.2.10 *pilot bit assembly, n*—designed to lock into the end section of drill rod for *wireline drilling* without sampling. The pilot bit can be either drag, roller cone, or diamond plug types. The bit can be set to protrude from the rod coring bit depending on the formation being drilled. **(D5876)**

3.2.11 *squeezing hole, n*—borehole whose walls move into the drilled opening and squeeze on the drill rods.

3.2.12 *wireline, n*—a cable made of steel strands connected to a drum hoist, used to raise and lower the core barrel, drill rods, or other equipment as needed in the drill hole.

3.2.13 *wireline drilling, n*—a rotary drilling process using special enlarged inside diameter drilling rods with special latching pilot bits or core barrels raised or lowered inside the rods with a wireline and overshot latching mechanism. **(D5876)**

4. Summary of Practice

4.1 *Drilling:*

4.1.1 Drilling is accomplished by circulating a drilling medium through the drill bit while rotating and lowering or advancing the string of drill rods as downward force is applied to a cutting bit. The bit cuts and breaks up the material as it penetrates the formation, and the drilling medium picks up the cuttings generated by the cutting action of the bit. The drilling medium, with cuttings, then flows outward through the annular space between the drill rods and drill hole, and carries the cuttings to the ground surface, thus cleaning the hole. The string of drill rods and bit is advanced downward, deepening the hole as the operation proceeds.

4.1.1.1 Fluid drilling is accomplished by circulating water or a water-based fluid with additives. Additives such as bentonite or polymers are frequently added to water to lubricate and cool the bit and to circulate (transport) cuttings to the surface. Drill fluid can also act to prevent cave or collapse of the drill hole. After the drilling fluid reaches the surface, it flows to a ditch or effluent pipe and into a settling pit where the cuttings settle to the bottom. Cuttings are sometimes run through a shaker to remove the larger particles. From the settling pit, the drilling fluid overflows into the main pit, from which it is picked up by the suction line of the mud pump and recirculated through the drill string.

NOTE 1—The decrease of mud velocity upon entering the mud pit may cause gelling of the mud and prevent cuttings from settling. Agitation of the mud in the pit can remedy the problem.

4.1.1.2 Air drilling is performed where introduction of fluids is undesirable. Air rotary drilling requires use of an air compressor with volume displacement large enough to develop sufficient air velocity to remove cuttings. Cuttings can be collected at the surface in cyclone separators. Sometimes a small amount of water or foam may be added to the air to enhance return of cuttings. Air drilling may not be satisfactory in unconsolidated and cohesionless soils under the groundwater table.

4.2 *Coring:*

4.2.1 Coring is the process of recovering cylindrical cores of rock by means of rotating a hollow steel tube (core barrel) equipped with a coring bit. The drilled core is carefully collected in the core barrel as the drilling progresses.

4.3 *Sampling:*

4.3.1 Once the core has been cut and the core barrel is full, the drill rods or overshot assembly are pulled and the core retrieved. Samples are packaged and shipped for testing (see Practices D5079).

---

[3] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org.

[4] Available from NSF International, P.O. Box 130140, 789 N. Dixboro Rd., Ann Arbor, MI 48113-0140, http://www.nsf.org.

5. Significance and Use

5.1 Rock cores are samples of record of the existing subsurface conditions at given borehole locations. The samples are expected to provide indications about the geological, physical, and engineering nature of the subsurface for use in the design and construction of an engineered structure. The core samples need to be preserved using specific procedures for a stipulated time (Practices D5079). The period of storage depends upon the nature and significance of the engineered structure.

5.2 Rock cores always need to be handled such that their properties are not altered in any way due to mechanical damage or changes in ambient conditions of moisture and temperature or other environmental factors.

6. Apparatus

6.1 *General*—Fig. 1 shows the schematic of a typical rock core drill setup (**2**). Essential components of the drilling equipment include the drilling rig with rotary power, hoisting systems, casing, rods, core barrels, including bits and liners, and pumps with circulating system. In addition, equipment should include necessary tools for hoisting and coupling and uncoupling the drill string and other miscellaneous items such as prefabricated mud pits and racks for rod stacking and layout. Normally, a drilling platform of planking is built up around the drilling site.

NOTE 2—This standard is a practice and while the apparatus given is the most common type, this does not preclude the use of other current or future drilling technologies.

6.1.1 Rock coring operations can proceed at high rotation rates. It is imperative the drill rig, rods, and core barrels are straight and have a balanced center of gravity to avoid whipping and resulting damage to cores and expensive bits.

6.2 *Drilling Rig*— The drill rig provides the rotary power and downward (or advance) force or hold-back force on the core barrel to core the rock. The preferred diamond drill coring equipment are designs with hydraulic or gear-driven variable speed hollow spindle rotary drill heads, although some core

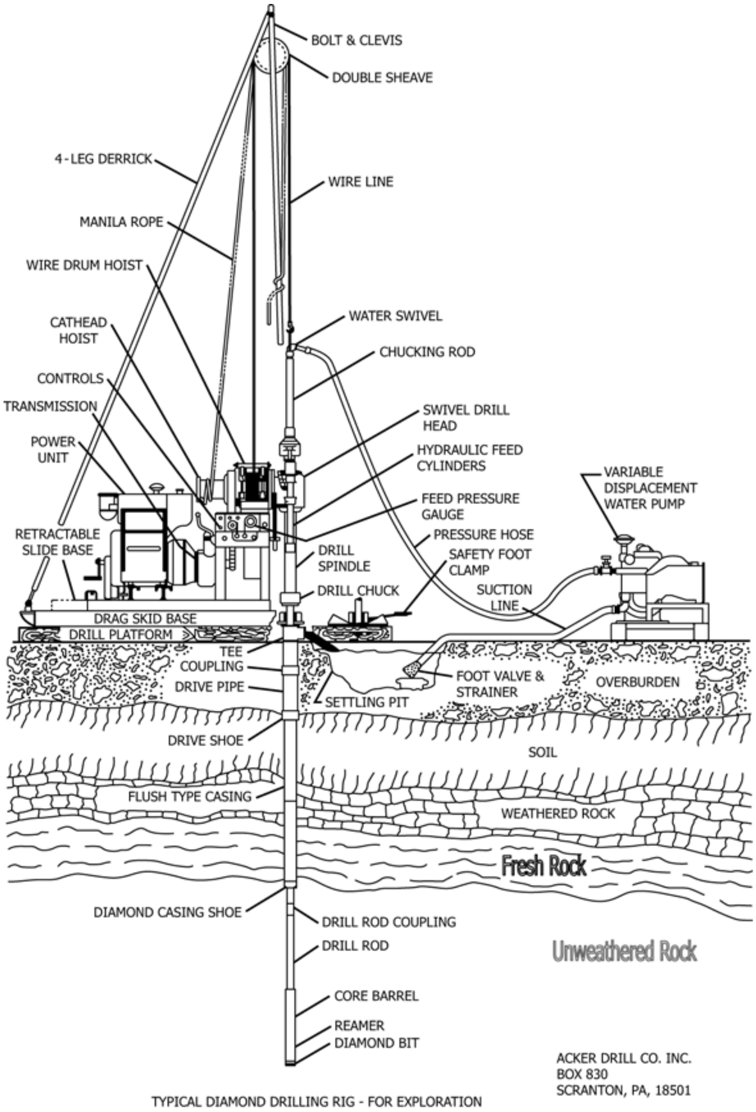


FIG. 1 Schematic of Typical Diamond Core Drill Set-up (2)

rigs are manufactured with gear or chain pulldown/retract systems. Precise control over bit pressure can best be accomplished by a variable setting hydraulic pulldown/retract system. Hydraulic systems are often equipped with a detent valve, which allows downfeed (or advance) rate to be set at a certain speed regardless of tool weight or down pressure exerted on the coring bit. Hydraulic feed drill rigs should be supplied with a hydraulic pressure gauge that can be related to bit pressures. Deep hole drill rigs should be equipped with hydraulic hold-back control so, if required, the full weight of the drill rods is not exerted on the bit when drilling downward. Diamond drill rigs can apply high rotation rates as high as 1000 rpm as opposed to normal rotary drills operating at 60 to 120 rpm (**3**). Most diamond core drills are equipped with a mast and powered hoist for hoisting heavy drill strings. A second wireline hoist is helpful for wireline drilling.

6.2.1 The drill rig frame is either skid or truck mounted and should be equipped with a slide base for ease in working around the drill hole. In special cases, the drilling rig may be mounted on a trailer, barge (for overwater drilling), or columns (for underground work). Some drill rigs are designed to be broken down into several pieces for transport into remote areas. The drilling rig power unit may be powered by hydraulics, air, electricity, gas, or diesel. Most surface skid or truck mounted rigs are diesel or gas powered.

6.2.2 Drilling directions are rarely vertical in underground applications, and smaller rigs are frequently equipped with swivel heads to accommodate drilling at angles. Special accommodations must be made for holding and breaking rods when drilling at high angles into crowns of adits. Either top drive drill or column mount machines with hydraulic or pneumatic rod jacks are equipped to handle up holes. For confined space drilling operations, drills are column mounted or mounted on small skids. Special power sources may be required for underground work due to air quality considerations. Remote power pack stations usually electric, hydraulic, compressed air, or a combination of the three. Electrically powered hydraulic systems are most common in underground use today

6.2.3 The platform may need to be constructed at the drilling site to provide a firm base upon which the drill rig is then placed. Platforms are also constructed in the vicinity of the drill hole for workers to hold equipment, serve as a datum, and to allow safe operations.

6.3 *Fluid or Air Circulation Systems:*

6.3.1 *Selection of Drill Media*—The two primary methods for circulating drill cuttings are water or water-based fluids or air with or without additives. The predominant method of drilling is water-based fluids. Water-based drilling is effective in a wide range of conditions both above and below the water table. Air drilling is selected when water-sensitive soils such as swelling clays or low density collapsible soils are encountered. Air drilling may also be required above the water table if special testing is required in the unsaturated zone. Air drilling is also convenient in highly fractured igneous rocks and porous formations where water-based fluid losses are unacceptable. The primary functions of the drill fluid are:

6.3.1.1 Remove drill cuttings,

6.3.1.2 Stabilize the borehole,

6.3.1.3 Cool and lubricate the bit,

6.3.1.4 Control fluid loss,

6.3.1.5 Drop cuttings into a settling pit,

6.3.1.6 Facilitate logging of the borehole, and

6.3.1.7 Suspend cuttings in the drill hole during coring.

6.3.1.8 No single drill fluid mixture can satisfy all of the above requirements perfectly. In the sections below, considerations for materials that could be used in drilling medium are given.

6.3.2 The pressure hose conducts the drilling fluid or air from the circulation pump or compressor to the swivel.

6.3.3 The swivel directs the drilling fluid or air to a rotating kelly or drill-rod column.

6.3.4 *Rotary Drilling with Water-based Drilling Fluids:*

6.3.4.1 The mud pit is a reservoir for the drilling fluid, and, if properly designed and used, provides sufficient flow velocity reduction to allow separation of drill cuttings from the fluid before recirculation. The mud pit can be a shallow, open metal tank with baffles or an excavated pit with some type of liner, and designed to prevent loss of drilling fluid. The mud pit can be used as a mixing reservoir for the initial quantity of drilling fluid, and, in some circumstances, for adding water and additives to the drilling fluid as drilling progresses. It may be necessary to have additional storage tanks for preparing fluids while drilling progresses.

6.3.4.2 The suction line, sometimes equipped with a foot valve or strainer, or both, conducts the drilling fluid from the mud pit to the fluid circulation pump.

6.3.4.3 The fluid circulation pump must be able to lift the drilling fluid from the mud pit and move it through the system against variable pumping heads at a flow rate to provide an annular velocity that is adequate to transport drill cuttings out of the drill hole.

6.3.4.4 *Water-based Drilling Fluids*—The four main classes of water-based drilling fluids are: (*1*) clean, fresh water, (*2*) water with clay (bentonite) additives, (*3*) water with polymeric additives, and (*4*) water with both clay and polymer additives. For commonly used materials added to water-based fluid, see Section 7 on Materials.

(*1*) Clean fresh water alone is often not acceptable for core drilling due to poor bit lubrication, erosion due to high velocities required for lifting cuttings, and excessive water loss. In water-sensitive soils, it is desirable to use drill additives to form drill hole wall cakes and prevent moisture penetration. In some cases, water may be required for piezometer installations where other fluid additives are not acceptable, but often newer synthetic polymer materials are acceptable for piezometer and well installations.

(*2*) Bentonitic drill muds are often used in rotary drilling applications. The bentonite should be added to water with vigorous mixing and recirculation to ensure uniform properties and to reach a dispersed deflocculated state. For diamond core drilling, low viscosity is usually required due to small clearances. The viscosity of a fluid-mud mixture is related to the solids content and particle shapes and alignments of the additives. During the high speed rotary drilling process, solids have a tendency to spin out and collect inside drill rods. For diamond drilling, low solids content is desirable. If mass is required to balance high hydrostatic pressures, additives such as barite or ilmenite (see 7.1.8) can be added to keep solids contents low.

(*3*) The need for low solids contents and good lubrication properties point to the use of polymer drill fluids. Natural or synthetic polymer fluids are the best additives for diamond core drilling. Polymer chains such as those from guar gum exhibit flow thinning characteristics in high velocity and shear conditions. Polymer fluids can be weighted with salts to balance hydrostatic pressures. Detergents or deflocculating agents can be added to discharge lines to assist in dropping cuttings to maintain fluid properties.

(*4*) Fluid management requires considerable experience for successful drilling and sampling. Important fluid parameters include viscosity and density, and these parameters can be tested to improve fluid properties. Test Method D4380 and American Petroleum Institute (API) test procedures are available for testing drill fluids. Fluid design can be improved by consultation with manufacturers, suppliers, and by review of literature (**2-8**). Because of a large number of suppliers, varying grades of drill fluid products, and varying requirements of each project, providing an exact procedure for design and mixing of drill fluids, is impossible.

6.3.5 *Rotary Drilling Using Air As the Circulation Medium:*

6.3.5.1 The air compressor should provide an adequate volume of air, without significant contamination, for removal of cuttings. Air requirements depend upon the drill rod and bit type, character of the material penetrated, depth of drilling below groundwater level, and total depth of drilling. Airflow rate requirements are usually based on an annulus upflow (or outflow) air velocity of about 3000 to 4000 ft/min (1000 to 1300 m/min) although air upflow (or outflow) rates of less than 3000 ft/min (1000 m/min) are often adequate for cuttings transport. Special reaming shells may be required to maintain air circulation between the annulus of the hole wall and large diameter drill rods (**9**). For some geologic conditions, air-blast erosion may increase the borehole diameter in easily eroded materials such that the 1000 m/min (3000 ft/min) circulation rate may not be appropriate for cuttings transport.

6.3.5.2 Compressed air alone often can transport cuttings from the borehole and cool the bit. Pure air alone does not work well in very moist soils. In moist, clayey matrices, mud rings and bit balling may occur. For some geologic conditions, water injected into the air stream will help control dust or break down "mud rings" that can form on the drill rods. If water is injected, the depth(s) of water injection should be documented. In these cases, adding water and a foaming agent to make a misting mixture is desirable (**3**). Under other circumstances, for example if the borehole starts to produce water, injection of a foaming agent may be required. The depth at which a foaming agent is added should also be recorded. If water infiltration into the borehole impedes circulation, the use of stiffer foams or slurries may be needed (**3**). Air drilling may not be satisfactory in unconsolidated or cohesionless soils under the groundwater table, and fluid drilling systems may be required.

6.3.5.3 The dust collector conducts air and cuttings from the borehole annulus past the drill rod column to an air cleaning device (cyclone separator).

6.3.5.4 The air cleaning device (cyclone separator) separates cuttings from the air returning from the borehole via the dust collector. A properly sized cyclone separator can remove practically all of the cuttings from the return air. A small quantity of fine particles is usually discharged to the atmosphere with the "cleaned" air. Some air cleaning devices consist of a cyclone separator alone and others use a cyclone separator combined with a power blower and sample collection filters. When foaming agents are used, a cyclone-type cuttings separator is not used and foam discharge is accumulated near the top of the borehole.

6.4 *Hole Diameters*— Selection of hole diameter and core size is the most important consideration when planning a coring program. Most rock coring operations are performed with casings and core barrels whose sizes have been standardized by the Diamond Core Drill Manufacturers Association (DCDMA) (**5,10**). Table 1 provides a summary of nomenclature used for drill hole sizing. For each size of hole, there is a family of casings, core barrels, bits, casing bits, and drill rods with the same primary letter symbol (A through Z) whose design is compatible. Furthermore, the size steps are such that the next smaller size letter equipment can be used inside the next larger group. This nesting of casings, barrels, and rods allows for tapering or telescoping of a drill hole through difficult formations. Since the core barrel must pass through the

TABLE 1 Diamond Core Drill Manufacturers Association Casing Specifications (10)

NOTE 1—W series casing is known as "flush-coupled casing". W series casing has flush inside diameter throughout, while X series casing has upset diameter with coupling inside diameter equal to flush wall inside diameter.

DCDMA Casing Design										
Size	Outside Diameter		Inside Diameter W Series		Inside Diameter X Series		Gallons Per 100 ft	Mass Per ft	Threads Per Inch	
	in.	mm	in.	mm	in.	mm			W series	X series
RW, RX	1.44	36.5	1.20	30.5	1.20	302.0	5.7	1.8	5	8
EW, EX	1.81	46.0	1.50	38.1	1.63	41.3	9.2	2.8	4	8
AW, AX	2.25	57.2	1.91	48.1	2.00	50.8	14.8	3.8	4	8
BW, BX	2.88	73.0	2.38	60.3	2.56	65.1	23.9	7.0	4	8
NW, NX	3.50	88.9	3.00	76.2	3.19	81.0	36.7	8.6	4	8
HW, HX	4.50	114.3	4.00	100.0	4.13	104.8	65.3	11.3	4	5
PW, PX	5.50	139.7	5.00	127.0	5.13	130.2		14.0	3	5
SW, SX	6.63	168.3	6.00	152.4	6.25	158.8		16.0	3	5
UW, UX	7.63	193.7	7.00	177.8	7.19	182.6			2	4
ZW, ZX	8.63	219.1	8.00	203.2	8.19	208.0			2	4

casings selected, anticipating the necessity for telescoping the hole is important so a large enough diameter is selected at the start.

NOTE 3—Inclusion of the following tables and use of letter symbols in the foregoing text is not intended to limit the practice to use of DCDMA tools. The table and the text references are included as a convenience to the user since the majority of tools in use do meet the DCDMA dimensional standards. Similar equipment of approximately equal size on the metric standard system is acceptable unless otherwise stipulated by the engineer or geologist.

6.4.1 Core diameter, barrel design, bit design, and drilling method have a direct influence on sample quality. Usually when drilling in delicate formations, larger diameter samples provide higher quality samples. Often, obtaining samples of the weaker seams or joints in the rock is critical to design. A larger diameter core barrel can often reduce shearing stresses imparted to a seam or joint in the core and thus reduce mechanical breakage. For core operations related to most surface drilling project explorations, the minimum core size would correspond to “N” sized borings.

6.4.2 In concrete coring operations, the primary consideration for selecting a core diameter is the maximum size aggregate. For interface shear strength determinations on lift lines, the core diameter should be 2½ to 3 times the maximum size aggregate (**11**) .

6.4.3 In underground hard rock drilling, smaller cores may be used for ease of operation.

6.5 *Casing*—For most coring operations, setting casings in overburden materials will be necessary, especially near the surface to control drill fluid circulation. Typically, water-sensitive soils and loose overburden soils are protected by casings that are set in competent bedrock or to firm seating at an elevation below the water-sensitive formation. The casing used should allow for unobstructed passage of the largest core barrel to be used, and should be free of upsets in inside diameter. A listing of DCDMA casing sizes is shown in Table 1. For rock coring operations, the flush inside diameter “W” series casing is used to allow for use of the matching core barrel. In some cases, flush coupled drive pipe can be used to support the hole. Drive pipe is available in thickness schedules 40, 80, and 160.

6.5.1 Casing and drill rod selection should be based on uphole (or outflow) velocity of the circulation system selected. Uphole (or outflow) velocity should be sufficient to bring up all drill cuttings.

6.5.2 Casing or temporary drill hole support can be accomplished through several methods. One casing advancement technique is to drill incrementally ahead of the casing and then drive the casing to the previous depth. Driven casings should be equipped with a hardened shoe to protect end threads. The inside diameter of the shoe should be flush with the casing inside diameter to avoid hang-ups of the core barrel. In some cases, water-sensitive zones may require cementing for stabilization. Casing can be equipped with diamond casing shoes that allow the casing to be advanced with rotary drilling. The casing shoe should have the same inside diameter as the casing. Casing “shoes” should not be confused with casing “bits” (**10**). Casing bits are only acceptable for temporary, rotary installation of casing where coring operations are not required, such as temporary installation of a large diameter telescoped casing. Casing “bits” have an inside diameter that is not large enough to pass a core barrel of the same nominal hole size. Hollow-stem augers may be used as casing through overburden soils. Liners may be used inside large diameter casings or augers to increase fluid circulation velocity and optimize cuttings return. If liners are used, they should not be driven and care should be taken to maintain true hole alignment.

6.6 *Drill Rods*—Drill rod selection should be based on consideration of the uphole (or outflow) velocity of the circulating fluids for the circulation system selected. Uphole velocity should be sufficient to bring up all drill cuttings. Most drilling operations are done with DCDMA drilling rods conforming to the dimensions given in Table 2. Drill rods are normally constructed of tubular steel and have a flush outside wall diameter. Drill rod sections usually have threaded female

TABLE 2 Diamond Core Drill Manufacturers Association Drill Rod Specifications (10)

Rod Type	Outside Diameter in.	Outside Diameter mm	Inside Diameter in.	Inside Diameter mm	Coupling Identification in.	Coupling Identification mm	Mass Per Foot, lbm	Threads Per Inch	Thread Type
				Drill Rods, W Series Drill Rod					
RW	1.094	27.8	0.719	18.3	0.406	10.3	1.4	4	Regular
EW	1.375	34.9	0.938	22.2	0.437	12.7	2.7	3	Regular
AW	1.750	44.4	1.250	31.0	0.625	15.9	4.2	3	Regular
BW	2.125	54.0	1.500	44.5	0.750	19.0	6.1	3	Regular
NW	2.625	66.7	2.000	57.4	1.38	34.9	7.8	3	Regular
HW	3.500	88.9	3.062	77.8	2.375	60.3	9.5	3	Regular
				WJ Series Drill Rod					
AWJ	1.75	44.5	1.43	36.4	0.63	16.1	3.6	5	Taper
BWJ	2.13	54.0	1.81	46.0	0.75	19.3	5.0	5	Taper
NWJ	2.63	66.7	2.25	57.0	1.13	28.8	6.0	4	Taper
KWJ	2.88	73.0	2.44	61.9	1.38	34.9	...	4	Taper
HWJ	3.50	88.9	2.88	73.1	1.75	44.5	...	4	Taper
				Old Standard					
E	1.313	33.3	0.844	21.4	0.438	11.1	...	3	Regular
A	1.625	41.3	1.266	28.6	0.563	14.3	...	3	Regular
B	1.906	48.4	1.406	35.7	0.625	15.9	...	5	Regular
N	2.375	60.3	2.000	50.8	1.000	25.4	...	4	Regular

connections machined in each end. The rods are connected by either removable or welded pins (in one end) strengthened by addition of material at the inside walls. Some drill rod pins are constructed of high strength steel because the joints are a weak link and are subject to failure. Some larger rods are composed of composite materials to reduce weight. Nonmagnetic rods are available for drill holes requiring use of magnetic surveying equipment.

6.6.1 Tables 3 and 4 lists dimensions of wireline and API drill rods that also can be used. Wireline drill rod dimensions are not standardized and are specific to individual manufacturers. The API internal flush joint rods have upset walls on the outside joint and should not be used in air drilling, as air erosion of the formation could occur at the joints.

6.7 *Conventional Core Barrels*—Many types of core barrels are available. A conventional core barrel is attached to the drilling rods (see 6.6) and the complete set of connected rods and barrel must be removed from the hole at the end of each core run. Torque is applied to the drill rods while the circulating fluid is pumped through the center of the drill rods to the bit. Fluid returns along the annulus between the borehole wall and barrel and drill rods. Conventional barrels are used in smaller drilling operations, such as short underground holes, or when intermittent sampling is to be performed. Most continuous high production coring today is performed with wireline equipment.

6.7.1 Several series of conventional core barrels have standardized dimensions set by the DCDMA (**10**) in North America. Other organizations such as the British Standards Institute have adopted DCDMA size conventions, while others have different standard dimensions such as metric or Swedish (Craelius) (**4**). The DCDMA WG, WM, WT series of barrels have standard dimensions as shown in Table 5. Most manufacturers make core barrels fitting the dimensional requirements of one of these series, but there may be variation of other design features such as inner liners, bearings, fluid routing, or core extrusion methods. Some manufacturers make core barrels that do not fit dimensional DCDMA standards for core diameters. An example is the “D_3 and D_4” series core barrels shown in Table 5. Use of other nonstandardized core barrels is acceptable if the type of barrel is appropriate for the drilling conditions and the type of barrel used is reported.

TABLE 4 American Petroleum Institute Drill Rod Dimensions (12)

API Tool Joints—Regular External Flush (in.-lb System)				
Type/size	Rod o.d. (in.)	Rod o.d. (mm)	Rod i.d. (in.)	Rod i.d. (mm)
API 2-⅜	3.125	79.4	1	25.4
API 2-⅞	3.75	95.3	1.25	31.8
API 3-½	4.25	108.0	1.5	38.1
API 4	5.25	133.4	1.75	44.5
API 4-½	5.75	146.1	2.25	57.2
API 5 ½	6.75	171.5	2.75	69.9
API 6 ⅝	7.75	196.9	3.5	88.9
API 7 ⅝	8.88	225.6	4.0	101.6.
API 8 ⅝	10.0	25.4	4.75	120.7
API Tool Joints—Regular Internal Flush				
Type/size	Rod o.d. (in.)	Rod o.d. (mm)	Rod i.d. (in.)	Rod i.d. (mm)
API 2-⅜	3.375	85.7	1.75	44.5
API 2-⅞	4.125	104.8	2.125	54.0
API 3-½	4.75	120.7	2.687	68.3
API 4	5.75	146.1	3.25	82.6
API 4-½	6.125	155.6	3.75	95.3

6.7.2 For most explorations and when rock types are unknown, it is desirable to specify a swivel type, double tube core barrel with a split inner barrel, or solid inner barrel with split liners (also known as “triple tube”). The barrel should be equivalent to, or better than, “M” series design to reduce fluid exposure. If the formation is poorly lithified, and contains soil-like layers such as shales with interbedded clay seams, a large diameter core barrel may be specified to aid in recovery. These desired components are discussed below.

6.7.3 Core barrels generally come in 5- or 10-ft core run lengths. Ten-foot core runs can be performed with good rock conditions. If soft, friable, or highly fractured formations are encountered, it may be necessary to select barrels with 5-ft core runs to reduce the possibility of blockages and improve core recovery.

6.7.4 Important design components of a conventional core barrel are tube type (triple, double, or single), inner tube rotation (rigid or swivel), core bit type, including fluid discharge locations (internal discharge - contacting core, or face discharge and waterway design), core lifter, and reaming shell.

6.7.5 *Single Tube Core Barrel*—The single tube core barrel is the simplest in design (see Fig. 2). The core is subjected to drill fluid circulation over its entire length. Once the core in the barrel is broken from parent material, it will rotate with the assembly. These effects break up all but the most competent

TABLE 3 Wireline Drill Rod Dimensions

Wireline Drill Rods								
Rod	Outside Diameter		Inside Diameter		Gallons	Weight	Threads	Thread
Type	in.	mm	in.	mm	Per 100 ft	Per lbm	Per Inch	Type
AQWL[A]	1.750	44.5	1.375	34.9	7.7	3.3	4	Taper
AXWL[B]	1.813	46.0	1.500	38.1	9.18	2.8	4	Regular
BQWL[A]	2.188	55.6	1.812	46.0	13.4	4.0	3	Taper
BXWL[B]	2.250	57.2	1.906	48.4	14.82	3.8	4	Regular
NQWL[A]	2.750	69.9	2.375	60.3	23.0	5.2	3	Taper
NXWL[B]	2.875	73.0	2.391	60.7	23.30	6.8	3	Regular
HQWL[A]	3.500	88.9	3.062	77.8	38.2	7.7	3	Taper
HXWL[B]	3.500	88.9	3.000	76.2	36.72	8.7	3	Regular
PQWL[A]	4.625	117.5	4.062	103.2	...	...	. . .	. . .
CPWL[B]	4.625	117.5	4.000	101.6	...	...	. . .	. . .

[A] Q Series rods are specific manufacturer’s design.

[B] X Series rods are specific manufacturer’s design.

TABLE 5 Approximated Core and Hole Diameters for Core Barrels

[A] Core barrel type/group	Set bit dimension inside diameter = core diameter		Set reaming shell = hole diameter	
	in.	mm	in.	mm
Conventional Core Barrels[B]				
RWT (d)	0.735	18.7	1.175	29.8
EWD$_3$	0.835	21.2	1.485	37.7
EWG (s.d.), EWM (d)	0.845	21.5	1.485	37.7
EWT (d)	0.905	23.0	1.485	37.7
AWD$_3$, AWD$_4$	1.136	28.9	1.890	48.0
AWG (s.d.), AWM (d)	1.185	30.1	1.890	48.0
AWT (d)	1.281	32.5	1.890	48.0
BWD$_3$, BWD$_4$	1.615	41.0	2.360	59.9
BWG (s.d.), BWM (d)	1.655	42.0	2.360	59.9
BWT (s.d.)	1.750	44.4	2.360	59.9
NWD$_3$, NWD$_4$	2.060	52.3	2.980	75.7
NWG (s.d.), NWM (d)	2.155	54.7	2.980	75.7
NWT (s.d.)	2.313	58.8	2.980	75.7
HWD$_3$, HWD$_4$	2.400	61.1	3.650	92.7
HWG (s.d.)	3.000	76.2	3.907	99.2
HWT (s.d.)	3.187	80.9	3.907	99.2
DCDMA Large Diameter—Double-Tube Swivel—Core Barrels				
2¾ × 3⅞	2.690	68.3	3.875	98.4
4 × 5½	3.970	100.8	5.495	139.3
6 × 7¾	5.970	151.6	7.750	196.8
Wireline Core Barrel Systems[C]				
AXWL (joy)	1.016	25.8	1.859	47.2
AQWL	1.065	27.1	1.890	48.0
BXWL	1.437	36.5	2.375	60.3
BQWL	1.432	36.4	2.360	60.0
BQ$_3$WL	1.313	33.4	2.360	60.0
NXWL	2.000	50.8	2.984	75.8
NQWL	1.875	47.6	2.980	75.7
NQ$_3$WL	1.75	44.4	2.980	75.7
HXWL	2.400	61.0	3.650	92.7
HQWL	2.500	63.5	3.790	96.3
HQ$_3$WL	2.375	60.3	3.790	96.3
CPWL	3.345	85.0	4.827	122.6
PQWL	3.345	85.0	4.827	122.6
PQ$_3$WL	3.25	82.6	4.827	122.6

[A] s = single tube; d = double tube.

[B] Conventional double-tube core barrels are available in either rigid or swivel designs. The swivel design inner barrel is preferred for sampling because it aids in preventing core rotation. In general, smallest core for given hole size results in best recovery in difficult conditions, that is, triple-tube core barrels. Use of double-tube-swivel type barrels with split liners is recommended in geotechnical explorations for best recovery and least sample damage.

[C] Wireline dimensions and designations may vary according to manufacturer.

core (**4, 12**). Because of fluid exposure and rotational effects, this barrel should not be used to sample weak, friable, and water-sensitive materials. Additional disadvantages of this core barrel include: poor diamond performance of the cutting bit in fractured or friable formations, frequent core blocking, and severe diamond erosion due to re-drilling of broken fragments. This system is only suitable for sampling massive, hard, competent, homogeneous rock or concrete. Due to these disadvantages, this core barrel type is not recommended for routine explorations.

6.7.5.1 In shallow applications, generally less than 5 ft (2 m) competent concrete or soil cement is cored with single tube masonry core barrels with portable drill rigs (**11**). If there is evidence of excessive core erosion, breakage, or blocking, use of double tube swivel type barrels should be considered.

6.7.6 *Double Tube Core Barrel*—Double tube core barrels contain an inner barrel that protects the core from contact with drill fluid and from erosion or washing from the circulating fluid. The bottom of the core may be subjected to fluid exposure depending on the locations of fluid discharge. Some barrel designs have fluid discharge near the lifter, near the bit, or on the bit face (see 6.7.7). The advantage of double tube design is greater protection of the core. Washing erosion is reduced and weaker zones can be recovered.

6.7.6.1 The inner barrel of double tube core barrels may be either solid or split. The barrel may be designed to accept split liners. Barrels accepting liners require a special inside diameter bit gauge. Use of a split barrel or inner liners is preferred for easier handling of cores. Sections of the cores containing weak seams are more likely to remain intact. The cores may be rolled onto PVC half rounds. The use of split liners or PVC half rounds aids in placement of core in core boxes and handling of cores that require sealing for moisture preservation. In certain materials, such as expansive shales or blocked high fractured materials, the split liner may spring apart even though it is taped before sampling. In these cases, removing the inner barrel may be difficult. Remedies include use of a shorter core barrel, triple tube design with extruder (see 6.7.7.1), or the solid liner.

6.7.6.2 Double tube core barrels come in two designs, either rigid or swivel type.

(*1*) *Rigid Double Tube Barrel*—This barrel is rarely used in practice today due to limitations listed below. In the rigid barrel design, the inner barrel is fixed and it spins at the same rate as the outer barrel. Rigid tube barrels have fewer working parts, but suffer from similar disadvantages as single tube barrels. Core recovery is poor and diamond wear in friable and fractured formations is excessive. In softer deposits, there will be rotation of broken core, core blockage, and resulting crushing and grinding, which causes excessive bit wear. This type of design is not preferred for routine explorations where rock conditions are not known, as the equipment is only acceptable in hard competent formations.

(*2*) *Swivel Type Double Tube Barrels*—In the swivel type barrel (Fig. 3 and Fig. 4 show typical barrels) the inner barrel is connected to the drill string through a bearing that allows the inner barrel to remain stationary during coring. The core is completely protected once it enters the liner. This design reduces rock crushing and grinding and resulting blockages. Depending on the fluid discharge point, the core may be exposed to fluids near the bottom of the barrel and there could be erosion of soft or fractured formations.

(*3*) Double tube swivel type core barrels are the best selection for drilling rock of varying hardness and fracture. This type of barrel is typically the minimum requirement when drilling explorations are for engineering structures where varying conditions would be encountered.

6.7.7 *Triple Tube Core Barrels*—The triple tube barrel is essentially a double tube barrel with a liner inside the inner tube. The inner liner is made from either split metal half rounds or tubular acrylic. The use of split liners increases efficiency in handling and logging. If the purpose of the exploration is solely for logging of cores, the use of solid acrylic liners may be acceptable.

6.7.7.1 Many manufacturers offer the triple tube option and barrels are available that also have hydraulic core extrusion

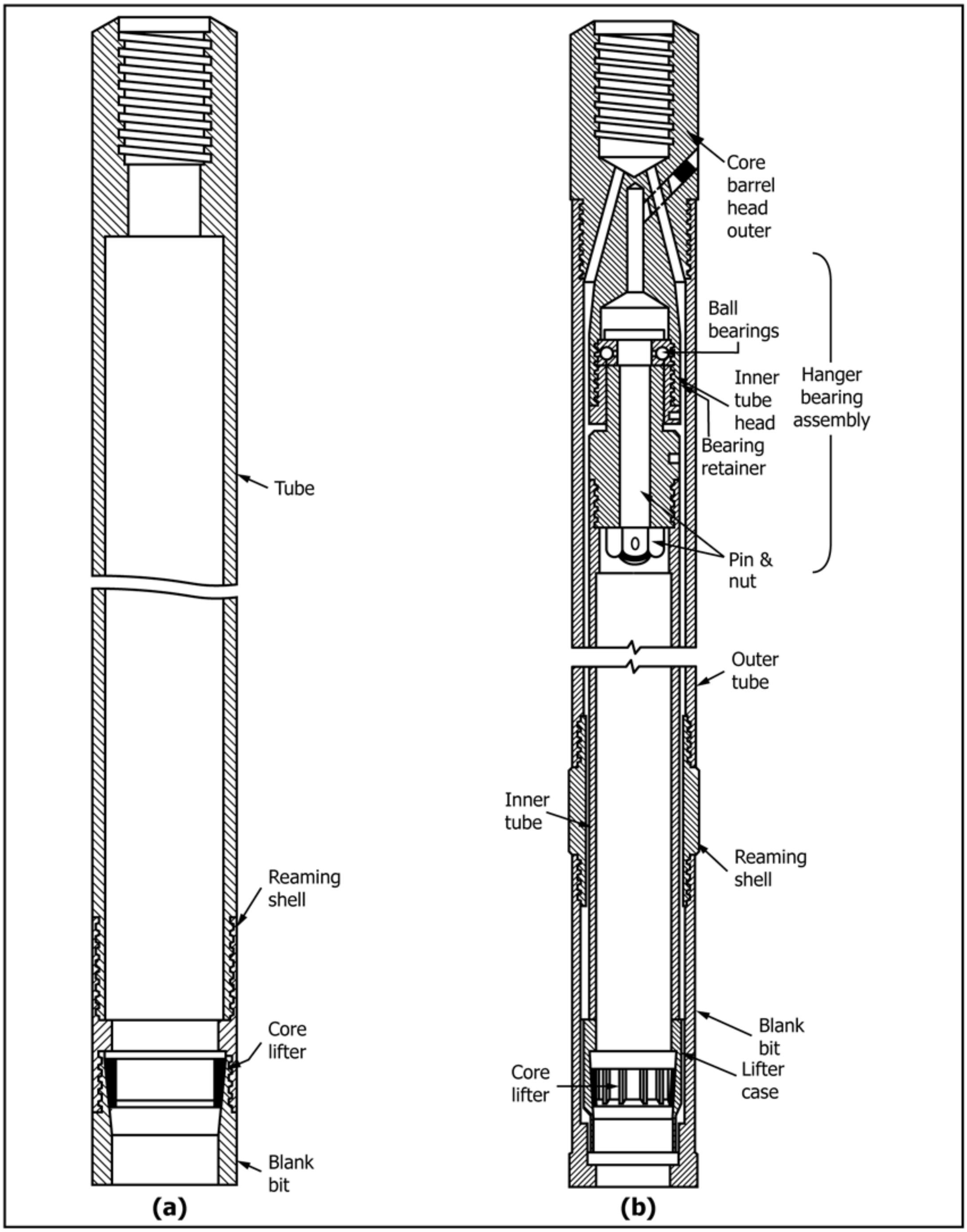


FIG. 2 Diagram of Two Types of Core Barrels: (a) Single Tube and (b) Double Tube

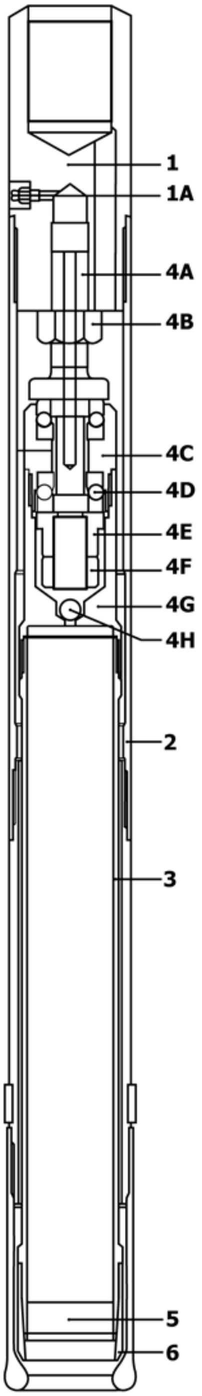
systems. These systems help with removing the inner liners by use of a piston in the top of the inner barrel. This feature is especially helpful if split liners are bowed apart by lateral expansion of the core. The extrusion systems allow for simple loading and unloading of liners.

6.7.8 *Conventional Barrel Standardized Designs*—DCDMA standardized barrels come in three designs, WG, WM, and WT series.

6.7.8.1 The "G" series barrels are the most simple in design and have a simple pin threaded bit into which the core lifter is inserted. Due to the simplicity of design, these barrels are the most rugged, with fewer parts and less maintenance. The only disadvantage is that the fluid exits above the lifter and the bottom of the core is exposed to fluids during drilling.

6.7.8.2 The "M" design core barrel is the best available tool for recovering of rock cores even in the most friable and caving stratums. The inner barrel is equipped with a lifter case that extends into the bit shank and therefore reduces exposure of the core to fluid during drilling. The fluid only contacts the core near the crown of the bit, and washing or eroding of the core

NWD4 - SERIES D4 CORE BARREL



NWD4 SERIES D4 CORE BARREL					
HOLE SIZE	CORE SIZE	OUTER TUBE O.D	OUTER TUBE I.D	INNER TUBE O.D	INNER TUBE I.D
2.980 in	2.060 in	2.906 in	2.562 in	2.375 in	2.135 in
75.7 mm	51.3 mm	73.8 mm	65.1 mm	60.3 mm	54.2 mm

NWD4 SERIES D4 CORE BARREL ASSEMBLIES
PART DESCRIPTION
Core Barrel Assembly - 5 ft (1.5 m)
Core Barrel Assembly - 10 ft (3.0 m)
Core Barrel Assembly - 5 ft (1.5 m) Split
Core Barrel Assembly - 10 ft (3.0 m) Split
SPARE PARTS FOR NWD4 SERIES D4 CORE BARREL
1. Core Barrel Head, NW Rod
A. Grease Fitting
2. Outer Tube, 5 ft (1.5 m), C.P. Ends
Outer Tube, 10 ft (3.0 m), C.P. Ends
3. Inner Tube, 5 ft (1.5 m), C.P. ID
Inner Tube, 10 ft (3.0 m), C.P. ID
Inner Tube, Split 5 ft (1.5 m), C.P. ID
Inner Tube, Split 10 ft (3.0 m), C.P. ID
4. Bearing Assembly
A. Bearing Shaft
B. Lock Nut
C. Bearing Retainer
D. Bearing, Thrust Ball (2 Required)
E. Hex Nut, Flanged
F. Hex Nut, Regular
G. Inner Tube Connector
H. Ball
5. Core Lifter, Skirtless
6. Inner Tube Shoe/Case, C.P. ID
7. Thread Protector Sub

FIG. 3 Typical Double Tube Swivel Type-Conventional Core Barrel

is minimized. Face discharge bits are also available for almost no core exposure to fluids. The DCDMA "M" designs have been modified by individual manufacturers. Barrels such as the D_4 type barrels are equivalent to "M" design barrels.

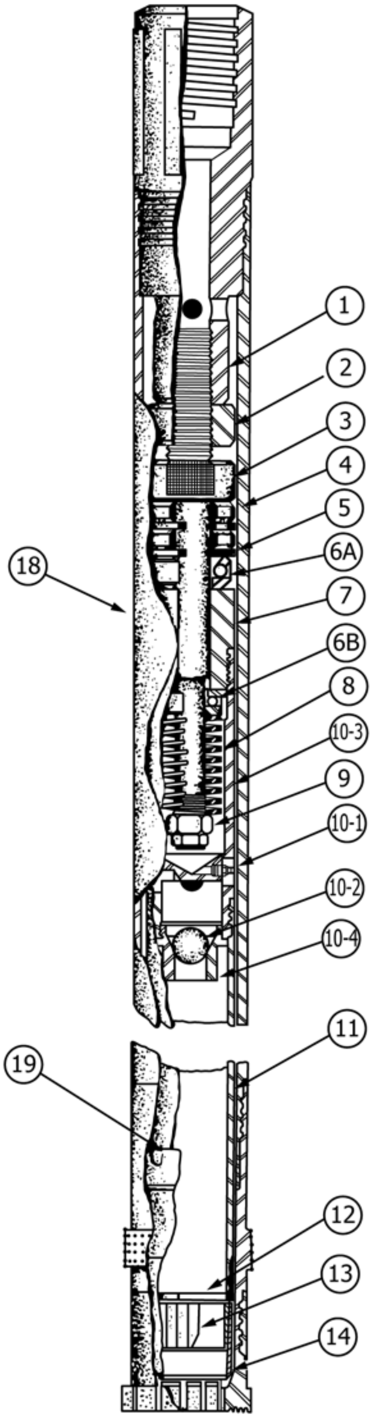
6.7.8.3 The "T" series design stands for thin walled or thin kerf. This design provides larger core-to-hole size ratio. This barrel style has a thin kerf and requires fewer diamonds and less torque for drilling. It gives good performance in hard, dense, and friable shattered rock formations (4). This type of core barrel is thin and lightweight and must be handled with care.

6.7.9 *Large Diameter, Double Tube, Swivel Design*—The large diameter conventional core barrel is similar in design to the double tube, swivel type, "WM" design, but with the

Double-Tube Swivel Type
STANDARD CONVENTIONAL SYSTEM

Parts List

NV2"Core Barrel



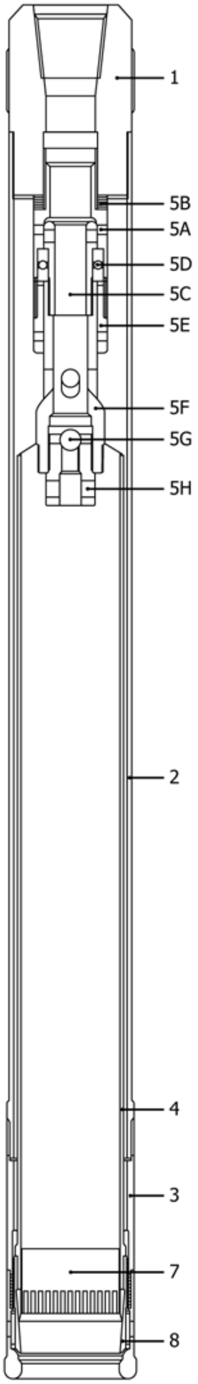
Item No.	Description	No. Req'd	Unit lbs	Weight kg
1-20	Core Barrel Assy 5 ft	—	76.0	34,5
1-20	Core Barrel Assy 10 ft	—	126.0	57,2
-	Core Barrel Assy 15 ft**	—	178.0	80,8
1-10	Head Assy	—	19.0	8,6
1	Outer Tube Head	1	8.7	3,9
2	Lock Nut	1	*	*
3	Spindle	1	3.1	1,4
4	Shut Off Valve	2	*	*
5	Valve Adjusting Washer	2	*	*
6A	Ball Thrust Bearing	1	*	*
6B	Hanger Bearing	1	*	*
7	Spindle Bearing	1	1.6	0,7
8	Compression Spring	1	*	*
9	Self Locking Nut	1	*	*
10	Inner Tube Cap Assy	—	3.6	1,6
10-1	Hydraulic Grease Fitting	1	*	*
10-2	Stainless Steel Ball	1	*	*
10-3	Inner Tube Cap	1	3.2	1,5
10-4	Check Valve Body	1	*	*
11	Inner Tube, 5 ft	1	12.3	5,6
11	Inner Tube, 10 ft	1	24.5	11,1
11	Inner Tube, 15 ft	1	38.0	17,2
12	Stop Ring	1	*	*
13	Fluted Core Lifter	1	*	*
14	Core Lifter Case	1	*	*
18	Outer Tube, 5 ft	1	44.0	20,0
18	Outer Tube, 10 ft	1	77.6	35,2
19	Inner Tube Stabilizer	1	*	*
20	Thread Protector (not shown)	1	2.5	1,1

Weighs less than one pound (0,45 kg)
The Core Barrel Assembly 15 foot, consists of one Head Assembly, one each Inner Tube 15 foot, Stop Ring, Core Lifter, Core Lifter Case, Outer Tube 5 foot, Outer Tube 10 foot, Thread Protector and two Inner Tube Stabilizers.

FIG. 4 Typical Double Tube Swivel Type-Core Barrel

addition of a ball valve in all the three sizes to control fluid flow. A sludge barrel to catch heavy cuttings is also incorporated on the two larger sizes (Fig. 5). The three sizes standardized by DCDMA are 2¾-in. (69.8 mm) by 3⅞-in. (98.4 mm), 4-in. (101.6 mm) by 5½-in. (139.7 mm), and 6-in. (152.4 mm) by 7¾-in. (196.8 mm). Other sizes such as 4⅝-in. (117.5 mm) by 3-in. (76.2 mm), 5¾-in. (146 mm) by 4-in. (101.6 mm), and 8-in. (203.2 mm) by 5⅞-in. (149.2 mm) have been designed by individual manufacturers. The larger barrels with increased annulus are suitable for larger rotary rig mud pumps and air

7-3/4 in × 5-7/8 in CORE BARREL



7-3/4 in × 5-7/8 in CORE BARREL					
HOLE SIZE	CORE SIZE	OUTER TUBE O.D.	OUTER TUBE I.D.	INNER TUBE O.D.	INNER TUBE I.D.
8.000 in	5.875 in	7.500 in	7.000 in	6.500 in	6.125 in
203.2 mm	149.2 mm	190.5 mm	177.8 mm	165.1 mm	155.6 mm

7-3/4 in × 5-7/8 in CORE BARREL ASSEMBLIES
PART DESCRIPTION
Core Barrel Assembly - 5 ft (1.5 m)
Core Barrel Assembly - 10 ft (3.0 m)
Core Barrel Assembly - 5 ft (1.5 m) Split
Core Barrel Assembly - 10 ft (3.0 m) Split
SPARE PARTS FOR 7-3/4 in × 5-7/8 in CORE
1. Core Barrel Head (4-1/2" A.P.I. Reg.)
2. Outer Tube, 5 ft (1.5 m)
Outer Tube 10 ft (3.0 m)
3. Outer Tube Sub
4. Inner Tube 5 ft (1.5 m), CP, ID
Inner Tube 10 ft (3.0 m), CP, ID
Inner Tube 5 ft (1.5 m) Split
Inner Tube 10 ft (3.0 m) Split
5. Bearing Assembly
A. Cartridge Cap
B. Shim, Set
C. Bearing Retainer
D. Bearing, Thrust, Ball
E. Cartridge Plug
F. Inner Tube Plug
G. Ball
H. Pressure Relief Plug
6. Inner Tube Connector, Split
7. Core Lifter, HF
8. Inner Tube Shoe, BW
9. Thread Protector Sub
10. Tube Clamp, 7-1/2 in (190.5 mm) (outer)
OPTIONAL EQUIPMENT
11. Core Lifter, Skirtless, HF

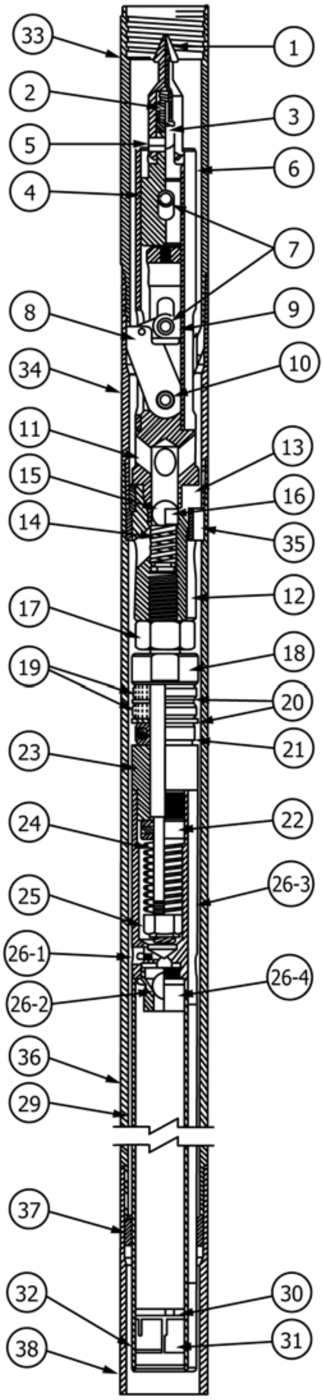
Note: If you do not see the item or size you are looking for, please contact you for additional product information.

FIG. 5 Typical Large Diameter Series —Conventional Core Barrel

compressors. Options include either conventional or face discharge bits with either conventional core lifter or spring finger basket retainers. Some core barrel systems can be converted to soil coring operations, but require carbide bit and a projecting cutting shoe. Some large diameter barrels are convertible from conventional to wireline coring operation.

6.8 *Wireline Core Barrels*—Wireline drilling for exploration in rock is a principal drilling system used for deep rock coring applications using surface mounted drill rigs (Fig. 6 and Fig. 7). In the wireline system, the drill rods are only removed from the hole to replace the coring bit, to free a stuck inner barrel, or to adjust the headspace of the inner barrel. The inner core barrel can be removed and replaced without removing the drill rods, allowing for continuous coring. The drill rods also act as a casing, and fluid is circulated from the bit through the annulus between the drill hole wall and drill rod. Wireline drill

NQ Core Barrel



Item No.	Description	No. Req'd	Unit lbs	Weight kg
1-38	Core Barrel Assy 5 ft	—	–	–
1-38	Core Barrel Assy 10 ft	—	–	–
1-32	Inner Tube Assy 5 ft	—	–	–
1-32	Inner Tube Assy 10 ft	—	–	–
1-28	Head Assy	—	–	–
1	Spearhead Point	1	*	*
2	Compression Spring	1	*	*
3	Detent Plunger	1	*	*
4	Spearhead Base	1	1.3	0,6
5	Spirol Pin, 7/16" × 1"	1	*	*
6	Retracting Case	1	–	–
7	Spring Pin, 1/2" × 2"	2	*	*
8	Latch	2	*	*
9	Link	2	*	*
10	Spring Pin, 1/12" × 1-1/2"	1	*	*
11	Upper Latch Body	1	2.9	1,3
12	Lower Latch Body	1	3.1	1,4
13	Landing Shoulder	1	–	–
14	Dry Hole Spring, Light (not installed)			
15	Stainless Steel Ball, 22 mm (not installed)			
16	Bushing (not installed)			
17	Hex Nut	1	*	*
18	Spindle	1	3.1	1,4
19	Shut Off Valve, Hard	2	*	*
20	Valve Adjusting Washer	2	*	*
21	Thrust Bearing	1	*	*
22	Hanger Bearing	1	*	*
23	Spindle Bearing	1	1.6	0,7
24	Compression Spring	1	*	*
25	Self Locking Nut	1	*	*
26	Inner Tube Cap Assy (consists of 26–1,–2,–3,–4)	—	3.3	1,5
26-1	Hydraulic Grease Fitting	1	*	*
26-2	Stainless Steel Ball, 22 mm	1	*	*
26-3	Inner Tube Cap	1	2.9	1,3
26-4	Check Valve Body	1	*	*
27	Landing Indicator Bushing (not installed)			
28	Dry Hole Spring, Medium (not installed)			
29	Inner Tube, 5 ft	1	12.3	5,6
29	Inner Tube, 10 ft	1	24.5	11,1
30	Stop Ring	1	*	*
31	Core Lifter	1	*	*
32	Core Lifter Case	1	1.6	0,7
33	Full-Hole H/T Tanged			
33	Locking Coupling**	1	5.9	2,7
34	Adapter Coupling	1	3.2	1,5
35	Landing Ring	1	*	*
36	Outer Tube, 5 ft	1	44.0	20,0
36	Outer Tube, 10 ft	1	77.6	35,2
37	Inner Tube Stabilizer	1	*	*
38	Thread Protector	1	2.5	1.1

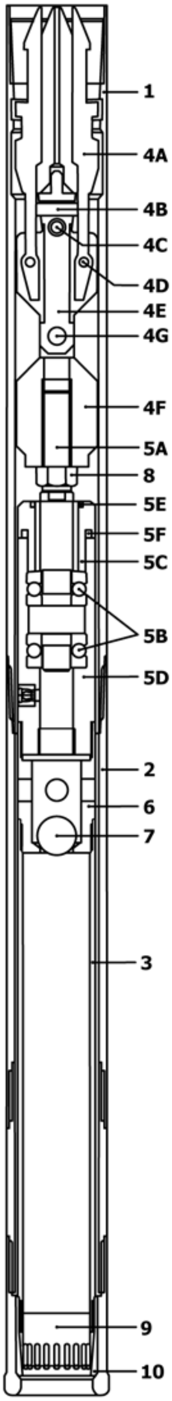
Weighs less than 1.0 lb (0,45 kg)
"H/T" means "Heat-Treated"

FIG. 6 Typical Wireline Rock Coring System

rod dimensions are not standardized. Table 3 lists the typical wireline rod sizes and Table 5 lists core barrel sizes of predominant types of wireline equipment available. Other systems such as heavy duty systems with differing dimensions may be available and are acceptable for use if dimensions are reported.

6.8.1 The inner barrel assembly is locked into the lead section of wireline drill rod by means of a retrievable overshot latching mechanism. A latching device locks into a complementary recess in the wall of the leading outer tube such that the outer tube could be rotated without causing the rotation of the inner tube. After the core run, the overshot mechanism is lowered through the rods and latches onto a spearhead on the top of the core barrel assembly and is hoisted to the surface with cable and wireline winch. The inner tube assembly consists of an inner tube with removable core lifter case and

NXB WIRELINE CORE BARREL



NXB WIRELINE CORE BARREL					
HOLE SIZE	**CORE SIZE**	**OUTER TUBE O.D.**	**OUTER TUBE I.D.**	**INNER TUBE O.D.**	**INNER TUBE I.D.**
2.980 in	1.875 in	2.875 in	2.391 in	2.200 in	1.969 in
75.7 mm	47.6 mm	73.0 mm	60.7 mm	55.9 mm	50.0 mm

NXB WIRELINE CORE BARREL ASSEMBLIES
PART DESCRIPTION
Core Barrel Assembly - 5 ft Complete (1.5 m)
Core Barrel Assembly - 10 ft Complete (3.0 m)
Core Barrel Assembly 5 ft (1.5 m) Split
Core Barrel Assembly 10 ft (3.0 m) Split
SPARE PARTS FOR NXB WIRELINE CORE BARREL
1. Locking Coupling
Locking Coupling, NQ Box Thread
2. Outer Tube 5 ft (1.5 m)
Outer Tube 10 ft (3.0 m)
3. Inner Tube 5 ft (1.5 m)
Inner Tube 10 ft (3.0 m)
Inner Tube, Split, 5 ft (1.5 m)
Inner Tube, Split, 10 ft (3.0 m)
4. Quad-Latch Pivot Head Assembly
A. Quad latch (4 required)
B. Spring - Blue (Top)
C. Spring - Red (Bottom)
D. Pin (4 required)
E. Head Base (Top)
F. Head Base (Bottom)
G. Pin
5. Bearing Assembly
A. Bearing Shaft
B. Bearing (2 required)
C. Bearing Retainer
D. Housing w/Zerk & cap
E. O-Ring
F. O-Ring
6. Inner Tube Connector
InnerTube Connection, Split
7. Ball
8. Nut
9. Core Lifter, Skirtless, Buttress
10. Inner Tube Shoe/Case, CP

FIG. 7 Typical Wireline Rock Coring System

core lifter at one end, and a removable inner tube head swivel bearing, suspension adjustment, and a latching device with a release mechanism at the opposite end. If continuous coring is not required, the retrievable inner core barrel assembly can be replaced with a pilot bit for hole advancement.

6.8.2 Wireline coring systems are designed for long life bits with wide kerf and impregnated or surface set diamonds. Both internal discharge and face discharge bits are available. The inner core barrel has a dual shut-off valve that stops fluid circulation to alert the driller of a core blockage.

6.8.3 The advantages of wireline drilling are:

6.8.3.1 Significant reduction in rod handling time compared with conventional core barrels.

6.8.3.2 Increased coring bit life with decreased diamond loss.

6.8.3.3 High core recovery.

6.8.3.4 Caving is reduced and rods aid to stabilize the drill hole walls.

6.8.3.5 Rods are flush or near flush both inside and outside and can be used as a temporary casing.

6.8.3.6 Various in-hole instrumentation packages can be sent through the end of the drill string to test the bottom of the hole. Wireline packer systems can be used for pressure water test (Test Method D4630).

6.8.3.7 Two inner barrel assemblies can be used for maximum productivity in continuous coring operations.

6.8.4 The disadvantages of wireline drilling are:

6.8.4.1 Equipment is more expensive than conventional equipment, and

6.8.4.2 Wireline systems are complicated and operations require additional training.

6.8.5 Table 5 lists common wireline core barrel sizes. They are available in "A" through "P" size. When rock samples are to be obtained for testing of engineering properties, "H" size is recommended, "N" is minimum, and "P" size will result in better recovery of difficult formations.

6.8.6 The wireline core barrel is essentially a double tube swivel type core barrel. Since the core lifter is part of the inner barrel assembly, exposure of the core to drill fluid is minimized similar to "M" style conventional core barrels. Most systems can be adjusted for front discharge (inside above bit gauge) or face discharge.

6.8.7 Most manufacturers offer a triple tube barrel, which is preferred for most operations. The third tube is a split inner liner that facilitates sample handling.

6.8.8 Some wireline barrels systems are convertible from soil sampling to rock sampling operation. These barrels are equipped with soil barrels that can lead in front of the core bit. Some systems are equipped with spring loaded soil core barrels. These systems are advantageous when soils or soft rock are encountered.

6.9 *Core Barrel Bits*—One of the most important equipment decisions in rock core drilling is the bit selection. Both the bit and reaming shell act together to cut the hole. There are many bit design factors involved when selecting the proper bit for good core recovery. Factors included in selection are:

6.9.1 Diamond type—source,

6.9.2 Diamond matrix (surface set or impregnated),

6.9.3 Rock hardness, grain size, and formation,

6.9.4 Drill power, and

6.9.5 Barrel type.

6.9.6 Bit selection is a trial and error process that may require several iterations. After a bit is selected, it is tried with the drill to be used. Penetration rate and bit life should be evaluated and a different design selected if necessary.

6.9.7 Important features of diamond drilling bits include crown shape, diamonds, and waterways. The crown is the end of the bit that contains a kerf equipped with cutting media. A round or semi-round kerf is frequently used with conventional core barrels. Flat, stepped, or v-ring designs are often used with wireline drilling with impregnated bits.

6.9.8 Important features of the diamonds themselves are the size, quality, quantity, setting, and matrix quality (**4**). Surface set bits are used in most conventional coring operations. The size of diamonds is expressed in equivalent stones per carat (SPC). The typical SPC range is from 20 to 100 for surface set bits, with the finer stones being used for harder rock matrixes. Larger diamonds are used for softer, more friable formations. Impregnated bits are fragments mixed with metal and pressed and sintered into the bit. The diamond fragments are throughout the crown and the bit is, in a sense, self-sharpening. Impregnated bits are used in more severe drilling conditions and in wireline drilling where long life is essential.

6.9.9 Waterway design is also an important aspect of bit selection. Surface channel routing of the fluids from inside gauge to outside is typical in conventional and wireline drilling for most crystalline rocks that are not sensitive to fluid erosion. Face discharge bits should be used for soft friable formations where fluid erosion is detrimental. Step-face discharge configurations further inhibit core erosion. Special flush discharge air ports are used with air and air-foam drilling operations. The softer the matrix, the larger the waterways must be to avoid blocking and plugging.

6.9.10 For very soft materials, it is not necessary to use diamonds as the cutting media. Diamonds can often be replaced with tungsten carbide or polycrystalline inserts for coring soft materials. Carbide and polycrystalline bits often have cutting teeth arranged in a sawtooth fashion. Polycrystalline bits (diamond grown to tungsten carbide substrates that are soldered or furnaced onto the crown) have replaced natural diamonds for coring in some softer sedimentary formations. Some core barrels, such as the large diameter series, can readily be changed from diamond rock coring to carbide soil sampling modes.

6.9.11 Manufacturers are an excellent resource to assist in selecting the matrix and style of bit, depending on rock conditions, drill power, and barrel type. Most manufacturers have a method for rating diamond matrices and bits into different series and groups (**3**). DCDMA has selection codes for impregnated bits (**10**). Manufacturers should be consulted for initial recommendations for your specific drilling conditions, and as the project progresses, they can work with the driller to refine designs and drilling technique. Based on wear patterns, it may be possible to switch series or design to optimize results. In hard competent formations, bit selection may be drill rig-dependent (rotation rate and advance forces). It is beyond the scope of this practice to address drill bit selection. In addition to manufacturers' advice, there are several useful references to provide information in evaluating causes for wear (**3**, **4**, **10**).

6.9.12 Most diamond bits have salvage value and should be returned to manufacturers for credit toward future purchases.

6.10 *Reaming Shells*—The reaming shell is a subassembly of a row or strip of material placed on the outside of the core barrel for some distance behind the core bit. It is designed to ream and enlarge the hole to a final diameter and must allow for adequate fluid circulation to the surface. The shell also acts as a collar or centralizer for the barrel. Manufacturers should be consulted for appropriate reaming shell designs for the formations to be drilled. They may be surface set with diamond bits, impregnated with diamond particles, inserted with tungsten carbide strips or slugs, hard faced with various types of hard surfacing materials, or furnished blank, as appropriate to the formation being cored.

6.11 *Core Lifters*—Core lifters are used to break the core from parent material at the end of a core run. As coring progresses, the lifter floats up in its beveled recessed slot in the shoe. After an increment of core has been drilled that corresponds to core barrel length, the rotation is stopped. Fluid is circulated until cuttings are cleared, and then the drill pipe is steadily retracted. The lifter will slide down the beveled shoe and impart an increasing grip on the core. The core frequently breaks near the base of the hole, and often a snap can be felt in the drill pipe as the core breaks from parent material.

6.11.1 Core lifters of the split ring type, either plain or hard surfaced, are recommended and must be maintained in good condition, along with core lifter cases or inner tubes extensions or inner tube shoes. Basket or finger type lifters with any necessary adapters may be used with core barrels if directed by the engineer or the geologist.

6.12 *Core Boxes*—These are durable waxed cardboard, metal, plastic, or wooden boxes with partitioned compartments for storing the core samples (see Practice D5079).

6.13 *Auxiliary Equipment*—The following auxiliary equipment is typically used for the rock core drilling project:

6.13.1 *Drilling bits*— roller rock bits, drag bits, chopping bits, boulder busters, and fishtail bits;

6.13.2 *Tools*—pipe wrenches, core barrel wrenches, chain tong, strap wrench, watch, RPM counter, lubrication equipment, core splitters, rod wicking, extruders, hand sieves or strainers, and marking and packaging tools;

6.13.3 *Rod holding equipment*—closed pulling ring, open iron ring, knife edge holding dog, holding iron, chucking rods, safety foot clamp, manila rope, bolt, and clevis pins;

6.13.4 *Fluid circulation equipment* —hoses, positive displacement pump along with packing and seals, water swivel, pressure gages, flow meters, water-level meters, and mud pit; and

6.13.5 *Drill area, platform, and leveling*—cribbing, planking, lumber, saw horses, metal saw horses with chain vise.

7. Reagents and Materials

7.1 *Water-Based Drill Fluid Additives*—Listed below are commonly used additives for water-based drilling fluids. Drilling additives in contact with drinking water aquifers should meet the requirements of NSF/ANSI 60 or those required by the rules and/or laws applicable for a specific locality.

NOTE 4—In some areas, certain types of drill fluid products are not allowed by state and local environmental authorities. Before using any drill fluid product, check with the authorities to determine its acceptability.

7.1.1 Beneficiated bentonite, a primary viscosifier and drill hole sealer, consists of montmorillonite with other naturally occurring minerals and various additives such as guar gum, sodium carbonate, or polyacrylates, or a combination thereof.

7.1.2 Unbeneficiated bentonite, a primary viscosifier and drill hole sealer, consists of montmorillonite with other naturally occurring minerals, but without additives such as guar gum, sodium carbonate, or polyacrylates.

7.1.3 Sodium carbonate powder (soda ash) is used to precipitate calcium carbonate from the drilling fluid water-base before adding other components. An increase in pH will occur with the addition of sodium carbonates. Sodium hydroxides (caustic soda) generally should not be used for this application.

7.1.4 Carboxylmethylcellulose powder (CMC) is sometimes used in a water-based fluid as a viscosifier and as an inhibitor to clay hydration. Some additives to water-based drilling-fluid systems retard clay hydration, thus inhibiting swelling of clays on the drill hole wall and "balling" or "smearing" of the bit.

7.1.5 Potassium chloride (muriated potash) or diammonium phosphate can be used as an inhibitor to clay hydration.

7.1.6 Polyacrylamide, a primary viscosifier and clay hydration inhibitor, is a polymer mixed with water to create a drilling fluid.

7.1.7 Guar gum, a primary viscosifier, drill-hole sealer, and hydration inhibitor, is a starch mixed with a water base. The water must be neutral to slightly acidic and hydrochloric acid is sometimes used to pre-treat the water base. Guar gum will degrade with time, but various chemicals can be used to accelerate decomposition.

7.1.8 Barium sulfate increases the density of water-based drilling fluids to help support the borehole wall. It is a naturally occurring high-specific gravity mineral processed to a powder for rotary drilling fluid applications.

7.1.9 Lost-circulation materials are added to the drilling fluid to seal the drill-hole wall when fluids are being lost through large pores, cracks, or joints. These additives usually consist of various coarse textured materials such as shredded paper or plastic, bentonite chips, wood fibers, or mica.

7.1.10 Attapulgite, a primary viscosifier for rotary drilling in high-salinity environments, is a clay mineral drilling-fluid additive.

8. Precautions

8.1 The drilling and sampling equipment shall be complete and in good order. A sufficient amount of drill rods, casings, drill bits, core barrels, core barrel liners, water meters, pumps, and pressure gages shall be in hand before the start of drilling. Measurement devices such as pressure gages and RPM counters shall be functioning in conformance with the manufacturer's specifications.

8.2 The use of fluid or air under high pressure may cause damage to formation materials by fracturing or excessive erosion if drilling conditions are not carefully maintained and monitored. If formation damage is evident and undesirable, other drilling method(s) should be considered.

8.2.1 Fluid pressure should be monitored during drilling. Fluid pressure at the bit should be as low as possible to maintain circulation and to reduce possibility of hydraulic fracturing or excessive erosion of surrounding materials. Normally, injection fluid pressures are fully monitored. Changes in fluid return and circulation pressure may indicate occurrence of excessive erosion, formation fluid loss, core blockage, or formation fracturing. Any abrupt changes or anomalies in the fluid pressure should be noted and documented, including the depth(s) of occurrence(s).

9. Procedure

9.1 Perform site inspections to determine locations of boreholes, and to select disposal sites for waste products during drilling.

9.1.1 Evaluate applicable methods for environmental protection and traffic regulation during core drilling.

9.1.2 Determine site accessibility and availability of water for core drilling operation. Check around the drill site for overhead obstructions or hazards, such as power lines, before raising the mast. A survey of underground and all other utilities is required before drilling to evaluate hazards.

9.2 Fabricate and assemble the drill mounting platform. The platform can take a variety of forms. The type of platform will depend on the terrain encountered, the stipulated depth of the borehole, and the accessibility of the drill site. Specialized mountings such as a barge or stilts or specially constructed towers are necessary to mount platforms for drilling over water.

9.3 For water-based fluid drilling operation, a mud pit is positioned to collect and filter fluid return flow. An initial quantity of drilling fluid is mixed, usually using the mud pit as the primary mixing reservoir.

9.3.1 For air-based circulation systems, the dust collector or cyclone separator is positioned and "sealed" to the ground surface.

9.4 Case any interval of the borehole that penetrates the overburden. This will prevent collapsing of loose materials into the borehole or loss of drill fluid. The casing should extend through the overburden and extend at least 5 ft (1.5 m) into the rock. Casing may be omitted if the borehole will stand open without caving. Deeper casing(s) or nested casing(s) may be required to facilitate adequate drill hole fluid circulation and hole control. Records of casing(s) lengths and depth intervals installed should be maintained and documented.

9.4.1 Surface casings can be installed using a variety of drilling methods. Hollow-stem auger drilling (Practice D6151) has been used successfully for surface casing and has an added benefit of obtaining samples of the overburden soils. The surface casing is normally backfilled, pressed, or sealed in place with bentonite or cement, or both.

9.4.2 A datum for measuring drill hole depth should be established and documented. This datum normally consists of a stake driven into stable ground surface, the top of the surface casing, or the drilling deck. If there is possibility for movement of the surface casing, it should not be used as a datum. If the hole is to be later surveyed for elevation, record and report the height of the datum to the ground surface.

9.5 The core barrel is assembled following manufacturers' instructions. Keep core barrels cleaned and lubricated and free from damage, dents, or other defects that might affect core quality. Inspect barrels for wear, clearances, dents, or galls. Check condition of core lifters, fluid passages, relief holes, ball checks, valve rubbers, and inner barrel stabilizers, if present. Assemble and disassemble core barrels with the correct tools for the job.

9.5.1 The inner tube of double tube core barrels must be positioned correctly for proper operation. For both conventional and wireline systems where fluid circulates between the bit and lifter case, check that the proper clearance is maintained for circulation. For wireline systems, this will require engaging the inner barrel while the outer barrel is held vertically. If clearances are not correct, they should be adjusted using the adjustment screw on top of the barrel assembly.

9.5.2 For swivel type inner barrels, inspect the bearing assemblies and confirm the inner barrel is free to rotate smoothly when assembled.

9.6 An initial assembly of lead drill rod and core barrel is attached to the drill mechanism through a spindle or below the drill head, and placed within the top of the surface casing. Hole depth is determined by keeping track of the length of the rod-bit assemblies and comparing its position relative to the established surface datum. Hole depth for increments of drilling, coring, and sampling is recorded on the drill log.

9.7 The drilling-fluid circulation pump or air compressor is activated, causing drilling fluid or air to circulate through the system.

9.8 Drilling fluid or air circulation is initiated and rotation and axial force are applied to the drill rod and bit until drilling progresses to a depth where: (*1*) when the core sample has fully entered the core barrel or blockage is apparent, (*2*) sampling or in-situ testing will be performed, or (*3*) the length of the drill-rod column limits further penetration.

9.8.1 Maintain fluid circulation at a rate suitable for the formation to be drilled. Fluid should be circulated at a rate sufficient to circulate cuttings and cool the bit. Fluid pressures should be monitored during drilling. Avoid drilling at excessive advance rate, which could cause plugging of the bit and core blockage and damage. Changes in fluid return and circulation pressures may indicate occurrence of excessive erosion, formation fluid loss, or formation fracturing. Any abrupt changes or anomalies in fluid pressure should be noted and documented, including depth(s) of occurrence(s).

9.8.2 Maintain air circulation at a rate suitable for the formation, and avoid circulation losses. Add water or foam as necessary to maintain circulation. Zones of low air return or no air return should be documented. Should air-blast erosion occur, depth(s) of the occurrence(s) should be noted and documented. Air is particularly susceptible to blocking off circulation and causing uplift to occur very quickly.

9.8.3 Samples of drill cuttings can be collected for analysis of materials penetrated. If cuttings samples are obtained, the depth(s) and interval(s) should be documented.

9.8.4 The selection of proper rotation rate and down feed (advance) or hold-back pressure depends on many factors. The drilling process is iterative in nature. Diamond drilling in a harder matrix usually requires higher rotation rates and down force pressures. With the correct material and equipment configurations, diamond bit performance is generally optimum at rotation rates of at least 400 rpm or greater. Rates of up to 1000 rpm can be used, depending on the material. However, too high a rate can cause tearing of the formation and core recovery problems. Softer materials with other bits such as polycrystalline, require slower rotation rates. Vibration is extremely important to the drill hole and core quality and must be minimized. Sufficient thrust needs to be transmitted to the bit so that bit elements can cut the rock. The goal is to find the rotation rate and thrust that will result in high quality core and acceptable bit life.

9.8.4.1 Monitor advance or down force pressure, or hold-back pressures, and rotation rates of drill rods during drilling. Observe the penetration rate and drill cuttings as they relate to the geologic strata being penetrated. Document occurrences of any significant abrupt changes and anomalies during drilling.

9.9 Rotation is stopped, the advance or down force pressure is released, and circulation is continued for a short time until the drill cuttings are removed from the borehole annulus. Circulation is stopped and the barrel is rested on the hole bottom to determine hole depth.

9.10 Remove the core barrel and the core from the borehole. Disassemble the core barrel and remove the core.

9.10.1 With double tube barrels, when the barrel is retracted, the core lifter grips the core and the core is normally broken from the base material at the base of the hole. The core lifter is located inside the barrel above the bit typically about 0.1ft. When the core is broken there will be a small pedestal of core left in the hole. As long as the lifter is not slipping, and core is of good quality, successive recoveries will be close to 100 %. If for some reason, the lifter case slips, there will be low recovery recorded and there will be a longer pedestal on the subsequent sampling event. If there appears to be excessive core on the subsequent run, or there is visible evidence of the lifter slipping, these occurrences should be noted. If it is obvious the pedestal was present, the length can be accounted for in determination of recovery (see 10.1) of the previous run. These occurrences and corrections should be appropriately noted in the drill report.

9.10.2 With single tube core barrels in shallow drilling operations, the core can be broken with a wedge and lifted by wire hoop to the surface.

9.11 Reassemble the core barrel and return it to the borehole. Check for proper barrel conditions as noted in 9.7. The use of two barrels can greatly speed coring operations; as one barrel is cleaned and reassembled the other is in use in coring.

9.12 Drilling depth is increased by attaching an additional drill-rod section(s) to the top of the previously advanced drill-rod column and resuming drilling operations in accordance with 9.8 – 9.12.

9.13 *Rock Core Handling*—Use of split inner barrel liners greatly increases the efficiency of handling of cores, especially in broken formations. Cores can be transferred into plastic half rounds for logging and sealing. Log, mark, preserve, and place and pack core samples in core boxes in accordance with Practice D5079. All mechanical breaks (MB), man or equipment related, of the core sample shall be recorded in the logs and by marking the cores in some consistent manner. Typically, this is by two parallel lines drawn perpendicular and crossing the mechanical break and labeled "MB".

9.14 *Rock Core Recovery*—Rock core shall be recovered continuously in the borehole. If core recovery of the solid portion of the subsurface material drops a significant amount below 100 % (see Section 10), modify the drilling procedure, that is, adjust the drilling RPM, down feed pressure, the drilling fluid type and flow, or change the type and the size of core barrel or bit used, until core recovery is improved to a level acceptable to the project geologist or project engineer. Minimize mechanical breaks in the core during core drilling as much as possible.

9.14.1 *Low Core Recovery*—Stop core drilling when core recovery of the solid portion equals or falls below 50 %, or whatever percent recovery level is unacceptable to the project. If recovering samples is important and low core recovery is not due to open voids, select a better core barrel or bit design and/or make additional changes in drilling procedures. In some cases, it may be necessary to attempt soil sampling techniques (**13**).

9.15 If conditions prevent advance of the drill hole to the stipulated depth, the borehole shall be cemented and redrilled, or reamed and cased, and advanced with a smaller size drill bit and core barrel, or abandoned, as directed by the engineer or geologist.

10. Calculation

10.1 *Calculate Core Recovery (CR):*

10.1.1 Determine the core recovery as the ratio of length of core recovered to the length drilled, and express as a percent.

$$\text{Core Recovery(CR)} = \qquad (1)$$

$$(\text{Length of the recovered core/Total length of the core run}) \times 100, \%$$

10.1.2 Areas where loss is likely to have occurred (soft seams, voids, fractures with edges that do not match, zones of decay, etc.) shall be noted.

NOTE 5—Core recovery values greater than 100% can occur in a given core run. This can occur when the previous core run was pulled, the core lifter slipped or core material fell out of the barrel and a rock core stub or lose sample was left at the bottom of the hole that was then picked up by the subsequent core run. Whenever a core run with a core recovery of less than 100% is obtained the possibility of a portion of the core sample being left in the hole should be considered and the respective core recovery values adjusted accordingly. Drillers must recognize when or if this happens because it is critical that the capacity of the sample barrel not be exceeded with the subsequent core run.

10.2 Calculate Rock Quality Designation (RQD) in accordance with Test Method D6032.

NOTE 6—The core recovery and RQD value is sensitive to the length of the coring run, quality of drilling and the type of equipment used to obtain the core as well as if there are open voids in the rock mass. The shorter the length of the core run, the greater the sensitivity of the core recovery and RQD calculation to a lower value.

NOTE 7—While the length of each core run can vary for different reasons there is no set rule that the core run length cannot be normalized or that adjacent core run or portion of runs cannot be combined to provide a more meaningful value for either the percent core recovery or the RQD. For example, calculation of the core recovery or RQD for a core run or runs in a given rock type. Professional judgment can be used as needed. However, many times this occurs naturally in the drilling process as zones of poor rock are encountered and run lengths are shortened to prevent blockage of the core bit and to enhance core recovery.

11. Report

11.1 Report the following information:

11.1.1 *Site Conditions*—Site description: description of the site and any unusual circumstances.

11.1.2 *Personnel*—document all personnel at the site during the drilling process, including the driller, helpers, geologist or logger, engineer, and other monitors or visitors.

11.1.3 Weather conditions during drilling.

11.1.4 Working hours, operating times, break-down times, and sampling times. Report any long-term delays in the drilling and installation process.

11.1.5 Report any unusual occurrences that may have happened during the exploration.

11.1.6 *Drilling Methods:*

11.1.6.1 Description of the coring system including type, sizes, core barrels, fluid pump, fluid circulation, and discharge systems. Note intervals of equipment change or drilling method changes and reasons for change.

11.1.6.2 Type, quantities, and drill hole locations of use of additives added to the circulation media. If changes to the circulating medium are made, such as addition of water or conversion to foam, the depth(s) or interval(s) of these changes should be documented.

11.1.6.3 Descriptions of circulation rates, cuttings returns, including quantities, over intervals used. Note the quantity and locations of loss of circulation and probable cause.

11.1.6.4 Descriptions of drilling conditions related to drilling pressures, rotation rates, and general ease of drilling related to subsurface materials encountered. These descriptions can be very general, and should report how the sampling of different materials progressed.

11.1.6.5 *Records of casing installed* —Report type, amount and times of installation. Record water levels (dates and elevation) observed during drilling.

11.1.7 *Sampling*—When core sampling or intact sampling at the base of the boring separate from coring operations, report condition of the base of the boring before sampling and any slough or cuttings present in the recovered sample. Samples of fluid circulation cuttings can be collected for analysis of materials being penetrated. If cuttings samples are taken, the depth(s) and interval(s) should be documented.

11.1.8 *In-situ Testing:*

11.1.8.1 For devices inserted below the base of the drill hole, report the depths below the base of the hole and any unusual conditions during testing.

11.1.8.2 For devices testing or seating at the drill hole wall, report any unusual conditions of the drill hole wall such as inability to seat pressure packers.

11.1.9 *Installations*—A description of completion materials and methods of placement, approximate volumes placed, intervals of placement, methods of confirming placement, and areas of difficulty or unusual occurrences.

11.2 *Boring Logs*—Boring logs should be completed in accordance with Guide D5434. Some information that the boring log should include is:

11.2.1 Project identification, boring number, location, orientation, date boring began, date boring completed, and drillers' name(s).

11.2.2 Elevation coordinates of the top of the borehole.

11.2.3 Elevation of, or depth to, groundwater surface, and any changes in water level, including the dates and times measured.

11.2.4 Elevations or depths at which the drilling fluid returns were lost and amount of return with depth. Report advance or down feed and hold-back pressures, rotation rates of drill rods, fluid/gas pressure, and circulations return during drilling. Report the penetration rate and drill cuttings as they relate to the geologic strata being penetrated. Document any significant abrupt changes and anomalies that occur during drilling.

11.2.5 Size, type, and design of core barrels used. Size, type, and set of core bits and reaming shells used. Size, type, and design and lengths of all casing used, and locations or elevations of casings used. Records of casing(s) lengths and depth intervals installed should be maintained and documented.

11.2.6 Length of each core run and the percentage of core recovery.

11.2.7 Driller's description of the core in each run, if no engineer or geologist was present.

11.2.8 Geologist's or engineer's description of the core recovered in each run. Subsurface description, including dip of strata, jointing, cavities, fissures, core loss, and any other observations made by the geologist, engineer, or the driller that could yield information about the formation encountered during drilling. Depth, thickness, and apparent nature of the filling of each soft seam or cavity encountered. Report the calculated RQD and Test Method D6032.

11.2.9 Any change in the character of the drilling fluid or drilling fluid return.

11.2.10 Reservoir, tidal, or current information, if the drilling is near or over a body of water.

11.2.11 Drilling time in minutes per foot and down feed gauge pressure, when applicable, and the RPM of the drill rods.

11.2.12 Notations of character of drilling, that is, soft, slow, easy, smooth, and others.

12. Precision and Bias

12.1 This practice does not produce numerical data; therefore, a precision and bias statement is not applicable.

12.2 The boring log reflects the subjective opinions of the engineer, the geologist, or the driller. Therefore, the designer must exercise proper prudence when interpreting the boring logs.

