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MOUNT POLLEY MINES

Tailings Storage Facility – Stage 7
2011 Construction Monitoring Manual

Submitted to:
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Vancouver, BC

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1.0 INTRODUCTION

1.1 Project Overview

Mount Polley Mine is a copper and gold mine owned by Imperial Metals Corporation and operated by Mount Polley Mining Corporation (MPMC). The site is located 56 km northeast of Williams Lake, British Columbia. Mount Polley began mine production in 1997 and operated until October 2001, when operations were suspended for economic reasons. In March 2005, the mine restarted production and has been in continuous operation since. The current mill throughput is approximately 20,000 tpd. Tailings are deposited as slurry into the tailings storage facility (TSF). The TSF is comprised of one overall embankment that is approximately 4.2km in length. The embankment, based upon original separate embankments, is subdivided into three (3) sections; referred to as the Main Embankment, Perimeter Embankment and South Embankment. Heights vary along the embankment and are approximately 45 m, 27 m, and 17 m respectively (based upon the Main, Perimeter and South nomenclature). The design and construction monitoring of the TSF embankments from mine start up to early 2011 had been completed under the direction of Knight Piésold Limited (KP). AMEC Earth and Environmental, a division AMEC Americas (AMEC) assumed the role of engineer of record for the TSF embankment as of 28 January 2011. The overall embankment has incorporated a staged expansion design utilizing a modified centerline construction methodology. The latest expansion was completed in August 2010, which entailed a four (4) m embankment raise to a crest elevation of 958 m.

1.2 Construction Schedule

The optimal construction season for placement of the moisture-sensitive till core material at the Mount Polley Project site typically falls between May and September. The 2011 Stage 7 Embankment raise (2.5 m to crest El. 960.5 m) is targeted for completion by the end of September 2011. Two-dimensional limit equilibrium stability analyses of the dam were undertaken to validate the stability of the 2011 raise, the results of the stability analyses is summarized in Appendix A.

For the 2011 construction season, MPMC will use a contractor to carry out the majority of earthworks associated with the annual raise. Haulage of waste rock and cell construction using tailings will be performed by MPMC.

1.3 Construction Monitoring

The general level of construction monitoring and QA/QC performed in previous years is to be continued, but MPMC will take a greater role and responsibility in this regard than has been previous practice. Specifically, MPMC will engage its own engineers, technicians, or summer student to provide full-time construction monitoring and field inspection. This monitor will, working under the direct supervision of Mr. Luke Moger of MPMC, produce daily progress/technical reports for MPMC and for AMEC.

At the commencement of construction, AMEC will provide approximately ten (10) days of full-time dayshift supervision during which AMEC will verify that construction methods consistent with design expectations are employed during dam construction, material specifications are adhered to and that the monitoring and testing requirements are understood by MPMC

personnel, and are being satisfied. This time would also be used to make certain that daily technical/progress reports are being completed properly, site and AMEC home office responsibilities are thoroughly understood by all parties, and lines of communication between the site and AMEC office-based support are clearly established and functional.

Once AMEC is satisfied that the design intent is being met, and that MPMC's field inspectors are fully trained and prepared to undertake the construction monitoring and reporting role with primarily remote support required by AMEC, AMEC will reduce monitoring presence to monthly visits (though actual timing will vary somewhat with visits timed for key construction activities such as foundation preparation and approval, and till core trench approval). To be successful, this arrangement will require MPMC's field inspector, devoted full-time to the dam construction project, to have good support and cooperation from senior Mt. Polley personnel, and from the Mt. Polley construction team, along with regular technical support as needed from AMEC project personnel.

Todd Martin, Senior Geotechnical Engineer and Daryl Dufault, Project Manager, will visit the site during construction activities. The objective of these senior personnel visits will be to view first-hand the construction, liaise in person with the MPMC construction monitor and other project personnel, discuss any issues with construction or design, and get a "look-ahead" so that any future upcoming issues can be proactively identified and resolved. These visits will also be used to ensure that a good working relationship is being maintained between AMEC and MPMC project personnel, which will be critical to AMEC having the requisite confidence to provide as-built report sign off following the end of each stage of dam raising.

1.4 Purpose of Manual

AMEC has prepared this manual for use by MPMC's on-site personnel and for AMEC's engineering support personnel, who will maintain close communication with the site throughout the construction season and carry out periodic site visits as required.

The objectives of this manual are as follows:

- Summarize the annual construction plans.
- Detail the technical specifications for the dam construction as presented in the design drawings.
- Outline the requirements for monitoring and reporting of the dam construction.
- Present the proposed performance monitoring procedures and design criteria.
- Clearly define the roles and responsibilities of both MPMC and AMEC personnel associated with the 2011 embankment construction activities.

2.0 CONSTRUCTION MONITORING AND TESTING REQUIREMENTS

2.1 Construction Activities

The 2011 construction of the TSF embankment will include the following activities:

- Foundation preparation abutment extensions to expose suitable foundation materials, including excavation of the cutoff trench.
- Development of glacial till borrow areas.
- Development of non-acid-generating (NAG) rock borrow areas (assumed to be mine rock).
- Development of the sand and gravel borrow area or production of sand and gravel from mine waste rock.
- Excavating, hauling, placing, and compacting acceptable structural fills and waste zones to raise the dam core and shell in accordance with design specifications.

The guidelines for quality control testing procedures outlined in this manual are to be observed during construction to satisfy and document that the dam is constructed in accordance with the design. The intent of this manual is to be clear and concise. If there is anything provided that raises questions amongst MPMC personnel, please immediately contact AMEC for clarification. The manual should allow for pragmatic and cost-effective construction that meets design requirements and, as such, any items found to be difficult to interpret or follow by MPMC should be immediately flagged and addressed.

2.2 Monitoring and Testing

The general monitoring and testing requirements for construction of the 2011 construction of the TSF embankment correspond to the construction activities outlined in Section 2.1; these general requirements are:

- Review and confirm that the prepared foundation areas are acceptable for support of structural fills.
- Review and confirm that the borrow materials are acceptable for use as structural fill.
- Monitor and test (where required) the placement and compaction of accepted structural fill.
- Monitor dam performance by reading and recording instruments in the dam(s) and preparing cumulative change and time plots of the results.
- Monitor drain performance by measuring flow and inspecting water quality.

These requirements are typical for similar structures and are consistent with past procedures at the mine. Construction monitoring of activities such as placement of structural fills and foundation preparation will proceed on a continuous basis. Schedules based on minimum test frequencies per unit volume of compacted structural fill will be followed for the various field and laboratory tests, with additional tests to be performed as required to reassess out-of-compliance results or at the discretion of AMEC.

The results of the monitoring and testing program will be reported to the appropriate parties (MPMC, AMEC) as they are obtained.

2.3 Organization and Responsibilities

2.3.1 Overall

At the commencement of the 2011 construction season, AMEC will provide a dayshift supervisor for approximately a ten (10) day period (longer if required), during which AMEC will monitor the construction methodology, material testing procedures, instrumentation monitoring frequency, and daily technical/progress reporting to ensure that the design specifications are satisfied. Drain performance will also be observed and reported.

After AMEC is satisfied that the design specifications intent is being met, site and AMEC home office responsibilities are thoroughly understood by all parties, and that the MPMC construction monitor is fully trained and capable to monitor and report on construction, MPMC will undertake day-to-day quality control for the construction. AMEC will continue to provide remote support though out the project, and conduct monthly site visits (actual timing of site visits will vary to coordinate with critical construction activities) to monitor ongoing progress on the embankment construction. To be successful, this arrangement will require that the MPMC field inspector is dedicated full-time to the dam construction project with support and cooperation of senior MPMC personnel, and from the MPMC construction team.

Figure 2.1 outlines the overall organizational structure for Stage 7 TSF embankment construction, while the responsibilities associated with the construction monitoring is summarized in Table 2.1.

2.3.2 MPMC Field Inspector

MPMC is to provide a full-time dayshift field inspector to monitor daily embankment expansion construction. The MPMC field inspector is to have support and cooperation from senior MPMC personnel and the construction team.

The responsibilities of MPMC field inspector will include:

- Monitor and photograph daily construction activities related to TSF embankment.
- Prepare daily technical/activity reports. (See Appendix B).
- Measure and record instrumentation readings on a weekly basis.
- Document and conduct material testing as per specifications.
- Report any non-compliance issues observed to AMEC and MPMC.

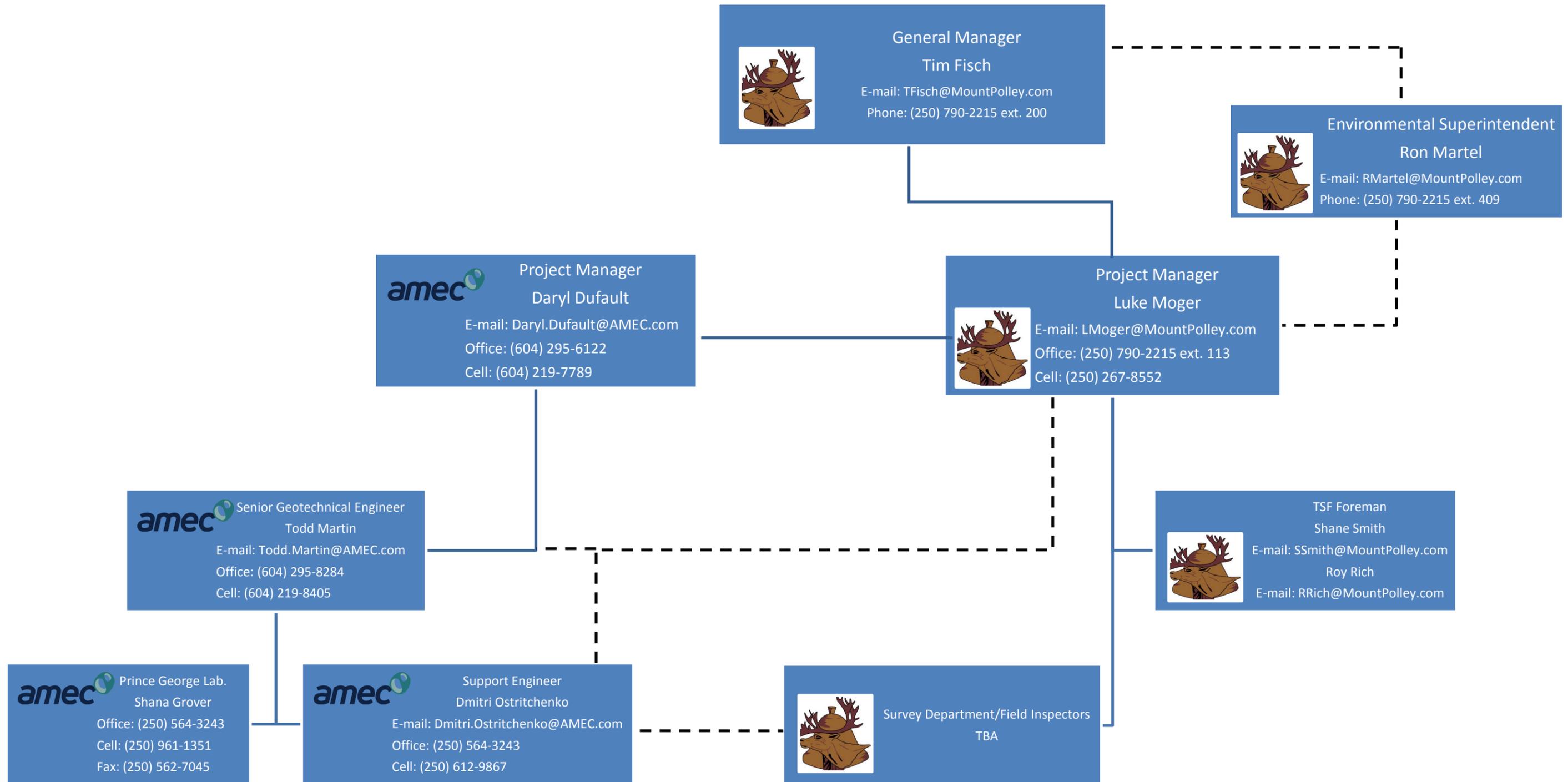


Figure 2.1: 2011 Construction Organization Chart

Table 2.1: Construction Monitoring Tasks

No.	Tasks Description	Responsibility
1.0	Foundation Preparation	
1.1	<u>Abutment Extensions:</u> Review of exposed soil and or rock conditions and confirmation that suitable dense, undisturbed, native soil, or sound bedrock conditions are exposed for dam construction.	AMEC
1.2	<u>Core Trench Construction:</u> Review of exposed soil and/or rock conditions, perform test pits as required to confirm the thickness of glacial till over bedrock along the core trench alignment. Review of core trench excavation and confirmation of proper excavation slopes. Direct rock excavation and cleaning work as deemed necessary.	AMEC
1.3	<u>Approval:</u> Review the provided photos of the foundation preparation and provide approval.	AMEC
2.0	Review of Borrow Areas and Materials	
2.1	<u>Glacial Till Borrow Pit:</u> <ul style="list-style-type: none"> Review cut slopes. Collect and prepare samples of borrow material for testing to assess both suitability of materials and to evaluate the Standard Proctor maximum dry density and optimum moisture content of the material. Report test results to AMEC and MPMC's Project Manager as they are obtained. 	MPMC
2.2	<u>NAG Rock Source:</u> <ul style="list-style-type: none"> Review the selective borrowing / classification of material for the coarse NAG rockfill. Visual verification of the material for conformance to the gradation specifications. Report observation and test results to MPMC's Project Manager as they are obtained. 	MPMC
2.3	<u>NAG Rock Source:</u> <ul style="list-style-type: none"> Monitoring the selective borrowing/classification/processing of material for the fine NAG rock transition zone. Sampling and testing the material for conformance to the gradation specifications. Report observation and test results to AMEC and MPMC's Project Manager as they are obtained. 	MPMC
2.4	<u>NAG Crushing Operation:</u> <ul style="list-style-type: none"> Monitoring the filter sand and gravel crushing and decking operation. Testing the material for conformance to the gradation specifications. Report observation and test results to AMEC and MPMC's Project Manager as they are obtained. 	MPMC
2.5	<u>Materials Approval:</u> <ul style="list-style-type: none"> Conduct quality assurance testing. Approve the materials to be used during construction of the embankment. 	AMEC
3.0	Review of Structural Fill Placement	
3.1	<u>Zone S:</u> <ul style="list-style-type: none"> Review and confirm that the locations of zone interfaces are in their correct locations. Confirm the width of the core zone is sufficient. Test the placed and compacted Zone S structural fill for in-place density. Collect samples for moisture content determinations and density (rock content) corrections. Collect samples of fill for confirmation index testing. Report observations and test results to AMEC and MPMC's Project Manager as they are obtained. 	MPMC
3.2	<u>Zone C:</u> <ul style="list-style-type: none"> Review and confirm that the NAG rock is in conformance to the gradation specifications. Observe and confirm the compaction specification is followed. 	MPMC
3.3	<u>Zone T:</u> <ul style="list-style-type: none"> Review and confirm that the NAG transition zone rock is in conformance to the gradation specifications. Observe and confirm the compaction specification is followed. Report observations and test results to AMEC and MPMC's Project Manager as they are obtained. 	MPMC
3.4	<u>Zone F:</u> <ul style="list-style-type: none"> Review and confirm that the zone interfaces are in their correct locations. Confirm the width of the filter zone is sufficient. Review and confirm that the crushed fine filter material is in conformance to the gradation specifications. Confirm via hand-excavated test pits that segregation of filter sand and gravel is not occurring. Report observations and test results to AMEC and MPMC's Project Manager as they are obtained. 	MPMC
3.5	<u>Zone U:</u> <ul style="list-style-type: none"> Review and confirm that the zone interface is in the correct location. Collect soil samples for gradation analysis. Monitor material reworking to ensure proper distribution within the cell. Report observations and test results to AMEC and MPMC's Project Manager as they are obtained. 	MPMC
4.0	Dam Performance Monitoring	
4.1	Coordinate weekly readings of vibrating wire piezometers and slope inclinometers during the construction; enter the data into a spreadsheet and submit the recorded data to AMEC for analysis. Also, prepare summary table of R_v values for till fill piezometers. Check piezometer levels against threshold levels, and immediately report any values approaching these levels.	MPMC
4.2	Review submitted weekly readings, prepare associated graphs and analyze the collected data.	AMEC
4.3	Report monitoring results to AMEC and MPMC's Project Manager as they are obtained.	AMEC
5.0	Construction Monitoring	
5.1	Meeting daily with MPMC's TSF Foreman and Project Manager to review the construction program, concerns, upcoming work, and other relevant issues.	MPMC
5.2	Meeting monthly with the MPMC Field Inspector, Project Manager and TSF Foreman.	MPMC/AMEC
5.3	Directing the survey personnel to address the survey requirements, results, etc.	MPMC
5.4	Addressing any concerns or out-of-compliance situations observed and recorded during construction.	MPMC/AMEC
6.0	Record Keeping	
6.1	Maintain daily construction site photographic record of construction activities.	MPMC
6.2	Completing daily construction reports, and delivering a copy to MPMC's Mine Superintendent, and by email to AMEC's Support Engineer.	MPMC
6.3	Completing monthly construction reports, with copies to MPMC's Project Manager and AMEC's Project Manager and Senior Geotechnical Engineer.	AMEC

2.3.3 AMEC Support Engineer

The AMEC Support Engineer will provide full-time construction monitoring at the commencement of the Stage 7 construction. After the MPMC Field Inspector has achieved sufficient confidence and commensurate approval, the AMEC Support Engineer will provide remote assistance by reviewing daily reports and instrumentation results as required. The AMEC Support Engineer will also perform monthly site visits (actual frequency to be determined by site performance) to verify construction methods and specifications are being adhered to.