12.3 This procedure produces data on rock type and rock quality and recovery factors such as RQD (Test Method D6032) that may reflect the biases of the persons collecting the data. Precision for determination of RQD will be addressed inTest Method D6032.

13. Keywords

13.1 diamond drilling; exploration; rock; rock coring; rock exploration; site characterization

REFERENCES

(1) *Drilling Safety Guide*, National Drilling Association, 3008 Millwood Ave., Columbia, SC, 29205.

(2) Acker III, W. L., *Basic Procedures for Soil Sampling and Core Drilling*, Acker Drill Co., Scranton, PA, 1974.

(3) *Australian Drilling Manual*, Australian Drilling Industry Training Committee Limited, PO Box 1545, Macquarie Centre, NSW 2113, Australia, 3rd Ed., 1992.

(4) Heinz, W.F., *Diamond Drilling Handbook*, South African Drilling Association, SADA, c/o SEIFSA, PO Box 1338, Johannesburg, Republic of South Africa, 2000, 1st Ed., 1985.

(5) *Drillers Handbook*, T.C. Ruda, and P.J. Bosscher, Eds, National Drilling Contractors Association, 3008 Millwood Avenue, Columbia, SC, June 1990.

(6) Shuter, E., and Teasdale, W., "Application of Drilling, Coring, and Sampling Techniques to Test Holes and Wells," Chapter F1, Book 2, Collection of Environmental Data, Techniques of Water-Resource Investigations of the United States Geological Survey, United States Government Printing Office, Washington, DC, 1989.

(7) *Groundwater and Wells*, F.G. Driscoll, 2nd Ed., Johnson Filtration Systems Inc., St. Paul, MN.

(8) "Baroid Drilling Fluid Products for Mineral Exploration," NL Baroid/NL Industries, Houston, TX, 1980.

(9) Teasdale, W.E., and Pemberton, R.R., "Wireline-Rotary Air Coring of the Bandelier Tuff, Los Alamos, New Mexico," Water Resources Investigations Report 84-4176, U.S. Geological Surey, Denver, CO, 1984 .

(10) *DCDMA Technical Manual*, Diamond Drill Core Manufacturers Association, 3008 Millwood Avenue, Columbia, SC, 1991.

(11) "Guidelines for Drilling and Testing Core Samples at Concrete Gravity Dams," GS-6365, Research Project 2917-5, Final Report, Report by Stone and Webster Inc. for Electric Power Research Institute, Palo Alto, CA, May 1989.

(12) Specifications for Drill Pipe and Drill String, Number 5D-92 and 7G-90, American Petroleum Institute.

(13) Core Recovery Techniques for Soft or Poorly Consolidated Materials, prepared for U.S. Bureau of Mines by Woodward Clyde Consultants, Contract J0275003, pp. 136. APL, 1978.

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D2113 – 08) that may impact the use of this standard. (November 1, 2014)

(1) Replaced "investigation" with "exploration" throughout standard.
(2) Added Note 2 to clarify that drilling apparatuses other than the common one mentioned were allowed and all other notes were renumbered accordingly.
(3) Reference D420 has been withdrawn due to no ballot action. Therefore, the reference was removed here and in 5.1 where it was referencd.
(4) Updated reference to NSF 60 in 2.3 to exclude the date and include ANSI.
(5) Removed 5.1 reference to D420, and in the second sentence "yield significant indications" was changed to "provide indications".
(6) Added 6.12: use of durable metal and plastic core boxes.
(7) Reworded 7.1 to stress that NSF/ANSI 60 may not be good enough in all localities where drilling may be performed.
(8) Subsection 9.4.1: Corrected the spelling for "auger".
(9) Subsection 9.10.1: Corrected spelling errors.
(10) Subsection 9.13: Discussion about mechanical breaks of cores and how to mark them was relocated from 9.14 and some rewording for more clarity for the user.
(11) Subsection 9.14: The last sentence was moved to 9.13 and rest of section reworded so that the 100% recovery was not taken as an absolute.
(12) Reworded 9.14.1 so that 50 % core recovery was not an absolute and to include the effects or considerations for voids.
(13) Section 10: Term (CR) was added to fit with the current literature and the formula changed accordingly. Also, wording and Note 5 was added to stress the importance of recognizing and recording properly core loss zones.
(14) Added Notes 6 and 7 to inform the user that core recovery and RQD can be or may need to be calculated other than the traditional way and that significantly different values could be obtained.

Designation: D2488 – 17$^{\varepsilon 1}$

Standard Practice for
Description and Identification of Soils (Visual-Manual Procedures)[1]

This standard is issued under the fixed designation D2488; 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 (ε) indicates an editorial change since the last revision or reapproval.

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

ε[1] NOTE—Editorially corrected Fig. 2 in March 2018.

---

1. Scope*

1.1 This practice covers procedures for the description of soils for engineering purposes.

1.2 This practice also describes a procedure for identifying soils, at the option of the user, based on the classification system described in Test Method D2487. The identification is based on visual examination and manual tests. It shall be clearly stated in reporting, the soil identification is based on visual-manual procedures.

1.2.1 When precise classification of soils for engineering purposes is required, the procedures outlined in Test Method D2487 shall be used.

1.2.2 In this practice, the identification procedures assigning a group symbol and name are limited to soil particles smaller than 3 in. (75 mm).

1.2.3 The identification portion of this practice is limited to naturally occurring soils. Specimens used for identification may be either intact or disturbed.

NOTE 1—This practice may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. (see Appendix X2).

1.3 The descriptive information in this practice may be used with other soil classification systems or for materials other than naturally occurring soils.

1.4 *Units*—The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are rationalized conversions to SI units that are provided for information only and are not considered standard. The sieve designations are identified using the "alternative" system in accordance with Practice E11.

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements see Section 8.

1.6 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D1452 Practice for Soil Exploration and Sampling by Auger Borings

D1586 Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils

D1587 Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes

D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration

---

[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

Current edition approved July 15, 2017. Published August 2017. Originally approved in 1966. Last previous edition approved in 2009 as D2488 – 09a. DOI: 10.1520/D2488-17E01.

[2] 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.

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

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)

D4427 Classification of Peat Samples by Laboratory Testing

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms in this standard, refer to Terminology D653.

3.1.2 *cobbles*—particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) sieve.

3.1.3 *boulders*—particles of rock that will not pass a 12-in. (300-mm) square opening.

3.1.4 *clay*—soil passing a No. 200 (75-µm) sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air-dried. For classification, a clay is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index equal to or greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line (see Fig. 4 of Test Method D2487).

3.1.5 *gravel*—particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve with the following subdivisions:

3.1.5.1 *coarse*—passes a 3-in. (75-mm) sieve and is retained on a ¾-in. (19-mm) sieve.

3.1.5.2 *fine*—passes a ¾-in. (19-mm) sieve and is retained on a No. 4 (4.75-mm) sieve.

3.1.6 *organic clay*—a clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil that would be classified as a clay, except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.7 *organic silt*—a silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.8 *peat*—a soil composed primarily of vegetable tissue in various stages of decomposition usually with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

3.1.9 *sand*—particles of rock that will pass a No. 4 (4.75-mm) sieve and be retained on a No. 200 (75-µm) sieve with the following subdivisions:

3.1.9.1 *coarse*—passes a No. 4 (4.75-mm) sieve and is retained on a No. 10 (2.00-mm) sieve.

3.1.9.2 *medium*—passes a No. 10 (2.00-mm) sieve and is retained on a No. 40 (425-µm) sieve.

3.1.9.3 *fine*—passes a No. 40 (425-µm) sieve and is retained on a No. 200 (75-µm) sieve.

3.1.10 *silt*—soil passing a No. 200 (75-µm) sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index less than 4, or the plot of plasticity index versus liquid limit falls below the "A" line (see Fig. 4 of Test Method D2487).

3.1.11 *fine-grained soils*—soils that are made up of 50 % or more particles that will pass a No. 200 (75 µm) sieve.

3.1.12 *coarse-grained soils*—soils that are made up of more than 50 % particles that will be retained on a No. 200 (75 µm) sieve.

4. Summary of Practice

4.1 Using visual examination and simple manual tests, this practice gives standardized criteria and procedures for describing and identifying soils.

4.2 The soil can be given an identification by assigning a group symbol(s) and name. The flow charts, Fig. 1a and Fig. 1b for fine-grained soils, and Fig. 2, for coarse-grained soils, can be used to assign the appropriate group symbol(s) and name. If the soil has properties which do not distinctly place it into a specific group, borderline symbols may be used, see Appendix X3.

5. Significance and Use

5.1 The descriptive information required in this practice can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

5.2 The descriptive information required in this practice should be used to supplement the classification of a soil as determined by Test Method D2487.

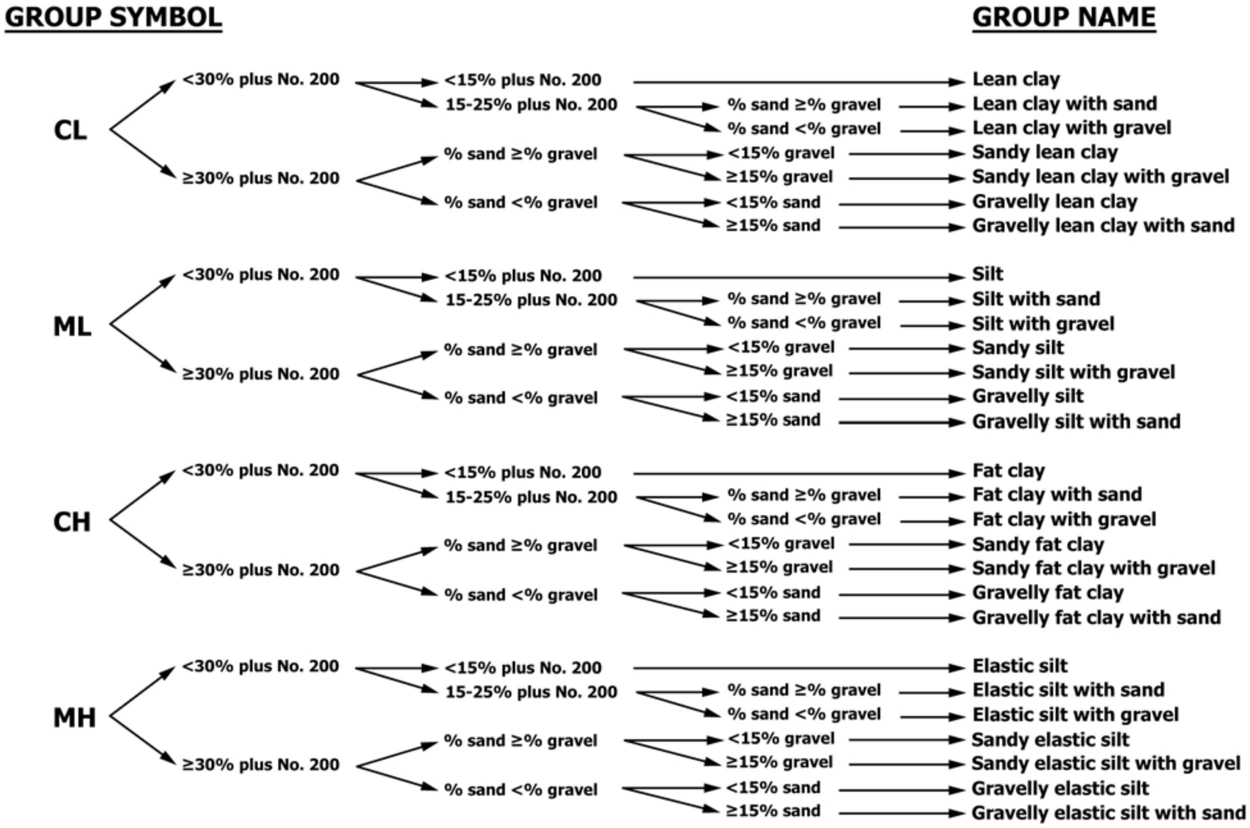
5.3 This practice may be used in identifying soils using the classification group symbols and names as prescribed in Test Method D2487. Since the names and symbols used in this practice to identify the soils are the same as those used in Test Method D2487, it shall be clearly stated in reports and all other appropriate documents, that the classification symbol and name are based on visual-manual procedures.

5.4 This practice is to be used for identification of soils in the field, laboratory, or any other location where soil samples are inspected and described.

5.5 This practice may be used to group similar soil samples to reduce the number of laboratory tests necessary for positive soil classification.

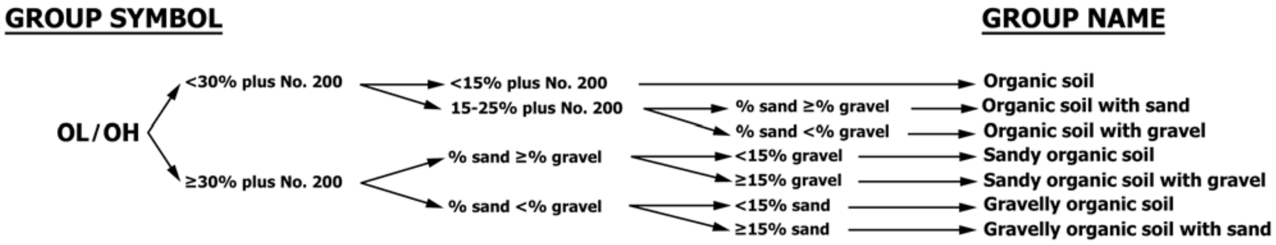
NOTE 2—The ability to describe and identify soils correctly is learned more readily under the guidance of experienced personnel, but it may also be acquired systematically by comparing numerical laboratory test results for typical soils of each type with their visual and manual characteristics.

5.6 Soil samples from a given boring, test pit or location which appear to have similar characteristics are not required to follow all of the procedures in this practice, providing at least one sample is completely described and identified. These samples may follow only the necessary procedures to determine they are "similar" and shall be labeled as such.



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the closest 5 %.

FIG. 1a Flow Chart for Identifying Inorganic Fine-Grained Soil (50 % or more fines)



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the closest 5 %.

FIG. 1 b Flow Chart for Identifying Organic Fine-Grained Soil (50 % or more fines)

5.7 This practice may be used in combination with Practice D4083 when working with frozen soils.

NOTE 3—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 D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Small Knife or Spatula*

6.2 *Test Tube and Stopper (optional)*

6.3 *Jar with Lid (optional)*

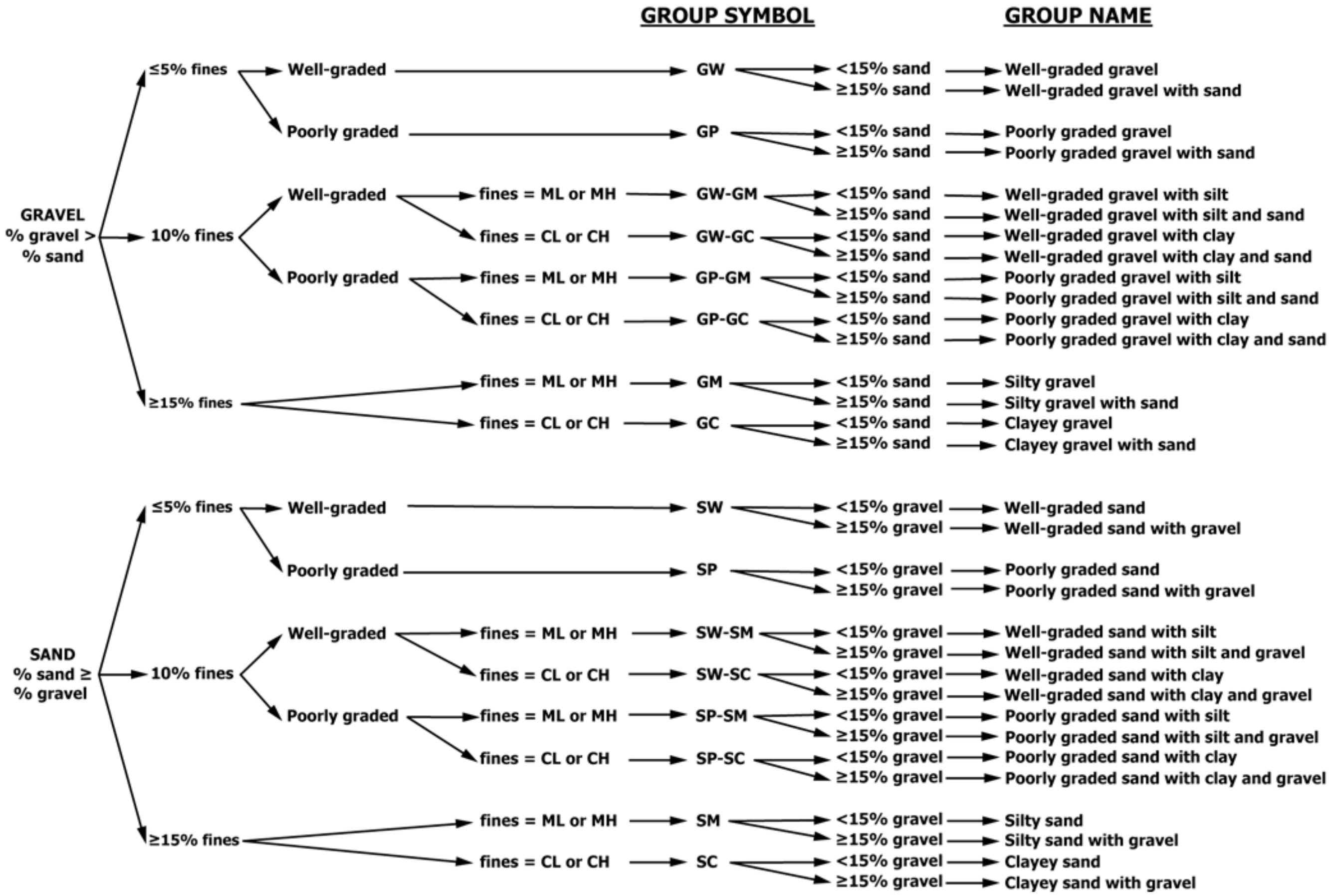
6.4 *Hand Lens (optional)*

6.5 *Shallow Pan (optional)*

7. Reagents

7.1 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean water from a city water supply or natural source, including non-potable water.

7.2 *Hydrochloric Acid*—A small bottle of dilute hydrochloric acid (HCl) one part HCl (10 *N*) to three parts distilled water (This reagent is optional for use with this practice). See Section 8.



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the closest 5 %.

NOTE—It is suggested that a distinction be made between *dual symbols* and *borderline symbols.*

Dual Symbol—A dual symbol is two symbols separated by a hyphen, for example, GP-GM, SW-SC, CL-ML used to indicate that the soil has been identified as having the properties of a classification in accordance with Test Method D2487 where two symbols are required. Two symbols are required when the soil has between 5 and 12 % fines or when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart.

Borderline Symbol—A borderline symbol is two symbols separated by a slash, for example, CL/CH, GM/SM, CL/ML. A borderline symbol should be used to indicate that the soil has been identified as having properties that do not distinctly place the soil into a specific group (see Appendix X3).

FIG. 2 Flow Chart for Identifying Coarse-Grained Soils (less than 50 % fines)

8. Safety Precautions

8.1 When preparing the dilute HCl solution of one part concentrated hydrochloric acid (10 *N*) to three parts of distilled water, slowly add acid into water following necessary safety precautions. Handle with caution, utilize personal protective equipment and store safely. If solution comes into contact with the skin or eyes, rinse thoroughly with water.

8.2 **Caution**—Acid shall be added to the water. Do not add water to the acid as this may cause an adverse reaction.

9. Sampling

9.1 The sample shall be considered to be representative of the stratum from which it was obtained by an appropriate, accepted, or standard procedure.

NOTE 4—Preferably, the sampling procedure should be identified as having been conducted in accordance with Practices D1452, D1587, or D2113, or Test Method D1586.

9.2 The sample shall be carefully identified as to origin.

NOTE 5—Remarks as to the origin may take the form of a boring number and sample number in conjunction with a project number, a geologic stratum, a pedologic horizon or a location description with respect to a permanent monument, a grid system or a station number and offset with respect to a stated centerline and a depth or elevation.

9.3 For accurate description and identification, the minimum amount of the specimen to be examined shall be in accordance with Table 1.

NOTE 6—If random isolated particles are encountered that are significantly larger than the particles in the soil matrix, the soil matrix can be accurately described and identified in accordance with the preceding table.

9.4 If the sample or specimen being examined is smaller than the minimum recommended specimen size, the report shall include a remark stating as such.

TABLE 1 Minimum Specimen Dry Mass Requirements

Maximum Particle Size, Sieve Opening	Minimum Specimen Size, by Dry Mass
No. 4 (4.75 mm)	0.25 lb (110 g)
⅜ in. (9.5 mm)	0.5 lb (220 g)
¾ in. (19.0 mm)	2.2 lb (1.0 kg)
1½ in. (38.1 mm)	18 lb (8.0 kg)
3 in. (75.0 mm)	132 lb (60.0 kg)

10. Descriptive Information for Soils

10.1 *Angularity*—Describe the angularity of the sand (coarse sizes only), gravel, cobbles, and boulders, as angular, subangular, subrounded, or rounded in accordance with the criteria in Table 2 and Fig. 3. A range of angularity may be stated, such as: subrounded to rounded.

10.2 *Shape*—Describe the shape of the gravel, cobbles, and boulders as flat, elongated, or flat and elongated if they meet the criteria in Table 3 and Fig. 4. Otherwise, do not mention the shape. Indicate the fraction of the particles that have the shape, such as: one-third of the gravel particles are flat.

10.3 *Color*—Describe the color. Color is an important property in identifying organic soils, and within a given locality it may also be useful in identifying materials of similar geologic origin. If the sample contains layers or patches of varying colors, this shall be noted and all representative colors shall be described. The color shall be described for moist samples. If the color represents a dry condition, this shall be stated in the report.

10.4 *Odor*—Describe the odor if organic or unusual.

10.4.1 Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation. This is especially apparent in fresh samples.

10.4.2 If the samples are dried, the odor may often be revived by moistening the sample and slightly heating it.

10.4.3 Odors from petroleum products, chemicals or other substances shall be described.

10.4.4 Some fumes emitting from soil samples, especially of a chemical nature, may pose a health risk. Proper safety protocols which may include the use of personal protective equipment must be followed in these instances. It is the responsibility of the user to determine the extent of the health risk and the correct protocols to follow.

10.5 *Moisture Condition*—Describe the moisture condition as dry, moist, or wet, in accordance with the criteria in Table 4.

10.6 *HCl Reaction*—Describe the reaction with HCl as none, weak, or strong, in accordance with the criteria in Table 5. Since calcium carbonate is a common cementing agent, a comment of its presence on the basis of the reaction with dilute hydrochloric acid is important.

10.7 *Consistency*—For intact fine-grained soil, describe the consistency as very soft, soft, firm, hard, or very hard, in accordance with the criteria in Table 6. This observation is inappropriate for soils with significant amounts of gravel.

TABLE 2 Criteria for Describing Angularity of Coarse-Grained Particles (see Fig. 3)

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

10.8 *Cementation*—Describe the cementation of intact coarse-grained soils as weak, moderate, or strong, in accordance with the criteria in Table 7.

10.9 *Structure*—Describe the structure of intact soils in accordance with the criteria in Table 8.

10.10 *Range of Particle Sizes*—For gravel and sand components, describe the range of particle sizes within each component as defined in 3.1.5 and 3.1.9. For example, about 20 % fine to coarse gravel, about 40 % fine to coarse sand.

10.11 *Maximum Particle Size*—Describe the maximum particle size found in the sample in accordance with the following information:

10.11.1 *Sand Size*—If the maximum particle size is a sand size, describe as fine, medium, or coarse as defined in 3.1.9. For example: maximum particle size, medium sand.

10.11.2 *Gravel Size*—If the maximum particle size is a gravel size, describe the maximum particle size as the smallest sieve opening that the particle will pass. For example, maximum particle size, 1½ in. will pass a 1½-in. (square opening) but not a ¾-in. (square opening).

10.11.3 *Cobble or Boulder Size*—If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle. For example: maximum dimension, 18 in. (450 mm).

10.12 *Hardness*—Describe the hardness of coarse sand and larger particles as hard, or state what happens when the particles are hit by a hammer, for example, gravel-size particles fracture with considerable hammer blow, some gravel-size particles crumble with hammer blow. "Hard" means particles do not crack, fracture, or crumble under a hammer blow.

10.13 Additional comments shall be noted, such as the presence of roots or root holes, difficulty in drilling or augering the hole, caving of the trench or hole, or the presence of mica.

10.14 A local or commercial name or a geologic interpretation of the soil, or both, may be added if identified as such.

10.15 A classification or identification of the soil in accordance with other classification systems may be added if identified as such.

11. Identification of Peat

11.1 A sample composed primarily of vegetative tissue in various stages of decomposition that has a fibrous to amorphous texture, usually a dark brown to black color, and an organic odor, shall be designated as highly organic and shall be identified as peat, PT. Peat samples shall not be subjected to the identification procedures described hereafter. Refer to D4427 for procedures on classifying peat.

12. Preparation for Identification

12.1 The soil identification portion of this practice is based on the portion of the soil sample that will pass a 3-in. (75-mm) sieve. The larger than 3-in. (75-mm) particles must be removed, manually for a loose sample, or ignored for an intact sample before classifying the soil.

(a) Rounded (b) Angular

(c) Subrounded (d) Subangular

FIG. 3 Typical Angularity of Bulky Grains

TABLE 3 Criteria for Describing Particle Shape (see Fig. 4)

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and elongated	Particles meet criteria for both flat and elongated

12.2 Estimate and note the percentage of cobbles and the percentage of boulders. Visual estimates will be based on the percentage by volume.

NOTE 7—Since the percentages of the particle-size distribution in Test Method D2487 are by dry mass, and the estimates of percentages for gravel, sand, and fines in this practice are by dry mass, it is recommended that the report state that the percentages of cobbles and boulders are by volume.

12.3 Of the fraction of the soil smaller than 3 in. (75 mm), estimate and note the percentage, by dry mass, of the gravel, sand, and fines (see Appendix X4 for suggested procedures).

NOTE 8—Since the particle-size components appear visually on the basis of volume, considerable experience is required to estimate the percentages on the basis of dry mass. Frequent comparisons with laboratory particle-size analyses should be made.

12.3.1 The percentages shall be estimated to the closest 5 %. The percentages of gravel, sand, and fines must add up to 100 %.

12.3.2 If one of the components is present but not in sufficient quantity to be considered 5 % of the smaller than 3-in. (75-mm) portion, indicate its presence by the term *trace*,

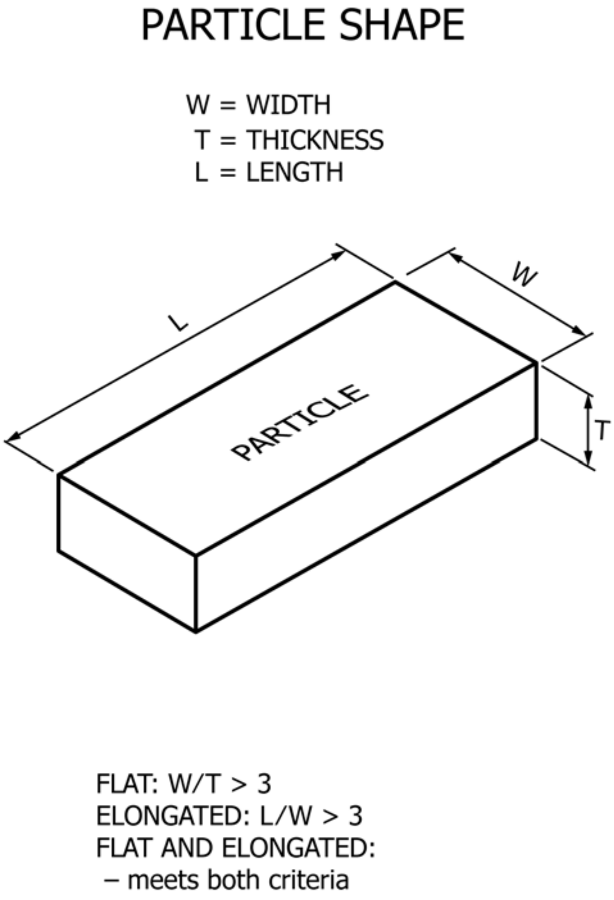


FIG. 4 Criteria for Particle Shape

TABLE 4 Criteria for Describing Moisture Condition

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

TABLE 5 Criteria for Describing the Reaction with HCl

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

TABLE 6 Criteria for Describing Consistency

Description	Criteria
Very soft	Thumb will penetrate soil more than 1 in. (25 mm)
Soft	Thumb will penetrate soil about 1 in. (25 mm)
Firm	Thumb will indent soil about ¼ in. (6 mm)
Hard	Thumb will not indent soil but readily indented with thumbnail
Very hard	Thumbnail will not indent soil

for example, trace of fines. A component quantity described as trace shall not be included in the total of 100 % for the components.

TABLE 7 Criteria for Describing Cementation

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

TABLE 8 Criteria for Describing Structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least ¼ in. (6 mm) thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

13. Preliminary Identification

13.1 The soil is *fine grained* if it contains 50 % or more fines. Follow the procedures for identifying fine-grained soils in Section 14.

13.2 The soil is *coarse grained* if it contains more than 50 % coarse-grained soils. Follow the procedures for identifying coarse-grained soils in Section 15.

14. Procedure for Identifying Fine-Grained Soils

14.1 Select a representative sample of the material for examination. Remove particles larger than the No. 40 (425 µm) sieve (medium sand and larger) until a specimen equivalent to about a handful of material is available. Use this specimen for performing the dry strength, dilatancy, and toughness tests.

14.2 *Dry Strength:*

14.2.1 From the specimen, select enough material to mold into a ball about 1 in. (25 mm) in diameter. Mold the material until it has the consistency of putty, adding water if necessary.

14.2.2 From the molded material, make at least three test specimens. A test specimen shall be a ball of material about ½ in. (12 mm) in diameter. Allow the test specimens to air dry or dry by artificial means, with a temperature not to exceed 140°F (60°C).

14.2.3 If the test specimen contains natural dry lumps, those that are about ½ in. (12 mm) in diameter may be used in place of the molded balls.

NOTE 9—The process of molding and drying usually produces higher strengths than those determined using natural dry lumps of soil.

14.2.4 Test the strength of the dry balls or lumps by crushing between the fingers. Note the strength as none, low, medium, high, or very high in accordance with the criteria in Table 9. If natural dry lumps are used, do not use the results of any of the lumps that are found to contain particles of coarse sand.

14.2.5 The presence of high-strength water-soluble cementing materials, such as calcium carbonate, may cause exceptionally high dry strengths. The presence of calcium carbonate

TABLE 9 Criteria for Describing Dry Strength

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very high	The dry specimen cannot be broken between the thumb and a hard surface

TABLE 11 Criteria for Describing Toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

can usually be detected from the intensity of the reaction with dilute hydrochloric acid (see 10.6).

14.3 *Dilatancy:*

14.3.1 From the specimen, select enough material to mold into a ball about ½ in. (12 mm) in diameter. Mold the material, adding water if necessary, until it has a soft, but not sticky, consistency.

14.3.2 Smooth the soil ball in the palm of one hand with the blade of a knife or small spatula. Shake horizontally, striking the side of the hand vigorously against the other hand several times. Note the reaction of water appearing on the surface of the soil. Squeeze the sample by closing the hand or pinching the soil between the fingers, and note the reaction as none, slow, or rapid in accordance with the criteria in Table 10. The reaction is the speed with which water appears while shaking, and disappears while squeezing.

14.4 *Toughness:*

14.4.1 Following the completion of the dilatancy test, the test specimen is shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread about ⅛ in. (3 mm) in diameter. (If the sample is too wet to roll easily, it should be spread into a thin layer and allowed to lose some water by evaporation.) Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about ⅛ in. (3 mm). The thread will crumble at a diameter of ⅛ in. (3 mm) when the soil is near the plastic limit. Note the pressure required to roll the thread near the plastic limit. Also, note the strength of the thread. After the thread crumbles, the pieces should be lumped together and kneaded until the lump crumbles. Note the toughness of the material during kneading.

14.4.2 Describe the toughness of the thread and lump as low, medium, or high in accordance with the criteria in Table 11.

TABLE 10 Criteria for Describing Dilatancy

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

14.5 *Plasticity*—On the basis of observations made during the toughness test, describe the plasticity of the material in accordance with the criteria given in Table 12.

14.6 Decide if the soil is an *inorganic* or an *organic* fine-grained soil (see 14.8). If inorganic, follow the steps given in 14.7.

14.7 *Identification of Inorganic Fine-Grained Soils:*

14.7.1 Identify the soil as a *lean clay*, CL, if the soil has medium to high dry strength, no or slow dilatancy, and medium toughness and plasticity (see Table 13).

14.7.2 Identify the soil as a *fat clay*, CH, if the soil has high to very high dry strength, no dilatancy, and high toughness and plasticity (see Table 13).

14.7.3 Identify the soil as a *silt*, ML, if the soil has no to low dry strength, slow to rapid dilatancy, and low toughness and plasticity, or is nonplastic (see Table 13).

14.7.4 Identify the soil as an *elastic silt*, MH, if the soil has low to medium dry strength, no to slow dilatancy, and low to medium toughness and plasticity (see Table 13).

NOTE 10—These properties are similar to those for a lean clay. However, the silt will dry quickly on the hand and have a smooth, silky feel when dry. Some soils that would classify as MH in accordance with the criteria in Test Method D2487 are visually difficult to distinguish from lean clays, CL. It may be necessary to perform laboratory testing for proper identification.

TABLE 12 Criteria for Describing Plasticity

Description	Criteria
Nonplastic	A ⅛-in. (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

TABLE 13 Identification of Inorganic Fine-Grained Soils from Manual Tests

Soil Symbol	Dry Strength	Dilatancy	Toughness and Plasticity
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	None	High

14.8 *Identification of Organic Fine-Grained Soils:*

14.8.1 Identify the soil as an *organic soil*, OL/OH, if the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soils will change color, for example, black to brown, when exposed to the air. Some organic soils will lighten in color significantly when air dried. Organic soils normally will not have a high toughness or plasticity. The thread for the toughness test will be spongy.

NOTE 11—In some cases, through practice and experience, it may be possible to further identify the organic soils as organic silts or organic clays, OL or OH. Correlations between the dilatancy, dry strength, toughness tests, and laboratory tests can be made to identify organic soils in certain deposits of similar materials of known geologic origin.

14.9 If the soil is estimated to have 15 to 25 % sand or gravel, or both, the terms "with sand" or "with gravel" (whichever is more predominant) shall be added to the group name. For example: "lean clay with sand, CL" or "silt with gravel, ML" (see Fig. 1a and Fig. 1b). If the percentage of sand is equal to the percentage of gravel, use "with sand."

14.10 If the soil is estimated to have 30 % or more sand or gravel, or both, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if there appears to be more sand than gravel. Add the word "gravelly" if there appears to be more gravel than sand. For example: "sandy lean clay, CL", "gravelly fat clay, CH", or "sandy silt, ML" (see Fig. 1a and Fig. 1b). If the percentage of sand is equal to the percent of gravel, use "sandy."

15. Procedure for Identifying Coarse-Grained Soils

(Contains more than 50 % coarse-grained soil)

15.1 The soil is a *gravel* if the percentage of gravel is estimated to be more than the percentage of sand.

15.2 The soil is a *sand* if the percentage of gravel is estimated to be equal to or less than the percentage of sand.

15.3 The soil is a *clean gravel* or *clean sand* if the percentage of fines is estimated to be 5 % or less.

15.3.1 Identify the soil as a *well-graded gravel*, GW, or as a *well-graded sand*, SW, if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes.

15.3.2 Identify the soil as a *poorly graded gravel*, GP, or as a *poorly graded sand*, SP, if it consists predominantly of one size (uniformly graded), or it has a wide range of sizes with some intermediate sizes obviously missing (gap or skip graded).

15.4 The soil is either a *gravel with fines* or a *sand with fines* if the percentage of fines is estimated to be 15 % or more.

15.4.1 Identify the soil as a *clayey gravel*, GC, or a *clayey sand*, SC, if the fines are clayey as determined by the procedures in Section 14.

15.4.2 Identify the soil as a *silty gravel*, GM, or a *silty sand*, SM, if the fines are silty as determined by the procedures in Section 14.

15.5 If the soil is estimated to contain 10 % fines, give the soil a dual identification using two group symbols.

15.5.1 The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP) and the second symbol shall correspond to a gravel or sand with fines (GC, GM, SC, SM).

15.5.2 The group name shall correspond to the first group symbol plus the words "with clay" or "with silt" to indicate the plasticity characteristics of the fines. For example: "well-graded gravel with clay, GW-GC" or "poorly graded sand with silt, SP-SM" (see Fig. 2).

15.6 If the specimen is predominantly sand or gravel but contains an estimated 15 % or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example: "poorly graded gravel with sand, GP" or "clayey sand with gravel, SC" (see Fig. 2).

15.7 If the field sample contains any cobbles or boulders, or both, the words "with cobbles" or "with cobbles and boulders" shall be added to the group name. For example: "silty gravel with cobbles, GM."

16. Report: Data Sheet(s)/Form(s)

16.1 Record as a minimum the following information (data):

16.1.1 Project specific information such as Project number, Project name, Project location if this information is available.

16.1.2 The person performing the soil identification.

16.1.3 Sample specific information including boring number, sample number, depth, sample location, such as test pit or station number etc. if this information is available.

16.1.4 The specimen characteristics which should be in the soil description are listed in Table 14. At a minimum the group name, group symbol and color shall be recorded.

NOTE 12—*Example: Clayey Gravel with Sand and Cobbles, GC*—About 50 % fine to coarse, subrounded to subangular gravel; about 30 % fine to coarse, subrounded sand; about 20 % fines with medium plasticity, high dry strength, no dilatancy, medium toughness; weak reaction with HCl; original field sample had about 5 % (by volume) subrounded cobbles, maximum dimension, 150 mm.

In-Place Conditions—Firm, homogeneous, dry, brown

Geologic Interpretation—Alluvial fan

NOTE 13—Other examples of soil descriptions and identification are given in Appendix X1 and Appendix X2.

NOTE 14—If desired, the percentages of gravel, sand, and fines may be stated in terms indicating a range of percentages, as follows:

Trace—Particles are present but estimated to be less than 5 %
Few—5 to 10 %
Little—15 to 25 %
Some—30 to 45 %
Mostly—50 to 100 %

16.2 If, in the soil description, the soil is identified using a classification group symbol and name as described in Test Method D2487, it must be distinctly and clearly stated in any

TABLE 14 Checklist for Description of Soils

1. Group name
2. Group symbol
3. Percent of cobbles or boulders, or both (by volume)
4. Percent of gravel, sand, and fines, or all three (by dry weight)
5. Particle-size range:
   Gravel—fine, coarse
   Sand—fine, medium, coarse
6. Particle angularity: angular, subangular, subrounded, rounded
7. Particle shape: (if applicable) flat, elongated, flat and elongated
8. Maximum particle size or dimension
9. Hardness of coarse sand and larger particles
10. Plasticity of fines: nonplastic, low, medium, high
11. Dry strength: none, low, medium, high, very high
12. Dilatancy: none, slow, rapid
13. Toughness: low, medium, high
14. Color (in moist condition)
15. Odor (mention only if organic or unusual)
16. Moisture: dry, moist, wet
17. Reaction with HCl: none, weak, strong

For intact samples:

18. Consistency (fine-grained soils only): very soft, soft, firm, hard, very hard
19. Structure: stratified, laminated, fissured, slickensided, lensed, homogeneous
20. Cementation: weak, moderate, strong
21. Local name
22. Geologic interpretation
23. Additional comments: presence of roots or root holes, presence of mica, gypsum, etc., surface coatings on coarse-grained particles, caving or sloughing of auger hole or trench sides, difficulty in augering or excavating, etc.

log forms, summary tables, reports, and the like, that the symbol and name are based on visual-manual procedures.

17. Precision and Bias

17.1 This practice provides qualitative information only, therefore, a precision and bias statement is not applicable.

18. Keywords

18.1 classification; clay; gravel; organic soils; sand; silt; soil classification; soil description; visual classification

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLES OF VISUAL SOIL DESCRIPTIONS

X1.1 The following examples show how the information required in 16.1 can be reported. The information that is included in descriptions should be based on individual circumstances and need.

X1.1.1 *Well-Graded Gravel with Sand (GW)*—About 75 % fine to coarse, hard, subangular gravel; about 25 % fine to coarse, hard, subangular sand; trace of fines; maximum size, 75 mm, brown, dry; no reaction with HCl.

X1.1.2 *Silty Sand with Gravel (SM)*—About 60 % predominantly fine sand; about 25 % silty fines with low plasticity, low dry strength, rapid dilatancy, and low toughness; about 15 % fine, hard, subrounded gravel, a few gravel-size particles fractured with hammer blow; maximum size, 1 in. (25 mm); no reaction with HCl (Note—Field sample size smaller than recommended).

In-Place Conditions—Firm, stratified and contains lenses of silt 1 to 2 in. (25 to 50 mm) thick, moist, brown to gray; in-place density 106 lb/ft^3; in-place moisture 9 %.

X1.1.3 *Organic Soil (OL/OH)*—About 100 % fines with low plasticity, slow dilatancy, low dry strength, and low toughness; wet, dark brown, organic odor; weak reaction with HCl.

X1.1.4 *Silty Sand with Organic Fines (SM)*—About 75 % fine to coarse, hard, subangular reddish sand; about 25 % organic and silty dark brown nonplastic fines with no dry strength and slow dilatancy; wet; maximum size, coarse sand; weak reaction with HCl.

X1.1.5 *Poorly Graded Gravel with Silt, Sand, Cobbles and Boulders (GP-GM)*—About 75 % fine to coarse, hard, subrounded to subangular gravel; about 15 % fine, hard, subrounded to subangular sand; about 10 % silty nonplastic fines; moist, brown; no reaction with HCl; original field sample had about 5 % (by volume) hard, subrounded cobbles and a trace of hard, subrounded boulders, with a maximum dimension of 18 in. (450 mm).

X2. USING THE IDENTIFICATION PROCEDURE AS A DESCRIPTIVE SYSTEM FOR SHALE, CLAYSTONE, SHELLS, SLAG, CRUSHED ROCK, AND THE LIKE

X2.1 The identification procedure may be used as a descriptive system applied to materials that exist in-situ as shale, claystone, sandstone, siltstone, mudstone, etc., but convert to soils after field or laboratory processing (crushing, slaking, and the like).

X2.2 Materials such as shells, crushed rock, slag, and the like, should be identified as such. However, the procedures used in this practice for describing the particle size and plasticity characteristics may be used in the description of the material. If desired, an identification using a group name and symbol according to this practice may be assigned to aid in describing the material.

X2.3 The group symbol(s) and group names should be placed in quotation marks or noted with some type of distinguishing symbol. See examples.

X2.4 Examples of how group names and symbols can be incorporated into a descriptive system for materials that are not naturally occurring soils are as follows:

X2.4.1 *Shale Chunks*—Retrieved as 2 to 4-in. (50 to 100-mm) pieces of shale from power auger hole, dry, brown, no reaction with HCl. After slaking in water for 24 h, material identified as "Sandy Lean Clay (CL)"; about 60 % fines with medium plasticity, high dry strength, no dilatancy, and medium toughness; about 35 % fine to medium, hard sand; about 5 % gravel-size pieces of shale.

X2.4.2 *Crushed Sandstone*—Product of commercial crushing operation; "Poorly Graded Sand with Silt (SP-SM)"; about 90 % fine to medium sand; about 10 % nonplastic fines; dry, reddish-brown.

X2.4.3 *Broken Shells*—About 60 % uniformly graded gravel-size broken shells; about 30 % sand and sand-size shell pieces; about 10 % nonplastic fines; "Poorly Graded Gravel with Silt and Sand (GP-GM)."

X2.4.4 *Crushed Rock*—Processed from gravel and cobbles in Pit No. 7; "Poorly Graded Gravel (GP)"; about 90 % fine, hard, angular gravel-size particles; about 10 % coarse, hard, angular sand-size particles; dry, tan; no reaction with HCl.

X3. SUGGESTED PROCEDURE FOR USING A BORDERLINE SYMBOL FOR SOILS WITH TWO POSSIBLE IDENTIFICATIONS.

X3.1 Since this practice is based on estimates of particle size distribution and plasticity characteristics, it may be difficult to clearly identify the soil as belonging to one category. To indicate that the soil may fall into one of two possible basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example: SC/CL or CL/CH.

X3.1.1 A borderline symbol may be used when the percentage of fines is estimated to be between 45 and 55 %. One symbol should be for a coarse-grained soil with fines and the other for a fine-grained soil. For example: GM/ML or CL/SC.

X3.1.2 A borderline symbol may be used when the percentage of sand and the percentage of gravel are estimated to be about the same. For example: GP/SP, SC/GC, GM/SM. It is practically impossible to have a soil that would have a borderline symbol of GW/SW.

X3.1.3 A borderline symbol may be used when the soil could be either well graded or poorly graded. For example: GW/GP, SW/SP.

X3.1.4 A borderline symbol may be used when the soil could either be a silt or a clay. For example: CL/ML, CH/MH, SC/SM.

X3.1.5 A borderline symbol may be used when a fine-grained soil has properties that indicate that it is at the boundary between a soil of low compressibility and a soil of high compressibility. For example: CL/CH, MH/ML.

X3.2 The order of the borderline symbols should reflect similarity to surrounding or adjacent soils. For example: soils in a borrow area have been identified as CH. One sample is considered to have a borderline symbol of CL and CH. To show similarity, the borderline symbol should be CH/CL.

X3.3 The group name for a soil with a borderline symbol should be the group name for the first symbol, except for:

CL/CH lean to fat clay
ML/CL clayey silt
CL/ML silty clay

X3.4 The use of a borderline symbol should not be used indiscriminately. Every effort shall be made to first place the soil into a single group.

X4. SUGGESTED PROCEDURES FOR ESTIMATING THE PERCENTAGES OF GRAVEL, SAND, AND FINES IN A SOIL SAMPLE

X4.1 *Jar Method*—The relative percentage of coarse- and fine-grained material may be estimated by thoroughly shaking a mixture of soil and water in a test tube or jar, and then allowing the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 s. The relative proportions can be estimated from the relative volume of each size separate. This method should be correlated to particle-size laboratory determinations.

X4.2 *Visual Method*—Mentally visualize the gravel size particles placed in a sack (or other container) or sacks. Then, do the same with the sand size particles and the fines. Then, mentally compare the number of sacks to estimate the percentage of plus No. 4 sieve size and minus No. 4 sieve size present. The percentages of sand and fines in the minus sieve size No. 4 material can then be estimated from the wash test (X4.3).

X4.3 *Wash Test (for relative percentages of sand and fines)*—Select and moisten enough minus No. 4 sieve size material to form a 1-in (25-mm) cube of soil. Cut the cube in half, set one-half to the side, and place the other half in a small dish. Wash and decant the fines out of the material in the dish until the wash water is clear and then compare the two samples and estimate the percentage of sand and fines. Remember that the percentage is based on weight, not volume. However, the volume comparison will provide a reasonable indication of grain size percentages.

X4.3.1 While washing, it may be necessary to break down lumps of fines with the finger to get the correct percentages.

X5. ABBREVIATED SOIL CLASSIFICATION SYMBOLS

X5.1 In some cases, because of lack of space, an abbreviated system may be useful to indicate the soil classification symbol and name. Examples of such cases would be graphical logs, databases, tables, etc.

X5.2 This abbreviated system is not a substitute for the full name and descriptive information but can be used in supplementary presentations when the complete description is referenced.

X5.3 The abbreviated system should consist of the soil classification symbol based on this standard with appropriate lower case letter prefixes and suffixes as:

Prefix:	Suffix:
s = sandy	s = with sand
g = gravelly	g = with gravel
	c = with cobbles
	b = with boulders

X5.4 The soil classification symbol is to be enclosed in parenthesis. Some examples would be:

Group Symbol and Full Name	Abbreviated
CL, Sandy lean clay	s(CL)
SP-SM, Poorly graded sand with silt and gravel	(SP-SM)g
GP, poorly graded gravel with sand, cobbles, and boulders	(GP)scb
ML, gravelly silt with sand and cobbles	g(ML)sc

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D2488 – 09a) that may impact the use of this standard. (July 15, 2017)

(1) Revised various sections to clarify wording.
(2) Added D4427 and E11 to Section 2 - Reference Documents.
(3) Added definitions for fine grained and coarse grained soils to Section 3.
(4) Replaced flow charts 1a, 1b and 2 with clearer versions.
(5) Corrected units in Table 1.
(6) Updated photos in Figure 3.
(7) Expanded Section 10 regarding sample order.
(8) Revised Section 16 - Report to conform to D18 SPM.

Designation: D6032/D6032M − 17

Standard Test Method for Determining Rock Quality Designation (RQD) of Rock Core[1]

1. Scope*

1.1 This test method covers the determination of the rock quality designation (RQD) as a standard parameter in drill core logging of a core sample in addition to the commonly obtained core recovery value (Practice D2113); however there may be some variations between different disciplines, such as mining and civil projects.

1.2 This standard does not cover any RQD determinations made by other borehole methods (such as acoustic or optical televiewer) and which may not give the same data or results as on the actual core sample(s).

1.3 There are many drilling and lithologic variations that could affect the RQD results. This standard provides examples of many common and some unusual situations that the user of this standard needs to understand to use this standard and cannot expect it to be all inclusive for all drilling and logging scenarios. The intent is to provide a baseline of examples for the user to take ownership and watch for similar, additional or unique geological and procedural issues in their specific drilling programs.

1.4 This standard uses the original calculation methods by D.U. Deere to determine an RQD value and does not cover other calculation or analysis methods; such as Monte Carlo.

1.5 The RQD in this test method only denotes the percentage of intact and sound rock in a core interval, defined by the test program, and only of the rock mass in the direction of the drill hole axis, at a specific location. A core interval is typically a core run but can be a lithological unit or any other interval of core sample relevant to the project.

1.6 RQD was originally introduced for use with conventional drilling of N-size core with diameter of 54.7 mm (2.155 in.). However, this test method covers all types of core barrels and core sizes from BQ to PQ, which are normally acceptable for measuring determining RQD as long as proper drilling techniques are used that do not cause excess core breakage or poor recovery, or both. See 6.3 for more information on this issue.

1.7 Only the RQD classification which correlates with the common tunneling classification that was presented by Deere[2,3] is covered in this test method. Other classification systems are not covered specifically but are mentioned in general and if used shall not be regarded as nonconformance with this standard.

1.8 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.8.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.9 The values stated in either SI units or inch-pound units [rational values are given in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this standard.

1.10 *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.*

1.11 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

---

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved March 1, 2017. Published April 2017. Originally approved in 1996. Last previous edition approved in 2008 as D6032 – 08. DOI: 10.1520/D6032_D6032M-17.

[2] Deere, D. U., and Deere, D. W., The Rock Quality Designation (RQD) After Twenty Years, *Rock Classification Systems for Engineering Purposes, ASTM STP 984*, 1988, pp. 91–101.

[3] Deere, D. U., and Deere, D. W., Rock Quality Designation (RQD) Index in Practice, *Contract Report G1–89–1*, Department of the Army Corps of Engineers, 1989.

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

Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standards:*[4]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D5079 Practices for Preserving and Transporting Rock Core Samples (Withdrawn 2017)[5]

D5878 Guides for Using Rock-Mass Classification Systems for Engineering Purposes

D6026 Practice for Using Significant Digits in Geotechnical Data

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *artificial core run, n*—run lengths, or intervals, created when logging the core to identify different zones or patterns of RQD in the rock mass.

3.2.2 *centerline method, n*—length of core sample measured along the centerline (core axis); see Appendix X1.

3.2.3 *core discing, n—in rock mechanics*, a phenomenon in which the drilled core breaks into disks with uniform spacing and shape due to the transient stress changes, and stress release during drilling.

3.2.4 *core recovery, n—in rock drilling*, the ratio of length of core sample recovered, both weathered and unweathered, to the length drilled, and expressed as a percent.

3.2.4.1 *Discussion*—Some literature is using a term called "total core recovery" to replace this definition. The added term "total" is an attempt to promote other types of core recovery definitions, one of which is "solid core recovery" and which is discussed in this standard and shown in the appendix to be technically flawed and should be discouraged. Therefore, it was decided to stay with a definition that is already recognized and has been used for many years in the drilling industry.

3.2.5 *core run, n—in rock drilling*, in the most basic usage, the length of the interval measured from the depth at which drilling to obtain a core sample was started to the depth at which drilling stopped and the core barrel was retrieved to recover the cored sample.

3.2.5.1 *Discussion*—If required, the core run used to calculate the RQD can also be defined to cover a specific interval or lithology in the core samples. The length of the core run may not be equal to the length of the core sample retrieved if there is any core loss or void(s) in the coring interval or if a stub of core is left at the bottom of the drill hole. Any core sample or stub left at the bottom of the core run must be accounted for in a consistent manner in the drill logs and RQD calculations.

3.2.6 *discontinuity, n—in geomechanics*, a general term denoting any separation in a rock mass having zero or low tensile strength and is the collective term for most types of joints, fractures, weak bedding planes, weak schistocity planes, weakness zones, and shears.

3.2.7 *drill break, n—in drilling*, any mechanical or man-made break in the core that was not naturally occurring.

3.2.8 *fully circular method, n—in geomechanics*, measurement of the core length only where the core has a full circular cross section along the core axis. See Appendix X1.

3.2.9 *intact core, n—in geomechanics*, any segment of core between two open/unbonded, natural or mechanical discontinuities.

3.2.10 *rock quality designation (RQD), n—in geomechanics*, a modified core recovery in which the ratio of length of core recovered to the total length drilled is modified such that only the length of the pieces of sound core that are equal to or greater than 100 mm [4 in.] in length, as measured along the core axis, are counted towards the length of core recovered, and this ratio is expressed as a percent.

3.2.11 *sound core, n—in rock drilling*, any core that is unweathered to moderately weathered and has sufficient strength to resist hand breakage.

3.2.11.1 *Discussion*—Most engineers and geologist understand what unweathered means but there is no one standard or definitions for "moderately weathered" or "resist hand breakage" and varies in the literature. However, most drillers and persons logging core usually have a good idea what either one means and would not be abused or would follow standard operating procedures used by their company. In general, hand breakage means something that cannot be indented with a finger nail and crumbles under firm blows with sharp end of a geological pick. Moderately weathered can vary in the literature. ISRM definitions for weathering were used for this standard.

3.2.12 *moderately weathered, n—in geology*, less than half of the rock material is decomposed and/or disintegrated to a soil; fresh or discolored rock is present either as a continuous framework or as core stones.

3.2.13 *tip to tip method, n—in geomechanics*, measurement of the core length as the distance between the highest point of the piece of the core along the borehole. See Appendix.

3.2.13.1 *Discussion*—This definition is only provide because it is used in the standard for discussions on why this measurement method is not used or approved by this standard and does not infer that the method is valid or applicable for RQD measurements

---

[4] 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.

[5] The last approved version of this historical standard is referenced on www.astm.org.

4. Summary of Test Method

4.1 The RQD denotes the percentage of intact and sound rock retrieved from a borehole orientated in any direction. All pieces of intact and sound rock core equal to or greater than 100 mm [4 in.] long are identified and recorded. The pieces are measured along the core axis (centerline method).

NOTE 1—The original paper by Deere states "over four inches" and many references vary between "over 4 inches" to "equal to or greater than 4 inches". This issue was posed to the D18.12 membership and the consensus was that the way it is typically been used in the field, equal to or greater than 100-mm [4 in.] is how it should be worded in this standard. References like Wikipedia do not always have the best information either and should not be assumed to be correct much less a consensus on this issue.

4.2 Pieces of core that are moderately or intensely weathered, contain numerous pores, or are friable, or any combination thereof, should not be included in the summation of pieces for the determination of the RQD. Where the core is known or believed to have been broken by handling or by the drilling process, the broken pieces (including core discing) are fitted together and counted as one piece and the pieces are fitted together, marked as a mechanical break (both on the cores and on the logs) and counted as one piece.

4.3 All the sections of core that meet the greater than or equal to 100-mm [4 inches] and soundness criteria are summed and then divided by the total length of the core run or interval of interest (see 4.3.1), as shown in Fig. 1, to give the value of RQD as a percent. Rock mechanics judgment may be necessary to determine if a piece of core qualifies as being intact and sound.

4.3.1 If required, the RQD may be determined for intervals other than a given core run. For example, determining the RQD for a given rock unit, rock type, a running value, or weighted average.

4.4 The RQD value is then used for classification of the rock quality based upon a rating system, such as the one in Deere's original paper and shown in Fig. 1 and is usually the default system to use. Some other classification system might be used, if required, at the drill site or later on in the data analysis process.

5. Significance and Use

5.1 The RQD was first introduced in the mid 1960s to provide a simple and inexpensive general indication of rock mass quality to predict tunneling conditions and support requirements. The recording of RQD has since become virtually standard practice in drill core logging for a wide variety of geotechnical explorations.

5.2 The use of RQD values has been expanded to provide a basis for making preliminary design and constructability decisions involving excavation for foundations of structures, or tunnels, open pits, and many other applications. The RQD values also can serve to identify potential problems related to bearing capacity, settlement, erosion, or sliding in rock foundations. The RQD can provide an indication of rock quality in quarries for issues involving concrete aggregate, rockfill, or large riprap.

5.3 The RQD has been widely used as a warning indicator of low-quality rock zones that may need greater scrutiny or require additional borings or other investigational work. This includes rocks with certain time-dependent qualities that by determining the RQD again after 24 h, under well-controlled conditions, can assist in determining durability.

5.4 The RQD is a basic component of many rock mass classification systems, such as rock mass rating (RMR) and Q-System, for engineering purposes. See D5878 and [2,3].

5.5 When needed, drill holes in different directions can be used to determine the RQD in three dimensions.

5.6 The concept of RQD can be used on any rock outcrop or excavation surface using line surveys as well. However, this topic is not covered by this standard.

NOTE 2—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 D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Interferences

6.1 Used alone, RQD is not sufficient to provide an adequate description of rock mass quality. The RQD does not account for discontinuity orientation, tightness, continuity, and gouge material. The RQD must be used in combination with other geological and geotechnical input.

6.2 The RQD is sensitive to the orientation of joint sets or other open or weak discontinuities with respect to the orientation of the core axis.[6] For example, a joint set parallel to the core axis may not, if at all, intersect the core sample, unless the drill hole axis happens to run along the joint plane. A joint set perpendicular to the core axis will intersect the core axis at intervals equal to the joint spacing. For intermediate orientations, the spacing of discontinuity intersections with the core will be a cosine function of angle between joints and the core axis.

6.3 The N-size are the optimal core barrel size for determining RQD. The RQD is also useful for larger core diameters provided the core diameter is clearly stated. The RQD calculated for core smaller than BQ may not be representative of the true quality of the rock mass. Larger sizes are preferred; and the smaller BQ and BWX sizes should be discouraged and; when used, should be identified with a disclaimer.

6.4 The RQD values obtained can be sensitive to the type of drill equipment and techniques that are used. Double or triple, split tube, core barrels are preferred over single tube barrels. Use of single tube core barrels will have additional issues to consider when making RQD determinations. Therefore, it is important to note what type of drill equipment and techniques were used as well as the personnel involved. Also, if conventional drilling is used, rather than, wire line drilling, then the

---

[6] Arild Palmstrom, Ph.D., Norconsult as, Norway, Measurements of and Correlations between Block Size and Rock Quality Designation (RQD), Published in *Tunnels and Underground Space Technology*, 20 (2005), 362-377

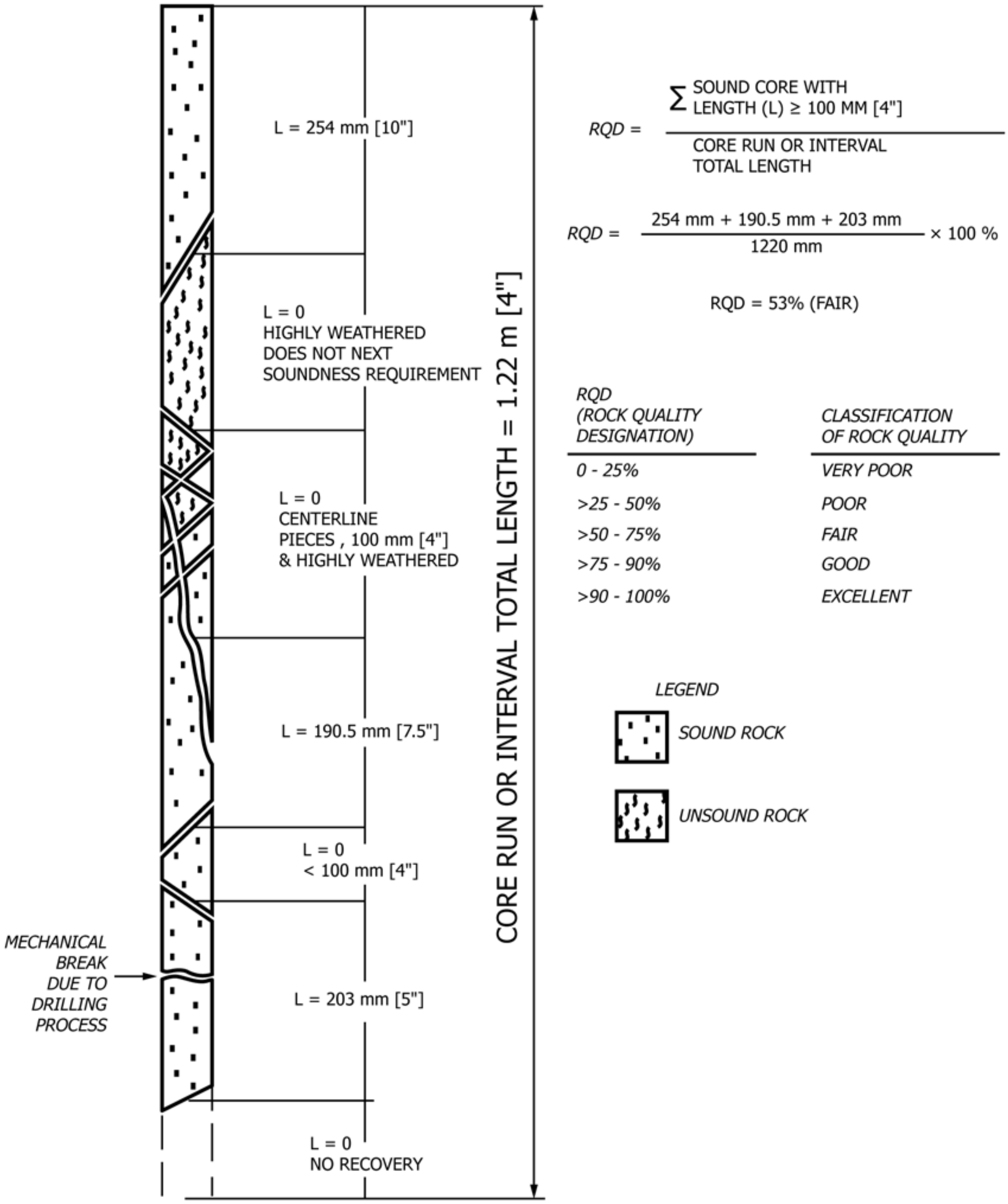


FIG. 1 Example of How RQD Data is Collected for a Core Run or Interval, and Calculated, Using the Centerline Method, and Then Classified. The rock quality classification shown is what was originally proposed by Deere[2,3]. Other rock quality classifications may be used.

potential for material to cave in the hole is greater. This can alter the RQD results and must be anticipated and handled appropriately.

6.5 Measurement of the length of the core pieces by any other method than the centerline method can produce erroneous results (see Appendix X1). Training and of logging personnel is therefore critical and be given consistent advice or training. This means that training and feedback must be given early during the drilling program when the core is still available or with the core photos.

6.6 The RQD index is sensitive to the length of the core run. For example, a 300-mm [11.8-in.] wide, highly fractured zone within a massive rock would result in RQD values of 90 %, 80 %, and 40 %. for respective core run lengths of 3 m [12.9 ft], 1.5 m [4.9 ft], and 0.5 m [1.6 ft]. Thus, the shorter the run length, the greater the sensitivity of the RQD and the lower its value (becoming equal to zero for a 300 mm [11.8 in.] core run encompassing the fractured zone).

6.7 Drill core samples can disc in certain stress conditions. Therefore, the RQD values can be effected by the stresses the drill hole encounter and the drill bit might generate and may need to be accounted for in the calculations as well as the report. These may be natural in situ stresses, manmade stresses due to surface or underground excavations, and/or those by the drilling equipment. Where discing occurs in diamond drill core, there should be no RQD penalty. Discing is a stress phenomenon unrelated to in situ rock.[7]

7. Procedure

7.1 Drilling of the rock core should be done in accordance with Practice D2113. It is important that proper drilling techniques and equipment are used to minimize core breakage or poor core recovery, or both.

7.2 There are several ways to define a core run for calculating RQD. Three of these ways are: (*1*) a core run as defined in this standard; (*2*) a change in formation or rock type could constitute an end of a core run; and (*3*) a core run can be a selected zone or interval of concern. In establishing a core run it is important to be consistent throughout a drill hole and to document how the core run was defined.

7.3 Retrieval, preservation, transportation, storage, and cataloging of the rock core should be done in accordance with Practices D5079. The RQD should be logged and the corresponding intervals photographed on site when the core is retrieved. This is because some rocks can disintegrate, due to poor curatorial handling, slaking, desiccation, stress relief, cracking or swelling, with time. For those rocks that disintegrate it is recommended that the RQD be measured again after 24 h, or as soon as possible thereafter, to assist in determining durability if it could be important to the intended use of the data.

7.4 Close visual examination of core pieces is required for assessing the type of open discontinuity (that is, natural, discing or mechanical break) and need to be properly recorded and marked accordingly.

7.5 Only those pieces of rock formed by natural breaks (that is, joints, shear zones, bedding planes, or cleavage planes that result in surfaces of separation) shall be considered for RQD purposes. Where discing occurs in diamond drill core, there should be no RQD penalty. Discing is a stress phenomenon unrelated to rock fabric. The core pieces on either side of core breaks caused by the drilling process, including where the core catcher may have broken the core, shall be fitted together and counted as one piece. Drilling breaks are usually evident by rough fresh surfaces. In some cases it may be difficult to differentiate between natural and drilling breaks. When in doubt, count as a natural break.

NOTE 3—When there is uncertainty about a break, the reasoning that it should be considered as natural is in order to be conservative in the calculation of RQD.

7.6 If there is not 100 % core recovery for a drill run, the length of any core left in the borehole should be taken into account by adding it to the run in which it was cored rather than the run in which it was retrieved. Thus, if the core recovery is not 100 %, the length of core in adjacent runs should be checked before the difference is attributed to a cavity, core loss or core gain.

NOTE 4—Drill parameter recorders can be a useful tool to use when drilling core to determine the location and reason for any gaps in the core run.

7.7 Record the top and bottom depths of each core run or interval to the nearest 1 cm [0.05 ft or 0.5 in.].

7.8 Measure all core piece lengths that are intact, sound and greater than or equal to 100 mm [4 in.] to the nearest 1 cm [0.05 ft or 0.5 in.] and record the length as well as the depths on a RQD data sheet (Fig. 2). Measure such pieces along the core axis (centerline method) as illustrated in Fig. 1 and Fig. X1.1. No other measurement method, such as tip to tip or fully circular (see Appendix X1), is allowed.

7.8.1 Pieces of core that are from highly weathered to residual soil, contain numerous pores, or are friable, or combination thereof, should not be included in the summation of pieces greater than or equal to 100 mm [4 in.] for the determination of the RQD. However, moderately weathered core that resists hand breakage should be included but an asterisk is used with the reported RQD value (RQD* =).

NOTE 5—The asterisk is what is in all of the references by Deere[2].

7.8.2 If any rejected piece of core is still included as part of the total length of core run or interval it should be noted in the report.

NOTE 6—Centerline measurements ensure that the RQD value resulting from the measurements is not dependent on the core diameter (See Appendix). Centerline measurements also avoid unduly penalizing resulting RQD values for cases where discontinuities parallel the core axis. Any other method used for accounting for fractures parallel to the core axis, while not advocated by this test method and in the literature, must be clearly stated.[2,3].

7.9 After each drill run reconcile the quality of data for the drill run. Determine if the sum of the individual core lengths greater than or equal to 100 mm plus the sum of material (which is <100 mm) plus the core loss (no recovery) does or doesn't equal the drilled run length. If not equal it should be determined if it is due to poor measurement technique or due to not accounting for core left down hole and the data adjusted accordingly. If needed, RQD determination may need to be assessed by looking at adjoining runs (or sometimes beyond adjoining runs) for core left down hole (and that is not washed away).

7.10 Sketch and/or photograph core features such as natural breaks, drilling breaks, lost core, voids, highly weathered pieces, and so forth (see Fig. 1). If possible to identify, any voids, cavities or core loss must be differentiated as such.

7.11 Include remarks concerning judgment decisions such as whether a break in a core is a natural break or a drilling break or why a piece of core longer than 100 mm [4 in.] was not considered to be intact or sound.

7.12 Record the sum of intact and sound core pieces longer than 100 mm [4 in.] long, and calculate the RQD value for the core run or interval being evaluated as shown in Section 8.

---

[7] *Hard Rock Miner's Handbook, Edition 5*, J.N. de la Vergne, Susan L. Andersen, Editor, 2008, Stantec Consulting Ltd., 10160 – 112 Street, Edmonton, Alberta, Canada.

RQD DATA SHEET	
Project Title:	
Project and drill hole Location:	
Boring Number:	Drill fluid used:
Core Box ID:	Location of drill logs:
Core Diameter, mm (in.)	Date/time sample collected:
Borehole orientation:	Logger(s):
Core barrel used:	Date/time Logged:
Driller(s):	Air Temperature, °C (°F):
Start of core run m (ft):	Checker(s):
End of core run, m (ft):	Date Checked:
Length of core run (interval):	Peer Review/Date
Curatorial History and other information: (Where logged, is this a secondary logging, drill fluid used, etc.)	

Segment	Drill Hole Depth, m (ft)	Length of core segment, mm (inch or ft)	Sound core (yes/no)	> or = 100 mm [4 inch] (yes/no)	Remarks, rock descriptions, core losses, other data and sketches or photographic information				
Start									
	Σ length of the sound core segments greater than or equal to 100 mm [4-in.]								
RQD = ...									
	Total length of core run or interval, mm (in.)								
Σ segments		to		of sound core greater than or equal to 100 mm [4-in.]:					
RQD (%) =		Rock Quality Classification[1]:							
•To do RQD calculations for other core segments repeat using above formula and those segments of data.									
			Page		of				
Footnotes	1. Rock Classifications used other than shown in ASTM D6032 should be noted in report and forms.								

FIG. 2 Example RQD Data Sheet

7.13 Indicate the rock quality classification for the core run or interval using the table in Fig. 1 if no other classification system is used.

8. Calculation or Interpretation of Results

8.1 *Calculation:*

8.1.1 Calculate as a percentage, the RQD of a core run or other artificial core run or interval as follows:

$$\text{RQD} = \frac{\Sigma \ \text{length of the sound core segments} > \text{or} = [4 \qquad \text{in.}] \times 100\%}{\text{Total length of core run or interval, mm [in.]}} \tag{1}$$

8.1.2 In accordance with Practice D6026, record the result to the nearest whole percent.

8.2 *Interpretation:*

8.2.1 Determine the rock quality classification for the actual or artificial core run or interval using the table in Fig. 1; which came from the common tunneling classifications may be used if applicable[2,7].

NOTE 7—Even though the table in Fig. 1 comes from a tunneling or underground perspective, and maybe outdated it is still a classification system that is well known and establish and worth reporting. The reason is that in lieu of any additional data it at least gives a rough idea of a starting point of what is there and words that the non-technical person can understand versus just the RQD numbers. Users should realize that other uses for RQD such as for foundation bearing and settlement, slope behavior or excavation evaluation may have different subjective descriptors for particular values of RQD and they should be used in any final reports.

8.2.2 Other rock quality classifications may be used that are more fitting for the project purpose but must be clearly noted in the report and any tables.

9. Report: Test Data Sheet(s)/Form(s)

9.1 A typical report may include the following:

NOTE 8—This section does not purport to list or infer any absolutes for all the information needed for a report. This will vary depending on the project requirements and which should be carefully communicated to all parties prior to the start of the drilling and core logging program. The list shows what is commonly good practice and was based upon case histories where many times it was found to be prudent to have more information rather than to little. It is up to the person recording the data to have everything needed to do the evaluation required.

9.1.1 Source of sample including project name, location, and, if known, date sample was drilled, curatorial history such as storage, shipping, and handling environment. The location may be specified in terms of borehole number and depth of core samples from the collar of the hole.

9.1.2 Description of drilling equipment, method, personnel, and hole orientation.

9.1.3 Physical description of each core run or interval including diameter, rock type and location and orientation of discontinuities, such as, apparent weakness planes, bedding planes, schistosity, and large inclusions or inhomogeneities, if any.

9.1.4 Date(s) of RQD data collection and sketches and/or photographs of core run(s) or interval(s).

9.1.5 General indication of any curatorial issues, drilling conditions, observations, and assumptions relevant to the accuracy of the RQD values or calculations.

9.1.6 A table and/or graphic depiction of RQD values and/or copies of any RQD data forms or sketches.

9.1.7 The rock quality classification for the core run or interval and the source of the classification.

10. Precision and Bias

10.1 *Precision*[8]—A round-robin study of the RQD index of cores of four selected types of sedimentary rock (anhydrite/calcite, calcareous shale, limestone, and anhydrite) with four replications per rock type was conducted in accordance with Practice E691 by eight experienced participants.[9] The repeatability and reproducibility statistics reported in Table 1 refer to within-participant and between-participant precision, respectively. The probability is approximately 95 % that two results obtained by the same participant on the same material will not differ by more than the repeatability limit *r*. Likewise, the probability is approximately 95 % that two results obtained by different participants on the same material will not differ by more than the reproducibility limit *R*. The precision statistics are calculated from the following equation:

$$r = 2\left(\sqrt{2}\right)s_r \tag{2}$$

where s_r = repeatability standard deviation, and

$$R = 2\left(\sqrt{2}\right)s_R \tag{3}$$

where s_R = reproducibility standard deviation.

NOTE 9—Some combinations of the means and *r* and *K* can result in RQD limits that exceed 100 % because the RQD values have been assumed to be normally distributed which may not reflect the actual underlying distribution of the RQD values.

10.2 *Bias*—There is no accepted reference value for this test method; therefore, bias cannot be determined.

11. Keywords

11.1 classification; index; logging; quality; rock; rock core

TABLE 1 RQD Index of Cores of Sedimentary Rock

Material (Rock Type)	Mean RQD, $\bar{x}$, %	Repeatability, *r*, % [A]	Reproducibility, *R*, % [A]
Anhydrite/calcite	86	28	28
Calcareous shale	60	32	40
Limestone	92	14	14
Anhydrite	86	20	20

[A] The numbers in the *r* and *R* columns are not to be taken as percentages of the means, but are applied as plus or minus terms to the respective means.

---

[8] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:ISRD18-1015.

[9] Pincus, H. J., and Clift, S. J., *Interlaboratory Testing Program for Rock Properties: Repeatability and Reproducibility of RQD Values for Selected Sedimentary Rocks*, PCN: 33-000011-38, ASTM Institute of Standards Research, 1994.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLES OF DIFFERENT CORE MEASUREMENT METHODS

Fig. X1.1

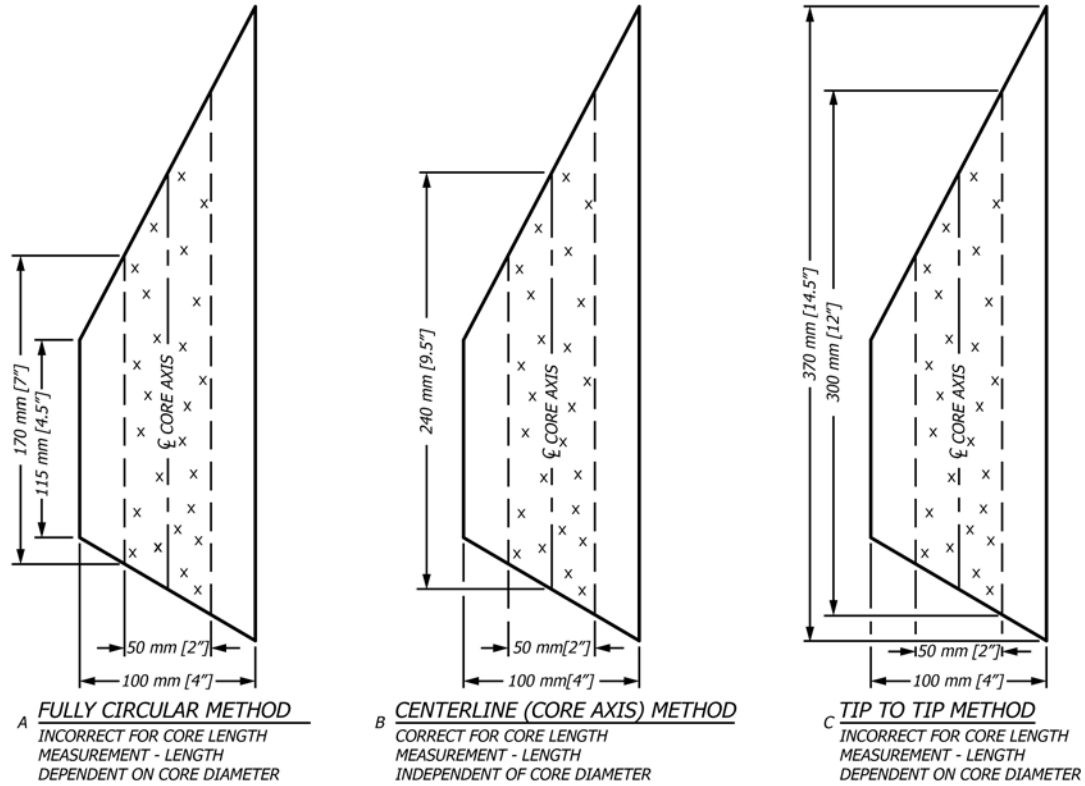


FIG. X1.1 Examples of Different Core Measurement Methods on 2-in. and 4-in. Diameter Cores and Why Only the Centerline Method is Acceptable for This Test Method

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D6032 – 08) that may impact the use of this standard. (March 1, 2017)

(1) Expanded Scope (Section 1) with 1.2 through 1.7 and added footnote references 2 and 3.
(2) Section 1: Updated units caveat and added SI units.
(3) Section 1: Added International caveat.
(4) Section 2: Added ASTM D5878.
(5) Section 3: Updated format for terminology and added 8 definitions specific to this standard.
(6) Section 4: Added a note (Note 1).
(7) Section 4: Original had only one section that was edited and 4.1, 4.2, 4.3.1, and 4.4 were added.
(8) Section 5 was significantly edited and updated.
(9) Fig. 1 was significantly edited and several errors corrected.
(10) An Interference section (Section 6) was added. Some material from other sections was moved that was better suited to be in this section as well.
(11) Footnotes 6 and 7 were added.
(12) Major re-write and expansion of Section 7.
(13) Three notes were added to Procedures section (Section 7).
(14) Expanded the title for the Calculations section (Section 8).
(15) Calculation section: Added more steps, edited formula and added rationalized units.
(16) Added Note 7 to Calculations section (Section 8).
(17) Report section title was edited to conform with blue book format.

(18) Added Note 8 to Report section (Section 9).

(19) Added Appendix X1 with figure showing the different core measurement methods.

(20) Table 1: Format of table was fixed.

ATTACHMENT 2 - PDI HB-2 SEISMIC EVALUATION AND DATA COLLECTION FOR CONTAINMENT WALL DESIGN

Project	Nuclear Metal Superfund Site, Concord, MA	Date	4 September 2020
Client	Remedial Design Work Plan	Page	1 of 4

1 INTRODUCTION

This Pre-Design Investigation (PDI) activity for the holding basin (HB) containment wall involves the seismic evaluation necessary to complete the Holding Basin containment wall design. The analysis and results from this PDI will provide data to develop the design criteria that the wall will need to meet.

The seismic evaluation will involve cross-hole geophysics to complete field shear wave measurements to characterize the soil and bedrock to support the data requirements needed for a site-specific ground response analysis. Bedrock ground motions for a 2,475-year return period earthquake will be determined using U.S. Geological Survey seismic hazard deaggregations. The bedrock ground motion selection will be completed by James Kaklamanos, of Kaklamanos Consulting, LLC. The bedrock ground motions will then be used by Haley & Aldrich, Inc. to complete a kinematic analysis to determine the seismically-induced bending moments the wall will need to resist under the design earthquake in accordance with the applicable design criteria referenced above. In addition, information obtained during this effort will be used to evaluate liquefaction potential of soils at the HB and perform pseudo-static slope stability analyses for the slope adjacent to the HB extending downward to bog.

2 OBJECTIVES

The objectives for performing the work described in this PDI are as follows:

- Drill six bedrock borings for crosshole geophysics. These bedrock boreholes will be drilled 10 to 15 ft. apart in a straight line for the proposed crosshole testing. The result will be two sets of three-hole arrays for cross-hole testing.
- Complete cross-hole seismic testing in substantial accordance with the ASTM D4428/D4428M-14, "Standard Test Methods for Crosshole Seismic Testing," attached in Section 2.
- Use information provided by the U.S. Geological Survey Earthquake Hazards Program to determine the design earthquake magnitude and develop site-specific bedrock ground motions under the design earthquake.
- Perform a kinematic analysis to determine seismically-induced wall bending moments.
- Evaluate liquefaction potential of soils at the HB.
- Perform pseudo-static slope stability analyses for the slope adjacent to the HB.

The results of this PDI will be used in developing the design criteria for the containment wall.

3 SCOPE OF WORK

The scope of work will include the drilling of the two sets of three-borehole arrays for the crosshole seismic testing in accordance with specifications of the ASTM D4428M-14 document. The boreholes for the crosshole testing shall be spaced 10 to 15 ft. apart, and each three-hole array will be installed in a straight line. Once the boreholes are completed, Geophysical Applications, Inc. will conduct the field shear wave measurements. The data collected will include the shear and compressional wave velocity information as a function of depth for the two crosshole arrays. The data will then be used to complete the seismic analyses including a kinematic analysis of the wall.

4 PROCEDURES

4.1 <u>Crosshole Seismic Testing and Analysis</u>

The procedures of ASTM D4428 require cased boreholes, and the casing is specified to be either PVC or aluminum. The boreholes will be completed by installing 3-inch ID PVC Schedule 40 casing, in each of the boreholes of each crosshole array. The cross-hole borehole locations are shown on Figure 1 and are spaced 10 to 15 ft. apart. Prior to conducting the cross-hole testing, a deviation survey will be completed.

The completed boreholes should meet the following requirements:

- The cased boreholes must be sufficiently straight to allow free passage of a cylinder 2.5 inches in diameter by 52 inches long. (This requirement ensures that the downhole source will pass freely through the casing.)
- The casings must be bottom capped and grouted for the full depth of the boreholes in accordance with ASTM D4428. Rigid grout will be utilized within bedrock, and non-rigid grout will be used within the overburden section of the boreholes.
- Prior to the testing, the boreholes should be filled with water.

Crosshole seismic testing will be performed to measure compressional (P) and shear-wave (S) velocities in overburden and bedrock, near the proposed containment wall that will be constructed and keyed into glacial till or bedrock. The crosshole seismic survey will be conducted in conformance with ASTM standard D4428-14, with some minor modifications as described below. In addition, full-waveform sonic logging of the bedrock intervals will be completed.

The equipment utilized will include Geostuff model BHG-2 and BHG-3 three-component geophones, mechanically clamped into each borehole by an expandable metal arm. The three geophone elements in each clamped geophone assembly are oriented in three orthogonal directions (e.g. X, Y and Z axes).

Seismic energy will be generated by a pneumatically-clamped reversible hammer. The hammer includes a packer assembly that expands to fit snugly inside the borehole, and a sliding hammer that can impact upon the packer via either upward or downward blows. This allows reversing the polarity of S-waves and facilitates identification of the S-wave arrival times. An accelerometer affixed to the packer assembly triggers the engineering seismograph (ABEM Terraloc Mark 6) to begin recording.

Crosshole seismic data will be recorded at 5-foot depth (or elevation) increments, per the ASTM standard. Typically, the data collection begins at the deepest test location, and the geophone/source assemblies are raised by 5-foot intervals for each subsequent test. Data reduction will be accomplished in a manner consistent with the ASTM standard, in Excel spreadsheets that calculate both the raypath distances between adjacent boreholes at each test depth (using the verticality observations described below), and P/S-wave velocities (by dividing the raypath distances by the measured seismic-arrival times). Seismic arrival-time measurements will be obtained either directly from the ABEM seismograph (using its built-in software), or Rimrock Geophysics' SIPT seismic-processing software.

Verticality of each borehole will be evaluated prior to crosshole-seismic testing. The boreholes should be arranged in a straight line, but the verticality of each borehole must also be determined so that the actual raypath distance between each borehole (at each test depth) is known. Typically, boreholes deviate somewhat from vertical, and that deviation can result in significant lengthening or shortening of the inter-borehole separation distances, versus the 10- or 15-foot spacings at the ground surface.

The verticality measurements will be completed with one of the televiewer logging probes that will also be utilized during the bedrock-borehole logging detailed in PDI HB-1 (ALT model ABI40 or OBI40). Those probes contain triaxial magnetometers and triaxial accelerometers, to track a borehole's deviation from vertical and magnetic north. The televiewer logs will be recorded at 0.015-foot depth increments, throughout the accessible depth range of each borehole.

Full-waveform sonic (FWS) velocity logging will also be performed at each borehole in each of the three-hole arrays, prior to the crosshole seismic measurements. A Mount Sopris model 2SAA-1000 full-waveform sonic probe will be used to provide these data. This probe includes a single transmitter, and two receivers. The two receivers allow measurement of P and S-wave interval velocities (i.e. between the two receivers). A three-foot long rubber acoustic-isolation section between the transmitter and receiver portions of the probe assures that seismic velocities will be measured via the formation around the borehole, and not simply through the probe body itself.

FWS data will be recorded at 0.3281-foot (0.1-meter) depth intervals, with a logging speed of 8 feet per minute. The transmitter will likely be set to produce a 20 kilohertz (kHz) output signal, to optimize velocity measurements in the bedrock portion of each borehole. Fixed gain control may be utilized during the downward run, and automatic gain control (AGC) will likely be utilized during the upward run. Functional operation of the FWS transmitter will be checked prior to each logging run (it will produce an audible clicking sound when the probe is aboveground). Post-survey data reduction (to calculated P- and S-wave velocities versus logged depth) will be performed with a full-waveform sonic-velocity module in ALT's WellCAD software. The resulting sonic-velocity data can be presented in WellCAD log plots, or tabulated in Excel spreadsheets.

4.2 Perform Seismic Analysis, Determine Design Loads for Containment Wall, and Evaluate Stability during Design Earthquake

Once the geophysics field work is completed, the seismic analysis will be conducted accordingly. The seismic analysis includes selection of input (bedrock) ground motions. The first step in selecting input ground motions is to develop the target response spectrum in accordance with relevant Massachusetts State Building Code (Ninth Edition) and the NRC Regulatory Guide 1.208, Appendix D. Considering the code and the NRC regulatory guide, the ASCE-7 design standard will be used to design the containment wall. The mapped spectral acceleration parameters will be used for determining the bedrock ground motion. The mapped spectral acceleration parameters are based upon a 2% probability of exceedance in 50 years [2475-yr return period], and then converted to a risk-targeted ground motion representing a 1% collapse risk in 50 years.

Using the ground motion parameters of the bedrock and the shear wave measurements from the cross-hole geophysics, a kinematic analysis of the proposed containment wall will be completed. The goal of the kinematic analysis is to determine the seismically-induced loads that the wall will need to withstand. It is anticipated that steel reinforcing may be needed to prevent cracking of the containment wall during the design seismic event. In addition, the seismic analyses will include the following evaluations: liquefaction potential, stability of the adjacent slope extending downward toward the bog, indication of bedrock faults based on observations made at the explorations performed during this PDI and PDI HB-1.

5 REPORTING

The status of this PDI, and results of the analyses will be provided to EPA during routine project meetings and status reports. The design criteria of the containment wall will be presented in the PDI Evaluation Report. Results and the outcome of the PDI will be incorporated into the 30% RD report.

ATTACHMENTS
Section 2 – ASTM Standards

Section 2
PDI HB-2 Standards

Designation: D4428/D4428M – 14

Standard Test Methods for Crosshole Seismic Testing[1]

This standard is issued under the fixed designation D4428/D4428M; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 These test methods are limited to the determination of the velocity of two types of horizontally travelling seismic waves in soil materials; primary compression (*P-wave*) and secondary shear (*S-wave*) waves. The standard assumes that the method used to analyze the data obtained is based on first arrival times or interval arrival times over a measured distance.

1.2 Acceptable interpretation procedures and equipment, such as seismic sources, receivers, and recording systems are discussed. Other items addressed include borehole spacing, drilling, casing, grouting, deviation surveys, and actual test procedures.

1.3 These test methods are primarily concerned with the actual test procedure, data interpretation, and specifications for equipment which will yield uniform test results.

1.4 All recorded and calculated values shall conform to the guide for significant digits and rounding established in Practice D6026.

1.4.1 The procedures used to specify how data are collected/recorded and calculated in these test methods are regarded as the industry standard. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives. Measurements made to more significant digits or better sensitivity than specified in these test methods shall not be regarded a nonconformance with this standard.

1.5 *Units*—The values stated in either SI units or inch-pound units [presented in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this test method.

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.*

2. Referenced Documents

2.1 *ASTM Standards:*

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *seismic wave train*—the recorded motion of a seismic disturbance with time.

4. Summary of Test Method

4.1 The Crosshole Seismic Test makes direct measurements of P-wave velocities, or S-wave velocities, in boreholes advanced primarily through soil. At selected depths down the borehole, a borehole seismic source is used to generate a seismic wave train. Downhole receivers are used to detect the arrival of the seismic wave train in offset borings at a recommended spacing of 3 to 6 m [10 to 20 ft]. The distance between boreholes at the test depths is measured using a borehole deviation survey. The borehole seismic source is connected to and triggers a data recording system that records the response of the downhole receivers, thus measuring the travel time of the wave train between the source and receivers.

---

[1] These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.09 on Cyclic and Dynamic Properties of Soils.

Current edition approved March 1, 2014. Published April 2014. Originally approved in 1984. Last previous edition approved in 2007 as D4428/D4428M – 07. DOI: 10.1520/D4428_D4428M-14.

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

The P-wave or S-wave velocity is calculated from the measured distance and travel time for the respective wave train.

5. Significance and Use

5.1 The seismic crosshole method provides a designer with information pertinent to the seismic wave velocities of the materials in question (**1**).[2] This data may be used as follows:

5.1.1 For input into static/dynamic analyses;

5.1.2 For computing shear modulus, Young's modulus, and Poisson's ratio (provided density is known or assumed);

5.1.3 For determining Seismic Site Class using the appropriate Building Code; and

5.1.4 For assessing liquefaction potential.

5.2 Fundamental assumptions inherent in the test methods are as follows:

5.2.1 Horizontal layering is assumed.

5.2.2 Snell's law of refraction applies to P-waves and S-waves and to the velocities derived from crosshole tests. If Snell's law of refraction is not considered in the analysis of Crosshole seismic testing data, the report shall so state, and the P-wave and S-wave velocities obtained may be unreliable for certain depth intervals near changes in stratigraphy (**2**).

NOTE 1—The quality of the results produced by these test methods is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection and so forth. Users of these test methods are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 The basic data acquisition system consists of the following:

6.1.1 *Energy Sources*—The source shall be rich in the type of energy required, that is, to produce good P-wave data, the energy source must transmit adequate energy to the medium in compression or volume change. Impulsive sources, such as explosives, hammers, or air guns, are all acceptable P-wave generators. To produce an identifiable S-wave, the source shall transmit energy to the ground primarily by distortion. Vertically polarized S-waves (SV) are most commonly measured, but horizontally polarized S-waves are also very useful. Fig. 1 and Fig. 2 show examples of impulse and vibratory seismic source wave trains respectively. For good S-waves, energy sources must be repeatable and, although not mandatory, reversible. The S-wave source must be capable of producing an S-wave train with an amplitude greater than the P-wave train.

6.1.2 *Receivers*—The receivers intended for use in the crosshole test shall be transducers having appropriate frequency and sensitivity characteristics to determine the seismic wave train arrivals. Typical examples include geophones and accelerometers. S-waves are typically in the range of 50 to 500 Hz depending on the soil properties and signal source mechanism while P-waves may be as high as 2000 Hz. It is important that the receivers have a flat response over this range of frequencies. This can be accomplished by using geophones with a resonance at or below 10 Hz or accelerometers with a resonance at or above 10 000 Hz. It is important that all receivers used in the testing be of the same type and with matched characteristics. Each receiving unit will normally consist of three receivers combined orthogonally to form a triaxial array, that is, one vertical and two horizontal receivers

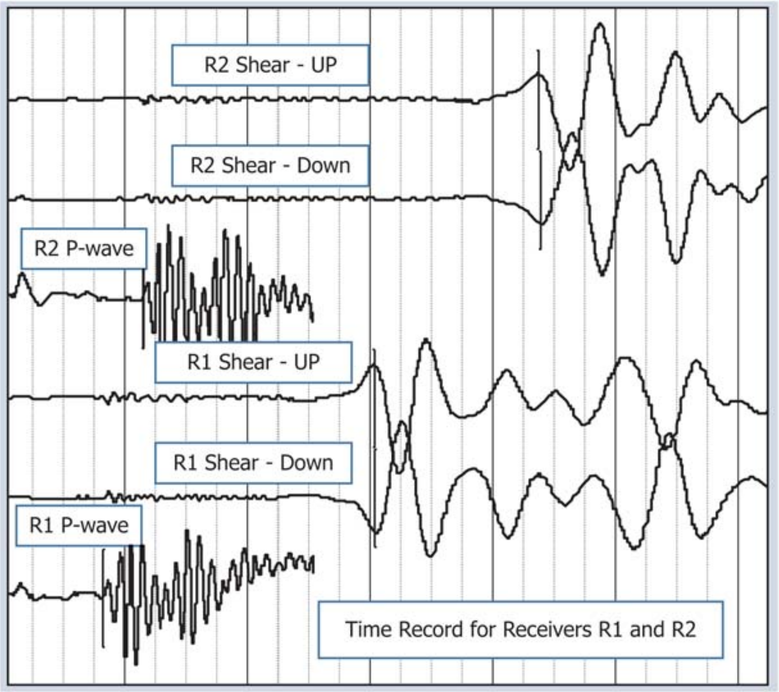


FIG. 1 Reversible Impulse Seismic Source Time Plot Showing Both P-Wave and S-Wave Trains

---

[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

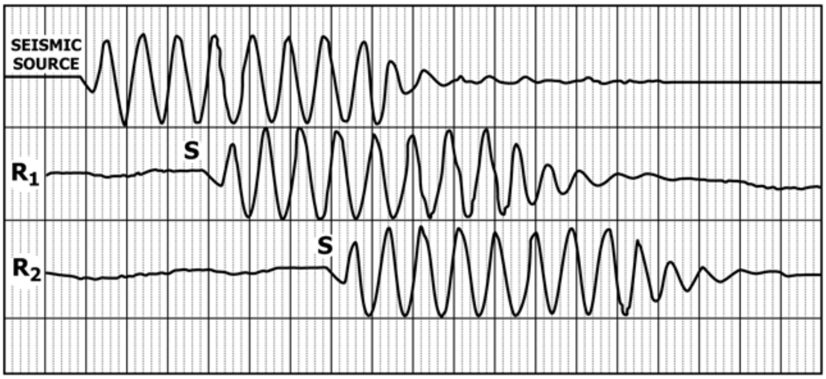


FIG. 2 Borehole Vibratory Seismic Source Time Plot (Produces S-Wave Train Only)

mounted at right angles, one to the other. In this triaxial arrangement, only the vertical component will be acceptable for determining the arrival of an SV-wave (S-wave in the vertical plane). Horizontally oriented receivers must be used for determining the arrival of an SH-wave (S-wave in the horizontal plane). The P-wave may be detected by any of the three components. The one oriented radially will provide the best sensitivity. Provision must be made for the receivers(s) to be held in firm contact with the sidewall of the borehole or casing. Examples of acceptable methods include: air bladder, wedge, stiff spring, or mechanical expander.

6.1.3 *Recording System:*

6.1.3.1 The system shall consist of separate recording channels, one for each receiver being recorded, having at least 12 bits of resolution. The timing accuracy of all instruments that are used in the travel time measurements shall be calibrated traceable to an appropriate government standards agency. Time scale accuracy may be demonstrated by inducing and recording an oscillating square wave signal of 1000 Hz derived from a calibrated quartz-controlled oscillator. Timing shall be to a resolution of 0.1 msec. Timing accuracy shall be demonstrated for all time scales used during the conduct of the tests.

6.1.3.2 Raw data shall be recorded directly without filtering except for the application of anti-aliasing filters which are set between 0.3 to 0.4 times the sampling frequency. Filtering or other post processing must pay attention to possible time shifting or distortion of the seismic wave train arrivals.

6.1.3.3 When velocities are determined using the travel time between a source (S) and two receivers (R1 and R2), the signals shall be recorded in a manner such that precision timing of the P- and S-wave arrival referenced to the instant of seismic source activation can be determined within 0.1 ms. For example, a seismic in-hole source and two receivers could be recorded multiple times to demonstrate accurate and consistent triggering by comparing the velocities determined for S-R1 and S-R2 with R1-R2 paths. When only two boreholes are used and velocities are determined by time interval S-R1, documentation of the trigger accuracy relative to the instant of seismic source generation must be provided. When velocities are determined using only the time interval between R1 and R2 and a simultaneous recording of R1 and R2, the trigger time is not needed.

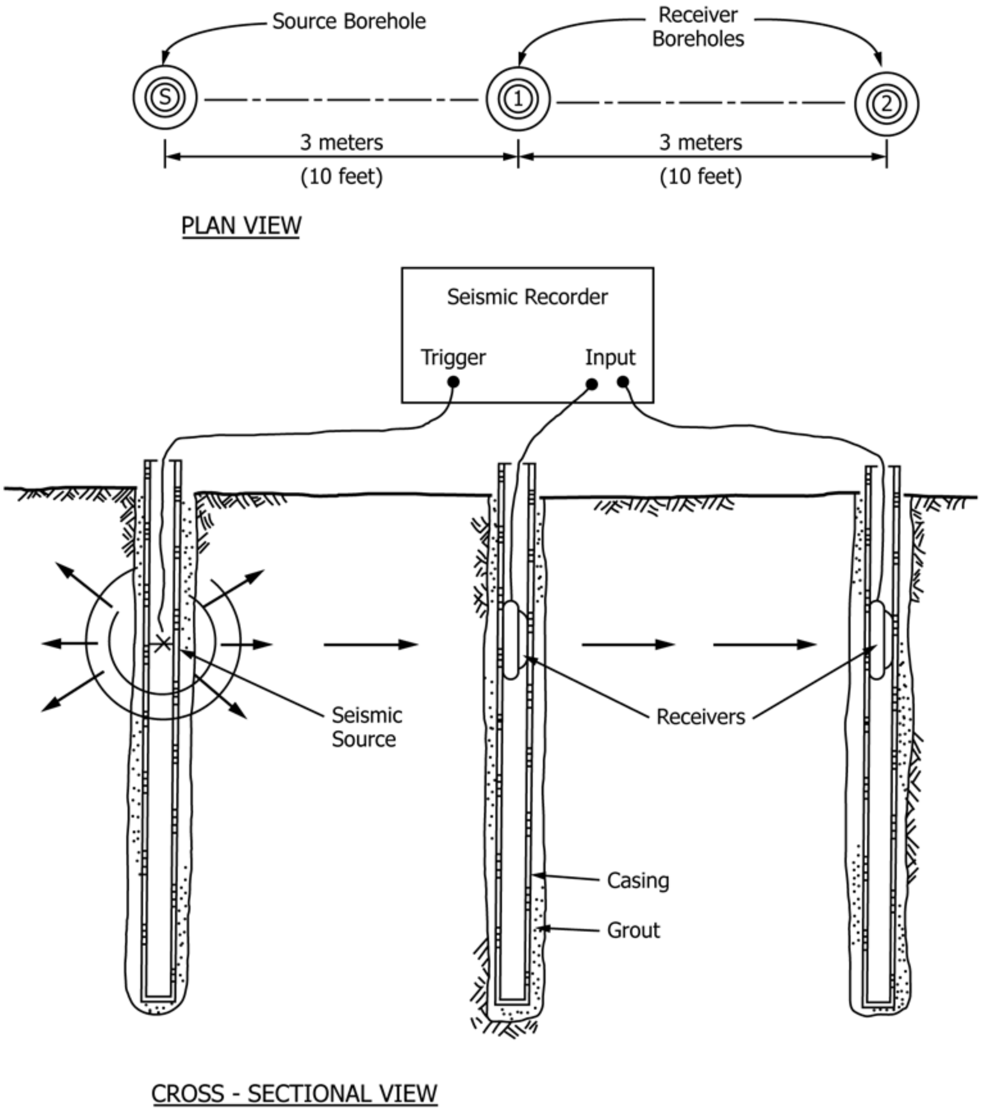
6.1.3.4 Permanent records shall be made of the seismic events to allow for subsequent review and analysis of the data.

7. Procedure

7.1 *Borehole Preparation:*

7.1.1 The recommended layout for crosshole testing incorporates three or more boreholes in line although two boreholes may be used. Three holes provide a level of redundancy not provided with two holes. Use of only two holes will be in compliance with this procedure if trigger accuracy is demonstrated and documented (6.1.3.3). Borehole spacing must be measured to a resolution of ±0.02 m. Borehole azimuth must be measured to a resolution of ±1 degrees of a designated reference direction. Borehole elevations must be measured to a precision of ±0.1 m. Spacing between the source borehole and the first receiver borehole shall be 1.5 to 3 m [5 to 10 ft] and the distance between subsequent receiver boreholes shall be 3 to 6 m [l0 to 20 ft] apart. A typical layout is illustrated in Fig. 3. For two boreholes, spacing between the source borehole and the receiver borehole shall be 1.5 to 5 m [5 to 15 ft].

7.1.1.1 *Borings with Casing*—If casing is used to house the receivers it shall be grouted in place. Drill the boreholes, with minimum sidewall disturbance, to a diameter no greater than required to perform the test. After the drilling is completed, case the borings with 50 to 100 mm [2 to 4 in.] inside diameter PVC pipe or aluminum casing, taking into consideration the size of the borehole source and downhole receivers. Before inserting the casing, close the bottom of the casing pipe with a cap which has a one way ball-check valve capable of accommodating 38 mm [1½ in.] outside diameter grout pipe. If a tremie pipe is used for the grouting, a ball check valve is not needed. Insert the casing down to the bottom of the borehole. Grout the casing in place by (*1*) inserting a 38 mm [1½ in.] PVC pipe through the center of the casing, contacting the one-way valve fixed to the end cap (Fig. 4 (left side)), or (*2*) by a small diameter grout tube inserted to the bottom of the borehole between the casing and the borehole sidewall (Fig. 4 (right side)). Another acceptable method would be to fill the borehole with grout which would be displaced by end-capped fluid-filled casing. The grout mixture shall be formulated to approximate closely the unit weight of the surrounding in situ material after solidification. That portion of the boring that penetrates rock shall be grouted with ordinary portland cement



NOTE 1—Spacing may vary with site conditions.

FIG. 3 Typical Crosshole Seismic Test

which will harden to a unit weight of about 22 kN/m^3 [unit weight of 140 lb/ft^3]. That portion of the boring in contact with soils, sands, or gravels shall be grouted with a mixture simulating the average unit weight of the medium (about 18 to 19 kN/m^3 [110 to 120 lb/ft^3]) by premixing 4.4 N [1 lb] of bentonite and 4.4 N [1 lb] of portland cement to 27N [6.25 lb] of water. Anchor the casing and pump the grout using a conventional, circulating pump capable of moving the grout through the grout pipe to the bottom of the casing and upward from the bottom of the borehole (Fig. 4). Using this procedure, the annular space between the sidewall of the borehole and the casing will be filled from bottom to top in a uniform fashion displacing mud and debris with minimum sidewall disturbance. Keep the casing anchored and allow the grout to set before deviation measurement or crosshole testing is performed. This grout mix will not set hard but will become a "rigid" gel. If shrinkage occurs near the mouth of the borehole, additional grout shall be inserted until the annular space is filled flush with the ground surface (**3**).

7.1.1.2 *Borings without Casing*—In some situations the survey may be performed without casing in the receiver holes. The receivers must be held in firm contact with the sidewall of the borehole during the measurements. The Borehole Deviation Survey (7.2) may be conducted with casing (if necessary) temporarily installed without being grouted in place.

7.2 *Borehole Deviation Survey*—A borehole deviation survey must be conducted in order to accurately determine the spacing at the elevations of the seismic tests.

7.2.1 Conduct a borehole deviation survey in all crosshole borings with an instrument capable of measuring the precise vertical alignment of each hole. The instrument must have the capability of determining tilt with a sensitivity of 0.3°. Information thus obtained will enable the investigator to compute

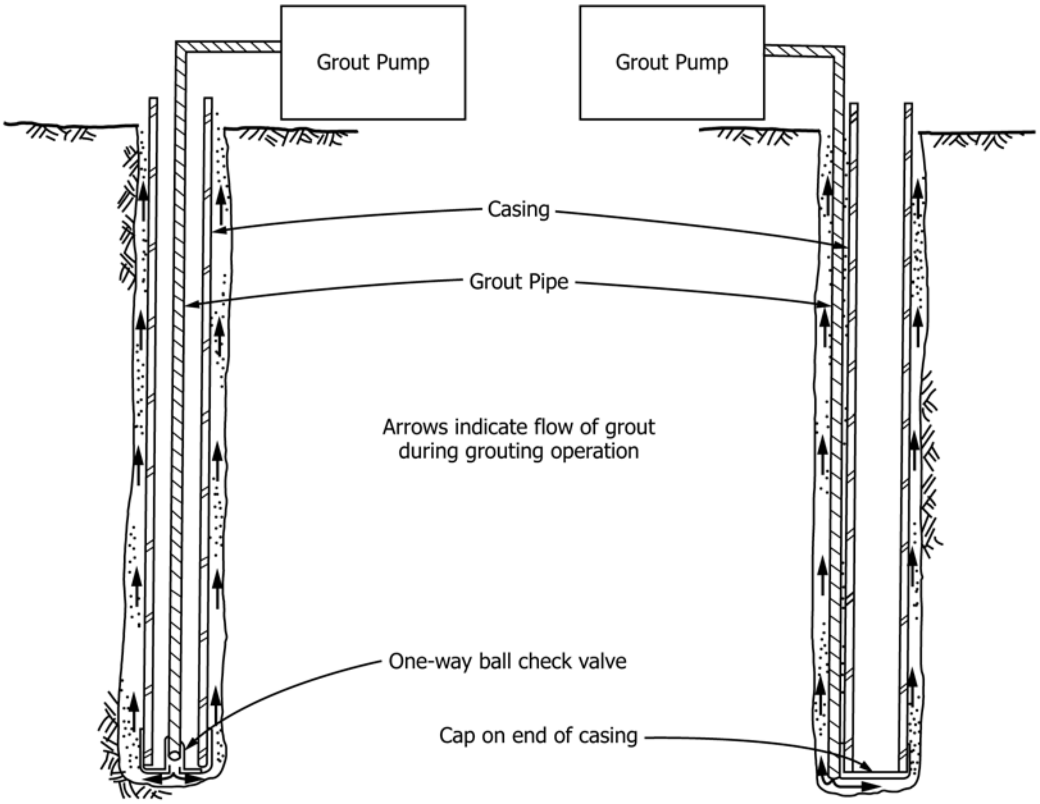


FIG. 4 Acceptable Grouting Techniques

the horizontal position at any depth within the borehole so that the actual distance between the holes can be computed.

7.2.1.1 Obtain deviation data at intervals not exceeding 3.0 m [10 ft] to the bottom of the boring. Repeat the measurements on the withdrawal trip at the same intervals so that closure can be determined at the mouth of the borehole.

7.3 *Crosshole Test:*

7.3.1 Begin the crosshole test by placing the energy source in the source hole at a depth no greater than 1.5 m [5 ft] (Fig. 3) into the stratum being investigated. Place the two receivers at the same elevation in each of the designated receiver holes. Clamp the source and receivers firmly into place. Check recording equipment and verify timing. Activate the energy source and display both receivers simultaneously on the recording device. Adjust the signal amplitude and duration such that the P-wave train or S-wave train, or both, are displayed in their entirety.

7.3.1.1 Best results will be obtained by performing two separate tests: one optimized for P-wave recovery (fastest sweep/recorder rate, higher gain settings) and the second for S-wave recovery (slower sweep/recorder rate, lower gain settings). If enhancement equipment is being used, repeatedly activate the energy source until optimum results are displayed. Perform the second test by lowering the energy source and receivers to a depth dictated by known stratification, but no greater than 1.5 m [5.0 ft] from the previous test locations in the borings and repeat the above procedure. Perform succeeding tests at intervals determined by stratification, or tests at depth intervals of 1.5 m [5 ft] until the maximum borehole depth has been reached.

8. Data Reduction and Interpretation

8.1 *Deviation Survey*—The primary objective of the borehole deviation survey is to establish the spatial position of the boreholes at all depths. Seismic wave velocities will be computed by determining the straight-line distance, l, from source to receivers. To do this, the following data are needed:

E_S = elevation of the top of the source hole,

E_G = elevation of the top of the geophone hole,

D_S = depth of the seismic source,

D_G = depth of the geophone,

L = horizontal distance between the top of the source hole and geophone hole,

ϕ = azimuth with respect to north from the top of the source hole to the geophone hole,

x_S = the north deviation of the source borehole at the source depth,

y_S = the east deviation of the source borehole at the source depth,

x_G = the north deviation of the geophone borehole at the geophone depth, and

y_G = the east deviation of the geophone borehole at the geophone depth.

8.1.1 The following equation determines the straight-line distance, l, from source to geophone using the data of 8.1:

$$l = \sqrt{[(E_S - D_S) - (E_G - D_G)]^2 + (L\cos\phi + x_G - x_S)^2 + (L\sin\phi + y_G - y_S)^2} \quad (1)$$

The apparent velocity is equal to *l* divided by the travel time between the source and the receiver. When computing the apparent velocity between two receivers, the distance is the difference between the distances from the source to the respective receivers.

8.2 *Wave Train Identification:*

8.2.1 Under ideal conditions the identification of the P-wave and S-wave arrivals will be similar to that shown in Fig. 1. In other situations some judgment is required to identify the S-wave arrival. The S-wave may often be identified on the seismic signature by the following characteristics:

8.2.1.1 A sudden increase in amplitude above that of the P-wave train, and

8.2.1.2 An abrupt change in frequency coinciding with the amplitude change.

8.2.1.3 If a reversible polarity seismic source is used, the S-wave arrival will be determined as that point meeting the criteria of 8.2.1.1 and 8.2.1.2 and where a 180° polarity change is noted to have occurred. An unclipped recording of the entire waveform under consideration must be made. A subsequent recording at higher gain may be made with wave clipping after a clearly identified arrival has been recorded.

8.2.2 If a vertically polarized S-wave vibratory source (as opposed to an impact source) is used, the time difference between Receivers 1 and 2 may provide the time interval information needed for S-wave velocity calculations without a well-defined initial arrival. (See Note 2 below.) This type of source does not generally produce easily identified P-wave signals.

NOTE 2—Other than ideal conditions often exist where first arrivals such as those shown in Fig. 1 cannot easily be determined from the time trace. This may be caused by wave reflections and other phenomena as the signal travels between the source and receiver. Signal analysis techniques that account for such effects must then provide a means for the determination of the S-wave and possibly P-wave wave velocities. These techniques are not addressed in this standard but are acceptable if documented in the report.

8.3 *Data Tabulation:*

8.3.1 Three separate travel times are computed from the measurements as follows:

8.3.1.1 Source to Receiver 1,

8.3.1.2 Source to Receiver 2, and

8.3.1.3 Time difference between Receivers 1 and 2.

8.3.2 Determine incremental velocity by dividing the difference in radial distances between the source and receivers R1 and R2 by the difference in arrival times between and R2 and R1. (See Note 3.)

NOTE 3—If the source trigger is not precisely calibrated or identified due to trigger errors, the only accurate velocity measurement is computed using the time difference between Receivers 1 and 2 along with the difference in radial distances from the source to each receiver.

9. Report: Test Data Sheet(s)/Form(s)

9.1 The methodology used to specify how data are recorded on the test data sheet/form, as given below, is covered in 1.4.

9.2 Record as a minimum the following general information (data):

9.2.1 Project description, operator, and weather conditions.

9.2.2 Make and model of borehole seismic source, downhole receivers, and recording equipment.

9.2.3 Borehole information, method of installation, casing diameter(s).

9.2.4 Distance between each borehole or borehole coordinates at ground surface.

9.3 Record as a minimum the following test data at each measurement depth:

9.3.1 Measured deviations of each bore hole,

9.3.2 Distance between each pair of borehole sets,

9.3.3 Travel time and velocity from Source to R1,

9.3.4 Travel time and velocity from Source to R2, and

9.3.5 Travel time and velocity between borehole pairs R1 and R2.

10. Precision and Bias

10.1 *Precision*—Test data on precision are not presented due to the nature of the soil tested by these test methods. It is either not feasible or too costly to have ten or more laboratories participate in a round-robin testing program at sites with uniform soil deposits covering the range of expected shear wave velocities Any variation observed in the data is just as likely to be due to geologic variation as to operator or field testing variation.

10.1.1 Subcommittee D18.09 is seeking any data from users of this test method that might be used to make a limited statement on precision.

10.2 *Bias*—There is no accepted reference value for these test methods; therefore, bias cannot be determined.

11. Keywords

11.1 accelerometers; compression waves; geophones; machine foundations; seismic waves; shear waves; wave velocity

REFERENCES

(1) Woods, R. D., "Measurement of Dynamic Soil Properties," *Proceedings of the ASCE Geotechnical Engineering Division Specialty Conference on Earthquake Engineering and Soil Dynamics*, ASCE, Vol I, 19–21 June 1978, pp. 91–178.

(2) Wightman, W. E., Jalinoos, F., Sirles, P., and Hanna, K., "Application of Geophysical Methods to Highway Related Problems," Federal Highway Administration, Central Federal Lands Highway Division, Lakewood, CO, Publication No. FHWA-IF-04-021, September 2003.

(3) Ballard, R. F., Jr., "Method for Crosshole Seismic Testing," *Geotechnical Engineering Division* , ASCE, Vol 102, No. GT12, December 1976, pp. 1261–1273.

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D4428/D4428M – 07) that may impact the use of this standard. (Approved March 1, 2014.)

(1) Revised Sections 1, 3, 5, 8, 9, and 10.
(2) Expanded Sections 6 and 7.
(3) Updated Figs. 1-4 and References Section.
(4) Removed Figs. 4 and 5, Tables 1 and 2, and Appendixes Section.

ATTACHMENT 3 - PDI HB-3: BENCH SCALE TESTING OF CONTAINMENT WALL MIX DESIGNS

Project	Nuclear Metal Superfund Site, Concord, MA	Date	4 September 2020
Client	Remedial Design Work Plan	Page	1 of 4

1 INTRODUCTION

This Pre-Design Investigation (PDI) activity for the holding basin (HB) containment wall will investigate the trench slurry mix design and barrier wall concrete mix design.

Potential trench slurry mixtures will be evaluated to identify type and approximate percentage of bentonite to be mixed with an on-site water source to provide temporary support of excavated panels for the containment wall prior to placing concrete backfill.

Potential concrete backfill mix designs will be evaluated to satisfy the minimum required permeability and strength criteria established during the PDIs for the 30% Design.

2 OBJECTIVES

The objectives for performing the work described in this PDI are as follows:

- Identify potential type and percentage of bentonite to be used in slurry for temporary support of excavated panels for the containment wall.
- Evaluate potential concrete backfill mix designs to satisfy minimum required permeability and strength criteria.

The results of this PDI will be used to develop a performance-based specification for barrier wall construction and assist contractors with selection of materials and mix designs as they prepare bids for barrier wall construction

3 SCOPE OF WORK

The scope of work will include laboratory testing for design of temporary trench slurry and permanent concrete backfill for the containment wall. The results will be used to develop performance-based specifications for the containment wall construction.

4 PROCEDURES

4.1 Mix Water Testing

Perform the following tests to evaluate water available on-site from the existing hydrant for mixing trench slurry:

- Hardness
- Total Dissolved Solids
- pH

- Electric Conductivity
- Alkalinity

4.2 Groundwater Testing

Perform the tests noted below to evaluate groundwater obtained from wells screened in three separate intervals that the wall will intercept: 1) Overburden sand and gravel; 2) Glacial Till 3) Shallow bedrock; and 4) Deeper bedrock. Water will be sampled from each of these intervals at up to three well clusters.

- pH
- Hardness
- Total Dissolved Solids
- Electrical conductivity
- Alkalinity
- Oxidation reduction potential (ORP)
- Chlorides
- Sulfates
- Compounds of Concern (COCs) – from ROD

The data will be evaluated to determine the chemical compatibility of the proposed concrete mix design relative to the chemistry of the groundwater that the wall will intercept.

4.3 Bentonite Slurry Testing

If results of mix water testing described in Section 4.1 indicate any of the tested parameters are not consistent with typical ranges acceptable for use of conventional bentonite products, perform tests on potential bentonite materials in accordance with the following ASTM Standards:

- Swell Index (ASTM D5890-19: Standard Test Method for Swell Index of Clay Mineral Component of Geosynthetic Clay Liners)

- Fluid Loss (ASTM D5891-19: Standard Test Method for Fluid Loss of Clay Component of Geosynthetic Clay Liners)

As part of the testing, the density of each slurry mix will also be recorded. This testing is not required if mix water test results do not indicate potential concerns with compatibility of conventional bentonite products.

4.4 Concrete Mix Backfill Testing

Mix up to five designs to provide required permeability determined based on outcome of our hydrogeologic and seepage analysis for the HB (anticipated to range between $1x10^{-6}$ cm/sec and $1x10^{-8}$ cm/sec), with minimum required unconfined compressive strength (assume 4,000 psi). Mix designs will include varying amounts of Xypex and/or other potential additives if needed to help achieve permeability requirements. Mix designs to be tested will include Portland cement and bentonite at variable percentages to achieve strength and hydraulic conductivity to be determined. Other additives such as MasterLife 300D will be evaluated if it is determined that high compressive strength concrete backfill is required. In addition, the aggregate size will likely be limited to ¾ inches in the project specifications.

Concrete strengths will be tested at 7, 14, and 28 days (per ASTM D1633-17: Standard Test Methods for compressive Strength of Molded Soil-Cement Cylinders).

Samples of selected mixes will be permeability tested using potable water from the laboratory as the permeant for an initial screen of sample performance. Testing will be performed in accordance with ASTM D5084-16a: Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter. Based on results of the initial screening, one or two mixes will be selected for further permeability testing using site groundwater obtained from wells at the HB as the permeant. Tests will be run with site groundwater obtained from four different screened intervals (overburden sand and gravel, glacial till, shallow bedrock, and deeper bedrock). The groundwater in some of these screened intervals is anticipated to have low level radioactive impacts, and this additional permeability testing will be performed at a laboratory licensed to handle such materials (Advanced Terra Testing, Inc., Lakewood, CO). As an initial screening of changes in chemistry from the concrete mix, pH and alkalinity of the influent and effluent will be tested during each of these permeability tests. Based on the variables including strength, hydraulic conductivity, and the seismic design criteria that will need to be considered, there may be more than 5-mixes evaluated.

Results of testing will be included in contract documents to provide contractors with an example of potential mix designs that will achieve design criteria. During construction, contractors will be responsible for preparing a suitable mix design based on materials and admixtures that they propose to use to satisfy the performance-based specification.

4.5 Future Considerations for PDI During 30% Design

The PDIs being completed as part of the RD/RA will result in a selected mix design for the proposed concrete containment wall. The in-situ soil stabilization (ISS) to be completed within the footprint of the Holding Basin will also be selected as part of the PDIs to determine the material that is able to sequester uranium within the Holding Basin soil and groundwater matrix. The proposed wall will be constructed through an area mixed with the selected material. The concrete containment wall may result in a change in pH and alkalinity adjacent to the wall. This change in chemistry may affect the ability of the ISS to sequester uranium. An evaluation of this change in chemistry will be completed as part of the 30% RD. It is expected that this evaluation will include preparing concrete cylinders using the proposed mix design and submerging the cylinders in lab prepared containers of water from the site. Groundwater from the overburden sand and gravel, glacial till, shallow rock, and deeper rock will be used along with samples of the soil mixed with the ISS materials to simulate the wall being subjected to the ISS and water chemistry. The water will be tested for pH and alkalinity at 7 days, 14 days, and 28 days to evaluate if the changes in chemistry are significant to the performance of the ISS sequestering uranium. The concrete cylinders will be submerged in a water bath for 7 days, the testing of the water will be completed, and the water will be purged and new water added for the 14 day test. Similar purging and water replacement will be conducted for the 28-day testing. This procedure will help determine if the concrete continues to change the pH and alkalinity after the initial concrete hydration reactions. It is expected that the changes in pH may be temporary. However, the proposed wall will effectively create a bathtub effect with no drain so the water behind the wall could have some pH and alkalinity impacts that could affect the reactions needed to sequester the uranium. A pumping and water recirculation system may need to be designed to remove the pH and alkaline water and either create a gradient from outside to inside the wall, or replace water pumped from inside the wall with natural groundwater from the outside of the wall to adjust the pH and alkalinity to be within the limits suitable for the sequestering of uranium in soil and groundwater within the Holding Basin.

5 REPORTING

The status of this PDI, and results will be provided to EPA during routine project meetings and status reports. Results and the outcome of the PDI will be incorporated into a separate PDI Evaluation Report and the 30% RD report.

ATTACHMENTS

Section 3 - ASTM Standards: ASTM D5890-19, ASTM D5891-19, ASTM D1633-17, and ASTM D5084-16a

Section 3
PDI HB-3 Standards

Designation: D5084 – 16a

Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter[1]

This standard is issued under the fixed designation D5084; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 These test methods cover laboratory measurement of the hydraulic conductivity (also referred to as *coefficient of permeability*) of water-saturated porous materials with a flexible wall permeameter at temperatures between about 15 and 30°C (59 and 86°F). Temperatures outside this range may be used; however, the user would have to determine the specific gravity of mercury and R_T (see 10.3) at those temperatures using data from *Handbook of Chemistry and Physics*. There are six alternate methods or hydraulic systems that may be used to measure the hydraulic conductivity. These hydraulic systems are as follows:

1.1.1 *Method A*—Constant Head

1.1.2 *Method B*—Falling Head, constant tailwater elevation

1.1.3 *Method C*—Falling Head, rising tailwater elevation

1.1.4 *Method D*—Constant Rate of Flow

1.1.5 *Method E*—Constant Volume–Constant Head (by mercury)

1.1.6 *Method F*—Constant Volume–Falling Head (by mercury), rising tailwater elevation

1.2 These test methods use water as the permeant liquid; see 4.3 and Section 6 on Reagents for water requirements.

1.3 These test methods may be utilized on all specimen types (intact, reconstituted, remolded, compacted, etc.) that have a hydraulic conductivity less than about 1×10^{-6} m/s (1×10^{-4} cm/s), providing the head loss requirements of 5.2.3 are met. For the constant-volume methods, the hydraulic conductivity typically has to be less than about 1×10^{-7} m/s.

1.3.1 If the hydraulic conductivity is greater than about 1×10^{-6} m/s, but not more than about 1×10^{-5} m/s; then the size of the hydraulic tubing needs to be increased along with the porosity of the porous end pieces. Other strategies, such as using higher viscosity fluid or properly decreasing the cross-sectional area of the test specimen, or both, may also be possible. The key criterion is that the requirements covered in Section 5 have to be met.

1.3.2 If the hydraulic conductivity is less than about 1×10^{-11} m/s, then standard hydraulic systems and temperature environments will typically not suffice. Strategies that may be possible when dealing with such impervious materials may include the following: *(a)* controlling the temperature more precisely, *(b)* adoption of unsteady state measurements by using high-accuracy equipment along with the rigorous analyses for determining the hydraulic parameters (this approach reduces testing duration according to Zhang et al. (**1**)[2]), and *(c)* shortening the length or enlarging the cross-sectional area, or both, of the test specimen (with consideration to specimen grain size (**2**)). Other approaches, such as use of higher hydraulic gradients, lower viscosity fluid, elimination of any possible chemical gradients and bacterial growth, and strict verification of leakage, may also be considered.

1.4 The hydraulic conductivity of materials with hydraulic conductivities greater than 1×10^{-5} m/s may be determined by Test Method D2434.

1.5 All observed and calculated values shall conform to the guide for significant digits and rounding established in Practice D6026.

1.5.1 The procedures used to specify how data are collected, recorded, and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.6 This standard also contains a Hazards section (Section 7).

1.7 The time to perform this test depends on such items as the Method (A, B, C, D, E, or F) used, the initial degree of

---

[1] This standard is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.04 on Hydrologic Properties and Hydraulic Barriers.

Current edition approved Aug. 15, 2016. Published August 2016. Originally approved in 1990. Last previous edition approved in 2016 as D5084–16. DOI: 10.1520/D5084-16A.

[2] The boldface numbers in parentheses refer to the list of references appended to this standard.

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

saturation of the test specimen and the hydraulic conductivity of the test specimen. The constant volume Methods (E and F) and Method D require the shortest period-of-time. Typically a test can be performed using Methods D, E, or F within two to three days. Methods A, B, and C take a longer period-of-time, from a few days to a few weeks depending on the hydraulic conductivity. Typically, about one week is required for hydraulic conductivities on the order of 1×10^{-9} m/s. The testing time is ultimately controlled by meeting the equilibrium criteria for each Method (see 9.5).

1.8 *Units*—The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are mathematical conversions, which are provided for information purposes only and are not considered standard, unless specifically stated as standard, such as 0.5 mm or 0.01 in.

1.9 *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:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))

D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

D1140 Test Methods for Determining the Amount of Material Finer than 75-μm (No. 200) Sieve in Soils by Washing

D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))

D1587 Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes

D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D2434 Test Method for Permeability of Granular Soils (Constant Head) (Withdrawn 2015)[4]

D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils (Withdrawn 2016)[4]

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4220 Practices for Preserving and Transporting Soil Samples

D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D4767 Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils

D5079 Practices for Preserving and Transporting Rock Core Samples

D6026 Practice for Using Significant Digits in Geotechnical Data

D6151 Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling

D6169 Guide for Selection of Soil and Rock Sampling Devices Used With Drill Rigs for Environmental Investigations

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of technical terms in this standard, refer to Terminology D653.

3.1.2 *head loss, Δh*—the change in total head of water across a given distance.

3.1.2.1 *Discussion*—In hydraulic conductivity testing, typically the change in total head is across the influent and effluent lines connected to the permeameter, while the given distance is typically the length of the test specimen.

3.1.3 *permeameter*—the apparatus (cell) containing the test specimen in a hydraulic conductivity test.

3.1.3.1 *Discussion*—The apparatus in this case is typically a triaxial-type cell with all of its components (top and bottom specimen caps, stones, and filter paper; membrane; chamber; top and bottom plates; valves; etc.).

3.1.4 *hydraulic conductivity, k*—the rate of discharge of water under laminar flow conditions through a unit cross-sectional area of porous medium under a unit hydraulic gradient and standard temperature conditions (20°C).

3.1.4.1 *Discussion*—In hydraulic conductivity testing, the term *coefficient of permeability* is often used instead of *hydraulic conductivity*, but *hydraulic conductivity* is used exclusively in this standard. A more complete discussion of the terminology associated with Darcy's law is given in the literature. (**3, 4**)

3.1.5 *pore volume of flow—in hydraulic conductivity testing*, the cumulative quantity of flow into a test specimen divided by the volume of voids in the specimen.

4. Significance and Use

4.1 These test methods apply to one-dimensional, laminar flow of water within porous materials such as soil and rock.

4.2 The hydraulic conductivity of porous materials generally decreases with an increasing amount of air in the pores of

---

[3] 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.

[4] The last approved version of this historical standard is referenced on www.astm.org.

the material. These test methods apply to water-saturated porous materials containing virtually no air.

4.3 These test methods apply to permeation of porous materials with water. Permeation with other liquids, such as chemical wastes, can be accomplished using procedures similar to those described in these test methods. However, these test methods are only intended to be used when water is the permeant liquid. See Section 6.

4.4 Darcy's law is assumed to be valid and the hydraulic conductivity is essentially unaffected by hydraulic gradient.

4.5 These test methods provide a means for determining hydraulic conductivity at a controlled level of effective stress. Hydraulic conductivity varies with varying void ratio, which changes when the effective stress changes. If the void ratio is changed, the hydraulic conductivity of the test specimen will likely change, see Appendix X2. To determine the relationship between hydraulic conductivity and void ratio, the hydraulic conductivity test would have to be repeated at different effective stresses.

4.6 The correlation between results obtained using these test methods and the hydraulic conductivities of in-place field materials has not been fully investigated. Experience has sometimes shown that hydraulic conductivities measured on small test specimens are not necessarily the same as larger-scale values. Therefore, the results should be applied to field situations with caution and by qualified personnel.

4.7 In most cases, when testing high swell potential materials and using a constant-volume hydraulic system, the effective confining stress should be about 1.5 times the swell pressure of the test specimen or a stress which prevents swelling. If the confining stress is less than the swell pressure, anomalous flow conditions my occur; for example, mercury column(s) move in the wrong direction.

NOTE 1—The quality of the result produced by this standard is dependent of the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing, sampling, inspection, etc.. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *Hydraulic System*—Constant head (Method A), falling head (Methods B and C), constant rate of flow (Method D), constant volume-constant head (Method E), or constant volume-falling head (Method F) systems may be utilized provided they meet the following criteria:

5.1.1 *Constant Head*—The system must be capable of maintaining constant hydraulic pressures to ±5 % or better and shall include means to measure the hydraulic pressures to within the prescribed tolerance. In addition, the head loss across the permeameter must be held constant to ±5 % or better and shall be measured with the same accuracy or better. A pressure gage, electronic pressure transducer, or any other device of suitable accuracy shall measure pressures to a minimum of three significant digits. The last digit may be due to estimation, see 5.1.1.1.

5.1.1.1 Practice D6026 discusses the use or application of estimated digits. When the last digit is estimated and that reading is a function of the eye's elevation/location, then a mirror or another device is required to reduce the reading error caused by parallax.

5.1.2 *Falling Head*—The system shall allow for measurement of the applied head loss, thus hydraulic gradient, to ±5 % or better at any time. In addition, the ratio of initial head loss divided by final head loss over an interval of time shall be measured such that this computed ratio is accurate to ±5 % or better. The head loss shall be measured with a pressure gage, electronic pressure transducer, engineer's scale, graduated pipette, or any other device of suitable accuracy to a minimum of three significant digits. The last digit may be due to estimation, see 5.1.1.1. Falling head tests may be performed with either a constant tailwater elevation (Method B) or a rising tailwater elevation (Method C), see Fig. 1. This schematic of a hydraulic system presents the basic components needed to meet the objectives of Method C. Other hydraulic systems or schematics that meet these objectives are acceptable.

5.1.3 *Constant Rate of Flow*—The system must be capable of maintaining a constant rate of flow through the specimen to ±5 % or better. Flow measurement shall be by calibrated syringe, graduated pipette, or other device of suitable accuracy. The head loss across the permeameter shall be measured to a minimum of three significant digits and to an accuracy of ±5 % or better using an electronic pressure transducer(s) or other device(s) of suitable accuracy. The last digit may be due to estimation, see 5.1.1.1. More information on testing with a constant rate of flow is given in the literature (**5**).

5.1.4 *Constant Volume-Constant Head (CVCH)*—The system, with mercury to create the head loss, must be capable of maintaining a constant head loss cross the permeameter to ±5 % or better and shall allow for measurement of the applied head loss to ±5 % or better at any time. The head loss shall be measured to a minimum of three significant digits with an electronic pressure transducer(s) or equivalent device, (**6**) or based upon the pressure head caused by the mercury column, see 10.1.2. The last digit may be due to estimation, see 5.1.1.1.

5.1.4.1 Schematics of two CVCH systems are shown in Fig. 2 and Fig. 3. In each of these systems, the mercury-filled portion of the tubing may be continuous for constant head loss to be maintained. For the system showed in Fig. 2, the head loss remains constant provided the mercury column is vertical and is retained in only one half of the burette system (left burette in Fig. 2). If the mercury spans both columns, a falling head exists. In the system shown in Fig. 3, the head loss remains constant provided the water-mercury interface on the effluent end remains in the upper horizontal tube, and the water-mercury interface on the influent end remains in the lower horizontal tube. These schematics present the basic components needed to meet the objectives of Method E. Other hydraulic systems or schematics that meet these objectives are acceptable.

5.1.4.2 These types of hydraulic systems are typically not used to study the temporal or pore-fluid effect on hydraulic conductivity. The total volume of the specimen is maintained constant using this procedure, thereby significantly reducing

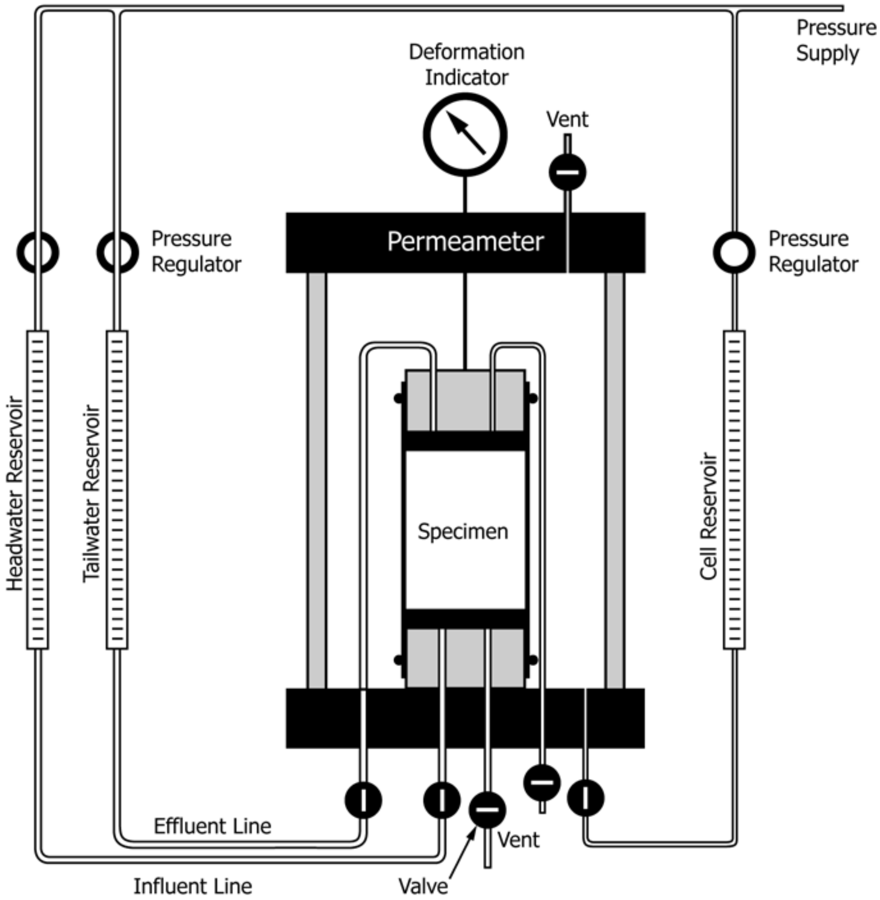


FIG. 1 Falling Head – Rising Tail System, Method C

effects caused by seepage stresses, pore fluid interactions, etc. Rather, these systems are intended for determining the hydraulic conductivity of a material as rapidly as possible.

5.1.4.3 *Hazards*—Since this hydraulic system contains mercury, special health and safety precautions have to be considered. See Section 7.

5.1.4.4 *Caution*—For these types of hydraulic systems to function properly, the separation of the mercury column has to be prevented. To prevent separation, the mercury and "constant head" tube have to remain relatively clean, and the inside diameter of this tube cannot be too large; typically a capillary tube is used. The larger diameter flushing tube (Fig. 2) is added to enable flushing clean water through the system without excessive mercury displacement. Traps to prevent the accidental flow of mercury out of the "Constant Head" tube or flushing tube are not shown in Fig. 2 and Fig. 3.

5.1.5 *Constant Volume-Falling Head (CVFH)*—The system, with mercury to create the head loss, shall meet the criteria given in 5.1.2. The head loss shall be measured to a minimum of three significant digits with an electronic pressure transducer(s) or equivalent device(s), (**6**) or based upon the differential elevation between the top surfaces of the mercury level in the headwater and tailwater tubes. The last digit may be due to estimation, see 5.1.1.1.

5.1.5.1 A schematic drawing of a typical CVFH hydraulic system is shown in Fig. 4 (**6**). Typically, the tailwater tube has a smaller area than the headwater tube to increase the sensitivity of flow measurements, and to enable flushing clean water through the system without excessive mercury displacement in the headwater tube. The schematic of the hydraulic system in Fig. 4 presents the basic components needed to meet the objectives of Method F. Other hydraulic systems or schematics that meet these objectives are acceptable. The development of the hydraulic conductivity equation for this type of system is given in Appendix X1.

5.1.5.2 See 5.1.4.2.

5.1.5.3 *Hazards*—Since this hydraulic system contains mercury, special health and safety precautions have to be considered. See Section 7.

5.1.5.4 *Caution*—For these types of hydraulic systems to function properly, the separation of the mercury column and entrapment of water within the mercury column have to be prevented. To prevent such problems, the mercury and tubes have to remain relatively clean. In addition, if different size headwater and tailwater tubes are used, capillary head might have to be accounted for, see Appendix X1, X1.2.3.2, and X1.4. Traps to prevent the accidental flow of mercury out of the tubes are not shown in Fig. 4.

5.1.6 *System De-airing*—The hydraulic system shall be designed to facilitate rapid and complete removal of free air bubbles from flow lines; for example, using properly sized tubing and ball valves and fittings without pipe threads. Properly sized tubing, etc., means they are small enough to

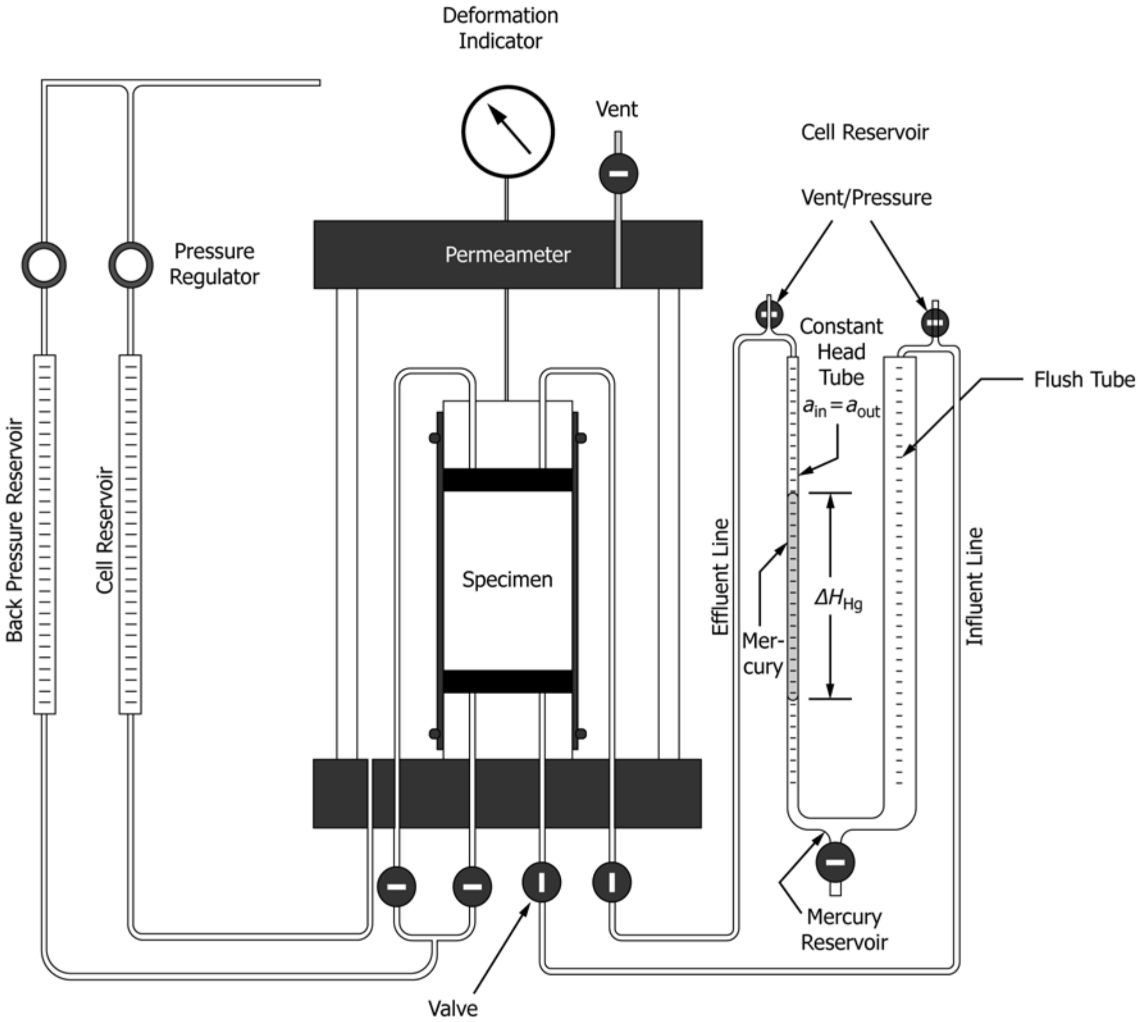


FIG. 2 Constant Volume – Constant or Falling Head System, Method E or F (6)

prevent entrapment of air bubbles, but not so small that the requirements of 5.2.3 cannot be met.

5.1.7 *Back Pressure System*—The hydraulic system shall have the capability to apply back pressure to the specimen to facilitate saturation. The system shall be capable of maintaining the applied back pressure throughout the duration of hydraulic conductivity measurements. The back pressure system shall be capable of applying, controlling, and measuring the back pressure to ±5 % or better of the applied pressure. The back pressure may be provided by a compressed gas supply, a deadweight acting on a piston, or any other method capable of applying and controlling the back pressure to the tolerance prescribed in this paragraph.

NOTE 2—Application of gas pressure directly to a fluid will dissolve gas in the fluid. A variety of techniques are available to minimize dissolution of gas in the back pressure fluid, including separation of gas and liquid phases with a bladder and frequent replacement of the liquid with de-aired water.

5.2 *Flow Measurement System*—Both inflow and outflow volumes shall be measured unless the lack of leakage, continuity of flow, and cessation of consolidation or swelling can be verified by other means. Flow volumes shall be measured by a graduated accumulator, graduated pipette, vertical standpipe in conjunction with an electronic pressure transducer, or other volume-measuring device of suitable accuracy.

5.2.1 *Flow Accuracy*—Required accuracy for the quantity of flow measured over an interval of time is ±5 % or better.

5.2.2 *De-airing and Compliance of the System*—The flow-measurement system shall contain a minimum of dead space and be capable of complete and rapid de-airing. Compliance of the system in response to changes in pressure shall be minimized by using a stiff flow measurement system. Rigid tubing, such as metallic or rigid thermoplastic tubing, or glass shall be used.

5.2.3 *Head Losses*—Head losses in the tubes, valves, porous end pieces, and filter paper may lead to error. To guard against such errors, the permeameter shall be assembled with no specimen inside and then the hydraulic system filled.

5.2.3.1 *Constant or Falling Head*—If a constant or falling head test is to be used, the hydraulic pressures or heads that will be used in testing a specimen shall be applied, and the rate of flow measured with an accuracy of ±5 % or better. This rate of flow shall be at least ten times greater than the rate of flow that is measured when a specimen is placed inside the permeameter and the same hydraulic pressures or heads are applied.

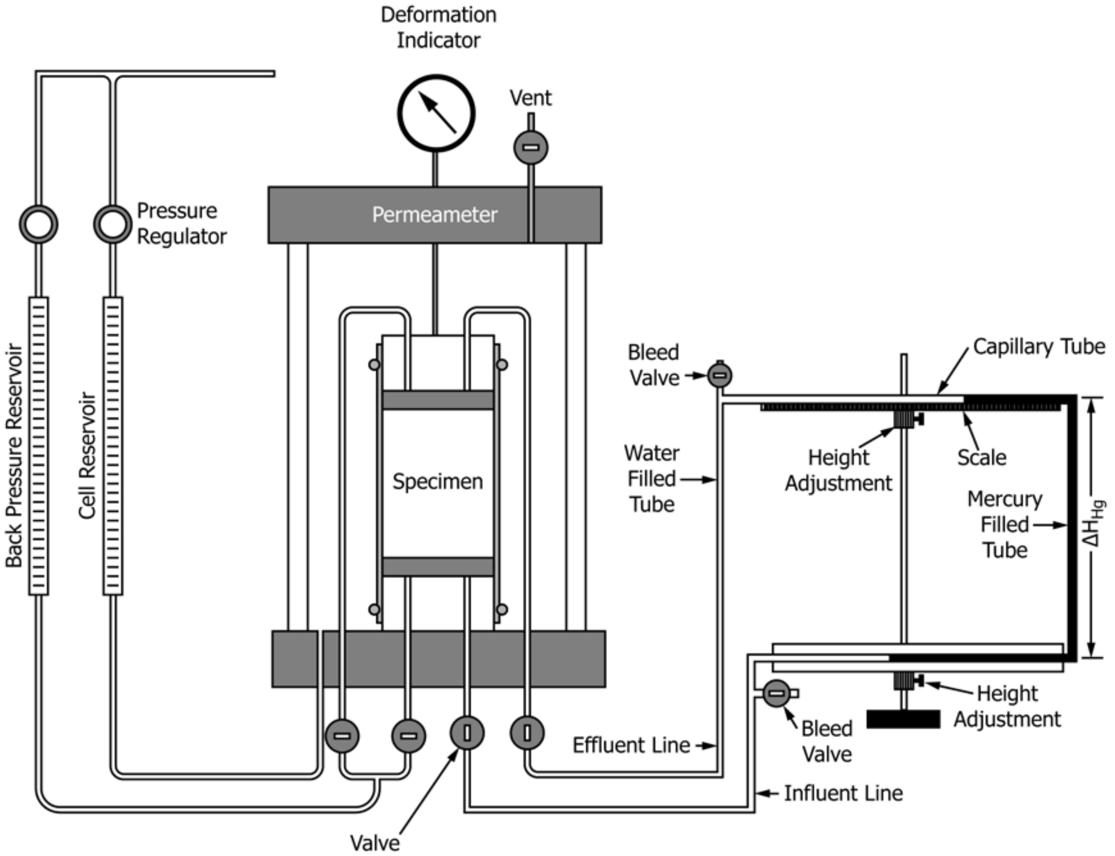


FIG. 3 Constant Volume—Constant Head System, Method E

5.2.3.2 *Constant Rate of Flow*—If a constant rate of flow test is to be used, the rate of flow to be used in testing a specimen shall be supplied to the permeameter and the head loss measured. The head loss without a specimen shall be less than 0.1 times the head loss when a specimen is present.

5.3 *Permeameter Cell Pressure System*—The system for pressurizing the permeameter cell shall be capable of applying and controlling the cell pressure to ±5 % or better of the applied pressure. However, the effective stress on the test specimen (which is the difference between the cell pressure and the pore water pressure) shall be maintained to the desired value with an accuracy of ±10 % or better. The device for pressurizing the cell may consist of a reservoir connected to the permeameter cell and partially filled with de-aired water, with the upper part of the reservoir connected to a compressed gas supply or other source of pressure (see Note 3). The gas pressure shall be controlled by a pressure regulator and measured by a pressure gage, electronic pressure transducer, or any other device capable of measuring to the prescribed tolerance. A hydraulic system pressurized by deadweight acting on a piston or any other pressure device capable of applying and controlling the permeameter cell pressure within the tolerance prescribed in this paragraph may be used.

NOTE 3—De-aired water is commonly used for the cell fluid to minimize potential for diffusion of air through the membrane into the specimen. Other fluids that have low gas solubilities such as oils, are also acceptable, provided they do not react with components of the permeameter. Also, use of a long (approximately 5 to 7 m) tube connecting the pressurized cell liquid to the cell helps to delay the appearance of air in the cell fluid and to reduce the flow of dissolved air into the cell.

5.4 *Permeameter Cell*—An apparatus shall be provided in which the specimen and porous end pieces, enclosed by a membrane sealed to the cap and base, are subjected to controlled fluid pressures. A schematic diagram of a typical permeameter cell and falling head (raising tailwater) hydraulic system is shown in Fig. 1.

5.4.1 The permeameter cell may allow for observation of changes in height of the specimen, either by observation through the cell wall using a cathetometer or other instrument, or by monitoring of either a loading piston or an extensometer extending through the top plate of the cell bearing on the top cap and attached to a dial indicator or other measuring device. The piston or extensometer should pass through a bushing and seal incorporated into the top plate and shall be loaded with sufficient force to compensate for the cell pressure acting over the cross-sectional area of the piston where it passes through the seal. If deformations are measured, the deformation indicator shall be a dial indicator or cathetometer graduated to 0.5 mm or 0.01 in. or better and having an adequate travel range. Any other measuring device meeting these requirements is acceptable.

5.4.2 In order to facilitate gas removal, and thus saturation of the hydraulic system, four drainage lines leading to the specimen, two each to the base and top cap, are recommended. The drainage lines shall be controlled by no-volume-change

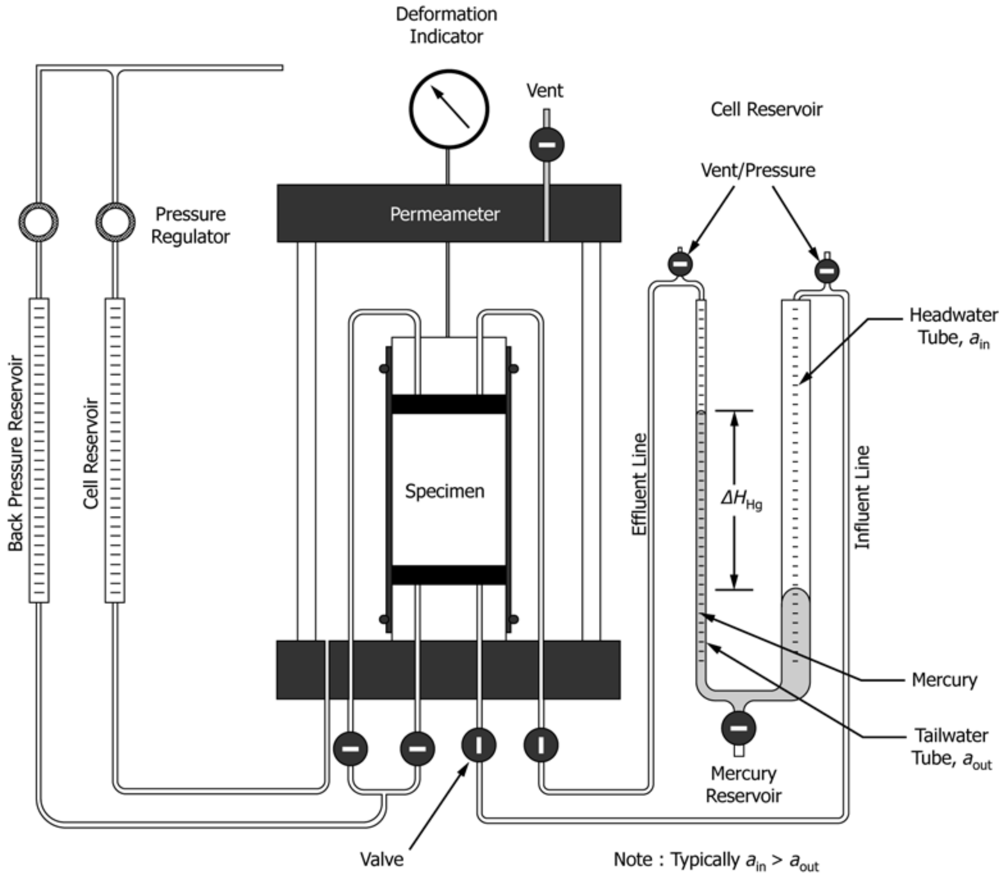


FIG. 4 Constant Volume – Falling Head System, Method F (6)

valves, such as ball valves, and shall be designed to minimize dead space in the lines.

5.4.3 *Top Cap and Base*—An impermeable, rigid top cap and base shall be used to support the specimen and provide for transmission of permeant liquid to and from the specimen. The diameter or width of the top cap and base shall be equal to the diameter or width of the specimen to ±5 % or better. The base shall prevent leakage, lateral motion, or tilting, and the top cap shall be designed to receive the piston or extensometer, if used, such that the piston-to-top cap contact area is concentric with the cap. The surface of the base and top cap that contacts the membrane to form a seal shall be smooth and free of scratches.

5.4.4 *Flexible Membranes*—The flexible membrane used to encase the specimen shall provide reliable protection against leakage. The membrane shall be carefully inspected prior to use. If any flaws or pinholes are evident, the membrane shall be discarded. To minimize restraint to the specimen, the diameter or width of the non-stretched membrane shall be between 90 and 95 % of that of the specimen. The membrane shall be sealed to the specimen base and cap with rubber O-rings for which the unstressed, inside diameter or width is less than 90 % of the diameter or width of the base and cap, or by any other method that will produce an adequate seal.

NOTE 4—Membranes may be tested for flaws by placing them around a form sealed at both ends with rubber O-rings, subjecting them to a small air pressure on the inside, and then dipping them into water. If air bubbles come up from any point on the membrane, or if any visible flaws are observed, the membrane shall be discarded.

5.4.5 *Porous End Pieces*—The porous end pieces shall be of silicon carbide, aluminum oxide, or other material that is not attacked by the specimen or permeant liquid. The end pieces shall have plane and smooth surfaces and be free of cracks, chips, and discontinuities. They shall be checked regularly to ensure that they are not clogged.

5.4.5.1 The porous end pieces shall be the same diameter or width (±5 % or better) as the specimen, and the thickness shall be sufficient to prevent breaking.

5.4.5.2 The hydraulic conductivity of the porous end pieces shall be significantly greater than that of the specimen to be tested. The requirements outlined in 5.2.3 ensure this criterion is met.

5.4.6 *Filter Paper*—If necessary to prevent intrusion of material into the pores of the porous end pieces, one or more sheets of filter paper shall be placed between the top and bottom porous end pieces and the specimen. The paper shall have a negligibly small hydraulic impedance. The requirements outlined in 5.2.3 ensure that the impedance is small.

5.5 *Equipment for Compacting a Specimen*—Equipment (including compactor and mold) suitable for the method of compaction specified by the requester shall be used.

5.6 *Sample Extruder*—When the material being tested is a soil core, the soil core shall usually be removed from the sampler with an extruder. The sample extruder shall be capable of extruding the soil core from the sampling tube in the same direction of travel in which the sample entered the tube and with minimum disturbance of the sample. If the soil core is not extruded vertically, care should be taken to avoid bending stresses on the core due to gravity. Conditions at the time of sample extrusion may dictate the direction of removal, but the principal concern is to keep the degree of disturbance minimal.

5.7 *Trimming Equipment*—Specific equipment for trimming the specimen to the desired dimensions will vary depending on quality and characteristics of the sample (material). However, the following items listed may be used: lathe, wire saw with a wire about 0.3 mm (0.01 in.) in diameter, spatulas, knives, steel rasp for very hard clay specimens, cradle or split mold for trimming specimen ends, and steel straight edge for final trimming of specimen ends.

5.8 *Devices for Measuring the Dimensions of the Specimen*—Devices used to measure the dimensions of the specimen shall be capable of measuring to the nearest 0.5 mm or 0.01 in. or better (see 8.1.1) and shall be constructed such that their use will not disturb the specimen.

5.9 *Balances*—The balance shall be suitable for determining the mass of the specimen and shall be selected as discussed in Specification D4753. The mass of specimens less than 100 g shall be determined to the nearest 0.01 g. The mass of specimens between 100 g and 999 g shall be determined to the nearest 0.1 g. The mass of specimens equal to or greater than 1000 g shall be determined to the nearest gram.

5.10 *Equipment for Mounting the Specimen*—Equipment for mounting the specimen in the permeameter cell shall include a membrane stretcher or cylinder, and ring for expanding and placing O-rings on the base and top cap to seal the membrane.

5.11 *Vacuum Pump*—To assist with de-airing of permeant liquid (water) and saturation of specimens.

NOTE 5—For guidance or avoiding excessive consolidation in the use of vacuum for specimen saturation, consult 8.2 of Test Method D4767.

5.12 *Temperature Maintaining Device*—The temperature of the permeameter, test specimen, and reservoir of permeant liquid shall not vary more than ±3°C or ±6°F or better. Normally, this is accomplished by performing the test in a room with a relatively constant temperature. If such a room is not available, the apparatus shall be placed in a water bath, insulated chamber, or other device that maintains a temperature within the tolerance specified above. The temperature shall be periodically measured and recorded.

5.13 *Water Content Containers*—The containers shall be in accordance with Method D2216.

5.14 *Drying Oven*—The oven shall be in accordance with Test Method D2216.

5.15 *Time Measuring Device(s)*—Devices to measure the duration of each permeation trial, such as either a clock with a second hand or a stopwatch (or equivalent), or both.

6. Reagents

6.1 *Permeant Water:*

6.1.1 The permeant water is the liquid used to permeate the test specimen and is also the liquid used in backpressuring the specimen.

6.1.2 The type of permeant water should be specified by the requestor. If no specification is made, one of the following shall be used: (*i*) potable tap water, (*ii*) a mixture of 0.0013 molar NaCl and 0.0010 molar $CaCl_2$, or (*iii*) 0.01 molar $CaCl_2$. The NaCl-$CaCl_2$ solution is representative of both typical tap waters and soil pore waters (**7**). The $CaCl_2$ solution has been used historically in areas with extremely hard or soft waters. The type of water used shall be indicated in the report.

6.1.2.1 The NaCl-$CaCl_2$ solution can be prepared by dissolving 0.76 g of reagent-grade NaCl and 1.11 g of reagent-grade $CaCl_2$ in 10 L of de-aired Type II deionized water.

6.1.2.2 The 0.01 $CaCl_2$ solution can be prepared by dissolving 11.1 g of reagent-grade $CaCl_2$ in 10 L of de-aired Type II deionized water.

6.1.2.3 Chemical interactions between a permeant liquid and the porous material may lead to variations in hydraulic conductivity. Distilled water can significantly lower the hydraulic conductivity of clayey soils (**3**). For this reason, distilled water is not usually recommended as a permeant liquid.

6.1.3 *Deaired Water*—To aid in removing as much air from the test specimen as possible, deaired water shall be used. The water is usually deaired by boiling, by spraying a fine mist of water into an evacuated vessel attached to a vacuum source, or by forceful agitation of water in a container attached to a vacuum source. If boiling is used, care shall be taken not to evaporate an excessive amount of water, which can lead to a larger salt concentration in the permeant water than desired. To prevent dissolution of air back into the water, deaired water shall not be exposed to air for prolonged periods.

7. Hazards

7.1 *Warning*—Mercury has been designated by many regulatory agencies as a hazardous material that can cause serious medical issues. Mercury, or its vapor, may be hazardous to health and corrosive to materials. Caution should be taken when handling mercury containing products. See the applicable product Safety Data Sheet (SDS) for additional information. Users should be aware that selling mercury or mercury containing products into your state or country may be prohibited by law.

7.1.1 Tubing composed of glass or other brittle materials may explode/shatter when under pressure, especially air. Therefore, such tubing should be enclosed. Establish allowable working pressures and make sure they are not exceeded.

7.2 *Precaution*—In addition to other precautions, store mercury in sealed shatterproof containers to control evaporation. When adding/subtracting mercury to/from the hydraulic system used in Method E or F, work in a well-ventilated area (preferably under a fume hood), and avoid contact with skin. Rubber gloves should be worn at all times when contact with mercury is possible.

7.2.1 Minimize uncontrolled flow of mercury out of the specialized hydraulic system by installing mercury traps or an inline check-valve mechanism. Minimize uncontrolled spills by using shatterproof materials or protective shields, or both.

7.2.2 If mercury comes into contact with brass/copper fittings, valves, etc., such items may rapidly become leaky. Therefore, where-ever practical use stainless steel fittings, etc.

7.2.3 Clean up spills immediately using a recommended procedure explicitly for mercury.

7.2.4 Dispose of contaminated waste materials containing mercury in a safe and environmentally acceptable manner.

8. Test Specimens

8.1 *Size*—Specimens shall have a minimum diameter of 25 mm (1.0 in.) and a minimum height of 25 mm. The height and diameter of the specimen shall be measured to three significant digits or better (see 8.1.1). The length shall vary by no more than ±5 %. The diameter shall vary by no more than ±5 %. The surface of the test specimen may be uneven, but indentations must not be so deep that the length or diameter vary by more than ±5 %. The diameter and height of the specimen shall each be at least 6 times greater than the largest particle size within the specimen. If, after completion of a test, it is found based on visual observation that oversized particles are present, that information shall be indicated on the data sheet(s)/form(s).

8.1.1 If the density or unit weight needs to be determined/recorded to four significant digits, or the void ratio to three significant digits; then the test specimens dimensions need to have four significant digits; that is, typically measured to the nearest 0.01 mm or 0.001 in.

8.1.2 Specimens of soil-cement and mixtures of cement, bentonite, and soils often have more irregular surfaces than specimens of soil. Thus, for these specimens the length and the diameter may vary by no more than ±10 %.

NOTE 6—Most hydraulic conductivity tests are performed on cylindrical test specimens. It is possible to utilize special equipment for testing prismatic test specimens, in which case reference to "diameter" in 8.1 applies to the least width of the prismatic test specimen.

8.2 *Intact Specimens*—Intact test specimens shall be prepared from a representative portion of intact samples secured in accordance with Practice D1587, Practice D3550, Practice D6151, or Practice D2113. In addition, intact samples may be obtained by "block sampling" (**8**). Additional guidance on other drilling and sampling methods is given in Guide D6169. Samples shall be preserved and transported in accordance with these requirements; for soils follow Group C in Practice D4220, while for rock follow either "special care" or "soil-like care," as appropriate in Practice D5079. Specimens obtained by tube sampling or coring may be tested without trimming except for cutting the end surfaces plane and perpendicular to the longitudinal axis of the specimen, provided soil characteristics are such that no significant disturbance results from sampling. Where the sampling operation has caused disturbance of the soil, the disturbed material shall be trimmed. Where removal of pebbles or crumbling resulting from trimming causes voids on the surface of the specimen that cause the length or diameter to vary by more than ±5 %, the voids shall be filled with remolded material obtained from the trimmings. The ends of the test specimen shall be cut and not troweled (troweling can seal off cracks, slickensides, or other secondary features that might conduct water flow). Specimens shall be trimmed, whenever possible, in an environment where changes in water content are minimized. A controlled high-humidity room is usually used for this purpose. The mass and dimensions of the test specimen shall be determined to the tolerances given in 5.8 and 5.9. The test specimen shall be mounted immediately in the permeameter. The water content of the trimmings shall be determined in accordance with Method D2216, to the nearest 0.1 % or better.

8.3 *Laboratory-Compacted Specimens*—The material to be tested shall be prepared and compacted inside a mold in a manner specified by the requester. If the specimen is placed and compacted in layers, the surface of each previously-compacted layer shall be lightly scarified (roughened) with a fork, ice pick, or other suitable object, unless the requester specifically states that scarification is not to be performed. Test Methods D698 and D1557 describe two methods of compaction, but any other method specified by the requester may be used as long as the method is described in the report. Large clods of material should not be broken down prior to compaction unless it is known that they will be broken in field construction, as well, or the requester specifically requests that the clod size be reduced. Neither hard clods nor individual particles of the material shall exceed ⅙ of either the height or diameter of the specimen. After compaction, the test specimen shall be removed from the mold, the ends scarified, and the dimensions and weight determined within the tolerances given in 5.8 and 5.9. After the dimensions and mass are determined, the test specimen shall be immediately mounted in the permeameter. The water content of the trimmings shall be determined in accordance with Method D2216 to the nearest 0.1 % or better.

8.4 *Other Preparation Methods*—Other methods of preparation of a test specimen are permitted if specifically requested. The method of specimen preparation shall be identified in the data sheet(s)/form(s).

8.5 After the height, diameter, mass, and water content of the test specimen have been determined, the dry unit weight shall be calculated. Also, the initial degree of saturation shall be estimated (this information may be used later in the back-pressure stage).

8.6 In some cases, the horizontal hydraulic conductivity of a sample needs to be determined. In that case, the specimen may be trimmed such that its longitudinal axis is perpendicular to the longitudinal axis of the sample. Obtaining a specimen having a diameter of 36 mm (1.4 in.) typically requires a cylindrical sample with a diameter equal to or greater than about 70 mm (2.8 in.) or a rectangular sample with a minimum dimension of about 40 mm (1.6 in.).

9. Procedure

9.1 *Specimen Setup:*

9.1.1 Cut two filter paper sheets to approximately the same shape as the cross section of the test specimen. Soak the two porous end pieces and filter paper sheets, if used, in a container of permeant water.

9.1.2 Place the membrane on the membrane expander. Apply a thin coat of silicon high-vacuum grease to the sides of the end caps. Place one porous end piece on the base and place one filter paper sheet, if used, on the porous end piece, followed by the test specimen. Place the second filter paper sheet, if used, on top of the specimen followed by the second porous end piece and the top cap. Place the membrane around the specimen, and using the membrane expander or other suitable O-ring expander, place one or more O-rings to seal the membrane to the base and one or more additional O-rings to seal the membrane to the top cap.

9.1.3 Attach flow tubing to the top cap, if not already attached, assemble the permeameter cell, and fill it with de-aired water or other cell fluid. Attach the cell pressure reservoir to the permeameter cell line and the hydraulic system to the influent and effluent lines. Fill the cell pressure reservoir with deaired water, or other suitable liquid, and the hydraulic system with deaired permeant water. Apply a small confining pressure of 7 to 35 kPa (1 to 5 psi) to the cell and apply a pressure less than the confining pressure to both the influent and effluent systems, and flush permeant water through the flow system. After all visible air has been removed from the flow lines, close the control valves. At no time during saturation of the system and specimen or hydraulic conductivity measurements shall the maximum applied effective stress be allowed to exceed that to which the specimen is to be consolidated.

9.2 *Specimen Soaking (Optional)*—To aid in saturation, specimens may be soaked under partial vacuum applied to the top of the specimen. Water under atmospheric pressure shall be applied to the specimen base through the influent lines, and the magnitude of the vacuum set to generate a hydraulic gradient across the specimen less than that which will be used during hydraulic conductivity measurements.

NOTE 7—Soaking under vacuum is applicable when there are continuous air voids in the specimen for example, specimens having a degree of saturation of less than about 85%. The specimen may swell when exposed to water; the effective stress will tend to counteract the swelling. However, for materials that tend to swell, unless the applied effective stress is greater than or equal to the swell pressure, the specimen will swell. In addition, see Note 5.

9.3 *Back-Pressure Saturation*—To saturate the specimen, back pressuring is usually necessary. Fig. 5 (**9**) provides guidance on back pressure required to attain saturation. Additional guidance on the back-pressure process is given by Black and Lee (**10**) and Head (**11**).

NOTE 8—The relationships presented in Fig. 5 are based on the assumption that the water used for back pressuring is deaired and that the only source for air to dissolve into the water is air from the test specimen. If air pressure is used to control the back pressure, pressurized air will dissolve into the water, thus reducing the capacity of the water used for back pressure to dissolve air located in the pores of the test specimen. The problem is minimized by using a long (>5 m) tube that is impermeable to air between the air-water interface and test specimen, by separating the back-pressure water from the air by a material or fluid that is relatively impermeable to air, by periodically replacing the back-pressure water with deaired water, or by other means.

9.3.1 During the saturation process, any change in the volume (swelling or compression of the void ratio, density, etc.) of the test specimen should be minimized. The easiest way to verify that volume changes are minor is to measure the height of the specimen during the back-pressuring process. Volume changes are considered minor if the resulting change in hydraulic conductivity is less than about one-half the acceptable error of 25 % given in 9.5.4, unless more stringent control on density or hydraulic conductivity, or both, is required. For this to occur the axial strain should be less than about 0.4 % for normally consolidated soils, or about 0.1 % for overconsolidated soils. See Appendix X2.

9.3.2 Take and record an initial reading of specimen height, if being monitored. Open the flow line valves and flush out of the system any free air bubbles using the procedure outlined in 9.1.3. If an electronic pressure transducer or other measuring device is to be used during the test to measure pore pressures or applied hydraulic gradient, bleed any trapped air from the device.