The responsibilities of AMEC Support Engineer are as follows:

- Provide remote assistance to MPMC Field Inspector on an as-needed basis.
- Review daily construction reports, communicate and document any concerns arising from the review to AMEC Project Manager and/or Senior Geotechnical Engineer.
- Review and interpretation of instrumentation reading plots, and communication of any concerns to AMEC Project Manager and/or Senior Geotechnical Engineer.
- Carry out monthly site visits to monitor construction progress and perform quality assurance testing.
- Prepare monthly progress reports summarizing construction activities, test results, and milestone achievements.
- Prepare site As-built/Annual Review Report.

2.3.4 AMEC Project Manager

AMEC's Project Manager will have overall responsibility for AMEC's role with upcoming and future dam raising projects. He will review all monthly construction progress reports. He will liaise with the AMEC Senior Geotechnical Engineer and MPMC Project Manager to review any problems that may arise.

The AMEC Project Manager will liaise with the AMEC Support Engineer and the MPMC Project Manager (and through him the MPMC Field Inspector), and will make site visits as deemed necessary during construction. The exact timing and duration of the site visits will be determined in consultation with MPMC's Project Manager so that critical aspects of the construction can be viewed during these visits.

The responsibilities of AMEC's Project Manager will include:

- Review weekly construction reports prepared by the AMEC Support Engineer and MPMC Field Inspector, and document and communicate any concerns arising from these reviews to MPMC's Project Manager and AMEC's Senior Geotechnical Engineer.
- Review instrumentation interpretations and communication of any concerns to MPMC's Project Manager and the AMEC Senior Geotechnical Engineer.
- Review monthly progress reports prepared by the AMEC Support Engineer and document and communicate any concerns arising from these reviews to MPMC's Project Manager and AMEC's Senior Geotechnical Engineer.

- Carry out periodic site visits as appropriate during the construction season, timed to coincide with critical aspects of the construction.
- Identification, review, and approval (in writing) of any design changes determined to be required by AMEC and/or MPMC's Project Manager.

2.3.5 AMEC Senior Geotechnical Engineer

AMEC's Senior Geotechnical Engineer will serve as the engineer of record for the Mount Polley TSF embankment. He will review weekly construction and instrumentation reports as required and review the As-built/Annual Review reports. AMEC's Senior Geotechnical Engineer will also conduct a site visit early in the construction season to become familiar with the site.

2.3.6 AMEC Soils Laboratory – Prince George

Confirmatory geotechnical index testing of borrow soils and filter material will be carried out in AMEC's Prince George office soils laboratory. AMEC's laboratory technician, based in Prince George, will be responsible for carrying out the required testing and reporting of results to the AMEC Support Engineer.

2.3.7 Soils Testing – Mount Polley Site

The Mount Polley site will have the capabilities to carry out sieve analysis for grain size determination of all granular materials as per the ASTM Standards presented in Appendix C. All test results will be completed by the MPMC Field Inspector, and are to be submitted to AMEC Support Engineer for review and approval.

2.3.8 MPMC Project Manager

MPMC's Project Manager shall assume overall responsibility for MPMC's construction management and MPMC's supervision, monitoring, and quality control testing activities when AMEC is not on site. This person shall ensure that the design specifications and the QA/QC requirements as outlined in this manual are adhered to. In the absence of the MPMC Project Manager, the TSF Foreman shall assume this role.

MPMC's Project Manager shall liaise with AMEC's Support Engineer, and AMEC's Project Manager to discuss construction progress, any problems encountered and their resolution, and the timing of site visits by AMEC personnel to view the construction.

The MPMC Project Manager will address any concerns raised by the Field Inspector/Support Engineer, including, but not limited to, the following:

- Placement of material unacceptable as dam fill.
- Unacceptable construction procedures (excessive lift thickness, inadequate compaction, inadequate foundation preparation, etc.).
- Non-compliance issues identified by the AMEC Support Engineer and MPMC Field Inspector that are not immediately rectified by the construction forces, be they those of the contractors or MPMC.

2.3.9 MPMC Environmental Superintendent

The MPMC Environmental Superintendent will address any concerns raised by the Field Inspector/Support Engineer as related to any potential environmental issues or concerns. Moreover full compliance with existing permits will be assessed and confirmed by the MPMC Environmental Superintendent.

2.3.10 MPMC Survey Crew

Survey control for the dam construction will be provided by MPMC. The MPMC surveyors will be responsible for the following tasks:

- Locating the centerline and cutoff trenches for the Dam as identified on the appropriate AMEC construction drawings.
- Establishing and maintaining upstream and downstream slope stakes as required during dam construction.
- Locating the upstream and downstream toes of the slopes in the field, based on the identified centerline locations.
- Providing location and elevation data as required by field staff.
- Collecting data required for the as-built drawings, including a complete survey of the cutoff trench, dam crest, and dam toe as constructed.

The Field Inspector will record survey data as provided for compacted density test locations, etc. in the daily construction reports.

3.0 MATERIALS TESTING AND CONSTRUCTION INSPECTION

3.1 General

The detailed technical requirements for the 2011 raise of the TSF Embankment are shown in attached Drawing 560.2011.01 through 560.2011.06. The technical requirements for the construction are indicated on attached drawing and are restated in Sections 3.3 through 3.6.

3.2 Estimated Fill Volumes

Table 3.1 below summarizes the estimated material quantities for Stage 7 expansion.

Table 3.1: Stage 7 Expansion (El. 960.5) Estimated Fill

Section	Estimated Fill Volumes (M ³)				
	Zone C	Zone T	Zone F	Zone S	Zone U
Main Embankment	55,000	6,000	6,000	17,000	77,000
Perimeter Embankment	87,000	9,000	9,000	27,000	144,000
South Embankment	47,000	5,000	5,000	15,000	77,000
Total	189,000	20,000	20,000	59,000	298,000

Notes:

1. Volumes are estimated from Drawings 560.2011.02 through 560.2011.06, and are rounded up to the nearest 1000 m³.
2. No settlement allowance has been considered.
3. Quantities are based on neat construction lines; with no contingency or allowance for overbuild.

3.3 Foundation Preparation, Inspection, and Approval

3.3.1 General

Foundation preparation for the 2011 dam construction along the abutment extensions are to be completed to the following specifications:

- All topsoil, organic material, soft or loose soils, and other deleterious materials are to be removed from the foundation area.
- The exposed abutment foundation subgrade will consist of dense to very dense glacial till, or bedrock.
- The abutment subgrade shall be proof-rolled with a smooth drum compactor.

Foundation preparation for the abutment cutoff trench extensions will be completed to the following specifications and in accordance with Detail 1 on Drawing 560.2011.03 in Appendix C.

- The cutoff trench shall extend a minimum of 0.5 m into the undisturbed glacial till, where the glacial till is in excess of 1 m thick.
- Where less than 1 m thickness of glacial till exists, the cutoff trench shall extend to sound bedrock with removal of weathered or fractured bedrock completed to the approval of the AMEC Support Engineer. Additional specifications related to bedrock encountered in the cutoff trench are provided in Section 3.3.4 below.

- The thickness of glacial till at the cutoff trench is to be confirmed by performing test pits at locations along the cutoff trench alignment selected by the AMEC Support Engineer.
- The cutoff trench shall be constructed with a minimum 2 m width at its base. Where bedrock is encountered, the AMEC Support Engineer may direct that overburden be removed for the full 5 m width of the Zone S core.
- The cutoff trench shall have side slopes of 1H:1V or flatter. Steeper slopes may be accepted in bedrock at the discretion of the AMEC Support Engineer.
- Surface runoff water or groundwater shall not be permitted to collect in the cutoff trench.

Prior to placement and compaction of structural fill in the cutoff trench excavation, the Field Inspector will send photos to the AMEC Support Engineer for review and, as appropriate, approval. The Field Inspector will verify that the cutoff trench is founded in the minimum specified depth of glacial till (and will conduct or oversee soil probing as required), or that the cutoff trench is founded on sound bedrock. Cutoff trench excavation inspections will be performed as required, and inspection dates and results will be tracked by the Field Inspector on copies of the construction drawings or by station number. MPMC surveyors will provide a survey pick-up of the cutoff trenches and maintain a project database for use in the as-built documentation.

3.3.2 Tie-In to Existing Till Core

The 2011 raise of the core zones of the embankment will involve placement of structural fill on the existing dam crests. On the existing dam crests, removal of the crest running surface (by grading it off the upstream edge of the dam crest) may be required, followed by removal and/or drying and re-compaction of any loose, over-wet zones within the till fill.

3.3.3 Foundation Preparation

The dam foundation areas for 2011 construction will be drained (where required) and will be stripped of all organic material, loose or soft soils, and all other deleterious materials. These unacceptable materials will be wasted in an approved manner, in an approved location as designated by MPMC personnel. Salvageable topsoil and organic material that could be used for reclamation will be stockpiled in appropriate locations for future use, as directed by MPMC's Project Manager.

Suitable dense subgrade for Zone S will be exposed for dam construction, then proof-rolled and scarified (if deemed necessary by the Support Engineer) prior to placement of structural fill. The exposed subgrade is to be protected from moisture softening due to surface water runoff or excessive precipitation.

The cutoff trench location will be identified in the field by surveyors, and the design vertical (depth) extent of the cutoff in native soil or weathered bedrock verified by test pits or soil probes that extend below the minimum specified trench depth (see Detail 1, Drawing 560.2011.03). The cutoff trench excavation will be protected from moisture softening due to surface water inflow or excessive precipitation. Water seeping into the cutoff trench excavation will be removed by pumping, and will not be permitted to collect and remain in the excavation.

Prior to placement and compaction of structural fill in the cutoff trench excavation, the Field Inspector will send photos of the prepared foundation to the AMEC Support Engineer for review and, as appropriate, approval. Inspections will occur as foundation areas are completed and the approval will be documented as part of the daily construction reports. Field copies (11X17" size) of the construction drawings and a photographic record will be maintained to identify foundation areas that have been inspected and approved, clearly indicating their date of inspection. Areas not approved for placement of structural fill by the AMEC Support Engineer are not to be covered with fill under any circumstances to avoid having to remove/replace materials.

The Support Engineer will report on the approved or unacceptable foundation areas to MPMC's Field Inspector, Project Manager and TSF Foreman. The Field Inspector will record the location and state of any unacceptable prepared foundation areas in the daily construction report. The contractor will be required to perform the appropriate work to the satisfaction of the AMEC Support Engineer.

3.3.4 Special Considerations for Bedrock Exposed in Till Cutoff Trench

If bedrock is encountered in the dam foundation cutoff trench, special considerations exist and special bedrock treatment measures may be required. Guidelines and procedures for dealing with bedrock exposed in the cutoff trenches are as follows:

Weathered or fractured bedrock is defined as bedrock that can be readily excavated by a dozer or a hoe excavator equipped with a digging bucket and that, based on visual assessment, is highly pervious to groundwater flow due to the presence of fractures/joints/faults. Sound (competent) bedrock, is defined as bedrock that can be excavated only with significant difficulty (or not at all) by a hoe excavator equipped with a digging bucket. When excavating in bedrock, frequent communication with AMEC Senior Geotechnical Engineer, and transmission of photographs is to be carried out.

If shear/fault zones are encountered within the bedrock exposed in the core to abutment contacts, the following information should be collected and passed on to AMEC's Senior Geotechnical Engineer:

- Photographs of the shear zone from a variety of vantage points (both close-ups and photos giving an overall perspective).
- Orientation (strike & dip) of the feature and its orientation relative to that of the core zone (i.e. does it provide a potential upstream-downstream seepage pathway?)
- Thickness and continuity.
- Infilling (clayey gouge, granular material). The infilling material should be sampled and sent to the AMEC Prince George soils laboratory for grain size and Atterberg limits testing.

AMEC's Senior Geotechnical Engineer, upon analysis of the information provided, will determine what (if any) special treatment is required for the shear/fault zone. Such treatment

may include hand excavation a few centimeters into the shear zone, followed by placement of bentonite powder in advance of till placement.

Once sound bedrock is encountered, the surface should be cleaned of loose materials using a hoe excavator equipped with a narrow cleaning bucket, followed by pressure washing using either air or water. Where the slope of the cleaned and approved sound bedrock surface, along the axis of the dam (i.e. up the abutment), is flatter than 1H:1V, then Zone S structural fill placement may proceed. Good compaction of the Zone S fill against the bedrock surface is required. If the undulations in the bedrock surface along the bottom of the trench are such that this cannot be achieved using dozers and the compactor, then such undulations (i.e. rock protrusions) should be removed if possible. If this is not possible, then compaction of thin till lifts with a walk-behind or plate-tamping compactor, or with tamping with a hoe bucket, will be required, to fill in the undulations. Once this is done, then normal spreading and compaction procedures can be undertaken.

Where the slope of the sound bedrock surface is steeper (overall) than 1H:1V, but flatter than 0.5H:1V, then the AMEC design office should be consulted for a decision on the need for any further treatment measures. Photographs of the bedrock surface should be sent to the design office. If the roughness of the rock surface is such that it is judged that effective compaction of till fill against the bedrock on the base of the trench cannot be achieved, then additional (small scale) bedrock excavation (removal of protrusions) should be attempted to attain a surface against which it is judged till fill can be effectively compacted. If this measure is unsuccessful, then one of the following additional measures will be required:

- (a) Additional (large scale) bedrock excavation should be undertaken to achieve a maximum 1H:1V overall slope for the bedrock surface. This can be achieved by mechanical means (dozers, hoe excavators), or by small scale, controlled drilling and blasting.
- (b) Dental concrete or shotcrete application will be required to fill in the undulations in the bedrock surface, and yield a maximum slope of 0.5H:1V, against which till fill can be effectively compacted.

Where the bedrock surface is steeper than 0.5H:1V, the same two measures outlined above will apply.

Where dental concrete is required against steep bedrock faces, it will likely be necessary to use formwork. Dental concrete, if used, will conform to the following specifications:

- 28 day strength – minimum 25 MPa if flyash included in mix, otherwise minimum 30 MPa.
- Water to cement ratio: 0.45:1 by mass.
- Air entrainment: to provide for 5% to 7% air entrainment.
- Cement to flyash ratio (if flyash used): 4:1 by mass, which would allow overall water:cement:flyash ratio of 0.45:0.8:0.2.

The dental concrete need not be of high strength. It does need to be sufficiently fluid that it will fill in irregularities in the bedrock surface to a reasonable extent. Addition of flyash to the mix would achieve that objective, as well as save on cement costs.

Should shotcrete be selected, then MPMC will prepare a mix design for review and approval by AMEC.

Prior to placement and compaction of structural fill in the cutoff trench excavation, the Field Inspector will send photos to the AMEC Support Engineer for approval. Core trench excavation inspections will be performed as required, and the Field Inspector will track inspection dates and results on copies of the construction drawings or by station number. MPMC surveyors will provide a survey pick-up of the core trench excavations and maintain a project database for use in the as-built documentation.

3.4 Borrow Materials Site Development and Operation

The proposed borrow pit will be subjected to laboratory testing and approval by AMEC's Support Engineer and Project Manager. During the TSF embankment construction, detailed documentation will be maintained to ensure the source of the material being placed is known and material testing requirements are satisfied.

Topsoil and other overburden judged to be unsuitable as structural fill will be stripped from the borrow pit and hauled to an acceptable waste dump.

The borrow material site shall be developed such that groundwater inflow and precipitation runoff are directed in a controlled manner to designated sump area(s) of the site, and then removed as required. External surface water runoff shall be prevented from flowing into the borrow materials area by construction of diversion ditches as required.

The performance of the cut slopes in borrow areas will be inspected and recorded as required by the MPMC Field Inspector for documentation within the construction reports. AMEC Support Engineer may request modifications to the excavation plan, including flattening of the slopes and water control measures, based on the observed performance of the cut slopes.

3.5 Material Specifications, Material Testing, Inspection, and Approval

The approved structural fill to be used for embankment construction is to meet the specifications shown on Drawing 560.2011.03. Additional comments pertaining to each of the zones are provided below.

3.5.1 Zone S (Core) – Glacial Till

The glacial till borrow materials approved for construction are to be well graded, organic-free mineral soils, having moisture contents near their optimum for compaction and conforming to the specified gradation envelope provided on Drawing 560.2011.03. The optimum moisture content range of the borrow soils is to be determined by Standard Proctor moisture-density relationship testing. A general guideline for allowable moisture contents for the Zone S

structural fill is $\pm 1\%$ of the optimum moisture content as determined by the Standard Proctor test.

Routine on-site laboratory testing of borrow soil includes determination of natural moisture content and material gradations. These determinations are used to correct the in-situ field density values obtained with the nuclear densometer (ND) or Moisture + Density Indicator (MDI) gauge. It is understood the MPMC Field Engineer will use the MDI gauge and the AMEC Support Engineer will use a nuclear densometer. Off-site testing to be carried out in AMEC's Prince George office soils laboratory includes confirmatory gradation, specific gravity, Atterberg limits, and Standard Proctor moisture-density relationships. Borrow material approved by the AMEC Support Engineer, based on the results of the above testing and other factors, may be used as structural fill for construction of the TSF embankment.

The proposed till borrow soils are to be visually inspected for consistency on a daily basis and tested once (1) per 10,000 m³ following ASTM standard tests: D698-07 (Standard Proctor determination), D422-07 (gradation test), D4318-10 (Atterberg Limits), D2216-10 (moisture determination); with a confirmatory duplicate off site gradational test once (1) per 20,000 m³. Testing frequency may gradually be reduced at the discretion of AMEC's Support Engineer if consistency in test values is established.

The approved Zone S structural fill is to be spread in 0.3 m loose lift thicknesses spread with a dozer and then compacted by a 10 ton vibratory smooth drum compactor. A minimum of 95% of the Standard Proctor maximum dry density is to be achieved.

The field QA/QC personnel will perform in-situ determinations of structural fill compacted density and moisture content utilizing the ND method (ASTM D6938-10) or with the MDI gauge (ASTM D6780). Periodic samples will be collected for laboratory rock and moisture content determinations as required to make corrections to the ND density calculation. In the event that a test result indicates that the fill did not achieve the specified density, subsequent fill placement will be suspended in the test area until additional compaction effort has been applied and positive test results are obtained.