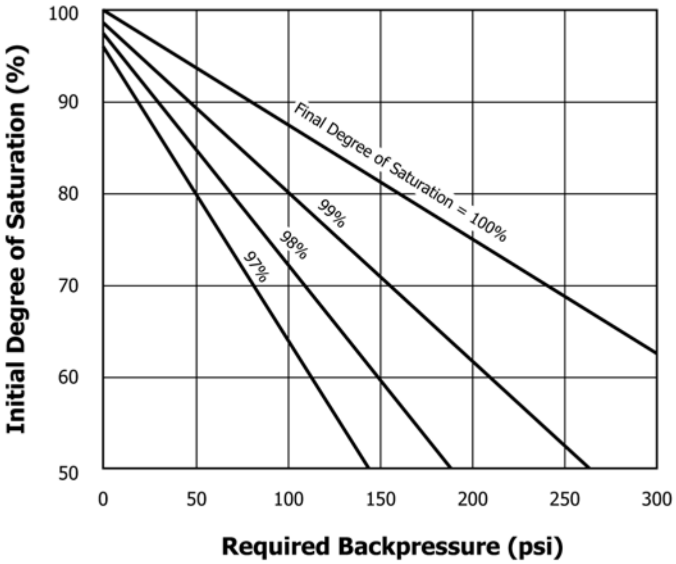


FIG. 5 Back Pressure to Attain Various Degrees of Saturation (9)

9.3.3 Adjust the applied confining pressure to the value to be used during saturation of the specimen. Apply back pressure by simultaneously increasing the cell pressure and the influent and effluent pressures in increments. The maximum value of an increment in back pressure shall be sufficiently low such that no point in the specimen is exposed to an effective stress in excess of that to which the specimen will be subsequently consolidated. At no time shall a head be applied such that the effective confining stress is <7 kPa (1 psi) because of the danger of separation of the membrane from the test specimen. Maintain each increment of pressure for a period of a few minutes to a few hours, depending upon the characteristics of the specimen. To assist in removal of trapped air, a small hydraulic gradient may be applied across the specimen to induce flow.

9.3.4 Saturation shall be verified with one of the three following techniques:

9.3.4.1 Saturation may be verified by measuring the *B* coefficient as described in Test Method D4767 (see Note 9). The test specimen shall be considered to be adequately saturated if the *B* value is ≥0.95, or for relatively incompressible materials, for example, rock, if the *B* value remains unchanged with application of larger values of back pressure. The *B* value may be measured prior to or after completion of the consolidation phase (see 9.4). An accurate *B*-value determination can only be made if no gradient is acting on the specimen and all pore-water pressure induced by consolidation has dissipated. That is, conform completion of primary consolidation before this determination; see Test Method D2435 or D4767 on how to confirm completion of primary consolidation.

NOTE 9—The *B* coefficient is defined for this type of test as the change in pore-water pressure in the porous material divided by the change in confining pressure. Compressible materials that are fully saturated with water will have a *B* value of 1.0. Relatively incompressible, saturated materials have *B* values that are somewhat less than 1.0 (**12**).

9.3.4.2 Saturation of the test specimen may be confirmed at the completion of the test by calculation of the final degree of saturation. The final degree of saturation shall be 100 ± 5 %. However, measurement of the *B* coefficient as described in 9.3.4.1 or use of some other technique (9.3.4.3) is strongly recommended because it is much better to confirm saturation prior to permeation than to wait until after the test to determine if the test was valid.

9.3.4.3 Other means for verifying saturation, such as observing the flow of water into the specimen when the back pressure is increased, can be used for verifying saturation provided data are available for similar materials to establish that the procedure used confirms saturation as required in 9.3.4.1 or 9.3.4.2.

9.4 *Consolidation*—The specimen shall be consolidated to the effective stress specified by the requester. Consolidation shall be accomplished in stages, with the increase in cell pressure minus back pressure (effective stress) in each new stage equal to or less than the effective stress in the previous stage that is, consolidation increment ratio of one or less.

NOTE 10—The test specimen may be consolidated prior to application of back pressure. Also, the back pressure and consolidation phases may be completed concurrently if back pressures are applied sufficiently slowly to minimize potential for overconsolidation of the specimen.

9.4.1 Record the specimen height, if being monitored, prior to application of consolidation pressure and periodically during consolidation.

9.4.2 Increase the cell pressure to the level necessary to develop the desired effective stress, and begin consolidation. Drainage may be allowed from the base or top of the specimen, or simultaneously from both ends.

9.4.3 (Optional) Record outflow volumes to confirm that primary consolidation has been completed prior to initiation of the hydraulic conductivity test. Alternatively, measurements of the change in height of the test specimen can be used to confirm completion of consolidation.

NOTE 11—The procedure in 9.4.3 is optional because the requirements of 9.5 ensure that the test specimen is adequately consolidated during permeation because if it is not, inflow and outflow volumes will differ significantly. However, for accurate *B*-value determination, saturation should be confirmed at the completion of consolidation (see 9.3.4.1). Recording outflow volumes or height changes is recommended as a means for verifying the completion of consolidation prior to initialization of permeation. Also, measurements in the change in height of the test specimen, coupled with knowledge of the initial height, provide a means for checking the final height of the specimen.

9.5 *Permeation:*

9.5.1 *Hydraulic Gradient*—When possible, the hydraulic gradient ($i = \Delta h/L$, for definitions of notation see 10.1) used for hydraulic conductivity measurements should be similar to that expected to occur in the field. In general, hydraulic gradients from <1 to 5 cover most field conditions. However, the use of small hydraulic gradients can lead to very long testing times for materials having low hydraulic conductivity (less than about 1×10^{-8} m/s). Somewhat larger hydraulic gradients are usually used in the laboratory to accelerate testing, but excessive gradients must be avoided because high seepage pressures may consolidate the material, material may be washed from the specimen, or fine particles may be washed downstream and plug the effluent end of the test specimen. These effects could increase or decrease hydraulic conductivity. If no gradient is specified by the requestor, the following guidelines may be followed:

Hydraulic Conductivity, m/s	Recommended Maximum Hydraulic Gradient
1×10^{-5} to 1×10^{-6}	2
1×10^{-6} to 1×10^{-7}	5
1×10^{-7} to 1×10^{-8}	10
1×10^{-8} to 1×10^{-9}	20
less than 1×10^{-9}	30

9.5.1.1 A higher gradient than given above may be used if the higher gradient can be shown not to change the hydraulic conductivity. For example, on a representative specimen, perform a hydraulic conductivity determination at $i = 30$ than at $i = 50$ or 100, or more. Determine which, if any, of the hydraulic conductivities (*k*) determined at these gradients are similar (that is, within the acceptable steady-state range given for the Method (A, B, C, D, E, or F). Any gradient equal to or less than the highest gradient yielding a similar hydraulic conductivity may be used for testing.

NOTE 12—Seepage pressures associated with large hydraulic gradients can consolidate soft, compressible specimens and reduce their hydraulic conductivity. Smaller hydraulic gradients (<10) may be necessary for such specimens.

9.5.2 *Initialization*—Initiate permeation of the specimen by increasing the influent (headwater) pressure (see 9.3.3). The effluent (tailwater) pressure shall not be decreased because air bubbles that were dissolved by the specimen water during backpressuring may come out of solution if the pressure is decreased. The back pressure shall be maintained throughout the permeation phase.

9.5.2.1 The maximum increase in headwater pressure cannot exceed 95 % of the effective consolidation stress. Alternatively, the difference between the cell pressure and the total headwater pressure cannot be less than 5 % of the effective consolidation stress.

9.5.2.2 At the start and end of each permeation trial, at t_1 and t_2, read and record the test temperature to the nearest 0.1°C. See Section 10. If the number of significant digits in the calculation of hydraulic conductivity at 20°C can be one, then the test temperature can be measured to the nearest degree Celsius.

9.5.3 *Time Measurements*—Measure and record the time at the start and end of each permeation trial (or its interval) to two or more significant digits. That is the time interval has to be greater than 9 s unless the time is recorded to the nearest 0.1 s.

9.5.4 *Constant Head Tests:*

9.5.4.1 *(Method A)*—Measure and record the required head loss across the tolerances and significant digits stated in 5.1.1 and 5.2.3 at the start and end of each permeation trial (as a minimum). The head loss across the permeameter shall be kept constant to ±5 % or better. Measure and record periodically the quantity of inflow as well as the quantity of outflow to a minimum of three significant digits. Also measure and record any changes in height of the test specimen, if being monitored (see Note 12). Continue permeation until at least four values of hydraulic conductivity are obtained over an interval of time in which: (*1*) the ratio of outflow to inflow rate is between 0.75 and 1.25, and (*2*) the hydraulic conductivity is steady. The hydraulic conductivity shall be considered steady if four or more consecutive hydraulic conductivity determinations fall within ±25 % or better of the mean value for $k \geq 1 \times 10^{-10}$ m/s or within ±50 % or better for $k < 1 \times 10^{-10}$ m/s, and a plot or tabulation of the hydraulic conductivity versus time shows no significant upward or downward trend.

9.5.4.2 *Method E (Constant Volume)*—Measure and record the required head loss across the permeameter to the tolerances and significant digits stated in 5.1.4. The head loss across the permeameter shall be kept constant to ±5 % or better. Measure and record, to a minimum of three significant digits, the quantity of either inflow (influent) or outflow (effluent). In this measurement the last digit may be due to estimation, see 5.1.1.1. In addition, measure and record any changes in the height of the test specimen, if being monitored (see Note 12). Continue permeation until at least two or more values of hydraulic conductivity (k) are steady. The hydraulic conductivity shall be considered steady if two or more consecutive k determinations fall within ±15 % or better of the mean value (two or more determinations) for $k \geq 1 \times 10^{-10}$ m/s or within ±50 % or better for $k < 1 \times 10^{-10}$ m/s.

9.5.5 *Falling-Head Tests (Methods B, C, and F)*—Measure and record the required head loss across the permeameter to the tolerances and significant digits stated in 5.1.2. Measure and record these head losses at the start and end of each permeation trial (as a minimum). At no time shall the applied head loss across the specimen be less than 75 % of the initial (maximum) head loss during the hydraulic conductivity determination (see Note 13). At the start and end of each trial, as a minimum, measure and record any changes in the height of the test specimen, if being monitored. To meet these requirements, especially for Method F, the initial head loss in each trial will most likely have to be reset to the same value (±5 %) used in the first trial. In addition, the "75 % criterion" mentioned above has to be adhered to closely.

9.5.5.1 *Methods B and C*—The volumes of outflow and inflow shall be measured and recorded to three significant digits (the last digit may be due to estimation, see 5.1.1.1). Measure and record these volumes at the start and end of each permeation trial (as a minimum). Continue permeation until at least four values of hydraulic conductivity are obtained over an interval of time in which: the ratio of outflow to inflow rate is between 0.75 and 1.25, and the hydraulic conductivity is steady (see 9.5.4.1).

NOTE 13—When the water pressure in a test specimen changes and the applied total stress is constant, the effective stress in the test specimen changes, which can cause volume changes that can invalidate the test results. The requirement that the head loss not decrease very much is intended to keep the effective stress from changing too much. For extremely soft, compressible test specimens, even more restrictive criteria may be needed. Also, when the initial and final head losses across the test specimen do not differ by much, great accuracy is needed to comply with the requirement of 5.1.2 that the ratio of initial to final head loss be determined with an accuracy of ±5 % or better. When the initial and final head loss over an interval of time do not differ very much, it may be possible to comply with the requirements for a constant head test (9.5.4) in which the head loss must not differ by more than ±5 % and to treat the test as a constant head test.

9.5.5.2 *Method F (Constant Volume)*—Continue permeation until at least two or more values of hydraulic conductivity (k) meet the requirements stated in 9.5.4.2.

9.5.6 *Constant Rate of Flow Tests (Method D)*—Initiate permeation of the specimen by imposing a constant flow rate. Choose the flow rate so the hydraulic gradient does not exceed the value specified, or if none is specified, the value recommended in 9.5.1. Periodically measure the rate of inflow, the rate of outflow, and head loss across the test specimen to the tolerances and significant digits given in 5.1.3. Also, measure and record any changes in specimen height, if being monitored. Continue permeation until at least four values of hydraulic conductivity are obtained over an interval of time in which the ratio of inflow to outflow rates is between 0.75 and 1.25, and hydraulic conductivity is steady (see 9.5.4.1).

9.6 *Final Dimensions of the Specimen*—After completion of permeation, reduce the applied confining, influent, and effluent pressures in a manner that does not generate significant volume change of the test specimen. Then carefully disassemble the permeameter cell and remove the specimen. Measure and record the final height, diameter, and total mass of the specimen. Then determine the final water content of the specimen by the procedure of Method D2216. Dimensions and mass of the test specimen shall be measured to the tolerances specified in 5.8 and 5.9.

NOTE 14—The specimen may swell after removal of back pressure as a result of air coming out of solution. A correction may be made for this effect, provided that changes in the length of the specimen are monitored during the test. The strain caused by dismantling the cell is computed from the length of the specimen before and after dismantling the cell. The same strain is assumed to have occurred in the diameter. The corrected diameter and actual length before the back pressure was removed are used to compute the volume of the test specimen prior to dismantling the cell. The volume prior to dismantling the cell is used to determine the final dry density and degree of saturation.

10. Calculation

10.1 *Constant Head and Constant Rate of Flow Tests:*

10.1.1 *Methods A and D*—Calculate the hydraulic conductivity, *k*, as follows:

$$k = \frac{\Delta Q \cdot L}{A \cdot \Delta h \cdot \Delta t} \qquad (1)$$

where:

k = hydraulic conductivity, m/s,
ΔQ = quantity of flow for given time interval Δt, taken as the average of inflow and outflow, m^3,
L = length of specimen, m,
A = cross-sectional area of specimen, m^2,
Δt = interval of time, *s*, over which the flow ΔQ occurs $(t_2 - t_1)$,
t_1 = time at start of permeation trial, date: hr:min:sec,
t_2 = time at end of permeation trial, date:hr:min:sec,
Δh = average head loss across the permeameter/specimen $((\Delta h_1 + \Delta h_2)/2)$, m of water,
Δh_1 = head loss across the permeameter/specimen at t_1, m of water, and
Δh_2 = head loss across the permeameter/specimen at t_2, m of water.

NOTE 15—The interval of time, Δt, can be measured directly using a stop watch or equivalent device, see 11.5.1. Units other than second(s), meters (m), etc., may be used providing an appropriate unit conversion factor (UCF) is used so *k* is in m/s or other units, if requested or customary (see Section 11).

10.1.2 *Method E*—Use the above Eq 1. If the height of the mercury column in the "Constant Head" tube is used to determine the head loss, Δh, use the following equation.

$$\Delta h = \Delta H_{Hg} \cdot \left(\frac{\rho_{Hg}}{\rho_w} - 1 \right) = \Delta H_{Hg} \cdot (G_{Hg} - 1) \qquad (2)$$

where:

ΔH_{Hg} = the peak to peak height of mercury column (see Fig. 2), m, and
ρ_{Hg} = the density of mercury, g/cm^3,
ρ_{wg} = the density of water, g/cm^3,
G_{Hg} = the ratio of the density of mercury to the density of water (specific gravity of mercury) at the test/trial temperature. See Table 1.

NOTE 16—For the constant-volume hydraulic systems, there is no head loss across the permeameter/specimen due to elevation head. Units other than seconds (s), meters (m), etc., may be used providing an appropriate UCF is used so *k* is in m/s or other units, if requested or customary (see Section 11).

TABLE 1 Specific Gravity of Mercury (G_{Hg})

Temperature (°C)	$G_{Hg} = (\rho_{Hg}/\rho_w)$
15	13.570
16	13.570
17	13.570
18	13.570
19	13.570
20	13.570
21	13.571
22	13.571
23	13.572
24	13.573
25	13.574
26	13.575
27	13.576
28	13.577
29	13.579
30	13.580

10.2 *Falling-Head Tests:*

10.2.1 *Constant Tailwater Pressure (Method B)*—Calculate the hydraulic conductivity, *k*, as follows:

$$k = \frac{a \cdot L}{A \cdot \Delta t} ln\left(\frac{\Delta h_1}{\Delta h_2} \right) \qquad (3)$$

where:

a = cross-sectional area of the reservoir containing the influent liquid, m^2, and
ln = natural logarithm (base e = 2.71828).

See Note 15.

10.2.2 *Increasing Tailwater Pressure (Method C)*—Calculate the hydraulic conductivity, *k*, as follows:

$$k = \frac{a_{in} \cdot a_{out} \cdot L}{(a_{in} + a_{out}) \cdot A \cdot \Delta t} ln\left(\frac{\Delta h_1}{\Delta h_2} \right) \qquad (4)$$

where:

a_{in} = cross-sectional area of the reservoir containing the influent/inflow liquid, m^2, and
a_{out} = cross-sectional area of the reservoir containing the effluent/outflow liquid, m^2.

See Note 15.

NOTE 17—For the case in which $a_{out} = a_{in} = a$, the equation for calculating *k* for a falling head test with a rising tailwater level is:

$$k = \frac{a \cdot L}{2 \cdot A \cdot \Delta t} ln\left(\frac{\Delta h_1}{\Delta h_2} \right) \qquad (5)$$

where:

a = area of the reservoirs containing either the influent/inflow or effluent/outflow liquid, m^2

10.2.3 *Constant-Volume System (Method F)*—Calculate the hydraulic conductivity, *k*, as follows:

$$k = \left(\frac{a_{in} \cdot a_{out}}{(a_{out} + a_{in})} \cdot \frac{1}{(G_{Hg} - 1)} \right) \cdot \frac{L}{A} \cdot \frac{1}{\Delta t} \cdot ln\left(\frac{\Delta h_1}{\Delta h_2} \right) \qquad (6)$$

10.2.3.1 If the differential elevation between the top surfaces of the mercury level in the headwater and tailwater tubes is used to determine the head loss, Δh, use the following equations.

a) For the head loss at the start of the permeation trial, h_1:

$$h_1 = (\Delta H_{Hg,1} + \Delta H_{Hg,c}) \cdot \left(\frac{\rho_{Hg}}{\rho_w} - 1 \right) = (\Delta H_{Hg,1} + \Delta H_{Hg,c}) \cdot (G_{Hg} - 1) \qquad (7)$$

where:

$\Delta H_{Hg,1}$ = difference in elevation between the top surfaces of the mercury level in the tailwater and headwater tubes at the start of the permeation trial, t_1 (see Fig. 3), m, and

$\Delta H_{Hg,c}$ = difference in elevation of mercury in the headwater and tailwater tubes of the manometer with equal pressures applied to both tubes, m. This value is positive if the inside diameter (ID) of the headwater tube is larger than the ID of the tailwater tube, and negative if the opposite is true. A discussion on capillary head is given in Appendix X1, X1.2.3.2 and X1.4. See Note 16.

b) For the head loss at the end of the permeation trial, Δh_2,:

$$\Delta h_2 = \Delta h_1 + \left(\left(-\Delta Hg_{tail} \right) \cdot \left(\frac{a_{out}}{a_{in}} + 1 \right) \cdot \left(G_{Hg} - 1 \right) \right) \tag{8}$$

where:

$-\Delta Hg_{tail}$ = the negative change in elevation of the mercury levels in the tailwater tube during the permeation trial, m.

The reason why ΔHg_{tail} is used instead of $\Delta Hg_{Hg,2}$ (difference in mercury levels at end of trial) is explained in Appendix X1, X1.3.2.1.

10.3 *Hydraulic Conductivity at Standard Temperature*—Correct the hydraulic conductivity to that for 20°C (68°F), k_{20}, by multiplying k by the ratio of the viscosity of water at test temperature to the viscosity of water at 20°C (68°F), R_T:

$$k_{20} = R_T \cdot K \tag{9}$$

with

$$R_T = 2.2902 \left(0.9842^{\,T} \right) / T^{\,0.1702} \tag{10}$$

where:

k_{20} = hydraulic conductivity corrected to 20°C, m/s

R_T = ratio of the viscosity of water at test temperature to the viscosity of water at 20°C

T = average test temperature during the permeation trial $((T_1 + T_2)/2)$, to the nearest 0.1°C.

T_1 = test temperature at start of permeation trial, to nearest 0.1°C, and

T_2 = test temperature at end of permeation trial, to nearest 0.1°C

10.3.1 The equation for R_T is only accurate to three significant digits between 5 and 50°C (41 and 122°F), see 1.1.

10.3.2 If the number of significant digits in the calculation of hydraulic conductivity at 20°C can be one, then the test temperature can be measured to the nearest °C.

11. Report: Test Data Sheet(s)/Form(s)

11.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.5.

11.2 Record as a minimum the following general information (data):

11.2.1 Sample/specimen identifying information, such as Project No., Boring No., Sample No., Depth, etc.

11.2.2 Any special selection and preparation process, such as removal of gravel or other materials, or identification of their presence, if "intact" specimen.

11.2.3 If the specimen is reconstituted, remolded or trimmed in a specialized manner (determine horizontal hydraulic conductivity, see 8.6), provide information on method of reconstitution, remolding, etc.

11.2.4 Name or initials of the person performing the test.

11.3 Record as a minimum the following test specimen data:

11.3.1 The measured specific gravity test (Test Method D854) or assumed value.

11.3.2 The initial mass, dimensions (length and diameter), area, and volume of the specimen, to either three or four significant digits (see 8.1 and 8.1.1).

11.3.3 The initial water content (nearest 0.1 percent), dry unit weight (three or four significant digits, see 8.1.1) and saturation (nearest percent) of the test specimen.

11.3.4 The final mass, dimensions (length and diameter), area, and volume of the specimen, to either three or four significant digits (see 8.1 and 8.1.1).

11.3.5 The final water content (nearest 0.1 percent), dry unit weight (three or four significant digits, see 8.1.1) and saturation (nearest percent) of the test specimen.

11.4 Record as a minimum the following test boundary conditions:

11.4.1 The type of permeant liquid used.

11.4.2 The magnitude of total back pressure (two significant digits or three if used in the head loss determination).

11.4.3 The effective consolidation stress (two or more significant digits).

11.4.4 The area of the headwater and tailwater tubes (such as burettes, reservoirs, U-tube manometers, etc.), as applicable (three or more significant digits).

11.4.5 The length (L) and area (A) of the test specimen during permeation (minimum of three significant digits).

11.4.5.1 These values can be determined based on either *a)* the initial dimensions of specimen plus any length/height and volume changes occurring during saturation and consolidation; or *b)* final dimensions of the test specimen, see 11.3.4.

11.5 Record as a minimum the following permeation data:

11.5.1 The date, time (or start and elapsed time), temperature (nearest 0.1°C see 10.3.2), head loss reading(s), flow reading(s) (if applicable), and deformation gage (if applicable) at the start and end of each trial/determination. Applicable measurements/readings and any averages/differences calculated using measurements/readings obtained shall have two or more significant digits, unless specified differently in Section 9.

11.5.2 The calculated initial hydraulic gradient and ending value if falling head Method B, C, or F is being used, and the hydraulic conductivity to two or more significant digits.

11.5.3 The average corrected hydraulic conductivity (k_{20}, see 10.3) for the values meeting the applicable requirements in 9.5.4 to 9.5.6. Record this value to two or three significant digits in units of m/s or other units, if requested or customary, for example, 7.1×10^{-10} or 7.13×10^{-10}m/s.

11.5.4 A graph or table of hydraulic conductivity versus time or pore volumes of flow is recommended, unless a constant-volume hydraulic system is used.

12. Precision and Bias

12.1 *Precision*—The precision of this test method is based on an interlaboratory study of D5084, Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter, conducted in 2008. Each of twelve laboratories tested three different soil types:

ML-1: Vicksburg silt (ASTM Reference Soil ML-1)
CH-1: Vicksburg clay (ASTM Reference Soil CH-1)
CL-1: Annapolis clay (ASTM Reference Soil CL-1)

All three soils are from the D18 ISR Reference Soils and Testing Program. Index properties for the soils are shown in Table 2. These properties are from the ASTM Reference Soils and Testing Program.

Every "test result" represents an individual determination. Each laboratory reported three replicate test results for the analyses. Practice E691 was followed for the design and analysis of the data; the details are given in ASTM Research Report RR:D18-D1018.[5]

12.1.1 *Repeatability Limit (r)*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "r" value for that material; "r" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

12.1.1.1 Repeatability limits are listed in Table 3.

12.1.2 *Reproducibility Limit (R)*—Two test results shall be judged not equivalent if they differ by more than the "R" value for that material; "R" is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

12.1.2.1 Reproducibility limits are listed in Table 3.

12.1.3 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice E177.

12.1.4 Any judgment in accordance with statements 12.1.1 and 12.1.2 would have an approximately 95 % probability of being correct.

12.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method. Therefore no statement on bias is being made.

12.3 The precision statement was determined through statistical examination of 104 results, from twelve laboratories, on the three soils described in 12.1.

13. Keywords

13.1 coefficient of permeability; constant head; constant rate of flow; constant volume; falling head; hydraulic barriers; hydraulic conductivity; liner; permeability; permeameter

TABLE 2 Index Properties for ASTM Reference Soils Used in Interlaboratory Study on Saturated Hydraulic Conductivity

ASTM Reference Soil ID	Liquid Limit per D4318 (%)	Plasticity Index per D4318 (%)	Specific Gravity of Soils per D854 (-)	Percent Finer than No. 200 Sieve per D1140 (%)
ML-1	27.3 ± 2.5	3.9 ± 4.5	2.725 ± 0.043	99.0 ± 0.3
CL-1	33.2 ± 1.4	13.4 ± 3.7	2.675 ± 0.030	88.5 ± 0.8
CH-1	59.7 ± 2.8	39.3 ± 7.0	2.726 ± 0.032	98.8 ± 0.4

TABLE 3 Hydraulic Conductivity Statistics from ILS Report RR:D18-D1018 (All Units in cm/s)

ILS Soil	Average $\bar{\chi}$	Repeatability Standard Deviation s_r	Reproducibility Standard Deviation s_R	Repeatability Limit r	Reproducibility Limit R
ML-1	1.2×10^{-6}	3.3×10^{-7}	4.4×10^{-7}	9.3×10^{-7}	1.2×10^{-6}
CL-1	3.8×10^{-8}	4.4×10^{-9}	6.2×10^{-9}	1.2×10^{-8}	1.8×10^{-8}
CH-1	3.6×10^{-9}	2.9×10^{-9}	4.7×10^{-9}	8.2×10^{-9}	1.3×10^{-8}

---

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D18-1018.

APPENDIXES

(Nonmandatory Information)

X1. DEVELOPMENT OF HYDRAULIC CONDUCTIVITY EQUATION FOR THE MERCURY CONSTANT VOLUME-FALLING HEAD HYDRAULIC SYSTEM

X1.1 *Introduction*—A schematic of a mercury constant volume-falling head hydraulic system is given in Fig. 4. In this figure, the falling head is applied by the difference in elevation between the mercury levels in the tailwater and headwater tubes of the mercury U-tube manometer. In designing this type of hydraulic system, the area of the tailwater tube (a_{out}) is made significantly smaller than that of the headwater tube (a_{in}). This is done for three reasons:

First, to increase the sensitivity of the flow/volume measurement;

Second, to decrease the time required to measure the hydraulic conductivity; and,

Third, so one can clean the hydraulic system by flushing water through the tailwater tube and out the headwater tube of the mercury U-tube manometer without loosing mercury.

X1.1.1 The tubing lines leading from the test specimen to mercury U-tube manometer are filled with water, as well as the spaces above the mercury in the manometer. Therefore, the volume of the saturated test specimen remains constant during permeation. This occurs because the components (water, tubing, and manometer) of the hydraulic system are relatively incompressible compared to soil. In addition, there is continuity of inflow and outflow of permeant water during permeation.

X1.1.2 The presentation of determining heads and head losses in a mercury constant volume-falling head hydraulic system is presented before the development of the hydraulic conductivity equation. This allows one to become familiar with the notation and required parameters before addressing that relatively complicated equation development process. The heads involved are the total head (H), pressure head (H_p), elevation head (H_e), capillary head (H_c), velocity head (H_v), and total head loss (Δh).

X1.2 *Determination of Total Head and Total Head Loss*

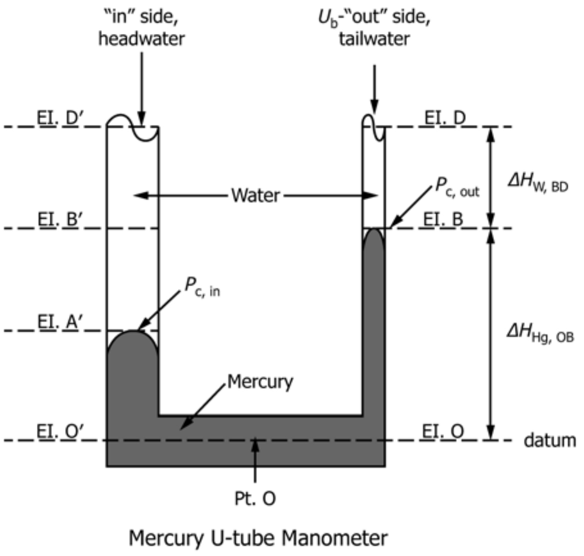
X1.2.1 *Total Head*—The total head is equal to the sum of the pressure head (H_p), elevation head (H_e), velocity head (H_v), and capillary head (H_c). Usually it is expressed in height of water, such as m or cm of water. In addition, the velocity head is assumed to be zero/insignificant providing the conditions specified in 4.4 through 5.2.3.2 are met. The pressure head is the height of a vertical column of static water that can be supported by the static pressure (p) at a given point. It may be expressed as

$$H_p = \text{UCF}\cdot\frac{p}{\rho_w \cdot g} \qquad \text{(X1.1)}$$

where:

H_p = the pressure head at given point (units of vertical height of water column, m),
UCF = a unit conversion factor,
p = the static pressure at a given point (units of force per unit area, kPa),
ρ_w = the density of the water (units of mass per unit volume, Mg/m^3), and
g = the acceleration of gravity, convert mass to force (9.80665 m/s^2 or 980.665 cm/s^2).

X1.2.2 The static pressure at any point within a confined fluid may be calculated as shown in Fig. X1.1, assuming there



Determination of pressure for Pt. O at EL. O on the "out" or tailwater side, $p_{o,\,out}$.

$$p_{o,\,out} = \text{UCF} \cdot (OB \cdot \rho_{Hg} \cdot g + \Delta P_{c,\,out} + BD \cdot \rho_W \cdot g + U_b)$$

or

$$= \text{UCF} \cdot (\Delta H_{Hg,\,OB} \cdot \rho_{Hg} \cdot g + \Delta P_{c,\,out} + \Delta H_{W,\,BD} \cdot \rho_W \cdot g + U_b)$$

where:

UCF = a unit conversion factor,
ρ_{Hg} = the density of mercury, g/cm^3 or Mg/m^3,
ρ_w = the density of water, g/cm^3 or Mg/m^3,
g = the acceleration of gravity, m/s^2 or cm/s^2,
$\Delta P_{c,\,out}$ = the change in pressure due to capillarity at the tube-water-mercury interface in the outflow or tailwater tube, and
U_b = the applied back pressure, kPa or kN/m^2

FIG. X1.1 Static Pressure Calculations

is no drop in pressure due to velocity head loss. This figure shows that fluid pressure for Point O at elevation El. O on the "out" or tailwater side may be expressed as:

$$p_{o,\ out} \approx \mathrm{UCF}\cdot\left(\Delta H_{Hg,OB}\cdot\rho_{Hg}\cdot g+\Delta p_{\ c,out}+\Delta H_{w,BD}\cdot\rho_{w}\cdot g+U_{b}\right) \quad (X1.2)$$

or

$$p\approx \mathrm{UCF}\cdot\left(\Delta H_{Hg}\cdot\rho_{\ Hg}\cdot g+\Delta p_{c}+\Delta H_{w}\cdot\rho_{\ w}\cdot g+U_{b}\right)$$

where:

ΔH_{Hg} = the differential height of the mercury column, m,
ρ_{Hg} = the density of the mercury, Mg/m^3,
ΔH_w = the differential height of the water column, m,
Δp_c = the change in pressure due to capillarity at the tube-water-mercury interface, kPa, and
U_b = the applied back pressure, kPa.

X1.2.3 For the above case, the pressure head (in height of water) is

$$H_{p}\approx \mathrm{UCF}\cdot\left(H_{Hg}\times\frac{\rho_{Hg}\cdot g}{\rho_{w}\cdot g}+H_{w}\times\frac{\rho_{w}\cdot g}{\rho_{w}\cdot g}+\frac{\Delta p_{c}}{\rho_{w}\cdot g}+\frac{U_{b}}{\rho_{w}\cdot g}\right) \quad (X1.3)$$

or

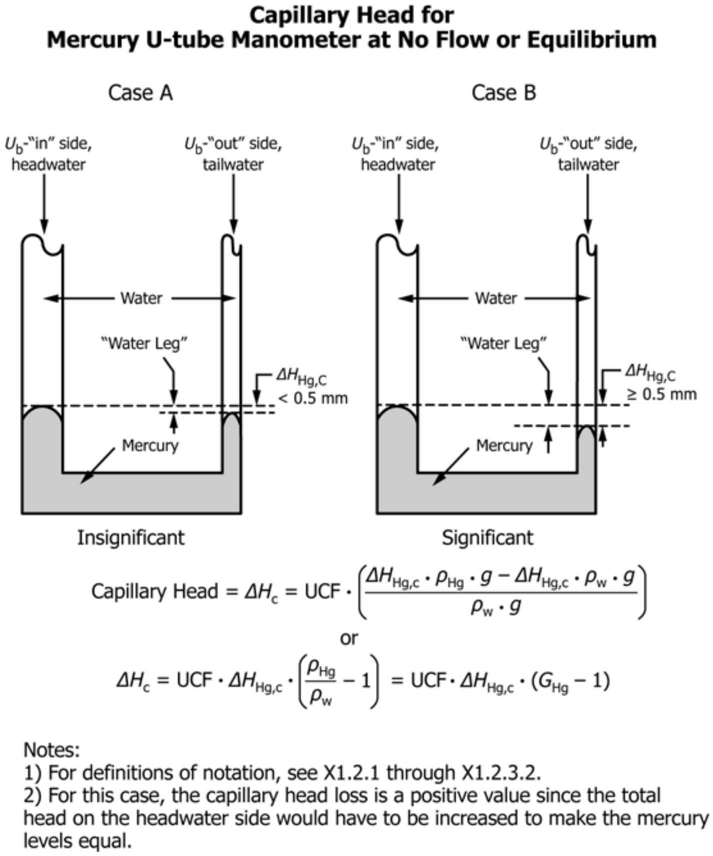
$$H_{p}\approx \mathrm{UCF}\cdot\left(H_{Hg}\times G_{Hg}+\Delta H_{w}+\Delta H_{c}+\frac{U_{b}}{\rho_{w}\cdot g}\right)$$

where:

G_{Hg} = the specific gravity of mercury at a given temperature, and
ΔH_c = the change in head due to capillarity, m of water, see X1.2.3.2

X1.2.3.1 *Velocity Head*—In most cases, the velocity head or velocity head loss is assumed equal to zero or insignificant, providing the requirements specified in 5.2.3 are met.

X1.2.3.2 *Capillary Head*—In most cases, the capillary head or capillary head loss is assumed equal to zero. However, in some mercury U-tube manometers, the difference in capillary head between the headwater and tailwater tubes; that is, the capillary head loss, ΔH_c is significant. Therefore, it has to be accounted for as shown in Fig. X1.2. To help one understand the derivation of $\Delta H_{\ c}$ in this figure, one has to remember to account for the "water leg" in the mercury U-tube manometer containing water instead of air. Subtracting away the "water leg" pressure does this. Also, the pressure difference measured



$$\text{Capillary Head} = \Delta H_c = \mathrm{UCF}\cdot\left(\frac{\Delta H_{Hg,c}\cdot\rho_{Hg}\cdot g-\Delta H_{Hg,c}\cdot\rho_{w}\cdot g}{\rho_{w}\cdot g}\right)$$

or

$$\Delta H_c = \mathrm{UCF}\cdot\Delta H_{Hg,c}\cdot\left(\frac{\rho_{Hg}}{\rho_{w}}-1\right) = \mathrm{UCF}\cdot\Delta H_{Hg,c}\cdot(G_{Hg}-1)$$

Notes:
1) For definitions of notation, see X1.2.1 through X1.2.3.2.
2) For this case, the capillary head loss is a positive value since the total head on the headwater side would have to be increased to make the mercury levels equal.

NOTE 1—For this case capillary head loss is a positive value since the total head on the head water side would have to be increased to make the mercury levels equal.

FIG. X1.2 Difference in Capillary Head in Mercury U-tube Manometer

by the manometer has to be converted to a pressure head by dividing it by $\rho_w \cdot g$. As shown in Fig. X1.2, the capillary head loss is

$$\Delta H_c = \Delta H_{Hg,c} \cdot (G_{Hg} - 1) \tag{X1.4}$$

where:

ΔH_c = capillary head loss in hydraulic system, m of water,

$\Delta H_{Hg,c}$ = differential height of mercury in the tailwater/outflow and headwater/inflow tubes of the manometer with equal pressure applied to each tube, m of mercury, and

G_{Hg} = specific gravity of mercury at test/trial temperature, see Table 1.

X1.2.3.2.1 As shown in Fig. X1.2, the application of either ΔH_c or $\Delta H_{Hg,c}$ is only necessary when $\Delta H_{Hg,c}$ is equal to or greater than 0.0005 m or 0.5 mm (0.02 in.). An explanation of how to measure ΔH_c is given in X1.4.

X1.2.4 *Total Head*—As stated above, the total head equals the sum of the pressure, elevation, velocity, and capillary heads. Since the change in velocity head is assumed to be zero and the change in capillary head is included in the pressure head calculation given above (Eq X1.3), the total head relationships at various points/elevations, as shown in Fig. X1.3, may be expressed as follows.

X1.2.4.1 Assuming there are no head losses in the tubing, the pressure head at Point Z ($H_{p,Z}$) equals the pressure head just above Point B ($H_{p,B}$), before the effect of capillary head; therefore

$$H_{p,Z} = H_{p,B} \textit{ and } H_{p,X} = H_{p,B'}$$

X1.2.4.2 By definition, the total head just above Point B equals the pressure plus elevation heads at that point, therefore

$$H_B = H_{p,B} + H_{e,OB} = \frac{U_b}{\rho_w \cdot g} + H_{e,OB}$$

and

$$H_{B'} = H_{p,B'} + H_{e,O'B'}$$

Assuming continuity in hydraulics, the pressure head at Point B' equals

$$H_{p,B'} = \frac{U_b}{\rho_w \cdot g} + \Delta H_{p,c,B} + H_{p,BA} + H_{p,AO} - H_{p,O'A'} - \Delta H_{p,c,A'} - H_{p,A'B'}$$

where:

$\Delta H_{p,c,B}$ = the change in capillary pressure head going from just above Point B to just below it, and

$\Delta H_{p,c,A'}$ = the change in capillary pressure head going from just below Point A' to just above it.

X1.3 *Total Head Loss*—Based on a detailed review of the hydraulic systems shown in Fig. X1.1, Fig. X1.2, and Fig. X1.3, one can come to the conclusion that the flow of fluid (permeant) will only occur when the difference in the mercury heights in the U-tube manometer is greater then equilibrium value, as shown in Fig. X1.2.

X1.3.1 *Initial Head Loss*—Using the total head discussion given above and the notation given in Fig. X1.3; the initial total-head loss (Δh_1) across the specimen is:

$$\Delta h_1 = H_X - H_Z = H_{B'} - H_B \tag{X1.5}$$

or

$$\Delta h_1 = H_{p,B'} - H_{p,B} =$$

$$= \frac{U_b}{\rho_w \cdot g} + \Delta H_{p,c,B} + H_{p,BA} + H_{p,AO}$$

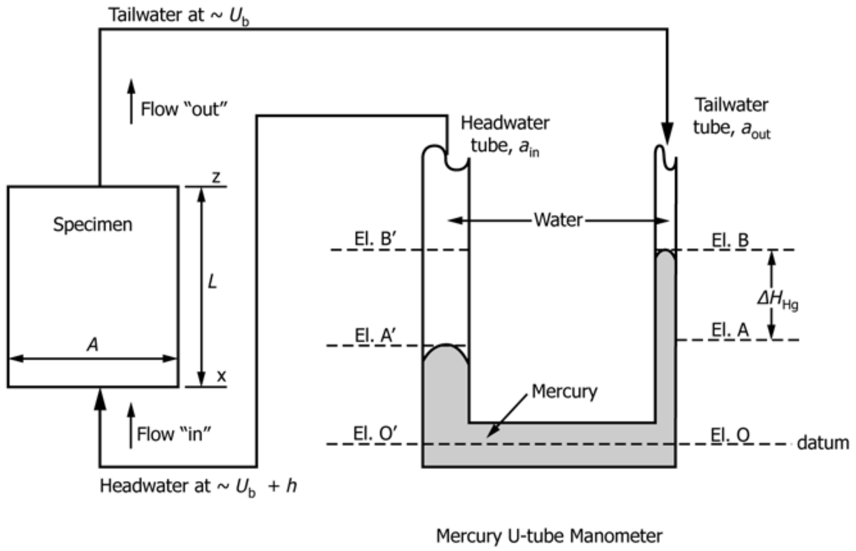


FIG. X1.3 Schematic of Mercury Constant Volume – Falling Head Hydraulic System for Head and Head Loss Equations

$$-H_{p,O'A'} - \Delta H_{p,c,A'} - H_{p,A'B'} - H_{p,B}$$

Since

$$H_{p,b} = \frac{U_b}{\rho_w \cdot g}, \tag{X1.6}$$

$$H_{p,AO} = H_{p,O'A',}\text{, and}$$

$$\Delta H_c = \Delta H_{p,c,B} - \Delta H,$$

therefore

$$\Delta h_1 = H_{p,BA} - H_{p,A'B'} + \Delta H_c \tag{X1.7}$$

Using generic notation instead of specific notation as given in Fig. X1.1 to Fig. X1.4, therefore

$$\Delta h_1 = \frac{\Delta H_{Hg,1} \cdot g}{\rho_W} - \Delta H_{Hg,1} + \Delta H_{Hg,c} \times \left(\frac{\rho_{Hg}}{\rho_W} - 1 \right) \tag{X1.8}$$

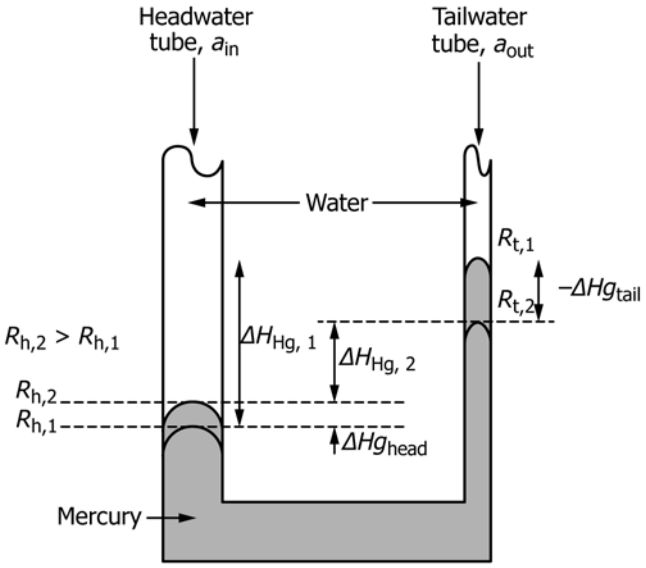
and rearranging, therefore

$$\Delta h_1 = (\Delta H_{Hg} + \Delta H_{Hg,c}) \cdot \left(\frac{\rho_{Hg}}{\rho_w} - 1 \right) \tag{X1.9}$$

$$\Delta h_1 = (\Delta H_{Hg,1} + \Delta H_{Hg,c}) \cdot (G_{Hg} - 1)$$

where:

Δh_{Hg} = the initial total-head loss at the start (t_1) of a given permeation trial, in m of water,



"Flow" Functions:

Flow "in" = $\Delta Q_{in} = \Delta Hg_{head} \cdot a_{in}$

Flow "out" = $-\Delta Q_{out} = -\Delta Hg_{tail} \cdot a_{out}$

Based on continuity, $\Delta Q_{in} = -\Delta Q_{out}$

Therefore, $\Delta Hg_{head} \cdot a_{in} = -\Delta Hg_{tail} \cdot a_{out}$

or

$$\Delta Hg_{head} = -\Delta Hg_{tail} \cdot \frac{a_{out}}{a_{in}}$$

"Head" Functions:

$$\Delta H_{Hg,2} = \Delta H_{Hg,1} + (-\Delta Hg_{tail}) - \Delta Hg_{head}$$

Substituting for ΔHg_{head},

$$\Delta H_{Hg,2} = \Delta H_{Hg,1} + (-\Delta Hg_{tail}) + \left(-\Delta Hg_{tail} \cdot \frac{a_{out}}{a_{in}} \right)$$

$$\Delta H_{Hg,2} = \Delta H_{Hg,1} + (-\Delta Hg_{tail}) \cdot \left(\frac{a_{out}}{a_{in}} + 1 \right)$$

Substituting for $\Delta H_{Hg,2}$ in the final head loss equation (X1.10) and rearranging,

$$\Delta h_2 = \left(\Delta H_{Hg,1} + \Delta H_{Hg,c} + (-\Delta Hg_{tail}) \cdot \left(\frac{a_{out}}{a_{in}} + 1 \right) \right) \cdot (G_{Hg} - 1)$$

or

$$\Delta h_2 = \Delta h_1 + \left((-\Delta Hg_{tail}) \cdot \left(\frac{a_{out}}{a_{in}} + 1 \right) \cdot (G_{Hg} - 1) \right)$$

FIG. X1.4 Relationship Between Change in Flow and Total Head Loss

ΔH_{Hg} = the initial differential height of mercury in the tailwater and headwater tubes of the manometer at the start (t_1) of a given permeation trial, in m,

$\Delta H_{Hg,c}$ = the positive differential height of mercury in the tailwater and headwater tubes of the manometer with equal pressures applied to both tubes, in m. This height differential is caused by the difference in capillary pressure heads within the two tubes making up the mercury U-tube manometer, see X1.2.3.2 and X1.4

ΔH

X1.3.2 *Final Head Loss*—The final total-head loss (Δh_2) across the specimen is

$$\Delta h_2 = (\Delta H_{Hg,2} + \Delta H_{Hg,c})\cdot(G_{Hg} - 1) \qquad \text{(X1.10)}$$

where:

Δh_2 = the final total-head loss at the end (t_2) Of a given permeation trial, in m of water,

$\Delta H_{Hg,2}$ = the final differential height of mercury in the tailwater and headwater tubes of the manometer at the end (t_2) of a given permeation trial, in m.

X1.3.2.1 The determination of $\Delta H_{Hg,2}$ requires two readings; that is, the elevation of the top surfaces of the mercury (meniscus) in the tailwater and headwater tubes. Each of these readings will have some error, especially the headwater reading. In addition, the change in the headwater readings between t_1 and t_2 is typically very small and at about the sensitivity to which readings can be made/estimated. Because of these factors, it is assumed that the accuracy of Δh_2 can increased by just measuring the change in elevation of the top surface mercury level in the tailwater tube and calculating what $\Delta H_{Hg,2}$ should be based on the area relationships between the tailwater and headwater tubes. As shown in Fig. X1.4, the following flow relationships can be established.

$$\Delta Q_{in} = \Delta Hg_{\ head}\cdot a_{in}$$

,

$$-\Delta Q_{out} = -\Delta Hg_{tail}\cdot a_{out}$$

NOTE X1.1—the symbol for height (H) has been omitted to keep the notation simpler, and

ΔQ_{in} = inflow of permeant water for given time interval (positive units of volume),

$-\Delta Q_{out}$ = outflow of permeant water for given time interval (negative units of volume),

ΔHg_{head} = positive change in elevation of the mercury level (top of meniscus) in the headwater tube (units of distance)

$-\Delta Hg_{tail}$ = negative change in elevation of the mercury level (top of meniscus) in the tailwater tube (units of distance),

a_{in} = area of the headwater/inflow tube containing mercury (units of area), and

a_{out} = area of the tailwater/outflow tube containing mercury (units of area)

Based on continuity of flow in a saturated specimen at constant volume,

$$\Delta Q\text{in} = -\Delta Q\text{out}$$

therefore,

$$\Delta Hg_{head}\cdot a_{in} = -\Delta Hg_{tail}\cdot a_{\ out} \qquad \text{(X1.11)}$$

or

$$\Delta Hg_{head} = -\Delta Hg_{tail}\cdot\frac{a_{out}}{a_{in}}$$

therefore,

$$\Delta H_{Hg,2} = \Delta H_{Hg,1} + (-\Delta Hg_{\ tail}) + \left(\ \Delta Hg_{tail}\cdot\frac{a_{out}}{a_{in}}\right) \qquad \text{(X1.12)}$$

or

$$\Delta H_{Hg,2} = \Delta H_{Hg,1} + (-\Delta Hg_{\ tail})\cdot\left(\frac{a_{\ out}}{a_{in}} + 1\right)$$

Substituting for $\Delta H_{Hg,2}$ and rearranging

$$\Delta h_2 = \left(\Delta H_{Hg,1} + \Delta H_{Hg,c} + (-\Delta Hg_{tail})\cdot\left(\frac{a_{out}}{a_{in}} + 1\right)\right)\cdot(G_{Hg} - 1) \qquad \text{(X1.13)}$$

or

$$\Delta h_2 = \Delta h_1 + \left((-\Delta Hg_{tail})\cdot\left(\frac{a_{out}}{a_{in}} + 1\right)\cdot(G_{Hg} - 1)\right)$$

X1.4 *Capillary Head Measurements*—The key to measuring the difference in capillary head (ΔH_c) between the headwater and tailwater tubes of the mercury U-tube manometer is to ensure that an equal water pressure is applied to both tubes. In addition, flow of water can occur under that equal water pressure. This can be accomplished by individually connecting the tailwater and headwater tubing lines to clean burettes containing water at equal elevation. These lines can not have any air bubbles in them. Then, apply the same air pressure to these two burettes. This air pressure should be similar to the back pressure applied during testing. Finally, adjust the height of one burette (typically the one connected to the headwater line) so the water level within each burette is equal. In making this height adjustment, make sure the water level in the headwater burette starts out below that of the tailwater burette. This simulates the direction of fluid flow during the test.

X1.4.1 Once the water level in the two burettes are level, determine the difference in elevation of the two mercury columns at the tops of their meniscuses. The mercury level in the tailwater tube (one with a smaller ID) should be below that in the headwater tube. If it is not, there is an error in applying equal pressures to the two tubes of the U-tube manometer, check for air in the lines, external pressure source, etc..

X1.4.2 If the mercury U-tube manometer being used is the version in which the tailwater tube is contained within the headwater tube, a different approach has to be used. A different approach is required since the mercury level in the tailwater tube is not visible at equilibrium. One approach would be to raise the headwater burette until the mercury levels (top of menisci) in the U-tube manometer (headwater and tailwater columns) are equal. Then determine the difference in elevation of the water levels in the headwater and tailwater burettes in m of water,

Next, convert ΔH_c to $\Delta H_{Hg,c}$ with

$\Delta H_{Hg,c} = \Delta H_c/(G_{Hg} - 1) = \Delta H_c/12.74$, in m of mercury. The value of 12.57 is good for temperatures ranging between 15°C and 25°C.

X1.5 *Falling-Head Hydraulic Conductivity Equation*—Darcy's law for hydraulic conductivity in a saturated medium requires that:

$$q = k \cdot i \cdot A = k \cdot \frac{\Delta h}{L} \cdot A \qquad \text{(X1.14)}$$

or

$$\Delta Q = k \cdot \frac{\Delta h}{L} \cdot A \cdot \Delta t$$

where:

q = rate of flow of the fluid (units of volume over time, m^3/s),
k = hydraulic conductivity or coefficient of permeability (units of length over time, m/s),
i = hydraulic gradient (no unit),
Δh = total head loss across a given length/test specimen (unit of height of water, m),
L = given length (test specimen) over which the total head loss occurs (unit of distance, m),
ΔQ = volume of flow for a given time interval (unit of volume, m^3), and
Δt = time interval (unit of time, s).

X1.5.1 For a differential volume of flow and time period, this equation becomes

$$d\Delta Q = k \cdot \frac{\Delta h}{L} \cdot A \cdot d\Delta t \qquad \text{(X1.15)}$$

where:

$d\Delta Q$ = differential volume of flow in a differential time period, and
$d\Delta t$ = differential time period.

X1.5.2 It can be demonstrated that the differential volume of flow is a function of the differential head loss, as shown below. From Fig. X1.4 or X1.3.2.1;

$$-\Delta Q = -\Delta Hg_{tail} \cdot a_{out} \qquad \text{(X1.16)}$$

or

$$-d\Delta Q = -d\Delta Hg_{tail} \cdot a_{out}$$

and from Fig. X1.4,

$$-d\Delta Hg_{tail} = \frac{dh}{1} \cdot \frac{a_{in}}{a_{out} + a_{in}} \cdot \frac{1}{(G_{Hg} - 1)} \qquad \text{(X1.17)}$$

By substituting for $-d\Delta Q$ and $-d\Delta Hg_{tail}$ from the above equations in Eq X1.15 we get,

$$-\frac{dh}{1} \cdot \frac{a_{in} \cdot a_{out}}{a_{out} + a_{in}} \cdot \frac{1}{(G_{Hg} - 1)} = k \cdot \frac{\Delta h}{L} \cdot A \cdot d\Delta t \qquad \text{(X1.18)}$$

or

$$d\Delta t = -\frac{L}{A} \cdot \frac{1}{k} \cdot \frac{1}{\Delta h} \cdot \frac{1}{(G_{Hg} - 1)} \cdot \frac{a_{in} \cdot a_{out}}{a_{out} + a_{in}} \cdot dh$$

By integrating between times t_1 and t_2 and h_1 and h_2 we get,

$$\int_{t_1}^{t_2} d\Delta t = \int_{\Delta h_1}^{\Delta h_2} -\frac{L}{A} \cdot \frac{1}{k} \cdot \frac{1}{\Delta h} \cdot \frac{1}{(G_{Hg} - 1)} \cdot \frac{a_{in} \cdot a}{a_{out} + a_{in}} \cdot dh$$

which yields the general constant volume-falling head equation,

$$\Delta t = -\frac{L}{A} \cdot \frac{1}{k} \cdot \frac{1}{(G_{Hg} - 1)} \cdot \frac{a_{in} \cdot a_{out}}{a_{out} + a_{in}} ln\left(\frac{\Delta h_2}{\Delta h_1}\right) \qquad \text{(X1.19)}$$

or

$$k = -\frac{L}{A} \cdot \frac{1}{\Delta t} \cdot \frac{1}{(G_{Hg} - 1)} \cdot \frac{a_{in} \cdot a_{out}}{a_{out} + a_{in}} ln\left(\frac{\Delta h_2}{\Delta h_1}\right)$$

Noting that,

$$-ln\frac{\Delta h_2}{\Delta h_1} = ln\frac{\Delta h_1}{\Delta h_2}$$

the equation becomes,

$$k = \left(\frac{a_{in} \cdot a_{out}}{(a_{out} + a_{in})} \cdot \frac{1}{(G_{Hg} - 1)}\right) \cdot \frac{L}{A} \cdot \frac{1}{\Delta t} \cdot ln\left(\frac{\Delta h_1}{\Delta h_2}\right) \qquad \text{(X1.20)}$$

where:

k = hydraulic conductivity of the test specimen at the test temperature, m/s,
Δh_1 = total head loss across length L at the start of a permeation trial; that is, initial total head loss, m of water,
Δh_2 = final total head loss across length L at the end of a permeation trial; that is, final total head loss, m of water,
Δt = elapsed time during a permeation trial; that is, $\Delta t = t_2 - t_1$, s,
a_{out} = area of the tailwater tube (tube with smaller ID), m^2,
a_{in} = area of the headwater tube, in m^2,
G_{Hg} = specific gravity of mercury (ρ_{Hg}/ρ_w) at the test temperature,
ρ_{Hg} = density of mercury at the test temperature, in Mg/m^3,
ρ_W = density of water at the test temperature, Mg/m^3,
$(G_{Hg}-1)$ = constant equal to 12.57 between 15 and 25°C,
L = length/height of the test specimen, in m,
A = area of the test specimen, in m^2,
ln = natural logarithm (base *e*),

and head loss equations from X1.3.1 and X1.3.2 are

$$\Delta h_1 = (\Delta H_{Hg,1} + \Delta H_{Hg,c}) \cdot (G_{Hg} - 1) \qquad \text{(X1.21)}$$

$$\Delta h_2 = \Delta h_1 + \left((-\Delta Hg_{tail}) \cdot \left(\frac{a_{out}}{a_{in}} + 1\right) \cdot (G_{Hg} - 1)\right) \qquad \text{(X1.22)}$$

where for Δh_1 and Δh_2:

$\Delta H_{Hg,1}$ = the initial difference in height of mercury in the tailwater and headwater tubes of the manometer at the start (t_1) of a given permeation trial, m;
$\Delta H_{Hg,c}$ = the positive difference in height of mercury in the tailwater and headwater tubes of the manometer with equal pressure applied to both tubes, m, (This height differential is caused by the difference in capillary pressure of the two tubes making up the mercury U-tube manometer); and,

$-\Delta Hg_{tail}$ = the negative change in height of the mercury level in the tailwater tube of the manometer during a given permeation trial, m.

X2. RELATIONSHIP BETWEEN CHANGE IN AXIAL STRAIN AND HYDRAULIC CONDUCTIVITY OF TEST SPECIMEN

X2.1 *Introduction*—It is important to understand how hydraulic conductivity (k) changes with changes in void ratio, dry unit weight, or volume change of a given test specimen. With this understanding, one can thereby know the accuracy to which volume changes need to be controlled while testing. For instance, if k is very sensitive to volume changes then the effective consolidation stress needs to be accurately controlled; also, any volume changes during the back-pressuring process would have to be minimized.

X2.1.1 The relationships presented in this appendix are for relatively plastic clays, CL or CH, with a plasticity index greater than about 10, but less than about 50.

X2.2 *Change in Void Ratio versus Hydraulic Conductivity*—A graphical representation of how hydraulic conductivity (k) varies with void ratio (e) is presented in Fig. X2.1. This figure graphically shows that the k decreases as e decreases. In addition, for a given change in void ratio (Δe) the rate of change in k is much more dramatic in the overconsolidated range than in the normally consolidated range. The definition for the terms/notation presented in this figure are:

k= given hydraulic conductivity, m/s,
k_L= lower bound k for given percent change in k, m/s,
k_U= upper bound k for given percent change in k, m/s,
Δk_L= lower bound change in k for given percent change (decimal form) in k, m/s/
% Change = the percent change (decimal form) in k,
Δe_L= the compressive change in void ration (decreasing change)
e_U= the swelling change in void ratio (increasing change), and
m = the ratio of Δe to $\Delta log\ k = \Delta e/log\ (k/k_L)$, 1/(m/s).

X2.3 Mathematical Relationship Between e and k—It can be shown that:

$$k_L = k + (-\Delta k_L) = k - \%Change \times k = (1 - \%Change) \times k \tag{X2.1}$$

or

$$k_U = (1 + \%Change) \times k$$

$$-\Delta k_L = log(1 - \%Change) \tag{X2.2}$$

or

$$\Delta k_U = log(1 + \%Change)$$

$$e_L = e + (-\Delta e_L) \tag{X2.3}$$

or

$$e_U = e + \Delta e_U$$

$$-\Delta e_L = m \times -\Delta k_L = m \times log(1 - \%Change), \tag{X2.4}$$

or

$$\Delta e_U = m \times \Delta k_U = m \times log(1 + \%Change)$$

X2.4 Based upon the theory of elasticity, the following relationships between axial strain (ε_a) and volumetric strain (ε_v), and volumetric strain and change in void ratio ($\Delta\varepsilon$) are:

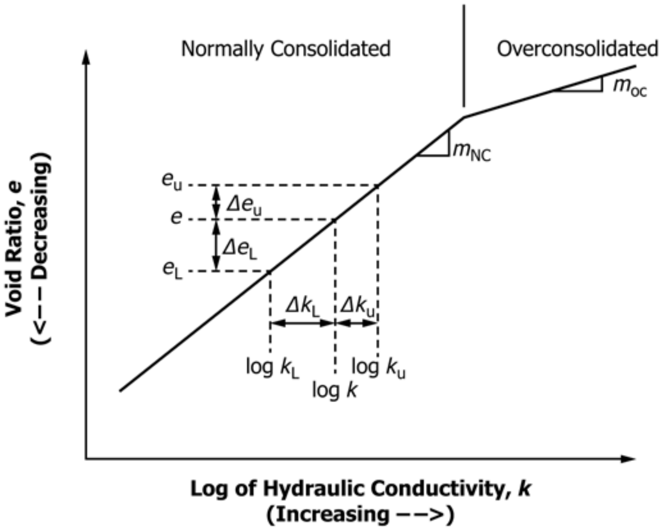


FIG. X2.1 Typical Relationship Between Void Ratio and Logarithm of Hydraulic Conductivity

$$\Delta\varepsilon_{\mathrm{a}} = \frac{1}{3}\cdot E_{\mathrm{c}}\cdot\Delta\varepsilon_{\mathrm{v}} = \left(\frac{1}{3}\cdot E_{\mathrm{c}}\cdot -\Delta\varepsilon_{L}\right)/(1-e_{\mathrm{o}}) \qquad (X2.5)$$

$\Delta\varepsilon_a$ = the change in compressive axial strain ($\Delta L/L_o$), m/m.

E_c = a constant to correct for the non-elastic response of hydraulic-conductivity test specimens. For test specimens having a height to diameter ratio of about one, this value is about 0.8 for normally consolidated (NC) specimens and 0.6 for overconsolidated (OC) specimens,

$\Delta\varepsilon_v$ = the change in compressive volumetric strain ($\Delta V/V_o$), m^3/m^3.

$-\Delta e$ = the compressive change in void ratio; that is, decreasing change,

e_o = the initial void ratio.

X2.5 Combining the above equations and rearranging:

$$\Delta\varepsilon_{\mathrm{a,NC}} = \frac{-1}{3\cdot E_{\mathrm{c}}}\cdot\frac{m_{NC}}{1+e_{\mathrm{o}}}\cdot log(1-\%Change) \qquad (X2.6)$$

or

$$\Delta\varepsilon_{\mathrm{a,OC}} = \frac{-1}{3\cdot E_{\mathrm{c}}}\cdot\frac{m_{\mathrm{OC}}}{1+e_{\mathrm{o}}}\cdot log(1-\%Change)$$

also

$$-\%Change = 10^{-\left(3\cdot E_{\mathrm{c}}\cdot\left(\frac{1+e_{\mathrm{o}}}{m}\right)\cdot\Delta\varepsilon_{\mathrm{a,L}}\right)} \qquad (X2.7)$$

$$+\%Change = 10^{-\left(3\cdot E_{\mathrm{c}}\cdot\left(\frac{1+e_{\mathrm{o}}}{m}\right)\cdot-\Delta\varepsilon_{\mathrm{a,U}}\right)}$$

where:

m_{NC} = $m$value in normally consolidated region, 1/[m/s], and

m_{OC} = m value in the overconsolidated region, 1/[m/s].

X2.5.1 Tavenas, et al. (**12**) indicates that m is about (⅓ to ½) × e_o for normally consolidated clays. For overconsolidated clay, it is assumed that m in the overconsolidated range is reduced by the same ratio that the compression index (C) is when going from the normally consolidated region (C_{NC}) to the overconsolidated region (C_{OC}). Therefore,

$$m_{OC}/m_{NC} = C_{OC}/C_{NC} \sim 0.185 + 0.002\times PI$$

where PI = plasticity index. This assumption is based on limited data, and in some cases, there was not any significant difference in m between the normally consolidated and overconsolidated regions. Based on the above, an initial void ratio of 0.8 and a plasticity index (PI) of 30, m_{NC} is about 0.33; while m_{OC} is about 0.082.

X2.5.2 Using the above m values and equations, and a % Change equal to 12.5 %, one could assume excess axial strains caused by a poor testing protocol should be less than the following values:

For normally consolidated soils:

$$\Delta\varepsilon_{a,NC} = \frac{-1}{3\cdot 0.8}\cdot\frac{0.33}{1.8}\cdot log0.875 = 0.0044 = 0.4\,\%$$

For overconsolidated consolidated soils:

$$\Delta\varepsilon_{a,OC} = \frac{-1}{3\cdot 0.6}\cdot\frac{0.082}{1.8}\cdot log0.875 = 0.00147 = 0.1\,\%$$

REFERENCES

(1) Zhang, M., Esaki, T., Olsen, H.W., and Mitani, Y., "Integrated Shear and Flow Parameter Measurement," *Geotechnical Testing Journal*, GTJODJ, Vol. 20, No. 3, September 1997, pp. 296–303.

(2) Zhang, M., Takahashi, M., Morin, R.H., Endo, H., and Esaki, T., "Determining the Hydraulic Properties of Saturated, Low-Permeability Geological Materials in the Laboratory: Advances in Theory and Practice," *Evaluation and Remediation of Low Permeability and Dual Porosity Environments*, ASTM STP 1415, Sara, M. N., and Everett, L. G., Eds., ASTM International, 2002, pp. 83-98

(3) Olson, R. E., and Daniel, D. E., "Measurement of the Hydraulic Conductivity of Fine-Grained Soils," *Permeability and Groundwater Contaminant Transport, ASTM STP 746*, Zimmie, T.F. and Riggs, C.O., Eds., ASTM, 1981, pp. 18–64.

(4) Daniel, D. E., and Trautwein, S. T. Eds., *Hydraulic Conductivity and Waste Containment Transport in Soil,ASTM STP 1142*, ASTM, 1994.

(5) Olson, H. W., Morin, R. H., and Nichols, R. W., "Flow Pump Applications in Triaxial Testing," *Advanced Triaxial Testing of Soil and Rock, ASTM STP 977*, Donaghe, R.T., Chaney, R.C., and Silver, M.L., Eds., ASTM, 1988, pp. 68–81.

(6) The hydraulic system presented is after Bjerrum, L., and Huder, J., "Measurement of the Permeability of Compacted Clays," *Proceedings of the Fourth International Conference on Soil Mechanics and Foundation Engineering*, Volume 1, 1957, pp. 6–8.

(7) Scalia, J. and Benson, C. (2010), "Effect of Permeant Water on the Hydraulic Conductivity of Exhumed Geosynthetic Clay Liners," *Geotechnical Testing Journal*, 33 (3), 201-211.

(8) Bureau of Reclamation, *Earth Manual, Part 2, 3rd Edition*, USBR 7100–89, U.S. Department of Interior, Bureau of Reclamation, Denver, CO, 1990.

(9) Lowe, J., and Johnson, T. C., "Use of Back Pressure to Increase Degree of Saturation of Triaxial Test Specimens," *Proceedings, ASCE Research Conference on Shear Strength of Cohesive Soils* , Boulder, CO, 1960.

(10) Black, A. W. and Lee, K. L. (1973), "Saturating Laboratory Samples by Back Pressure," *Journal of the Soil Mechanics and Foundation Division*, ASCE, Vol. 99, No. SM1, Proc. Paper 9484, Jan., pp. 75–93.

(11) Head, K. H., (1986), *Manual of Soil Laboratory Testing, Volume 3: Effective Stress Tests*, Pentech Press Limited, Graham Lodge, London, United Kingdom, pp. 787–796.

(12) Tavenas, F., Leblond, P., Jean, P., and Leroueil, S., (1983), "The Permeability of Natural Soft Clays, Part I and Part II, *Canadian Geotechnical Journal*, Volume 20, 1983.

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (2010) that may impact the use of this standard. (August 1, 2016)

(1) Revised 6.1.2.

Designation: D5890 − 19

Standard Test Method for
Swell Index of Clay Mineral Component of Geosynthetic Clay Liners[1]

This standard is issued under the fixed designation D5890; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers an index method that enables the evaluation of swelling properties of a clay mineral in reagent water for estimation of its usefulness in geosynthetic clay liners (GCLs). This test method is not applicable for clays with polymers.

1.2 It is adapted from United States Pharmacopeia (USP-NF-XVII) test method for bentonite.

1.3 Powdered clay mineral is tested after drying to constant weight at 105 ± 5 °C; granular clay mineral should be ground to 100 % passing a 150-µm (No. 100) U.S. Standard Sieve with a minimum of 65 % passing a 75-µm (No. 200) U.S. Standard Sieve. The bentonite passing the 150-µm U.S. Standard Sieve is used for testing after drying to constant weight at 105 ± 5 °C.

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

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Section 8.

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1193 Specification for Reagent Water
D4643 Test Method for Determination of Water Content of Soil and Rock by Microwave Oven Heating
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
E1 Specification for ASTM Liquid-in-Glass Thermometers
E145 Specification for Gravity-Convection and Forced-Ventilation Ovens
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E725 Test Method for Sampling Granular Carriers and Granular Pesticides

2.2 *United States Pharmacopeia Standard:*[3]

USP-NF-XVII Bentonite

3. Terminology

3.1 *Definitions:*

3.1.1 *oven-dried, adj*—the condition of a material that has been heated under prescribed conditions of temperature and humidity until there is no further significant change in its mass.

4. Significance and Use

4.1 Clay mineral is a major functional component of GCL systems that reduces the hydraulic conductivity of industrial, waste, or ground water through the liner.

4.2 Clay mineral quality can vary significantly and affect the hydraulic conductivity of the GCL composite. This test method evaluates a significant property of clay mineral that relates to performance.

5. Atmosphere Conditions

5.1 *Atmospheric Conditions*—The atmospheric conditions of the laboratory performing swell index of clay mineral

---

[1] This test method is under the jurisdiction of ASTM Committee D35 on Geosynthetics and is the direct responsibility of Subcommittee D35.04 on Geosynthetic Clay Liners.

Current edition approved May 1, 2019. Published May 2019. Originally approved in 1995. Last previous edition approved in 2018 as D5890 – 18. DOI: 10.1520/D5890-19.

[2] 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.

[3] Available from U.S. Pharmacopeia (USP), 12601 Twinbrook Pkwy., Rockville, MD 20852.

component of geosynthetic clay liners shall be: relative humidity between 50 to 70 % and a temperature of 21 ± 2 °C (70 ± 4 °F).

6. Apparatus

6.1 *Mortar and Pestle or Laboratory Hammer Mill,* for grinding clay mineral to required particle sizing.

6.2 *U.S. Standard Sieve,* 150 µm (No. 100), 75 µm (No. 200).

6.3 *Drying Oven,* thermostatically controlled, preferably forced-draft type, meeting requirements of Specification E145, and capable of maintaining a uniform temperature of 105 ± 5 °C throughout the drying chamber.

6.4 *Desiccator,* of suitable size, containing indicator silica gel. It is preferable to use desiccant which changes color to indicate when it needs reconstitution.

6.5 *Laboratory Balance,* 100-g capacity, ±0.01-g accuracy and precision.

6.6 *Weighing Paper,* or small weighing dish.

6.7 *Glass Cylinder,* graduated TC (to contain), Class A volumetrically calibrated, with 1-mL subdivisions and ground glass stopper, high form with approximately 180-mm height from inside base to 100-mL mark.

6.8 *Wash Bottle,* for dispensing reagent water.

6.9 *Spatula,* flat-blade, to dispense clay mineral powder into cylinder; vibrating spatula should not be used, since the delivery quantity may not be adequately controlled.

6.10 *Mechanical Ten-Minute Timer.*

6.11 *ASTM Calibration Immersion Thermometer,* (Specification E1).

6.12 *Microwave Oven*—A microwave oven, preferably with a vented chamber, is suitable. The required size and power rating of the oven is dependent on its intended use. Ovens with variable power controls and input power ratings of about 700 W have been found to be adequate for this use. Variable power controls are important and reduce the potential for overheating the test specimen.

NOTE 1—Microwave ovens equipped with built-in scales and computer controls have been developed for use in drying soils. Their use is compatible with this test method.

6.13 *Balances*—All balances must meet the requirements of Guide D4753 and this section. A Class GP1 balance of 0.01-g readability is required for samples having a mass of up to 200 g (excluding mass of sample container).

6.14 *Sample Containers*—Suitable containers made of material resistant to corrosion and change in mass upon repeated heating, cooling, exposure to materials of varying pH, and cleaning. Microwave sample containers should be microwave safe.

6.15 *Container Handling Apparatus*—Gloves, tongs, or suitable holder for moving and handling hot containers after drying.

7. Reagents

7.1 *Purity of Reagents*—Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Specification D1193, Type I, II, or III (see Table X1.1). Such water is best prepared by distillation or the passage of tap water through an ion exchange resin.

8. Hazards

8.1 Handle hot containers with a container holder.

8.2 Safety precautions supplied by the manufacturer of the microwave/oven should be observed.

8.3 Do not use metallic containers in a microwave oven (if used).

9. Samples, Specimens, and Test Units

9.1 For testing from a large bulk (for example, >1 t) before the GCL production, carry out sampling in accordance with Test Method E725.

10. Procedure

10.1 Grind the clay mineral sample to 100 % passing a 150-µm (No. 100) U.S. Standard Sieve and a minimum of 65 % passing a 75-µm (No. 200) U.S. Standard Sieve with a mortar and pestle or laboratory hammer mill, as required. The total mass of the test specimen shall be a minimum of 100 g.

10.2 The container to be used for drying should be oven dried thoroughly and subsequently placed into a desiccator until ready for use so that the tare weight of the container will be recorded.

10.3 Determine and record the tare of the specimen container.

10.4 Place the test specimen in the individual container. Determine the mass of the container and clay specimen as delivered, using a balance selected on the basis of the sample mass. Record the value of the clay specimen.

NOTE 2—To prevent mixing of samples and yielding of incorrect results, all containers should be numbered and the container numbers shall be recorded on the laboratory data sheets.

10.5 Place the container with the clay specimen in the drying oven. Dry the clay specimen to a constant mass. Maintain the drying oven at 105 ± 5 °C. The time required to obtain constant mass will vary depending on the type of material, oven type and capacity, and other factors.

NOTE 3—In most cases, drying a test sample overnight (about 12 to 16 h) is sufficient for conventional ovens. In cases where there is doubt concerning the adequacy of drying, drying should be continued until the change in mass after two successive periods (greater than 1 h) of drying is less than 0.1 %. In this case, it should be verified that excessive drying does not influence the swelling performance of the clay. This can be done by comparing the swelling values after the first drying period (about 12 to 16 h) and the swelling values of bentonite being dried for a longer time period.

NOTE 4—If a microwave oven is used to dry the test specimen(s), the user of this test method should follow the drying procedures as stated in Test Method D4643. It is further recommended to run a comparison test between the microwave oven and the drying oven to demonstrate that the microwave oven gives similar values as the drying oven and that excessive drying does not change the swelling performance of the clay.

NOTE 5—Since some dry materials may absorb moisture from moist samples, dried samples should be removed before placing moist samples in the same oven. However, this would not be applicable if the previously dried specimens will remain in the drying oven for an additional time period of about 16 h.

10.6 After the material has dried to constant mass, remove the container from the oven (and replace the lid if used). Allow the material and container to cool to room temperature in a desiccation unit or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents or its being heated, or both. Determine the mass of the container and oven-dried material using the same balance as used previously. Subtract the tare of the container from the mass of the sample to determine the sample's constant dry mass. Record this value.

10.7 Weigh 2.00 ± 0.01 g of dried and finely ground clay mineral onto a weighing paper.

10.8 Add 90 mL reagent water to the clean 100-mL graduated cylinder.

10.9 Remove not more than a 0.1-g increment of clay mineral from weighing dish or paper and carefully dust it over the entire surface of water in the graduated cylinder over a period of approximately 30 s. Do not use a funnel that may concentrate the clay mineral in a poorly hydrated agglomerate. Allow the clay mineral to wet, hydrate, and settle to the bottom of the graduated cylinder for a minimum period of 10 min.

10.10 Add additional increments of the clay mineral powder in periods of 10 min, allowing the clay mineral to swell without air being trapped in between, following the details in 10.9, until the entire 2.00-g sample has been added.

10.11 After the final increment has settled, carefully rinse any adhering particles from the sides of the cylinder into the water column, raising the water volume to the 100-mL mark.

10.12 Place the glass stopper on the cylinder and allow it to stand undisturbed for a minimum of 16 h from the last incremental addition. After 2 h, inspect the hydrating clay mineral column for trapped air or water separation in the column. If present, gently tip the cylinder at a 45° angle and roll slowly to homogenize the settled clay mineral mass. Allow the graduated cylinder with the hydrating clay mineral to remain undisturbed for a minimum of 16 h before recording the volume of the hydrated clay mass and its temperature.

10.13 After the minimum 16-h hydration period from the last increment addition, record the volume level in millilitres (mL) at the top of the settled clay mineral to the nearest 0.5 mL. Observe the distinct change in appearance at the upper surface of the settled clay mineral. Any low-density flocculated material (sometimes lighter in coloration to white) shall be ignored for this measurement. Record the observed volume of hydrated clay mineral to the nearest 0.5 mL.

10.14 If a recognizable swelling still occurs after the minimum hydration period from the last increment addition (more than 10 % of the previous reading in a 4-h period), continue recording the volume of the hydrated clay mass and its temperature to a maximum of 48 h after the last increment addition.

10.15 Carefully immerse the thermometer and measure the temperature of the slurry. Record the temperature of the hydrated clay mineral to ±0.5 °C.

11. Report

11.1 Report the following information:

11.1.1 Source of clay mineral, including sample identification or lot number,

11.1.2 Method of sampling used,

11.1.3 ASTM standard test method number used to perform the test,

11.1.4 Any modifications to the test method or unusual observations which may affect the test results, and

11.1.5 Swell index as mL/2 g to the nearest 0.5 mL after the minimum 16-h hydration period from the last clay increment addition and, if applicable, to the maximum recorded hydration period from the last clay increment addition.

12. Precision and Bias

12.1 *Interlaboratory Test Program*—An interlaboratory study of the test method was run in 1999. The design of the experiment was similar to that of Practice E691. Seven different clay mineral samples were distributed to ten laboratories. Three sets of test results were generated for each sample by each of the laboratories.

12.2 *Test Results*—The precision information is given in Table 1. The average swell index values ranged from 20 to 36 for the seven clay mineral samples tested. However, since the statistics were not related to the magnitude of the test result, the precision values have been presented in terms of coefficients of variation, CV %.

12.3 *Bias*—The procedure in Test Method D5890 for measuring the swell index of clay mineral component of geosynthetic clay liners has no bias because the values of swell index can be defined only in terms of this test method.

13. Keywords

13.1 bentonite; clay; geosynthetic clay liner; microwave; oven drying; swell; swell index

TABLE 1 Test Results

Statistic	ILS Range
Within-laboratory repeatability limit, CV % *r*	2 to 5 %
Between-laboratory reproducibility limit, CV % *R*	7 to 22 %
95 % confidence limit Within-laboratory repeatability, 2.8 CV % *r*	6 to 14 %
95 % confidence limit Between-laboratory reproducibility, 2.8 CV % *R*	20 to 61 %

APPENDIXES

(Nonmandatory Information)

X1. ADDITIONAL REAGENT INFORMATION

X1.1 See Table X1.1.

TABLE X1.1 Additional Reagent Information

	Type I	Type II	Type III
Electrical conductivity, max, µS/cm at 298 K (25 °C)	0.056	1.0	0.25
Electrical resistivity, min, MΩ·cm at 298 K (25 °C)	18	1.0	4.0
pH at 298 K (25 °C)	[A]	[A]	[A]
Total organic carbon (TOC), max, µg/L	100	50	200
Sodium, max, µg/L	1	5	10
Chlorides, max, µg/L	1	5	10
Total silica, max, µg/L	3	3	500

Microbiological contamination—When bacterial levels need to be controlled, reagent grade types should be further classified as follows:

	Type A	Type B	Type C
Maximum heterotrophic bacteria count	10/1000 mL	10/100 mL	100/10 mL
Endotoxin, EU/mL[B]	<0.03	0.25	not applicable

[A] The measurement of pH in Type I, II, and III reagent waters has been eliminated from this specification because these grades of water do not contain constituents in sufficient quantity to significantly alter the pH.

[B] EU = Endotoxin Units.

X2. CHECKLIST

Check list for ASTM D5890 Swell Index of Clay Mineral Component of GCLs

Source of clay (GCL type, received from, etc.):

____

GCL Roll / Identification number: ____

Method of sampling: ____

10. Procedure

10.1 Grinding (min. 100g): 100% Passing 150 µm (No. 100) Yes ☐ No ☐
min. 65% passing 75 µm (No. 200) Yes ☐ No ☐
both passing components mixed together Yes ☐ No ☐

10.2 Thoroughly dried container for weighing Yes ☐ No ☐

10.3 Tare weight of container (10.2): ____

10.4 Mass of container with clay specimen: ____

10.5 a) Whole composite ground sample dried at 105° C? Yes ☐ No ☐
Duration of drying in hours: ________________ hours
Moisture content of sample before/after drying: ________ / _______ %
After 2 drying periods (>1 hour) moisture change less than 0.1%? Yes ☐ No ☐

10.5 b) If 10.5 a) answered No, was ASTM D4643 followed: Yes ☐ No ☐
Was note 4 followed (comparing results from oven drying vs. microwave): Yes ☐ No ☐
Duration of drying in hours: ________________ hours
Moisture content of sample before/after drying: ________ / _______ %

10.6 Record mass of container with clay specimen: ________________________________
Subtract tare weight of container (10.3): ____________________________________
Result: ___________________________________

10.7 Weighing of 2 g of whole composite ground sample? Yes ☐ No ☐

10.8 Selected ASTM D1193 water type (7.1): Type I ☐ Type II ☐ Type II ☐

Other water type: ____

Added 90 mil of water to cylinder Yes ☐ No ☐

10.9 Added of no more than 0.1 g increments of clay (dusty addition) during approx. 30s onto the entire water surface (10 minute waiting period before next clay increment is added): Yes ☐ No ☐

10.10 Added remaining 0.1 g clay increments in periods of 10 minutes, according to 10.9, without any air traps. Yes ☐ No ☐

10.11 10 minutes after final clay increment, carefully rinsing with 10 mil of water Yes ☐ No ☐

10.12 Allow 16 hours to settle after final clay increment added. 2 hours, hereafter, inspect hydrating clay for e.g. trapped air.
45° cylinder tipping for homogenisation needed? Yes ☐ No ☐
If tipped allow another 16 hours to settle.

10.13 Record volume to nearest 0.5 ml: ___________ ml

10.14 Recognizable swelling (more than 10% after 4 hours)? Yes ☐ No ☐
If "Yes," record swell volume, water temperature, and hours after last reading:
Volume [ml] _____ water temperature °C or °F _______ time after last reading [h] _______

10.15 Measure water temperature (±0.5°C): __________°C

10.1.4 Modifications / Other findings

____

____

____

____

Name and signature of person performing test

Name, printed: ________________________ Date: _________________________

Signature: ____________________

Date of test performance ________________________

Name and address of lab performing test:

____

____

Designation: D5891/D5891M − 19

Standard Test Method for
Fluid Loss of Clay Component of Geosynthetic Clay Liners[1]

This standard is issued under the fixed designation D5891/D5891M; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers an index method that enables the evaluation of fluid loss properties of a clay mineral film deposited on a filter paper from a 6 % solids slurry of clay mineral at 100-psi (kPa) pressure as a measure of its usefulness for permeability or hydraulic conductivity reduction in geosynthetic clay liners (GCL). This test method is not applicable for clays with polymers.

1.2 This test method is adapted from American Petroleum Institute drilling fluid specifications for bentonite.

1.3 Powdered clay mineral is tested as produced; granular clay mineral should be ground to 100 % passing a 100 mesh U.S. Standard Sieve with a minimum of 65 % passing a 200 mesh U.S. Standard Sieve with the whole ground product used for testing.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*[2]

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D1193 Specification for Reagent Water
E1 Specification for ASTM Liquid-in-Glass Thermometers
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E725 Test Method for Sampling Granular Carriers and Granular Pesticides

2.2 *API Standard:*[4]

API RP 131 Recommended Practice for Laboratory Testing of Drilling Fluids

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to API Standards and ASTM definitions for GCL products.

4. Significance and Use

4.1 Clay mineral is the functional component of GCL that reduces the hydraulic conductivity of industrial waste or ground water through the liner.

4.2 Clay mineral quality can vary significantly and affect the hydraulic conductivity of the GCL composite. This test method evaluates a significant property of clay mineral that relates to performance.

5. Atmosphere Conditions

5.1 *Atmospheric Conditions*—The atmospheric conditions of the laboratory performing fluid loss of clay mineral component of geosynthetic clay liners shall be: relative humidity between 50 to 70 % and a temperature of 21 ± 2 °C [70 ± 4 °F].

6. Apparatus

6.1 *Laboratory Balance,* 100-g capacity, ±0.01-g accuracy and precision.

---

[1] This test method is under the jurisdiction of ASTM Committee D35 on Geosynthetics and is the direct responsibility of Subcommittee D35.04 on Geosynthetic Clay Liners.

Current edition approved Aug. 1, 2019. Published August 2019. Originally approved in 1995. Last previous edition approved in 2016 as D5891/D5891M – 02 (2016)$^{\varepsilon 1}$. DOI: 10.1520/D5891_D5891M-19.

[2] When bentonite is removed from a GCL product for testing, it may include adhesives that can influence test results.

[3] 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.

[4] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org.

6.2 *Weighing Paper,* or small weighing dish.

6.3 *Graduated Cylinder,* 500 ± 5-mL graduated TD (to deliver) with 10-mL subdivisions, Class A volumetrically calibrated; 10 ± 0.1-mL graduated cylinder, graduated TC (to contain) with 0.1-mL subdivisions.

6.4 *U.S. Standard Sieve,* 100 mesh, 200 mesh, and automated sieve shaker.

6.5 *Mortar and Pestle or Laboratory Hammer Mill,* for grinding clay mineral to required particle sizing.

6.6 *ASTM Calibration Immersion Thermometer,* 0 to 105 ± 0.5 °C (see Specification E1).

6.7 *Mixer*—11 000 ± 300 rpm under load with single sine-wave impeller approximately 25 mm [1.0 in.] in diameter (mounted flash side up).[5] The impeller shall be replaced when it weighs a minimum of 5.1 g, from an original mass of about 5.5 g. New blades will be weighed prior to installation in order to ensure conformance to manufacturing criteria. Mixer speed under sample loading shall be determined and documented once every 90 days unless the manufacturer has documented objective evidence to extend calibration time.

NOTE 1—Sterling Multimixer Model 9B with 9B29X impeller blades or equivalent may be obtained from the suppliers given in Footnote 6.

6.8 *Mixing Container*—Approximate dimensions are 180 mm [7 in.] deep, 97-mm [3¹³⁄₁₆-in.] inner diameter at top, and 70-mm [2¾-in.] inner diameter at bottom.[6]

NOTE 2—Mixing containers or equivalent may be obtained from the suppliers given in Footnote 5.

6.9 *Timers,* 30 min, two interval, mechanical or electrical, precision ±0.1 min.

6.10 *Spatula,* flat blade, to dislodge clay mineral clumps adhering to the mixing container walls.

6.11 *Covered or Sealed Container,* of 400- to 600-mL capacity.

6.12 *Ambient Temperature/Low-Pressure Filter Press,* conforming to API RP 131, Section 3.2. This filter press consists mainly of a cylindrical cell having an inside diameter of 76.2 mm [3 in.] and a height of at least 64.0 mm [2.5 in.]. This chamber is made of materials resistant to strongly alkaline solutions, and is so fitted that a pressure medium can be conveniently admitted into and bled from the top. Arrangement is also such that a sheet of 90-mm filter paper can be placed in the bottom of the chamber just above a suitable support. The filtration area is 4580 ± 60 mm^2 [7.1 ± 0.1 in.^{2}]. Below the support is a drain tube for discharging the filtrate into a graduated cylinder. Sealing is accomplished with gaskets, and the entire assembly supported by a stand. A mini-press or half-area press does not directly correlate with the results obtained when using the above described standard-sized press. Pressure can be applied with any nonhazardous fluid medium, either gas or liquid. Presses are equipped with pressure regulators and can be obtained with portable pressure cylinders, midget pressure cartridges, or means of utilizing hydraulic pressure.

NOTE 3—Ambient temperature/low-pressure filter press conforming to API RP 131, Section 3.2, or equivalent, may be obtained from the suppliers given in Footnote 6.

6.13 *Filter Paper,* 90 mm, very dense, hardened with smooth, lint-free surface; either Whatman No. 50, S & S No. 576, or Fann Filter Part No. 206051 must be used.[7] These papers have high wet strength permitting application of high pressure during filtration. They also have good resistance to alkalies and acids.

7. Reagents

7.1 *Purity of Reagents*—Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Specification D1193, Type I, II, or III. Such water is best prepared by distillation or the passage of tap water through an ion-exchange resin.

7.2 Specification D1193 for reagent water, Type I, II, or III.

8. Hazards

8.1 *Safety Precautions*—Establish appropriate safety and health practices for high-pressure equipment prior to use.

9. Sampling and Selection

9.1 Conduct the sampling in accordance with Test Method E725.

10. Procedure

10.1 Grind the clay mineral sample to greater than 100 % passing a 100 mesh U.S. Standard Sieve, and a minimum of 65 % passing a 200-mesh U.S. Standard Sieve with a mortar and pestle or laboratory hammer mill as required.

10.2 Weigh 22.50 ± 0.01 g of the whole composite of finely ground clay mineral with "as-received" moisture, typically 5 to 15 %, onto a weighing paper. If bentonite is removed from a GCL product, the bentonite would be dried to less than 15 % moisture prior to weighing.

10.3 Measure 350 ± 5 mL of reagent water with the 500-mL graduated cylinder and added to the mixing cup. Place the cup on the mixer, and add the clay mineral slowly over approximately 30 s.

10.4 After stirring for 5 ± 0.5 min, remove the container from mixer, and scrape its sides with the spatula to dislodge any clay clinging to the container wall. Ensure that all of the dislodged clay mineral clinging to the spatula is incorporated into the suspension.

10.5 Replace the container on the mixer, and continue to stir for a cumulative total stirring time of 20 ± 0.1 min. The

---

[5] For example, Sterling Multimixer Model 9B with 9B29X impeller blades available from Fann Instrument Co., P.O. Box 4350, Houston, TX 77210, has been found suitable for this purpose.

[6] For example, Hamilton Beach Mixer Cup No. M110-D, or equivalent, has been found suitable for this purpose. Mixing containers supplied by Fann Instrument Co., P.O. Box 4350, Houston, TX 77210.

[7] If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

container may need to be removed from the mixer and the sides scraped to dislodge any clay clinging to container walls after another 5 or 10 min of stirring.

10.6 Age the clay mineral suspension for a minimum of 16 h in a sealed or covered container at ambient temperature. Record the initial temperature, final temperature, and actual hydration aging time.

10.7 After aging the clay mineral suspension, shake vigorously to break its gel strength, and then pour the suspension into the mixer container. Stir the suspension on the mixer for 5 ± 0.5 min to completely disperse the clay mineral slurry.

10.8 Assemble the dry filter cell with filter paper and gaskets, and immediately after remixing the clay mineral slurry, pour it into the filter cell and complete assembly of the filter cell. Place the filter cell in the filter frame and close the relief valve. Place a 10-mL graduated cylinder under the filter cell drain tube.

10.9 Set one timer for 7.5 ± 0.1 min and the second timer for 30 ± 0.1 min. Start both timers and adjust pressure on the fluid loss cell to 100 ± 2 psi. Starting the timers and adding 100 psi pressure should be completed in less than 15 s. Supply pressure by compressed air, nitrogen, helium, or carbon dioxide.

10.10 At 7.5 ± 0.1 min on the first timer, remove the graduated cylinder and any adhering liquid on the drain tube, and discard. Immediately place a clean, dry 10-mL graduated cylinder under the drain tube, and collect the fluid for 22.5 ± 0.1 min to the end of the second timer. This corrects the fluid loss value for any initial unpredictable spurt loss from the fluid loss cell. Remove the graduated cylinder after the second time interval and record the volume of fluid collected.

11. Calculation

11.1 Calculate the fluid loss in millilitres using Eq 1:

$$\text{Fluid loss volume} = 2(\text{mL filtrate volume for last 22.5 min. interval})\ \text{mL} \tag{1}$$

12. Report

12.1 Report the following information:

12.1.1 Source of clay mineral, including sample identification or lot number,

12.1.2 Method of sampling used,

12.1.3 ASTM test method number used to perform the test,

12.1.4 Any modifications to the test method or unusual observations which may affect the test results,

12.1.5 Calculated fluid loss as millilitres to the nearest 0.1 mL, and

12.1.6 Temperature of the slurry at the start and completion of the test to the nearest 0.5 °C.

13. Precision and Bias

13.1 *Interlaboratory Test Program*—An interlaboratory study of the test method was run in 1999. The design of the experiment was similar to that of Practice E691. Seven different clay mineral samples were distributed to seven laboratories. Three sets of test results were generated for each sample by each of the laboratories.

13.2 *Test Results*—The precision information is given in Table 1. The average fluid loss values ranged from 9 to 22 for the seven clay mineral samples tested. However, since the statistics were not related to the magnitude of the test result, the precision values have been presented in terms of coefficients of varaiation, CV %.

13.3 *Bias*—The procedure in Test Method D5891/D5891M for measuring the fluid loss value of the clay mineral component of geosynthetic clay liners has no bias because the values of swell index can be defined only in terms of this test method.

TABLE 1 Test Results

Statistic	ILS Range
Within-laboratory repeatability limit, CV %^{r}	1.8 to 4.7 %
Between-laboratory reproducibility limit, CV %^{R}	6 to 18 %
95 % confidence limit Within-laboratory repeatability, 2.8 CV %^{r}	5 to 13 %
95 % confidence limit Between-laboratory reproducibility, 2.8 CV %^{R}	11.8 to 51 %

Check list for ASTM D5891 Fluid Loss of Clay Mineral Component of GCLs

6.7 Apparatus

Type of mixer used: ____

Mixing speed used: ______________________ [rpm] ± ___________ [rpm]
(Per standard: 11,000 rpm] ± 300 rpm)

Type of sine-wave impeller: ____

Diameter of impeller (per standard 25 mm / 1 in.): _________________ [mm] or [in.]

Mass of impeller (per standard 5.5 g – 5.1 g): ___________________________ [g]

6.13 Filter Paper

Whatman No. 50, S&SNo. 576 ____ ☐

Fann Filter, Part Number: 206051 ____________________________________ ☐

9. Sampling

Source of clay (GCL/bentonite type, received from, sample identification or lot number, etc.):

____

Method of sampling: ____

10. Procedure

Measure moisture content of bentonite as received: _______________________ [%]

☐ Oven at temperature: _________ °C _________ [hours]

☐ Microwave type: ________________ Output ________ [Watt]

Drying duration ________________ [minutes]

10.1 Moisture content of as received bentonite ≤ 15% Yes ☐ No ☐

If ≤ 15%: Grind: 100 % Passing US standard #100 mesh Yes ☐ No ☐
and min. 65 % passing US standard #200 mesh Yes ☐ No ☐

If > 15%: dry bentonite down to ≤ 15%; method of drying:

☐ Air dried: ____________ [hours] ☐ Oven at temperature: _____ °C _____ [hours]

☐ Microwave type: ____________________________ Output ____________ [Watt]

Drying time:_____[minutes]

Final moisture content of bentonite:___________________ [%]

Grind: 100 % Passing US standard #100 mesh Yes ☐ No ☐
and min. 65 % passing US standard #200 mesh Yes ☐ No ☐

10.2 If bentonite moisture content ≤ 15%:

Mix passing components (10.1) together to 22.5 g ± 0.01 g Yes ☐ No ☐

10.3 Fill 500 ml graduated cylinder with 350 ml ± 5 ml Yes ☐ No ☐

Cylinder size: height: ___________ [cm] diameter: ________________[cm]

Water weighed (350 g ± 5 g) Yes ☐ No ☐ _______________ [g]

Selected ASTM D1193 water type (7.1 and 7.2): Type I ☐ Type II ☐ Type III ☐

Other water type: ____

Add bentonite slowly over 30 s, while mixer is turned on: Yes ☐ No ☐

10.4 Mixing (with mixer 6.7) time 5 minutes ± 30 s: Yes ☐ No ☐

Incorporate dislodged bentonite in suspension Yes ☐ No ☐

10.5 Additional mixing (with mixer 6.7) time 20 minutes ± 6 s: Yes ☐ No ☐

Check on dislodged bentonite after 5 or 10 minutes
and incorporate in suspension Yes ☐ No ☐

10.6 At ambient temperature age bentonite suspension in sealed container for
minimum 16 hours: Yes ☐ No ☐

Ambient temperature: ____________ [°C] Ageing time: _______________ [hours]

Measure suspension temperature to nearest 0.5°C:

Initial temperature:__________[°C] Final temperature: _______________[°C]

10.7 Shake strongly suspension till it breaks and mix 5 minutes ± 30 s:
(with mixer 6.7) Yes ☐ No ☐

10.8 Prior to test, ensure that the filter plate is dry and clean. Yes ☐ No ☐

Pour slurry immediately after mixing (10.7) into filter cell on top of filter paper and gasket, place in frame, close relief valve and place 10 ml cylinder under drain tube:
Yes ☐ No ☐

10.9 After setting two timers at 7.5 minutes s ± 6 s and 30 minutes ± 6 s. When starting both timers adjust pressure to 100 psi ± 2 psi within 15 s
Yes ☐ No ☐

Supply pressure: compressed air ☐ nitrogen ☐ helium ☐ carbon dioxide ☐

10.10 At 7.5 minutes s ± 6 s remove 10 ml cylinder and adhering liquid on drain tube and immediately place a clean 10 ml cylinder under drain tube for collection for remaining 22.5 minutes ± 6 s: Yes ☐ No ☐

Remove 10 ml cylinder after remaining 22.5 minutes ± 6 s
Record reading (nearest 0.1 ml) of second 10 ml cylinder: ____________________ [ml]

11. Calculate Fluid Loss Volume: 2 × (reading of 10.10) = ____________________ [ml]

Modifications / Other findings.

____

____

____

____

____

____

____

Name and signature of person performing test Date: ____________________

Name, printed: ____________________ Signature: ____________________

Date of test performance ____________________

Name and address of lab performing test:

____

____

Designation: D1633 − 17

Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders[1]

This standard is issued under the fixed designation D1633; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers the determination of the compressive strength of soil-cement using molded cylinders as test specimens.

1.2 Two alternative procedures are provided as follows:

1.2.1 *Method A*—This procedure uses a test specimen prepared in a mold complying with Test Methods D698 (4.0 in. (101.6 mm) in diameter and 4.6 in. (116.8 mm) in height), sometimes referred to as a proctor mold, resulting in a height over diameter ratio of 1.15. This test method may be used only on materials with 30 % or less retained on the 19.0-mm (¾-in.) sieve. See Note 2.

1.2.2 *Method B*—This procedure uses a test specimen with a height over diameter ratio of 2.0 prepared in a cylindrical mold in accordance with Practice D1632 (2.8 in. (71.1 mm) in diameter and 9.0 in. (229 mm) in height). This test method is applicable to those materials that pass the 4.75-mm (No. 4) sieve.

1.3 *Units*—The values stated in inch-pound units are to be regarded as standard, except as noted in below. The values given in parentheses are mathematical conversions to SI units, and are provided for information only and are not considered standard. Sieve sizes are identified by the standard designations in Specification E11. The alternative sieve size designation given in parentheses is for information only and does not represent a different standard sieve size.

1.3.1 The gravitational system of inch-pound units is used when dealing with inch-pound units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs.

1.3.2 The slug unit of mass is almost never used in commercial practice, that is, density, balances, etc. Therefore, the standard unit for mass in this standard is either kilogram (kg) or gram (g), or both. Also, the equivalent inch-pound unit (slug) is not given/presented in parentheses.

1.3.3 It is common practice in the engineering/construction profession to concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two separate systems of units; that is, the absolute system and the gravitational system. It is scientifically undesirable to combine the use of two separate sets of inch-pound units within a single standard. As stated, this standard includes the gravitational system of inch-pound units and does not use/present the slug unit for mass. However, the use of balances or scales, recording pounds of mass (lbm) or recording density in lbm/ft^3 shall not be regarded as nonconformance with this standard.

1.4 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026 unless superseded by this test method.

1.4.1 The procedures used to specify how data are collected/recorded and calculated in the standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of these test methods to consider significant digits used in analysis methods for engineering data.

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

---

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.15 on Stabilization With Admixtures.

Current edition approved Nov. 1, 2017. Published November 2017. Originally approved in 1959. Last previous edition approved in 2007 as D1633 – 00(2007), which was withdrawn in July 2016 and reinstated in November 2017. DOI: 10.1520/D1633-17.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C42/C42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

D559 Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures

D560 Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))

D1632 Practice for Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D6026 Practice for Using Significant Digits in Geotechnical Data

E4 Practices for Force Verification of Testing Machines

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms in this standard, refer to Terminology D653.

4. Significance and Use

4.1 Method A makes use of the same compaction equipment and molds commonly available in soil laboratories and used for other soil-cement tests. It is considered that Method A gives a relative measure of strength rather than a rigorous determination of compressive strength. Because of the lesser height to diameter ratio (1.15) of the cylinders, the compressive strength determined by Method A will normally be greater than that for Method B.

4.2 Method B, because of the greater height to diameter ratio (2.00), gives a better measure of compressive strength from a technical viewpoint since it reduces complex stress conditions that may occur during the shearing of Method A specimens.

4.3 In practice, Method A has been more commonly used than Method B. As a result, it has been customary to evaluate or specify compressive strength values as determined by Method A. A factor for converting compressive strength values based on height to diameter ratio is given in Section 8.[3]

Note 1—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 D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *Compression Testing Machine*—This machine may be of any type having sufficient capacity and control to provide the rate of loading prescribed in 7.2. The testing machine shall be equipped with two steel bearing blocks with hardened faces, one of which is a spherically seated head block that normally will bear on the upper surface of the specimen, and the other a plain rigid block on which the specimen will rest. The bearing block surfaces intended for contact with the specimen shall have a Rockwell hardness of not less than HRC 60. The bearing faces shall be at least as large, and preferably slightly larger, than the surface of the specimen to which the load is applied. The bearing faces, when new, shall not depart from a plane by more than 0.0005 in. (0.013 mm) at any point, and they shall be maintained within a permissible variation limit of 0.001 in. (0.02 mm). In the spherically seated block, the diameter of the sphere shall not greatly exceed the diameter of the specimen and the center of the sphere shall coincide with the center of the bearing face. The movable portion of this block shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction. The compression shall be verified in accordance with Practice E4 at least annually to determine if indicated loads are accurate to ±1.0 % in the applicable range of loading.

5.2 *Molds and Compaction Equipment,* in accordance with Test Methods D559 or D560 for Method A; Practice D1632 for Method B.

5.3 *Balances*—A Class GP5 balance meeting the requirements of Guide D4753 for a balance of 1-g readability and a Class GP2 balance meeting the requirments of Guide D4753 for a balance of 0.1-g readability.

5.4 *Measuring Device*—A Measuring device suitable for measuring the heights and diameters of test specimens to the nearest 0.01 in. (0.25 mm).

6. Test Specimens

6.1 Prepare the test specimens as follows:

6.1.1 *Method A*—Specimens are prepared in accordance with Test Methods D559 or D560 using molds 4.0 in. (101.6 mm) in diameter and 4.584 in. (116.4 mm) in height.

6.1.2 *Method B*—Specimens are prepared in accordance with Practice D1632 using molds 2.8 in. (71.1 mm) in diameter and 9.0 in. (299 mm) in height.

---

[2] 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.

[3] For additional discussion on the significance and use of compressive strength results, see the *Soil-Cement Laboratory Handbook*, Chapter 4, Portland Cement Association, Skokie, IL, 1971, pp 31 and 32.

NOTE 2—These methods may be used for testing specimens of other sizes. If the soil sample includes material retained on the 4.75-mm (No. 4) sieve, it is recommended that Method A be used, or that larger test specimens, 4.0 in. (101.6 mm) in diameter and 8.0 in. (203.2 mm) in height, be molded in a manner similar to Method B.

6.2 Moist cure the specimens in accordance with Practice D1632.

6.3 At the end of the moist-cure period, immerse the specimens in water for 4 h.

6.4 Remove the specimens from the water and complete the following procedures as soon as practicable, keeping specimens moist by a wet burlap or blanket covering.

NOTE 3—Other conditioning procedures, such as air or oven drying, alternate wetting and drying, or alternate freezing and thawing may be specified after an initial moist curing period. Curing and conditioning procedures shall be given in detail in the report.

6.5 Take a minimum of three height measurements (approximately 120° apart), and at least two diameter measurements (approximately 90° apart). Calculate the average height and diameter.

6.6 Record the mass of the test specimen.

6.7 Check the smoothness of the faces with a straightedge. If necessary, cap the faces to meet the requirements of the section on Capping Specimens of Practice D1632.

7. Procedure

7.1 Place the lower bearing block on the table or platen of the testing machine directly under the spherically seated (upper) bearing block. Place the specimen on the lower bearing block, making certain that the vertical axis of the specimen is aligned with the center of thrust of the spherically seated block. As this block is brought to bear on the specimen, rotate its movable portion gently by hand so that uniform seating is obtained.

7.2 Apply a constant rate of deformation without shock to produce an approximate rate of strain of 0.05 in./min (1.3 mm/min). Alternatively, the load may be applied at a constant rate that results in a rate of stress of 10 to 30 psi/s (70 to 210 kPa/s). Apply the load until it decreases steadily, indicating failure. Record the maximum load carried by the specimen during the test to the nearest 10 lbf (45 N).

7.3 Determine the water content of the test specimen in accordance with Test Method D2216 using the entire specimen, unless capped. If the specimen is capped, break away as much material as practical from the capping, for the water content specimen.

8. Calculation

8.1 Calculate the unit compressive strength of the specimen by dividing the recorded maximum load by the cross-sectional area.

NOTE 4—If desired, make allowance for the ratio of height to diameter (h/d) by multiplying the compressive strength of Method B specimens by the factor 1.10. This converts the strength for an h/d ratio of 2.00 to that for the h/d ratio of 1.15 commonly used in routine testing of soil-cement (see Section 4). This conversion is based on that given in Method C42/C42M, which has been found applicable for soil-cement.

8.2 Calculate the unit weight of the test specimen(s) using the dimensions and mass recorded in Section 6.

9. Report: Test Data Sheet(s)/Form(s)

9.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s) is covered in 1.4.

9.2 Record as a minimum the following general information (data):

9.2.1 Date specimen(s) was prepared;

9.2.2 Testing date, operator name, location, and unique conditions.

9.3 Record as a minimum the following test specimen data:

9.3.1 Specimen identification number,

9.3.2 Diameter and height,

9.3.3 Cross-sectional areas,

9.3.4 Maximum load carried by the specimen,

9.3.5 Conversion factor for height to diameter ratio (see Note 3), if used,

9.3.6 Compressive strength,

9.3.7 Age of specimen,

9.3.8 Mass of specimen,

9.3.9 Unit weight of specimen,

9.3.10 Water content of test specimen, and

9.3.11 Details of curing and conditioning periods.

10. Precision and Bias

10.1 The precision and bias of this test method have not been established by an interlaboratory test program. However, based on test data from Packard (1962)[4] and Packard and Chapman (1963)[5] the following may serve as a guide as to the variability of compressive strength test results.

10.1.1 Tests were performed in a single lab on 122 sets of duplicate specimens molded from 21 different soil materials. The average difference in strength on duplicate specimens was 8.1 % and the median difference was 6.2 %. These values are expressed as the percent of the average strength of the two specimens as follows:

$$\% \text{ Difference} = \frac{(\text{high value} - \text{low value})}{(\text{high value} + \text{low value})/2} \times 100 \qquad (1)$$

The distribution of the variation is shown in Fig. 1. The data cover a wide range of cement contents and compressive strengths.

11. Keywords

11.1 compressive strength; soil-cement; soil stabilization

---

[4] Packard, R. G., "Alternate Measures for Measuring Freeze-Thaw and Wet-Dry Resistance of Soil-Cement Mixtures," *Highway Research Bulletin*, 353, Transportation Research Board, 1962, pp 8–41.

[5] Packard, R. G., and Chapman, G. A., "Developments in Durability Testing of Soil-Cement Mixtures," *Highway Research Record*, No. 36, Transportation Research Board, 1963, pp 97–122.

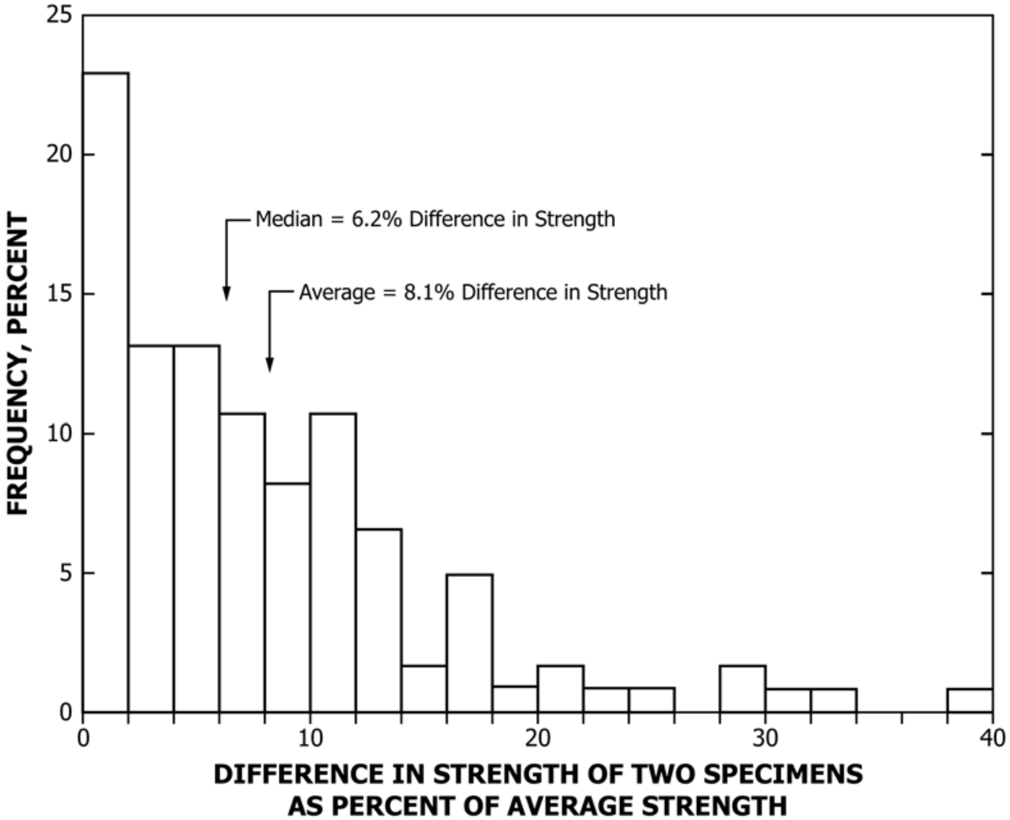


FIG. 1 Distribution of Variation of Test Results for 122 Sets of Duplicate Specimens

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (2000 (Reapproved 2007)) that may impact the use of this standard. (November 1, 2017)

(1) Clarified wording in 1.2.1 and 1.2.2.
(2) Updated caveats in Section 1 and renumbered sections as applicable.
(3) Updated 2.1 references
(4) Updated 3.1 Definitions statement.
(5) Updated Note 1.
(6) Added clarification wording in 5.1.
(7) Added balances and measuring device to the Apparatus section.
(8) Added clarification wording and procedural steps in Sections 6 and 7.
(9) Added calculation of unit weight in Section 8.
(10) Updated and expanded the Report section.

ATTACHMENT 4 - PDI HB-4: CHARACTERIZATION OF SOILS FOR COVER DESIGN AND SLOPE STABILITY

Project	Nuclear Metal Superfund Site, Concord, MA	Date	4 September 2020
Client	Remedial Design Work Plan	Page	1 of 4

1 INTRODUCTION

This Pre-Design Investigation (PDI) activity for the holding basin (HB) containment will investigate the geotechnical properties of sloped areas of the site. Existing slopes in some areas of the site pose risk for slope failure or limit access for equipment during investigatory activities and future remedial activities, including around the HB, the Cooling Pond (including the gabion wall at the northern end), and the Sphagnum Bog. Maintaining stable slopes with adequate safety factors is critical for executing the PDIs and implementing the selected remedial actions outlined in the Record of Decision (ROD) for the site.

The data collected during PDI HB-4 will be used to design the cover system for the HB cap, and to assess the stability of the side slopes of the HB, the Cooling Pond and associated gabion wall, and the bog. The HB containment design includes raising the grade inside the basin and the installation of a low permeability cover to cap the HB. The cap is currently planned to be constructed with a gentle slope to approximately match the existing ground surface surrounding the HB.

2 OBJECTIVES

The objectives for performing the work described in this PDI are as follows:

- Collect geotechnical data of the subgrade soil within the HB, which will be subject to additional loading from the HB cover design. This data will support the HB cover design.
- Collect shallow geologic data within the HB, and at the Cooling Pond and the bog, and collect field vane shear measurements of organic soils at the bog.
- Perform a slope stability analysis for the slopes along the HB, the Cooling Pond and associated gabion wall, and the bog.

3 SCOPE OF WORK

The scope of work will include test borings, shallow hand auger probes, and field vane shear measurements. The data collected from the testing borings, probes, and shear measurements will be used to perform a slope stability analysis for the HB, the Cooling Pond and associated gabion wall, and the bog.

4 PROCEDURES

4.1 Borings

To characterize subsurface conditions, four borings will be advanced within the footprint of the HB. We anticipate that the borings will be completed with a track-mounted drill rig. A winch may be necessary to lower the rig in order to access the Holding Basin boring locations safely.

The borings will be advanced using a sonic drill rig fitted with an auto-hammer to drive split spoons continuously at least 10 ft into naturally deposited soil. Soil from each boring will be logged continuously as temporary casing is set. Details of the drilling is further discussed in Attachment 6. Soil density will be estimated at each strata encountered based on Standard Penetration Test N-values, and up to 6 samples will be collected for grain size distribution testing.

Borings will be grouted to the surface following their completion and the liner will be repaired as needed. Locations of the proposed borings are shown on Figure 4.

4.2 Hand Probes

Several hand probes will be advanced to depths of up to 5 ft using a post-hole auger or bit auger within different areas of the site, as described below.

Area	Number of Hand Probes	Purpose
Cooling Pond	Six transects with up to three probes each (See Figure 4)	Evaluate shallow subsurface profile and estimate geotechnical soil properties.
Bog	Five transects with up to three individual probes each in proposed excavation area in Bog. Also, three transects down slope between Holding Basin and Bog with up to three probes each on slope and three probes each in the Bog (See Figure 4).	Determine thickness of the organic stratum in Bog. Evaluate shallow subsurface profile and estimate geotechnical soil properties along slope between Holding Basin and Bog.

Soils will be logged at each location and up to six samples will be collected for grain size distribution testing.

4.3 Field Vane Shear Measurements

Field vane shear tests will be performed at up to 24 locations in the Bog during this PDI, provided that the organic soils are not too fibrous for the testing equipment. The tests will be performed in 2-ft vertical intervals at each location to the bottom of the organic soils. Testing will be performed adjacent to probes performed in the Bog located as described above in Section 4.2. The data collected during the field vane shear tests will be used to estimate the shear strength of the organic soils to support slope stability analysis.

Field vane shear testing will be performed with Precision-Type or a Geonor-Type Torque Vane. Field vane shear testing will be performed in accordance with NMI-S-006 Operating Procedure, included in the FSP. Locations of the proposed field vane shear tests are shown on Figure 4.

4.4 Grain Size Distribution Analysis

Up to 8 soil samples will be tested for grain size distribution to support the slope stability analyses. Grain size distribution will be performed using sieve analysis and hydrometer methods in accordance with the following ASTM International Standards:

- ASTM D6913/D6913M-17: Standard Test Methods for Particle Size Distribution (Gradation) of Soils Using Sieve Analysis
- ASTM D7928-17 Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis

Copies of these standards are included in Section 4.

4.5 Gabion Wall Test Pits

Two test pits are planned to be excavated behind the Gabion Wall to confirm the cross section identified in historical drawings shown on Figure 4. Test pits will be excavated to depths of approximately 15 ft using a track-mounted excavator. Excavated material will be backfilled into the test pit.

4.6 Gabion Wall Survey

Three survey points will be installed at the top, middle, and bottom of the Gabion Wall along two transects to evaluate plumbness of the wall.

Approximate locations of the proposed survey points are shown on Figure 4, which also shows the historic drawing of the original Gabion Wall design.

4.7 Slope Stability Analysis

Slope stability analysis will be performed for the finished grade elevations of the proposed HB cap and containment wall (including adjacent site slopes), and the existing side slopes surrounding the Cooling Pond (including the gabion wall) and bog. Slope stability analysis will be performed using the *Slide2* 2018 software by Rocscience. *Slide2* is a two-dimensional equilibrium slope stability program for evaluating factors of safety of circular and non-circular failure in soil or rock slopes. The program analyzes the stability of slip surfaces using vertical or non-vertical slice limit equilibrium methods under specified boundary conditions.

The slope stability model will be built using topographic conditions and geologic profiles observed during the subsurface explorations performed in this PDI. Properties of subsurface material, such as unit weight, strength, cohesion and friction angle, will be estimated based on field observations, new test borings performed for HB wall design (see PDI HB-1), previous borings, grain size distribution results, and vane shear wave testing performed in this PDI.

The model will evaluate slope stability under existing conditions for the Cooling Pond, the bog, and the Gabion Wall. The model will evaluate slope stability of the HB under proposed design conditions, as well as under construction conditions such as during remedial excavations at adjacent areas. Each model will evaluate conditions for static, pseudo-static, and post-earthquake conditions. Results of the slope stability modeling will be used in the HB cap design and will inform the need for stability improvement measures during construction of the future remedial activities. Additional models may be developed to evaluate the effectiveness of the designed stability improvement measures. As an example, temporary sheeting is expected to be used to excavate sediment from the bog. It may be necessary to consider leaving the sheeting permanently to achieve more stable sideslopes.

4.8 IDW Management

Investigation-derived waste (IDW) generated during the work described herein will include soil cuttings from subsurface explorations, including borings and hand probes. Excess soil will be used as backfill within the borehole.

5 REPORTING

The status of this PDI and results will be provided to EPA during routine project meetings and status reports. Results and the outcome of the PDI will be incorporated into a separate PDI Evaluation Report and the 30% RD report.

ATTACHMENTS
  Section 4 – ASTM Standards

Section 4
PDI HB-4 Standards

Designation: D6913/D6913M – 17

Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis[1]

This standard is issued under the fixed designation D6913/D6913M; 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 (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Although this test method has been used for many years, there are vast testing variations due to soil types and conditions. The test is more complicated and complex than would be expected. Multiple procedures are being presented along with new terminology. Although these procedures are not new, they will now be defined and explained. Some examples of these new terms are composite sieving, designated separating sieve and subspecimen. This test method outlines the majority of conditions and procedures but does not cover every conceivable variation or contingency. The table of contents in the Scope section is added to enable the user to easily find a specific topic or requirement. Only sections/subsections with titles are presented. Therefore, numbered subsections will not be continuous in some cases, as indicated in the Scope section.

1. Scope

1.1 Soils consist of particles with various shapes and sizes. This test method is used to separate particles into size ranges and to determine quantitatively the mass of particles in each range. These data are combined to determine the particle-size distribution (gradation). This test method uses a square opening sieve criterion in determining the gradation of soil between the 3-in. (75-mm) and No. 200 (75-µm) sieves.

1.2 The terms, soils and material, are used interchangeably throughout the standard.

1.3 In cases where the gradation of particles larger than 3 in. (75 mm) sieve is needed, Test Method D5519 may be used.

1.4 In cases where the gradation of particles smaller than No. 200 (75-µm) sieve is needed, Test Method D7928 may be used.

1.5 Typically, if the maximum particle size is equal to or less than 4.75 mm (No. 4 sieve), then single-set sieving is applicable. Furthermore, if the maximum particle size is greater than 4.75 mm (No. 4 sieve) and equal to or less than 9.5 mm (⅜-in sieve), then either single-set sieving or composite sieving is applicable. Finally, if the maximum particle size is equal to or greater than 19.0 mm (¾-in sieve), composite sieving is applicable. For special conditions see 10.3.

1.6 Two test methods are provided in this standard. The methods differ in the significant digits recorded and the size of the specimen (mass) required. The method to be used may be specified by the requesting authority; otherwise Method A shall be performed.

1.6.1 *Method A*—The percentage (by mass) passing each sieve size is recorded to the nearest 1 %. This method must be used when performing composite sieving. For cases of disputes, Method A is the referee method.

1.6.2 *Method B*—The percentage (by mass) passing each sieve size is recorded to the nearest 0.1 %. This method is only applicable for single sieve-set sieving and when the maximum particle size is equal to or less than the No. 4 (4.75-mm) sieve.

1.7 This test method does not cover, in any detail, procurement of the sample. It is assumed that the sample is obtained using appropriate methods and is representative.

1.8 *Sample Processing*—Three procedures (moist, air dry, and oven dry) are provided to process the sample to obtain a specimen. The procedure selected will depend on the type of sample, the maximum particle-size in the sample, the range of particle sizes, the initial conditions of the material, the plasticity of the material, the efficiency, and the need for other testing on the sample. The procedure may be specified by the requesting authority; otherwise the guidance given in Section 10 shall be followed.

1.9 This test method typically requires two or three days to complete, depending on the type and size of the sample and soil type.

---

[1] This test method 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 April 15, 2017. Published May 2017. Originally approved in 2004. Last previous edition approved in 2009 as D6913 – 04(2009)$^{\varepsilon 1}$. DOI: 10.1520/D6913-17.

1.10 This test method is ***not*** applicable for the following soils:

1.10.1 Soils containing fibrous peat that will change in particle size during the drying, washing, or sieving procedure.

1.10.2 Soils containing extraneous matter, such as organic solvents, oil, asphalt, wood fragments, or similar items. Such extraneous matter can affect the washing and sieving procedures.

1.10.3 Materials that contain cementitious components, such as cement, fly ash, lime, or other stabilization admixtures.

1.11 This test method may not produce consistent test results within and between laboratories for the following soils and the precision statement does not apply to them.

1.11.1 Friable soils in which the sieving processes change the gradation of the soil. Typical examples of these soils are some residual soils, most weathered shales and some weakly cemented soils such as hardpan, caliche or coquina.

1.11.2 Soils that will not readily disperse such as glauconitic clays or some dried plastic clays.

1.11.3 To test these soils, this test method must be adapted, or altered, and these alterations documented. Depending on the design considerations, a specialized gradation-testing program could be performed. The alterations could require the washing and sieving procedures to be standardized such that each specimen would be processed in a similar manner.

1.12 Some materials that are not soils, but are made up of particles may be tested using this method. However, the applicable sections above should be used in applying this standard.

1.13 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

1.13.1 The procedures used to specify how data are collected/recorded and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of these test methods to consider significant digits used in analysis methods for engineering design.

1.14 *Units*—The dimensional values stated in either SI units or inch-pound units are to be regarded as standard, such as 200-mm or 8-in. diameter sieve. Except, the sieve designations are typically identified using the "alternative" system in accordance with Practice E11, such as 3 in. and No. 200, instead of the "standard" system of 75 mm and 75 µm, respectively. Only the SI units are used for mass determinations, calculations, and reported results. However, the use of balances or scales recording pounds of mass (lbm) shall not be regarded as nonconformance with this standard.

1.15 A summary of the symbols used in this test method is given in Annex A1.

1.16 *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.*

1.17 *Table of Contents*—All tables and figures appear at the end of this standard.

1.18 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates

C702 Practice for Reducing Samples of Aggregate to Testing Size

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))

D1140 Test Methods for Determining the Amount of Material Finer than 75-μm (No. 200) Sieve in Soils by Washing

D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4220/D4220M Practices for Preserving and Transporting Soil Samples

D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D5519 Test Methods for Particle Size Analysis of Natural and Man-Made Riprap Materials

D6026 Practice for Using Significant Digits in Geotechnical Data

D7928 Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *General:*

3.1.1 An overview of terms used in the sieving processes is presented in Fig. 1(a) using a tabular format and in Fig. 1(b) using a flowchart format. In addition, Fig. 1(a) includes symbols used in the sieving processes.

3.1.2 There are two types of definitions in the following sections. There are definitions that are general (see 3.2) and others that are specific to this standard (see 3.3). To locate a definition, it may be necessary to review both sections. The definitions are in alphabetical order.

3.2 *Definitions:*

3.2.1 For definitions of general terms used in this test method, refer to Terminology D653.

3.2.2 *composite sieving, v—in sieving*, the process of separating a large specimen on a designated separating sieve to obtain coarser and finer particle-size portions. The coarser portion is sieved using the coarser sieve set. The finer portion is subsampled to obtain a subspecimen of manageable size (mass) and this subspecimen is sieved using the finer sieve set. The results of both sieve sets (coarser and finer) are combined mathematically to determine the gradation of the large specimen.

3.2.2.1 *Discussion*—In some cases the subspecimen may require another separation; that is, using a 2nd designated separating sieve and resulting in a 2nd coarser portion and 2nd subspecimen obtained from the 2nd finer portion.

3.2.3 *cumulative material retained (cumulative retained material or cumulative mass retained), n—in sieving*, the mass of material retained on an individual sieve plus the masses of material retained on all the coarser sieves in a given stack/set of sieves.

3.2.4 *cumulative percent retained, n—in sieving*, the ratio of cumulative material retained on a given sieve to the mass of the specimen, expressed in percent.

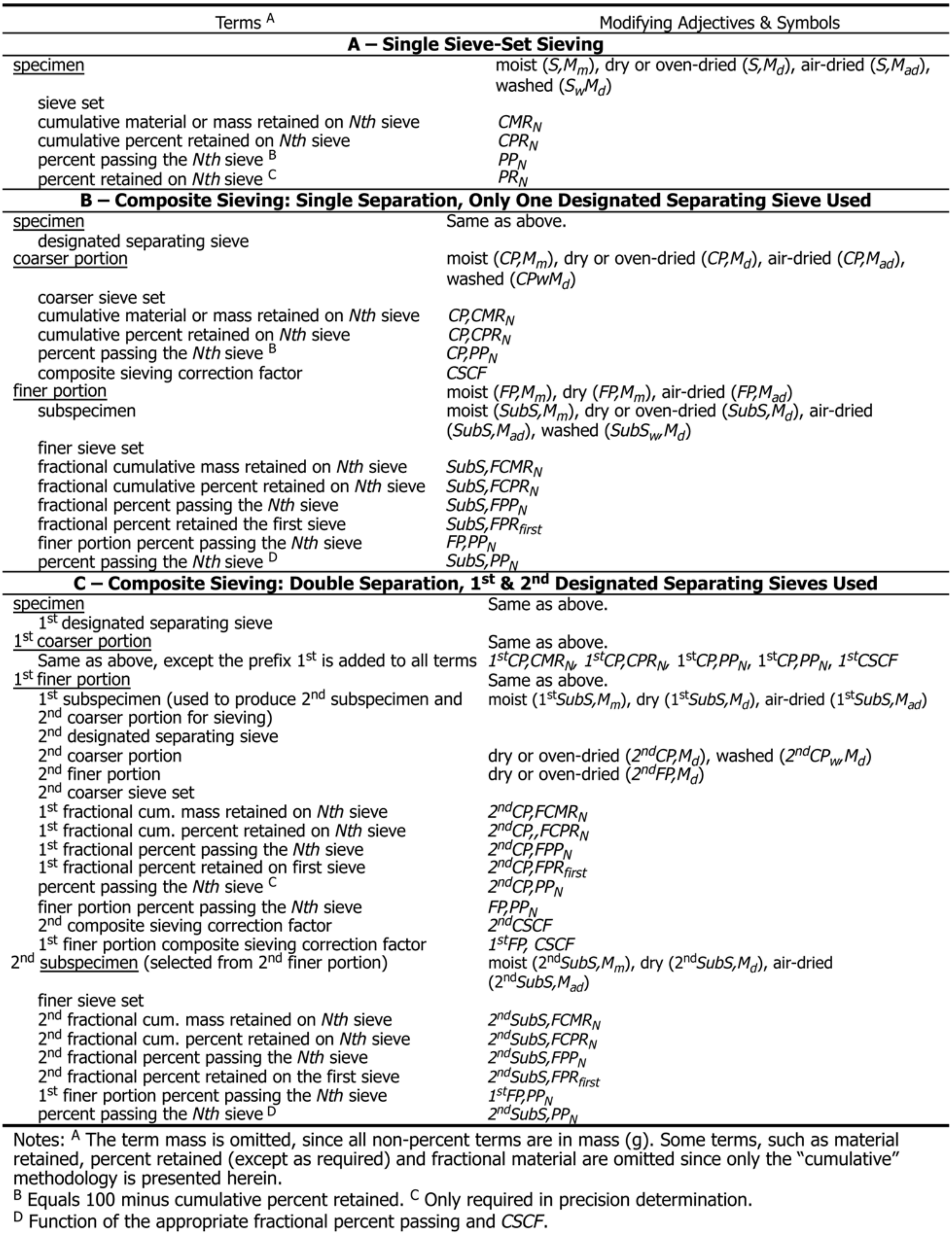
3.2.5 *designated separating sieve, n—in composite sieving*, the sieve selected to separate the specimen into coarser and finer portions for composite sieving.

3.2.5.1 *Discussion*—The designated separating sieve size is a standard sieve size typically ranging from the ¾-in. (19.0-mm) sieve to the No. 10 (2.00-mm) sieve. There can be two designated separating sieves used in composite sieving, that is the 1st subspecimen can be separated on a 2nd designated separating sieve to obtain a 2nd coarser portion and a 2nd subspecimen obtained from the 2nd finer portion.

3.2.6 *fractional cumulative material retained, n—in composite sieving*, when sieving a subspecimen, the mass of material retained on an individual sieve plus the masses of material retained on all the coarser sieves in a given sieve set.

---

[2] 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.



Terms [A]	Modifying Adjectives & Symbols
A – Single Sieve-Set Sieving	
specimen	moist (S,M_m), dry or oven-dried (S,M_d), air-dried (S,M_{ad}), washed (S_wM_d)
sieve set	
cumulative material or mass retained on *Nth* sieve	CMR_N
cumulative percent retained on *Nth* sieve	CPR_N
percent passing the *Nth* sieve [B]	PP_N
percent retained on *Nth* sieve [C]	PR_N
B – Composite Sieving: Single Separation, Only One Designated Separating Sieve Used	
specimen	Same as above.
designated separating sieve	
coarser portion	moist (CP,M_m), dry or oven-dried (CP,M_d), air-dried (CP,M_{ad}), washed ($CPwM_d$)
coarser sieve set	
cumulative material or mass retained on *Nth* sieve	CP,CMR_N
cumulative percent retained on *Nth* sieve	CP,CPR_N
percent passing the *Nth* sieve [B]	CP,PP_N
composite sieving correction factor	$CSCF$
finer portion	moist (FP,M_m), dry (FP,M_m), air-dried (FP,M_{ad})
subspecimen	moist ($SubS,M_m$), dry or oven-dried ($SubS,M_d$), air-dried ($SubS,M_{ad}$), washed ($SubS_w,M_d$)
finer sieve set	
fractional cumulative mass retained on *Nth* sieve	$SubS,FCMR_N$
fractional cumulative percent retained on *Nth* sieve	$SubS,FCPR_N$
fractional percent passing the *Nth* sieve	$SubS,FPP_N$
fractional percent retained the first sieve	$SubS,FPR_{first}$
finer portion percent passing the *Nth* sieve	FP,PP_N
percent passing the *Nth* sieve [D]	$SubS,PP_N$
C – Composite Sieving: Double Separation, 1st & 2nd Designated Separating Sieves Used	
specimen	Same as above.
1st designated separating sieve	
1st coarser portion	Same as above.
Same as above, except the prefix 1st is added to all terms	$1^{st}CP,CMR_N$, $1^{st}CP,CPR_N$, $1^{st}CP,PP_N$, $1^{st}CP,PP_N$, $1^{st}CSCF$
1st finer portion	Same as above.
1st subspecimen (used to produce 2nd subspecimen and 2nd coarser portion for sieving)	moist ($1^{st}SubS,M_m$), dry ($1^{st}SubS,M_d$), air-dried ($1^{st}SubS,M_{ad}$)
2nd designated separating sieve	
2nd coarser portion	dry or oven-dried ($2^{nd}CP,M_d$), washed ($2^{nd}CP_w,M_d$)
2nd finer portion	dry or oven-dried ($2^{nd}FP,M_d$)
2nd coarser sieve set	
1st fractional cum. mass retained on *Nth* sieve	$2^{nd}CP,FCMR_N$
1st fractional cum. percent retained on *Nth* sieve	$2^{nd}CP,,FCPR_N$
1st fractional percent passing the *Nth* sieve	$2^{nd}CP,FPP_N$
1st fractional percent retained on first sieve	$2^{nd}CP,FPR_{first}$
percent passing the *Nth* sieve [C]	$2^{nd}CP,PP_N$
finer portion percent passing the *Nth* sieve	FP,PP_N
2nd composite sieving correction factor	$2^{nd}CSCF$
1st finer portion composite sieving correction factor	$1^{st}FP, CSCF$
2nd subspecimen (selected from 2nd finer portion)	moist ($2^{nd}SubS,M_m$), dry ($2^{nd}SubS,M_d$), air-dried ($2^{nd}SubS,M_{ad}$)
finer sieve set	
2nd fractional cum. mass retained on *Nth* sieve	$2^{nd}SubS,FCMR_N$
2nd fractional cum. percent retained on *Nth* sieve	$2^{nd}SubS,FCPR_N$
2nd fractional percent passing the *Nth* sieve	$2^{nd}SubS,FPP_N$
2nd fractional percent retained on the first sieve	$2^{nd}SubS,FPR_{first}$
1st finer portion percent passing the *Nth* sieve	$1^{st}FP,PP_N$
percent passing the *Nth* sieve [D]	$2^{nd}SubS,PP_N$

Notes: [A] The term mass is omitted, since all non-percent terms are in mass (g). Some terms, such as material retained, percent retained (except as required) and fractional material are omitted since only the "cumulative" methodology is presented herein.

[B] Equals 100 minus cumulative percent retained. [C] Only required in precision determination.

[D] Function of the appropriate fractional percent passing and *CSCF*.

FIG. 1 (a) Typical Terminology and Symbols Used in Sieving Processes

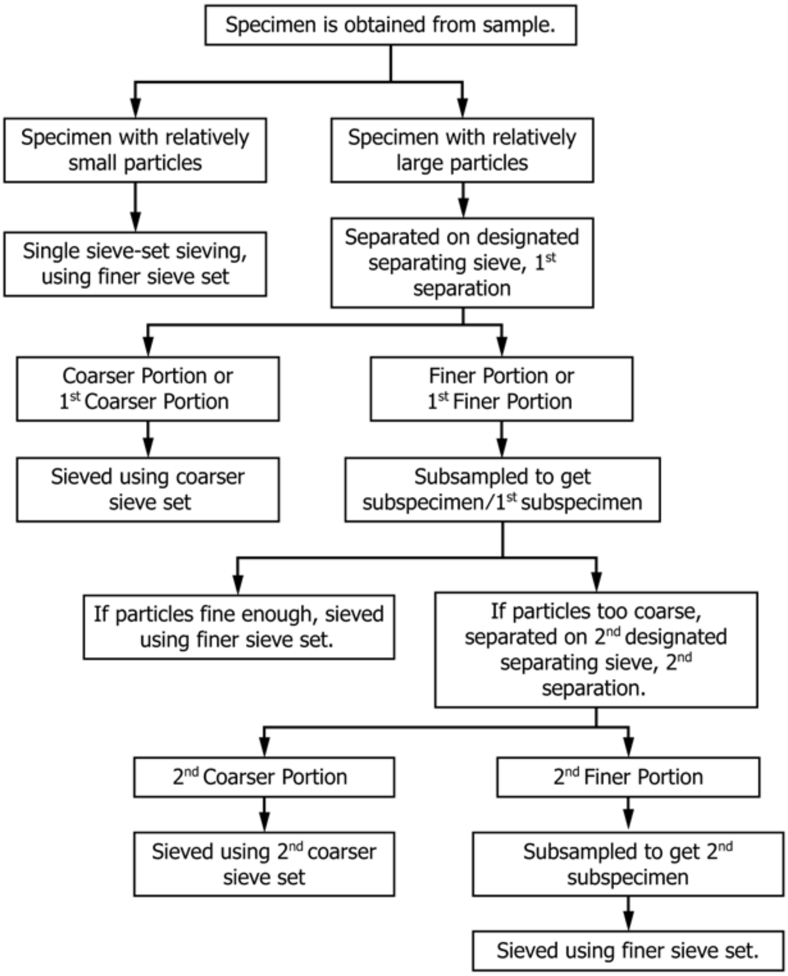


FIG. 1 (b) Terminology Flowchart for Sieving Processes *(continued)*

3.2.7 *fractional cumulative percent retained, n—in composite sieving*, the ratio of fractional cumulative material retained on a given sieve to the mass of the subspecimen, expressed in percent.

3.2.8 *fractional material retained, n—in composite sieving*, when sieving a subspecimen, the mass of material retained on an individual sieve.

3.2.9 *fractional percent passing, n—in composite sieving*, the portion of material by mass in the subspecimen(s) passing a given sieve expressed in percent.

3.2.9.1 *Discussion*—When two subspecimens are used, there will be a 1st and 2nd fractional percent passing.

3.2.10 *fractional percent retained, n—in composite sieving*, the ratio of fractional material retained on a given sieve to the mass of the subspecimen, expressed in percent.

3.2.11 *gradation, n—in soil*, the proportion by mass of various particle sizes.

3.2.11.1 *Discussion*—This proportion is usually presented in tabular format (sieve size and percent passing) or graphical format (percent passing versus logarithm of the sieve size in mm). The graphical format is referred to as particle-size distribution or gradation curve.

3.2.12 *maximum particle size, n—in sieving*, the smallest sieve size from the standard sieve set on which less than one percent of the sample would be retained.

3.2.12.1 *Discussion*—For practical purposes, estimate the maximum particle size as equal to the smallest sieve size from the standard sieve set in which it appears that all the material being tested would pass through that sieve. The maximum particle size is needed to determine the required mass of the specimen and subspecimen.

3.2.13 *maximum sieve size, n—in sieving*, the smallest sieve size that is larger than any particle in the specimen or subspecimen.

3.2.14 *minimum sieve size, n—in sieving*, the smallest sieve size in a sieve set used in sieving the specimen or subspecimen.

3.2.14.1 *Discussion*—This size is either the size of the designated separating sieve (1st or 2nd) or the No. 200 (75-µm) sieve.

3.2.15 *percent passing, n—in sieving*, the portion of material by mass in the specimen passing a given sieve expressed in percent.

3.2.15.1 *Discussion*—This value is equal to the cumulative material retained in a given sieve set divided by the mass of the specimen, subtracting that ratio from one, and then multiplying by 100. For composite sieving, it would be the fractional percent passing multiplied by the composite sieving correction factor (*CSCF*).

3.2.16 *particle size distribution, n*—see *gradation*.

3.2.17 *percent retained, n—in sieving*, the ratio of the material retained on a given sieve to the mass of the specimen, expressed in percent.

3.2.18 *saturated surface-dry condition, n—in coarse-grained soils*, a state in which the soil particles are basically saturated with water, but there are not visible films of water.

3.2.19 *sieve set, n—in sieving*, a set of standard sized sieves. For single sieve-set sieving, the sieve set will range from the maximum sieve size to the No. 200 (75-µm) sieve. For composite sieving, there will be a coarser sieve set and a finer sieve set. Together, these sets will range from the maximum sieve size to the No. 200 (75-µm) sieve. The designated separating sieve will be used as the minimum size in the coarser set and the maximum size in the finer set.

3.2.20 *sieve size, n—in sieving*, the size of the opening in the wire cloth of a given sieve in mm or µm.

3.2.21 *single sieve-set sieving, v—in sieving*, the process in which only one set of sieves is needed to determine the gradation of the specimen from the maximum particle size to the No. 200 (75-µm) sieve.

3.2.21.1 *Discussion*—Typically, this applies to specimens having a maximum particle size of 9.5 mm (⅜ in.) or less when using Method A or a maximum particle size of 4.75 mm (No. 4 sieve) or less when using Method B and the distribution of particles less than the No. 200 (75-µm) sieve is not needed.

3.2.22 *splitting, v—in sampling or subsampling*, the process of stockpile sampling, quartering material, or passing material through a splitter or riffle box to obtain a representative portion of that material for testing; that is, a specimen or subspecimen.

3.2.22.1 *Discussion*—A description of stockpile sampling, and quartering and splitting material is given in Annex A2, A2.1.1 through A2.1.3.

3.2.23 *standard shaking period, n—in sieving*, a time period ranging from 10 to 20 minutes that a mechanical sieve shaker operates during the sieving process and which has been verified to satisfy the requirements for sieving thoroughness.

3.2.24 *standard sieve set, n—in sieving soils*, the group of fourteen specific sieve sizes required to determine the gradation of soils between and including the 3-in. (75-mm) and No. 200 (75-µm) sieves, as listed in Table 1.

3.2.24.1 *Discussion*—Most of these sieve sizes are different than those used in aggregate testing for concrete (Test Method C136), especially for sieves finer than the No. 4 (4.75 mm).

3.2.25 *subspecimen, n—in composite sieving*, a representative portion of the material passing the designated separating sieve; that is, the finer portion.

3.2.25.1 *Discussion*—When composite sieving requires multiple designated separating sieves, there will be more than one subspecimen. The 1st subspecimen (that is, the subspecimen from the finer portion) would be separated into a 2nd coarser portion and a 2nd finer portion that would be subsampled to obtain the 2nd subspecimen.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *coarser portion, n—in composite sieving*, the portion of the specimen retained on the designated separating sieve.

3.3.1.1 *Discussion*—When two designated separating sieves are used, there will be a 1st and 2nd coarser portion.

3.3.2 *coarser sieve set, n—in composite sieving*, the sieve set that ranges from the maximum sieve size to the designated separating sieve size.

3.3.2.1 *Discussion*—When two designated separating sieves are used, the 1st coarser sieve set ranges from the maximum sieve size to the 1st designated separating sieve size. The 2nd coarser sieve set would range from the 1st designated separating sieve size to the 2nd designated separating sieve size.

3.3.3 *composite sieving correction factor (CSCF), n—in composite sieving*, a factor used to convert the fractional percent passing determined from sieving the subspecimen to the percent passing for the specimen. The *CSCF* is equal to the percent passing the designated separating sieve size in the coarser portion sieve set (that is, the last sieve in the coarser portion set). This value shall be calculated to one more digit than required (0.1 %) to reduce rounding errors.

3.3.3.1 *Discussion*—When two designated separating sieves are used, there will be a 1st and 2nd*CSCF*.

3.3.4 *finer portion, n—in composite sieving*, the portion of the specimen passing the designated separating sieve.

3.3.4.1 *Discussion*—When two designated separating sieves are used, the 1st subspecimen obtained from the 1st finer portion will be separated into a 2nd coarser portion and 2nd finer portion, from which the 2nd subspecimen is obtained.

TABLE 1 Standard Sieve Set[A]

Sieve Designation in Accordance with E11			
Alternative	Standard	Alternative	Standard
Lid		No. 10	2.00 mm
3 in.	75 mm	No. 20	850 µm
2 in.	50 mm	No. 40	425 µm
1-½ in.	37.5 mm	No. 60	250 µm
1 in.	25.0 mm	No. 100	150 µm
¾ in.	19.0 mm	No. 140	106 µm
⅜ in.	9.5 mm	No. 200	75 µm
No. 4	4.75 mm	Pan	

[A] A lid is typically not used or needed when using rectangular coarser sieves having dimensions greater than 200 mm or 8 in.

3.3.5 *finer sieve set, n—in composite sieving*, the sieve set that ranges from the last designated separating sieve size to the No. 200 (75-µm) sieve.

3.3.5.1 *Discussion*—When composite sieving requires a 2nd subspecimen, the finer sieve sets ranges from the 2nd separating sieve size to the No. 200 (75-µm) sieve.

3.3.6 *insignificant sieve, n—in precision of test results*, any sieve which has 1 % or less cumulative material retained during the sieve analysis.

3.3.7 *separating, v—in composite sieving*, the process of dividing a specimen or subspecimen into two portions, the coarser (retained) and finer (passing) portions, using a designated separating sieve.

3.3.7.1 *Discussion*—When composite sieving requires two designated sieves, there will be a 1st and 2nd coarser portion, finer portion and subspecimen.

3.3.8 *significant sieve, n—in precision of test results*, any sieve which has more than 1 % of cumulative material retained during the sieve analysis.

4. Summary of Test Method

4.1 This test method is used to determine the particle-size distribution (gradation) of a soil sample. A representative specimen must be obtained from the sample by one of three procedures (moist, air-dried or oven-dried). For specimens containing relatively small particles, the specimen is sieved in its entirety, using single sieve-set sieving. However, the specimen may contain a wide range of particle sizes and may require separating the soil into two, or three size ranges for more efficient sieving, using one or two designated separating sieve(s). This process is termed composite sieving. For a single separation (two portions), the coarser portion is sieved in its entirety, while the finer portion is split into a smaller subspecimen for sieving. These results are mathematically combined. For specimens containing very large particles, the specimen may require two separations; that is, three portions (1st and 2nd coarser portions and 2nd finer portion), see Fig. 1(a) and Fig. 1(b). Prior to sieving, as applicable, the material will be washed to remove fine particles and oven dried. The material to be sieved will be placed on the coarsest sieve size of each sieve set and mechanically shaken. The mass of particles retained on each sieve will be determined. The results will produce a tabulation of sieve sizes versus percent passing that can be graphically presented as a gradation curve (a plot of the percent passing versus the log of the particle size in mm.).

4.2 Flowcharts outlining the requirements of the various sieving processes covered above are presented below in four figures, Fig. 2 through Fig. 4(b).

5. Significance and Use

5.1 The gradation of the soil is used for classification in accordance with Practice D2487.

5.2 The gradation (particle-size distribution) curve is used to calculate the coefficient of uniformity and the coefficient of curvature.

5.3 Selection and acceptance of fill materials are often based on gradation. For example, highway embankments, backfills, and earthen dams may have gradation requirements.

5.4 The gradation of the soil often controls the design and quality control of drainage filters, and groundwater drainage.

5.5 Selection of options for dynamic compaction and grouting is related to gradation of the soil.

5.6 The gradation of a soil is an indicator of engineering properties. Hydraulic conductivity, compressibility, and shear strength are related to the gradation of the soil. However, engineering behavior is dependent upon many factors (such as effective stress, stress history, mineral type, structure, plasticity, and geologic origins) and cannot be based solely upon gradation.

NOTE 1—The quality of the result produced by these test methods 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 D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of these test methods are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Sieves*—Each sieve shall conform to the requirements of Specification E11. Generally, these sieve frames are circular and 200 mm or 8 in. in diameter, and either full (50 mm or 2 in.) or half height (25 mm or 1 in.). The sieve height generally depends upon the number of sieves typically required in the sieve set, the particle sizes being sieved, and the size and type of the sieve shaker. Particles having dimensions exceeding or relatively close to the sieve heights cannot be sieved in the sieve stack, but individually. Therefore, in a stack of sieves, the ratio of sieve height or spacing between rectangular sieves to sieve cloth opening shall exceed 2. Larger frames that conform to Specification E11 are acceptable but require special considerations for reinforcement.

6.1.1 *Standard Sieve Set*—This set consists of all the sieve sizes listed in Table 1. Additional sieves sizes may be added if requested or needed to reduce sieve overloading. In addition, some larger sieve sizes may be omitted during the sieve analysis depending on the maximum particle size; however, at least one sieve in the sieving process shall have 100 percent passing.

6.1.2 *Washing Sieve, No. 200 (75-µm)*—A No. 200 (75-µm) sieve with a minimum height above the screen of 50 mm or 2 in. to prevent loss of retained material while washing. Stainless steel sieve cloth is preferred because it is more durable, and less prone to damage or wear. The sieve may be reinforced with a larger mesh underneath the 75-µm cloth. The reinforcement wire cloth (backing) should not have a mesh coarser than the No. 20 (850-µm) wire cloth. The reinforcement wire cloth should be bonded to the sieve frame along with the No. 200 (75-µm) wire cloth, not bonded to the sieve frame below where the No. 200 (75-µm) wire cloth was attached. In addition, it is good practice to use a flattened backing cloth (rolled or calendered backing cloth), so it is less abrasive to the No. 200 (75-µm) wire cloth.

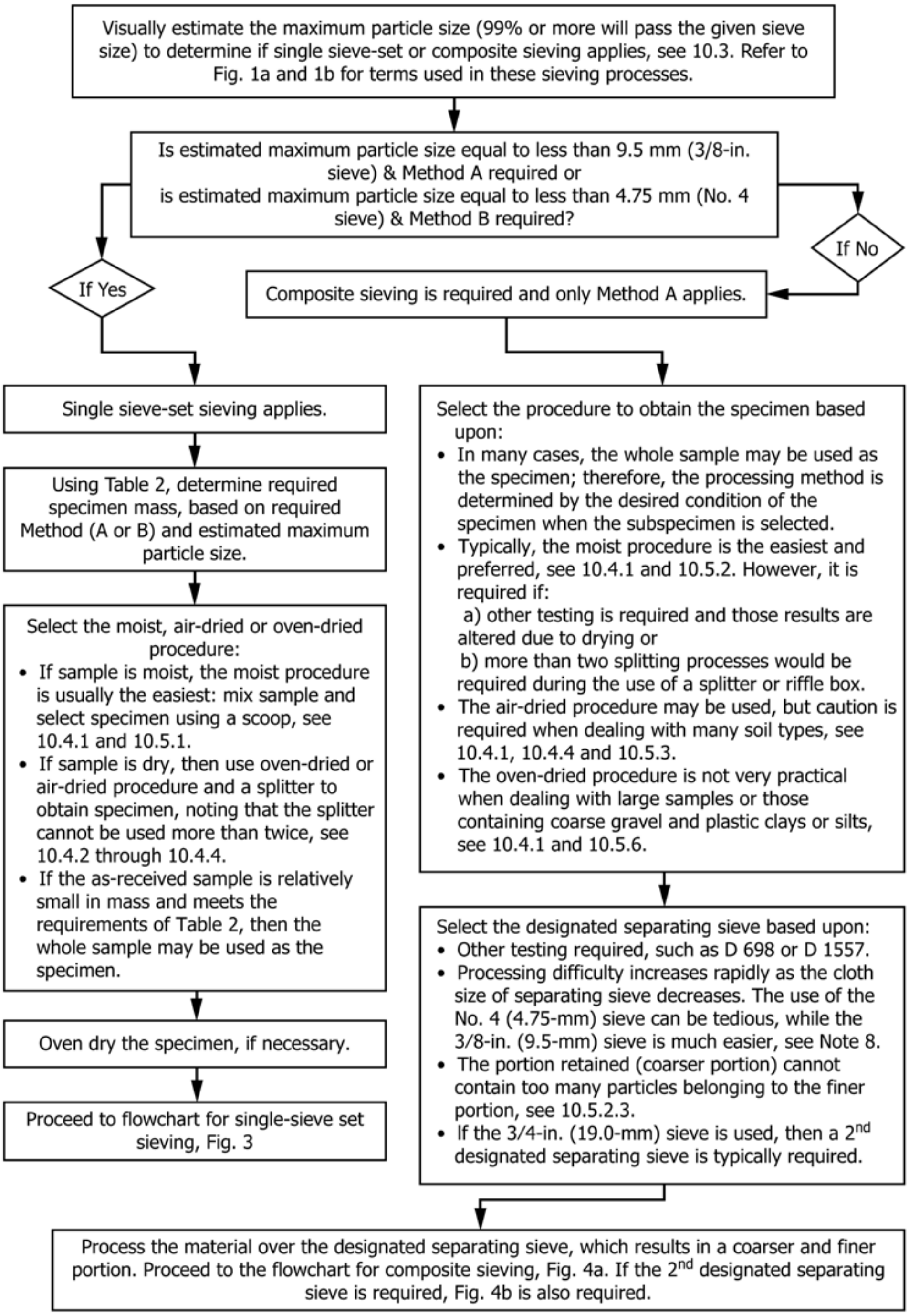
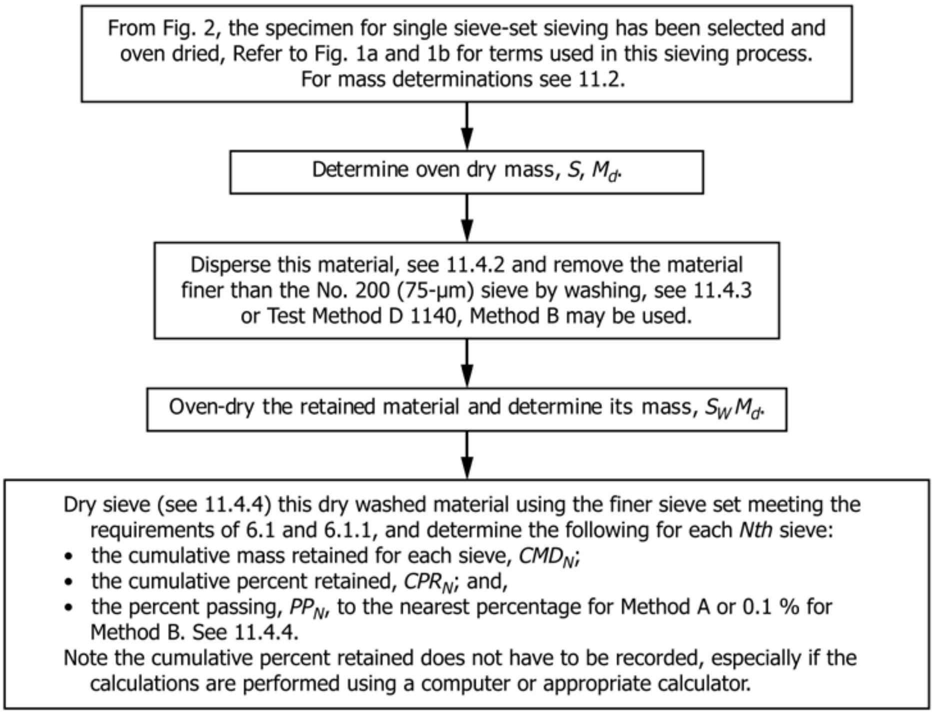


FIG. 2 Decision Flowchart for Sieving Processes

6.1.3 *Designated Separating Sieve*—A sieve used to separate the specimen into two portions (coarser and finer portion) in composite sieving. The designated separating sieve shall conform to Specification E11. It may be necessary to have various sizes of sieves to use as designated separating sieves. Normally, these are not the same sieves that are used in the stack of sieves (sieve set) placed in the sieve shaker. Typically, the 1st designated separating sieve is rectangular and quite large, while the 2nd designated separating sieve is either 200-mm or 8-in. in diameter.

6.2 *Washing Sink with Spray Nozzle*—A sink having a spray nozzle attached to a flexible line to facilitate the washing and material transferring processes without spillage. In addition, the spray nozzle shall be such that the rate of water flow can be easily controlled. The temperature of the water shall be



From Fig. 2, the specimen for single sieve-set sieving has been selected and oven dried, Refer to Fig. 1a and 1b for terms used in this sieving process. For mass determinations see 11.2.

Determine oven dry mass, S, M_d.

Disperse this material, see 11.4.2 and remove the material finer than the No. 200 (75-µm) sieve by washing, see 11.4.3 or Test Method D 1140, Method B may be used.

Oven-dry the retained material and determine its mass, $S_W M_d$.

Dry sieve (see 11.4.4) this dry washed material using the finer sieve set meeting the requirements of 6.1 and 6.1.1, and determine the following for each *Nth* sieve:

- the cumulative mass retained for each sieve, CMD_N;
- the cumulative percent retained, CPR_N; and,
- the percent passing, PP_N, to the nearest percentage for Method A or 0.1 % for Method B. See 11.4.4.

Note the cumulative percent retained does not have to be recorded, especially if the calculations are performed using a computer or appropriate calculator.

FIG. 3 Flowchart for Single Sieve-Set Sieving

relatively close to room temperature to prevent changing the dimensions of the sieve cloth and health and safety concerns.

6.3 *Mechanical Sieve Shaker*—A device that holds a stack of sieves while imparting sufficient motion to the sieves to meet the sieving thoroughness requirements covered in 8.2. The "Standard Shaking Period" must be from 10 to 20 minutes. The shaker shall have a timing device or a timing device shall be used in conjunction with the shaker.

NOTE 2—Shakers imparting a motion that causes the particles on the sieves to bounce and turn so that all particles have ample opportunity in various orientations to the sieve openings will typically meet this sieving thoroughness requirement. A sieve shaker that has a smooth horizontal and/or vertical gyratory/orbital motion will typically ***not*** meet this sieving thoroughness requirement, since the particles will not be bouncing and turning.

6.4 *Balances*—For single sieve-set sieving, one balance will be used. For composite sieving, more than one balance may be necessary. Balances must conform to the requirements of Specification D4753; that is, having a readability (with no estimation) to determine the mass of the specimen or subspecimen to a minimum of three significant digits for Method A or a minimum four significant digits for Method B. The mass of the specimen can be determined in parts (multiple mass determinations). The balance used to determine the cumulative material retained or the fractional cumulative material retained on any given sieve has to have a readability equal to or better than that used to determine the mass of the specimen/subspecimen.

NOTE 3—Preferably the balance should have a taring capability so that the mass of material can be directly determined without subtracting the mass of the container. This feature is immensely useful during the sieving process to determine the mass of the cumulative material retained or when making multiple mass determinations to determine specimen's mass.

6.5 *Drying Oven*—Thermostatically controlled oven, capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber. These requirements typically require the use of a forced-draft oven.

6.6 *Sieving Containers*—The containers used to: *(a)* contain the sieving specimen or material which will be sieved, such as coarser portion; *(b)* remove the retained material from the sieve(s); *(c)* collect and transfer that material; and, *(d)* contain the cumulative material retained.

6.6.1 *Specimen Containers*—Smooth walled containers, without tight corners to trap material, made of material resistant to corrosion and change in mass upon repeated heating, cooling, specimen soaking, and cleaning. The containers should be large enough to enable soaking of the specimen. The container should facilitate the transfer of the specimen from the container to the washing sieve (No. 200 (75 µm) or designated separating sieve) and back by a rinsing/washing operation, and allow for decanting the clear wash water from the container.

6.6.2 *Collection/Transfer Container*—This container is used to collect the material retained on a given sieve and to transfer it to the container holding the cumulative retained material during the sieving process. The container must be larger in diameter than the sieve. A smoothsurface 230-mm (9-in.) pie pan may be used along with a 25-mm (1-in.) paintbrush to assist in transferring all the material. The color of this container shall enhance the observation that all material has been transferred.

6.6.3 *Cumulative Mass Container*—This container shall be large enough to receive the retained material contained in the collection/transfer device without any loss. The mass should be

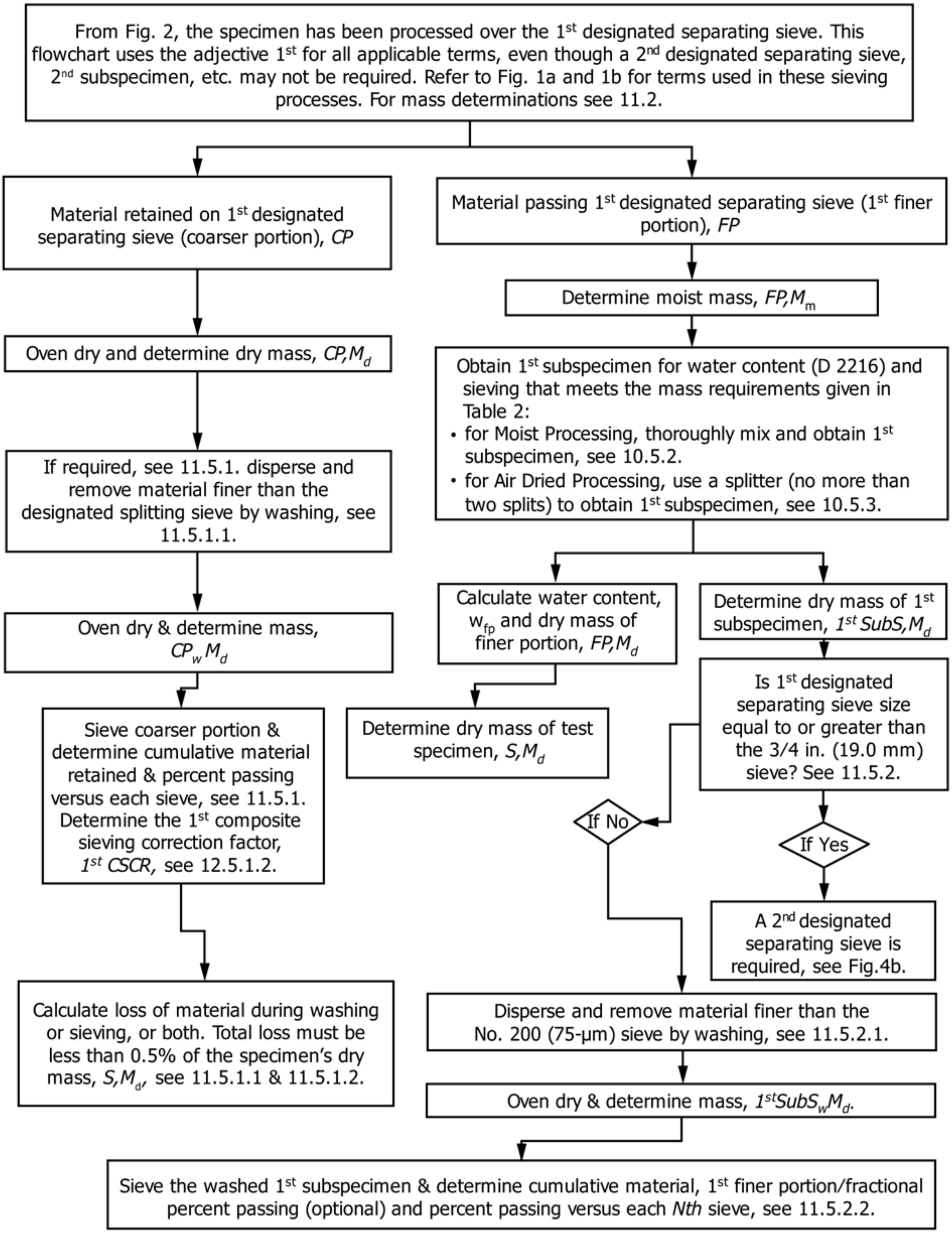
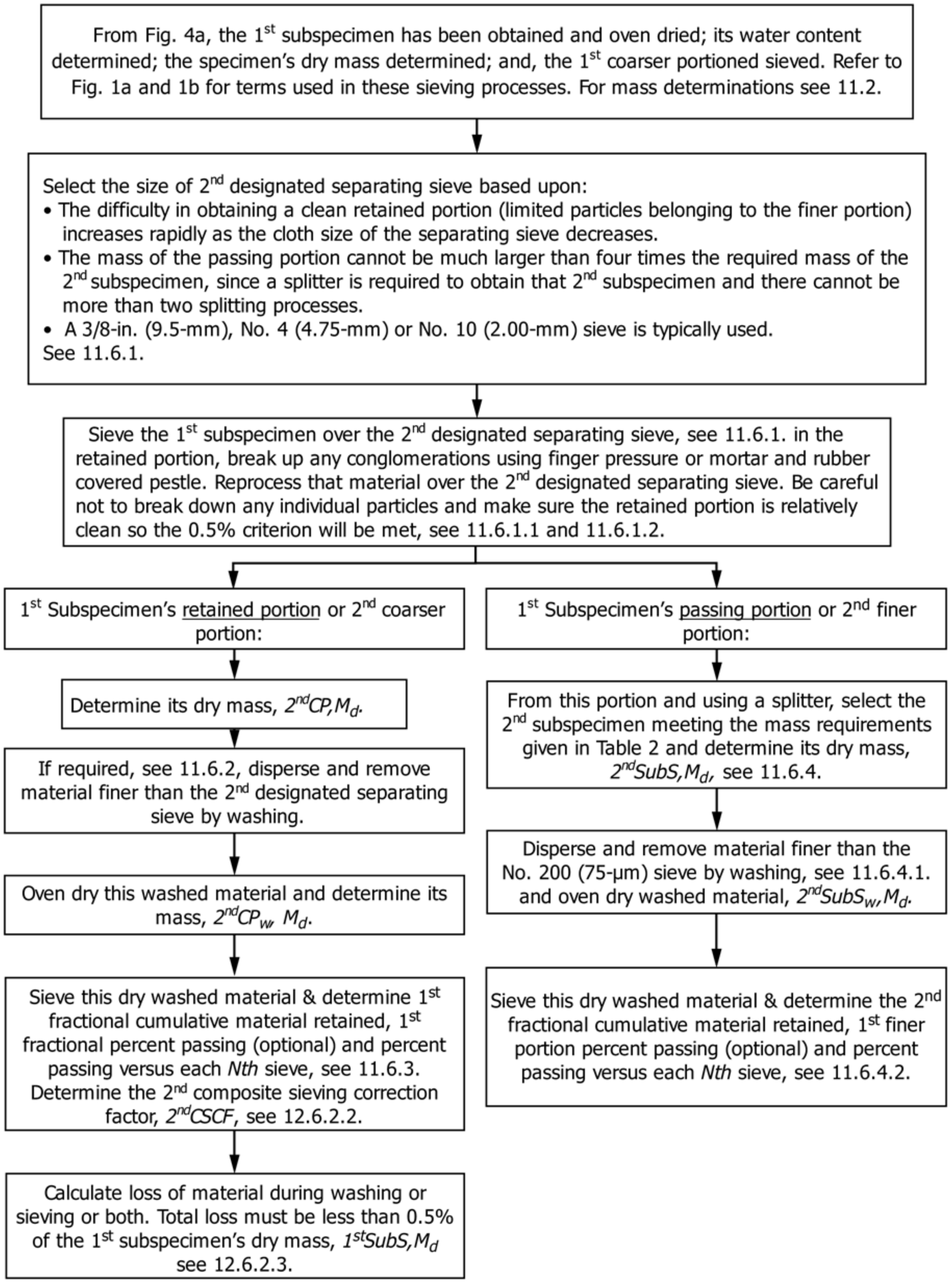


FIG. 4 (a) Flowchart for Composite Sieving—Single Separation



From Fig. 4a, the 1st subspecimen has been obtained and oven dried; its water content determined; the specimen's dry mass determined; and, the 1st coarser portioned sieved. Refer to Fig. 1a and 1b for terms used in these sieving processes. For mass determinations see 11.2.

Select the size of 2nd designated separating sieve based upon:

- The difficulty in obtaining a clean retained portion (limited particles belonging to the finer portion) increases rapidly as the cloth size of the separating sieve decreases.
- The mass of the passing portion cannot be much larger than four times the required mass of the 2nd subspecimen, since a splitter is required to obtain that 2nd subspecimen and there cannot be more than two splitting processes.
- A 3/8-in. (9.5-mm), No. 4 (4.75-mm) or No. 10 (2.00-mm) sieve is typically used.

See 11.6.1.

Sieve the 1st subspecimen over the 2nd designated separating sieve, see 11.6.1. in the retained portion, break up any conglomerations using finger pressure or mortar and rubber covered pestle. Reprocess that material over the 2nd designated separating sieve. Be careful not to break down any individual particles and make sure the retained portion is relatively clean so the 0.5% criterion will be met, see 11.6.1.1 and 11.6.1.2.

1st Subspecimen's retained portion or 2nd coarser portion:

Determine its dry mass, $2^{nd}CP, M_d$.

If required, see 11.6.2, disperse and remove material finer than the 2nd designated separating sieve by washing.

Oven dry this washed material and determine its mass, $2^{nd}CP_w, M_d$.

Sieve this dry washed material & determine 1st fractional cumulative material retained, 1st fractional percent passing (optional) and percent passing versus each *Nth* sieve, see 11.6.3. Determine the 2nd composite sieving correction factor, $2^{nd}CSCF$, see 12.6.2.2.

Calculate loss of material during washing or sieving or both. Total loss must be less than 0.5% of the 1st subspecimen's dry mass, $1^{st}SubS, M_d$ see 12.6.2.3.

1st Subspecimen's passing portion or 2nd finer portion:

From this portion and using a splitter, select the 2nd subspecimen meeting the mass requirements given in Table 2 and determine its dry mass, $2^{nd}SubS, M_d$, see 11.6.4.

Disperse and remove material finer than the No. 200 (75-µm) sieve by washing, see 11.6.4.1. and oven dry washed material, $2^{nd}SubS_w, M_d$.

Sieve this dry washed material & determine the 2nd fractional cumulative material retained, 1st finer portion percent passing (optional) and percent passing versus each *Nth* sieve, see 11.6.4.2.

FIG. 4 (b) Flowchart for Composite Sieving—Double Separation *(continued)* less than the taring capacity of the balance so that the cumulative mass retained can be determined directly (see Note 3). In most cases, the specimen/subspecimen container can be used. This test method assumes that the mass of the cumulative retained material is determined directly. This approach is easier than determining the mass of retained material on each sieve.

6.7 *Sieve Brushes*—Brushes to assist in the removal of the material retained on the smaller (≤200-mm or 8-in.) diameter and finer sieve sizes (≤¾-in. (19.0-mm)). The brushes shall have the following characteristics:

6.7.1 The bristles shall be firmly attached to the brush handle so that the bristles do not become part of the retained material.