The in-situ MDI gauge testing of the till fill is specified at a minimum frequency of one (1) test per lift per 150 linear meters of compacted Zone S fill. Test site locations will be identified by three dimensions: elevation, chainage along setting out line (S.O.L) and perpendicular distance upstream or downstream of S.O.L. or crest. Test site elevations will be based on the elevations shown on the slope stakes maintained by the MPMC surveyors, or otherwise determined by the QA/QC personnel. The field density testing schedule is intended to provide sufficient construction inspection of the compacted fill within the dam while permitting the QA/QC personnel enough time to assess the field density values, complete the associated soils testing, and fulfill other monitoring/inspection duties on site.

A sample of placed Zone S material should be taken from the dam for grain size determination once (1) per 10,000 m³ of material placed. This sampling and testing should be offset from the grain size testing of the borrow material. A sample is to be sent to Prince George for grain size testing every 20,000 m³ of material placed.

3.5.2 Zone F (Filter) – Manufactured Sand and Gravel

The sand and gravel filter material is to be well graded, organic-free mineral soil, falling within the gradation envelope shown on Drawing 560.2011.03. Preliminary grain size testing of stockpiled material is to be carried out on site in order to establish the suitability of the material prior to its use as fill in the dam. Manufactured sand and gravel is assumed to be crushed on site utilizing NAG.

Routine testing of produced material is to be carried out to ensure the material is within specification. The test program should determine if the manufacturing process is consistent, and if the produced material is within the gradational specification. During production of the manufactured sand and gravel, on site testing of this material will consist of a gradational test once (1) per 5,000 m³; with a confirmatory duplicate off site gradational test once (1) per 10,000 m³.

Zone F material is to be placed in maximum lift thicknesses of 0.6 m. Care will be taken during handling and placement of the material to minimize segregation. A sample of placed Zone F material should be taken from the dam for grain size determination once (1) per 5,000 m³ of material placed. This sampling and testing should be offset from the grain size testing of the stockpile material. A sample is to be sent to Prince George for grain size testing every 10,000 m³ of material placed. Zone F is to be compacted utilizing previously established compaction pattern of a minimum of four passes with a 10 ton vibratory smooth drum. Visual inspection after compaction will be carried out and approved by the MPMC Field Inspector.

3.5.3 Zone T (Transition) – Fine NAG Rock Transition

Fine NAG rock transition material shall be confirmed to be NAG by MPMC, and shall fall within the gradation limits indicated on Drawing 560.2011.03. On site testing of this material includes visual determination of upper and lower bound grain sizes, suitability of rock hardness, and a gradational test once (1) per 5,000 m³. Off site testing of this material, will consist of a gradational test once (1) per 10,000 m³. Special care shall be taken during sampling to ensure that representative samples are obtained. Photographs of this material when exposed in the excavated filter trenches are to be taken frequently, as the best means of assessing the ability of Zone T to serve as a filter for Zone F is through visual means.

The fine NAG rock transition zone serves as filter protection for the adjacent Zone F filter sand and gravel which in turn serves as filter protection for the Zone S core. The importance of conformance with gradation specifications for both of these filter zones cannot be over emphasized.

Prior to placement of Zone T material adjacent to the Zone C Rock Shell, the Zone C/Zone T interface is to be inspected for openwork areas created by concentrations of larger size rocks. Removal of openwork areas will be carried out prior to placement of Zone T.

Zone T material is to be placed in maximum lift thicknesses of 0.6 m. Care will be taken during handling and placement of the material to minimize segregation. Zone T lifts will be compacted by uniform routing of haul trucks and spreading equipment. Visual inspection after compaction will be carried out and approved by the MPMC Field Inspector.

3.5.4 Zone C (General Rockfill) – Coarse NAG Rock Shell

Coarse NAG rockfill shall be confirmed to be NAG by MPMC prior to being used as fill on the dam. QA/QC personnel are to visually confirm that particles no larger than 1 m are used as structural fill. Larger sizes are to be dozed away from the contact with Zone T.

The rockfill shell (Zone C) will be constructed using approved coarse NAG rockfill, placed in lift thicknesses of 2 m or less. The Zone C lifts will be compacted by uniform routing of haul trucks and spreading equipment. Some degree of compaction of Zone C is required nearer Zone T as excessive settlement of the rockfill could disrupt the continuity of the overlying transition and fine filter materials (Zones T and F respectively). If Zone C material contains appreciable quantities of fines, and the compacted lift surfaces assume a 'pavement' type appearance that might impede vertical drainage, then these lift surfaces may require scarification prior to placement of a subsequent lift.

3.5.5 Zone U (Upstream Fill) –Select Fill

The selected upstream fill (Zone U) will be constructed using cells of total tailings. The cells are constructed by confining the discharged tailings with berms. The confining berms are to have a culvert to allow for the water and fine materials to escape into the TSF. The coarse tailings sand that settles out into the cells are to be constantly reworked with the help of a dozer to ensure proper distribution within the cells, provide compaction and to expedite the excess water drainage. This construction method has been used and proved effective in previous TSF embankment raises. In areas of the dam (along the Main Embankment) where there is not sufficient tailings line pressure to deposit with the cell method, NAG mine waste rock will be substituted for Zone U Material.

3.6 Criteria for Suspension of Work

The till borrow material is highly sensitive to moisture in terms of its compaction characteristics and workability. Consequently, during periods of wet weather, construction of the core zone will be suspended. Adequate slopes will be maintained on till fill surfaces, and they will be sealed with a smooth drum vibratory roller, to promote surface water runoff and prevent excessive softening of compacted fill. Moisture-softened lifts must be removed or scarified, dried to acceptable moisture content and re-compacted.

Embankment construction work will stop for the season when freezing weather prevents acceptable fill placement and compaction.

4.0 TEST PROCEDURES

4.1 Scheduled Tests

The following tests, as described by the American Society for Testing and Materials (ASTM), will be used for quality control of materials and earthworks during the 2011 construction.

ASTM Standard Practice	Designation
Particle Size Analysis of Soils (Gradation test)	D422-07
Water (Moisture) Content of Soil and Rock	D2216-10
Liquid Limit, Plastic Limit, and Plasticity Index of Soils	D4318-10
Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft ³ (600 kN-m/m ³))	D698-07
Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)	D6938-10
Correction of Unit Weight and Water Content for Soils Containing Oversize Particles	D4718-07
Standard Test Method for Water Content and Density of Soil in Place by Time Domain Reflectometry	D6780-05

Laboratory and field procedures for each test are provided in the corresponding ASTM Standard Practice document. Copies of those standards for the tests to be performed on site are provided in Appendix C of this manual. Moistures and density tests will be conducted by the Field Inspectors and Engineers on site. Replicate samples of those tests carried out on site will be forwarded to the AMEC Prince George laboratory for confirmation testing, typically at a rate of one confirmation test per fifteen field tests. Limits and proctor tests will be carried out in the AMEC Prince George soils laboratory.

The tests outlined above will be carried out initially at the minimum frequencies indicated on Drawing 560.2011.03. As trends and consistency in the test results develop, AMEC's Support Engineer may reduce testing frequencies where deemed appropriate.

4.2 Additional/Supplemental Tests

Determinations of specific gravity (ASTM D854-10) for the approved glacial till and borrow soils may be required if significant material changes are observed. These tests will be conducted at the AMEC Prince George laboratory, following the Standard Practice noted below. Typically, two or three specific gravity determinations would be required for each soil type.

4.3 Sample Collection Procedures

Samples to be transported to the AMEC Prince George laboratory for field laboratory verification testing will be sealed to minimize soil moisture losses, and shipped in an expedient manner.

The shipping address of the Prince George lab is:

Attn: Shana Grover or Dmitri Ostritchenko
AMEC Earth and Environmental
3456 Opie Crescent
Prince George, BC
V2N 2P9

The Field Inspector shall include transmittals with the samples outlining the tests to be carried out for each respective sample. These transmittals will be faxed to AMEC Prince George Laboratory (250-562-7045) and emailed to AMEC's Support Engineer in advance of the shipment. The Prince George laboratory will ensure that the label information attached to each sample is incorporated onto the corresponding test sheets, and that copies of the test sheets and results are forwarded to the Field Inspectors and the AMEC Support Engineer as the tests are completed.

Samples collected by the Field Inspectors for the scheduled tests during the 2011 construction will be identified by a detailed labeling scheme, the following is an example:

Sample Label	
Project name:	Mt. Polley Mines Project
Construction:	Stage 7 Raise – 2011
Material:	<i>Glacial Till (Zone S)</i>
Source:	<i>Main Embankment</i>
Location:	<i>Elev. 960, 1 m d/s of CL, sta 21+00</i>
Date:	<i>06/20/11</i>
Sample Number:	<i>06/20/11-(initials)1</i>
Sample Destination:	AMEC Prince George laboratory
Test Type(s):	<i>Standard Proctor, Gradation</i>

Sample locations, material descriptions, and other relevant notes will be recorded by the Field Inspectors. The sample label information, accompanying field notes, and test results will be included in the construction reports as part of the permanent record of the 2011 construction program.

Samples will be collected and preserved in a manner consistent with their scheduled tests, such as the placing and sealing of samples for natural moisture content determinations in plastic bags.

5.0 REPORTING

5.1 Construction Documentation

The Field Inspector will document the monitoring and testing program for Stage 7 Embankment raise construction by means of daily construction reports, field and laboratory test sheets, weekly progress reports, survey reports as provided, and notes from relevant on-site meetings, discussions, and decisions. Other documents, such as borrow area excavation diagrams or dam construction progress maps, may be included with the construction records. A photographic record will also be maintained on site. Select photographs will be captioned, dated, and included in the final as-built report.

5.2 Daily Construction Reports and Test Records

Borrow pit development, dam construction, site conditions, weather, and other related field activities will be documented each day on daily construction reports. Field copies of Drawing 560.2011.2 (letter size) will be annotated with sample and/or test locations, notes, etc. on an as-required basis. Each annotated drawing will be attached to its corresponding daily construction report. Records of all samples collected and test results will be maintained by the Field Inspectors on standard laboratory test forms. Copies of each day's dam performance monitoring data are to be kept with the daily reports as they are generated. A sample copy of a daily report is provided in Appendix B.

The Field Inspector has the responsibility for the preparation of the reports. The daily reports will be submitted by noon of the following day to MPMC's Project Manager in hard copy and electronically, with a copy also emailed to AMEC's Support Engineer.

5.3 Monthly Progress Reports

Monthly progress reports will be prepared by the AMEC Support Engineer for those periods when active construction is ongoing; documenting the construction activities, equipment in use, construction supervision and quality control testing activities, borrow area development, and conformance of quality control test results with the design specifications. The monthly progress report shall include copies of all instrumentation and survey monument data, plan and sections showing the areas of construction and progress to date and a brief discussion on these enclosures and milestones of the past months activities. These reports will be issued to MPMC's Project Manager, AMEC's Project Manager and Senior Geotechnical Engineer, and the appropriate Ministry representative(s).

5.4 As-Built Report/Annual Review

AMEC will prepare a report summarizing the construction methodology followed and documenting the as-built dam conditions for the 2011 construction season. This as-built report for 2011 will be combined with the 2011 annual review report. The report will be confirmation that the dam was raised in conformance with design intent, and will serve as a guide for construction of TSF embankment in subsequent years.

The as-built report will also outline any modifications made in the field to the initial methods of foundation preparation; borrow soils excavation, hauling, placement, and compaction; or other relevant work. Documentation of any such refinements made during construction will be of benefit for subsequent dam raising. The as-built report will also include recommendations pertinent to the construction and QA/QC monitoring of future dam construction.

MPMC will mark-up the construction drawings based on as-built surveys of the raised dam. These marked-up drawings will be used by AMEC to produce CADD as-built drawings for the report.

6.0 INSTRUMENTATION & MONITORING

6.1 General

As part of the 2011 construction program AMEC will conduct a full review of the instrumentation currently functional for the TSF embankment. Recommendations for replacement or additional instruments will be presented in a separate report.

6.2 Inclinometers

Five inclinometers have been installed in the main embankment to measure the potential displacement in the glaciolacustrine unit that underlies the embankment. One of the inclinometers has sustained damage (SI01-01), while another (SI01-02) is showing slight deviations (less than 3mm). The need for additional inclinometers will be assessed during the 2011 construction period.

6.3 Vibrating Wire Piezometer

The vibrating wire piezometers are required for monitoring changes in pore pressure during construction and dam foundation pore pressure changes over time. As the dam height increases, undrained response of the compacted till fill to load addition results in near-immediate increases in pore pressure. The data obtained provides the pore pressure parameters that are used for limit equilibrium stability analyses. This information will continue to be required for monitoring the short and long term performance of the structure and for design optimization of future raises.

During active construction the piezometers are to be read weekly and the data reduced and plotted such that a minimum amount of time lapses between the recording of the data and the inclusion of the charts in the monthly report. Based on dam performance the reading frequency may be increased or decreased to provide requisite information for design stewardship at the discretion of the AMEC Senior Geotechnical Engineer. The piezometer readings shall be plotted in terms of equivalent hydraulic head in elevation units. All plots shall be prepared at the same scale to facilitate comparison. The Field Inspector shall indicate on these plots when construction activities have taken place within 100m of S.O.L chainage from the piezometers. This is required so that changes in piezometric pressures and measured displacements can be correlated with construction activities.

7.0 CLOSURE NOTE

This report has been prepared for the exclusive use of Mount Polley Mining Corporation for specific application to the area within this report. Any use which a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility of such third parties. AMEC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report. It has been prepared in accordance with generally accepted engineering geology and geotechnical engineering practices. No other warranty, expressed or implied, is made.

If you have any questions about the content of this manual, please do not hesitate to call.

Respectfully submitted,

**AMEC Earth & Environmental,
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REFERENCES

AMEC (2006). "Dam Safety Review Mt. Polley Mine - Tailings Storage Facility" December.

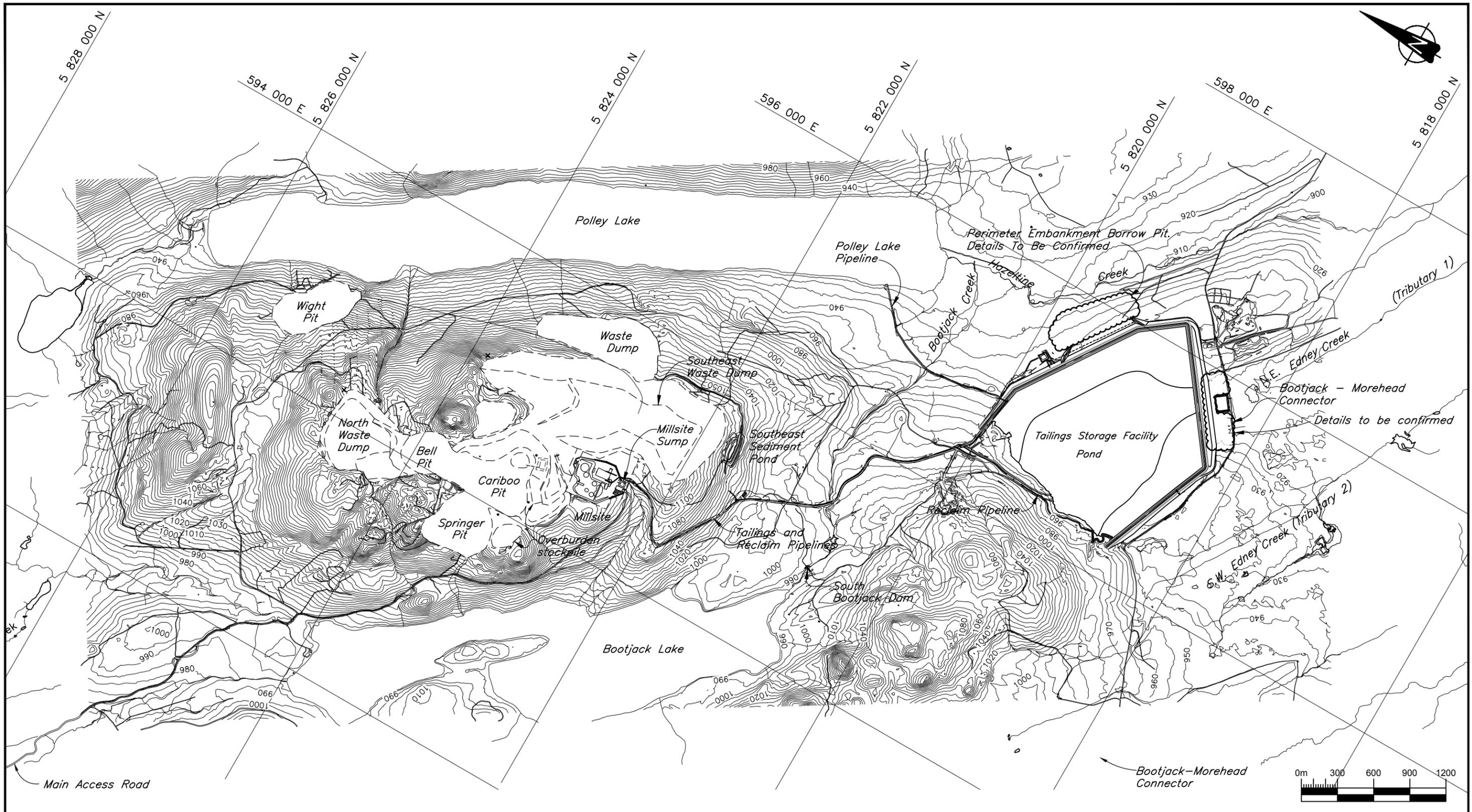
KP (2005). "Mount Polley Mine – Design of the Tailings Storage Facility to Ultimate Elevation", June 18.

KP (2007). "Mount Polley Mine – Stage 6 Design of the Tailings Storage Facility", June 18.