6.7.2 The bristles shall be firm and small enough to readily remove the particles entangled in the sieve openings, but made of a material that will not damage the wire cloth or wear rapidly. Wire bristles, even brass, shall ***not*** be used on wire cloth size finer than No. 20 (850–µm).

6.7.3 The bristles shall be capable of contacting the boundary between the wire cloth and sieve's frame.

6.7.4 The brush's handle shall be such that one's hand can easily control the brushing motion and pressure. An example being, the handle is above the bristles (like a paintbrush) or inclined (30- to 45-degree angle) to the bristle's head (like a vegetable brush or bent toothbrush).

6.7.5 The bristles have to be small in diameter and soft when brushing wire cloth size equal to or less than the No. 100 (150-µm) mesh. Small diameter, soft bristles will remove the particles without any re-alignment of the wire cloth.

6.7.6 Brushes meeting these requirements are relatively small round or rectangular stiff paintbrushes with shortened bristles, soft to hard toothbrushes with bent handles, and vegetable brushes with shortened bristles.

6.8 *Miscellaneous Items*—Miscellaneous items such as wash bottle, spatula, and stirring rod may be useful.

6.9 *Splitter or Riffle Box (optional, but may be needed during composite sieving)*—A device to obtain a representative smaller portion (specimen) from a larger portion (sample). This device has an even number of equal width chutes, but not less than eight, which discharge alternately to each side of the splitter. For dry material having particles coarser than the ⅜-in. (9.5-mm) sieve size, the minimum width of the chutes shall be approximately 1-½ times the largest particle in material being split, but not less than 12.5 mm or ½ in. For dry material finer than or equal to the ⅜-in. (9.5-mm) sieve size, the minimum chute width shall be approximately 1-½ times the largest particle in the material, but not less than approximately 3 mm or ⅛ in. The splitter shall be equipped with two or more receptacles to hold the two halves of the material following splitting. It shall also be equipped with a hopper/feed chute (preferably lever activated or having a cut-off gate) and a straight-edged pan or dustpan that has a width equal to or slightly less than the over-all width of the assembly of chutes, by which the dry material may be fed at a controlled rate to the chutes. The splitter and accessory equipment shall be so designed that the material will flow smoothly without restriction or loss of material.

Note 4—Some splitters are designed such that the width of the chutes can be adjusted.

6.10 *Quartering Accessories (optional)*—A hard, clean, level surface, or durable nonporous fabric or plastic sheet approximately 2 by 2.5 m or 6 by 8 ft; a straight-edged scoop, shovel, or trowel; and a broom or brush.

6.11 *Mortar and Rubber-Covered Pestle (optional)*—Apparatus for breaking up aggregations of air-dried or oven-dried soil particles without breaking up any individual particles.

6.12 *Low Temperature Drying Oven (optional)*—Thermostatically controlled oven, capable of maintaining a uniform temperature not to exceed 60°C throughout the drying chamber, for use in air-dried processing.

6.13 *Ultrasonic Water Bath (optional)*—The ultrasonic water bath must be large enough to hold a beaker or flask containing the material to be dispersed prior to washing. The water level in the bath should be equal or higher than the water level in the specimen container.

6.14 *Dispersion Shaker (optional)*—A platform, wrist action or similar type shaker having a gyratory, orbital, reciprocating, or similar motion to assist in the dispersion process by continuously agitating the soaking soil.

7. Reagents

7.1 *Sodium Hexametaphosphate*—Also referred to as sodium metaphosphate, is the dispersion agent used to disperse some fine-grained soils after oven drying and prior to washing. Fine-grained soils requiring the use of a dispersant are those that do not readily slake in water, such as some fat clays and most tropical soils.

7.1.1 For materials needing a chemical dispersant, the dispersant can be added either directly to the soaking material (dry addition) or by adding a dispersant solution to the material, plus water as necessary.

7.1.1.1 *Dry Addition*—Add about 4 grams of sodium hexametaphosphate for each 100 mL of water that has been added to the soaking material and stir to distribute the dispersant throughout the material.

7.1.1.2 *Solution*—Make a solution by using 40 g of sodium hexametaphosphate and 1,000 g distilled, deionized, or demineralized water. Add the solution to the material, plus water if needed and stir to distribute the dispersant throughout the material. The solution must be less than one week old and thoroughly mixed or shaken prior to use. The date of preparation must be indicated on the bottle or in a log.

Note 5—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action.

8. Preparation of Apparatus

8.1 *Verification of Sieves*—Prior to ***initial use***, evaluate each sieve for general condition of the wire cloth as specified in Test Method One of Specification E11. That method provides the following evaluation instructions, "view the sieve cloth against a uniformly illuminated background. If apparent deviations, for example, weaving defects, creases, wrinkles, and foreign matter in the cloth, are found, the wire cloth (sieve) is unacceptable." This evaluation shall be documented. Unacceptable sieves shall be replaced and discarded or returned to the manufacturer for repair (wire cloth).

8.1.1 *Verification Interval*—The same evaluation shall be performed and documented at 6-month intervals on all sieves that are placed in continuous service. However, for sieves that have a limited usage of less than about 1,000 sieve analyses per 6-month interval, then this interval may be increased to 12 months. Sieves that contain excessive soil particles (about 10 % of the sieve openings contain particles) shall be thoroughly cleaned. An ultrasonic water bath may be used to clean the finer sieve sizes, while a stiffer brush or pointed tool can be used to clean the coarser sieves.

8.1.2 During each sieving process, the sieves finer than and including the No. 100 (150-µm) sieve shall be checked for damaged cloth, such as tearing at the frame contact. This check can be done while the retained material is being removed from the sieve during the sieving process. This check does not need to be documented.

8.2 *Verification of Mechanical Sieve Shaker and Standard Shaking Period*—Prior to ***initial use***, the mechanical sieve shaker shall be checked for sieving thoroughness using applicable sieve sets (typically used coarser and finer) and representative material. In addition, the standard shaking period shall be determined for each applicable sieve set. For each size sieve set, follow the guidance given for single sieve-set sieving (see 11.4). Use enough material (specimen) of known mass (g or kg) such that each sieve in the set, except one or two, will have some retained material but no sieve will be overloaded. Shake the sieve set for ten minutes with the mechanical shaker. Upon completion of mechanical shaking, start with the largest sieve size and place the snug-fitting lid on top of the sieve and the pan underneath it. Shake each sieve by hand, for about one minute using the hand shaking procedure (see 8.2.3). For each sieve, determine the mass of material retained on the sieve and in the pan, to the nearest 0.01 g or one part in 1,000, whichever is largest. The ratio of the material mass in the pan to the specimen's mass multiplied by 100 for each sieve shall be less than 0.5 % (see Note 6). If all ratios are less than 0.5 %, the sieve shaker with a 10-minute shaking period is adequate and shall be used as the standard shaking period for that sieve set. If any ratio is equal to or exceeds 0.5 %, repeat the process using a 15-minute shaking period. If this shaking period meets the above criterion, then it shall be used as the standard shaking period for that sieve set, unless a shorted shaking period, like 12 minutes is verified as adequate. If the 15-minute shaking period fails, then try the maximum allowable shaking period of 20 minutes. If the 20-minute shaking period fails, then the mechanical sieve shaker shall be considered inadequate for sieving. It shall either be repaired or discarded. After repair, repeat the instructions given above to determine the standard shaking period.

8.2.1 *Large Mechanical Sieve Shaker*—If a larger mechanical sieve shaker is used to shake large diameter (greater than 200 mm or 8 in.) or rectangular sieve sets and hand shaking is not practicable, then transfer the retained material in appropriate increments to a 200- mm or 8-in. diameter sieve of equal sieve designation, with lid and pan, and shake for one minute. Follow the instructions given above to determine the standard shaking period for each sieve set.

8.2.2 *Verification Interval*—The same verification shall be performed and documented at 12-month intervals for each sieve shaker placed in continuous service. However, for sieve shakers that have a limited usage of less than about 1,000 sieve analyses per 12-month interval, then this interval may be increased to 24 months. Not all sieve set sizes (coarser and finer) have to be re-verified unless the standard shaking time changes for the sieve set being verified. The finer sieve set or the set having the longest standard shaking period shall be used for re-verification.

NOTE 6—For example, after hand shaking the No. 4 (4.75 mm) sieve, the amount of material retained in the pan is 0.20 g. If the specimen mass is 100.00 g, then the ratio is 0.2% = ((0.20/100.00)*100). In this example, if the amount in the pan had been greater than 0.50 g, the ratio would exceed 0.5 % and the verification process would be repeated with a longer time interval.

8.2.3 *Hand Sieve Shaking Procedure*—For 200-mm or 8-in. diameter sieves, hold the individual sieve, with lid and pan, in a slightly inclined (about 15°) position in one hand. Strike the side of the sieve sharply with the heel of the other hand using an upward motion and at a rate of about 150 times per minute, turn the sieve about one sixth of a revolution at intervals of about 25 strokes. Continue for about one minute.

8.2.3.1 For larger diameter or rectangular sieves, transfer the retained material to 200-mm or 8-in. diameter sieves, in appropriate portions to prevent overloading (see 11.3), and follow the above instructions for each portion.

9. Sampling

9.1 *General*—This test method does not cover, in any detail, procurement of the sample. It is assumed that the sample is obtained using appropriate methods and is representative. However, the testing agency shall preserve all samples in accordance with Practice D4220/D4220M, Group B; except if the as-received sample does not meet those requirements. In that case, the water content of the material does not have to be maintained. The mass of the sample shall meet or exceed the mass requirements for the specimen, as given in Table 2 (see 10.2).

9.2 *Sample Sources*—The sample for a sieve analysis can be from a variety of sources and contain a wide range of particle sizes. Typically, samples for sieve analysis are obtained in the following forms: bulk samples (large bag or bucket samples), small bag or jar samples, tube samples, or specimens from other tests (such as strength, consolidation or hydraulic conductivity). In some cases, (for example, compaction testing) prior testing may cause a reduction of particle sizes. For these cases, the sieve analysis may be required on the initial specimen, or the degraded specimen or both. An overview of how specimens may be selected for various sample types is given below; whereas details for obtaining specimens from samples are in Section 10.

9.2.1 *Bulk Samples*—Generally, bulk samples are obtained because multiple tests are needed or large particles are present, or both. In addition, the bulk sample will usually become the

TABLE 2 Minimum Mass Requirement for Specimen

Maximum Particle Size of Material (99 % or more passes)		Minimum Dry Mass of Specimen, g or kg[A]	
Alternative Sieve Designation	Maximum Particle Size, mm	Method A Results Reported to Nearest 1 %	Method B Results Reported to Nearest 0.1 %
No. 40	0.425	50 g	75 g
No. 10	2.00	50 g	100 g
No. 4	4.75	75 g	200 g[B]
⅜ in.	9.5	165 g[C]	[D]
¾ in.	19.0	1.3 kg[C]	[D]
1 in.	25.4	3 kg[C]	[D]
1-½ in.	38.1	10 kg[C]	[D]
2 in.	50.8	25 kg[C]	[D]
3 in.	76.2	70 kg[E]	[D]

[A] Specimen masses should not significantly exceed (by more than about 50 %) the presented values because excessively large specimens may result in sieve overloading, (see 11.3) and increase the difficulty of specimen processing.

[B] The same as "C," except multiplied by 10.

[C] These values are based on the mass of an individual spherical shaped particle, at the given sieve, multiplied by 100 then 1.2 (factor to account uncertainty) and finally rounded to a convenient number.

[D] Specimens of this size require composite sieving. The sample sizes required for reporting results to 0.1 % are not practical and the possible errors associated with composite sieving causes this sensitivity to be unrealistic for specimens with these larger size particles.

[E] Same as "C," except 1.2 factor is omitted.

specimen and composite sieving will be required. If other testing is needed, these tests should be coordinated with the sieve analysis so that all specimens are obtained efficiently and representatively using moist (preferred) or air-dried procedure. For example, Test Method D698 or D1557 is frequently requested on bulk samples in addition to the sieve analysis. For this test, it is probably most efficient to process the as-received sample, now a specimen, over the designated separating sieve having either the ¾-in. (19.0-mm), ⅜-in. (9.5-mm) or No. 4 (4.75- mm) sieve and obtain the sieve specimens (coarser and finer portions) during this processing. Although oversize particles (coarser portion) are not used in testing with D698 or D1557, the composite sieve analysis should be calculated to represent both the bulk sample and the compaction material (two gradations). Flowcharts presenting an overview of this procedure are presented in Fig. 2 through Fig. 4(b).

9.2.2 *Jar and Small Bag Samples*—Depending on the sample's gradation, it may be necessary to use the entire sample for the specimen. Observe and estimate the maximum particle size. If the amount of material in the sample is less than the minimum mass required (as given in Table 2), note that the specimen is undersized. If the amount (by mass) of sample is much more (by about 50 %) than needed, the sample can be reduced using moist (preferred) or oven-dried procedure. If there is other testing to be obtained from the sample, it may be better to perform the other testing, such as water content and specific gravity and then sieve the used material. Note on the data sheet if prior testing has been performed on the specimen. This approach cannot be used for tests that might alter the gradation of the soil, such as Atterberg Limits.

9.2.3 *Intact Tube Samples*—To obtain a sieve analysis specimen from an intact tube sample, extrude either the entire sample, or a portion. Observe and estimate the maximum particle size. Use moist procedure (see 10.4.1) to obtain the necessary specimen.

9.2.4 *Samples from Prior Testing*—Frequently, after strength, hydraulic conductivity, consolidation or other testing has been completed, that specimen or a portion of it (from water content) is used for a sieve analysis specimen. The entire specimen can be used or split using the most appropriate procedure for specimen selection (moist or oven dried). If the specimen mass is less than required according to Table 2, note that the specimen is undersized on the data sheet. There may be conditions when it is undesirable to test the entire specimen due to the nonhomogeneity of the specimen. If there are layers in the specimen, it may be necessary and more useful to determine the gradation of individual layers.

10. Specimen

10.1 *General*—This section is separated into four parts. The mass requirement for the specimen is given in the first part (*Minimum Mass Requirement*). In the second part on *Selection of Sieving Procedure*, the determination of which sieving procedure applies, single sieve-set or composite sieving, is explained. In the third part on *Specimen Procurement*, an overview of the three applicable procedures (moist, air dried and oven dried) for use in obtaining a specimen from the sample and processing it for sieving is given. Following this overview is a discussion about special considerations relating to soils that readily segregate. In the fourth part on *Specimen Procurement and Processing Requirements*, details are given on how the above moist, air-dried and oven-dried procedures are to be applied to obtain a specimen(s) and prepare it for single sieve-set or composite sieving.

10.2 *Minimum Mass Requirement*—The minimum dry mass needed for a sieve analysis specimen is based on the maximum particle size in the sample and the test method (Method A or B) used to record the data. Based on the estimated maximum particle size, use Table 2 to determine the minimum mass of the specimen in g or kg.

10.3 *Selection of Sieving Procedure*—As shown in Fig. 2, the first decision step in this test method is to estimate the maximum particle size contained in the sample and then determine, based on the assigned Method (A or B), if the single sieve-set sieving or composite sieving procedure is to be used.

10.3.1 *Single Sieve-Set Sieving*—For Method A, this procedure applies to samples having a maximum particle size equal to or less than 9.5 mm (3⁄8-in. sieve). For Method B, this procedure applies to samples having a maximum particle size equal to or less than 4.75 mm (No. 4 sieve). However, if the material is ***not*** relatively well graded, then these acceptable maximum particle sizes may be smaller. If Method B is assigned and the sample has a maximum particle size larger than 4.75 mm, then this non-conformance should be noted on the data sheet and if necessary, inform the requesting authority. In addition, switch to Method A and if necessary, composite sieving.

10.3.1.1 Single sieve-set sieving ***could*** apply to samples having a maximum particle size up to 19.0 mm (3⁄4-in. sieve) or possibly the 25.4 mm (1-in. sieve); providing Method A applies and the mass of the specimen meets the requirements presented in Table 2. In addition, it depends on the gradation of the sample, the size (diameter) of sieves being used, and if the tester wants to sieve the specimen in portions.

10.3.2 *Composite Sieving*—This procedure applies to samples having a maximum particle size equal to or greater than 19.0 mm (3⁄4-in. sieve), unless 10.3.1.1 applies.

10.4 *Specimen Procurement*—This test method presents three procedures to obtain a representative specimen from the sample (moist, air-dried and oven-dried). In these procedures, the terms moist, air-dried or oven-dried refer to the condition of the material or sample as it is being processed to obtain the specimen. Additional guidance for splitting material to obtain a representative portion (specimen) using a splitter, quartering or moist stockpile sampling (Practice C702, Methods A, B and C, respectively) is given in Annex A2.

10.4.1 *Moist Procedure*—The sample is processed and split using moist stockpile sampling or quartering, if needed, in a moist, as-received state to obtain a representative specimen, unless the material is excessively wet or dry. This procedure is the preferred method for soils that readily segregate in a dry state such as coarse-grained soils with or without fines, or fine-grained soils containing coarse-grained particles, see 10.4.4. In addition, it is the preferred method for any sample containing soil whose properties are altered due to drying, and testing to determine those properties is necessary. These soil types may include most organic soils; many highly plastic fine-grained soils; tropical soils; and soils containing halloysite. Examples of such testing may include compaction, Atterberg Limits, specific gravity, and gradation by sedimentation. For samples requiring composite sieving, the sample typically becomes the specimen and requires additional processing as covered in 10.5.2.

10.4.2 *Air-Dried Procedure*—The sample is air dried, and then processed and split, if needed, using only a splitter to obtain the required specimen. The specimen is oven dried, washed, re-dried and then sieved. For samples requiring composite sieving, the sample typically becomes the specimen and requires additional processing as covered in 10.5.5.

10.4.3 *Oven-Dried Procedure*—The sample is oven dried, and then processed and split using only a splitter, if needed, to obtain the required specimen. The specimen is washed, re-dried, and then sieved. For samples, especially large ones requiring composite sieving and other testing, this procedure is typically not practical and shall not be used for soil types mentioned in 10.4.1.

10.4.4 *Discussion on Segregating Soils*—There are some special considerations relating to soils that readily segregate (such as gravels and sands, with or without fines). Experience gained from the ASTM Reference Soils and Testing Program and obtained at AASHTO Materials Reference Laboratory (AMRL) has clearly demonstrated the following conclusions. When dealing with soils that readily segregate and are in an air-dried or oven-dried state, the splitting processes (Practice C702, Method A) cannot be used more than a few times to obtain a representative specimen. The resulting specimen will have less fine sand and finer particles than the sample. This standard specifies when using a splitter, there cannot be more than two splitting operations (splits) to obtain the specimen. This number is based on judgment. There will be cases when more or less splits would be appropriate; however, use extreme caution in selecting more than two splits. For referee testing two splits cannot be exceeded. The method to obtain representative specimens from these soils requires that the soils be in a moist state. The water content should optimize bulking or be slightly wetter than the saturated surface-dry condition. This water content is to the point that the surface of the soil should look slightly wet but there are no signs of free water exiting the soil. This will reduce the potential for particle segregation and loss. The sample can be mixed and readily scooped/shoveled to obtain representative portions of the material (Practice C702, Method C, see A2.1.3). This procedure is especially useful if the maximum particle size is less than about 19.0 mm (3⁄4-in. sieve).

10.5 *Specimen Procurement and Processing Requirements:*

10.5.1 *Moist Procedure, Single Sieve Set Sieving*—If single sieve-set sieving applies, as determined in 10.3, then either select the whole sample or split the sample after it is mixed in the as-received condition, unless it is too dry or wet for processing to obtain a representative specimen, see 10.5.1.2.

10.5.1.1 If the sample contains standing water or is very wet; then it may be dried back to a moist state, as defined in 10.4.1, 10.4.4, or A2.1.3, by air-drying or oven-drying (60°C). If oven drying is used, the sample is placed in a low temperature, drying oven (not to exceed 60°C) and mixed frequently to avoid excessive drying of any portion of the sample. If the sample is too dry; then water can be added (preferably by spraying) while the sample is being mixed to a moist state.

10.5.1.2 After mixing, obtain a representative specimen having the required mass (Table 2) by taking one or more scoops from the sample. The number of scoops shall increase as the mass of the specimen increases and come from various locations, and each scoop shall have about an equal mass, see A2.1.3. Place all the material in the scoop into the specimen container of known mass (g or kg). In this process, do not attempt to obtain an exact mass or increase the specimen size by adding very small amounts of material. For relatively well-graded coarse-grained soils, especially relatively clean ones containing gravel and coarse sand; do not add material by shaking it off the edge of the scoop. All of these processes could result in altering the gradation of the specimen. Oven dry the specimen (110 ± 5°C), see Notes 7 and 8. Record the identification of the specimen container and the mass (g or kg) of the container on the data sheet. Proceed to Section 11 on *Procedure (Sieving)*.

NOTE 7—For non-referee testing, it is acceptable practice to determine the oven-dried mass of a specimen or subspecimen, based on its moist mass and water content determined to the nearest 1 % for Method A or 0.1 % for Method B.

NOTE 8—This procedure for selecting material from a sample is basically the same as that presented in Practice C702, Method C—Miniature Stockpile Sampling (Damp Fine Aggregate Only) and summarized in A2.1.3.

10.5.2 *Moist Procedure, Composite Sieving*—For composite sieving, typically the whole sample becomes the specimen. If splitting is needed, obtain a representative portion by either the moist stockpile sampling procedure, as described in 10.5.1.2 or quartering (see A2.1.2). For an overview of the composite sieving method, refer to Fig. 2 through Fig. 4(b). In composite sieving, the following information must be obtained:

(a) The oven-dried mass of the coarser portion retained on designated separating sieve, CP,M_d in g or kg,

(b) The moist mass of the finer portion passing the designated separating sieve, FP,M_m in g or kg,

(c) The water content of a subspecimen obtained from the finer portion, w_{fp} in %,

(d) The calculated oven-dry mass of the finer portion, FP,M_d in g or kg, and

(e) The oven-dry mass of the subspecimen obtained from the finer portion for sieving over the finer sieve set, $SubS,M_d$ in g or kg.

10.5.2.1 If necessary, adjust the moisture condition of the material by drying or adding water as described in 10.5.1.1.

10.5.2.2 Select a designated separating sieve following the guidance given in 9.2.1 on *Bulk Samples* and Note 9. Process the specimen over this sieve. Manually or mechanically shake, or wiggle the finer portion through the sieve and collect both the coarser and finer portions. Remove any large conglomerations from the designated separating sieve and break them into individual particles or into conglomerations that are smaller than the openings in the designated separating sieve. Return the soil to the designated separating sieve and continue processing. Do not apply pressure that could damage the sieve. If fines are adhering to the coarser particles, scrape or brush these larger particles and dislodge the fines. If the fines are adhering into large clumps, use knives or spatulas to cut the clumps into chucks that will pass the designated separating sieve.

NOTE 9—Smaller cloth size of the designated separating sieve increases the difficulty in processing the material and having a limited amount of the fines adhering to the retained particles. In addition, selection of the designated separating sieve size may be based on ease of separating the specimen, additional testing to be performed, or convenience. For very plastic, clayey materials, it is easier to select a larger designated separating sieve. For materials that need compaction testing using either D698 or D1557, it is easiest to use the sieve (either No. 4 (4.75 μm), ⅜ in. (9.5 mm) or ¾ in. (19.0 mm)) necessary for the compaction method. Some laboratories are equipped with two sets of mechanical sieve shakers depending on size range, and, hence, the selection would be based on the equipment. There can be more than one designated separating sieve used in composite sieving, because the first subspecimen can be split again to obtain a second subspecimen.

10.5.2.3 *Coarse Portion Acceptable Loss (CP_L)*—It is usually not possible to remove all the fines (particles that would pass the designated separating sieve) adhering to the retained coarser particles. For the finer portion to be representative, the amount adhering to the retained coarser particles has to be less than 0.5 % of the dry mass of the specimen (S,M_d), see Note 9. If it appears that the material adhering to the retained portion will exceed the 0.5 % criterion, then the retained portion must be washed using a minimum amount of water and the washings added to the portion passing the designated separating sieve. The actual value will be determined at the end of the test.

10.5.2.4 Place the coarser portion in a suitable container of known mass (g or kg) and oven dry it (110 ± 5°C). Record the container identification and mass on the data sheet. If the water content of the coarser portion is needed (for example, to report the as received condition), determine it in accordance with Test Method D2216. Record the oven dry mass of the coarser portion, CP,M_d in g or kg.

10.5.2.5 Determine and record the moist mass (g or kg) of finer portion, using a balance meeting the requirements given in 6.4 and 11.2. Depending on the size of this portion, this mass determination can be done in increments as the material is being processed or after it has been processed. Record this moist mass as FP,M_m in g or kg.

10.5.2.6 Mix the moist finer fraction and obtain a representative subspecimen for both a water content determination and sieving using the moist stockpile sampling procedure, see 10.5.1.2. The finer portion subspecimen shall have a mass meeting the requirements given in Table 2. Record the container identification, mass of the container, and mass of the container plus moist material representing the finer portion subspecimen. The balance used shall meet or exceed the requirements of Test Method D2216 for water contents determined to the nearest 1 % or better.

10.5.2.7 Oven-dry the subspecimen in the oven at 110 ± 5°C. Calculate and record the water content, w_{fp}. Determine and record the dry mass of the subspecimen as $SubS,M_d$ in g or kg. If this subspecimen requires a second separation, (see Fig. 4(a) and Fig. 4(b)—composite sieving with double separation) processing the second subspecimen will be performed later (see 11.6).

10.5.2.8 Determine the dry mass of the specimen (coarser portion plus finer portion) in g or kg, see 12.4, and proceed to Section 11 on *Procedure (Sieving)*.

10.5.3 *Air Dried Procedure, General*—This method requires the use of a splitter to obtain a specimen from a sample that has been air-dried, unless the whole sample is tested. Therefore, this procedure can only be used for smaller samples in which no more than two splitting processes will be necessary, see 10.4.4. Typically, this procedure would only be used for soils coming from an arid region in which the soil will become air-dried and when other testing requires an air-dried condition.

10.5.3.1 Depending on the size of the sample, place the material either on a tray(s)/pan(s), smooth tarp/plastic sheet/ etc. or sealed-smooth floor (prevent loss of fines) and air-dry. Alternatively, an oven not exceeding 60°C may be used. Upon the completion of air-drying; place the material into either a container or pile. During this process, break apart any noticeable aggregations of soil particles. This can be done by hand or using a mortar and rubber-covered pestle or similar method that does not break the individual particles.

10.5.4 *Air Dried Procedure, Single Sieve-Set Sieving*—If this applies, as covered in 10.3; then either test the whole sample, noting its mass cannot be too large (Table 2) or after mixing, obtain a representative specimen having the required mass (Table 2) using a splitter and noting the above requirements and those in Annex A2, Sample to Specimen Reduction Methods, A2.1 and A2.1.1.

10.5.4.1 Place the specimen in a container of known mass (g or kg) and oven-dry the material at 110 ± 5°C. Record the identification of the specimen container, and mass of the container on the data sheet. Determine and record the dry mass of the specimen as S,M_d in g or kg. For non-referee testing, this dry mass may be based on an auxiliary water content of similar air-dried material (see Note 7).

10.5.4.2 Proceed to Section 11 on *Procedure (Sieving)*.

10.5.5 *Air Dried Procedure, Composite Sieving*—If composite sieving applies, as determined in 10.3, follow the moist procedure, as outlined in 10.5.2 through 10.5.2.8 to obtain the specimen and process it for composite sieving, except for the following:

(a) The sample is air-dried prior to any processing, see 10.5.4.1.

(b) The moist masses become air-dried masses.

(c) The water content of the coarser portion is not applicable.

(d) To obtain the subspecimen from the finer portion, the applicable guidance given in 10.5.3 shall be followed instead of that given in 10.5.2.6.

10.5.5.1 Proceed to Section 11 on *Procedure Sieving*).

10.5.6 *Oven-Dried Procedure, General*—This method requires the use of a splitter to obtain a specimen from a sample that has been oven-dried, unless the whole sample is tested. Therefore, this procedure can only be used for smaller samples in which no more than two splitting processes will be necessary, see 10.4.2 and 10.4.4. This procedure shall only be used when other testing is not necessary or needed, see 1.8 and 10.4.1. See 10.5.2 for comments on composite sieving.

10.5.6.1 Place the sample on a tray(s)/pan(s) and oven dry at 110 ± 5°C overnight or until thoroughly dry, see Test Method D2216. Upon the completion of drying; place the material into either a container or pile. During this process, break apart any noticeable aggregations of soil particles. This can be done by hand or using a mortar and rubber-covered pestle or similar method that does not break the individual particles.

10.5.7 *Oven Dried Procedure, Single Sieve-Set Sieving*—If this applies, as covered in 10.3; then either test the whole sample, noting its mass cannot be too large (Table 2) or after mixing, obtain a representative specimen having the required mass (Table 2) using a splitter and noting the above requirements and those in Annex A2, Sample to Specimen Reduction Methods, A2.1 and A2.1.1. Record the identification of the specimen container, and mass (g or kg) of the container on the data sheet. Determine and record the dry mass of the specimen as S,M_d in g or kg.

10.5.7.1 Proceed to Section 11 on *Procedure (Sieving)*.

10.5.8 *Oven Dried Procedure, Composite Sieving*—If composite sieving applies, as determined in 10.3, procure the specimen following the applicable guidance given in 10.5.4 through 10.5.4.2. Double check that the specimen's mass and its container has been determined and recorded. Select a designated separating sieve following the guidance given in 9.2.1 and Note 9. Process the specimen over this sieve following the applicable guidance given in 10.5.2.2 and 10.5.2.3.

10.5.8.1 Record the oven-dry mass of the coarser portion, CP,M_d in g or kg.

10.5.8.2 Mix the finer portion and obtain a representative subspecimen having the required mass (Table 2) using a splitter, see requirements given in 10.4.4. Record the container identification, mass of the container, and mass of the container plus dry material representing the finer-portion subspecimen. Calculate and record the dry mass of the subspecimen, $SubS,M_d$ in g or kg.

10.5.8.3 Proceed to Section 11 on *Procedure (Sieving)*.

11. Procedure (Sieving)

11.1 *General*—There are several different ways to determine the percent passing, since there are several different approaches to determine the amount of material retained on each sieve in a given sieve set. As previously stated, the procedure presented in this test method is to determine and record the mass of the cumulative material retained upon any given sieve within any given sieve set, since it is the easiest approach to present. However, this does not mean that other approaches are in nonconformance with this test method. One alternate approach would be to determine the amount of material retained on each sieve within a given sieve set, and then adjust the method of calculation to determine the percent passing.

11.1.1 The sieving process is usually accomplished using a mechanical sieve shaker (see 6.3); however, hand shaking is permissible, especially for the coarser sieves (larger than about the ¾-in. (19.0-mm). For referee testing, a mechanical sieve shaker shall be used for the portion passing the ¾-in. (19.0-mm) sieve.

11.1.2 The proper gradation of a specimen cannot be obtained if one or more sieves are overloaded during the sieving process, see 11.3 on *Sieve Overloading*.

11.2 *Mass Measurements*—The following details supplement the requirements presented in 6.4 on *Balances*. Determine the mass of the specimens to a minimum of three significant digits for Method A or a minimum of four significant digits for Method B. For subspecimens, only Method A applies. Determine the mass (g or kg) of the cumulative material retained using a balance having the same readability or better as was used to determine the mass of the specimen or subspecimen, see Note 3. This balance does not have to be the same one used to determine the mass of the specimen.

11.3 *Sieve Overloading*—The overloading of a sieve occurs when too many particles are retained on a sieve such that all particles do not have an opportunity to reach a sieve opening a number of times during sieve shaking. To prevent sieve overloading, the quantity of material retained on an individual sieve must be less than or equal to that specified in Table 3.

11.3.1 To avoid overloading, it is often necessary to divide large specimens or subspecimens into several portions. Each portion would be sieved and the amount retained on each sieve would be recorded. Then, the masses retained on a given sieve from all the sieved portions would be added as explained in 11.4.5.2.

11.3.2 If overloading has occurred, the specimen or subspecimen must be re-sieved in several portions or using sieves having a larger area.

11.4 *Single Sieve-Set Sieving*—A summary of terms used in single sieve-set sieving is presented in Fig. 1(a) and Fig. 1(b) while Fig. 3 presents a flowchart of this sieving process.

11.4.1 *Specimen Mass*—Check that the following had been determined and recorded in accordance with Section 10; the dry mass of the specimen, the identification of the specimen container and the procedure used to obtain that specimen (moist, air-dried or oven-dried). Record this mass as S,M_d in g or kg.

11.4.2 *Specimen Dispersion*—Prior to washing the specimen on the No. 200 (75-µm) washing sieve, the specimen shall be dispersed by one of the following procedures. However, in no case shall a mechanical mixer (with metal blade) be used to disperse the soil, since such mixers have a tendency to degrade (breakdown) coarse-grained particles. Wrist action shakers or similar agitating devices are acceptable, see 6.14.

11.4.2.1 *Soaking without a Dispersant*—Cover the specimen (soil) with tap water and allow it to soak for at least 5 minutes. Longer soaking periods are typically needed as the amount of fines or the plasticity of the fines or both increases. During this soaking period, the soil and water can be agitated using a stirring rod, spatula, dispersion shaker or similar device to facilitate the dispersion process or to check that the soil is dispersed. If clumps of particles or clods are detected, then this method of dispersion is not effective (see Note 10) and proceed to 11.4.2.2. A dispersion shaker shall not be used for relatively clean coarse-grained soils (such as: GP, SP, GP-GM, SP-SM, SP-SC).

NOTE 10—It is not easy to evaluate effective dispersion. Use visual or manual means or both to detect clumps of particles that would indicate incomplete or ineffective dispersion.

11.4.2.2 *Soaking with a Dispersant*—In accordance with Section 7, add the sodium hexametaphosphate either directly (dry addition) or in solution. Follow the instructions in 11.4.2.1. If this method of dispersion is not effective, the ultrasonic water bath could be used or additional time allowed for dispersion.

11.4.2.3 *Using an Ultrasonic Water Bath*—This procedure may be used for soils that are difficult to disperse. Place the specimen and container in the ultrasonic water bath following the guidance given in 6.13. The water in the specimen container should contain dispersant. If the size of the specimen container is not appropriate to fit into the ultrasonic water bath, then transfer the specimen to a suitable one, noting that the specimen can be dispersed in portions.

11.4.3 *Washing Specimen*—At the end of the soaking-dispersion period, the fines (minus No. 200 (75-µm) sieve material) are removed by washing using this procedure or by following the applicable portions of Method B given in Test Method D1140. The apparatus used shall meet the requirements given in 6.1.2 and 6.2.

TABLE 3 Overloading Limits for Standard Sieve Set

Alternative Sieve Designation	Standard Sieve Designation	Number of Grain Layers on Given Sieve	Maximum Mass Retained on 200-mm (8-in.) Diameter Sieve, g[A]	Maximum Mass Retained on 305-mm (12-in.) Diameter Sieve, g	Maximum Mass Retained on 370- by 580-mm (14.6- by 22.8-in.) Sieve, g
3 in.	75 mm	0.8	2 700	6 100	18 000
2 in.	50 mm	0.9	2 000	4 500	13 000
1-½-in.	37.5 mm	0.9	1 500	3 400	10 000
1 in.	25 mm	1	1 100	2 500	7 000
¾ in.	19.0 mm	1	900	2 000	6 000
⅜ in.	9.5 mm	1.25	550	1 200	3 600
No. 4	4.75 mm	1.5	325	730	2 000
No. 10	2.00 mm	2	180	410	1 000
No. 20	850 µm	3	115	260	800
No. 40	425 µm	4	75	170	500
No. 60	250 µm	5	60	140	400
No. 100	150 µm	6	40	90	300
No. 140	106 µm	6	30	70	200
No. 200	75 µm	6	20	50	100

[A] For sieve sizes other than those listed above, determine the surface area of the sieve(s) cloth being used in m^2 and divide this number by 0.028 m^2 (the approximate surface area of a 200-mm or 8-in. diameter sieve). Then multiply this area ratio by the masses listed in this column to form a column of acceptable masses for the different sieve area of interest. Round these values, so the significant digits are similar to those presented.

11.4.3.1 *General Precautions*—Washing specimens larger than about 200 g should be done in increments. For masses containing particles coarser than No. 4 (4.75-mm) sieve, all of the material should ***not*** be placed directly on the washing sieve (No. 200 or 75-µm), especially for brass cloth. In this case, a coarser size sieve (No. 40 or larger) shall be inserted above the washing sieve. It is necessary to see through this coarser sieve to check if the washing sieve is clogging (often the No. 40 sieve obscures this view and a No. 20 (850 µm) sieve is a better choice).

11.4.3.2 *Transfer Specimen*—Transfer the dispersed specimen, or a portion of the specimen to the washing sieve or the coarser sieve inserted above the washing sieve by pouring or any means that prevents spillage. During this process, stop pouring if any material loss will occur due to clogging of the washing sieve, and unclog the washing sieve, see Note 11. After emptying the dispersed specimen container, wash any remaining material onto the washing sieve or the coarser sieve inserted above it using the spray nozzle, wash bottle, or similar method.

11.4.3.3 *Washing*—Wash the specimen (material) on the washing sieve by means of a stream of water from the spray nozzle. Continually check to see if the washing sieve has clogged (see Note 11). The velocity of the water shall not cause any splashing of the material out of the sieve. The water temperature shall remain close to room temperature (see 6.2). To facilitate the washing process, the retained material may be lightly manipulated by hand while it is against the side of the sieve or above it, taking care not to lose any retained material. A wash shaker may be used to aid in the washing process. No downward pressure should be exerted on the retained material or sieve cloth to avoid forcing particles through the sieve or causing damage to the sieve. When the coarser sieve is being used, remove it from above the washing sieve as soon as the coarser material is washed and transfer it to the specimen container (see 11.4.3.4). Continue washing the specimen on the No. 200 (75-µm) sieve until the wash water is clear.

NOTE 11—If clogging of the washing sieve occurs, lightly hand tap the side or the bottom of the washing sieve until it is unclogged. Another method to unclog the washing sieve is gently spray a small amount of water up through the bottom of the washing sieve, then use the tapping approach to assist in the drainage of wash water.

11.4.3.4 *Transfer Washed Specimen*—Using a washing process, return the portion retained on the washing sieve and coarser sieve, if used, to its original specimen container or new container of known mass in g or kg. This can be done by washing the retained material to one side of the sieve, by tilting the sieve and allowing the wash water to pass through the sieve. Then, slowly wash this material into the container using as little wash water as possible, such that water will not fill and overflow the container. If the container approaches overflowing, stop the transfer process and decant the clear water from the container. Decant as much water from the container as practical without losing any retained material, and dry to a constant mass in an oven at 110 ± 5°C. This drying period will most likely be shorter than the overnight period suggested in D2216, because the retained material does not contained any fines. After oven drying, allow the container to cool, determine and record the dry mass of the washed material, S_wM_d in g or kg.

11.4.4 *Dry Sieving*—Dry sieving is accomplished by sieving the oven-dried washed material over an appropriate sieve set using a mechanical sieve shaker for a standard shaking period (see 8.2) and in such a manner that prevents the overloading of any given sieve (see 11.3). Then, the cumulative material retained for each sieve within a sieve set by mass or cumulative mass retained is determined. Based on these measurements, the percent passing each sieve is determined. The following procedure assumes that a stack of 200-mm or 8-in. diameter sieves is being used. However, the use of other sieve sizes or configurations is not prohibited providing they meet the requirements given in Sections 6, 8, and this section.

11.4.4.1 *Sieve Set*—Assemble an appropriate stack of sieves from the standard set given in Table 1 and meeting the requirements given in 6.1. The largest sieve size shall be such that 100 % of the washed (sieving) material passes through it. Do not omit any standard sieves sizes between the largest sieve size and the No. 200 (75-µm) sieve, but it is permissible to include additional sieves. Assemble the stack of sieves with the largest sieve size at the top. Add the remaining sieves in descending sieve size. Add the pan on the bottom and the lid on the top on the sieve stack, if appropriate. If there are too many sieves to fit into the sieve shaker, it is permissible to separate this set into a coarser subset and a finer subset. It is also permissible to use "half height" sieves, see 6.1. Some sieves are designed to stack on top of each other, and other sieves are inserted like drawers into the shaker. Either type is acceptable.

11.4.4.2 *Mechanical Shaking*—Pour the dried washed material from its container onto the sieve at the top of the sieve stack. Then brush any material remaining in the container onto that sieve. The container should be close to the sieve to prevent spillage and creation of dust. Cover the stack of sieves with the lid, if applicable, and place the sieve set in the sieve shaker. Shake the sieve set for the standard shaking period established in 8.2 (using a timing device) for that sieve shaker and size sieve set. Avoid overloading the sieves, see 11.3. Upon completion of shaking, remove the sieve set for determination of the cumulative material retained for each sieve, as covered below.

11.4.5 *Cumulative Material/Mass Retained* (Hereafter referred to as cumulative mass retained.)

11.4.5.1 *First Sieve*—Remove the lid from the sieve set, verify that no material was retained on the top (largest size) sieve (record 0.0 g or kg in the cumulative mass retained column, CMR_N). If material is retained on the top sieve, determine and record its mass, CMR_N, in accordance with 11.2 in g or kg. Transfer that retained material to the next larger sieve size in the standard sieve set, see Table 1. Add the pan and lid and hand shake that sieve following the procedure given in 8.2.3 on *Hand Sieve Shaking*. Shake until either the entire retained material has passed that sieve or for about one minute. Verify that no material was retained on that sieve by recording 0.0 g or kg as appropriate. Transfer the contents of the pan to the cumulative mass container (see 6.6.3).

11.4.5.2 *Remaining Sieves*—Remove the next sieve and turn the sieve upside down such that the retained material falls onto the collection/transfer device (see 6.6.2) without spillage or creating dust. Any material remaining in the sieve may be gently removed using a sieve brush (see 6.7). Take care to avoid distortion or damage of the sieve cloth (see 6.7.1 through 6.7.6). Next transfer this retained material to the container (see 6.6.3) holding the cumulative mass retained, *CMRN*. Determine, in accordance with 11.2 and record the mass (g or kg) contained in this container, CMR_N. Continue in this manner for the remaining *Nth* sieves and pan.

11.4.5.3 When using the cumulative mass retained method, sieve-overloading problems are not immediately apparent, but they shall be checked for during this process, see 11.3. Conversely, when the data sheet lists the overloading masses and the mass on each sieve is recorded, any problems due to overloading will be immediately noticed. If overloading occurred, re-sieve the material in accordance with the instructions provided in 11.3.1. In the case where the sieving process is done in parts, such as to prevent overloading or overloading has occurred, then there is more than one set of partial cumulative mass retained determinations to be recorded and combined to determine the cumulative mass retained, CMR_N. This will require either special or multiple data sheets.

11.4.5.4 Proceed to Section 12 on *Calculations*.

11.5 *Composite Sieving, Single Separation*—Refer to Fig. 1(a) and Fig. 1(b) for the terms used in composite sieving and Fig. 4(a) for a flowchart of these sieving processes. When composite sieving is necessary, the following items requiring sieving were obtained during the processing of the specimen and identified on the data sheet, as covered in Section 10 on *Specimen*. These items are:

(a) The oven-dried mass of the portion retained on designated separating sieve; that is the coarser portion, CP,M_d in g or kg.

(b) The oven-dried mass of the subspecimen obtained from the finer portion, $SubS,M_d$ in g or kg.

11.5.1 *Coarser Portion*—If the coarser portion is clean (free of material finer than the designated separating sieve) or already washed (see 10.5.2.3), and the testing is not used as referee testing, the coarser portion will not need to be washed. It is permissible to consider the coarser portion to be clean if 0.5 % or less of that finer material (based on specimen's dry mass, S,M_d) would be or are removed from the coarser portion while sieving or washing, or both. Washing is not needed under these conditions. For referee testing, the coarser portion shall be washed.

11.5.1.1 *Dispersing and Washing*—Follow the applicable instructions provided in 11.4.2 to disperse the coarser faction and 11.4.3 to wash the coarser portion after dispersion, while noting the following:

(a) Soaking in water, will usually suffice,

(b) Washing is done on either the designated separating sieve used to separate the specimen into a coarser and finer portion, or another sieve of equal size (designation, see Table 1); and,

(c) During washing or the dispersion process fine particles may be brushed off coarser particles.

11.5.1.2 Return the retained washed portion to the same container and oven dry to a constant mass (110 ± 5°C). Determine and record the dry mass (g or kg) of the washed coarser portion, CP_wM_d, following the instructions provided in 11.2. The calculation of the acceptable percent loss during washing or sieving, or both of the coarser portion is covered in Section 12 on *Calculations*, 12.5.1.3. This calculation is performed after the sieving of the coarser portion. If CF_L is greater than 0.5 %, the sieve analysis is in nonconformance (unless the washings were added to the finer portion) and this factor shall be noted on the data sheet.

11.5.1.3 *Dry Sieving Coarser Portion*—Using this clean or washed coarser portion, follow the applicable instructions given in 11.4.4 (*Dry Sieving*) and 11.4.5 (*Cumulative Mass Retained*), while noting the finest sieve size in the coarser sieve set is the size of the designated separating sieve, ***not*** the No. 200 (75-µm) sieve. Determine and record these values of cumulative mass retained in the coarser sieve set and for each *Nth* sieve as CP,CMR_N in g or kg, Determine and record the mass of material contained in the pan, CP,MR_{pan} in g or kg. The calculation of the acceptable percent loss during washing or sieving, or both of the coarser portion is covered in Section 12 on *Calculations*, 12.5.1.3. If CF_L is greater than 0.5 %, the sieve analysis is in nonconformance and this factor shall be noted on the data sheet.

11.5.2 *Subspecimen from Finer Portion*—If the size of the designated separating sieve is equal to or larger than the ¾-in. (19.0-mm) sieve, then this subspecimen will have to be separated again, or washed and sieved in portions, see 10.3.1.1. If separation over a 2^{nd} designated separation sieve is necessary, then additional processing and sieving is needed, as covered in 11.6.3. If a 2^{nd} separation is ***not*** necessary (see Fig. 4(a)), then this subspecimen can be sieved as described below.

11.5.2.1 *Dispersing and Washing Subspecimen*—Wash the subspecimen following the applicable instructions provided in 11.4.2 to disperse the subspecimen and 11.4.3 to wash the subspecimen after dispersion. After oven drying, allow the container to cool, determine and record the dry mass of the washed material, $SubS_wM_d$ in g or kg.

11.5.2.2 *Dry Sieving Subspecimen*—Using the above dry washed subspecimen, dry sieve this material and determine the cumulative masses retained following the applicable instructions given in 11.4.4 through 11.4.5.3 and noting the following changes:

(a) The coarsest sieve size in the finer sieve set is the size of the designated separating sieve.

(b) For these cumulative mass retained values, they are identified as fractional cumulative mass retained on each *Nth* sieve as $SubS,FCMR_N$ in g or kg.

(c) There should not be any material retained on the coarsest sieve in the finer sieve set. Retained material indicates that the specimen was not split properly or there is a difference in openings in the sieve cloth between the designated separating sieve and the one in the finer sieve set. If the mass of material retained on this sieve, $SubS,MR_{first}$, is equal to or less that 2 % of the subspecimen's mass, $SubS,M_d$, then record the mass in g or kg. There might not be an identifiable space provided on the data sheet for this value, especially in composite sieving with double separations. In that case, record the value in the margin next to the appropriate sieve size.

(d) If the mass retained on this sieve exceeds 2 %, then the sieve analysis is in nonconformance and this factor noted on the data sheet, but record that value and determine the remaining $SubS,FCMR_N$ values. If this continually occurs, then the testing laboratory shall first review its splitting methodology for errors, and then verify that the sieve cloth of the sieves involved meet the full requirements of Specification E11, or replace those sieves with new ones.

11.5.2.3 Proceed to Section 12 on *Calculations*.

11.6 *Composite Sieving, Double Separation*—The 1st subspecimen will be processed over a 2nd designated separating sieve for composite sieving with double separation. See Fig. 1(a) and Fig. 1(b) for summary and flowchart of terms used and Fig. 4(a) and Fig. 4(b) for a flowchart of these sieving processes.

11.6.1 *Separating 1st Subspecimen*—Select the size of the 2nd designated separating sieve; usually this sieve size is the ⅜-in. (9.5-mm), No. 4 (4.75 mm), or No. 10 (2.00-mm) sieve. When selecting this sieve, remember that as the size of the designated separating sieve decreases, it is more difficult to obtain a representative 2nd subspecimen and meet the 0.5 % criterion on loss of material during washing and sieving of the 2nd coarser portion (see 11.6.2).

11.6.1.1 Sieve the 1st subspecimen over the 2nd designated separating sieve using the mechanical sieve shaker and appropriate standard shaking period and in increments to prevent sieve overloading. Separately collect the retained and passing portions.

11.6.1.2 Closely check the retained material for material finer than the 2nd designated separating sieve, if noted, they can be broken up by hand or by using a mortar and rubber-covered pestle. Re-sieve that material over the 2nd designated separating sieve by hand sieving (see 8.2.3) and add the retained and passing portions to the appropriate container.

11.6.2 *Dispersing and Washing 2nd Coarser Portion*—Recheck the retained material, if the amount of adhering particles appears to exceed 0.5 % of $1^{st}SubS,M_d$ then wash those fines into the container containing the second 2nd finer portion (that is, the material passing the 2nd designated separating sieve) and oven dry (110 ± 5°C) both portions ($2^{nd}CP_wM_d$ and 2nd finer portion). If the amount of finer material appears to be equal or less that this 0.5 % criterion; then determine and record the dry mass, $2^{nd}CP,M_d$ in g or kg and then sieve the 2nd coarser portion using the 2nd coarser sieve set. In addition, if this 2nd coarser portion is washed and it appears the adhering particles will not exceed 0.5 %, then the washings do not have to be added to the 2nd finer portion. For referee testing, the 2nd coarser portion has to be washed following the applicable instructions given in 11.5.1.1, while noting the following.

11.6.2.1 Determine and record the oven-dry mass (g or kg) of the 2nd coarser portion before and after washing as $2^{nd}CP,M_d$ and $2^{nd}CP_wM_d$, respectively.

11.6.2.2 The calculation of acceptable loss on washing criterion of 0.5 % is now based on the mass (g or kg) of the 1st subspecimen, $1^{st}SubS,M_d$. This calculation is covered in Section 12 on *Calculations*, 12.6.2.3.

11.6.3 *Dry Sieving 2nd Coarser Portion*—Using this clean or washed 2nd coarser portion, follow the applicable instructions given in 11.4.4 (*Dry Sieving*) and 11.4.5 (cumulative mass retained), while noting the following.

11.6.3.1 The coarsest and finest sieve sizes in this 2nd coarser sieve set are the size of the 1st and 2nd designated separating sieve, respectively.

11.6.3.2 The mass (g or kg) of material retained on the coarsest sieve shall not exceed 2 % of the dry mass of the 1st subspecimen; see 11.5.2.2, Items c and d.

11.6.3.3 The mass of the material in the pan, plus loss on washing, if applicable, cannot exceed 0.5 % criterion.

11.6.3.4 The calculations related to the 2nd coarser portion are covered in 12.6.2.1 through 12.6.2.5.

11.6.4 *2nd Subspecimen*—Using a splitter (see 6.9 and 10.4.4), split the 2nd finer portion to obtain the 2nd subspecimen having a mass (g or kg) meeting the requirements given in Table 2. Following the instructions provided in 11.2, determine and record the mass of the 2nd subspecimen as $2^{nd}SubS,M_d$ in g or kg.

11.6.4.1 *Dispersing and Washing 2nd Subspecimen*—Wash the 2nd subspecimen following the applicable instructions provided in 11.5.2.1. After oven drying, allow the container to cool, determine and record the dry mass of the washed material, $2^{nd}SubS_wM_d$ in g or kg.

11.6.4.2 *Dry Sieving 2nd Subspecimen*—Using this oven-dried, washed 2nd subspecimen; dry sieve this material and determine the 2nd fractional cumulative masses (g or kg) retained following the applicable instructions given in 11.5.2.2, while noting the following:

(a) The coarsest sieve size in this finer sieve set is the size of the 2nd designated separating sieve.

(b) For these cumulative masses retained values, they are identified as 2nd fractional cumulative mass retained for each *Nth* sieve as $2^{nd}SubS,CMR_N$ in g or kg.

(c) As stated in 11.5.2.2, Item c and d, there should not be any material retained on the coarsest sieve in this finer sieve set and the same 2 % criterion is applicable, except the mass (g or kg) of the 2nd subspecimen ($2^{nd}SubS,M_d$) is used instead of the 1st subspecimen ($1^{st}SubS,M_d = SubS,M_d$).

11.6.4.3 Proceed to Section 12 on *Calculations*, 12.6.3 through 12.6.4.2.

12. Calculations

12.1 *General*—Refer to Fig. 1(a) and Fig. 1(b) for the typical terms used in sieving and data reduction. The cumulative mass retained (*CMR*) or fractional cumulative mass retained (*FCMR*) recorded for each *Nth* sieve, CMR_N or $FCMR_N$, will be used to calculate a percent passing (*PP*) each *Nth* sieve, PP_N. These results will be tabulated and may be presented graphically. Depending on the assigned/selected method, the results are rounded and presented to either the nearest 1 % (Method A) or 0.1 % (Method B), except for composite sieving, when only Method A applies. The graphical presentation is a plot of percent passing versus log of particle size (mm). The individual points should be connected by a smooth curve.

12.1.1 In the calculations presented below the masses can be in either g or kg. All sieving masses are dry (oven), unless noted otherwise.

12.1.2 In performing calculations needing intermediate values, the data sheet does not have to provide spaces for those values. For example, when calculating the percent finer, the needed intermediate calculation of cumulative percent retained does not have to be recorded.

12.1.3 The equations are given for calculation of percent passing. To calculate the percent retained necessary in determining the precision of this test method, see 14.1.2.1.

12.1.4 A summary of the symbols used below, along with their definition is given in the Annex A1 on Symbols.

12.2 *Sieve Overloading*—The details for determining when a sieve(s) is overloaded during the sieving process is given in 11.3. The only calculation involved is to determine the dry mass of material retained on each *Nth* sieve in g and then compare that value with the maximum allowable value given in Table 3. When the *CMR* sieving process is used, the dry mass retained on the *Nth* sieve, MR_N, is as follows:

$$MR_N = CMR_N - CMR_{N-1} \tag{1}$$

where:

MR_N = mass retained on the *Nth* sieve, g,
CMR_{N-1} = cumulative mass retained on the sieve above the *Nth* sieve, g, and
CMR_N = cumulative mass retained on the *Nth* sieve (in this case the sieve being checked for overloading), g.

12.3 *Single Sieve-Set Sieving, Percent Passing*—For single sieve-set sieving (specimens not requiring composite sieving), calculate the percent passing each *Nth* sieve as follows:

$$PP_N = 100\left(1 - CMR_N/S,M_d\right) \tag{2}$$

where:

PP_N = percent passing the *Nth* sieve, %,
CMR_N = cumulative mass retained on the *Nth* sieve; that is, the mass of material retained on the *Nth* sieve and those above it, g or kg, and
S,M_d = dry mass of the specimen, g or kg.

12.4 *Composite Sieving, Mass of Specimen*—Calculate the dry mass of the specimen, S,M_d as follows:

$$S,M_d = CP,M_d + \left(\frac{FP,M_m}{1+\frac{w_{fp}}{100}}\right) \tag{3}$$

where:

S,M_d = dry mass of the specimen, g or kg,
CP,M_d = dry mass of the coarser portion, g or kg,
FP,M_m = moist or air-dried mass of the finer portion, g or kg, and
w_{fp} = water content of the finer portion, %.

12.5 *Composite Sieving, Single Separation*—The percent passing the coarser portion (*CP*) is calculated using the same approach as for single sieve-set sieving. For the subspecimen obtained from the finer portion; a composite sieving correction factor (*CSCF*) is required to convert the subspecimen's fractional percent passing to the specimen's percent passing, since only a portion of the specimen is sieved. Multiple approaches can be used to make this correction and they are in conformance with this test method, provided the calculated results are the same. In the presentation below, the percent passing values are identified related to the portion being dry sieved, such as CP,PP_N and $SubS,PP_N$; however, this distinction is not necessary on the data sheet. This approach is being done to allow the user to easily distinguish which portion is being calculated to determine the percent passing the specimen.

12.5.1 *Composite Sieving, Coarser Portion (CP):*

12.5.1.1 *CP, Percent Passing*—Calculate the percent passing each *Nth* sieve in the coarser sieve set as follows:

$$CP,PP_N = 100\left(1 - \left(CP,CMR_N/S,M_d\right)\right) \tag{4}$$

where:

CP,PP_N = specimen's percent passing the *Nth* sieve in the coarser sieve set while sieving the coarser portion of the specimen, %, and
CP,CMR_N = coarser portion's cumulative mass retained on the *Nth* sieve in the coarser sieve set, g or kg.

12.5.1.2 *CP, Composite Sieving Correction Factor (CSCF)*—The *CSCF* is equal to the percent passing the designated separating sieve size in the coarser sieve set (that is, the last/bottom sieve in that set). This value, CP,PP_{last}, shall be calculated and recorded to at least one more digit than required (nearest 0.1 %) to reduce rounding errors.

12.5.1.3 *CP, Acceptable Loss During Washing and Sieving*—Calculate the percent loss of the coarser portion during washing or sieving, or both as follows:

$$CP_L = 100\left(\left(\left(CP,M_d - CP_wM_d\right) + CP,MR_{pan}\right)/S,M_d\right) \tag{5}$$

where:

CP_L = percent of the coarser portion lost during washing and dry sieving, %,
CP,M_d = dry mass of the coarser portion, g or kg,
CP_wM_d = dry mass of the coarser portion after washing, g or kg, and
P,MR_{pan} = dry mass retained in the pan after dry sieving the coarser portion, g or kg.

The percent loss is acceptable if the value of CP_L is less than or equal to 0.5 %.

12.5.2 *Composite Sieving, Subspecimen (finer portion):*

12.5.2.1 *Percent Passing, Specimen (combined coarser and finer portions)*—In the approach presented, the fractional percent passing the subspecimen is corrected by the *CSCF* so it represents the percent passing the specimen. Calculate the percent passing each *Nth* sieve in the finer sieve set, $SubS,PP_N$ as follows:

$$SubS,PP_N = CSCF \times SubS,FPP_N = CSCF\left(1 - \left(SubS,FCMR_N/SubS,M_d\right)\right) \tag{6}$$

where:

$SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set, %,
$SubS,FPP_N$ = subspecimen's fractional percent passing the *Nth* sieve in the finer sieve set, decimal (*not in %*),

$SubS,FCMR_N$ = subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg, and

$SubS,M_d$ = dry mass of the subspecimen, g or kg.

12.5.2.2 *Subspecimen, Acceptable Fractional Percent Retained*—As covered in 11.5.2.2, there should not be any material retained on the first/top sieve, same size as the designated separating sieve, in the finer sieve set; however, when there is, the fractional percent retained shall not exceed 2 %. Calculate the fractional percent retained on the first sieve as follows:

$$SubS,FCPR_{first} = 100\left(SubS,FCMR_{first}/SubS,M_d\right) \qquad (7)$$

where:

$SubS,FCPR_{first}$ = fractional cumulative percent retained on the first sieve (sieve size equal to the designated separating sieve) in the finer sieve set, %, and

$SubS,FCMR_{first}$ = fractional cumulative mass retained on the first sieve in the finer sieve set, g or kg. (This mass is actually the mass retained since there is not any sieve above it.)

12.5.2.3 *Percent Passing, Acceptance Criterion*—If material is retained on the designated separating-sieve size in the fine sieve set, then there will be two percent passing values for the same sieve size. If this occurs, the percent passing value from the coarser sieve set shall be the accepted value in determining the gradation of the specimen.

12.5.3 *Finer Portion, Percent Passing (optional)*—As mentioned in 9.2.1, there are cases where the gradation of the finer portion might be necessary, especially when other testing, such as compaction, are performed. In this case, the fractional percent passing the subspecimen, $SubS,FPP_N$ in %, represents the percent passing the finer portion, FP,PP_N. Calculate those values as follows:

$$FP,PP_N = 100\left(1 - \left(SubS,FCMR_N/SubS,M_d\right)\right) \qquad (8)$$

where:

FP,PP_N = finer portion's percent passing the *Nth* sieve, %.

12.6 *Composite Sieving, Double Separation*—The methodology for these calculations is similar to that for calculating composite sieving with single separation, the only basic changes are the addition of new terms, see Fig. 1(a) and Fig. 1(b), and one additional set of calculations relating to the 2nd subspecimen. Therefore, review those figures and the comments presented in 12.5.

12.6.1 *1st Coarser Portion*—The percent passing, *CSCF* and acceptable loss calculations are the same as covered above, see Composite Sieving-Coarser Portion, 12.5.1, except the prefix 1st is added to all terms and symbols.

12.6.2 *1stSubspecimen*—In this case, the subspecimen is not sieved in its entirety, but is separated into a coarser and finer portion (2nd coarser portion and 2nd finer portion). The needed calculations associated with sieving the 2nd coarser portion and associated components are given below.

12.6.2.1 *Percent Passing, 2nd Coarser Portion*—Calculate the percent passing each *Nth* sieve in the 2nd coarser sieve set as follows:

$$2^{nd}CP,PP_N = 1^{st}CSCF \times 2^{nd}CP,FPP_N = 1^{st}CSCF\left(1 - \left(2^{nd}CP,CMR_N/SubS,M_d\right)\right) \qquad (9)$$

where:

$2^{nd}CP,PP_N$ = specimen's percent passing the *Nth* sieve in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %,

$1^{st}CSCF$ = 1st composite sieving correction factor, which is equal to the percent passing the designated separating sieve size in the 1st coarser sieve set while sieving the coarser portion of the specimen, %,

$2^{nd}CP,FPP_N$ = 2nd coarser portion's fractional percent passing the *Nth* sieve in the 2nd coarser sieve set, decimal (*not in %*), and

$2^{nd}CP,CMR_N$ = 2nd coarser portion's fractional cumulative mass retained on *Nth* sieve in the 2nd coarser sieve set, g or kg.

12.6.2.2 *2nd Coarser Portion, Composite Sieving Correction Factor (2ndCSCF)*—The *2ndCSCF* is equal to the percent passing the 2nd designated separating sieve size in the 2nd coarser sieve set (that is, the last/bottom sieve in that set) while sieving the coarser portion of the 1st subspecimen. This value, $2^{nd}CP,PP_{last}$, shall be calculated and recorded to at least one more digit than required (nearest 0.1 %) to reduce rounding errors.

12.6.2.3 *2nd Coarser Portion, Acceptable Loss on Sieving and Washing*—The calculation and acceptance criterion for the 2nd coarser portion are the same as covered above, see 12.5.1.3, except the prefix 2nd is added to the applicable terms and symbols, and the dry mass of the specimen is replaced by the dry mass of the 1st subspecimen, as shown in the following equation:

$$2^{nd}CP_L = 100\left(\left(\left(2^{nd}CP,M,_d - 2^{nd}CP_wM_d\right) + 2^{nd}CP,MR_{pan}\right)/1^{st}SubS,M_d\right) \qquad (10)$$

where:

$2^{nd}CP_L$ = percent of the 2nd coarser portion lost during washing and dry sieving, %,

$2^{nd}CP,M,_d$ = dry mass of the 2nd coarser portion, g or kg,

$2^{nd}CP_wM_d$ = dry mass of the 2nd coarser portion after washing, g or kg, and

$2^{nd}CP,MR_{pan}$ = dry mass retained in the pan after dry sieving the coarser portion, g or kg.

12.6.2.4 *2nd Coarser Portion, Acceptable Fractional Percent Retained*—As covered in 11.6.3.2, there should not be any material retained on the first/top sieve, same size as the designated separating sieve, in the 2nd coarser sieve set; however, when there is, the fractional percent retained shall not exceed 2 % of the dry mass of the 1st subspecimen. Calculate the fractional percent retained on the first sieve as follows:

$$2^{nd}CP,FPR_{first} = 100\left(2^{nd}CP,FCMR_{first}/SubS,M_d\right) \qquad (11)$$

where:

$2^{nd}CP,FPR_{first}$ = 1^{st} fractional percent retained on the first sieve (sieve size equal to the designated separating sieve) in the 2^{nd} coarser sieve set while sieving the coarser portion of the 1^{st} subspecimen, %, and

$2^{nd}CP,FCMR_{first}$ = 1^{st} fractional cumulative mass retained on the first sieve in the 2^{nd} coarser sieve set, g or kg. (This mass is actually the mass retained since there is not any sieve above it.)

12.6.2.5 *Percent Passing, Acceptance Criterion*—If material is retained on the designated separating-sieve size in the 2^{nd} coarser sieve set, then there will be two percent passing values for the same sieve size. If this occurs, the percent passing value from the 1^{st} coarser sieve set shall be the accepted value in determining the gradation of the specimen.

12.6.3 *2^{nd} Subspecimen*—The needed calculations associated with sieving the 2^{nd} subspecimen are given below.

12.6.3.1 *Percent Passing, 2^{nd} Subspecimen*—Calculate the percent passing each *Nth* sieve in the finer sieve set as follows:

$$2^{nd}SubS,PP_N = 2^{nd}CSCF \times 2^{nd}SubS,FPP_N = 2^{nd}CSCF\left(1 - \left(2^{nd}SubS,FCMR_N/2^{nd}SubS,M_d\right)\right) \qquad (12)$$

where:

$2^{nd}SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set while sieving the 2^{nd} subspecimen, %,

$2^{nd}CSCF$ = 2^{nd} composite sieving correction factor, which is equal to the percent passing the 2^{nd} designated separating sieve size in the 2^{nd} coarser sieve set while sieving the coarser portion of the 1^{st} subspecimen, %,

$2^{nd}SubS,FPP_N$ = 2^{nd} subspecimen's fractional percent passing the *Nth* sieve in the finer sieve set, decimal (not in %),

$2^{nd}SubS,FCMR_N$ = 2^{nd} subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg, and

$2^{nd}SubS,M_d$ = dry mass of the 2^{nd} subspecimen, g or kg.

12.6.3.2 *2^{nd} Subspecimen, Acceptable Fractional Percent Retained*—As covered in 11.6.2.2, there should not be any material retained on the first/top sieve, same size as the designated separating sieve, in the finer sieve set; however, when there is, the fractional percent retained shall not exceed 2 %. Calculate the fractional percent retained on the first sieve as follows:

$$2^{nd}SubS,FPR_{first} = 100\left(2^{nd}SubS,FCMR_{first}/2^{nd}SubS,M_d\right) \qquad (13)$$

where:

$2^{nd}SubS,FPR_{first}$ = 2^{nd} fractional percent retained on the first sieve (sieve size equal to the 2^{nd} designated separating sieve) in the finer sieve set while sieving the 2^{nd} subspecimen, %, and

$2^{nd}SubS,FCMR_{first}$ = 2^{nd} fractional cumulative mass retained on the first sieve in the finer sieve set while sieving the 2^{nd} subspecimen, g or kg. (This mass is actually the mass retained since there is not any sieve above it.)

12.6.3.3 *Percent Passing, Acceptance Criterion*—If material is retained on the 2^{nd} designated separating-sieve size in the finer sieve set while sieving the 2^{nd} subspecimen, then there will be two percent passing values for the same sieve size. If this occurs, the percent passing value from the coarser sieve set shall be the accepted value in determining the gradation of the specimen.

12.6.4 *1^{st} Finer Portion, Percent Passing (optional)*—As mentioned in 9.2.1, there are cases where the gradation of the specimen's 1^{st} finer portion might be necessary, especially when other testing, such as compaction, are performed. In this case, the fractional percent passing the 2^{nd} coarser portion, $2^{nd}CP,FPP_N$ in %, is representative of the percent passing the 1^{st} finer portion, $1^{st}FP,PP_N$, up to the 2^{nd} designated separating sieve size. Calculate those values as follows:

$$1^{st}FP,PP_N = 100\left(1 - \left(2^{nd}CP,FCMR_N/SubS,M_d\right)\right) \qquad (14)$$

where:

$1^{st}FP,PP_N$ = 1^{st} finer portion's percent passing the *Nth* sieve in the 2^{nd} coarser sieve set while sieving the coarser portion of the 1^{st} subspecimen, %.

While the $1^{st}FP,PP_N$ calculations associated with the 2^{nd} finer portion or 2^{nd} subspecimen are given below.

12.6.4.1 *2^{nd} Finer Portion, Composite Sieving Correction Factor (optional)*—When the gradation of the 1^{st} finer portion is needed and the 1^{st} subspecimen is separated, then an additional composite sieving correction factor is necessary to convert the fractional percent passing the 2^{nd} subspecimen to a percent passing which is representative of the 1^{st} finer portion. This *CSCF* is identified as *FP,CSCF* and is equal to either the fractional percent passing the 2^{nd} designated separating sieve size in the 2^{nd} coarser sieve set, or the 1^{st} finer portion's percent passing the last/bottom sieve in the 2^{nd} coarser sieve set, FP,PP_{last}, as calculated above (see 12.6.4) and recorded to at least one more digit than required (nearest 0.1%) to reduce rounding errors.

12.6.4.2 *1^{st} Finer Portion, Percent Passing for 2^{nd} Subspecimen (optional)*—In this case, the 2^{nd} fractional percent passing the finer sieve set, $2^{nd}SubS,FPP_N$ in % has to be corrected by the *FP,CSCF* (see 12.6.4.1) to represent the percent passing the finer portion, $1stFP,PP_N$. Calculate those values as follows:

$$1^{st}FP,PP_N = FP,CSCF\left(1 - \left(2^{nd}SubS,FCMR_N/2^{nd}SubS,M_d\right)\right) \qquad (15)$$

where:

FP,CSCF = 1^{st} finer portion's composite sieving correction factor, which is equal to the finer portion's percent passing the last/bottom sieve in 2^{nd} coarser sieve set,%.

13. Report: Test Data Sheets(s)/Form(s)

13.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.13. If the test results (gradation) are reported in tabular or graphical format for other than the laboratory's data records, then those values have to be representative of the method used (Method A or B). The percent passing values must be rounded to the appropriate percentage before tabulating or plotting; that is, the nearest 1 % and 0.1 % for Method A and B, respectively. However, the laboratory's test data sheet(s)/form(s) do not have to meet this requirement, if the method used (Method A or B) is clearly identified.

13.2 Record as a minimum the following information (data):

13.2.1 Identification of the material being tested, such as project identification, boring number, sample number, depth, and test number.

13.2.2 Name or initials of person performing the test and date(s).

13.2.3 Visual classification of the soil being tested (estimate group name and symbol in accordance with Practice D2487).

13.2.4 Test method used (Method A, or B).

13.2.5 The procedure used to obtain the specimen(s) from the sample, such as moist, air dried, or oven dried, see 1.8 and Section 10.

13.2.6 If any soil or material was excluded from the specimen, describe the excluded material. If any problems were encountered, describe the problems.

13.2.7 Indicate if composite sieving was used and the size of the designated separating sieve(s). If material is retained on the designated separating sieve size in the finer sieve set, then document that the percent retained (*PR*) does not exceed the 2 % criterion (see 11.5.2.2, Item c and d; 11.6.3.2 and 11.6.4.2, Item c) on sieving those portion(s)).

13.2.8 Indicate if the ultrasonic bath or shaking apparatus or both were used during the dispersion process.

13.2.9 Any prior testing performed on specimen.

13.2.10 All mass measurements (to the appropriate significant digits or better).

13.2.11 Tabulation of percent passing (PP) for each sieve, preferably to either the nearest 1 % or 0.1 % in accordance with Method A or B, respectively, see 13.1. Note this percentage should have an extra digit associated with designated separating sieve sieves.

13.2.12 *(Optional)*—A graph of the percent passing versus log of particle size in mm.

14. Precision and Bias

14.1 *Precision*—Criteria for judging the acceptability of test results obtained by this test method using single sieve-set sieving on SP soil types are presented in 14.1.3 and 14.1.4. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program. In this program, the Moist Procedure, Method A (except two extra digits were recorded) and Single Sieve-Set Sieving procedures were used. The oven-dry mass of the specimen ranged between 97.56 g and 120.83 g, with an average value of 109.88 g and less than 30 % of the mass of the specimen was retained on any given sieve. In addition, some laboratories performed three replicate tests on the SP soil sample provided (triplicate test laboratories), while other laboratories performed a single test (single test laboratories). However, the data was processed twice to obtain a precision statement for both Method A and B. A description of the soil tested is given in 14.1.5. Testing precision may vary due to the specimen preparation procedure (moist, air-dried or oven-dried), the soil's gradation, and variations in the testing method used (Method A or B). If sample variability is assumed to be negligible, the analyses of the sieve data obtained in this program and others clearly indicate the following regarding sieving precision:

(a) Sieving precision cannot be accurately defined for an insignificant sieve (sieve in which 99 percent or more of the soil passes);

(b) Sieving precision is mainly a function of the amount of soil retained on a given sieve and the acceptable range in the size of the openings of a given sieve cloth;

(c) Sieving precision is also effected by sieve overloading, particle shape, and the slope of the gradation curve; and

(d) These items are interconnected in some manner, which has not been determined.

Additionally, judgement is necessary when applying these precision estimates to another soil.

14.1.1 *Precision Data Analysis*—Typically, precision statements include one or two variables per test, therefore, statements are presented in tabular format. However, in a sieve analysis, there are multiple variables (that is, a result for each sieve size) per test, therefore, it was determined that a non-tabular format would be appropriate.

14.1.1.1 As covered in Practices E177 and E691 and for most test methods, precision statements consist of two main components for each set of test results: Single-Operator Results (Within-Laboratory Repeatability) and Interlaboratory Results (Between-Laboratory Reproducibility). In addition, repeatability and reproducibility are composed of three key variables, the average value, the standard deviation (s) and the acceptable range of two results ($d2s$ or 95 % limit). The $d2s$ or 95 % limit is calculated as $1.960\times\sqrt{2}\times s$, as defined by Practice E177.

14.1.1.2 Based on the above, equations were developed to determine the repeatability and reproducibility standard deviation (s_r and s_R, respectively) as a function of the average percent retained on a given sieve ($avgPR_N$) for each set of test results (Method A and B). All values of $avgPR_N$ were less than 30 %. The equations developed are based on the upper bound (a straight line on which or below which all of the data points fall) of s_r or s_R versus $avgPR_N$ relationship, except if an unusually high outlier was noted. Then, using the appropriate s_r or s_R value, the repeatability limit (r) and reproducibility limit (R) can be determined, that is the acceptable range of two results or the $d2s$ or 95 % limit.

14.1.2 *Calculation of Precision*—To compare two test results using single sieve-set sieving and either Method A or B, use the following sequence to determine either the repeatability and reproducibility limit for each *Nth* sieve size of interest.

14.1.2.1 For both reported test results, determine the percent retained on a given *Nth* sieve (PR_N) which is a significant sieve (that is one in which less than 99 % passes or more than 1 % cumulative mass is retained). This PR_N is equal to the percent passing in the previous sieve (PP_{N-1}) less the percent passing for the given *Nth* sieve (PP_N). In this calculation, use the appropriate rounded PP_N value, for Method A to nearest 1 % and for Method B to nearest 0.1 %. This calculation is shown as follows:

$$PR_N = PP_{N-1} - PP_N \tag{16}$$

where:

PR_N = percent retained on *Nth* sieve, using single sieve-set sieving, %,

PP_{N-1} = percent passing the sieve previous to the *Nth* sieve, for Method A to nearest whole % and Method B to nearest 0.1 %, and

PP_N = percent passing the *Nth* sieve, for Method A to nearest whole % and Method B to nearest 0.1 %.

Then average the two values obtained for each *Nth* sieve size, without rounding, to determine the average percent retained for that *Nth* sieve size, $avgPR_N$. This $avgPR_N$ value shall not exceed 30 %. If it does, the precision shall not be determined for any sieve size within that test result (sieve analysis).

14.1.2.2 Use this $avgPR_N$ value and the appropriate precision equation in 14.1.3 or 14.1.4 to determine the repeatability standard deviation (s_r) or reproducibility standard deviation (s_R). Then, multiply this result by 1.960×√2 (or 2.772) and round the result as appropriate, for Method A to nearest 1 % and Method B to nearest 0.1 %. This value is either the Repeatability Limit (*r*) or the Reproducibility Limit (*R*), depending on the s_r or s_R equation used.

14.1.2.3 Determine the absolute (positive) difference between the two PR_N test values (PR_N) and compare it to the appropriate limit, *r* or *R* to see if that difference is acceptable; that is, PR_N is equal to or less than the appropriate *r* or *R* value. For significant sieves only, repeat this process for each pair of results. If there is a non-acceptable value, then both sets of test results shall be checked for any calculation and rounding errors and all sieves involved shall be checked for apparent deviations, for example, weaving defects, creases, wrinkles, foreign matter in the cloth, as covered in Specification E11, Test Method One. If other comparisons of test results continue to obtain non-acceptable values, then the determination of the size distribution of wire cloth openings shall be determined for all sieves involved, in accordance with Specification E11, Test Method Three. A set of example calculations is given in Appendix X2.

14.1.2.4 *Acceptance Criteria*—Duplicate test results (sieve analyses) are considered valid if no more than one sieve size has a non-acceptable value, as determined in 14.1.2.3. If a nonacceptable value is obtained for more than one sieve size, then one or both of the sets of test results (sieve analyses) are non-acceptable.

14.1.3 *Triplicate Test Precision Data (TTPD)*—The precision equations given below are based upon three replicate tests performed by each triplicate test laboratory on samples of an SP-type soil and upon information provided in 14.1 through 14.1.1.2. These equations are to be applied in accordance with 14.1.2. These equations apply specifically to the soil that was tested in the interlaboratory testing program.

14.1.3.1 *TTPD-Method A Repeatability*—This repeatability standard deviation for a given *Nth* sieve size ($As_{r,N}$) is equal to 0 % for $avgPR_N$ values equal to or less than 2 %. For $avgPR_N$ values greater than 2 %, calculate $As_{r,N}$ in % using the following equation:

$$As_{r,N} = 0.022 \times avgPR_N + 0.21 \tag{17}$$

14.1.3.2 *TTPD-Method A Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($As_{R,N}$ in %) is calculated using the following equation:

$$As_{R,N} = 0.073 \times avgPR_N + 0.43 \tag{18}$$

14.1.3.3 *TTPD-Method B Repeatability*—This repeatability standard deviation for a given *Nth* sieve size ($Bs_{r,N}$) is equal to the larger of 0.02 % or that using the following equation:

$$Bs_{r,N} = 0.0197 \times avgPR_N + 0.0055 \tag{19}$$

14.1.3.4 *TTPD-Method B Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($Bs_{R,N}$) is equal to the larger of 0.28 % or that using the following equation:

$$Bs_{R,N} = 0.0821 \times avgPR_N + 0.0110 \tag{20}$$

14.1.4 *Single Test Precision Data (STPD)*—In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test. This is common practice in the design and construction industry. The equations given below are based upon the first test result from the triplicate test laboratories and the single test result from the other laboratories on samples of an SP-type soil and upon information provided in 14.1 through 14.1.1.2. These equations are to be applied in accordance with 14.1.2. The equations presented apply specifically to the soil that was tested in the interlaboratory testing program.

14.1.4.1 *STPD-Method A Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($As_{R,N}$ in %) is calculated using the following equation:

$$As_{R,N} = 0.038 \times avgPR_N + 0.65 \tag{21}$$

14.1.4.2 *STPD-Method B Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($Bs_{R,N}$) is equal to the larger of 0.382 % or that using the following equation:

$$Bs_{R,N} = 0.0462 \times avgPR_N + 0.357 \tag{22}$$

14.1.5 *Soil Type*—Based on the interlaboratory results, the soil used in the program is described below in accordance with Practice D2487. In addition, the local name of the soil is given: SP—Poorly graded sand, SP, 20 % coarse sand, 48 % medium sand, 30 % fine sand, 2 % fines, yellowish brown. Local name—Frederick sand.

14.1.6 *Discussion on Precision:*

14.1.6.1 The *TTPD* presents a rigorous interpretation of triplicate test data in accordance with Practice E691 from pre-qualified laboratories. *STPD* is derived from test data that would represent common practice.

14.1.6.2 It is quite possible that precision data presented for Method B is not as precise as it should be since a larger specimen should have been tested.

14.1.6.3 The precision data presented cannot be accurately applied to coarse-grained soils containing gravel size particles where more than 1 % gravel is contained in the sample/specimen. This statement is based on the precision data presented in Test Method C136, which demonstrated that the sieving precision decreases substantially when gravel specimens are tested versus sand specimens.

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

15. Keywords

15.1 gradation; grain size; particle size; particle-size distribution; sieve analysis; sieving

ANNEXES

(Mandatory Information)

A1. SYMBOLS

$1^{st}CSCF$ = 1st composite sieving correction factor, which is equal to the percent passing the designated separating sieve size in the 1st coarser sieve set while sieving the coarser portion of the specimen, %
$FP,CSCF$ = 1st finer portion's composite sieving correction factor, which is equal to the finer portion's percent passing the last/bottom sieve in 2nd coarser sieve set, %
$1^{st}FP,PP_N$ = 1st finer portion's percent passing the *Nth* sieve in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %
$2^{nd}CP,FCMR_N$ = 2nd coarser portion's fractional cumulative mass retained on *Nth* sieve in the 2nd coarser sieve set, g or kg
$2^{nd}CP,FPP_N$ = 2nd coarser portion's fractional percent passing the *Nth* sieve in the 2nd coarser sieve set, decimal (not in %), or in %
$2^{nd}CP,FPR_{first}$ = 1st fractional percent retained on the first sieve (sieve size equal to the designated separating sieve) in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %
$2^{nd}CP,M_d$ = dry mass of the 2nd coarser portion, g or kg
$2^{nd}CP,MR_{pan}$ = dry mass retained in the pan after dry sieving the coarser portion, g or kg
$2^{nd}CP,PP_N$ = specimen's percent passing the *Nth* sieve in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %
$2^{nd}CP_L$ = percent of the 2ndcoarser portion lost during washing and dry sieving, %
$2^{nd}CP_w,M_d$ = dry mass of the 2nd coarser portion after washing, g or kg
$2^{nd}CSCF$ = 2nd composite sieving correction factor, which is equal to the percent passing the 2nd designated separating sieve size in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %
$2^{nd}SubS,FCMR_{first}$ = 2nd fractional cumulative mass retained on the first sieve in the finer sieve set while sieving the 2nd subspecimen, g or kg (This mass is actually the mass retained since there is not any sieve above it.)
$2^{nd}SubS,FCMR_N$ = 2nd subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg
$2^{nd}SubS,FPP_N$ = 2nd subspecimen's fractional percent passing the *Nth*th sieve in the finer sieve set, decimal (not in %) or in %
$2^{nd}SubS,FPR_{first}$ = 2nd fractional percent retained on the first sieve (sieve size equal to the 2nd designated separating sieve) in the finer sieve set while sieving the 2nd subspecimen, %
$2^{nd}SubS,M_d$ = dry mass of the 2nd subspecimen, g or kg
$2^{nd}SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set while sieving the 2nd subspecimen, %
AASHTO = American Association of State Highway and Transportation Officials
AMRL = AASHTO Materials Reference Laboratory
$As_{r,N}$ = Method A repeatability standard deviation for a given *Nth* sieve
$As_{R,N}$ = Method A reproducibility standard deviation for a given *Nth* sieve
$avgPR_N$ = average of two percent retained values on the *Nth* sieve between two laboratories or within laboratory
$Bs_{r,N}$ = Method B repeatability standard deviation for a given *Nth* sieve
$Bs_{R,N}$ = Method B reproducibility standard deviation for a given *Nth* sieve
CMR_N = cumulative mass retained on the th sieve; that is, the mass of material retained on the *Nth* sieve and those above it, g or kg
CMR_{N-1} = cumulative mass retained on the sieve above the *Nth* sieve, g or kg
CP,CMR_N = coarser portion's cumulative mass retained on the *Nth* sieve in the coarser sieve set, g or kg
CP,M_d = dry mass of the coarser portion, g or kg
CP,MR_{pan} = dry mass retained in the pan after dry sieving the coarser portion, g or kg
CP,PP_N = specimen's percent passing the *Nth* sieve in the coarser sieve set while sieving the coarser portion of the specimen, %

CP_L = percent of the coarser portion lost during washing and dry sieving, %
CP_w,M_d = dry mass of the coarser portion after washing, g or kg
$CSCF$ = composite sieving correction factor
$d2s$ = acceptable range of two results (or 95 % limit) calculated as $1.960\times\sqrt{2}\times s$, as defined by Practice E177
FP,M_m = moist or air-dried mass of the finer portion, g or kg
FP,PP_N = finer portion's percent passing the *Nth* sieve, %
MR_N = mass retained on the *Nth* sieve, g or kg
PP = percent passing, %
PP_N = percent passing the *Nth* sieve, %
PR = percent retained, %
s = standard deviation, units of calculation
S,M_d = dry mass of the specimen, g or kg
s_r = repeatability (within laboratory) standard deviation
s_R = reproducibility (between laboratories) standard deviation
$STPD$ = single test precision data
$SubS,FCMR_{first}$ = fractional cumulative mass retained on the first sieve in the 2nd coarser sieve set, g or kg (This mass is actually the mass retained since there is not any sieve above it.)
$SubS,FCMR_{first}$ = fractional cumulative mass retained on the first sieve in the finer sieve set, g or kg (This mass is actually the mass retained since there is not any sieve above it.)
$SubS,FCMR_N$ = subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg
$SubS,FCPR_{first}$ = fractional cumulative percent retained on the first sieve (sieve size equal to the designated separating sieve) in the finer sieve set, %
$SubS,FPP_N$ = subspecimen's fractional percent passing the *Nth* sieve in the finer sieve set, decimal (not in %) or in %
$SubS,M_d$ = dry mass of the subspecimen, g or kg
$SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set, %
$TTPD$ = triplicate test precision data
w_{fp} = water content of the finer portion, %
ΔPP_N = absolute (positive) difference between two PR_N test values (within laboratory or between laboratories)

A2. SAMPLE TO SPECIMEN SPLITTING/REDUCTION METHODS

A2.1 *General*—It is possible that bulk samples, jar samples, or specimens from prior testing may be significantly larger than needed for a sieve analysis. To reduce these samples to an appropriate specimen size, several techniques are applicable. The type and sizes of particles contained within the sample will influence the specimen processing and selection. Practice C702 provides details of mechanical splitting, quartering and miniature stockpile sampling for aggregate. When testing soils, these methods are adapted based on soil type. The goal is to have the specimen accurately represent the sample. Loss of particles (finer sizes) and segregation of particles are the most common problems when obtaining a specimen and most frequently occur during low or no moisture situations. Likewise, it is difficult to obtain a representative specimen if the sample contains excess or free water.