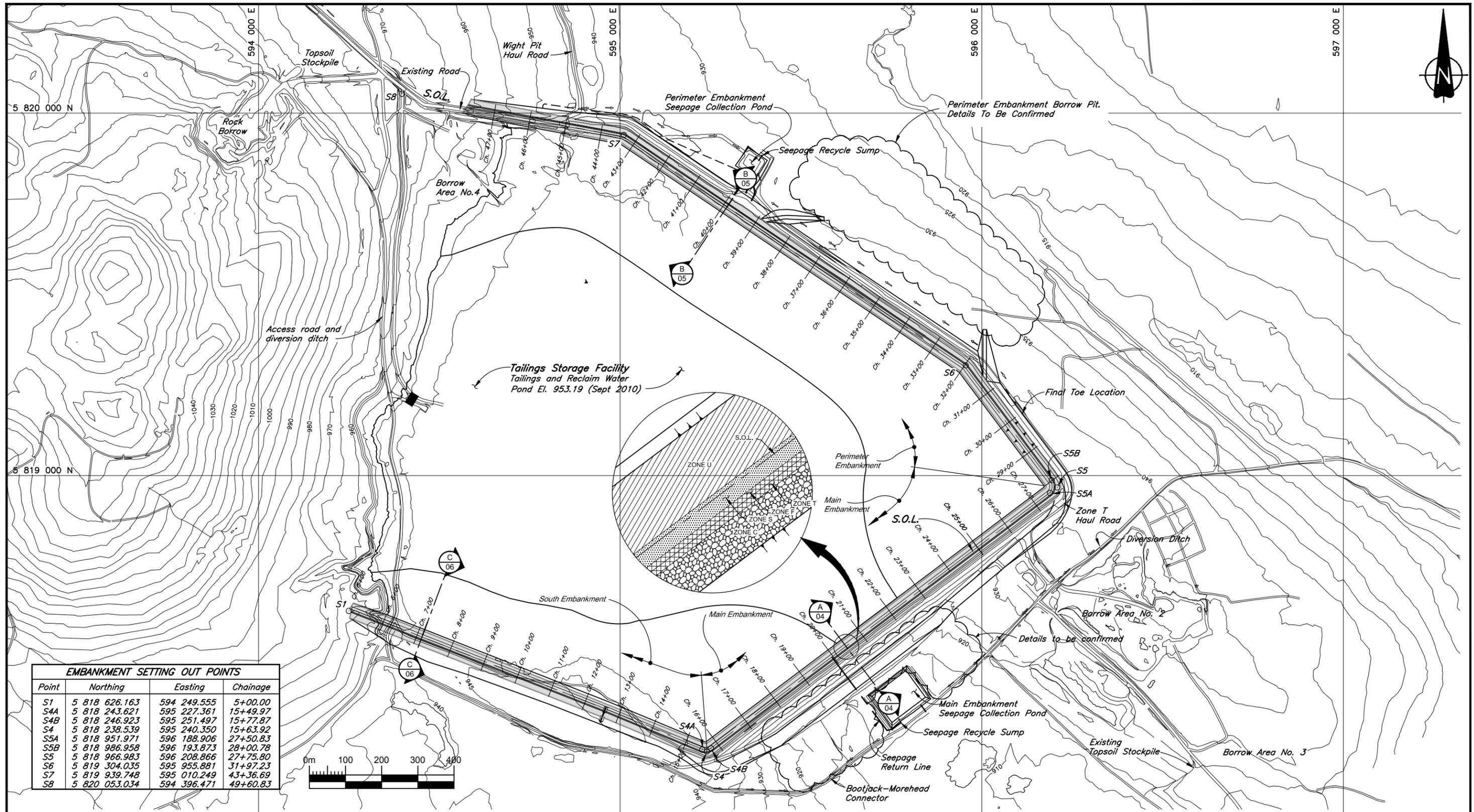
KP (2011). "Mount Polley Mine – Tailings Storage Facility Report on Stage 6B Construction", January 25.

KP (2011). "Mount Polley Mine – Tailings Storage Facility Report on 2010 Annual Inspection", January 25.

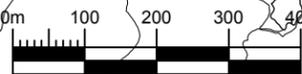
DRAWINGS



NOTE: 1. Base drawing from Knight Piesold Ltd., 100_r0.dwg.							CLIENT: AMEC Earth & Environmental 3456 Opie Crescent Prince George, BC, CANADA V2N 2P9 Tel. (250) 564-3243 Fax (250) 562-7045		DWN BY: I.Macleod	TITLE STAGE 7 TAILINGS EMBANKMENT GENERAL SITE PLAN PROJECT MOUNT POLLEY MINE TAILING STORAGE FACILITY	DATE: APRIL 2011
						CHK'D BY: D.Ostritschenko			PROJECT NO: VM00560		
						DATUM: NAD83			REV. NO.: B		
		4/19/2011	ISSUED FOR CONSTRUCTION	TM	DO	PROJECTION: UTM Zone 10			DRAWING No. 560.2011.01		
		4/14/2011	DRAFT - NOT FOR CONSTRUCTION	TM	DO	SCALE: AS SHOWN					
	REV	DATE	ISSUE/REVISION DESCRIPTION	ENG.	APPR.						



EMBANKMENT SETTING OUT POINTS			
Point	Northing	Easting	Chainage
S1	5 818 626.163	594 249.555	5+00.00
S4A	5 818 243.621	595 227.361	15+49.97
S4B	5 818 246.923	595 251.497	15+77.87
S4	5 818 238.539	595 240.350	15+63.92
S5A	5 818 951.971	596 188.906	27+50.83
S5B	5 818 986.958	596 193.873	28+00.78
S5	5 818 966.983	596 208.866	27+75.80
S6	5 819 304.035	595 955.881	31+97.23
S7	5 819 939.748	595 010.249	43+36.69
S8	5 820 053.034	594 396.471	49+60.83



LEGEND:	
	Upstream Fill
	Till Core
	Filter
	Transition
	Rock Fill

NOTE:
 1. Base drawing from KP drawing 102_r0.dwg
 2. For material specifications see 560.2011.03
 3. S.O.L. - Setting Out Line

REV	DATE	ISSUE/REVISION DESCRIPTION	ENG.	APPR.
B	4/19/2011	ISSUED FOR CONSTRUCTION	TM	DO
A	4/14/2011	DRAFT - NOT FOR CONSTRUCTION	TM	DO

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DWN BY:	I.Macleod
CHK'D BY:	D.Ostritchenko
DATUM:	NAD83
PROJECTION:	UTM Zone 10
SCALE:	AS SHOWN

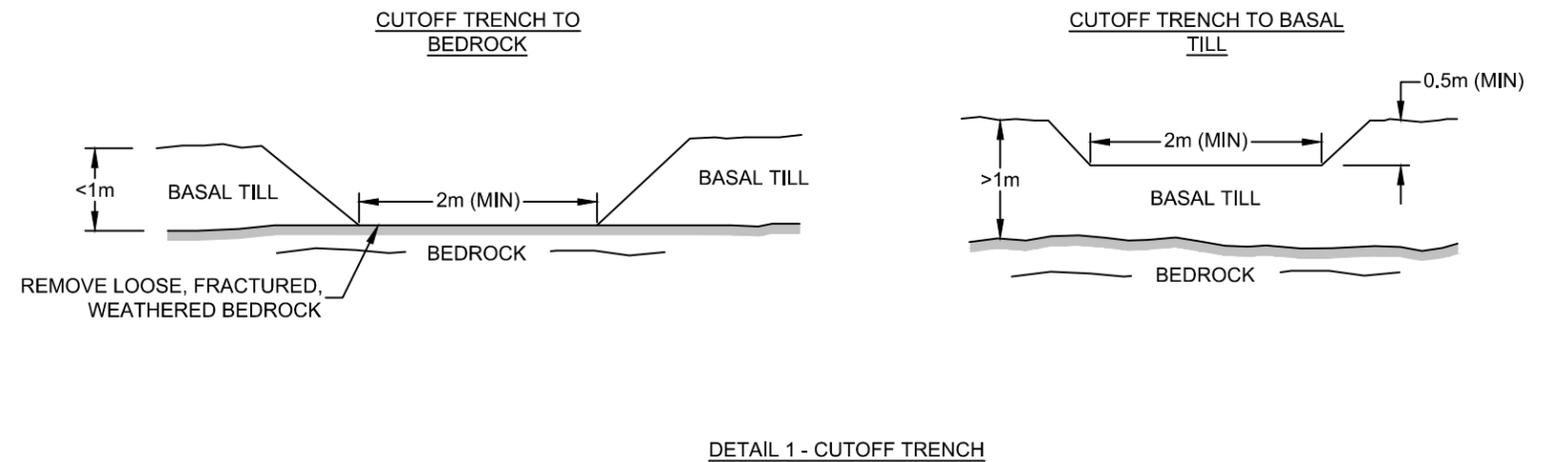
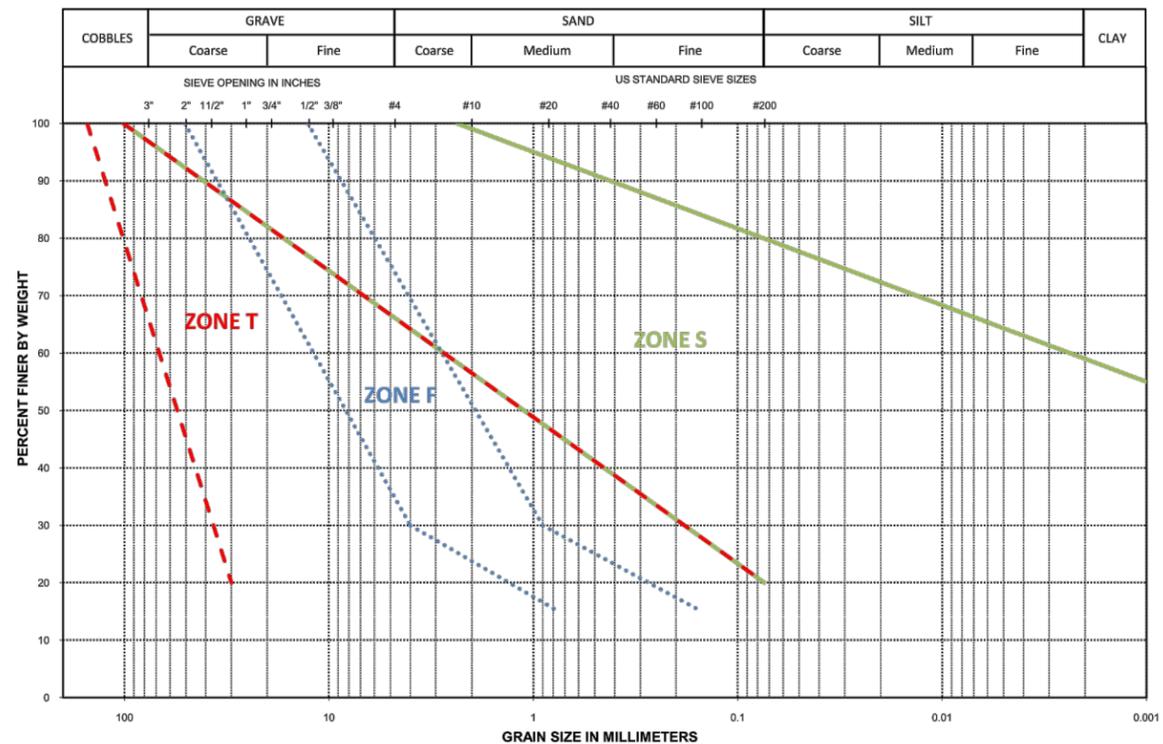
TITLE: **STAGE 7 TAILINGS EMBANKMENT PLAN VIEW**

PROJECT: **MOUNT POLLEY MINE TAILING STORAGE FACILITY**

DATE:	APRIL 2011
PROJECT NO.:	VM00560
REV. NO.:	B
DRAWING No.:	560.2011.02

EMBANKMENT ZONE	DESCRIPTION	MATERIAL TYPE	SPECIFICATIONS	SUBGRADE OR BASE PREPARATION	PLACEMENT AND COMPACTION	ON SITE CONSTRUCTION TESTING	OFF SITE CONSTRUCTION TESTING
	TILL CORE	GLACIAL TILL	Well graded till moisture content at ±1% of optimum. (See Gradation Envelope below)	Strip all topsoil and organic material. Excavate cutoff trench as per detail. (See Detail 1) Strip all frost softened and weakened soils, proof roll then scarify base soils.	Placed, moisture conditioned and spread in maximum 300mm loose lifts. Vibratory compaction to 95% of standard proctor maximum dry density.	Source Classification D422-07: 1 per 10,000 m ³ per source. In-Place Testing D6780-05: 1 per lift per 150 linear m or 1 per day per lift; D422-07: 1 per 10,000m ³ offset to source.	Source Classification D698-07, D4318-10, D2216-10: 1 per 10,000 m ³ per source; D422-07: 1 per 20,000 m ³ per source. In-Place Testing D422-07: 1 per 20,000m ³ offset to source.
	FILTER	SAND AND GRAVEL	Sand and gravel sized material. (See Gradation Envelope below)	Strip all frost softened and weakened soils. Smooth roll base soils.	Placed, and spread in maximum 600mm loose lifts. Vibratory compaction minimum of 4 passes utilizing a 10 ton smooth drum.	Source Classification D422-07: 1 per 5,000 m ³ per source. In-Place Testing D422-07: 1 per 5,000 m ³ offset to source. Visual in-place inspection of compaction and zone dimension.	Source Classification D422-07: 1 per 10,000 m ³ per source. In-Place Testing D422-07: 1 per 10,000 m ³ offset to source.
	TRANSITION	FINE ROCKFILL (NAG)	Cobble and gravel sized material. (See Gradation Envelope below)	Strip all frost softened and weakened soils. Smooth roll base soils.	Placed, and spread in maximum 600mm loose lifts. Compacted by uniform routing of haul trucks and spreading equipment	Confirmation of waste rock inertness, as required. D422-07: 1 per 5,000m ³ . Visual in-place inspection of material size, compaction, and zone dimension.	D422-07: 1 per 10,000 m ³ .
	ROCKFILL	GENERAL ROCKFILL (NAG)	Nominal 1m maximum particle size.	Strip all frost softened and weakened soils. Smooth roll base soils.	Placed and spread in maximum 2000mm loose lifts. Maximum lift slope 1.3H:1V compacted by haul traffic and spreading equipment. Boulder-rich rockfill not to be placed adjacent to fine rock transition zone.	Confirmation of waste rock inertness, as required. Visual in-place inspection of material size and placement.	
	UPSTREAM FILL	SELECT FILL	Cell construction is to be utilized. Constant reworking of the tailings is needed to ensure proper distribution within the cell.		Placement and compaction requirements to be determined based on material selection.		

MATERIAL GRADATION LIMITS



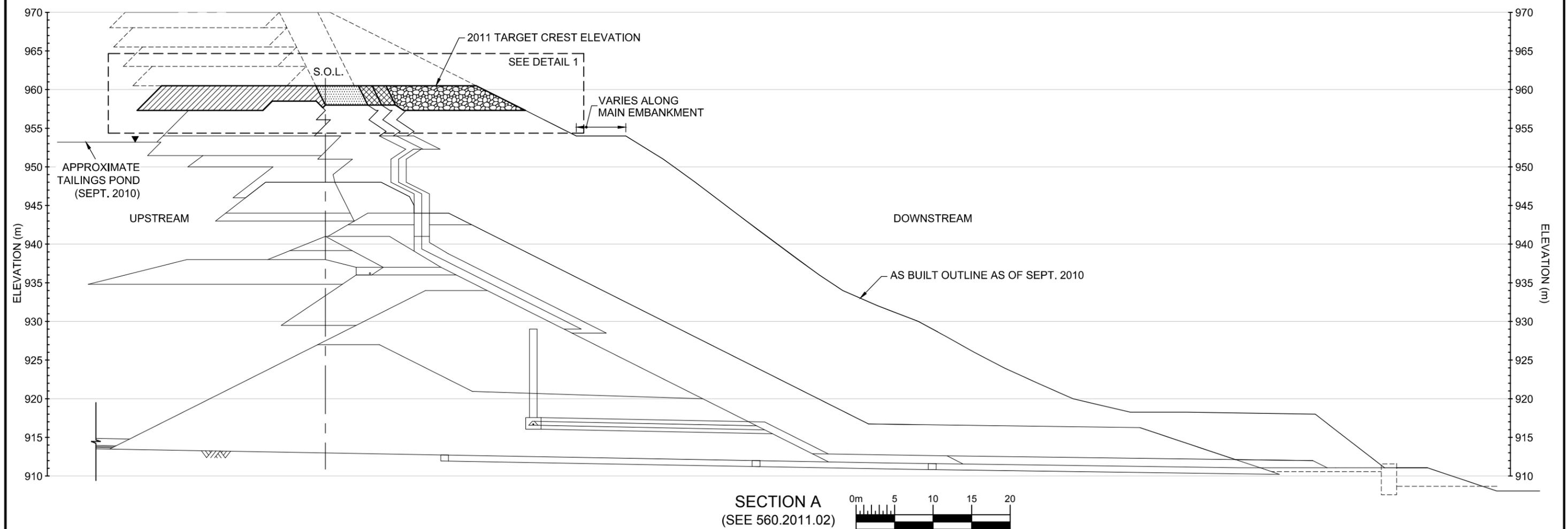
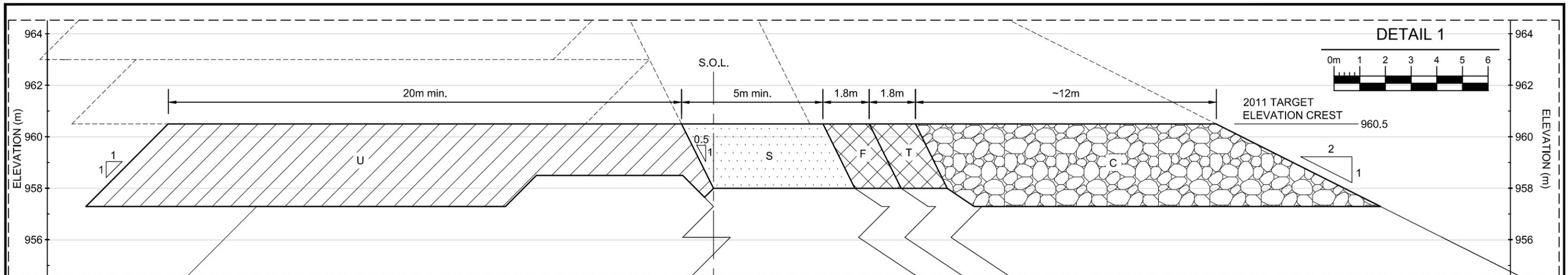
NOTE:
 1. Base drawing from Knight Piésold Ltd., 104_r0.dwg.
 2. ASTM standards are attached in Appendix C

REV	DATE	ISSUE/REVISION DESCRIPTION	ENG.	APPR.
4	4/19/2011	ISSUED FOR CONSTRUCTION	TM	DO
3	4/14/2011	DRAFT - NOT FOR CONSTRUCTION	TM	DO

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DWN BY: I.Macleod	TITLE STAGE 7 FILL MATERIAL SPECIFICATIONS	DATE: APRIL 2011
CHK'D BY: D.Ostritchenko		PROJECT NO: VM00560
DATUM: NAD83	PROJECT MOUNT POLLEY MINE TAILING STORAGE FACILITY	REV. NO.: B
PROJECTION: UTM Zone 10		DRAWING No. 560.2011.03
SCALE: NTS		



LEGEND:

	Stage 7 Expansion		Till Core
	Planned Expansions		Filter
	Upstream Fill		Transition
			Rockfill

NOTE:

1. Previous raises from KP drawing 215_r0.dwg
2. For material specifications see 560.2011.03
3. S.O.L. - Setting Out Line

REV	DATE	ISSUE/REVISION DESCRIPTION	ENG.	APPR.
1	4/19/2011	ISSUED FOR CONSTRUCTION	TM	DO
2	4/14/2011	DRAFT - NOT FOR CONSTRUCTION	TM	DO

CLIENT:

Imperial Metals

AMEC Earth & Environmental

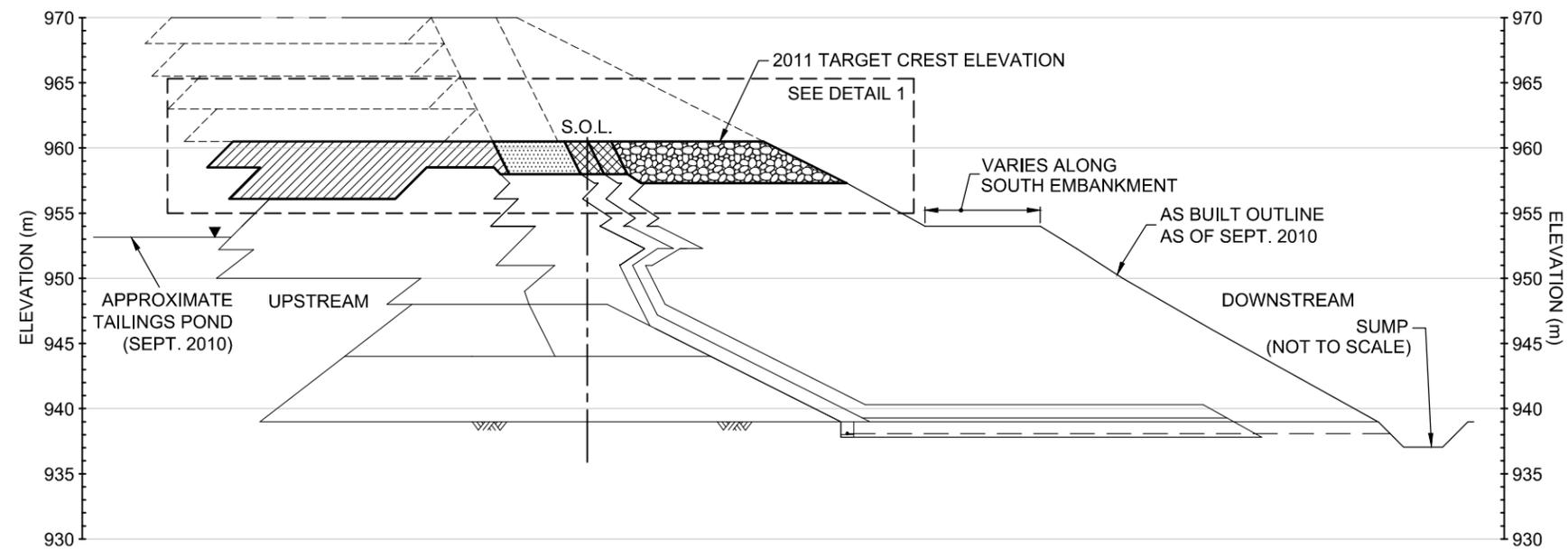
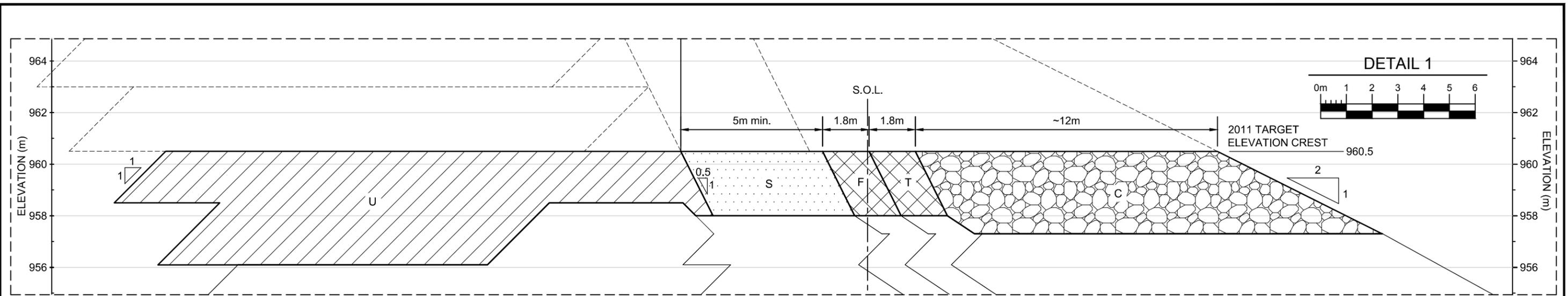
3456 Opie Crescent
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 Tel. (250) 564-3243
 Fax (250) 562-7045

DWN BY: I.Macleod
 CHK'D BY: D.Ostritchenko
 DATUM: NAD83
 PROJECTION: UTM Zone 10
 SCALE: AS SHOWN

TITLE: **STAGE 7 MAIN EMBANKMENT
 2011 PLANNED RAISE**

PROJECT: **MOUNT POLLEY MINE
 TAILING STORAGE FACILITY**

DATE: APRIL 2011
 PROJECT NO: VM00560
 REV. NO.: B
 DRAWING No. 560.2011.04



SECTION C
(SEE 560.2011.02)

LEGEND:

	Stage 7 Expansion		Till Core
	Planned Expansions		Filter
	Upstream Fill		Transition
			Rock Fill

- NOTE:
1. Previous raises based from KP drawing 235_r0.dwg
 2. For material specifications see 560.2011.03
 3. S.O.L. - Setting Out Line

REV	DATE	ISSUE/REVISION DESCRIPTION	ENG.	APPR.
1	4/19/2011	ISSUED FOR CONSTRUCTION	TM	DO
2	4/14/2011	DRAFT - NOT FOR CONSTRUCTION	TM	DO

CLIENT:

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 Fax (250) 562-7045

DWN BY: I.Macleod
 CHK'D BY: D.Ostritschenko
 DATUM: NAD83
 PROJECTION: UTM Zone 10
 SCALE: AS SHOWN

TITLE: **STAGE 7 SOUTH EMBANKMENT
2011 PLANNED RAISE**

PROJECT: **MOUNT POLLEY MINE
TAILING STORAGE FACILITY**

DATE:	APRIL 2011
PROJECT NO.:	VM00560
REV. NO.:	B
DRAWING No.:	560.2011.06

APPENDIX A
Stability Analysis

**Mount Polley Mine
Tailing Storage Facility
2011 Stage 7 Expansion Stability Analyses**

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1.0 INTRODUCTION

Mount Polley Mine is wholly owned by Imperial Metals Corporation and operated by the Mount Polley Mining Corporation (MPMC), and is located 56 kilometres northeast of Williams Lake. Mount Polley began mine production in 1997 and operated until October 2001 when operations were suspended for economic reasons. In March 2005, the mine restarted production and has been in continuous operation since. Currently, it is estimated that the mill throughput is approximately 20,000 tpd. Tailings are deposited as slurry into the tailings storage facility (TSF). The TSF is comprised of one overall embankment that is approximately 4.2km in length. The embankment, based upon original separate embankments, is subdivided into three (3) sections referred to as the Main Embankment, Perimeter Embankment and South Embankment. Heights vary along the embankment and are approximately 45m, 27m, and 17m respectively, (based upon the Main, Perimeter and South nomenclature). The design and construction monitoring of the TSF embankments to date has been completed under the direction of Knight Piésold Limited (KP). The overall embankment has incorporated a staged expansion design utilizing a modified centreline construction methodology. The latest expansion was completed in August 2010, which entailed a four (4) m embankment raise to a consistent crest elevation of 958 m.

AMEC Earth & Environmental (AMEC) was retained by MPMC to provide design and construction monitoring for future expansions. To facilitate the additional volume of tailings from planned operations, the next expansion (Stage 7) is scheduled for 2011 and entails a 2.5m embankment raise to a crest elevation of 960.5 m.

The objective of the analyses presented herein was to assess the short-term stability of the TSF under static loading conditions. The factor of safety (FoS) required for long-term conditions is 1.5, while for the short-term conditions the FoS required is 1.3; both values consistent with the Canadian Dam Association Guidelines (CDA) (CDA, 2007) which is an industry standard for these facilities and endorsed for use by regulatory authority in British Columbia.

The analyses presented herein considered the stability related only to the 2011 expansion. This analyses is considered consistent with the short-term conditions but, at the same time, we would use the long-term CDA requirements for target values. In order to complete the stability analyses, three as-built sections of the embankments were modeled. The locations of these sections are shown in Appendix A, Figure 1.1.

2.0 ANALYSIS PARAMETERS AND METHODOLOGY

2.1 General

Two-dimensional limit equilibrium stability analyses were carried out using the computer code SLOPE/W (GeoStudio, 2007). The analyses utilized the Morgenstern-Price method of slices solution. There are seven main materials incorporated into the analyzed sections, Zone S (compacted till fill), Zone C (rockfill), tailings, foundation tills (ablation, basal), glaciolacustrine/glaciofluvial sediments, and bedrock. The material properties used for the analyses are based on previously established parameters assumed by KP (2005) with minor

modifications deemed appropriate by AMEC. The parameters used in the stability analyses presented herein are summarized in Table 2.1.

The stability of the three dam sections is dependent on the strength of the downstream rockfill shell and foundation materials. The compacted till core is supported by the downstream rockfill shell and does not directly contribute to the stability of the embankment.

2.2 Material Parameters

Compacted Till Fill

Not enough information is currently available to confirm or modify the material parameters, thus the material properties assumed by KP are utilized.

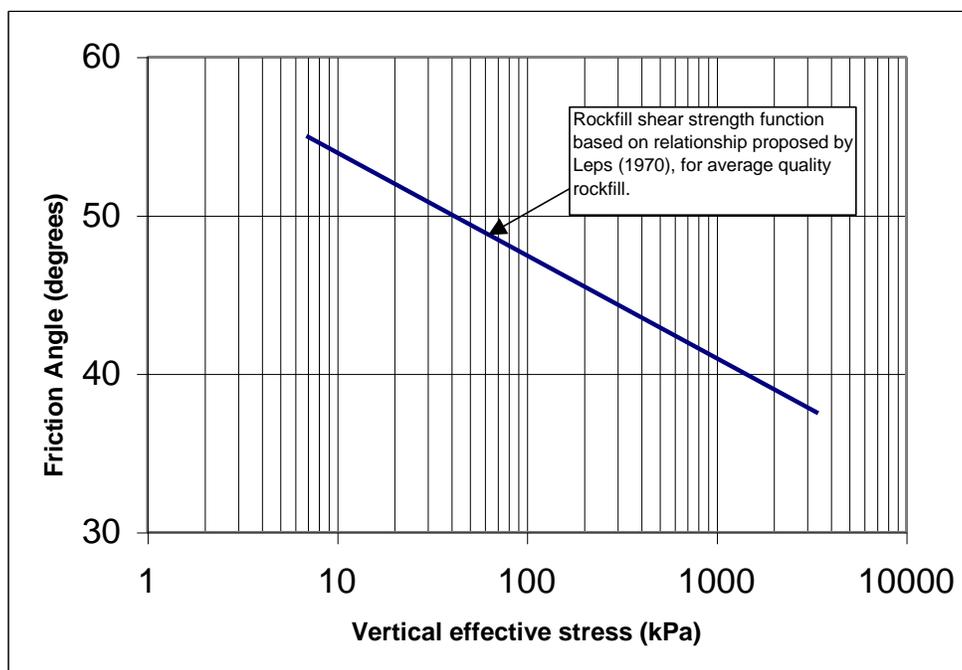
Rockfill

The rockfill shear strength is taken as stress-level dependent as per Leps (1970), as illustrated in Figure 2.1.

It is anticipated that the rockfill used for construction of the 2011 expansion will be comparable to that used for the past dam raises. As such, the trend for average rockfill was used because the rockfill is anticipated to be:

- strong and durable with high compressive strength;
- well-graded, and comprised of highly angular rock; and
- will receive moderate compactive effort.

Figure 2.1 Shear Strength Relationship Used for Rockfill



In-Situ Foundation

KP (2005) summarized the foundation conditions for the dam as follows:

“The tailings basin is generally blanketed by naturally occurring well graded low permeability glacial till which functions as an in-situ soil liner and precludes seepage loss from the facility. However, a basin liner was constructed just upstream of the Main Embankment to ensure that the basin liner had a minimum thickness of 2 meters throughout the tailings basin. The constructed basin liner was tied into the Main Embankment core zone and the existing basin liner where the in-situ thickness exceeded 2 m.

The foundation conditions at the Main Embankment consist of low permeability glacial till material at surface underlain by fluvial and lacustrine silts up to 20 m thick. The foundation conditions at the Perimeter Embankment consist of low permeability glacial till throughout that is generally in excess of 5 m. The foundation conditions at the South Embankment consist of a relatively thin, low permeability glacial till material overlying bedrock. The glacial till is a few meters thick but its thickness is not consistent throughout the South Embankment foundation. It is important not to expose the fractured bedrock and to ensure that the glacial till cover is at least 2 m thick throughout the foundation and that it is tied into the core zone.

Laboratory testwork on the foundation soils indicates that the materials have adequate shear strength to ensure foundation stability of the embankments. Artesian pressures exist at the base of the Main Embankment. Pressure relief wells trenches have been installed at this location to depressurize the underlying glaciofluvial deposits.”

Summary of Material Strength Parameters

The material strength parameters used in the stability analyses are as summarized in Table 2.1.

Table 2.1 Material Strength Parameters

Material	γ_b (Bulk Unit Weight) (kN/m ³)	ϕ' (Friction Angle) (degrees)	c' (Cohesion) (kPa)
Rockfill (Zone C)	22	Defined by Lep's (1970) shear normal function for average quality rockfill (Note 1)	0
Compacted Till Fill (Zone S)	22	35	0
Ablation Till	21	26	0
Glaciolacustrine/Glaciofluvial	20	33 24 (residual)	0
Glacial Till	21	33	0
Tailings	18	30 (drained) $S_u/\sigma_v' = 0.1$ (undrained)	0

Note 1. The shear normal function used for the rockfill accounts for the stress-level dependency of the normalized shear strength as expressed by the effective friction angle (ϕ') – see Figure 2.1.

2.3 Pore Pressure Assumptions

Where possible, the current phreatic surfaces were derived from vibrating wire piezometer readings installed in the embankments or into the embankment foundation, as reported in Stage 6B construction report (KP, 2011). Where no piezometric pressure data was available, the phreatic surface was estimated using typical phreatic surfaces observed from similar projects.

The phreatic surface for the 2011 expansion was estimated by increasing current phreatic surface on the upstream side of the core by 2.5 m, equivalent to the Stage 7 raise, while maintaining the phreatic surface downstream of the core.

The rockfill was assigned zero pore pressure except where located below the phreatic surface, below which pore pressures at any given point were taken as hydrostatic.

Artesian conditions are modelled in the main embankment to reflect the pore pressures observed in the glaciolacustrine/glaciofluvial sediment unit in that area. Note that as stated in KP's Stage 6 Construction Report (KP, 2007) piezometric trigger level of 15m above ground reduces the FoS to 1.1. For Stage 7 expansion the same piezometric trigger level is adopted.

2.4 Minimum Factor of Safety Criteria

The minimum FoS criteria for design is 1.3 for short-term (during construction) and 1.5 for long-term (closure) steady state conditions.



3.0 STABILITY ANALYSES RESULTS

The stability analyses of the TSF 2011 expansion were carried out for three sections of the embankment described above. These sections are typical as-built sections as reported in the Stage 6B Construction report (KP, 2011). In addition to the stability analysis of the expansion the current embankment stability was assessed to establish a FoS baseline for comparison. The sections modeled are shown in Figures 3.1 through 3.4 in Appendix A, with a summary provided below in Table 3.1 Factor of Safety Summary.

Table 3.1 Factor of Safety Summary

Section Embankment	Current Conditions	2011 Stage 7 Expansion	Approximate FoS Reduction
Main (Ch. 20+45)	1.8	1.7	3%
Main (Ch.20+45) Glaciolacustrine (Residual)	1.4	1.4	0%
Perimeter (Ch. 39+90)	2.1	2.0	5%
South (Ch. 7+15)	2.6	2.4	10%

The stability analyses identified that the main embankment was the critical stability section for the 2011 expansion. To analyze the 2011 expansion impact on the overall stability of the embankment, a comparison between the current conditions and 2011 expansion was performed. A FoS reduction of about 3% was observed in the main embankment, while a 0% reduction was observed utilizing residual strength in the glaciolacustrine unit and deemed insignificant to the overall stability of the embankment. Similarly, due to the negligible reduction in FoS, the seismic stability situation would remain unchanged relative to KP's 2007 analyses and the deformations would still be considered negligible. Thus, the stability requirement is satisfied for the 2011 expansion.