A2.1.1 *Mechanical Splitting*—This method is used only on dry samples that contain little or no fines. If the sample appears to create dust during the splitting, the sample has lost fines and mechanical splitting should be limited. For all soils, the splitting method may be used a maximum of two times, see 10.4.4. The splitter or riffle box shall conform to 6.9. The sample is placed in a feeder pan and distributed evenly throughout the pan. Pour the sample from the pan, into the hopper/feed chute, open the gate, if applicable, and allow the specimen to feed into the two catch pans. This process can be repeated once.

A2.1.2 *Quartering*—This method can be used on moist samples (see Practice C702), however it is often difficult and requires effort to collect all the finer particles. The sample is placed on a clean nonporous smooth surface (floor or sheet) and is thoroughly mixed using shovels, scoops, or spoons as appropriate for the sample size. Then, mound the sample into a cone-type shape by placing each shovelful or scoop on top of the preceding material. Flatten the cone to form a disk. Using a straight edge, or knife, divide the disk into wedge-shaped quarters. Remove two opposing quarters. Remix the remaining two quarters. Repeat this process until the mass of the remaining two quarters is greater than the minimum mass requirement, but less than 1.5 times the minimum mass requirement. If the sample is in a dry state, then this process can be repeated only once.

A2.1.3 *Miniature Stockpile Sampling*—This method is only applicable for moist samples. The sample is placed on a clean nonporous smooth surface and is thoroughly mixed using shovels, scoops or spoons as appropriate for the sample size. Then, mound the sample into a cone-type shape by placing each shovel full or scoop on top of the preceding shovel full or scoop of material. If desired, flatten the cone to form a disk. Using a scoop, obtain material from at least five locations in the pile. Scoop until the mass of the specimen is greater than the minimum mass requirement. Do not attempt to take very small scoops in order to obtain an exact mass because this could skew the particle-size distribution. In some cases, when working with relatively small samples and materials finer than the ⅜-in. (9.5-mm) sieve, a single scoop should be adequate.

A2.2 *Sample Processing Recommendations Based on Soil Type*—Estimate the soil classification using D2488. Then, use the following recommendations in conjunction with those given in Sections 9 and 10.

A2.2.1 *Clean Gravel (GW, GP) and Clean Sand (SW, SP)*—The condition of this sample should be moist or dry (air or oven). Either moist or dry (air or dry) processing can be used, although moist processing is probably easier, especially for sandy soils. The sample will require composite sieving if there are gravel size particles, see 10.3. If sample splitting is necessary to obtain a specimen, the sample can be mechanically split (dry processing), quartered (moist or dry processing), or sampled from a miniature stockpile (moist processing), to obtain a specimen. Refer to 10.4.1 (moist), 10.4.2 (air dried) or 10.4.3 (oven dried) for additional guidance.

A2.2.2 *Gravel with Fines (GM, GC, GC-GM, GW-GM, GW-GC, GP-GM, GP-GC)*—These soil types are the most difficult to obtain a gradation. The difficulty increases with increasing plasticity of the fines. The sample/specimen *will* require composite sieving due to the gravel size particles, see 10.3. Some of the fines may adhere to the gravel particles. Moist processing can be difficult, but with dry processing, it is often impossible or impractical to obtain a representative specimen. If the fine material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. If sample reduction is necessary, the sample can be quartered or sampled from a miniature stockpile to obtain a specimen. Then, it can be processed over the designated separating sieve as described in 10.5.2.

A2.2.3 *Sand with Silt Fines (SW-SM, SP-SM, SM)*—These soils should be processed in a moist state, see 10.5.1. The sample may require composite sieving if there is a wide range of particle sizes. The fines will frequently segregate from the sand and care must be taken to obtain a representative specimen. Moist processing will reduce the probability of segregation of fines. If sample reduction to obtain a specimen is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2

A2.2.4 *Sand with Clay and Silt Fines or Clay Fines (SW-SC, SP-SC, SC, SC-SM) and Clays (CL, CL-ML, CH)*—These soils are processed in a moist state. If the fine material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. Complete drying of these materials usually creates hard lumps that can be difficult to disperse or break apart, see 10.5.2. The sample may require composite sieving if there is gravel size particles, see 10.3. If sample reduction is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2.

A2.2.5 *Silts with Sand or Gravel, or Both (ML, MH)*—These soils are processed in a moist state. If the fine material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. The material may contain large particles and therefore require composite sieving, see 10.3. If sample reduction is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2.

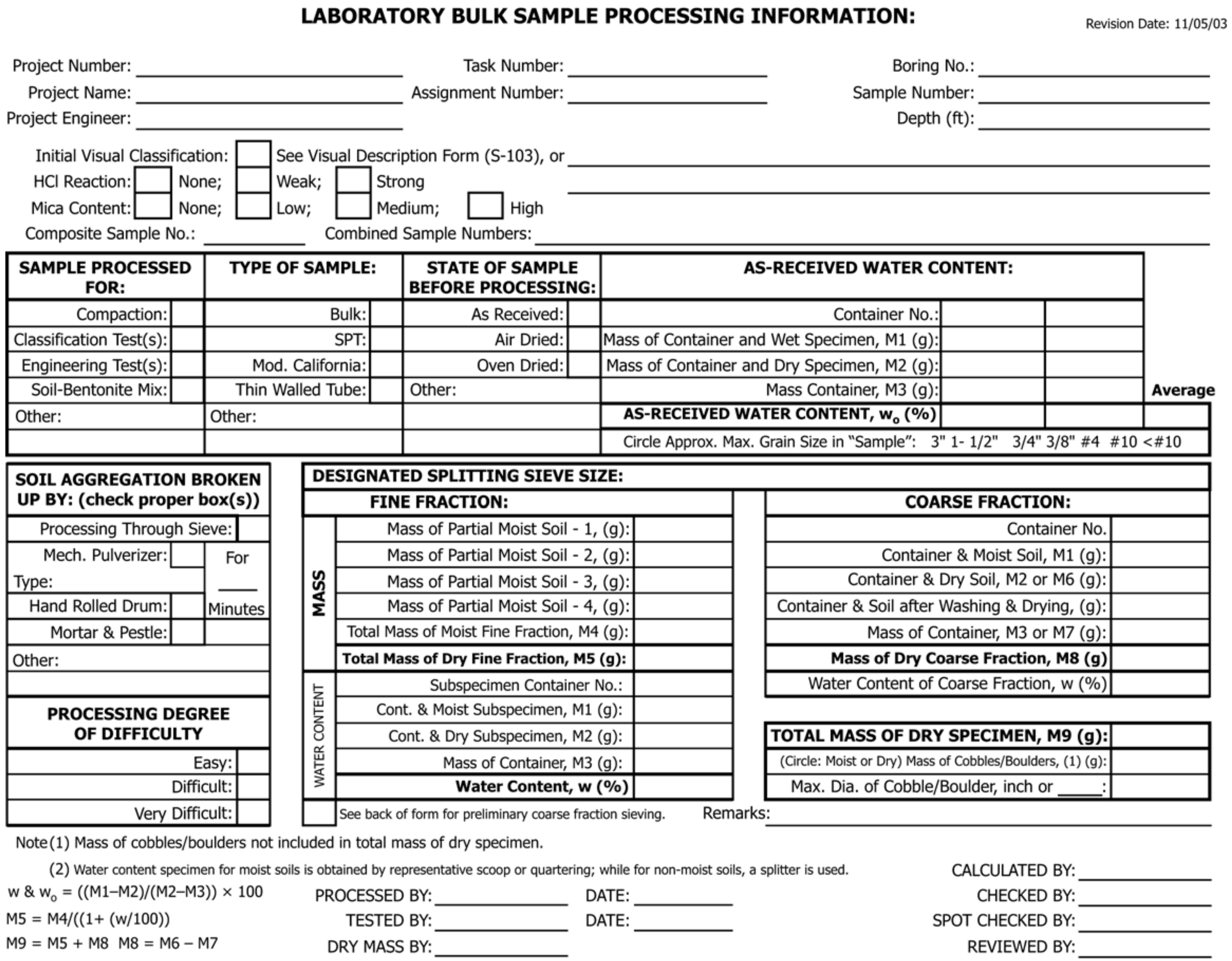
A2.2.6 *Organic Soils with Sand or Gravel, or Both (OL, OH)*—The organic soils are processed moist. If the material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. The material may contain large particles and therefore require composite sieving. Some of the organic material may easily break apart during processing. If sample reduction is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2.

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE TEST DATA SHEETS/FORMS

X1.1 *General*—Two example data sheets are presented. Fig. X1.1 presents a data sheet that may be used in processing bulk samples in which a sieve-analysis specimen, or other testing, or both is needed. Fig. X1.2 presents a data sheet that may be used to record the sieve analysis data.



LABORATORY BULK SAMPLE PROCESSING INFORMATION:

Revision Date: 11/05/03

Project Number: ____________ Task Number: ____________ Boring No.: ____________
Project Name: ____________ Assignment Number: ____________ Sample Number: ____________
Project Engineer: ____________ Depth (ft): ____________

Initial Visual Classification: ☐ See Visual Description Form (S-103), or ____________
HCl Reaction: ☐ None; ☐ Weak; ☐ Strong
Mica Content: ☐ None; ☐ Low; ☐ Medium; ☐ High
Composite Sample No.: ________ Combined Sample Numbers: ____________

SAMPLE PROCESSED FOR:		**TYPE OF SAMPLE:**		**STATE OF SAMPLE BEFORE PROCESSING:**		**AS-RECEIVED WATER CONTENT:**			
Compaction:		Bulk:		As Received:		Container No.:			
Classification Test(s):		SPT:		Air Dried:		Mass of Container and Wet Specimen, M1 (g):			
Engineering Test(s):		Mod. California:		Oven Dried:		Mass of Container and Dry Specimen, M2 (g):			
Soil-Bentonite Mix:		Thin Walled Tube:		Other:		Mass Container, M3 (g):			**Average**
Other:		Other:				**AS-RECEIVED WATER CONTENT, w_o (%)**			
						Circle Approx. Max. Grain Size in "Sample": 3" 1- 1/2" 3/4" 3/8" #4 #10 <#10			

SOIL AGGREGATION BROKEN UP BY: (check proper box(s))		
Processing Through Sieve:		
Mech. Pulverizer:		For ____ Minutes
Type:		
Hand Rolled Drum:		
Mortar & Pestle:		
Other:		
PROCESSING DEGREE OF DIFFICULTY		
Easy:		
Difficult:		
Very Difficult:		

DESIGNATED SPLITTING SIEVE SIZE:

	FINE FRACTION:	
MASS	Mass of Partial Moist Soil - 1, (g):	
	Mass of Partial Moist Soil - 2, (g):	
	Mass of Partial Moist Soil - 3, (g):	
	Mass of Partial Moist Soil - 4, (g):	
	Total Mass of Moist Fine Fraction, M4 (g):	
	Total Mass of Dry Fine Fraction, M5 (g):	
WATER CONTENT	Subspecimen Container No.:	
	Cont. & Moist Subspecimen, M1 (g):	
	Cont. & Dry Subspecimen, M2 (g):	
	Mass of Container, M3 (g):	
	Water Content, w (%)	
	See back of form for preliminary coarse fraction sieving.	

COARSE FRACTION:	
Container No.	
Container & Moist Soil, M1 (g):	
Container & Dry Soil, M2 or M6 (g):	
Container & Soil after Washing & Drying, (g):	
Mass of Container, M3 or M7 (g):	
Mass of Dry Coarse Fraction, M8 (g)	
Water Content of Coarse Fraction, w (%)	

TOTAL MASS OF DRY SPECIMEN, M9 (g):	
(Circle: Moist or Dry) Mass of Cobbles/Boulders, (1) (g):	
Max. Dia. of Cobble/Boulder, inch or _____:	

Remarks: ____________

Note (1) Mass of cobbles/boulders not included in total mass of dry specimen.

(2) Water content specimen for moist soils is obtained by representative scoop or quartering; while for non-moist soils, a splitter is used.

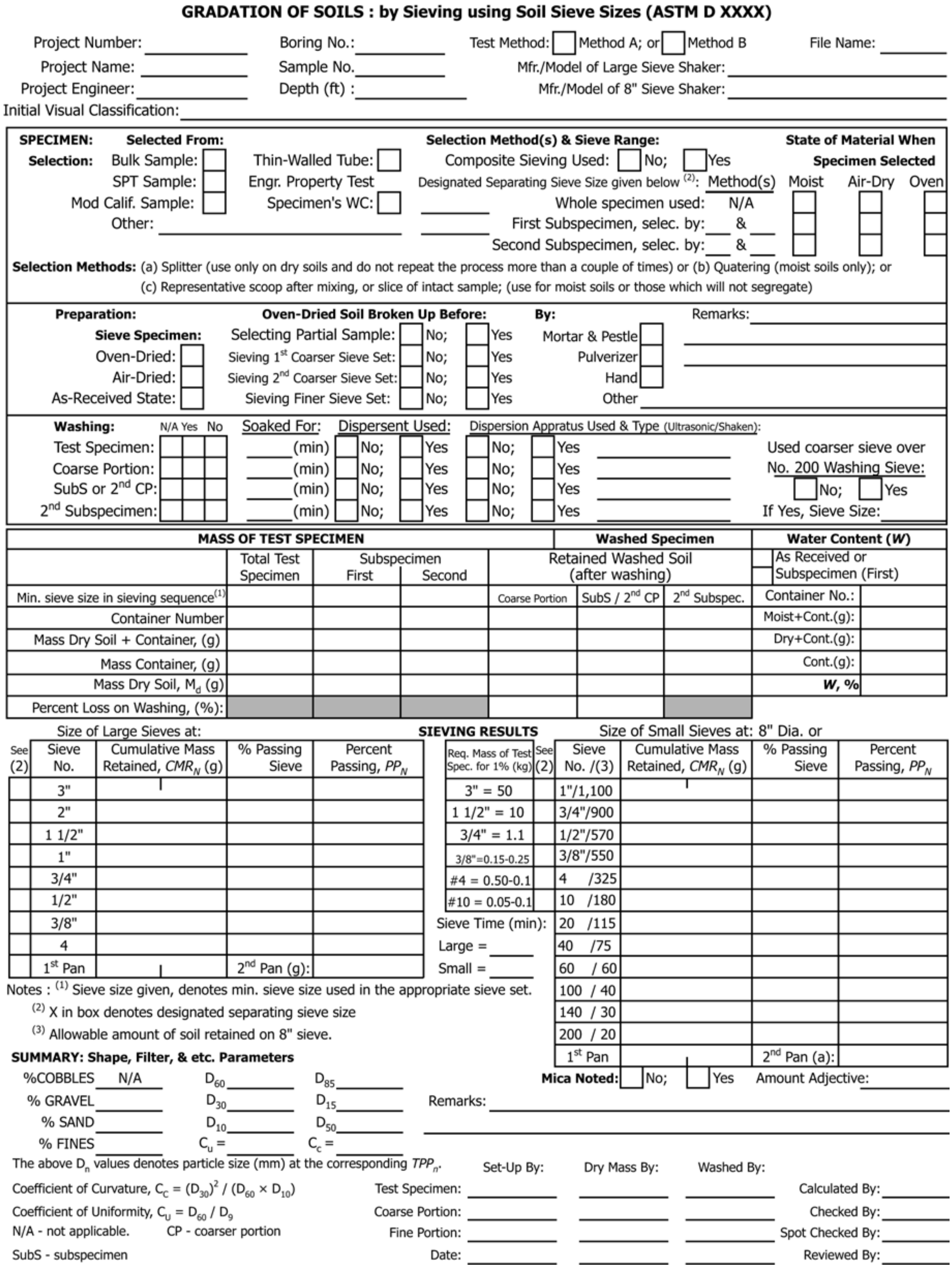
w & w_o = ((M1–M2)/(M2–M3)) × 100
M5 = M4/((1+ (w/100))
M9 = M5 + M8 M8 = M6 – M7

PROCESSED BY: ____________ DATE: ________
TESTED BY: ____________ DATE: ________
DRY MASS BY: ____________

CALCULATED BY: ____________
CHECKED BY: ____________
SPOT CHECKED BY: ____________
REVIEWED BY: ____________

Copy of ProcessBulkSample.xls, Bulk Sample 11/05/03

FIG. X1.1 Example Bag Sample Processing Data Sheet



GRADATION OF SOILS : by Sieving using Soil Sieve Sizes (ASTM D XXXX)

Project Number: ____________ Boring No.: __________ Test Method: ☐ Method A; or ☐ Method B File Name: ________
Project Name: ____________ Sample No. __________ Mfr./Model of Large Sieve Shaker: ____________________
Project Engineer: ____________ Depth (ft) : ____________ Mfr./Model of 8" Sieve Shaker: ____________________
Initial Visual Classification: ____

SPECIMEN: Selected From:

Selection: Bulk Sample: ☐ SPT Sample: ☐ Mod Calif. Sample: ☐ Other: ______________________
Thin-Walled Tube: ☐ Engr. Property Test Specimen's WC: ☐

Selection Method(s) & Sieve Range:
Composite Sieving Used: ☐ No; ☐ Yes
Designated Separating Sieve Size given below (2): Method(s)
________ Whole specimen used: N/A
________ First Subspecimen, selec. by: ___ & ___
Second Subspecimen, selec. by: ___ & ___

State of Material When Specimen Selected

	Moist	Air-Dry	Oven
Whole specimen used	☐	☐	☐
First Subspecimen	☐	☐	☐
Second Subspecimen	☐	☐	☐

Selection Methods: (a) Splitter (use only on dry soils and do not repeat the process more than a couple of times) or (b) Quatering (moist soils only); or (c) Representative scoop after mixing, or slice of intact sample; (use for moist soils or those which will not segregate)

Preparation:

Sieve Specimen: Oven-Dried: ☐ Air-Dried: ☐ As-Received State: ☐

Oven-Dried Soil Broken Up Before:
Selecting Partial Sample: ☐ No; ☐ Yes
Sieving 1st Coarser Sieve Set: ☐ No; ☐ Yes
Sieving 2nd Coarser Sieve Set: ☐ No; ☐ Yes
Sieving Finer Sieve Set: ☐ No; ☐ Yes

By: Mortar & Pestle ☐ Pulverizer ☐ Hand ☐ Other ______________

Remarks: ____________________

Washing:	N/A	Yes	No	Soaked For:	Dispersent Used:	Dispersion Appratus Used & Type (Ultrasonic/Shaken):	
Test Specimen:	☐	☐	☐	_____(min)	☐ No; ☐ Yes	☐ No; ☐ Yes	______________
Coarse Portion:	☐	☐	☐	_____(min)	☐ No; ☐ Yes	☐ No; ☐ Yes	______________
SubS or 2nd CP:	☐	☐	☐	_____(min)	☐ No; ☐ Yes	☐ No; ☐ Yes	______________
2nd Subspecimen:	☐	☐	☐	_____(min)	☐ No; ☐ Yes	☐ No; ☐ Yes	______________

Used coarser sieve over No. 200 Washing Sieve: ☐ No; ☐ Yes
If Yes, Sieve Size: ________

MASS OF TEST SPECIMEN				Washed Specimen			Water Content (*W*)	
	Total Test Specimen	Subspecimen First	Second	Retained Washed Soil (after washing)			☐ As Received or ☐ Subspecimen (First)	
Min. sieve size in sieving sequence(1)				Coarse Portion	SubS / 2nd CP	2nd Subspec.	Container No.:	
Container Number							Moist+Cont.(g):	
Mass Dry Soil + Container, (g)							Dry+Cont.(g):	
Mass Container, (g)							Cont.(g):	
Mass Dry Soil, M_d (g)							***W*, %**	
Percent Loss on Washing, (%):	▨	▨	▨			▨		

SIEVING RESULTS

Size of Large Sieves at:

See (2)	Sieve No.	Cumulative Mass Retained, CMR_N (g)	% Passing Sieve	Percent Passing, PP_N
	3"			
	2"			
	1 1/2"			
	1"			
	3/4"			
	1/2"			
	3/8"			
	4			
	1st Pan		2nd Pan (g):	

Size of Small Sieves at: 8" Dia. or

Req. Mass of Test Spec. for 1% (kg)	See (2)	Sieve No. /(3)	Cumulative Mass Retained, CMR_N (g)	% Passing Sieve	Percent Passing, PP_N
3" = 50		1"/1,100			
1 1/2" = 10		3/4"/900			
3/4" = 1.1		1/2"/570			
3/8"=0.15-0.25		3/8"/550			
#4 = 0.50-0.1		4 /325			
#10 = 0.05-0.1		10 /180			
Sieve Time (min):		20 /115			
Large = _____		40 /75			
Small = _____		60 / 60			
		100 / 40			
		140 / 30			
		200 / 20			
		1st Pan		2nd Pan (a):	

Notes : (1) Sieve size given, denotes min. sieve size used in the appropriate sieve set.
(2) X in box denotes designated separating sieve size
(3) Allowable amount of soil retained on 8" sieve.

SUMMARY: Shape, Filter, & etc. Parameters

%COBBLES N/A D_{60} ________ D_{85} ________
% GRAVEL ________ D_{30} ________ D_{15} ________
% SAND ________ D_{10} ________ D_{50} ________
% FINES ________ C_u = ________ C_c = ________

Mica Noted: ☐ No; ☐ Yes Amount Adjective: ________
Remarks: ____

The above D_n values denotes particle size (mm) at the corresponding TPP_n.

Coefficient of Curvature, $C_C = (D_{30})^2 / (D_{60} \times D_{10})$

Coefficient of Uniformity, $C_U = D_{60} / D_9$

N/A - not applicable. CP - coarser portion

SubS - subspecimen

	Set-Up By:	Dry Mass By:	Washed By:	
Test Specimen:	__________	__________	__________	Calculated By: ________
Coarse Portion:	__________	__________	__________	Checked By: ________
Fine Portion:	__________	__________	__________	Spot Checked By: ________
Date:	__________	__________	__________	Reviewed By: ________

FIG. X1.2 Example Gradation of Soils Data Sheet

X2. PRECISION: EXAMPLE CALCULATIONS

X2.1 *General*—Two sets of example calculations are provided for comparing test results (sieve analyses) obtained within and between laboratories. The first example, Fig. X2.1, presents results for sieve analyses using Method A (data to the nearest whole percentage) and based upon the triplicate test precision data. The second example, Fig. X2.2, presents results for sieve analyses using Method B (data to the nearest 0.1 %) and based upon the triplicate and single test precision data.

Method A - Example Calculations for Within Laboratory Precision (Repeatability)
Based Upon Triplicate Test Precision Data

Equation for Repeatability Standard Deviation: $As_{r,n}$= 0.022 × $avgPR_n$ + 0.21 or 0 if $avgPR_n$ is equal to or less than 2%

Alternate Sieve Size	Lab 14 Test Results Percent Passing, PP_n Trial Number 1	2	Percent Retained, PR_n Trial Number 1	2	Average Percent Retained, $avgPR_n$	Method A - Repeatability Standard Deviation, $As_{r,n}$	Repeatability Limit, r (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus r	Acceptability: ΔPR_n =or< r Yes or No
No.4	100	100	0	0	N/A	N/A	N/A	N/A	N/A	N/A
10	80	81	20	19	19.5	0.639	2	1	–1	Yes
20	59	61	21	20	20.5	0.661	2	1	–1	Yes
40	33	33	26	28	27	0.804	2	2	0	Yes
60	10	11	23	22	22.5	0.705	2	1	–1	Yes
100	4	4	6	7	6.5	0.353	1	1	0	Yes
140	3	3	1	1	1	0	0	0	0	Yes
200	2	2	1	1	1	0	0	0	0	Yes
									Precision Acceptance:	Valid Duplicates

Method A - Example Calculations for Between Laboratory Precision (Reproducibility)
Based Upon Triplicate Test Precision Data

Equation for Reproducibility Standard Deviation: $As_{r,n}$= 0.073 × $avgPR_n$ + 0.43

Alternate Sieve Size	Percent Passing, PP_n Laboratory ID 1A	23A (2)	Percent Retained, PR_n Laboratory ID 1A	23A	Average Percent Retained, $avgPR_n$	Method A - Reproducibility Standard Deviation, $As_{R,n}$	Reproducibility Limit, R (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus R	Acceptability: ΔPR_n =or< R Yes or No
No.4	100	100	0	1	N/A	N/A	N/A	N/A	N/A	N/A
10	81	81	19	19	19	1.817	5	0	–5	Yes
20	60	58	21	23	22	2.036	6	2	–4	Yes
40	35	27	25	31	28	2.474	7	6	–1	Yes
60	11	9	24	18	21	1.963	5	6	1	No
100	3	3	8	6	7	0.941	3	2	–1	Yes
140	2	2	1	1	1	0.503	1	0	–1	Yes
200	2	0	0	2	1	0.503	1	2	1	No
									Precision Acceptance:	Non-acceptable

Note: (1) A special spreadsheet function is used to round values without any extra digits; therefore, the displayed value is the value in the cell.
(2) Some data was adjusted to create non-acceptable data.

FIG. X2.1 Precision Example Calculations: Method A—Triplicate Test Precision Data

Method B - Example Calculations for Within Laboratory Precision (Repeatability)
Based Upon Triplicate Test Precision Data

Equation for Repeatability Standard Deviation: $Bs_{r,n} = 0.022 \times avgPR_n + 0.21$ or 0.02, whichever is larger

Lab 14 Test Results Alternate Sieve Size	Percent Passing, PP_n Trial Number A	B	Percent Retained, PR_n Trial Number A	B	Average Percent Retained, $avgPR_n$	Method A-Repeatability Standard Deviation, $Bs_{r,n}$	Repeatability Limit, r (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus r	Acceptability: ΔPR_n = or< r Yes or No
No. 4	100.0	100.0	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A
10	80.0	80.8	20.0	19.2	19.60	0.3916	1.1	0.8	–0.3	Yes
20	59.4	60.6	20.6	20.2	20.40	0.4074	1.1	0.4	–0.7	Yes
40	33.1	33.5	26.3	27.1	26.70	0.5315	1.5	0.8	–0.7	Yes
60	10.5	11.1	22.6	22.4	22.50	0.4488	1.2	0.2	–1.0	Yes
100	3.6	3.7	6.9	7.4	7.15	0.1464	0.4	0.5	0.1	No
140	2.6	2.9	1.0	0.8	0.90	0.0232	0.1	0.2	0.1	No
200	2.0	2.0	0.6	0.9	0.75	0.0203	0.1	0.3	0.2	No
									Precision Acceptance:	Invalid Duplicates

Method B - Example Calculations for Between Laboratory Precision (Reproducibility)
Based Upon Single Test Precision Data

Equation for Reproducibility Standard Deviation: $Bs_{R,n} = 0.0462 \times avgPR_n + 0.357$ or 0.382, whichever is larger

Alternate Sieve Size	Percent Passing, PP_n Laboratory ID 1A	26	Percent Retained, PR_n Laboratory ID 1A	26	Average Percent Retained, $avgPR_n$	Method A-Reproducibility Standard Deviation, $As_{R,n}$	Reproducibility Limit, R (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus R	Accceptability: ΔPR_n = or< R Yes or No
No. 4	100.0	100.0	0.0	1.0	N/A	N/A	N/A	N/A	N/A	N/A
10	80.9	81.0	19.1	19.0	19.05	1.2371	3.4	0.1	–3	Yes
20	59.9	60.9	21.0	20.1	20.55	1.3064	3.6	0.9	–3	Yes
40	34.7	34.6	25.2	26.3	25.75	1.5467	4.3	1.1	–3	Yes
60	10.8	12.2	23.9	22.4	23.15	1.4265	4.0	1.5	–3	Yes
100	3.4	3.6	7.4	8.6	8.00	0.7266	2.0	1.2	–1	Yes
140	2.3	2.4	1.1	1.2	1.15	0.4101	1.1	0.1	–1	Yes
200	1.8	1.9	0.5	0.5	0.50	0.3820	1.1	0.0	–1	Yes
									Precision Acceptance:	Acceptable

Note: (1) A special spreadsheet function is used to round values without any extra digits; therefore, the displayed value is the value in the cell.

FIG. X2.2 Precision Example Calculations: Method B—Triplicate and Single Test Precision Data

Designation: D7928 – 17

Standard Test Method for
Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis[1]

This standard is issued under the fixed designation D7928; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the quantitative determination of the distribution of particle sizes of the fine-grained portion of soils. The sedimentation or hydrometer method is used to determine the particle-size distribution (gradation) of the material that is finer than the No. 200 (75-µm) sieve and larger than about 0.2-µm. The test is performed on material passing the No. 10 (2.0-mm) or finer sieve and the results are presented as the mass percent finer versus the log of the particle diameter.

1.2 This method can be used to evaluate the fine-grained fraction of a soil with a wide range of particle sizes by combining the sedimentation results with a sieve analysis resulting in the complete gradation curve. The method can also be used when there are no coarse-grained particles or when the gradation of the coarse-grained material is not required or not needed.

NOTE 1—The significant digits recorded in this test method preclude obtaining the grain size distribution of materials that do not contain a significant amount of fines. For example, clean sands will not yield detectable amounts of silt and clay sized particles, and therefore should not be tested with this method. The minimum amount of fines in the sedimentation specimen is 15 g.

1.3 When combining the results of the sedimentation and sieve tests, the procedure for obtaining the material for the sedimentation analysis and calculations for combining the results will be provided by the more general test method, such as Test Methods D6913 (Note 2).

NOTE 2—Subcommittee D18.03 is currently developing a new test method "Test Method for Particle-Size Analysis of Soils Combining the Sieve and Sedimentation Techniques."

1.4 The terms "soil" and "material" are used interchangeably throughout the standard.

1.5 The sedimentation analysis is based on the concept that larger particles will fall through a fluid faster than smaller particles. Stokes' Law gives a governing equation used to determine the terminal velocity of a spherical particle falling through a stationary liquid. The terminal velocity is proportional to the square of the particle diameter. Therefore, particles are sorted by size in both time and position when settling in a container of liquid.

1.5.1 Stokes' Law has several assumptions which are: the particles are spherical and smooth; there is no interference between the particles; there is no difference between the current in the middle of the container and the sides; flow is laminar; and the particles have the same density. These assumptions are applied to soil particles of various shapes and sizes.

1.6 A hydrometer is used to measure the fluid density and determine the quantity of particles in suspension at a specific time and position. The density of the soil-water suspension depends upon the concentration and specific gravity of the soil particles and the amount of dispersant added. Each hydrometer measurement at an elapsed time is used to calculate the percentage of particles finer than the diameter given by Stokes' Law. The series of readings provide the distribution of material mass as a function of particle size.

1.7 This test method does not cover procurement of the sample or processing of the sample prior to obtaining the reduced sample in any detail. It is assumed that the sample is obtained using appropriate methods and is representative of site materials or conditions. It is also assumed that the sample has been processed such that the reduced sample accurately reflects the particle-size distribution (gradation) of this finer fraction of the material.

1.8 *Material Processing*—Material is tested in the moist or as-received state unless the material is received in an air-dried state. The moist preparation method shall be used to obtain a sedimentation test specimen from the reduced sample. Air-dried preparation is only allowed when the material is received in the air-dried state. The method to be used may be specified by the requesting authority; however, the moist preparation method shall be used for referee testing.

1.9 This test method is **not** applicable for the following soils:

1.9.1 Soils containing fibrous peat.

---

[1] This test method 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 May 1, 2017. Published May 2017. Originally approved in 2016. Last previous edition approved in 2016 as D7928 – 16$^{\varepsilon 1}$. DOI: 10.1520/D7928-17

1.9.2 Soils containing less than approximately 5 % of fine-grained material (Note 1).

1.9.3 Soils containing extraneous matter, such as organic solvents, oil, asphalt, wood fragments, or similar items (Note 3).

NOTE 3—If extraneous matter, such as wood, can be easily removed by hand, it is permissible to do so. However, there may be cases where the extraneous matter is being evaluated as part of the material and it should not be removed from the material.

1.9.4 Materials that contain cementitious components, such as cement, fly ash, lime, or other stabilization admixtures.

1.10 This test method may not produce consistent test results within and between laboratories for the following soils. To test these soils, this test method must be adapted and these adaptations documented.

1.10.1 Soils that flocculate during sedimentation. Such materials may need to be treated to reduce salinity or alter the pH of the suspension.

1.10.2 Friable soils in which processing changes the gradation of the soil. Typical examples of these soils are some residual soils, most weathered shales, and some weakly cemented soils.

1.10.3 Soils that will not readily disperse, such as glauconitic clays or some dried plastic clays.

1.11 Samples that are not soils, but are made up of particles may be tested using this method. The applicable sections above should be used in applying this standard.

1.12 *Units*—The values stated in SI units are to be regarded as standard. Except the sieve designations, they are identified using the "alternative" system in accordance with Practice E11, such as 3-in. and No. 200, instead of the "standard" of 75-mm and 75-µm, respectively. Reporting of test results in units other than SI shall not be regarded as non-conformance with this test method. The use of balances or scales recording pounds of mass (lbm) shall not be regarded as nonconformance with this standard.

1.13 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

1.13.1 The procedures used to specify how data are collected/recorded and calculated in the standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of these test methods to consider significant digits used in analysis methods for engineering data.

1.14 *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.*

1.15 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1140 Test Methods for Determining the Amount of Material Finer than 75-µm (No. 200) Sieve in Soils by Washing
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220/D4220M Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D6026 Practice for Using Significant Digits in Geotechnical Data
D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E100 Specification for ASTM Hydrometers
E126 Test Method for Inspection, Calibration, and Verification of ASTM Hydrometers

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *reduced sample, n*—the minus ⅜-in. (9.5-mm) sieve or finer material that has been separated from the sample and then worked to reduce the mass while still having sufficient quantity to meet the minimum mass requirements of Table 1.

3.2.2 *sample, n*—material collected without limitation on the total mass or size range of particles meeting the minimum mass requirements provided in Table 1.

3.2.3 *sedimentation sample, n*—the minus No. 10 (2.0-mm) or finer material that is separated from the reduced sample

---

[2] 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.

TABLE 1 Minimum Dry Mass Requirements

Maximum Particle Size of Material (99% or more passing)		Minimum Dry Mass	Comments on separating and splitting requirements for sample reduction
Sieve Designation	Particle Size, mm		
6 in.	152.4	500 kg	Several separations
3 in.	76.2	70 kg	Several separations
1 in.	25.4	3 kg	At least one separation
¾ in.	19.1	1.3 kg	Most likely one separation
⅜ in.	9.5	165 g	Separation for sedimentation analysis
No. 10	2.0	50 g	Splitting only

using the separation sieve from which the sedimentation specimen and water content are obtained.

3.2.4 *sedimentation specimen, n*—the material obtained from the sedimentation sample having a maximum particle-size no greater than the No. 10 (2.0-mm) sieve to be used in the sedimentation test and in sufficient quantity to satisfy the minimum mass requirements of Table 1.

3.2.5 *separation sieve, n*—the No. 10 (2.0-mm) sieve or finer (Note 4) used to separate the reduced sample to obtain the material for the sedimentation sample.

NOTE 4—The methodology for using a sieve finer than the No. 10 (2.0 mm) is not defined in this standard. The methodology used to obtain a representative sample using a sieve finer than the No. 10 (2.0 mm) is not the same as obtaining the representative sample using the No. 10 (2.0 mm) sieve as presented in this standard. Additional effort or steps are necessary to make sure the material passing the finer sieve adequately represents the sample. Such additional effort or steps should be documented if using a sieve finer than the No. 10 (2.0 mm) sieve to obtain the sedimentation specimen.

4. Summary of Test Method

4.1 This test method is used to determine the particle-size distribution (gradation) of material finer than the No. 200 (75-µm) sieve as a percentage of the mass used in the sedimentation test.

4.2 When the source material contains particles larger than the ⅜-in. (9.5-mm) sieve, a reduced sample passing the ⅜-in. (9.5-mm) sieve shall be obtained using techniques presented in Test Methods D6913 or another standard. This reduced sample shall meet the minimum mass requirements in Table 1 for the ⅜-in. (9.5-mm) sieve. The material is processed using the moist (referee) preparation method unless the material is received in the air-dried state.

4.3 The entire reduced sample is separated using the separation sieve. The sedimentation sample is then split to obtain the appropriate mass for the sedimentation test specimen and a water content test specimen.

4.4 The sedimentation test specimen is mixed with a dispersing agent and test water. The slurry is allowed to condition and is then thoroughly mixed and placed in a cylinder with additional test water. Readings are taken with a hydrometer and thermometer over specific time intervals.

4.5 The mass of particles passing specified particle diameters are calculated and recorded. The results produce a tabulation of particle size versus percent passing that can be graphically presented as a gradation curve. The plot is typically expressed as percent passing/finer than the separation sieve size versus the log of the particle size in millimetres.

5. Significance and Use

5.1 Particle-size distribution (gradation) is a descriptive term referring to the proportions by dry mass of a soil distributed over specified particle-size ranges. The gradation curve generated using this method yields the amount of silt and clay size fractions present in the soil based on size definitions, not mineralogy or Atterberg limit data.

5.2 Determination of the clay size fraction, which is material finer than 2 µm, is used in combination with the Plasticity Index (Test Methods D4318) to compute the activity, which provides an indication of the mineralogy of the clay fraction.

5.3 The gradation of the silt and clay size fractions is an important factor in determining the susceptibility of fine-grained soils to frost action.

5.4 The gradation of a soil is an indicator of engineering properties. Hydraulic conductivity, compressibility, and shear strength are related to the gradation of the soil. However, engineering behavior is dependent upon many factors, such as effective stress, mineral type, structure, plasticity, and geological origin, and cannot be based solely upon gradation.

5.5 Some types of soil require special treatment in order to correctly determine the particle sizes. For example, chemical cementing agents can bond clay particles together and should be treated in an effort to remove the cementing agents when possible. Hydrogen peroxide and moderate heat can digest organics. Hydrochloric acid can remove carbonates by washing and Dithionite-Citrate-Bicarbonate extraction can be used to remove iron oxides. Leaching with test water can be used to reduce salt concentration. All of these treatments, however, add significant time and effort when performing the sedimentation test and are allowable but outside the scope of this test method.

5.6 The size limits of the sedimentation test are from about 100 µm to about 1 µm. The length of time required to obtain a stable initial reading on the hydrometer controls the upper range of results, and the test duration controls the lower range.

5.7 The shape and density of the grains are important to the results. Stokes' Law is assumed to be valid for spherical particles even though fine silt- and clay-sized particles are more likely to be plate-shaped and have greater mineral densities than larger particles.

NOTE 5—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 D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Hydrometer*—ASTM hydrometer type 151H or 152H. These hydrometers shall conform to the requirements in Specification E100. See Annex A1.

6.2 *Sedimentation Cylinder*—At least two glass cylinders essentially having a height of about 457 mm, an inside diameter between 55 and 64 mm, and a capacity of 1,000 mL. The cylinders shall have an indication mark at 1,000 ± 5 mL. One cylinder is used for the soil suspension and the other one can be used as the control cylinder or the wash cylinder. The control cylinder shall have the same amount of dispersant as the soil suspension cylinder. See Annex A1.

6.3 *Separation Sieve*—No. 10 (2-mm) or finer sieve used to separate the reduced sample. This sieve is subjected to rough operation and shall not be used for quantitative grain size analysis.

6.4 *Thermometric Device*—A thermometric device capable of measuring the temperature range within which the test is being performed readable to 0.5°C or better and having an accuracy of at least ±0.5°C. The thermometric device must be capable of being immersed in the suspension and reference solutions to a depth ranging between 25 and 80 mm. Full immersion, also known as complete or total immersion thermometers, shall not be used. The thermometric device shall be standardized by comparison to a nationally or internationally traceable thermometric device and shall include at least one temperature reading within the range of testing. The thermometric device shall be standardized at least once every twelve months. The same thermometric device shall be used for all measurements.

6.5 *Timing Device*—A clock, stopwatch, digital timer, or comparable device readable to one second or better.

6.6 *Balance*—Balances shall conform to the requirements of Specification D4753.

6.6.1 To determine the mass of the specimen, the balance shall have readability without estimation of 0.01 g. The capacity of this balance will need to exceed the mass of the container plus soil used to contain the soil suspension after the completion of the sedimentation test. In general, a balance with a minimum capacity of 1,800 g is sufficient.

6.7 *Drying Oven*—Vented, thermostatically controlled oven capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber. These requirements typically require the use of a forced-draft oven.

6.8 *Plate*—A clean, nonporous, smooth, solid surface that is large enough to pile and split about 500 g of material. The surface shall not be made of any type of paper product.

6.9 *Specimen-Mixing Container*—A 250-mL glass beaker or equivalent inert container with enough capacity to hold the specimen, the test water, and dispersant.

6.10 *Temperature Maintaining Device*—Unless otherwise specified by the requesting agency, the standard test temperature shall be in the range of 22 ± 5°C. In addition, the temperature of the soil suspension shall not vary more than ±2°C. Normally, this temperature maintenance is accomplished by performing the test in a room with a relatively constant temperature. If such a room is not available, the cylinders shall be placed in an automatically temperature controlled insulated chamber or water bath that maintains a temperature within the tolerance specified above.

6.11 *Soil Suspension Oven-Drying Container*—A container having smooth walls and capable of holding approximately 1.5-L of the soil suspension. This container shall have a tight fitting lid or fit into a desiccator, to prevent moisture gain during cooling of the oven-dried specimen.

6.12 *Dispersion Apparatus*—Use one of the following devices to disperse the specimen; however for referee testing, the stirring apparatus shall be used.

6.12.1 *Stirring Apparatus (Referee)*—A mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a minimum speed of 10,000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate between 19.0-mm and 37.5-mm above the bottom of the dispersion cup (Note 6).

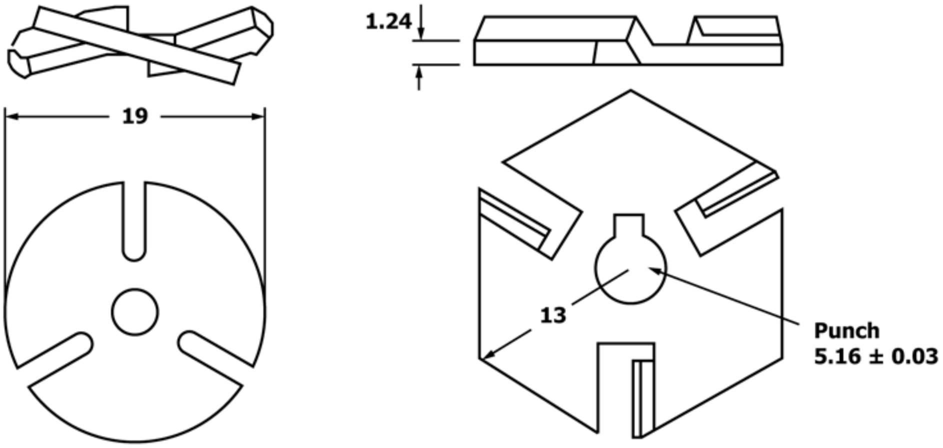
NOTE 6—The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the requirements established by the inch-pound apparatus.

6.12.1.1 *Dispersion Cup*—A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed. The cup shall contain two sets of three long baffle rods and two sets of three short baffle rods rigidly mounted to the interior sides of the cup. This cup is used with the stirring apparatus.

6.12.2 *Air Jet Dispersion Device (Optional)*—A tube type or other comparable device that uses compressed air to disperse the slurry (Note 7). The device requires an air source capable of providing up to 0.0024 m^3/s of air to operate the device, such that pressures of 69 and 172 kPa can be achieved. The device shall be fitted with a pressure gauge on the line between the device and the air source. Water may condense in the lines when not in use and this water must be removed. There are two ways to remove the water: use of a water trap or purging the lines before use. If a water trap is used, it shall be installed on the air line in such a manner to prevent condensed water from entering the slurry. This device shall not be used in referee testing.

NOTE 7—Use of this device or others, causes differing amounts of dispersion and should be used with caution. Information on how to appropriately use this device should be obtained from the manufacturer. 0.0024 m^3/s is equivalent to 5 ft^3/min. The device typically needs at least 0.0009 m^3/s (2 ft^3/min) to operate and therefore, some small air compressors are not capable of supplying sufficient air to operate the device.

6.13 *Agitator (Optional/Referee)*—A hand-held device to mix the soil suspension in the sedimentation cylinder prior to testing, as shown in Fig. 3. The agitator must not have any type of metal, such as a screw head, protruding from the bottom of the disk. To aid in strengthening the connection between the rod and the disk, a smaller disk (about 25 mm or less) having similar thickness and material as the larger disk, may be



Type A **Type B**

Dimensional Equivalents[A]

mm	in.
19	0.75
13	0.51
5.16 ± 0.03	0.203 ± 0.001
1.24	0.049 (No. 18 BW Ga.)

Note: All dimensions are shown in millimetres unless otherwise noted.

[A] The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the technical requirements established by the inch-pound apparatus.

FIG. 1 Detail of Stirring Paddles

inserted on top of and in the center of the larger disk. This device shall be used for referee testing.

6.14 *Agitation of the Soil Slurry*—Any of the following items may be used to break up the soil aggregations as described in 11.1:

6.14.1 *Erlenmeyer Flask*—A glass flask having a capacity between 250-mL and 500-mL.

6.14.2 *Dispersion Shaker*—A platform, wrist action or similar type shaker having a gyratory, orbital, reciprocating, or similar motion to assist in the dispersion process by continuously agitating the soaking soil.

6.14.3 *Ultrasonic Water Bath*—The ultrasonic water bath must be large enough to hold a beaker or flask containing the soil slurry to be agitated for use in the sedimentation test. The water level in the bath should be equal to or higher than the water level in the specimen container.

6.15 *Desiccator (Optional)*—A desiccant containing device of suitable size used to prevent moisture gain during cooling of the oven-dried specimen.

6.16 *Mortar and Rubber-Covered Pestle (Optional)*—Apparatus suitable for breaking up aggregations of air-dried soil particles without breaking individual particles.

6.17 *Miscellaneous Items*—Items such as a wash/rinse bottle (squirt bottle), rubber scraper, spatula, and stirring rod may be useful.

7. Reagents and Materials

7.1 *Sodium Hexametaphosphate* $(NaPO_3)_6$—Also referred to as sodium metaphosphate is the dispersion agent (deflocculant) required to prevent the fine particles in suspension from coalescing or flocculating (Note 8). Consult the Safety Data Sheet (SDS) for specific information regarding this chemical.

7.2 *Isopropyl Alcohol*—Also referred to as isopropanol alcohol or rubbing alcohol is used as a foam inhibitor. Commercially available in concentrations ranging from 70 % to 99 %.

7.3 *Test Water*—Distilled or demineralized water is the only permissible test fluid. The use of tap water is not permitted.

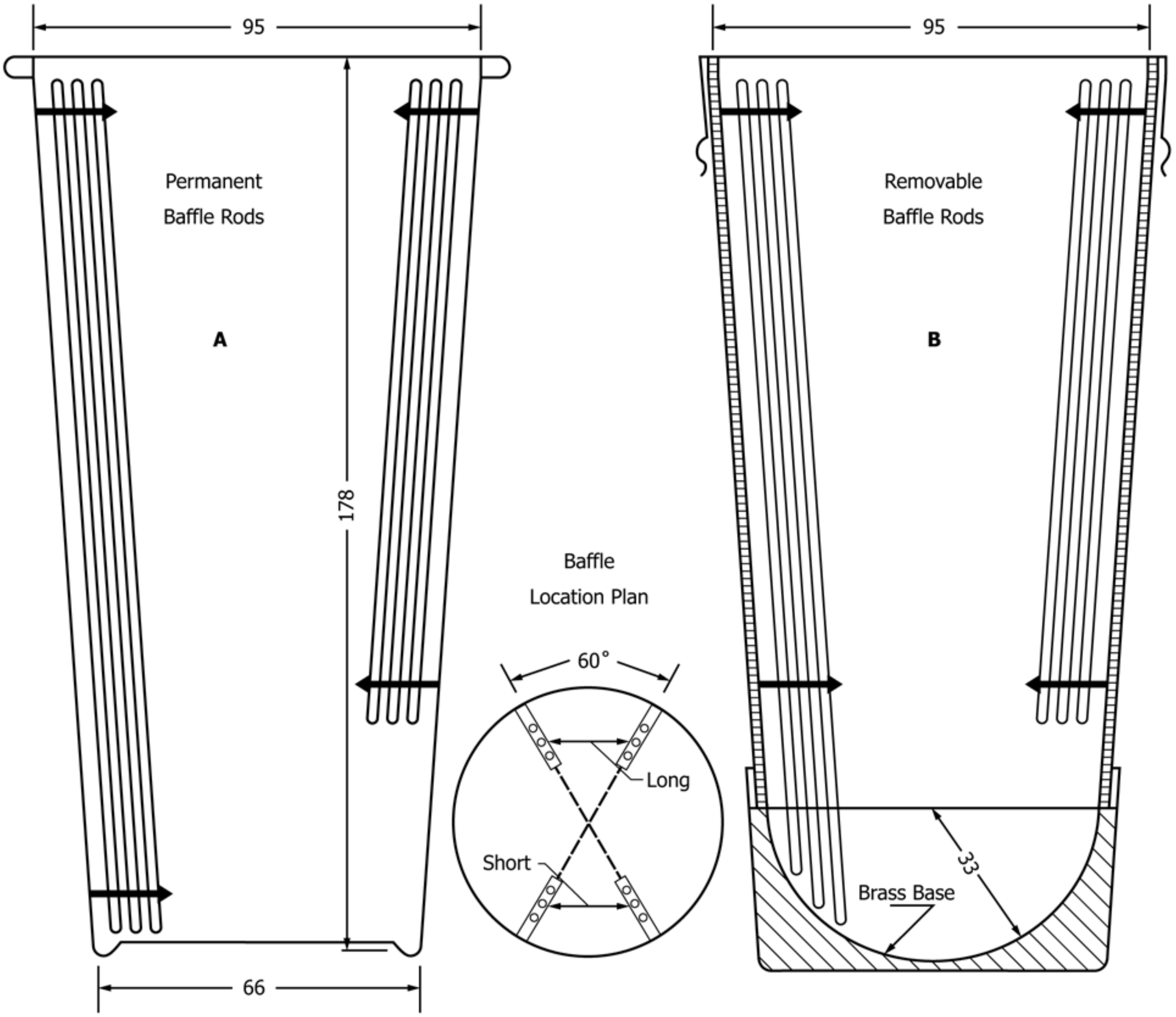
NOTE 8—Fine-grained soils requiring the use of a dispersant are those that do not readily slake in water, such as some highly plastic clays and most tropical soils. Typically, 5 grams per test of dispersant is used to prevent flocculation and is added directly to the soil, such that the concentration will equal 5 g/L in the final soil suspension volume. The chemical formula for the dispersant shown above is approximate.

8. Sampling

8.1 *General*—This test method does not address, in any detail, procurement of the sample. It is assumed the sample is obtained using appropriate methods and is representative of the material under evaluation. However, the testing agency shall preserve all samples in accordance with Practice D4220/D4220M, Group B, except if the as-received sample does not meet those requirements. In which case, the water content of the material does not have to be maintained.

8.2 Where data from this test are to be used for correlation with other laboratory or field test data, use the same material as used for these tests where possible and as much is practical.

8.3 The sample can be from a variety of sources and contain a wide range of particle sizes. Typically, samples for particle-size analysis are obtained from the following sources: large bags or buckets, small bags, jar samples, tube samples, or



Dimensional Equivalents[A]	
mm	in.
33	1.30
66	2.60
95	3.75
178	7.01

Note: All dimensions are shown in millimetres unless otherwise noted.

[A] The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the technical requirements established by the inch-pound apparatus.

FIG. 2 Dispersion Cup

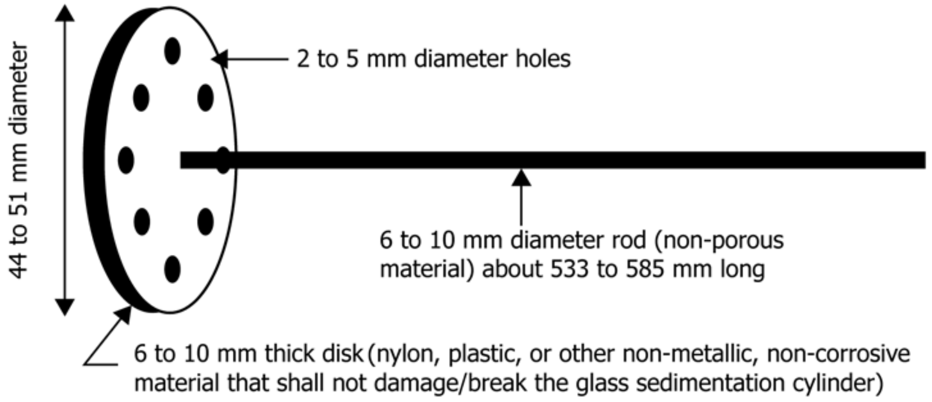
specimens from other tests, such as consolidation, hydraulic conductivity or strength tests. In some cases, such as compaction testing, prior testing may have caused a reduction in particle sizes; therefore, it may be required to obtain a sample of the original material, the degraded sample, or both. Test Methods D6913, Section 9, gives additional information regarding sampling from the different sources.

8.3.1 Preserve the sample at its original moisture condition unless excluded above, and at no time shall the sample be allowed to undergo undesirable temperature changes such as freezing or heating.

8.4 When the sample contains particles larger than the ⅜-in. (9.5-mm) sieve, it shall be processed to obtain the reduced sample. If particle-size separation is necessary, process the sample to meet this requirement using the separation procedures provided in Test Methods D6913.

8.4.1 The reduced sample shall have a maximum particle size that passes through the ⅜-in. (9.5-mm) sieve.

8.4.2 The mass of the reduced sample shall meet or exceed the mass requirements given in Table 1.



Dimensional Equivalents[A]	
mm	in.
2 to 5	0.0781 to 0.200
6 to 10	0.250 to 0.375
533 to 585	22 ± 1
44 to 51	1.75 to 2.00

Note: All dimensions are shown in millimetres unless otherwise noted.

[A] The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the technical requirements established by the inch-pound apparatus.

FIG. 3 Detail of Agitator

8.4.3 Preserve the original moisture condition of the reduced sample, and at no time shall the reduced sample be allowed to undergo undesirable temperature changes such as freezing or heating.

9. Preparation of the Test Specimen

9.1 *Specimen Procurement*—This standard presents two preparation methods to obtain the sedimentation specimen from the reduced sample: moist and air-dried. In these preparation methods, moist and air-dried refers to the condition of the material or sample as it is being reduced to an appropriate particle size and mass. The test shall not be performed on oven-dried material. The moist preparation method shall be used for referee testing and for samples not received in the air-dried state. The air-dried method shall only be used on materials received in the air-dried state (Note 9). Since some fine-grained, air-dried soils aggregate, a mortar and rubber covered pestle is used to break up aggregations. Care must be taken to avoid disintegration or reduction of individual particles. Use only enough force as necessary to break up the aggregations without destroying the individual particles. Additional guidance for splitting material to obtain a representative specimen using a splitter, quartering, or moist stockpile sampling is given in Test Methods D6913, Annex A2.

NOTE 9—Air drying causes irreversible changes to the clay particles that cause permanent flocculations and decreases the fine fraction.[3]

9.2 *Moist Preparation (Referee)*—This preparation method shall be used for materials not received in the air-dried state. This method is especially important for any soil whose properties are altered due to drying such as, most organic soils, many highly plastic fine-grained soils, tropical soils and soils containing halloysite. The material is thoroughly mixed to obtain a uniform reduced sample. Intact fine-grained samples should be chopped/reduced into small pieces, less than approximately 13 mm, and mixed to make uniform. Test water can be added to assist in making a uniform sample. There is no need to process the fine-grained materials through a sieve.

9.3 *Air-Dried Preparation*—This preparation method shall only be used if the sample is received in the dried condition. In order to obtain a uniform reduced sample, the sample is blended at room temperature.

9.4 If the reduced sample contains particles which are larger than the No. 10 (2.0-mm) sieve, the material shall be separated using a No. 10 (2.0-mm) or finer sieve. Process the entire reduced sample over the No. 10 (2.0-mm) or finer sieve using a rubber scraper and, if needed, test water to aid in working the material through the sieve. Check that the material retained on the sieve does not contain aggregations of finer particles. Any aggregations should be broken and passed through the sieve. It is not necessary that the separation be totally complete but the material passing the sieve shall be representative. The material passing the separation sieve is termed the sedimentation sample and shall meet the minimum mass requirement of Table 1. Record the separation sieve size that is used to separate the sample.

9.5 Estimate the amount of moist mass needed for the sedimentation test using the equation (Note 10):

$$M_{mest} = H_c \times \left(\frac{100}{\%est}\right) \times \left(1 + \left(\frac{w_{cest}}{100}\right)\right) \quad (1)$$

where:

M_{mest} = estimated moist mass, nearest 1 g,

---

[3] Sridharan, A., Jose, B.T., and Abraham, B.M., Technical Note on “Determination of Clay Size Fraction of Marine Clays,” *Geotechnical Testing Journal*, GTJODJ, Vol. 14, No. 1, March 1991, pp. 103-107.

H_c = hydromter capacity, g (either 45 for 151H or 55 for 152H),
$\%est$ = estimated percentage of material passing the No. 200 (75-µm) sieve, nearest 1 %, and
w_{cest} = estimated water content, nearest 1 %.

NOTE 10—The mass of the sedimentation test specimen should be selected based on the amount of material that will be in suspension at the time of the first reading. The capacity of the 152H hydrometer is about 55 g of dry soil and the capacity of the 151H is about 45 g. The wet mass should be adjusted to account for the water content and the fraction of particles larger than the No. 200 (75-µm) sieve. For example, if the water content is estimated at 20 %, using a 151H hydrometer, and an estimated percent passing the No. 200 (75-µm) sieve of 95 %, the estimated moist mass needed is 57 g.

9.6 If the sedimentation sample contains sufficient material, then split or quarter the sedimentation sample into at least two portions: one for the water content determination and one for the sedimentation test. The water content specimen shall contain 50 ± 10 g of material.

9.7 If the sedimentation sample has limited material, reduce the mass to obtain the sedimentation specimen. Do not obtain a water content specimen. Obtain the dry mass, M_d, of the sedimentation specimen at the end of the test as discussed in 11.12 and calculated in 12.1.2.

NOTE 11—If there is enough material after splitting/quartering to obtain the necessary masses for both the sedimentation and water content specimens, the sedimentation sample is considered to have sufficient material. If there is not enough material to obtain both the necessary masses of the specimens, the sedimentation sample is considered to have limited material.

9.8 Record the mass of the moist soil, M_m, used for the sedimentation test to the nearest 0.01 g.

9.9 Place the sedimentation specimen in the specimen-mixing container and record the identification of the specimen-mixing container.

9.10 If sufficient material is available, immediately use the other specimen for determination of the water content in accordance with Test Methods D2216, and record the water content, w_c, to the nearest 0.1 %.

10. Verification/Preparation of Apparatus

10.1 *Hydrometer*—Check and record the dimensions of the 151H or 152H hydrometers as presented in Annex A1 in accordance with the interval listed in the Annex. The hydrometer shall be free of cracks and chips, which can compromise the integrity of the hydrometer. The body and stem of a hydrometer seldom change over time, unless they have been subjected to corrosive materials or have been damaged, that is, chipped or cracked. They only need to be checked before use or after damage has been suspected or seen. Since it is possible for the paper scale inside the hydrometer stem to slide down, the length of the stem above and below the top and bottom graduations, respectively, as well as the hydrometer reading in the test water, shall be checked and documented according to the interval presented in Annex A1 to make sure the scale has remained in its proper place. If the scale has moved, the hydrometer shall be replaced.

10.1.1 *Hydrometer Readings*—Hydrometer readings are taken to the nearest ¼ division (Note 12). Reading the hydrometer can be difficult. A properly placed hydrometer should neither bob nor rotate appreciably when released in the soil suspension. It is important for the stem to be dry and clean when inserting it into the soil suspension. If the stem is wet above the reading point it will add mass to the hydrometer causing the reading to be too low. If the stem is not clean, variations in the meniscus rise will result. In this application, the hydrometers are always read at the top of the meniscus for the reason stated in 10.3.

NOTE 12—Reading the 152H hydrometer to the nearest ¼ division during the first 5 to 8 minutes of the test can be difficult. During that time it is acceptable to read the 152H hydrometer to the nearest ½ division.

10.1.2 To insert the hydrometer correctly do the following: First, make sure the stem is dry. Then, gently hold it by the stem with one or both hands and slowly lower it to the depth at which it just floats. This insertion process should take between 5 to 15 seconds.

10.2 *Temperature-Density Correction*—During a test, the suspension fluid density changes, therefore calculations for the quantity of particles in suspension must account for fluid density changes due to temperature, presence of dispersant and the meniscus rise. The temperature-density correction is shifting the hydrometer scale, which is factory set for distilled water at 20°C. There are two ways to determine this correction: take companion measurements in a control cylinder filled with the reference solution during the testing or generate a reusable, calibration relationship. Both options require the use of a reference solution composed of test water and the same amount of dispersant used in the sedimentation test cylinder. The meniscus correction is automatically accounted for in the temperature-density correction for both options by consistently reading the hydrometer at the top of the meniscus as described in 10.3.

10.2.1 *Reference Solution*—The reference solution shall be prepared with the same amount of dispersant as the soil suspension. Fill a control cylinder to the 1,000 mL mark with a mixture of test water and the same amount of dispersant used in the soil suspension cylinder. The test water and dispersant shall be well mixed such that no visible crystals can be seen and the reference solution shall be agitated to make sure the dispersant is adequately mixed throughout the control cylinder.

10.2.1.1 *Companion Measurements*—Use a control cylinder filled with the reference solution in conjunction with the soil suspension cylinder to obtain the correction. Position the control cylinder in the same temperature controlled location as the test cylinders so that all cylinders are at or near the same temperature. For each hydrometer and temperature reading taken in the soil suspension cylinder, take a corresponding hydrometer reading and temperature reading in the control cylinder. However, it is permissible for one control cylinder hydrometer reading taken at the start of the sedimentation test to be used for the initial series of time readings in the soil suspension up to 30 minutes. It is also permissible for one control cylinder temperature reading taken at the start of the sedimentation test to be used for the initial series of time readings in the soil suspension up to the first 30 minutes if the temperature changes in the soil suspension cylinder vary less than 0.5°C between each temperature reading. Record the elapsed time and the hydrometer and temperature readings of the control cylinder on the data sheet(s) only when measured (Note 13).

NOTE 13—Readings taken in one control cylinder may be used for multiple test cylinders. Therefore, if the hydrometer and temperature readings in the control cylinder are only taken once during the first 30 minutes of the test, only that reading is recorded on each of the data sheet(s) to which it applies. These measured readings are not to be written in for the other times during the first 30 minutes when a measurement was not actually determined.

10.2.2 *Calibration Relationship*—This option generates a general calibration relationship between the hydrometer reading of a control cylinder filled with the reference solution and the temperature, which eliminates the need for companion measurements during the test. A temperature-based general calibration relationship is required and established for each hydrometer. A sedimentation cylinder is filled to the 1,000 mL mark with test water with the same amount of dispersant used in the soil suspension. Be sure the solution is thoroughly mixed and the temperature is allowed to equilibrate. Then insert the hydrometer as described in 10.1.2. Take the reading at the top of the meniscus and record this reading and the temperature of the solution. Rinse the hydrometer well with test water between readings and dry it prior to taking the next reading. Increase/Decrease the temperature of the cylinder, allow it to come to temperature equilibrium and repeat the measurement process. Take at least five different hydrometer and temperature readings within the range of temperatures expected during the sedimentation test. Calculate the constant A or B as discussed below.

10.2.2.1 The 151H hydrometer measures the specific gravity of the fluid relative to distilled water at 20°C. The calibration measurements are used to compute the constant A in the following equation. The standard deviation of the five measurements shall be less than 0.0005. The average value of A is used when computing the temperature-density correction.

$$A = R_{151,t} + (7.784 \times 10^{-6} \times T_t) + (4.959 \times 10^{-6} \times T_t^2) \tag{2}$$

where:

A = average specific gravity shift (151H hydrometer), nearest 0.0001,
$R_{151,t}$ = 151H specific gravity hydrometer at reading, t, in reference solution, readable to 0.00025 or better,
T = temperature at reading, t, readable to 0.5°C or better, and
t = subscript indicating the reading number during calibration.

10.2.2.2 The 152H hydrometer measures the mass of particles (specific gravity of 2.65) in a suspension of distilled water at 20°C. The temperature-density correction provides the offset mass reading for the hydrometer for a specific temperature and dispersant concentration. The calibration measurements are used to compute the constant B in the following equation. The standard deviation of the 5 measurements shall be less than 0.5 g/L. The average value of B is used when computing the temperature-density correction.

$$B = R_{152,t} + (1.248 \times 10^{-2} \times T_t) + (7.950 \times 10^{-3} \times T_t^2) \tag{3}$$

where:

B = average mass reading shift (152H hydrometer), nearest 0.1,
$R_{152,t}$ = mass in reference solution hydrometer at reading, t, readable to 0.25 g/L or better,
T = temperature at reading, t, readable to 0.5°C or better, and
t = subscript indicating the reading number during calibration.

NOTE 14—The equations relating the hydrometer readings to temperature are based on the same water density-temperature expression as used in Test Methods D854. For the 151H specific gravity hydrometer, the constants in the water density-temperature equation from Test Methods D854 are divided by the density of water at 20°C (0.99821 g/mL). For the 152H mass in suspension hydrometer, the constants are multiplied by 1606 setting the scale to read mass of solids in solution for a particle specific gravity of 2.65.

10.3 *Meniscus Correction*—Hydrometers are designed to be read at the fluid surface, however, the fluid is wetting to the glass such that the soil suspension will rise up the hydrometer making a reading at the fluid surface impossible at times. It is common practice to read the hydrometer at the top of the meniscus and it must be taken there even when it is possible to see through the soil suspension. The meniscus rise has a small impact on the effective depth determination since the reading is taken slightly above the surface of the suspension. This rise causes a change to the third significant digit in the computed particle size. The meniscus correction is performed before initial use of the hydrometer and after damage has been suspected or noticed.

10.3.1 The meniscus correction, C_m, as shown in Fig. 4, is determined by inserting the hydrometer with a clean and dry stem and without bobbing into the test water with the proper amount of dispersant. The reading at the top of the meniscus and the reading where the plane of water surface intersects the stem are recorded. The difference between these two readings is the meniscus correction, C_m. In accordance with Test Method E126, the latter reading shall be obtained using the following guidance. Observe a point slightly below the plane of the water surface and raise the line of vision until this surface, seen in an ellipse, becomes a straight line. The point where this line cuts the hydrometer scale is the hydrometer reading. Holding a white card behind the cylinder just below the water level will improve the visibility of the surface. The

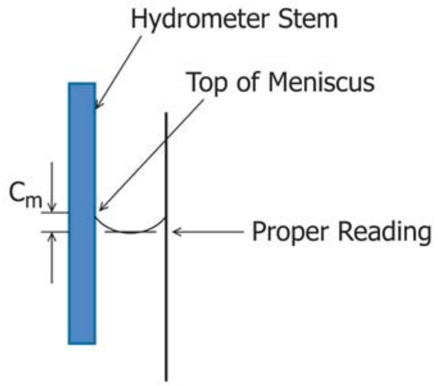


FIG. 4 Meniscus Correction Diagram

hydrometer readings shall be recorded to the nearest ¼ division. The meniscus correction is a positive number for either hydrometer used.

10.4 *Effective Depth*—The effective depth, also referred to as "true depth," is used in the calculation of the particle fall distance for each reading. The effective depth is defined as the center of (volume) buoyancy of the hydrometer to the surface of the soil suspension. The equation to calculate the effective depth when the hydrometer is inserted and removed between readings requires certain dimensional measurements in order to do the calculation. Refer to Fig. 5.

10.4.1 Determine and record the volume of the hydrometer bulb, V_{hb}, to the nearest 1 cm^3 using the procedure given in Annex A1.3.4. The bulb includes everything from the bottom tip up to the base of the stem.

10.4.2 Determine and mark the center of (volume) buoyancy, c_b, using the procedure given in A1.3.5.

10.4.3 Measure the distance between the center of (volume) buoyancy, c_b, and the maximum hydrometer reading H_{r2}, as well as the minimum hydrometer reading, H_{r1}. Record both values to the nearest 0.1 cm. Refer to Fig. 5.

10.4.4 Measure and record the inside cross-sectional area of the sedimentation cylinder, A_c, to the nearest 0.1 cm^2 using the procedure given in A1.4.2.1.

10.5 *Sedimentation Cylinder*—Check and record the dimensions of the sedimentation cylinders as presented in Annex A1 in accordance with the interval presented in Annex A1.

10.6 *Sieves*—See Practice E11 for the verification requirements of the sieves used in this test method.

10.7 *Miscellaneous*—The ancillary equipment used in conjunction with these test methods shall be calibrated/verified/checked according the intervals listed in Practice D3740 and performed in accordance with their applicable standards.

11. Procedure

11.1 Add 5.0 ± 0.1 g of sodium hexametaphosphate to the sedimentation specimen in the specimen-mixing container obtained in 9.9 or dissolve this amount of dispersant in 100 mL of test water and add it to the sedimentation specimen. Record to the nearest 0.01 g the actual amount of dispersant, M_{disp}, placed in the container or dissolved in the test water. If added directly to the sedimentation specimen, add at least 100 mL of test water to the specimen and dispersant to form a slurry of milkshake consistency. The amount of test water to be added during this step should be sufficient enough only to facilitate the process of breaking apart the soil aggregations. Mix the contents with a spatula or similar device until all of the soil aggregations are broken-up (Note 15).

NOTE 15—If hand mixing is not efficient, use a 250 to 500 mL Erlenmeyer flask along with either a wrist or orbital dispersion (mechanical) shaker to vigorously agitate the soil slurry in a minimum of 150 mL of test water for a few hours or until all the soil aggregations are broken-up. Be aware the dispersion cup has a capacity of about 400 mL and the stirring apparatus is only efficient in dispersing soil aggregations that will pass between the baffle rods. An ultrasonic water bath, along with the flask, may also be used to agitate the slurry.

11.2 Prior to the overnight conditioning period, disperse the slurry using either the stirring apparatus or an air jet device.

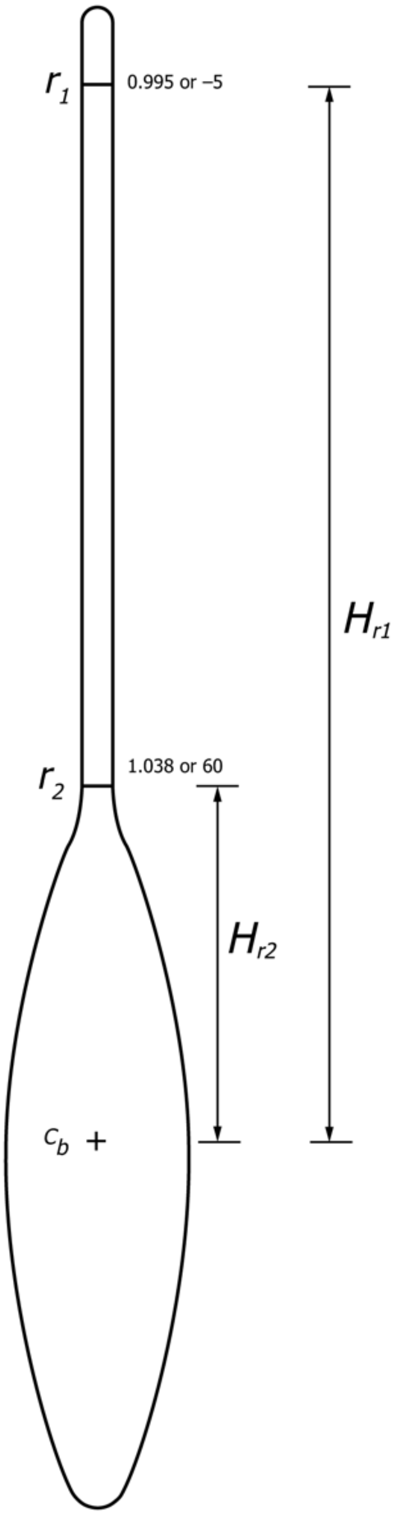


FIG. 5 Effective Depth Dimensional Measurements

11.2.1 If using the stirring apparatus, transfer the slurry to the dispersion cup. Use a wash/rinse bottle filled with test water to aid in the transfer and make sure all of the slurry has been transferred to the dispersion cup. Add additional test water as necessary such that the cup is half full, then use the stirring apparatus to blend the soil for about 1 minute.

11.2.1.1 Transfer all the dispersed slurry into the sedimentation cylinder. Use the wash/rinse bottle filled with test water as needed to make sure all of the slurry is transferred to the cylinder. Add test water to the sedimentation cylinder to bring the bottom of the meniscus of the slurry to the 1,000 mL ± 1 mm mark. Proceed to 11.3.

11.2.2 If using the tube type air jet device, transfer the slurry to the sedimentation cylinder. Use a wash/rinse bottle filled with test water to aid in the transfer and make sure all of the slurry has been transferred to the cylinder. Add additional test water as necessary to bring the volume to no more than 250 mL in the sedimentation cylinder.

11.2.2.1 Before placing the device into the cylinder, slowly allow air to flow until the gauge reads 7 kPa. This initial pressure is needed to prevent the slurry from entering the air jets when the device is inserted into the cylinder and to remove any water that has condensed in the lines. Then, slowly lower the device into the slurry. Make sure the rubber stopper is securely in place at the top of the cylinder to prevent the slurry from being ejected from the cylinder.

11.2.2.2 For clayey soils increase the pressure to 172 kPa and for sandy soils increase the pressure to 69 kPa. Once the pressure is reached, disperse the slurry for five minutes. At the end of five minutes, reduce the pressure to 7 kPa and lift the air jets out of the slurry and wash any slurry remaining on the device back into the cylinder. Once the device is washed off, turn off the air flow to the device and add test water to the sedimentation cylinder to bring the bottom of the meniscus of the slurry to the 1,000 mL ± 1 mm mark. Proceed to 11.3.

11.3 Mix the slurry using the agitator (referee) or the tipping method (Note 16). The agitator device is the preferred/referee method for mixing. Check for the presence of foam on top of the slurry after mixing. If a significant amount of foam is present, it may be necessary to reduce the foam using isopropyl alcohol just prior to the start of testing (See 11.7.1).

11.3.1 To use the agitator, insert the paddle to the lower ¼ of the cylinder. Stroke the agitator at a rate of about one cycle per second over a distance of several centimeters to dislodge any material stuck to the bottom of the cylinder. After the material is dislodged, the agitator should be rapidly moved downwards until the paddle almost comes into contact with the bottom of the cylinder and then upwards with a slower motion. The downward stroke should take about one to two seconds while the upward stroke should take about two to three seconds. As this process is repeated, the elevation of the starting position of the agitation cycle is raised until the bottom of the agitator is significantly above the mid-height of the soil suspension. Keep the paddle submerged at all times during mixing. Mix for about one minute or until the suspension appears uniform.

11.3.2 To use the tipping method, first place a rubber stopper in the open end of the cylinder or use the palm of the hand to cover the opening. Then turn the cylinder upside down and back for a period of one minute to complete the agitation of the slurry (Note 17). Using the cylinder tipping method is not very efficient and tipping for more than one minute will typically be required when testing highly plastic clays. This method of agitation may leave some soil aggregations. Use of the agitator is greatly encouraged.

NOTE 16—When using the tipping method, there will likely be some soil particles remaining on the rubber stopper or hand and on the sides of the sedimentation cylinder above the 1,000 mL mark. Be careful not to lose much material by scraping the material adhering to the rubber stopper or hand off onto the rim of the cylinder. Do not rinse these particles back into the cylinder. The minor loss of mass (~0.02 g or less, if care is taken) is less critical with respect to the calculations than the addition of water (~5 mL) to the cylinder.

NOTE 17—The number of turns during this minute should be approximately 60 counting the turn upside down and back as two turns. Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorously shaking of the cylinder while it is inverted.

11.4 If using a companion measurement to obtain the temperature-density correction, prepare the reference solution in a control cylinder by dissolving the same amount (5.0 ± 0.1 g) of sodium hexametaphosphate as used in the soil suspension cylinder in test water. Add test water to the sedimentation cylinder to bring the bottom of the meniscus of the solution to the 1,000 mL ± 1 mm mark.

11.5 Cover the cylinder(s) to prevent evaporation and allow the cylinder(s) to sit overnight either in a temperature controlled insulated chamber or water bath or in an area of relatively constant temperature. This conditioning period allows the temperature to equilibrate and for the specimen to deflocculate (Note 18). The soil slurry is now referred to as a soil suspension since the specimen is basically ready for testing.

11.6 At the end of the conditioning period, check the suspension for indications of flocculation (Note 19). If the suspension has indications of flocculation, then the test is invalid and the suspension should be discarded since it has been contaminated with dispersant. A new specimen would need to be treated to prevent flocculation. Such treatment is beyond the scope of this test method.

NOTE 18—Strong interparticle bonding can occur in suspension having high salt concentrations. The dispersant will not be effective in breaking these bonds. In such circumstances the salt should be leached from the soil before proceeding with the sedimentation test. This leaching results in a considerable increase in effort and difficulty to process the material and is not discussed in this standard.

NOTE 19—Flocculation of clay particles can be difficult to detect. Minor flocculation will shift the particle-size distribution (gradation) towards a finer fraction. Moderate flocculation will cause a plateau in the curve as the sedimentation process stops. Major flocculation will completely halt sedimentation at an early stage. Only major flocculation is visually detectable showing a lack of material collected at the bottom of the cylinder, a surface layer of clear fluid, or horizontal cracks in the suspension.

11.7 Once the suspension has temperature equilibrated and deflocculated, the suspension shall once again be mixed to create a uniform suspension. Repeat the mixing procedure as described in 11.3. Upon completion of agitation, make sure the cylinder is on a stable surface and in a location where it will not be subjected to any jarring or disturbance and immediately start the timer as directed in either 11.7.2 or 11.7.3. If using a temperature controlled water bath, immediately place the cylinder back into the water bath after agitation.

11.7.1 If significant foam develops on top of the suspension after mixing, immediately add up to three drops of isopropyl alcohol to the suspension to reduce or eliminate the foam.

11.7.2 If using the agitator, start the timer when the paddle of the agitator breaks the surface of the soil suspension. After removing the agitator allow the "free" liquid on it to drain back into the sedimentation cylinder.

11.7.3 If using the tilting method, start the timer after completion of the last inversion.

11.8 Hydrometer readings shall be taken at elapsed times of approximately, 1, 2, 4, 15, 30, 60, 240, and 1440 minutes. Additional readings can be taken to better define the particle-size distribution (gradation) relationship.

11.8.1 About 15 to 20 seconds before a reading is required, gently place the hydrometer into the sedimentation cylinder to a depth approximately equal to the level at which it will float as described in 10.1.2. At the prescribed elapsed times and when the hydrometer is stable, read and record the hydrometer reading, r_m, to the nearest ¼ division, and record the elapsed time, t_m.

11.8.2 When removing the hydrometer from the suspension, the removal process should take about 5 to 10 seconds and be with a steady motion. Generally there will be a drop of suspension at the tip of the hydrometer. Touch the tip to the inside lip of the cylinder and allow the drop to flow back into the cylinder.

11.8.3 With a spinning motion, place the hydrometer into a wash cylinder filled with test water to clean off the hydrometer (Note 20). Once the hydrometer is clean, remove and dry it off prior to the next reading or the reading in the control cylinder if using companion measurements.

NOTE 20—While it is ideal to rinse the hydrometer off in a wash cylinder that can be easily cleaned, it is permissible to rinse the hydrometer in another suitable container filled with test water providing there is ample room for the hydrometer to spin.

11.9 Immediately after taking a hydrometer reading, gently insert the thermometric device into the soil suspension and record the temperature, T_m, to the nearest 0.5°C or better. Do not allow the thermometric device to create disturbance in the suspension. After removing the thermometric device, cover the cylinder to prevent evaporation when the time between the readings exceeds five minutes.

11.9.1 The temperature reading taken at the start of the sedimentation test may be used for the initial series of time readings up to 30 minutes. The temperature does not need to be measured more frequently than 30 minutes and shall be recorded at the elapsed times of actual measurements.

11.10 When using a companion measurement to determine the temperature-density correction, the hydrometer, $r_{d,m}$, and temperature, T_m, readings of the control cylinder shall be measured and recorded in accordance with 10.2.1.1.

11.11 If the dry mass, M_d, of the sedimentation specimen has been or will be determined from a companion specimen, the soil suspension is now ready to be washed over the No. 200 (75-µm) sieve.

11.11.1 Pour the soil suspension over the No. 200 (75-µm) sieve. Take care in transferring the soil suspension from the cylinder to the wash sieve so as not to lose material. Make sure there is no remaining material in the cylinder and that the wash water is running clear before transferring the material retained on the sieve into the oven drying container. Record the identification of the container and proceed to 11.13.

11.12 If the dry mass, M_d, of the sedimentation specimen was not determined using the water content taken in 9.10, then the dry mass is obtained from the soil suspension used for the sedimentation test.

11.12.1 After the last hydrometer reading is obtained, transfer all of the soil suspension to the oven drying container as described in 6.11. To facilitate the complete removal of all of the suspension, agitate the cylinder to distribute the soil as described in 11.3 (Note 21). Pour the agitated suspension into the container and record the identification of the container. If using the container as the tare to calculate the dry mass, also record the mass of the container prior to adding the suspension to the nearest 0.01 g. Use a wash/rinse bottle to aid in transferring the slurry.

NOTE 21—It is not necessary to duplicate the exact requirements of 11.3 in order to sufficiently distribute the soil. Use only as many turns (tipping method) or strokes (agitator method) as needed to dislodge the material from the bottom of the cylinder. The purpose of this agitation is to reduce the amount of additional water needed to remove all of the suspension from the cylinder. Additional test water may be added to thoroughly clean the cylinder and remove all of the suspension.

11.12.2 Dry the suspension to a constant mass in the drying oven at 110 ± 5°C. Usually constant mass is achieved after 24 hours when forced-draft type ovens are used. If there is any uncertainty if the specimen has thoroughly dried, it is necessary to perform the constant mass test after an additional six hours in the drying oven, to verify it has indeed completely dried before proceeding (Note 22).

NOTE 22—Determining the dry mass after the test adds additional time and consideration. Because the oven must remove large amounts of water, the drying time takes longer and the constant mass check interval is extended. The large surface area of the specimen in the container allows the material to potentially absorb more moisture from the air as it cools.

11.12.3 Remove the container from the drying oven and allow it to cool in a desiccator or a tightly covered/sealed container. After the container has cooled, determine and record the dry mass of the soil plus dispersant, M_{dd}, to the nearest 0.01 g.