A more comprehensive embankment stability assessment will be carried out after additional information is gathered during the 2011 expansion and instrumentation installation program.

REFERENCES

CDA (Canadian Dam Association), 2007. *Dam Safety Guidelines*.

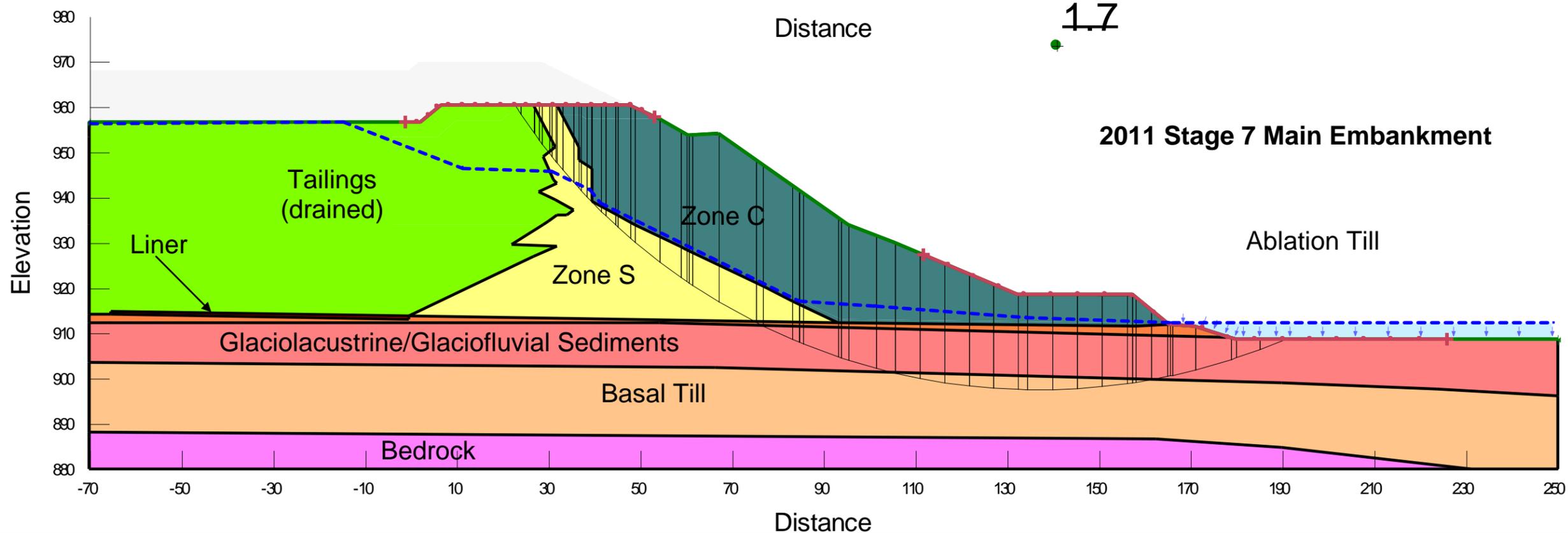
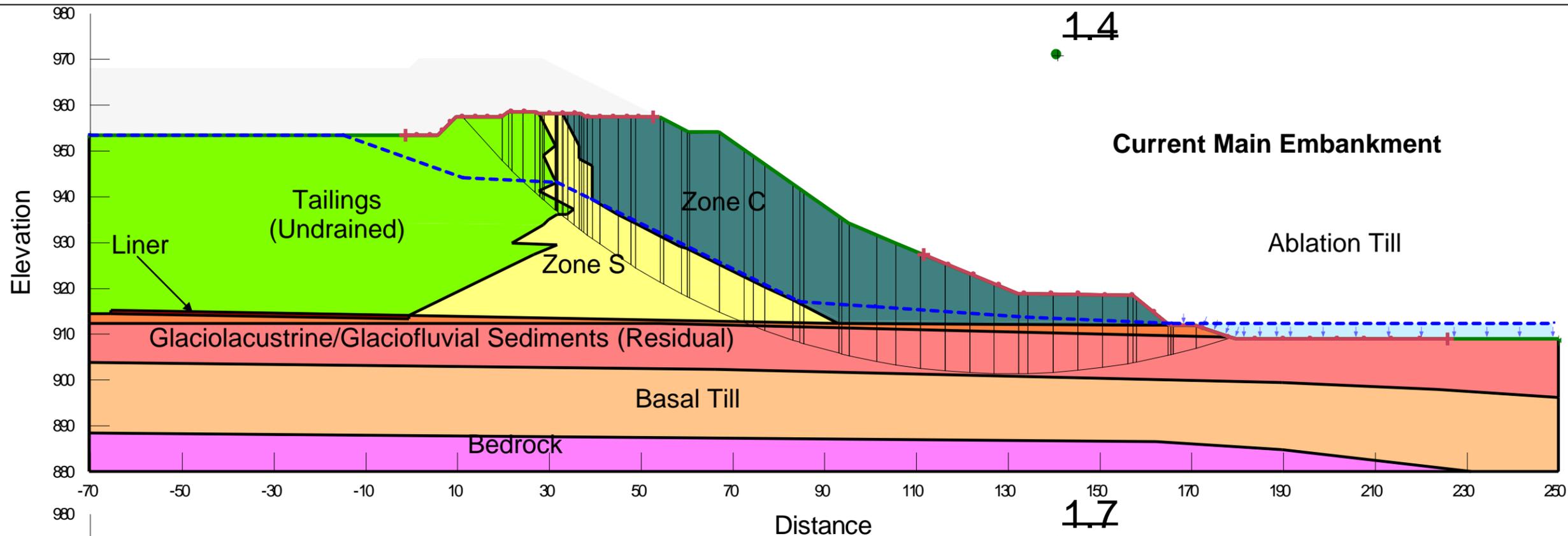
GeoStudio, 2007 (Version 7.17, Build 4921). Geo-Slope International, Ltd. Calgary, Alberta, Canada.

Knight Piésold Limited, 2011. *Tailing Storage Facility Report of Stage 6B Construction*. January 25, 2011.

Knight Piésold Limited, 2005. *Design of the Tailings Storage Facility to Ultimate Elevation*. March 14, 2005.

Leps, T.M., 1970. *Review of Shearing Strength of Rockfill*. ASCE Journal of the Soil Mech. and Found. Eng. Div., SM4. July 1970. pp. 1159-1170.

APPENDIX A - Stability Analysis



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MOUNT POLLEY MINE



DATE PREPARED: MARCH 2011

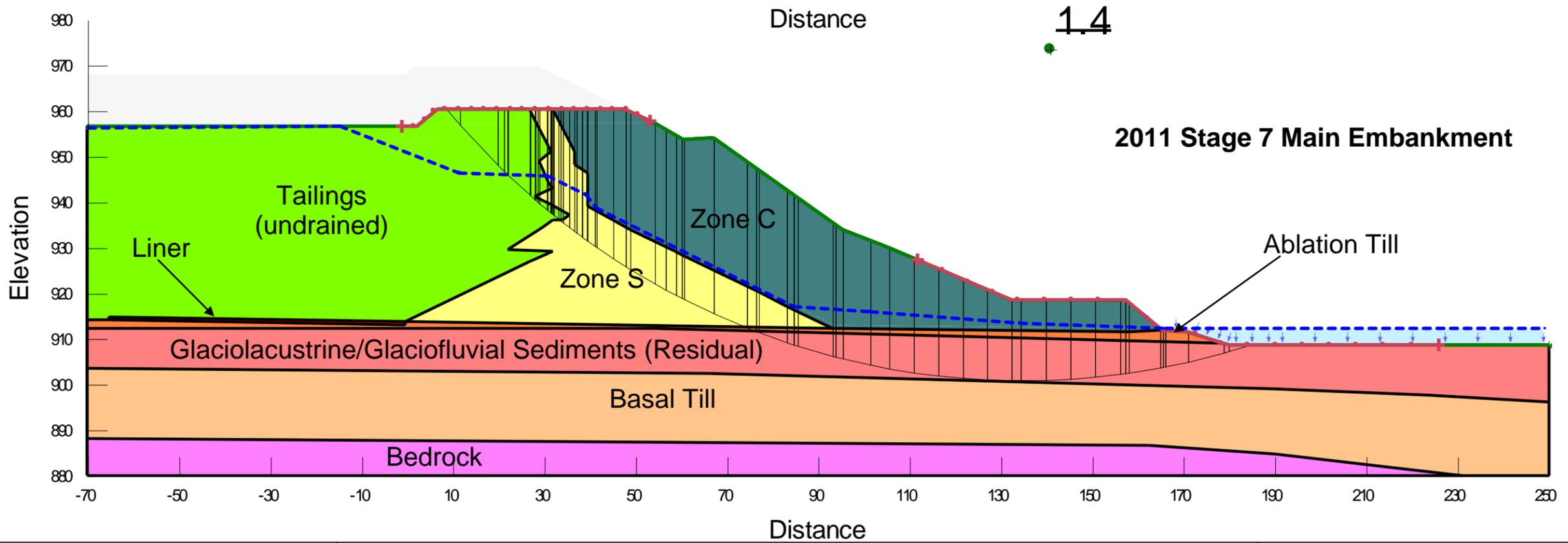
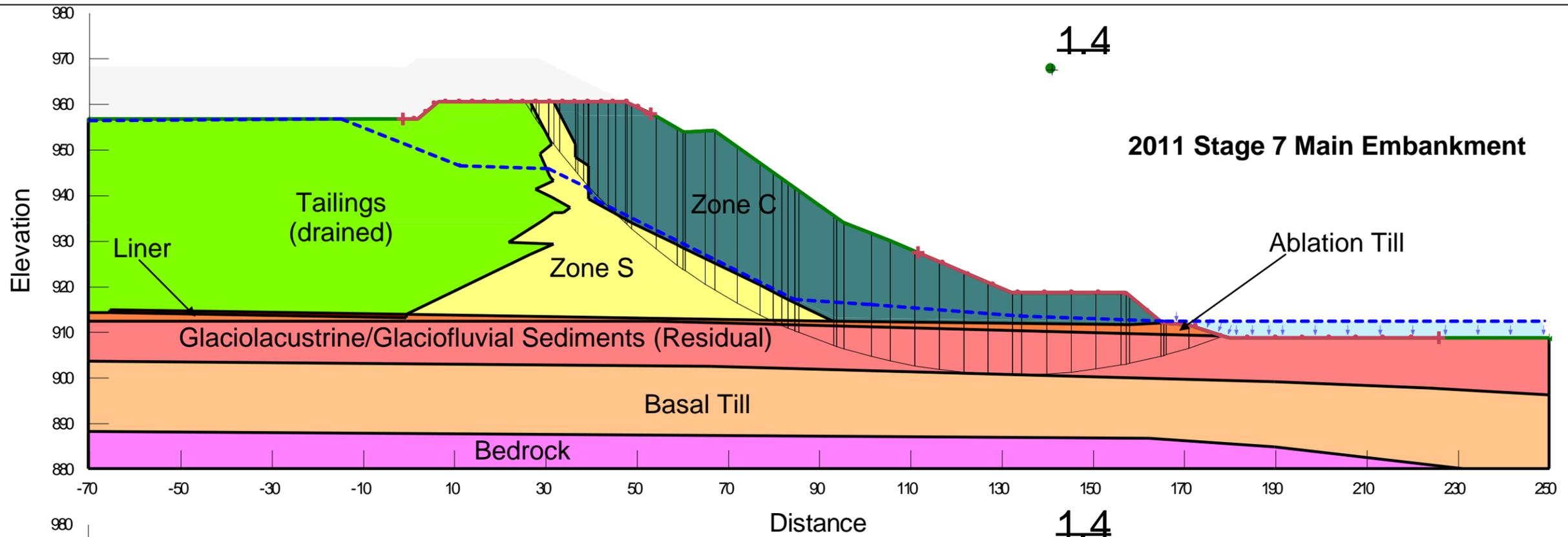
SCALE: AS SHOWN

PREPARED BY: D.OSTRITCHENKO

PROJECT No: VG00560

SLOPE/W SLABILITY ANALYSIS
Figure 3.1

Main Embankment



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MOUNT POLLEY MINE



DATE PREPARED: MARCH 2011

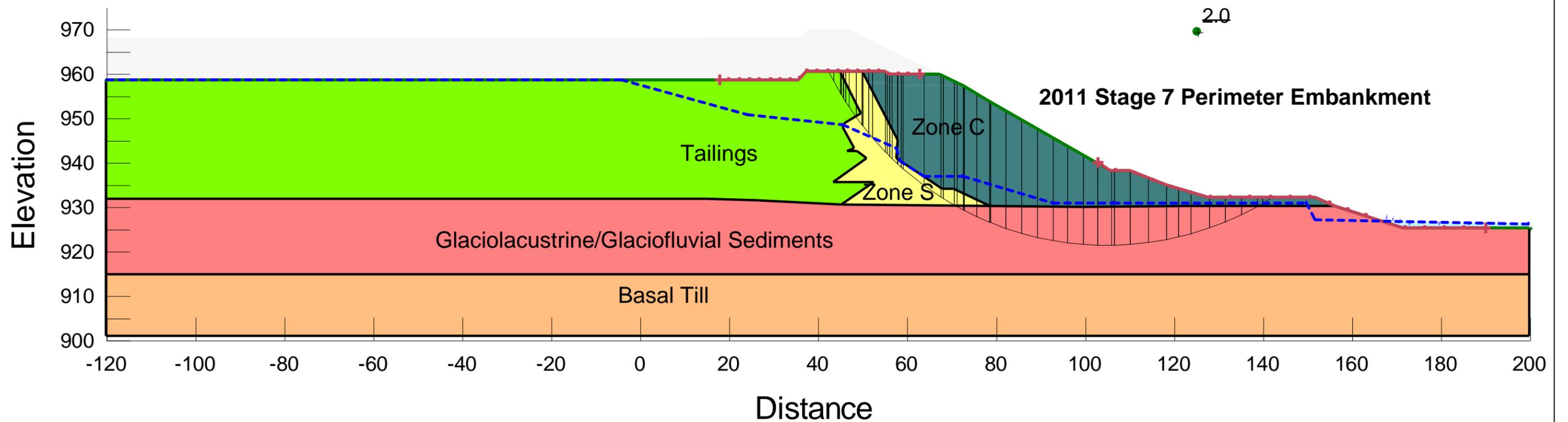
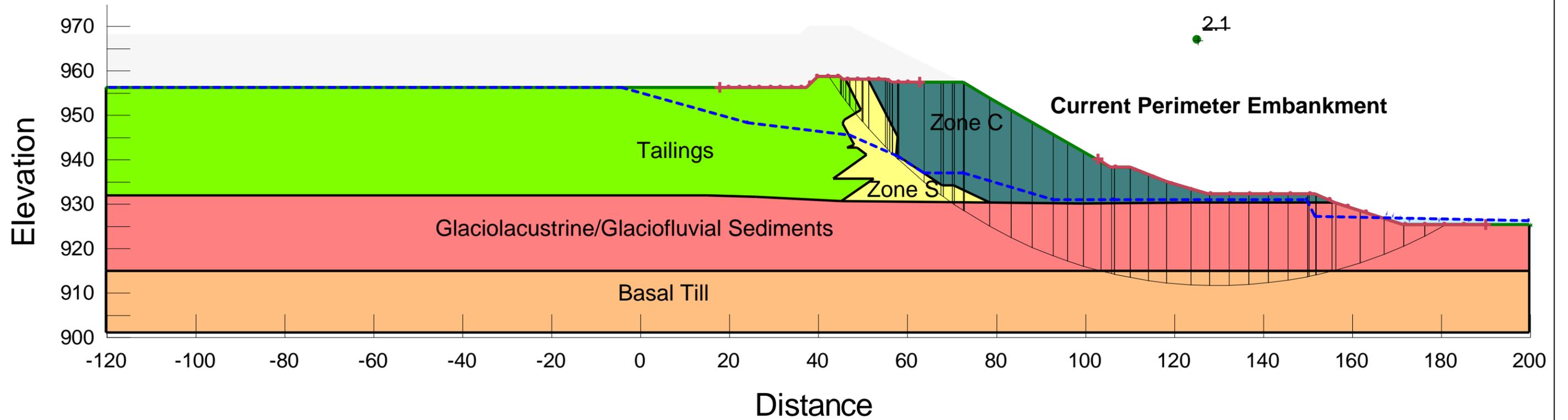
SCALE: AS SHOWN

PREPARED BY: D.OSTRITCHENKO

PROJECT No: VG00560

SLOPE/W SLABILITY ANALYSIS
Figure 3.2

Main Embankment Residual



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DATE PREPARED: MARCH 2011

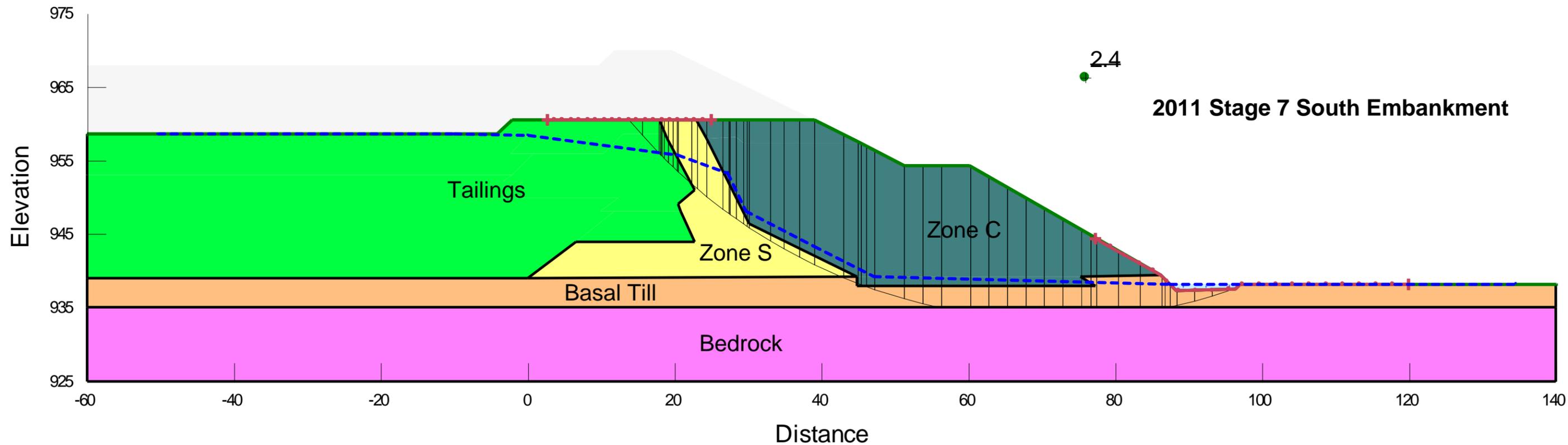
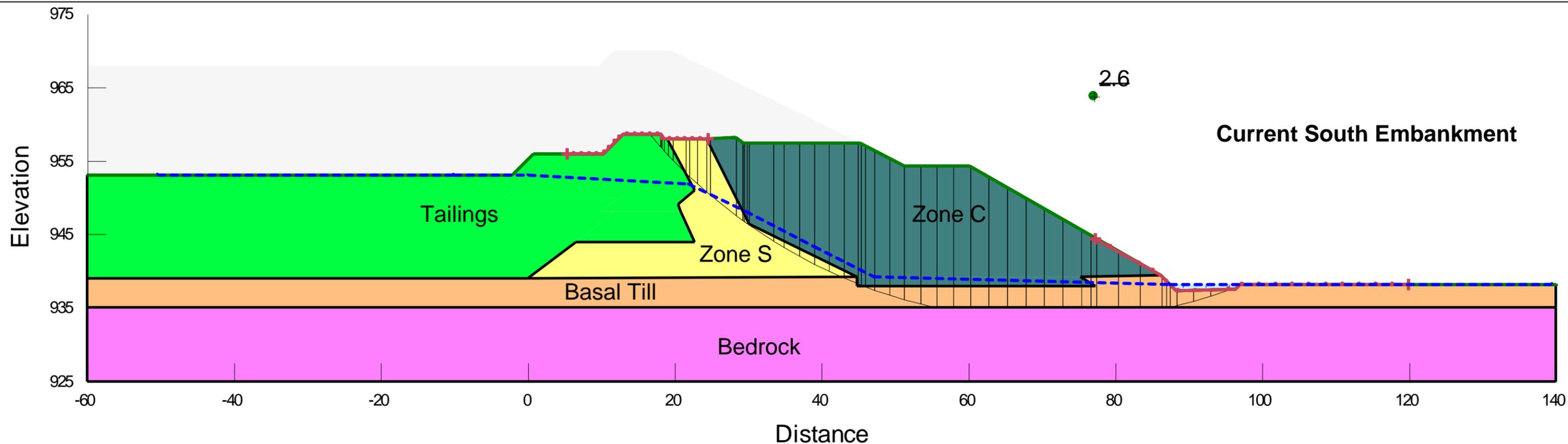
SCALE: AS SHOWN

PREPARED BY: D.OSTRITCHENKO

PROJECT No: VG00560

SLOPE/W SLABILITY ANALYSIS
Figure 3.3

Perimeter Embankment



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DATE PREPARED: MARCH 2011

SCALE: AS SHOWN

PREPARED BY: D.OSTRITCHENKO

PROJECT No: VG00560

SLOPE/W SLABILITY ANALYSIS
Figure 3.4

South Embankment

APPENDIX B

Sample Daily Construction Report

DATE: **7/10/2011**

DAILY REPORT NO.: TSF11-07-10

PROJECT TITLE: TSF Embankment

AMEC PROJECT No: VM00560

HOURS WORKED: 12 hours (7:00 AM to 7:00PM)

WEATHER: 12° C (Rain in the morning cloud in Afternoon)

DESCRIPTION OF WORK PERFORMED TODAY

Construction Activities:

- Placement Zone C @ ch. 20+00 to 21+00, el. 959.5m, full width, 1m lift, dozer
- Placement Zone S @ ch. 34+00 to 35+50, el. 960.0m, 2m wide (near Zone U,) 0.35m lift, dozer
- Placement Zone F @ ch. 35+50 to 36+00, el. 959.5m, full width, 0.6m lift, excavator
- Compaction Zone S @ ch. 32+00 to 34+00, el. 960.0m, full width, vibratory sheeps foot
- Compaction Zone F/T @ ch. 17+00 to 19+00, el. 958.5m, 4 passes, vibratory smooth drum
- Final grading @ ch.10+00 to 14+00
- Ongoing cell construction Zone U @ ch. 39+00 to 42+00, dozer
- Established downstream/upstream slope stakes @ 43+50 to 47+50, el. 959.0m
- Zone F/T boundary established @ 43+50 to 47+50 el. 959.0m

- Activity, changeage, top elevation, perpendicular distance/width, depth, equipment used, other comments. (highlight information out of scope/needng attention)

Material Testing:

- 07/5/11-DO20 - gradation test - Approved
- 07/8/11-DO21 - gradation test - Received, **Awaiting Approval**
- 07/10/11-DO22 - gradation test, Atterberg Limits - Shipped to PG lab

- Sample ID - Type of Test(s) - Status of the Test (Sample removed from the list day after Approval)

Compaction Testing:

- D50: Ch. 32+25, 10m upstream of SOL, @ 985.5m (5819384, 596050) - 96%
- D51: Ch. 32+75, 12m upstream of SOL, @ 985.5m (5819399, 596052) - 99%
- D52: Ch. 33+25, 14m upstream of SOL, @ 985.5m (5819445, 596080) - 94% (Failed, requested recompaction between 32+75 to 34+00)
- D53: Ch. 33+25, 11m upstream of SOL, @ 985.5m (5819490, 596094) - 93% (Failed, requested recompaction between 32+75 to 34+00)
- D52a: Ch. 33+25, 13m upstream of SOL, @ 985.5m (5819446, 596080) - 99% Retest
- D53a: Ch. 33+25, 10m upstream of SOL, @ 985.5m (5819491, 596093) - 101% Retest

- Test ID: changeage, offset from SOL, elevation (Northing, Easting) - Result Comments

Instrumentation Monitoring:

- Read all Main Embankment Piezos (07-10-11 Piezo Data.xlsx)

- Activity (submitted file name reference)

REMARKS (Delays, interruptions, extra work activities, unusual occurrences, etc. relevant to today's work)

- if rainy weather continuous placement of Zone S should be suspended.
- Down one excavator, scheduled to be back in 1 week.

CRITICAL INFORMATION

- 07/08/11-DO21 Immediate Approval Needed
- Lift thickness questionable for Zone S between ch. 34+00 to 35+50 @960.0m - Please Comment

Field Inspector:

Signature

Field Inspector

Title

10-Jul-11
Date

MPMC Site Engineer:

Signature

Site Engineer

Title

10-Jul-11
Date



DATE: 7/10/2011

DAILY REPORT NO.: TSF11-07-10

PROJECT TITLE: TSF Embankment

AMEC PROJECT No: VM00560

DAILY PHOTOGRAPHS

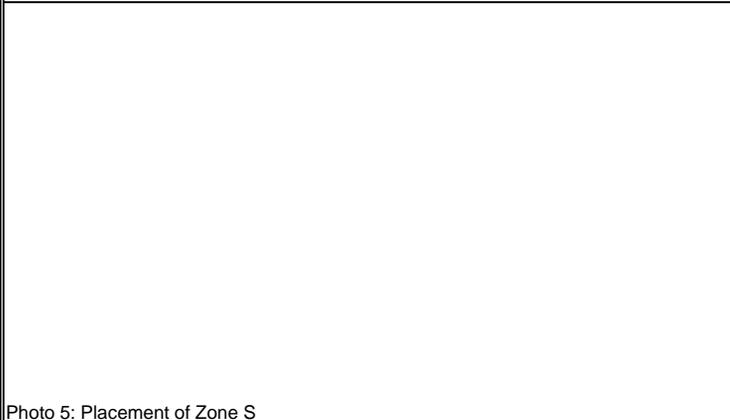


Photo 5: Placement of Zone S

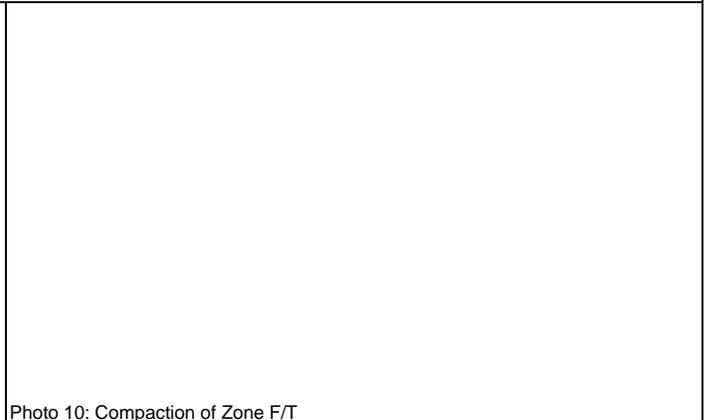


Photo 10: Compaction of Zone F/T

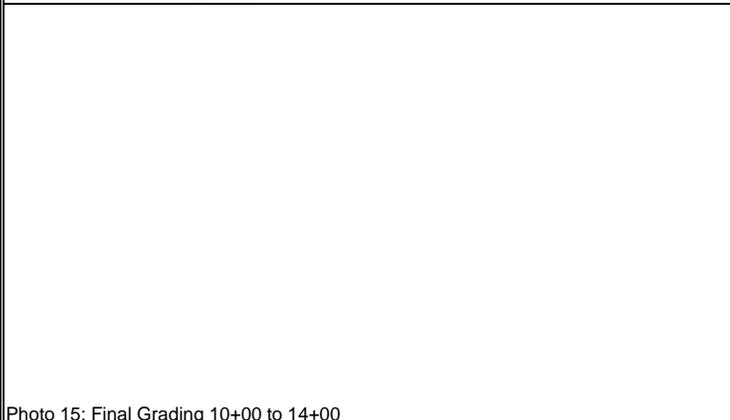


Photo 15: Final Grading 10+00 to 14+00

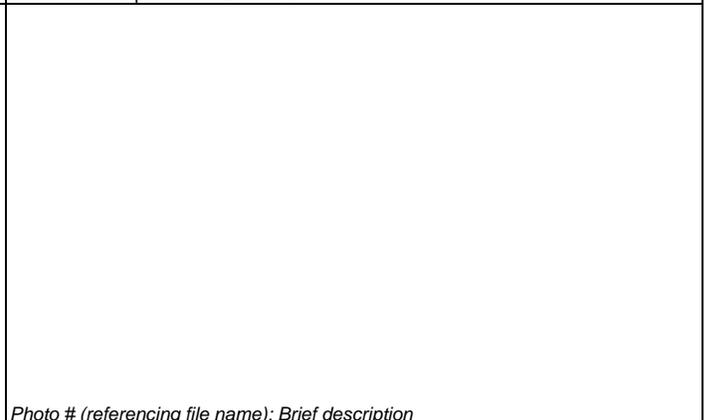
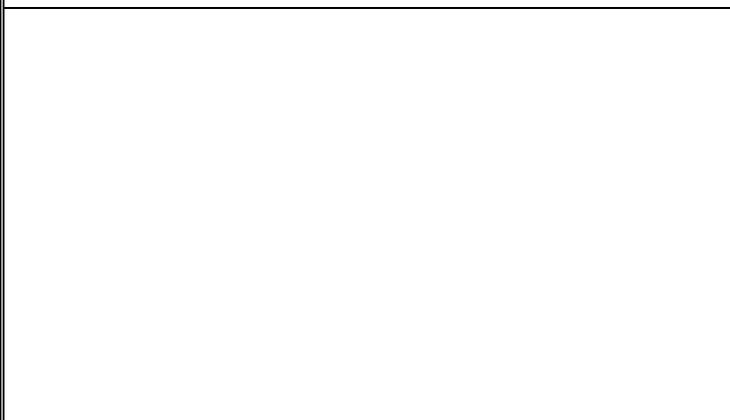


Photo # (referencing file name): Brief description



Distribution List:

APPENDIX C

ASTM Test Standards



Standard Test Method for Particle-Size Analysis of Soils¹

This standard is issued under the fixed designation D 422; 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 in soils. The distribution of particle sizes larger than 75 μm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 μm is determined by a sedimentation process, using a hydrometer to secure the necessary data (**Note 1** and **Note 2**).

NOTE 1—Separation may be made on the No. 4 (4.75-mm), No. 40 (425- μm), or No. 200 (75- μm) sieve instead of the No. 10. For whatever sieve used, the size shall be indicated in the report.

NOTE 2—Two types of dispersion devices are provided: (1) a high-speed mechanical stirrer, and (2) air dispersion. Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20- μm size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 μm .

2. Referenced Documents

2.1 ASTM Standards:²

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants

E 11 Specification for Wire Cloth and Sieves for Testing Purposes

E 100 Specification for ASTM Hydrometers

2.2 ASTM Adjuncts:

Air-Jet Dispersion Cup for Grain-Size Analysis of Soil³

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 Oct. 15, 2007. Published October 2007. Originally approved in 1935. Last previous edition approved in 2002 as D 422 – 63 (2002) ϵ^1 .

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 ASTM International Headquarters. Order Adjunct No. ADJD0422.

3. Apparatus

3.1 **Balances**—A balance sensitive to 0.01 g for weighing the material passing a No. 10 (2.00-mm) sieve, and a balance sensitive to 0.1 % of the mass of the sample to be weighed for weighing the material retained on a No. 10 sieve.

3.2 **Stirring Apparatus**—Either apparatus A or B may be used.

3.2.1 Apparatus A shall consist of a mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10 000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber, as shown in **Fig. 1**. The shaft shall be of such length that the stirring paddle will operate not less than $\frac{3}{4}$ in. (19.0 mm) nor more than 1 $\frac{1}{2}$ in. (38.1 mm) above the bottom of the 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.

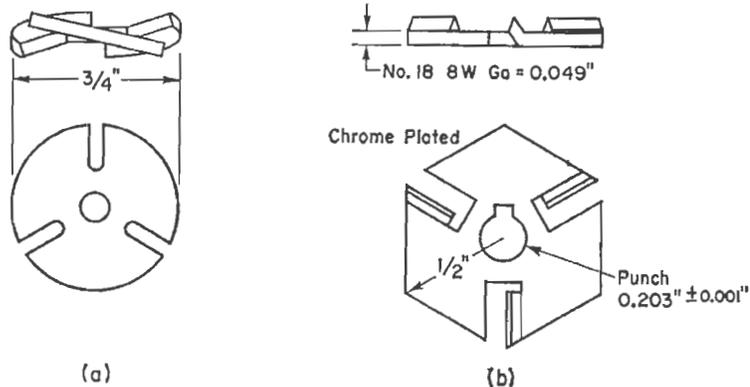
3.2.2 Apparatus B shall consist of an air-jet dispersion cup (See drawing³) (**Note 3**) conforming to the general details shown in **Fig. 3** (**Note 4** and **Note 5**).

NOTE 3—The amount of air required by an air-jet dispersion cup is of the order of 2 ft³/min; some small air compressors are not capable of supplying sufficient air to operate a cup.

NOTE 4—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

NOTE 5—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

3.3 **Hydrometer**—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litre of suspension, and conforming to the requirements for hydrometers 151H or 152H in Specifications **E 100**. Dimensions of both hydrometers are the same, the scale being the only item of difference.



Metric Equivalents					
in.	0.001	0.049	0.203	1/2	3/4
mm	0.03	1.24	5.16	12.7	19.0

FIG. 1 Detail of Stirring Paddles

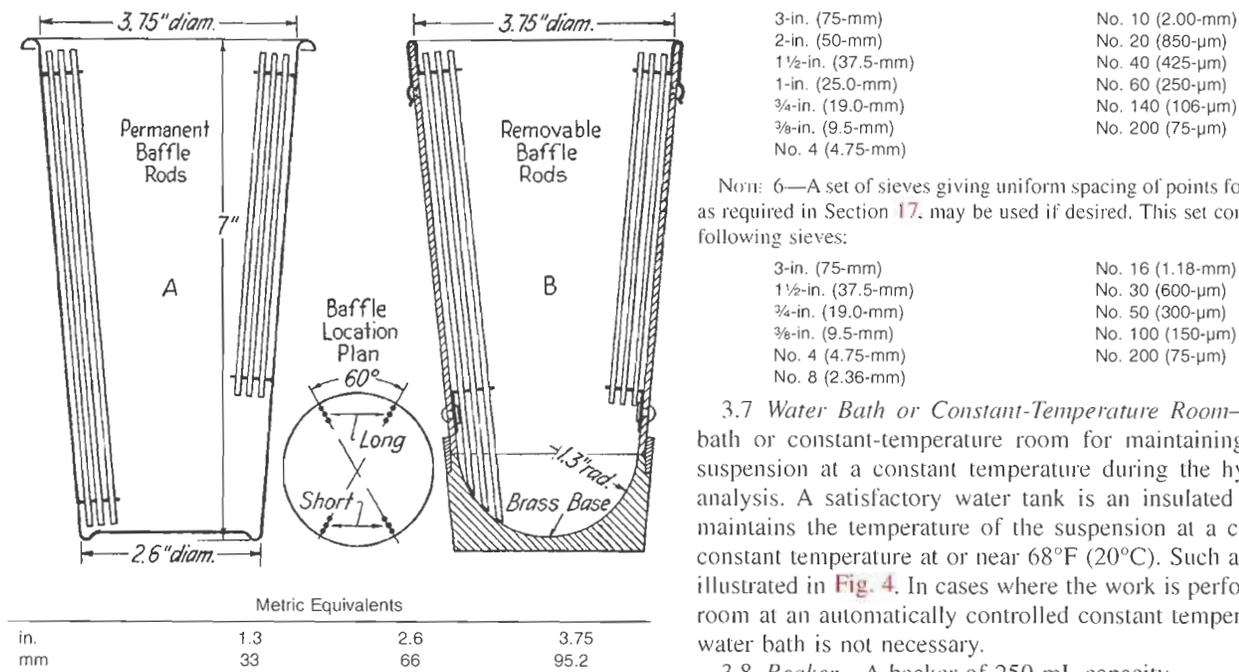


FIG. 2 Dispersion Cups of Apparatus

3.4 *Sedimentation Cylinder*—A glass cylinder essentially 18 in. (457 mm) in height and 2½ in. (63.5 mm) in diameter, and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000-mL mark is 36 ± 2 cm from the bottom on the inside.