11.12.4 After recording the dry mass of soil plus dispersant, M_{dd}, cover the specimen with tap water and allow the specimen to soak. During soaking, gently stir the specimen to facilitate the separation of particles. Pour the soaked material over the No. 200 (75- µm) sieve. Take care in transferring the soil suspension from the container to the wash sieve so as not to lose material. Make sure there is no remaining material in the container and that the wash water is running clear before transferring the material retained on the sieve into the oven drying container. Record the identification of the container if a different container is used and proceed to 11.13.

NOTE 23—Test Methods D1140 provides information on the washing technique to use.

11.13 Dry the retained material to a constant mass in the drying oven at 110 ± 5°C. Usually constant mass is achieved overnight (~12-16 hours) when forced-draft type ovens are used. If there is any uncertainty if the specimen has thoroughly dried, perform the constant mass test after an additional two hours in the drying oven, to verify it has indeed completely dried before proceeding.

11.14 Remove the container from the drying oven and allow it to cool in a desiccator or cover the container with a tight fitting lid. After the container has cooled, determine and record the dry mass of the soil retained on the No. 200 (75-µm) sieve, M_{dr}, to the nearest 0.01g. During the washing process, the dispersant has been removed and the resulting dry mass will only include the particles retained on the sieve.

12. Calculations

12.1 Calculate the dry mass, M_d, of the sedimentation specimen using either of the following methods.

12.1.1 *Dry Mass Using Moist Mass and Water Content*—Using the water content, w_c, of the companion specimen determined in 9.6 and the initial moist mass, M_m, of the sedimentation specimen, calculate the dry mass of the sedimentation specimen based as follows:

$$M_d = \frac{M_m}{1 + \left(\frac{w_c}{100}\right)} \tag{4}$$

where:

M_d = mass of dry soil, nearest 0.01 g,
M_m = mass of moist soil, nearest 0.01 g, and
w_c = water content, nearest 0.1 %.

12.1.2 *Dry Mass Using The Sedimentation Specimen*—Calculate the dry mass, M_d, of the sedimentation specimen based on the oven-dried material as obtained in 11.12 using the following equation:

$$M_d = M_{dd} - M_{disp} \tag{5}$$

where:

M_d = mass of dry soil, nearest 0.01 g,
M_{dd} = mass of dry soil plus dispersant, nearest 0.01 g, and
M_{disp} = mass of dispersant, nearest 0.01 g.

12.2 *Temperature-Density Correction: Calibration Relationships*—When using the calibration relationship to determine the hydrometer offset reading, $r_{rd,m}$, calculate the corrected hydrometer reading using the equation below that corresponds to the hydrometer used during the test.

12.2.1 For the 151H hydrometer, compute the offset reading for each sedimentation test reading using the following equation:

$$r_{d,m} = A - 7.784 \times 10^{-6} \times T_m - 4.959 \times 10^{-6} \times T_m^2 \tag{6}$$

where:

$r_{d,m}$ = 151H specific gravity hydrometer offset at reading, m, nearest 0.0001 (dimensionless),
A = average specific gravity shift (151H hydrometer), nearest 0.0001 (dimensionless),
T = temperature at reading, m, readable to 0.5°C or better, and
m = subscript indicating the reading number during the sedimentation test.

12.2.2 For the 152H hydrometer, compute the offset reading value for each sedimentation test reading using the following equation:

$$r_{d,m} = B - 1.248 \times 10^{-2} \times T_m - 7.950 \times 10^{-3} \times T_m^2 \tag{7}$$

where:

$r_{d,m}$ = 152H g/L hydrometer offset at reading, m, nearest 0.1 g/L,
B = average mass shift (152H hydrometer), nearest 0.1 g/L,
T = temperature at reading, m, readable to 0.5°C or better, and
m = subscript indicating the reading number during the sedimentation test.

12.3 *Temperature-Density Correction: Companion Measurement*—When using the companion measurement to obtain the temperature-density correction, use the recorded hydrometer offset reading taken in the control cylinder, $r_{d,m}$, that corresponds to the hydrometer used during the test.

12.4 *Mass Percent Finer*—For each hydrometer reading taken in the soil suspension, compute the mass of material still in suspension as a percentage of the sedimentation specimen using the appropriate equation for the type of hydrometer used during the test.

12.4.1 For each 151H hydrometer reading, calculate and record the mass percent finer using the following equation:

$$N_m = \left(\frac{G_s}{G_s - 1}\right)\left(\frac{V_{sp}}{M_d}\right)\rho_c(r_m - r_{d,m}) \times 100 \tag{8}$$

where:

N_m = mass percent finer material at reading m, nearest 1 %,
V_{sp} = volume of suspension, nearest 0.1 cm^3,
ρ_c = mass density of water at the temperature of manufacturer calibrated, g/cm^3 (Note 24),
M_d = dry soil mass of the sedimentation specimen, nearest 0.01 g,
G_s = specific gravity of soil, nearest three significant digits, (dimensionless),
r_m = hydrometer reading in suspension at reading m, readable to 0.00025 (dimensionless),
$r_{d,m}$ = hydrometer offset reading from reference solution at same temperature as reading m, nearest 0.0001 (dimensionless), and
m = subscript indicating the reading number during the sedimentation test.

NOTE 24—The mass density of water at the time of calibration is dependent upon the temperature at time of calibration. H151 and H152 hydrometers are calibrated to 20°C, which gives a mass density of 0.98821 g/cm^3.

12.4.2 *Mass Percent Finer*—For each 152H hydrometer reading, calculate and record the mass percent finer using the following equation:

$$N_m = 0.6226 \times \left(\frac{G_s}{G_s - 1}\right) \times \left(\frac{V_{sp}}{M_d}\right)(r_m - r_{d,m}) \times \left(\frac{100}{1000}\right) \tag{9}$$

where:

0.6226 = correction factor to adjust for particle specific gravity,

r_m = hydrometer reading in suspension at reading m, readable to 0.25 g/L, and
$r_{d,m}$ = hydrometer offset reading from reference solution at same temperature as reading m, nearest 0.1 g/L.

12.5 *Effective Depth*—This value is used in the calculation of the particle fall distance for each hydrometer reading. The following equation is used to calculate the travel distance of the particles when the hydrometer is inserted immediately before a reading and is removed until the next reading.

$$H_m = H_{r2} + \left(\frac{(H_{r1} - H_{r2})}{(r_2 - r_1)} \times (r_2 - r_m + C_m)\right) - \left(\frac{V_{hb}}{2A_c}\right) \tag{10}$$

where:

H_m = distance particles fall at reading m when the hydrometer is inserted only for an individual reading, 2 significant digits, cm,
V_{hb} = volume of the hydrometer bulb up to the base of the stem, nearest 1 cm^3,
A_c = cross-sectional area of the sedimentation cylinder, nearest 0.1 cm^2,
H_r = distance between the center of (volume) buoyancy and the minimum (H_{r2}) and maximum (H_{r1}) hydrometer readings nearest 0.1 cm,
r_m = hydrometer reading in suspension at reading m, 151H: readable to 0.00025 (dimensionless) 152H: readable to 0.25 g/L,
C_m = meniscus correction: 151H nearest 0.25 division (dimensionless) 152H: nearest 0.25 g/L,
r = the minimum (r_2) and maximum (r_1) hydrometer reading (dimensionless or g/L), and
m = subscript indicating the reading number during the sedimentation test.

12.6 *Maximum Particle Diameter in Suspension*—For each hydrometer reading, calculate and record the particle diameter of the soil using the following equation:

$$D_m = \left(\sqrt{\frac{18\mu}{\rho_w g(G_s - 1)} \cdot \frac{H_m}{t_m}}\right) \times 10 \tag{11}$$

where:

D_m = particle diameter, two significant digits, mm,
μ = viscosity of water at 20°C, 0.0100 g/cm-s,
ρ_w = mass density of water at 20°C, 0.99821 g/cm^3,
g = acceleration dues to gravity, 980.7 cm/s^2,
G_s = specific gravity of soil, three significant digits (dimensionless),
t_m = elapsed (fall) time, two significant digits, s,
H_m = particle fall distance, two significant digits, cm, and
m = subscript indicating the reading number during the sedimentation test.

12.7 *Percent Passing the No. 200 (75-µm)*—Calculate the percent passing the No. 200 (75-µm) sieve using the following equation:

$$P_p = 100\left(1 - \frac{M_{dr}}{M_d}\right) \tag{12}$$

where:

P_p = percent passing the No. 200 (75-µm) sieve, nearest 0.1 %,
M_d = initial dry mass of the sedimentation specimen without dispersant, nearest 0.01 g, and
M_{dr} = dry mass retained on the No. 200 (75-µm) sieve, nearest 0.01 g.

13. Report: Test Data Sheet(s)/Form(s)

13.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.13 and in Practice D6026.

13.2 Record as a minimum the following general information (data):

13.2.1 Identification of the material being tested, such as the project identification, boring number, sample number, and depth.

13.2.2 Test number, if any, testing dates and the initials of the person(s) who performed the test.

13.2.3 The sample preparation method used: moist or air-dried

13.2.4 The specific gravity of the sedimentation specimen and indicate if the value is assumed or measured.

13.2.5 The following apparatus identification used during the test:

13.2.5.1 Hydrometer type (151H or 152H) and identification number.

13.2.5.2 Sedimentation cylinder identification number.

13.2.5.3 Thermometric device identification number.

13.2.5.4 Balance identification number.

13.2.5.5 Oven identification number.

13.2.5.6 Wet washing sieve identification number.

13.2.6 Description and classification of the soil in accordance with Practice D2488 or when Atterberg limit data are available, Practice D2487.

13.2.7 Describe any material that was excluded from the specimen.

13.2.8 Describe any problems that were encountered.

13.2.9 Indicate any prior testing performed on the specimen.

13.3 Record as a minimum the following test specimen data:

13.3.1 The size of the separation sieve used.

13.3.2 The estimated percentage passing the No. 200 (75-µm) sieve, moist mass, and water content calculated or used in 9.5.

13.3.3 The water content of the material passing the No. 10 (2.0 mm) or finer sieve, if determined.

13.3.4 Moist mass of the sedimentation specimen.

13.3.5 Dry mass of the sedimentation specimen and indicate how obtained: using companion water content or direct measurement after testing.

13.3.6 Amount of dispersant used in the test.

13.3.7 The dry mass of the specimen plus dispersant, if applicable.

13.3.8 The percent passing the No. 200 (75-µm) sieve.

13.3.9 The start time and date of the test.

13.3.10 Indicate if a foam inhibitor was used.

13.3.11 The maximum particle diameter of the material for each hydrometer reading.

13.3.12 The mass percent finer for each hydrometer reading.

13.3.13 The hydrometer, temperature, elapsed time, offset, and effective depth readings from the sedimentation test.

13.3.14 Tabulation of the mass percent finer including the particle diameter in mm.

13.3.15 A graph of the percent passing versus the log of particle size in mm.

NOTE 25—Appendix X1 shows an example data sheet and an example of the graphical display of the results of the test.

14. Precision and Bias

14.1 *Precision*—Test data on precision is not presented due to the nature of the soil materials tested by this test method. An ISR round-robin testing program was conducted; however, the data has not yet been compiled. Subcommittee D18.03 is in the process of determining how to report the data from the ISR round-robin testing.

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

15. Keywords

15.1 clay; grain-size; hydrometer analysis; particle-size distribution (gradation); sedimentation; sieve analysis; silt

ANNEX

A1. CHECK OF HYDROMETER AND SEDIMENTATION CYLINDER

(Mandatory Information)

A1.1 *General*—There are many factors controlling the overall accuracy of sedimentation (hydrometer) test results. This section covers how the equipment constants used in calculating the sedimentation (hydrometer) test results are determined or checked. The equipment tolerances for the hydrometer and sedimentation cylinder are presented below.

A1.2 *Hydrometer Standard Dimensions* —The 152H and 151H hydrometers have specified dimensions in accordance with Specification E100, as shown in Fig. A1.1, and the hydrometer constants or equipment accuracy checks are listed with the accepted tolerances and summarized below.

A1.2.1 The distance from the key reference point on the nominal scale to the top or bottom of the hydrometer bulb H_t and H_b in mm. The key reference point on the nominal scale for 152H hydrometers is 0.0 g/L and 1.000 specific gravity for a 151H hydrometer.

A1.2.1.1 H_t = 103 – 130 mm, with an average of 116.5 mm.

A1.2.1.2 H_b = 244 – 246 mm.

A1.2.2 The overall length of the hydrometer bulb, H_{Lb} in mm.

A1.2.2.1 H_{Lb} = 115 – 142 mm, with an average of 128.5 mm.

A1.2.3 The distance from the top or bottom of the hydrometer's bulb to the maximum diameter of the bulb, H_{ct} or H_{cb} in mm (Note A1.1).

NOTE A1.1—It is possible for the maximum diameter and the center of (volume) buoyancy to have different locations on the bulb. When calculating effective depth, the location of the center of (volume) buoyancy should be used to calculate H_{r1} and H_{r2}, not the location of the maximum diameter.

A1.2.3.1 H_{ct} or H_{cb} = 58 – 71 mm, with an average of 64.5 mm assuming the volume of the bulb is symmetrical.

A1.2.4 The distance from the key reference point on the nominal scale to the center of the bulb's volume, H_{Lc} in mm.

A1.2.4.1 H_{Lc} = 174 – 188 mm, with an average of 181 mm.

A1.2.5 The length of the quoted nominal scale as stated in Specification E100, H_s in mm.

A1.2.5.1 H_s = 82 – 84 mm, with an average of 83 mm.

A1.2.6 The distance between scale divisions, ΔH_s in mm/division (Note A1.2).

A1.2.6.1 ΔH_s for 152H: Quoted scale of 0 – 50 g/L or 50 divisions, ΔH_s = 1.66 ± 0.02 mm. Full (actual) scale is -5 – 60 g/L.

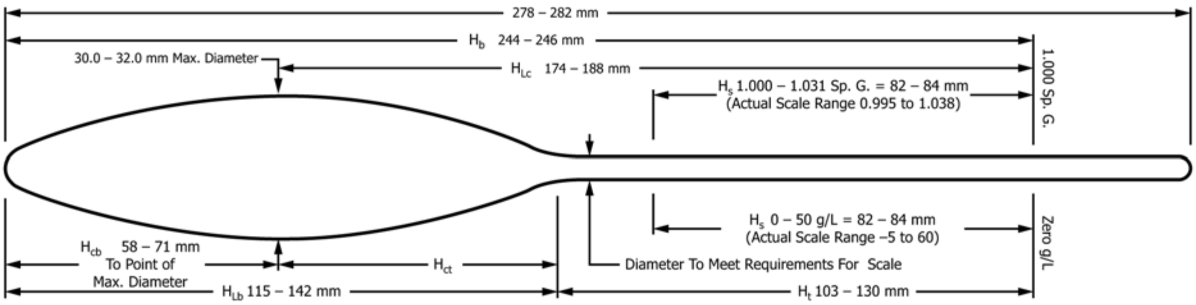


FIG. A1.1 Soil Hydrometer (151H or 152H)

A1.2.6.2 151H: Quoted scale of 1.000 – 1.031 specific gravity or 31 divisions, $\Delta H_s = 2.68 \pm 0.03$ mm. Full (actual) scale is 0.995 – 1.038 specific gravity.

A1.2.7 The submerged volume of the hydrometer bulb, V_{hb} in mL or cm^3.

A1.2.7.1 V_{hb} is not a constant and shall be measured for each hydrometer.

A1.2.8 The accuracy of the scale key reference point(s) on the hydrometer scale.

A1.2.8.1 The scale key reference point for the 152H hydrometer is 0.0 ± 1 g/L and 1.000± 0.001 specific gravity for the 151H hydrometer read at the bottom of the meniscus.

A1.2.9 The length of the stem above and below the scale in mm.

A1.2.9.1 Stem shall be uniform and extend at least 15 mm above the top of the graduation and remain cylindrical for at least 3 mm below the lowest graduation.

NOTE A1.2—It is assumed that ΔH_s is uniform over the length of the scale; however, this assumption is not true in accordance with Test Method E126. The equation in Test Method E126 works fine for the 151H hydrometers, but not for the 152H hydrometers since they start at zero. Based on the Test Method E126 equation, the difference in ΔH_s at the top and bottom of the 151H scale is about 6 %.

A1.3 *Checking the Dimensions*—The dimensions provided in A1.2.1 through A1.2.8 shall be checked and documented prior to use. The dimensions provided in A1.2.9 shall be checked and documented once every 12 months. If any of the standard dimensions do not fall within the allowable ranges, the hydrometer shall not be used.

A1.3.1 *Distance/Length*—The length dimensions shall be made and recorded to the nearest 0.5 mm. They can be made using either, and given in order of preference: a height gauge (digimatic, dial, or vernier), calipers (digimatic, dial, or vernier), or a ruler and square (the square is used to transcribe the measurement from the hydrometer to the ruler). The line of contact between the hydrometer stem and bulb can be established and marked using one of two methods. The first choice is to measure the diameter of the stem with calipers, increasing this measurement by about 1 mm and marking the spot where the calipers encounter the bulb. The other method is to visually determine this line of contact and mark it. The visual determination may be assisted by feeling the contact point with fingers. Marking can be accomplished by placing lengthwise a thin strip of label paper/marking tape across the line of contact and then marking it with a pencil.

A1.3.2 *Scale Length*—The quoted scale length shall be measured and recorded to the nearest 0.5 mm using either calipers or a machinist ruler. The distance between scale divisions is simply that length divided by the number of divisions and recorded to the nearest 0.01 mm/div. The error stated in Note A1.1 is ignored.

A1.3.3 *Scale Key Reference Points*—The 152H hydrometer should read 0.0 ± 1 g/L and 1.000 ± 0.001 specific gravity for the 151H hydrometer at the bottom of the meniscus when placed in distilled water that is free of gas bubbles at the calibration temperature of the hydrometers. At temperatures other than the calibration temperature of the hydrometer, the required reading shall be adjusted by the ratio of the density of water at the calibration temperature to the density of water at the check temperature. The check temperature shall be measured to the nearest 0.5°C and the density value associated with that temperature obtained from Table A1.1. If the hydrometer does not read within the allowable range, it shall not be used.

A1.3.4 *Volume*—The volume dimension, V_{hb}, shall be made and recorded to the nearest 1 cm^3 using either the direct or indirect method. The direct method is done by inserting the hydrometer into a graduated cylinder filled with test water having a minimum scale sensitivity of 5 mL per division. Read and record the volume in the cylinder prior to inserting the hydrometer to the nearest 2 mL. Insert the hydrometer into the test water just to the base of the stem then read and record the volume to the nearest 2 mL. The volume of the hydrometer is the difference in the volume readings before and after insertion into the test water. The volume is the average of three determinations that are within 2 mL of each other. The indirect method is done by determining the mass of the hydrometer. The volume can be measured by placing a partially filled beaker of room temperature test water on a balance, zero or tare the balance, and then lowering the hydrometer into the water just to the base of the stem. While holding the hydrometer in place, read and record the mass of displaced water to the nearest 0.1 g. Using an approximate mass density of water equal to unity (1), the volume of the hydrometer bulb in cm^3 will be equal to the mass reading.

A1.3.5 *Center of (Volume) Buoyancy*—Determine the center of (volume) buoyancy using the direct or indirect method described in A1.3.4, except the bulb is inserted until the mass or water level change is half of the volume of the bulb as determined in A1.3.4.

A1.4 *Sedimentation Cylinder Dimensions*—The sedimentation cylinder constants or equipment accuracy checks are listed with the accepted tolerances and summarized below. The cylinder shall be checked and documented prior to use.

A1.4.1 The accuracy of key volume mark is 1,000 ± 5 mL in mL or cm^3.

A1.4.1.1 *Volume*—Verify the 1,000 mL mark is correct by performing the following steps. Place the cylinder on a balance and zero it. Add distilled water free of air bubbles, having a known temperature, T, nearest 1°C, to the cylinder until the balance reads the required mass, M_w. The mass, M_w, in g, equals 1,000 times the density of water, ρ_w, at T taken from Table A1.1. Read the water level at the bottom of the meniscus. The level should be within about 5 mL or ~2 mm of the 1,000 mL mark on the cylinder. If the mark is not correct, remark the cylinder with the correct 1,000 mL line or do not use the cylinder. If the cylinder is remarked, the correct or incorrect line shall be clearly marked as such to prevent misuse of the incorrect line marking. Record the volume to the nearest 0.1 cm^3.

A1.4.2 The inside area, A_c, in cm^2.

A1.4.2.1 *Area*—Determine the inside area of the cylinder, A_c, by using a commercial-grade meter stick or tape measure

TABLE A1.1 Density of Water (ρ_w) Versus Temperature (*T*)[A]

T	ρ_w	*T*	ρ_w	*T*	ρ_w	*T*	ρ_w
(°C)	(g/ML)	(°C)	(g/ML)	(°C)	(g/ML)	(°C)	(g/ML)
15.0	0.99910	16.0	0.99895	17.0	0.99878	18.0	0.99860
.1	0.99909	.1	0.99893	.1	0.99876	.1	0.99858
.2	0.99907	.2	0.99891	.2	0.99874	.2	0.99856
.3	0.99906	.3	0.99890	.3	0.99872	.3	0.99854
.4	0.99904	.4	0.99888	.4	0.99871	.4	0.99852
.5	0.99902	.5	0.99886	.5	0.99869	.5	0.99850
.6	0.99901	.6	0.99885	.6	0.99867	.6	0.99848
.7	0.99899	.7	0.99883	.7	0.99865	.7	0.99847
.8	0.99898	.8	0.99881	.8	0.99863	.8	0.99845
.9	0.99896	.9	0.99879	.9	0.99862	.9	0.99843
19.0	0.99841	20.0	0.99821	21.0	0.99799	22.0	0.99777
.1	0.99839	.1	0.99819	.1	0.99797	.1	0.99775
.2	0.99837	.2	0.99816	.2	0.99795	.2	0.99773
.3	0.99835	.3	0.99814	.3	0.99793	.3	0.99770
.4	0.99833	.4	0.99812	.4	0.99791	.4	0.99768
.5	0.99831	.5	0.99810	.5	0.99789	.5	0.99766
.6	0.99829	.6	0.99808	.6	0.99786	.6	0.99764
.7	0.99827	.7	0.99806	.7	0.99784	.7	0.99761
.8	0.99825	.8	0.99804	.8	0.99782	.8	0.99759
.9	0.99823	.9	0.99802	.9	0.99780	.9	0.99756
23.0	0.99754	24.0	0.99730	25.0	0.99705	26.0	0.99679
.1	0.99752	.1	0.99727	.1	0.99702	.1	0.99676
.2	0.99749	.2	0.99725	.2	0.99700	.2	0.99673
.3	0.99747	.3	0.99723	.3	0.99697	.3	0.99671
.4	0.99745	.4	0.99720	.4	0.99694	.4	0.99668
.5	0.99742	.5	0.99717	.5	0.99692	.5	0.99665
.6	0.99740	.6	0.99715	.6	0.99689	.6	0.99663
.7	0.99737	.7	0.99712	.7	0.99687	.7	0.99660
.8	0.99735	.8	0.99710	.8	0.99684	.8	0.99657
.9	0.99732	.9	0.99707	.9	0.99681	.9	0.99654
27.0	0.99652	28.0	0.99624	29.0	0.99595	30.0	0.99565
.1	0.99649	.1	0.99621	.1	0.99592	.1	0.99562
.2	0.99646	.2	0.99618	.2	0.99589	.2	0.99559
.3	0.99643	.3	0.99615	.3	0.99586	.3	0.99556
.4	0.99641	.4	0.99612	.4	0.99583	.4	0.99553
.5	0.99638	.5	0.99609	.5	0.99580	.5	0.99550
.6	0.99635	.6	0.99607	.6	0.99577	.6	0.99547
.7	0.99632	.7	0.99604	.7	0.99574	.7	0.99544
.8	0.99629	.8	0.99601	.8	0.99571	.8	0.99541
.9	0.99627	.9	0.99598	.9	0.99568	.9	0.99538

[A] Reference: CRC Handbook of Chemistry and Physics, David R. Lide, Editor-In-Chief, 74th Edition, 1993 – 1994.

reading in cm or mm. Insert the meter stick or tape measure into the cylinder until it touches the inside bottom of the cylinder. Read and record the distance from the inside bottom of the cylinder to the 1,000 mL mark to the nearest 1 mm. Repeat this procedure at two more locations on the inside bottom of the cylinder for a total of three readings. Determine and record the average distance, D_{1000}, to the nearest 1 mm. Calculate and record the area of the cylinder, A_c, ($A_c = 1{,}000 \times (10/D_{1000})$) to the nearest 0.1 cm^2.

NOTE A1.3—For example, if the 1,000 mL mark is determined to be 360 mm from the inside bottom of the cylinder, the inside area is 27.8 cm^2 and the diameter is then 59.5 mm. For a 63.5 mm inside diameter cylinder, the 1,000 mL mark should be approximately 316 mm from the inside bottom.

A1.4.3 The inside area's uniformity above the key volume mark.

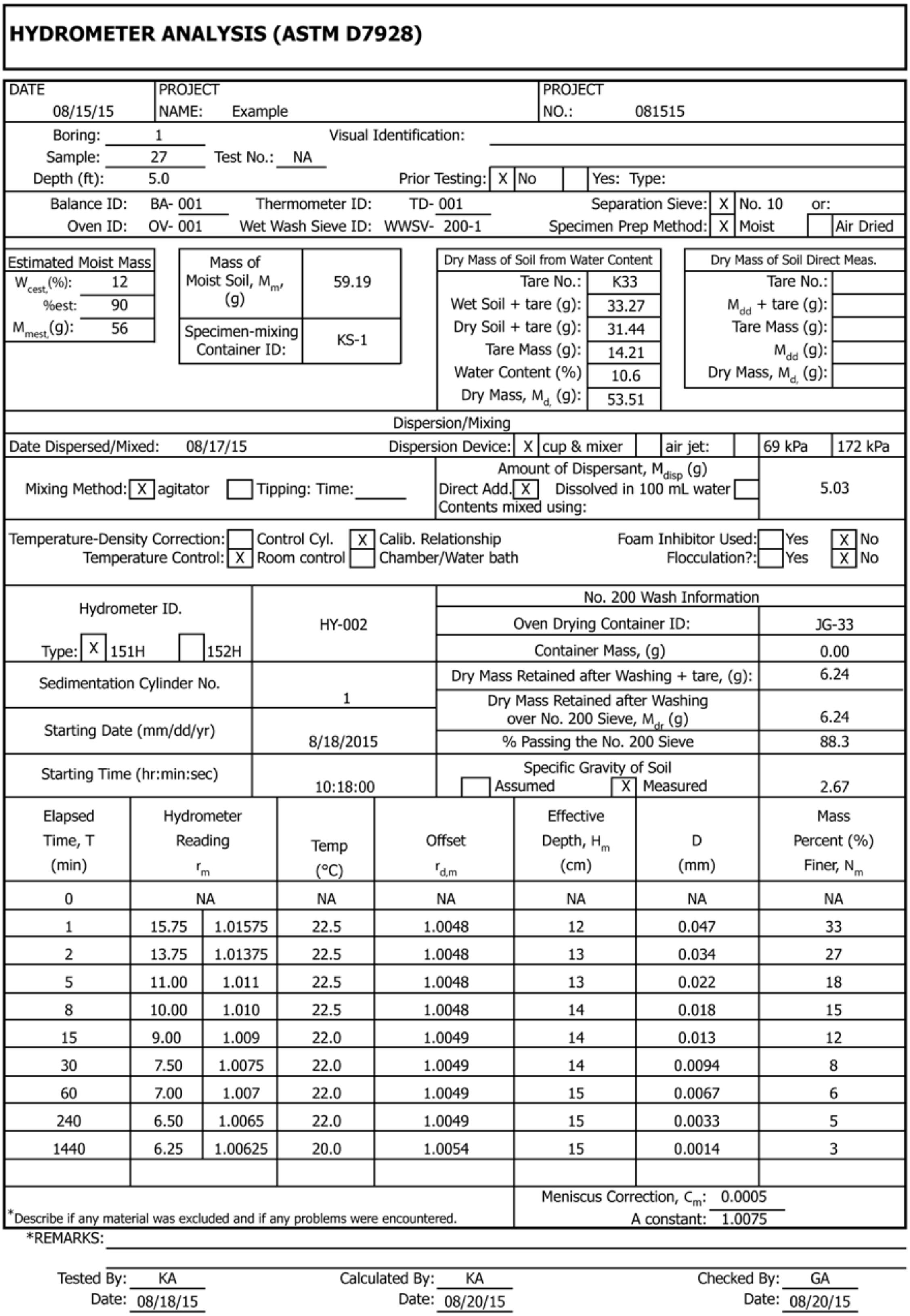
A1.4.3.1 *Area Uniformity*—Determine and record the uniformity of the area above the 1,000 mL. Add 150 ± 1 mL or 150 ± 1g × ρ_w at *T* of bubble free, distilled water to the cylinder filled with 1,000 mL of distilled water. If the water surface raises 150 × (10/A_c) ± 0.25 mm, then the area is considered uniform. If this tolerance isn't met, the cylinder shall not be used.

APPENDIX

X1. EXAMPLE DATA SHEETS, GRAPH, AND EQUIPMENT CHECKS

(Nonmandatory Information)

X1.1 *General*—The data sheets in Fig. X1.1and Fig. X1.2 are provided as examples to assist the user by showing results of the calculations performed. Fig. X1.3 is provided as an example of how the results of Fig. X1.1 can be displayed graphically. Fig. X1.1 data is calculated using the calibration relationship and Fig. X1.2 data is calculated using the companion cylinder. Figs. X1.4-X1.6 are examples of typical checks of the hydrometer and sedimentation cylinder. Fig. X1.7 is an example of the meniscus correction and determination of the A constant for a 151H hydrometer.



HYDROMETER ANALYSIS (ASTM D7928)

DATE: 08/15/15
PROJECT NAME: Example
PROJECT NO.: 081515

Boring: 1
Visual Identification:
Sample: 27
Test No.: NA
Depth (ft): 5.0
Prior Testing: ☒ No ☐ Yes: Type:

Balance ID: BA- 001
Thermometer ID: TD- 001
Separation Sieve: ☒ No. 10 or:
Oven ID: OV- 001
Wet Wash Sieve ID: WWSV- 200-1
Specimen Prep Method: ☒ Moist ☐ Air Dried

Estimated Moist Mass	
$W_{cest,}$(%):	12
%est:	90
$M_{mest,}$(g):	56

Mass of Moist Soil, M_m, (g)	59.19
Specimen-mixing Container ID:	KS-1

Dry Mass of Soil from Water Content	
Tare No.:	K33
Wet Soil + tare (g):	33.27
Dry Soil + tare (g):	31.44
Tare Mass (g):	14.21
Water Content (%)	10.6
Dry Mass, $M_{d,}$ (g):	53.51

Dry Mass of Soil Direct Meas.	
Tare No.:	
M_{dd} + tare (g):	
Tare Mass (g):	
M_{dd} (g):	
Dry Mass, $M_{d,}$ (g):	

Dispersion/Mixing

Date Dispersed/Mixed: 08/17/15
Dispersion Device: ☒ cup & mixer ☐ air jet: ☐ 69 kPa ☐ 172 kPa
Mixing Method: ☒ agitator ☐ Tipping: Time:
Amount of Dispersant, M_{disp} (g): 5.03
Direct Add. ☒ Dissolved in 100 mL water ☐
Contents mixed using:

Temperature-Density Correction: ☐ Control Cyl. ☒ Calib. Relationship
Temperature Control: ☒ Room control ☐ Chamber/Water bath
Foam Inhibitor Used: ☐ Yes ☒ No
Flocculation?: ☐ Yes ☒ No

Hydrometer ID. Type: ☒ 151H ☐ 152H	HY-002
Sedimentation Cylinder No.	1
Starting Date (mm/dd/yr)	8/18/2015
Starting Time (hr:min:sec)	10:18:00

No. 200 Wash Information	
Oven Drying Container ID:	JG-33
Container Mass, (g)	0.00
Dry Mass Retained after Washing + tare, (g):	6.24
Dry Mass Retained after Washing over No. 200 Sieve, M_{dr} (g)	6.24
% Passing the No. 200 Sieve	88.3
Specific Gravity of Soil ☐ Assumed ☒ Measured	2.67

Elapsed Time, T (min)	Hydrometer Reading r_m		Temp (°C)	Offset $r_{d,m}$	Effective Depth, H_m (cm)	D (mm)	Mass Percent (%) Finer, N_m
0	NA		NA	NA	NA	NA	NA
1	15.75	1.01575	22.5	1.0048	12	0.047	33
2	13.75	1.01375	22.5	1.0048	13	0.034	27
5	11.00	1.011	22.5	1.0048	13	0.022	18
8	10.00	1.010	22.5	1.0048	14	0.018	15
15	9.00	1.009	22.0	1.0049	14	0.013	12
30	7.50	1.0075	22.0	1.0049	14	0.0094	8
60	7.00	1.007	22.0	1.0049	15	0.0067	6
240	6.50	1.0065	22.0	1.0049	15	0.0033	5
1440	6.25	1.00625	20.0	1.0054	15	0.0014	3

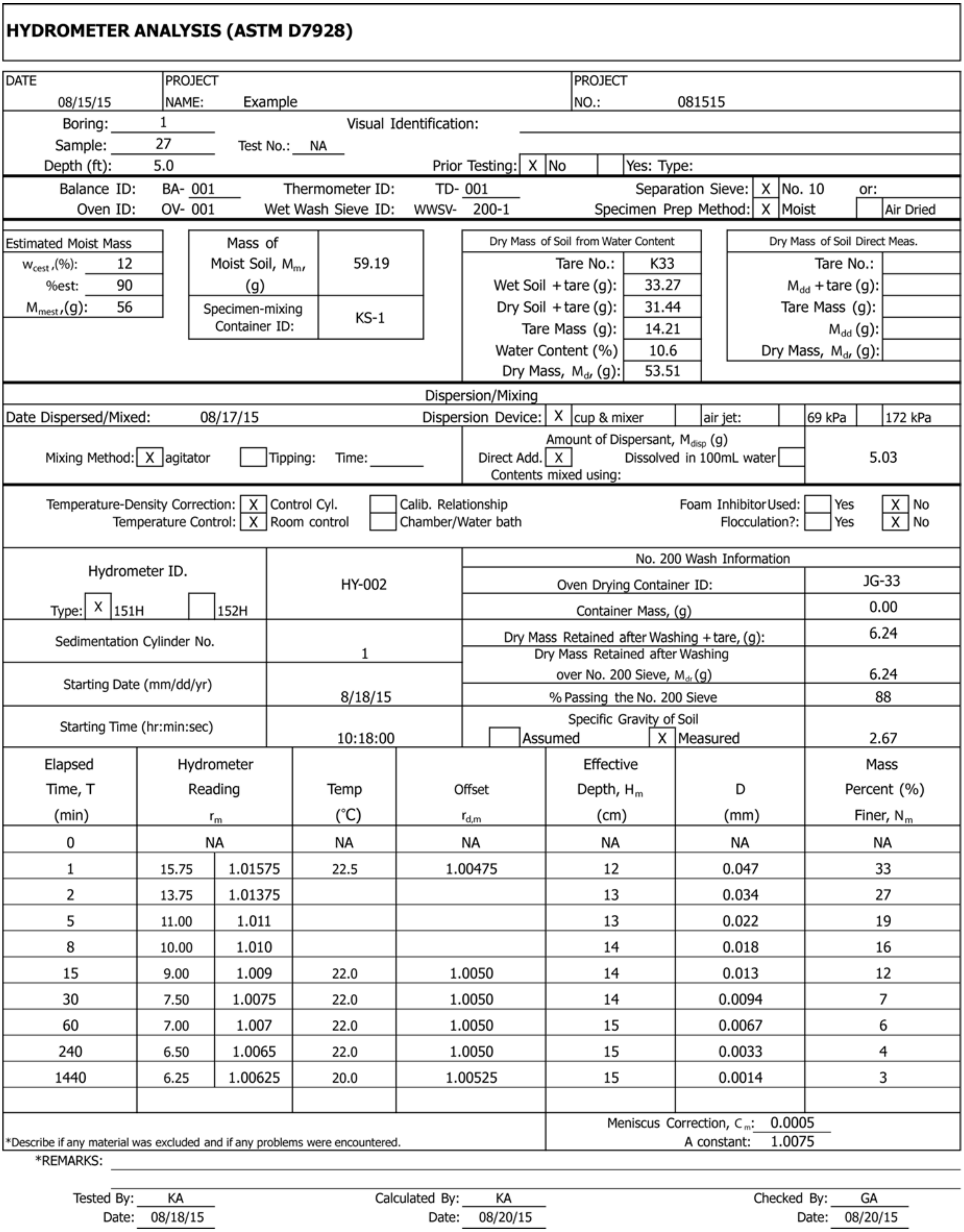
*Describe if any material was excluded and if any problems were encountered.

Meniscus Correction, C_m: 0.0005
A constant: 1.0075

*REMARKS:

Tested By: KA
Date: 08/18/15
Calculated By: KA
Date: 08/20/15
Checked By: GA
Date: 08/20/15

FIG. X1.1 Example Data Sheet Using Calibration Relationship



HYDROMETER ANALYSIS (ASTM D7928)

DATE 08/15/15	PROJECT NAME: Example	PROJECT NO.: 081515

Boring: 1 Visual Identification:
Sample: 27 Test No.: NA
Depth (ft): 5.0 Prior Testing: ☒ No ☐ Yes: Type:

Balance ID: BA- 001 Thermometer ID: TD- 001 Separation Sieve: ☒ No. 10 or:
Oven ID: OV- 001 Wet Wash Sieve ID: WWSV- 200-1 Specimen Prep Method: ☒ Moist ☐ Air Dried

Estimated Moist Mass	
w_{cest},(%):	12
%est:	90
M_{mest},(g):	56

Mass of Moist Soil, M_m, (g)	59.19
Specimen-mixing Container ID:	KS-1

Dry Mass of Soil from Water Content	
Tare No.:	K33
Wet Soil + tare (g):	33.27
Dry Soil + tare (g):	31.44
Tare Mass (g):	14.21
Water Content (%)	10.6
Dry Mass, M_d, (g):	53.51

Dry Mass of Soil Direct Meas.	
Tare No.:	
M_{dd} + tare (g):	
Tare Mass (g):	
M_{dd} (g):	
Dry Mass, M_d, (g):	

Dispersion/Mixing

Date Dispersed/Mixed: 08/17/15 Dispersion Device: ☒ cup & mixer ☐ air jet: ☐ 69 kPa ☐ 172 kPa

Mixing Method: ☒ agitator ☐ Tipping: Time: ______

Amount of Dispersant, M_{disp} (g): Direct Add. ☒ Dissolved in 100mL water ☐ Contents mixed using: 5.03

Temperature-Density Correction: ☒ Control Cyl. ☐ Calib. Relationship Foam Inhibitor Used: ☐ Yes ☒ No
Temperature Control: ☒ Room control ☐ Chamber/Water bath Flocculation?: ☐ Yes ☒ No

Hydrometer ID. Type: ☒ 151H ☐ 152H	HY-002	No. 200 Wash Information Oven Drying Container ID:	JG-33
		Container Mass, (g)	0.00
Sedimentation Cylinder No.	1	Dry Mass Retained after Washing + tare, (g):	6.24
		Dry Mass Retained after Washing over No. 200 Sieve, M_{dr} (g)	6.24
Starting Date (mm/dd/yr)	8/18/15	% Passing the No. 200 Sieve	88
Starting Time (hr:min:sec)	10:18:00	Specific Gravity of Soil ☐ Assumed ☒ Measured	2.67

Elapsed Time, T (min)	Hydrometer Reading r_m		Temp (°C)	Offset $r_{d,m}$	Effective Depth, H_m (cm)	D (mm)	Mass Percent (%) Finer, N_m
0	NA		NA	NA	NA	NA	NA
1	15.75	1.01575	22.5	1.00475	12	0.047	33
2	13.75	1.01375			13	0.034	27
5	11.00	1.011			13	0.022	19
8	10.00	1.010			14	0.018	16
15	9.00	1.009	22.0	1.0050	14	0.013	12
30	7.50	1.0075	22.0	1.0050	14	0.0094	7
60	7.00	1.007	22.0	1.0050	15	0.0067	6
240	6.50	1.0065	22.0	1.0050	15	0.0033	4
1440	6.25	1.00625	20.0	1.00525	15	0.0014	3

Meniscus Correction, C_m: 0.0005
A constant: 1.0075

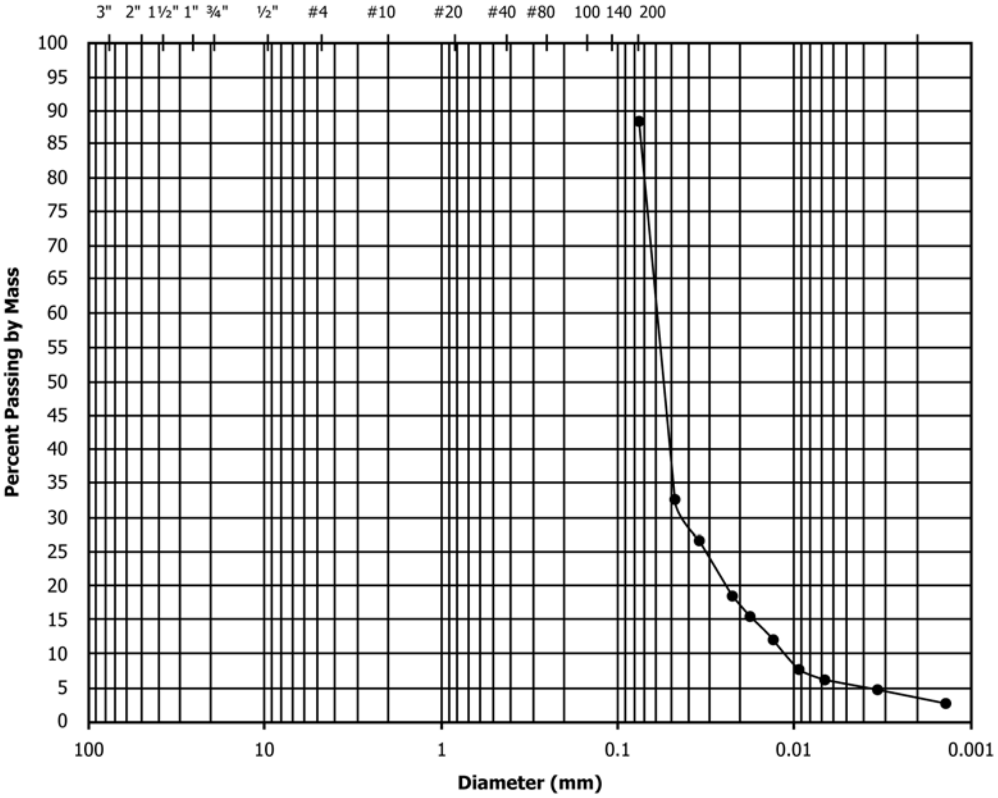
*Describe if any material was excluded and if any problems were encountered.

*REMARKS:

Tested By: KA Date: 08/18/15
Calculated By: KA Date: 08/20/15
Checked By: GA Date: 08/20/15

FIG. X1.2 Example Data Sheet Using Companion Measurement

PARTICLE SIZE DISTRIBUTION
ASTM D7928



Sand (%)	Fines (%)	
11.7	**88.3**	
	Silt	Clay
	85.0	3.3

Project No.: 081515 -- Project Name: Example
Boring: 1
Sample: 27 - Depth: 5 ft.

FIG. X1.3 Typical Graph of Data

Check of Hydrometers

Procedure: D7928

Date: 08/01/15

Date Due*: Before use/After Repair

Location: Soils Lab

Temperature 22 °C = 72 °F

*1 yr due date for items marked with *.

Check/Standard Equipment

Type:	Caliper
Manufacturer:	Pittsburgh
Model Number:	68304
Serial Number:	NA
Instrument Number:	XCD-001
Date Due:	20/03/16

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/16

Type:	Balance
Manufacturer:	Sartorius
Model Number:	3102-1S
Serial Number:	0032950176
Instrument Number:	BA-003
Date Due:	6/8/16

Instrument Identification/Data

Type	Hydrometer
Manufacturer	Chase
Model Number	NA
Serial Number	305055
Instrument Number	HY-002 ☒ 151H ☐ 152H
Previous Verification Date:	New

Check Data

	Instrument	PASS/FAIL	Tolerance (mm)
Top of Scale to Top of Hydrometer Bulb, H_t, (mm):	112.0	PASS	103-130
Top of Scale to Bottom of Hydrometer Bulb, H_b, (mm):	246.0	PASS	244-246
Overall Length of Hydrometer Bulb, H_{Lb} (mm):	134.0	PASS	115-142
Top of Hydrometer Bulb to Maximum Diameter, H_{ct}, (mm):	63.0	PASS	58-71
Bottom of Hydrometer Bulb to Maximum Diameter, H_{cb}, (mm)^1:	71.0	PASS	58-71
Top of Scale (1.000) to Maximum Diameter, H_{Lc}, (mm):	174.0	PASS	174-188
Nominal Scale Length (1.000-1.031 or 0-50 g/L), (mm):	82.0	PASS	82-84
Distance Between Scale Divisions, ΔH_s, (mm/div):	2.65	PASS	1.64-1.68 2.65-2.71
Submerged Volume of Hydrometer Bulb, V_{hb}, (cm^3)^2:	54	PASS	NA
Scale Reference Point (Sp.Gr or g/L)^3:	1.001	PASS	1.001-0.999 1.0-1.0
*Stem extends 15 mm above the top graduation?:	Yes	PASS	Yes
*Stem cylindrical for at least 3 mm below lowest graduation?:	Yes	PASS	Yes
Stem Diameter (mm):	5.2	PASS	NA
Center of (Volume) Buoyancy, C_b, (cm^3):	27.0	PASS	NA
Top of Scale (0.995) to Center of Buoyancy, H_{r1}, (mm):	186.0	PASS	NA
Bottom of Scale (1.038) to Center of Buoyancy, H_{r2}, (mm)^1:	70.0	PASS	NA

^{2} Mass of Displaced Water

1 53.9 g

2 53.9 g

3 53.9 g

Avg. 53.9 g

^{3} Temperature (°C): 22.0

Scale Rdg: 1.0001

Adj. Rdg: 1.0005

Equip. Status (Conforms/Nonconforms*): ____

*Who was notified? ____

Action Taken: ____

Checked By: KA

Date: 08/01/15

Input By: KA

Date: 08/01/15

Sticker Applied By: Not Applicable

Date: –

Checked By: GA

Date: 08/01/15

FIG. X1.4 Example Hydrometer Check

Check of Sedimentation Cylinders

Procedure: ASTM D7928
Location: Soils Lab

Date: 08/01/15
Date Due: Before Use/After Repair
Temperature 27 °C = 80 °F

Check/Standard Equipment

Type:	Caliper
Manufacturer:	Pittsburgh
Model Number:	68304
Serial Number:	NA
Instrument Number:	XCD-001
Date Due:	3/20/2016

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/2016

Type:	Balance
Manufacturer:	Sartorius
Model Number:	3102-1S
Serial Number:	0032950176
Instrument Number:	BA-003
Date Due:	6/8/2016

Type:	Tape Measure
Instr. No.:	1
Date Due:	NA

Instrument Identification/Data

Type	Sedimentation Cylinder
Manufacturer	Kimax/Durham Geo
Model Number	NA
Serial Number	NA
Instrument Number	2
Previous Verification Date:	New

Check Data

	Instrument	PASS/FAIL	Tolerance (mm)
Height of Cylinder (mm):	451	PASS	~457
Temperature, °C	27	PASS	NA
Mass of Cylinder with water (g):	1002.1	PASS	NA
Density of Water, g/mL	0.99652	PASS	NA
Inside Area before adjustment, cm^2:	28.1	PASS	22.9-32.2
Calculated Inside Diameter (mm):	60	PASS	55-64
Unadjusted Volume, mL	999	PASS	995-1005
Adjusted Mass of Cylinder w/ water (g):			NA
Adjusted Volume, mL			995-1005
Inside Area after adjustment, cm^2:			22.9-32.2
Area Uniformity (mm):	53.3	PASS	53.2-53.7

	Inside Ht. (mm) Orig.	Inside Ht. (mm) Adj.
1	356	
2	356	
3	356	
Avg:	356	

Amt. added: 149 mL

Equip. Status (Conforms/Nonconforms*): Conforms
*Who was notified?
Action Taken:

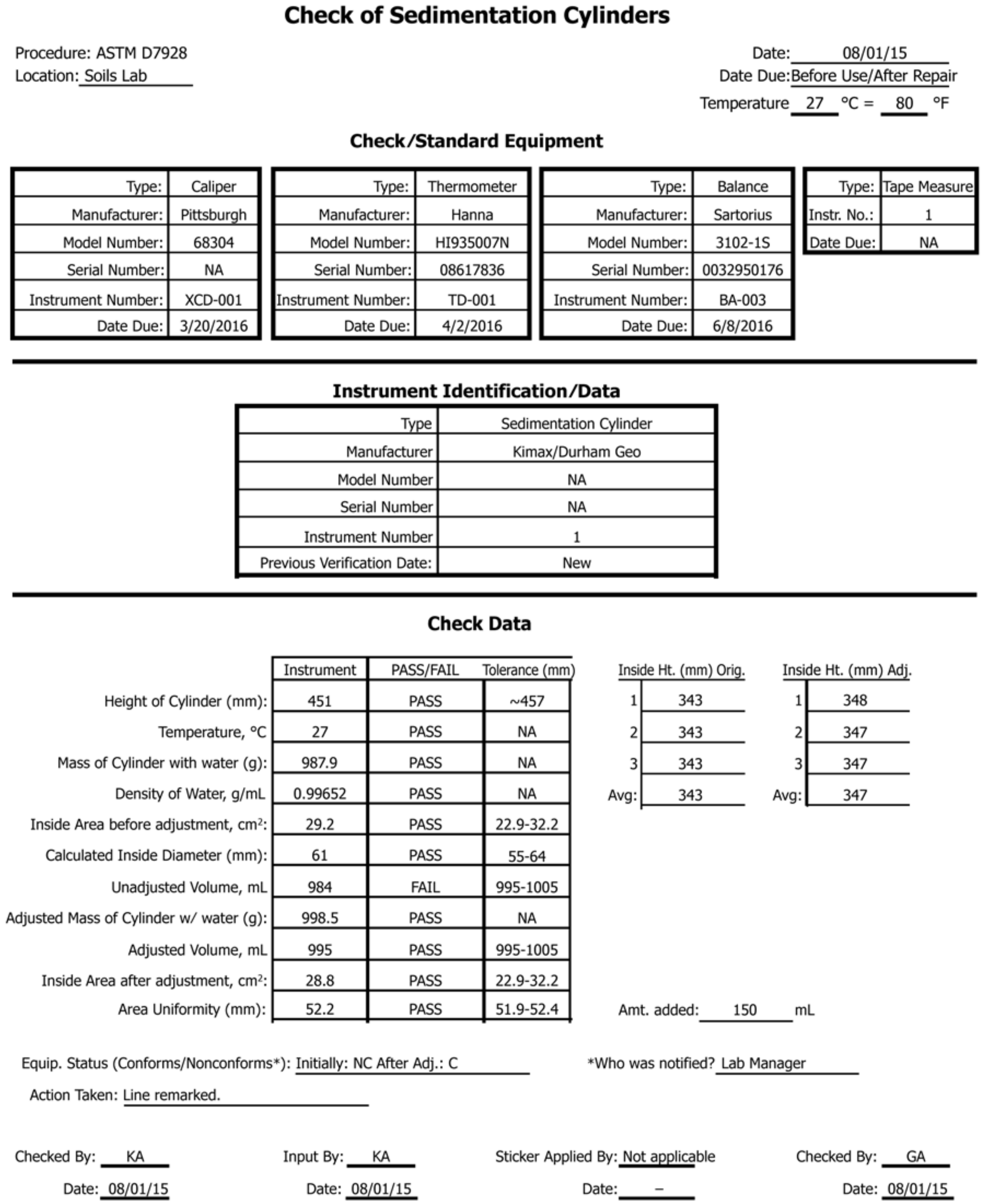
Checked By: KA
Date: 08/01/15

Input By: KA
Date: 08/01/15

Sticker Applied By: Not applicable
Date: –

Checked By: GA
Date: 08/01/15

FIG. X1.5 Example Sedimentation Cylinder Check—No Adjustment



Check of Sedimentation Cylinders

Procedure: ASTM D7928
Location: Soils Lab

Date: 08/01/15
Date Due: Before Use/After Repair
Temperature 27 °C = 80 °F

Check/Standard Equipment

Type:	Caliper
Manufacturer:	Pittsburgh
Model Number:	68304
Serial Number:	NA
Instrument Number:	XCD-001
Date Due:	3/20/2016

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/2016

Type:	Balance
Manufacturer:	Sartorius
Model Number:	3102-1S
Serial Number:	0032950176
Instrument Number:	BA-003
Date Due:	6/8/2016

Type:	Tape Measure
Instr. No.:	1
Date Due:	NA

Instrument Identification/Data

Type	Sedimentation Cylinder
Manufacturer	Kimax/Durham Geo
Model Number	NA
Serial Number	NA
Instrument Number	1
Previous Verification Date:	New

Check Data

	Instrument	PASS/FAIL	Tolerance (mm)
Height of Cylinder (mm):	451	PASS	~457
Temperature, °C	27	PASS	NA
Mass of Cylinder with water (g):	987.9	PASS	NA
Density of Water, g/mL	0.99652	PASS	NA
Inside Area before adjustment, cm^2:	29.2	PASS	22.9-32.2
Calculated Inside Diameter (mm):	61	PASS	55-64
Unadjusted Volume, mL	984	FAIL	995-1005
Adjusted Mass of Cylinder w/ water (g):	998.5	PASS	NA
Adjusted Volume, mL	995	PASS	995-1005
Inside Area after adjustment, cm^2:	28.8	PASS	22.9-32.2
Area Uniformity (mm):	52.2	PASS	51.9-52.4

	Inside Ht. (mm) Orig.		Inside Ht. (mm) Adj.
1	343	1	348
2	343	2	347
3	343	3	347
Avg:	343	Avg:	347

Amt. added: 150 mL

Equip. Status (Conforms/Nonconforms*): Initially: NC After Adj.: C

*Who was notified? Lab Manager

Action Taken: Line remarked.

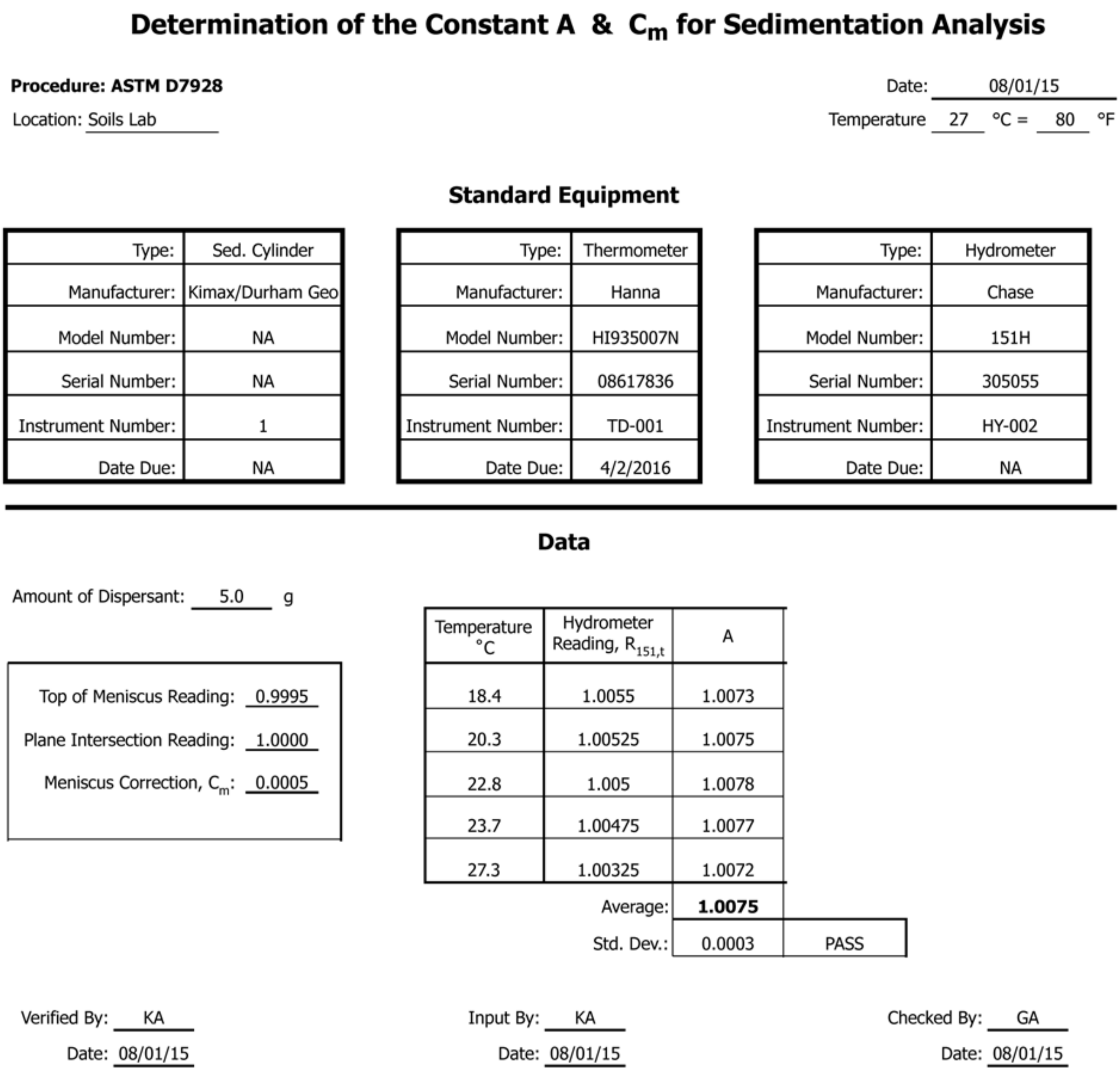
Checked By: KA
Date: 08/01/15

Input By: KA
Date: 08/01/15

Sticker Applied By: Not applicable
Date: –

Checked By: GA
Date: 08/01/15

FIG. X1.6 Example Sedimentation Cylinder Check—Adjustment



Determination of the Constant A & C_m for Sedimentation Analysis

Procedure: ASTM D7928

Date: 08/01/15

Location: Soils Lab

Temperature 27 °C = 80 °F

Standard Equipment

Type:	Sed. Cylinder
Manufacturer:	Kimax/Durham Geo
Model Number:	NA
Serial Number:	NA
Instrument Number:	1
Date Due:	NA

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/2016

Type:	Hydrometer
Manufacturer:	Chase
Model Number:	151H
Serial Number:	305055
Instrument Number:	HY-002
Date Due:	NA

Data

Amount of Dispersant: 5.0 g

Top of Meniscus Reading: 0.9995

Plane Intersection Reading: 1.0000

Meniscus Correction, C_m: 0.0005

Temperature °C	Hydrometer Reading, $R_{151,t}$	A	
18.4	1.0055	1.0073	
20.3	1.00525	1.0075	
22.8	1.005	1.0078	
23.7	1.00475	1.0077	
27.3	1.00325	1.0072	
	Average:	**1.0075**	
	Std. Dev.:	0.0003	PASS

Verified By: KA
Date: 08/01/15

Input By: KA
Date: 08/01/15

Checked By: GA
Date: 08/01/15

FIG. X1.7 Example of Constant A and Meniscus Correction Determination

ATTACHMENT 5 - PDI HB-5: SEEPAGE ANALYSIS FOR CONTAINMENT WALL DESIGN

Project	Nuclear Metal Superfund Site, Concord, MA	Date	4 September 2020
Client	Remedial Design Work Plan	Page	1 of 3

1 INTRODUCTION

This Pre-Design Investigation (PDI) activity for the holding basin (HB) containment involves a seepage analysis to assess seepage potential within the overburden and bedrock aquifers. The analysis and results from this PDI will inform the design of the hydraulic and physical properties of the proposed HB wall, including hydraulic conductivity of the wall, depth and thickness.

The HB wall will be designed to prevent groundwater from flowing out of the basin for a minimum of 200 years, and to the extent reasonably achievable, for 1,000 years. The containment wall will be constructed using slurry wall construction methods consisting of a clam shell bucket to excavate the overburden soil and hydromill equipment as necessary to excavate through the glacial till and bedrock if the wall is to be keyed into glacial till or bedrock. A low permeability cover will also be constructed to cap the HB.

2 OBJECTIVES

The objectives for performing the work described in this PDI are as follows:

- Build a finite element seepage model using the *SEEP/w* software.
- Conduct parametric seepage modeling to evaluate the HB containment wall design.

The results of this PDI will inform the design of the HB containment wall, including the depth that the wall must extend (into till or bedrock), the thickness and hydraulic conductivity of the wall.

3 SCOPE OF WORK

The scope of work will include the development and testing of a seepage model using *SEEP/w* software. The seepage model will be constructed using data collected from PDI-HB-1 through PDI-HB-4, and the results of the seepage modelling will be used to determine the design parameters of the HB containment wall.

4 PROCEDURES

4.1 <u>Build a SEEP/w Model</u>

Using data collected from PDI-HB-1 through PDI-HB-4 a finite element, two-dimensional model of the site will be developed using the *SEEP/w* software from Geoslope. *SEEP/w* is a numerical modeling software which allows the user to simulate groundwater flow in cross section. Up to three (3) critical seepage sections will be evaluated, and transient parametric analyses performed, to estimate the minimum wall construction parameters to meet performance criteria.

The following site-specific information collected from other HB PDIs will be input into *SEEP/w* to develop a model representative of site conditions.

Parameter	**PDI**
Subsurface Geology Stratigraphic Sequence Depth to Bedrock	PDI-HB-1 and PDI-HB-4
Aquifer Properties (Bedrock and Overburden) Hydraulic Conductivity Saturated Thickness	PDI-HB-1
Geophysical Properties Location of Water Bearing Fractures Orientation of fractures	PDI-HB-1
Containment Wall Properties Wall Thickness Wall Hydraulic Conductivity	PDI-HB-3

4.2 Perform Seepage Analysis

Once the model is developed, a series of iterations will be run to simulate groundwater flow in cross sections of the site under different conditions by inputting and changing the model parameters. A range of practical design parameters will be parametrically adjusted to alternate containment wall designs. We will evaluate wall embedment depth, wall hydraulic conductivity, and wall thickness. Figure 5 shows a profile of the different depths of the wall that will be evaluated.

Below is a summary of the expected ranges for the design parameters.

Wall Design Parameter	**Expected Range**
Hydraulic Conductivity	$1x10^{-8}$ to $1x10^{-6}$ cm/sec
Wall depth (Embedment into till or rock)	80 ft (5 ft. into till) to 100 ft (5 to 25 ft. into bedrock)
Thickness	2 to 4 ft

5 REPORTING

The status of this PDI and results will be provided to EPA during routine project meetings and status reports. Results and the outcome of the PDI will be incorporated into a separate PDI Evaluation Report and the 30% RD report.

HALEY
ALDRICH

www.haleyaldrich.com

ATTACHMENT 6 - REPORT ON
RD PRE-DESIGN INVESTIGATIONS – NMI SITE
HOLDING BASIN INVESTIGATIONS
DRILLING AND SAMPLING IMPLEMENTATION PLAN
(PDI HB-1, HB-2, AND SSS-5)
CONCORD, MASSACHUSETTS

by
Haley & Aldrich, Inc.
Boston, Massachusetts

for
de maximis, inc.

File No. 131884-003
September 2020

Table of Contents

1. Objectives and Scope

The Pre-Design Investigation (PDI) activities for the Holding Basin (HB) involves the investigation of the subsurface soil and rock characteristics for purposes of designing the containment wall and cover system for the Holding Basin. In addition, soil characteristics will be evaluated for slope stability analyses, and determining appropriate methods of soil and sediment excavation from the Cooling Pond and Sphagnum bog. Similar drilling methods will be used for evaluating the characteristics of soil that may be used for backfill as outlined in PDI SSS-5.

The objectives for performing the drilling and soil testing described in this PDI are as follows:

- Characterize the geotechnical parameters including density of the overburden and characteristics of the bedrock by collecting soil and rock samples for grain size distribution testing of the soil, and abrasivity testing of the rock (PDI HB-1)
- Determine the geophysical properties of the bedrock and identify the location and orientation of water bearing zones and fractures within the bedrock (PDI HB-2)
- Determine the depth and extent of the glacial till stratum, the depth to bedrock within the proposed HB containment wall and measure the hydraulic conductivity of each discrete zone of overburden soils and bedrock.
- Evaluate the presence of subsurface structures associated with the pump house which would need to be removed during construction of the HB containment wall.
- Evaluate thickness and soil characteristics along steep slopes as it relates to the Holding Basin, Cooling Pond and adjacent bog, and the associated changes in grade during and after construction.
- Characterize soil density, thickness and geotechnical characteristics of soil on the property for purposes of using the soil as backfill to replace the impacted soil that will be excavated and disposed of at an off-site location. A portion of the existing hill on the property appears to have suitable fill material above the groundwater table as outlined in PDI SSS-5.

The results of these PDIs will support the design of the containment wall, Holding Basin cap, and provide information of soils for designing and specifying the means and methods of excavation, regrading and backfilling along steep slopes of the Holding Basin, Cooling Pond and Sphagnum bog.

The objective of this Implementation Plan is to outline the steps for the geotechnical drilling and soil sampling in support of the data collection for the containment wall design, and means of excavating soil and sediment at the toe of steep slopes within the Cooling Pond, and adjacent to the Holding Basin and the Sphagnum bog.

The procedures described below are augmented by the field sampling and laboratory procedures described in the Field Sampling Plan (FSP) and Quality Assurance Project Plan (QAPP). If applicable, work will be completed in accordance with the Health Physics Procedure (HPP) for Conduct of Radiological Work (HP-NMI-01). Additional references to standard operating procedures (SOPs) are added to specific work procedures listed below.

2. General Procedures

The following procedures will be considered for all proposed drilling along the containment wall alignment for PDI HB-1, related to general access, processing and post-sampling activities.

2.1 ACCESS

PDI HB-1 will be conducted along the proposed containment wall alignment from the elevation of the existing liner edge and along the paved access to the former pump house. Conditions at boring locations include the following: paved surfaces, gravel at the top of the Holding Basin slope, wooded area between the Holding Basin and the sphagnum bog and the Cooling Pond.

Prior to sampling, each proposed sampling location will be located using a hand-held GPS unit or by scaling off known existing features, and each location will be reviewed for access and general field condition considerations. Pre-decontaminated ("clean") or new sampling equipment, supplies, glassware, etc. will be mobilized to each sampling location, either carried by hand or transported using a wagon sled or using a field vehicle depending on accessibility. Routes to proposed sampling locations will be reviewed to follow general project guidelines related to different zones to be established at the site (eg. Contaminated Soil Zone, Contaminant Reduction Zone, etc.). Actual routes and paths through wooded areas will be determine to most safely access each sampling location, with least disturbance to the surrounding area. Although some limited clearing has been conducted at the site, additional clearing of trees, branches, brush, leaves, etc. may be necessary to access the locations and to create stable platforms for the drilling equipment. Disturbance to surficial soils will be limited, and the use of matting and plywood will be used as necessary to minimize disturbance.

If applicable, all equipment and tools that will enter the restricted area and that might contact radioactive contaminated areas are subject to screening by an HP according to the Radiological Surveys HPP (HP-NMI-05 in the Field Sampling Plan [FSP], RDWP Appendix I) to determine if background levels of radiation exist on the equipment prior to exposure to on-site soils. Additionally, disposable barriers may be applied as directed by the on-site HP or RSO to prevent contaminating equipment and tools while in the restricted area. The driller and consultant personnel are asked to only bring tools and equipment into the restricted area that are deemed essential to complete the task because tools and equipment will be subject to screening by HP and RSO before leaving the restricted area and, depending on impacts and ability to decontaminate, may have to be disposed of if contaminated.

Before entering the restricted area, workers will review and sign the specific radiation work permit for drilling and soil sampling activities and don the required personal protective equipment (PPE) and monitoring equipment as specified in the radiation work permit and/or instructed by the RSO or HP. Prior to initiating work, the staff will consult with the HP and RSO to determine an approach for screening and transporting equipment to the decontamination area and back so that work can progress efficiently.

For locations where a drill rig is utilized, the driller will create an exclusion zone around the drill rig. The exclusion zone does not need to be a physical barrier and may be demarcated with traffic cones. Only the driller and driller's helper should enter the exclusion zone. Other field personnel may enter the zone only when invited and supervised by the driller.

2.2 SAMPLE PROCESSING

At each land-based test boring location, polyethylene sheeting will be placed to create a small, dedicated area to temporarily stage sampling equipment and supplies, and to process the soil samples. Small sample processing areas will be constructed at each drilling/sampling location to process soil samples collected by the drilling rigs.

Refer to the applicable project-Field Sampling Plan (FSP) (Appendix I of the Remedial Design Work Plan, *de maximis,* September 2020), the Standard Operating Procedures (SOPs) located as Appendix I of the FSP, and Quality Assurance Project Plan (QAPP) (Appendix G of the Remedial Design Work Plan, *de maximis,* September 2020) for further details related to sample processing, glassware, preservation, chains of custody, decontamination, and field documentation requirements and procedures for the sample collection activities.

For activities where a drill rig is used, after work areas and processes have been established, drilling will commence with continuous sampling. Soil cores will be extracted and carried to the logging area by the driller or the driller's helper. The boring will be advanced, and the soil cores will continue to be extracted until the final depth of the boring is reached. Once bedrock is encountered, the temporary casing will be set at the depth identified by the field geologist or engineer.

Once the casing is set, rock coring will commence. The driller will use diamond core drilling methods with a wireline core barrel system to allow for the retrieval of rock core in 5 ft. increments. The driller may proceed faster than the field engineer or geologist, so cores might need to be staged in liners near the logging area for soil, or in core boxes for the rock core; however, the driller should not begin advancing the next boring until approved by the field engineer or geologist. After a soil core has been set in the logging area, the core liner will be cut open and logged by the field engineer or geologist using the USCS and following the soil description SOP (NMI-S-006, in the FSP). After rock core has been set into the core box in the logging area, the rock will be classified by the field geologist using the rock core description SOP (NMI-S-006) and the ASTM Standards D2113 and D6032.

If appropriate, soils and rock core will be initially screened with a handheld radiation survey instrument to ensure radiation levels are at a level where the core is safe to handle as determined by the HP and approved by the on-site RSO. If the soil is deemed unsafe by the HP or RSO, other protocols will be followed as directed by the HP or RSO. If the soil is safe to handle without further controls, the soils will be logged by the field engineer or geologist and following the soil description SOP (NMI-S-006, in the FSP). If the soil is deemed unsafe by the HP or RSO, other protocols will be followed as directed by the HP or RSO.

After logging, the soil core rock core will be screened again using the handheld radiation survey instrument by the HP, and the count rate per minute will be logged.

2.3 FOLLOWING PROCESSING

After sample processing is completed, the dedicated sampling equipment will be bagged for disposal and the remaining equipment will be decontaminated prior to reuse. Refer to the Investigative Derived Waste (IDW) Handling and Storage (SOP NMI-005) and Field and Heavy Equipment Decontamination Procedures (SOP NMI-007) Standard Operating Procedures (SOPs)for additional details related to those items.

Following completion of the sampling, the completed piezometer, soil and sediment sampling, or sphagnum bog peat probing locations will be captured with a hand-held GPS unit. Completed sediment and soil sample locations will be marked with a flag or wood stake with flagging attached. Subsequently, all completed piezometer, probing and sampling locations will be surveyed by a professional land surveyor. The elevation of the reference mark on the piezometers will also be determined by the surveyor. Markers will be labeled with the sample location name.

At the end of the sampling day, all soil and sediment samples collected will be screened by the onsite Radiological Laboratory to determine the concentration and total radioactivity prior to shipment. Gamma spectroscopy will be used to identify the isotope and assign activity present in each sample. The samples will be grouped to comply with Department of Transportation (DOT) and International Air Transport Association (IATA) guidelines. This data will also be provided to the receiving laboratory for approval prior to shipment.

If applicable, each time staff or equipment leaves the restricted area, they must be screened out of the restricted area under the guidance of the HP following the Personnel Monitoring and Decontamination HPP (HP-NMI-06, in the FSP) and sign out of the specific radiation work permit. All waste and PPE generated during the field event should be bagged appropriately and will be handled and dispose of as directed by the RSO and described in the investigation derived waste (IDW) handling and storage SOP (NMI-5 in the FSP) and Radioactive Waste HPPs HP-NMI-19 and HP-NMI-27 in the FSP. If soil IDW is generated that can be placed back in the borehole, it will be handled and stored following the IDW handling and storage SOP (NMI-5 in the FSP) and Radioactive Waste HPPs HP-NMI-19 and HP-NMI-27 in the FSP.

Prior to equipment and tools being released from the NMI site, additional decontamination may be needed and screening with swab samples will be required as described in the Heavy Equipment Decontamination and Free Release HPP (HP-NMI-25) and determined by the on-site RSO.

3. Implementation Procedures: Test Borings for Holding Basin Containment Wall Design and Construction and Groundwater Sampling and Testing

3.1 TEST BORINGS FOR CMTS, OBSERVATION WELLS AND CROSS-HOLE SEISMIC TESTING

A total of 8 borings will be continuously sampled from the ground surface to the top of bedrock. Each sample will be collected by split spoon samplers using the standard penetration testing (SPT) testing procedure. The boreholes will be advanced using Sonic drilling methods or drive and wash drilling methods. These borings will be advanced a minimum of 20 to 50 ft. into bedrock. To allow for down-hole geophysics after completion of each of these 8-boreholes, temporary casing will be set through the till and weathered rock interface such that no weathered or highly fractured rock will fall into the borehole or jam the down-hole geophysics instrumentation.

Six of these boreholes will be completed with the installation of Continuous Multi-level Tubes (CMTs). The open zone or channel of each CMT will be determined based on the down-hole geophysics. Up to 7-channels will be used to allow for discrete water levels of the overburden, weathered rock, upper rock and deeper rock zones. Selected channels of the CMTs will be duplicated. There are seven available channels in a CMT. Certain formations, such as the weathered rock zone, may have two channels dedicated to the same layer so sampling and continuous water level monitoring can be conducted on the same layer at the same time.

The other two continuously sampled borings will be part of the cross-hole seismic arrays being installed. These two borings will be the center boring of each three-hole array. The location of the PVC and type of grout will be determined based on the down-hole geophysics for each of these seismic arrays.

The CMT boreholes and the two center boreholes for the cross-hole seismic arrays will be advanced following the approach in Standard Operating Procedure (SOP) NMI-S-004, in the FSP. This approach, in summary, consists of the following:

1. The CMT and two cross-hole seismic boreholes will be advanced using Rotosonic drilling methods with a 4.75-inch diameter core barrel and 6-inch diameter override casing (or similar), which will be advanced using 2 ft. sections at a time to allow for the sampling using SPT methods. Both SPT samples will be collected using the Split spoon sampler, and the rotosonic core will be retrieved as part of the advancement of the borehole so over-sized gravel or cobbles will be adequately characterized. In the event there is highly variable SPT (loose versus dense) blow counts within the same lithology at the same elevation within multiple boreholes, a drive and wash drilling rig will be mobilized to confirm if the variability is due to the rotosonic drilling action or typical variability to the subsurface soils.
2. The SPT samples will be driven using a calibrated auto-hammer. The boring will be advanced through the overburden and approximately 2 to 3 feet into competent bedrock as determined by the field engineer or geologist in coordination with the driller and project manager. SPT blow counts will be recorded, and each split spoon sample will be logged by the field geologist in accordance with Unified Soil Classification System following guidance in SOP NMI-S-006. After logging, soil cores will be containerized in labeled IDW drums as described in SOP NMI-005. The field engineer or geologist will additionally monitor and document drilling rates and

water losses if it is necessary for the driller to use water during drilling (e.g. to keep heaving sands from entering the sonic casing). The SPT sampling methods will also be conducted in conformance with ASTM D1586.

3. Once the override casing is properly seated approximately 2 to 3 feet into competent bedrock, the driller will retool the drilling rig and advance a 3.75-inch diameter (HQ) or 4.8-inch diameter (PQ) (or similar) bedrock borehole using wireline coring methods. During wireline coring, the field geologist will inspect the rock cores for rock type, fracture characteristics and weathering following the guidance in SOP NMI-S-006. Rock cores will be containerized in labeled drums per SOP NMI-005. Additionally, the field geologist will continue to monitor drilling rates and water loss will be tracked as a minimum volume to be removed during well development. The rock core drilling and description will be conducted in general conformance with ASTM D2113 and D6032, respectively.

4. Wireline coring will advance to a depth of approximately 20 to 50 feet below the top of bedrock for the CMTs and cross-hole seismic holes.

5. After reaching the final boring depth, the casing will remain in the borehole and the driller will move onto the next borehole. The open borehole with the casing is now ready for the down-hole geophysics to be completed as discussed in PDI HB-1 and HB-3. The down-hole geophysics will be used to determine the location(s) of water bearing fractures as well as the location of fractures inferred from the rock cores and water loss to the formation observed during coring as a function of depth. The location of each channel of the CMTs will be determined considering all this data.

6. The CMTs will be installed in accordance with the CMT specifications, guidance in SOP NMI-GW-003, in the FSP, and final construction recorded by the field engineer or geologist, including top and bottom of each CMT channel, top and bottom of filter pack, quantities of filter pack sand, choker sand (if used), bentonite chips (if used), and bentonite powder and cement used in the cement/bentonite grout.

7. Observation wells and the other cross-hole seismic locations will be installed in separate boreholes located adjacent to three of the CMTs and seismic holes, respectively. The observation wells and cross-hole seismic locations will be advanced using Rotosonic drilling methods with a 4.75-inch diameter core barrel and 6-inch diameter override casing (or similar), which will be advanced using 5 to 10 ft. sections at a time. Samples will be collected to supplement the samples from the SPT samples. The wells will be advanced to the designated depths based on results from the down-hole geophysical testing. The crosshole boreholes will be advanced to 50 ft. into the bedrock.

8. The following describes the observation well construction.

   - Bentonite chips or a mixture of bentonite chips and sand from the bottom of the borehole to approximately 1-foot below the proposed bottom depth of the well screen. The 1-foot internal between the top of the chips and the bottom of the well screen should be filled with #00 “choker sand” to prevent fines from the bentonite entering the well screen;

   - 5- or 10-foot long, 2-inch diameter, 10-slot Schedule 40 polyvinyl chloride (PVC) well screen (length and location determined based on location(s) of inferred water bearing fractures);

- 2-inch diameter schedule 40 PVC riser from the top of the well screen to the ground surface;
- Morie #0 sand filter pack placed from the bottom of the well screen to 2 feet above the top of the well screen;
- One foot of choker sand (Morie #00) overlaying filter pack;
- Three (3) feet of bentonite chip seal overlaying choker sand;
- Tremied cement/bentonite grout mixture from the bentonite seal to the ground surface after the bentonite chip seal has sufficiently hydrated; and
- Flush-mount or standpipe protective casing to prevent surface water inundation and provide security

9. A minimum of 48 hours after installation of the wells and the CMTs, the screened interval will be developed using a surge block equipped with a check valve (e.g., Waterra inertial pump) to flush the filter pack, and then the screened interval will be purged using a submersible pump or bladder pump. The screened interval will be considered developed when turbidity readings are below 5 NTUs or at least five screened interval volumes total of purge water have been removed (see SOP NMI-GW-002) in addition to the water lost to the formation during drilling. Purge water from the well will be containerized in labeled drums or fractionation tanks in accordance with SOP NMI-005.
10. After completing development of the three new monitoring wells (HA20-CMT-3(OW), HA20-CMT-5(OW), and HA20-CMT-6(OW)), and each CMT channel, the wells and CMT channels will be purged using the low flow sampling pump (submersible or bladder pump) and sampled using a flow-through apparatus in accordance with sampling procedures outlined in in SOPs NMI-002, NMI-003, and NMI-GW-010. Samples will be collected for the following analytes and submitted a certified analytical laboratory in accordance with chain of custody and sample shipping procedures listed in SOP NMI-010.
    - 1,4-dioxane via USEPA Method 8270 selected ion monitoring (SIM)
    - Volatile organic compounds (VOCs) via USPEA Method 8260
    - Total and dissolved uranium, arsenic, cobalt, manganese, and thorium via USEPA Method 6020A inductively coupled plasma – mass spectrometry (ICP-MS)
11. The cross-hole seismic boreholes will be completed by installing 3-inch diameter Schedule 40 PVC casing in each borehole of the crosshole array. The PVC casing will have a bottom cap and the bedrock portion of the cased section will be backfilled with rigid grout. The overburden section of each crosshole borehole will be backfilled with non-rigid grout in accordance with ASTM D4428. Details of the seismic testing is provided in Appendix C, PDI HB-2.

3.2 TEST BORINGS FOR EVALUATING SOIL FOR BACKFILL

This section describes the borings proposed to evaluate the soil characteristics on the western slope for purposes of using the soil for backfill on the property following the excavation of the contaminated soil.

The borings proposed for characterizing soil for backfill as outlined in PDI SSS-5 in Appendix A will be drilled using similar methods as described above. These borings will be terminated at a depth of 10 ft.

below groundwater and will not penetrate bedrock. Wells will also be installed following the same methods as described above.

3.3 BOREHOLE GEOPHYSICS

This section describes the borehole geophysics to be conducted at each of the 6-CMT boreholes and two of the seismic crosshole borings. Borehole geophysical logging will be conducted to confirm the locations of fractures and/or fracture zones and identify water-bearing fractures in each CMT borehole and within the two center boreholes of the seismic crosshole arrays. The CMT channel sections will be determined using the borehole geophysics as well as the observations made of the collected rock core. A detailed description of the borehole logging including how each downhole tool will be used to evaluate the location and nature of the intercepted fractures is provided Appendix C PDI HB-1, Section 4.3. The geophysicist is expected to mobilize to the site two times for the work. Four boreholes will be done during each mobilization. This is due to the limited amount of drill casing available. The casing needs to remain in the ground until the down-hole work is complete.

1. Geophysical logging will start no sooner than 48-hours after the completion of drilling and development and will be conducted by a qualified subcontractor.

2. The geophysical logging will include the caliper log, fluid temperature and resistivity, acoustic and optical televiewer, and heat pulse flow meter (HPFM) testing under ambient and pumping conditions. The borehole geophysical data will be used in conjunction with field observations during drilling (e.g., water production) to identify intervals with significant inflow/outflow.

3. The borehole data collected during geophysical logging will inform the selection of borehole intervals for CMT channels, and for the construction of permanent monitoring well(s) within the boreholes located adjacent to the three deeper CMT installations. Additionally, the data will be used for mapping the fractures encountered within the two crosshole arrays.

4. The small amounts of IDW water generated during the pumping associated with HPFM logging will be containerized in a steel 55-gallon drum (or other suitable container) and combined and managed with the IDW generated during drilling and well development.

3.4 HYDROGEOLOGIC TESTING AND ANALYSIS

A series of tests are planned to estimate the hydraulic conductivity of each hydrogeologic unit within the area of the proposed Holding Basin containment wall. Slug testing will follow procedures outlined in SOP NMI-GW-019. Slug tests will be conducted on each of the observation wells and on each CMT interval that has two designated channels for the same screened interval. In this case, one channel can be used to pump water from, and the other channel screened in the same interval will be used for monitoring water levels using pressure transducers.

Additional testing will include short duration pumping test of each of the observation wells. Transducers will be set within each channel of the adjacent CMTs and each of the OWs along the alignment of the proposed HB containment wall. The pumping tests will be less than 8 hours in duration and will be intended to provide pumping and response data for evaluating the hydraulic conductivity of each layer and if there are vertical upward or downward gradients between layers under static and pumping conditions. This data will be used in conjunction with the chemical testing data of each hydrogeologic unit to evaluate the potential mass flux of contaminants of concern.

3.5 DEMOBILIZATION

This section describes the steps necessary for the demobilization of equipment between field activities.

1. All waste and PPE generated during the field event should be bagged appropriately and will be handled and dispose of as directed by the RSO and described in the investigation derived waste (IDW) handling and storage SOP (NMI-5 in the FSP) and Radioactive Waste HPPs HP-NMI-19 and HP-NMI-27 in the FSP. Drummed soil and water is to be transported to the designated area for temporary storage prior to transport for disposal off-site. All this material is classified as IDW, and will be handled and stored following the IDW handling and storage SOP (NMI-5 in the FSP) and Radioactive Waste HPPs HP-NMI-19 and HP-NMI-27 in the FSP.
2. Prior to equipment and tools being released from the NMI site, additional decontamination may be needed and screening with swab samples will be required as described in the Heavy Equipment Decontamination and Free Release HPP (HP-NMI-25) and determined by the on-site RSO.