3.5 *Thermometer*—A thermometer accurate to 1°F (0.5°C).

3.6 *Sieves*—A series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of Specification E 11. A full set of sieves includes the following (Note 6):

- 3-in. (75-mm)
- 2-in. (50-mm)
- 1½-in. (37.5-mm)
- 1-in. (25.0-mm)
- ¾-in. (19.0-mm)
- ⅝-in. (9.5-mm)
- No. 4 (4.75-mm)
- No. 10 (2.00-mm)
- No. 20 (850-µm)
- No. 40 (425-µm)
- No. 60 (250-µm)
- No. 140 (106-µm)
- No. 200 (75-µm)

NOTE: 6—A set of sieves giving uniform spacing of points for the graph, as required in Section 17, may be used if desired. This set consists of the following sieves:

- 3-in. (75-mm)
- 1½-in. (37.5-mm)
- ¾-in. (19.0-mm)
- ⅝-in. (9.5-mm)
- No. 4 (4.75-mm)
- No. 8 (2.36-mm)
- No. 16 (1.18-mm)
- No. 30 (600-µm)
- No. 50 (300-µm)
- No. 100 (150-µm)
- No. 200 (75-µm)

3.7 *Water Bath or Constant-Temperature Room*—A water bath or constant-temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature at or near 68°F (20°C). Such a device is illustrated in Fig. 4. In cases where the work is performed in a room at an automatically controlled constant temperature, the water bath is not necessary.

3.8 *Beaker*—A beaker of 250-mL capacity.

3.9 *Timing Device*—A watch or clock with a second hand.

4. Dispersing Agent

4.1 A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7).

NOTE: 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action. Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing

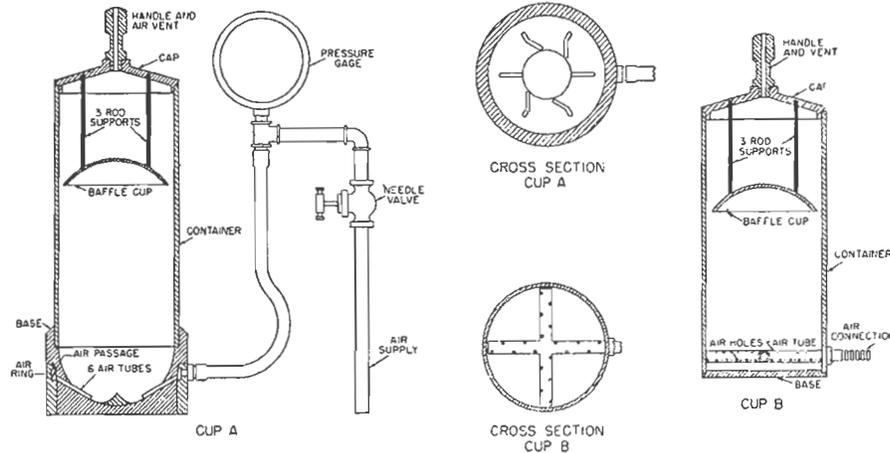
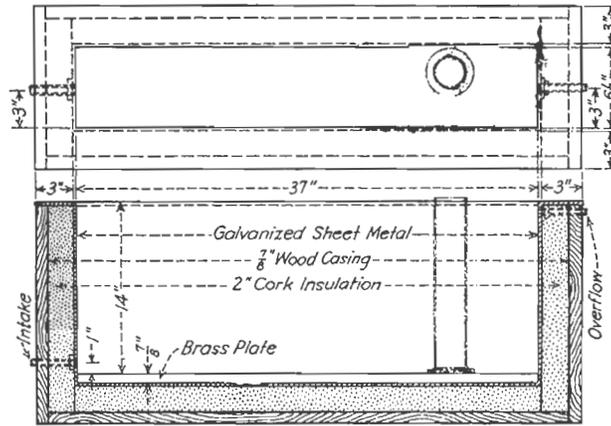


FIG. 3 Air-Jet Dispersion Cups of Apparatus B



Metric Equivalents						
in.	7/8	1	3	6 1/4	14	37
mm	22.2	25.4	76.2	158.2	356	940

FIG. 4 Insulated Water Bath

solutions should have the date of preparation marked on them.

4.2 All water used shall be either distilled or demineralized water. The water for a hydrometer test shall be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath; or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the temperature of the room. The basic temperature for the hydrometer test is 68°F (20°C). Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed.

5. Test Sample

5.1 Prepare the test sample for mechanical analysis as outlined in Practice D 421. During the preparation procedure the sample is divided into two portions. One portion contains

only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Practice D 421, shall be sufficient to yield quantities for mechanical analysis as follows:

5.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles,	Approximate Minimum Mass of Portion, g
in. (mm)	
3/8 (9.5)	500
3/4 (19.0)	1000
1 (25.4)	2000
1 1/2 (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

5.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

5.2 Provision is made in Section 5 of Practice D 421 for weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 12.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

6. Procedure

6.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm), 2-in. (50-mm), 1½-in. (37.5-mm), 1-in. (25.0-mm), ¾-in. (19.0-mm), ⅝-in. (9.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.

6.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass % of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

6.3 Determine the mass of each fraction on a balance conforming to the requirements of 3.1. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely the original mass of the quantity sieved.

HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING THE NO. 10 (2.00-mm) SIEVE

7. Determination of Composite Correction for Hydrometer Reading

7.1 Equations for percentages of soil remaining in suspension, as given in 14.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

7.1.1 Both soil hydrometers are calibrated at 68°F (20°C), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

7.1.2 Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

7.1.3 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

7.2 For convenience, a graph or table of composite corrections for a series of 1° temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

7.3 Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151H the composite correction is the difference between this reading and one; for hydrometer 152H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

8. Hygroscopic Moisture

8.1 When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of from 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at 230 ± 9°F (110 ± 5°C), and weigh again. Record the masses.

9. Dispersion of Soil Sample

9.1 When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g.

9.2 Place the sample in the 250-mL beaker and cover with 125 mL of sodium hexametaphosphate solution (40 g/L). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

9.3 At the end of the soaking period, disperse the sample further, using either stirring apparatus A or B. If stirring apparatus A is used, transfer the soil-water slurry from the beaker into the special dispersion cup shown in Fig. 2, washing any residue from the beaker into the cup with distilled or demineralized water (Note 9). Add distilled or demineralized water, if necessary, so that the cup is more than half full. Stir for a period of 1 min.

NOTE 9—A large size syringe is a convenient device for handling the water in the washing operation. Other devices include the wash-water bottle and a hose with nozzle connected to a pressurized distilled water tank.

9.4 If stirring apparatus B (Fig. 3) is used, remove the cover cap and connect the cup to a compressed air supply by means of a rubber hose. A air gage must be on the line between the cup and the control valve. Open the control valve so that the gage indicates 1 psi (7 kPa) pressure (Note 10). Transfer the

soil-water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 mL, but no more.

NOTE 10—The initial air pressure of 1 psi is required to prevent the soil-water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

9.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil-water slurry to the sedimentation cylinder.

10. Hydrometer Test

10.1 Immediately after dispersion, transfer the soil-water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 mL.

10.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (**Note 11**). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

NOTE 11—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 vigorous shaking of the cylinder while it is in the inverted position.

10.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about 20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem. Since it is not possible to secure readings at the bottom of the meniscus.

10.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

11. Sieve Analysis

11.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75- μ m) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at $230 \pm 9^\circ\text{F}$

($110 \pm 5^\circ\text{C}$) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

CALCULATIONS AND REPORT

12. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

12.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

12.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the $\frac{3}{8}$ -in. (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the $\frac{3}{8}$ -in. sieve and retained on the No. 4 sieve. For the remaining sieves, continue the calculations in the same manner.

12.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 12.2) by the total mass of sample and multiply the result by 100.

13. Hygroscopic Moisture Correction Factor

13.1 The hygroscopic moisture correction factor is the ratio between the mass of the oven-dried sample and the air-dry mass before drying. It is a number less than one, except when there is no hygroscopic moisture.

14. Percentages of Soil in Suspension

14.1 Calculate the oven-dry mass of soil used in the hydrometer analysis by multiplying the air-dry mass by the hygroscopic moisture correction factor.

14.2 Calculate the mass of a total sample represented by the mass of soil used in the hydrometer test, by dividing the oven-dry mass used by the percentage passing the No. 10 (2.00-mm) sieve, and multiplying the result by 100. This value is the weight W in the equation for percentage remaining in suspension.

14.3 The percentage of soil remaining in suspension at the level at which the hydrometer is measuring the density of the suspension may be calculated as follows (**Note 13**): For hydrometer 151H:

$$P = [(100\ 000/W) \times G/(G - G_1)](R - G_1) \quad (1)$$

NOTE 13—The bracketed portion of the equation for hydrometer 151H is constant for a series of readings and may be calculated first and then multiplied by the portion in the parentheses.

For hydrometer 152H:

$$P = (R/a/W) \times 100 \quad (2)$$

where:

a = correction fraction to be applied to the reading of hydrometer 152H. (Values shown on the scale are computed using a specific gravity of 2.65. Correction factors are given in **Table 1**).

- P = percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension,
- R = hydrometer reading with composite correction applied (Section 7),
- W = oven-dry mass of soil in a total test sample represented by mass of soil dispersed (see 14.2), g,
- G = specific gravity of the soil particles, and
- G_l = specific gravity of the liquid in which soil particles are suspended. Use numerical value of one in both instances in the equation. In the first instance any possible variation produces no significant effect, and in the second instance, the composite correction for R is based on a value of one for G_l .

15. Diameter of Soil Particles

15.1 The diameter of a particle corresponding to the percentage indicated by a given hydrometer reading shall be calculated according to Stokes' law (Note 14), on the basis that a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension. According to Stokes' law: see Table 2

$$D = \sqrt{[30n/980(G - G_l)] \times L/T} \quad (3)$$

where:

- D = diameter of particle, mm,
- n = coefficient of viscosity of the suspending medium (in this case water) in poises (varies with changes in temperature of the suspending medium),
- L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, cm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (see Table 2)),
- T = interval of time from beginning of sedimentation to the taking of the reading, min,
- G = specific gravity of soil particles, and
- G_l = specific gravity (relative density) of suspending medium (value may be used as 1.000 for all practical purposes).

TABLE 1 Values of Correction Factor, α , for Different Specific Gravities of Soil Particles^A

Specific Gravity	Correction Factor ^A
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

^A For use in equation for percentage of soil remaining in suspension when using Hydrometer 152H.

TABLE 2 Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes^A

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm
1.000	16.3	0	16.3	31	11.2
1.001	16.0	1	16.1	32	11.1
1.002	15.8	2	16.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
1.005	15.0	5	15.5		
1.006	14.7	6	15.3	36	10.4
1.007	14.4	7	15.2	37	10.2
1.008	14.2	8	15.0	38	10.1
1.009	13.9	9	14.8	39	9.9
1.010	13.7	10	14.7	40	9.7
1.011	13.4	11	14.5	41	9.6
1.012	13.1	12	14.3	42	9.4
1.013	12.9	13	14.2	43	9.2
1.014	12.6	14	14.0	44	9.1
1.015	12.3	15	13.8	45	8.9
1.016	12.1	16	13.7	46	8.8
1.017	11.8	17	13.5	47	8.6
1.018	11.5	18	13.3	48	8.4
1.019	11.3	19	13.2	49	8.3
1.020	11.0	20	13.0	50	8.1
1.021	10.7	21	12.9	51	7.9
1.022	10.5	22	12.7	52	7.8
1.023	10.2	23	12.5	53	7.6
1.024	10.0	24	12.4	54	7.4
1.025	9.7	25	12.2	55	7.3
1.026	9.4	26	12.0	56	7.1
1.027	9.2	27	11.9	57	7.0
1.028	8.9	28	11.7	58	6.8
1.029	8.6	29	11.5	59	6.6
1.030	8.4	30	11.4	60	6.5
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				

^A Values of effective depth are calculated from the equation:
 $L = L_1 + 1/2 [L_2 - (V_B/A)]$ (5)

where:

- L = effective depth, cm,
- L_1 = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, cm,
- L_2 = overall length of the hydrometer bulb, cm,
- V_B = volume of hydrometer bulb, cm³, and
- A = cross-sectional area of sedimentation cylinder, cm²

Values used in calculating the values in Table 2 are as follows:

- For both hydrometers, 151H and 152H:
- L_2 = 14.0 cm
- V_B = 67.0 cm³
- A = 27.8 cm²

For hydrometer 151H:

- L_1 = 10.5 cm for a reading of 1.000
- = 2.3 cm for a reading of 1.031

For hydrometer 152H:

- L_1 = 10.5 cm for a reading of 0 g/litre
- = 2.3 cm for a reading of 50 g/litre

NOTE 14—Since Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the

diameter of spheres that would fall at the same rate as the soil particles.

15.2 For convenience in calculations the above equation may be written as follows: see Table 3

$$D = K\sqrt{LT} \quad (4)$$

where:

K = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 3. The value of K does not change for a series of readings constituting a test, while values of L and T do vary.

15.3 Values of D may be computed with sufficient accuracy, using an ordinary 10-in. slide rule.

NOTE 15—The value of L is divided by T using the A - and B -scales, the square root being indicated on the D -scale. Without ascertaining the value of the square root it may be multiplied by K , using either the C - or CI -scale.

16. Sieve Analysis Values for Portion Finer than No. 10 (2.00-mm) Sieve

16.1 Calculation of percentages passing the various sieves used in sieving the portion of the sample from the hydrometer test involves several steps. The first step is to calculate the mass of the fraction that would have been retained on the No. 10 sieve had it not been removed. This mass is equal to the total percentage retained on the No. 10 sieve (100 minus total percentage passing) times the mass of the total sample represented by the mass of soil used (as calculated in 14.2), and the result divided by 100.

16.2 Calculate next the total mass passing the No. 200 sieve. Add together the fractional masses retained on all the sieves, including the No. 10 sieve, and subtract this sum from the mass of the total sample (as calculated in 14.2).

16.3 Calculate next the total masses passing each of the other sieves, in a manner similar to that given in 12.2.

16.4 Calculate last the total percentages passing by dividing the total mass passing (as calculated in 16.3) by the total mass of sample (as calculated in 14.2), and multiply the result by 100.

17. Graph

17.1 When the hydrometer analysis is performed, a graph of the test results shall be made, plotting the diameters of the particles on a logarithmic scale as the abscissa and the percentages smaller than the corresponding diameters to an arithmetic scale as the ordinate. When the hydrometer analysis is not made on a portion of the soil, the preparation of the graph is optional, since values may be secured directly from tabulated data.

18. Report

18.1 The report shall include the following:

18.1.1 Maximum size of particles,

18.1.2 Percentage passing (or retained on) each sieve, which may be tabulated or presented by plotting on a graph (Note 16).

18.1.3 Description of sand and gravel particles:

18.1.3.1 Shape—rounded or angular,

18.1.3.2 Hardness—hard and durable, soft, or weathered and friable,

18.1.4 Specific gravity, if unusually high or low,

18.1.5 Any difficulty in dispersing the fraction passing the No. 10 (2.00-mm) sieve, indicating any change in type and amount of dispersing agent, and

18.1.6 The dispersion device used and the length of the dispersion period.

NOTE 16—This tabulation of graph represents the gradation of the sample tested. If particles larger than those contained in the sample were removed before testing, the report shall so state giving the amount and maximum size.

18.2 For materials tested for compliance with definite specifications, the fractions called for in such specifications shall be reported. The fractions smaller than the No. 10 sieve shall be read from the graph.

18.3 For materials for which compliance with definite specifications is not indicated and when the soil is composed almost entirely of particles passing the No. 4 (4.75-mm) sieve, the results read from the graph may be reported as follows:

- (1) Gravel, passing 3-in. and retained on No. 4 sieve %
- (2) Sand, passing No. 4 sieve and retained on No. 200 sieve %
 - (a) Coarse sand, passing No. 4 sieve and retained on No. 10 sieve %
 - (b) Medium sand, passing No. 10 sieve and retained on No. 40 sieve %

TABLE 3 Values of K for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

Temperature,°	Specific Gravity of Soil Particles									
	C	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01530	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356	0.01338
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338	0.01321
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321	0.01305
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.1323	0.01305	0.01289
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289	0.01273
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273	0.01258
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258	0.01243
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243	0.01229
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229	0.01215
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215	0.01201
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201	0.01188
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188	0.01175
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01225	0.01208	0.01191	0.01175	0.01162
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162	0.01149
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149	

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(c) Fine sand, passing No. 40 sieve and retained on No. 200 sieve	% 1-in.
(3) Silt size, 0.074 to 0.005 mm	% ¾-in.
(4) Clay size, smaller than 0.005 mm	.....	% ⅜-in.	.....
Colloids, smaller than 0.001 mm	.....	% No. 4 (4.75-mm)	.....
		No. 10 (2.00-mm)	.....
		No. 40 (425-µm)	.....
		No. 200 (75-µm)	.....

18.4 For materials for which compliance with definite specifications is not indicated and when the soil contains material retained on the No. 4 sieve sufficient to require a sieve analysis on that portion, the results may be reported as follows (Note 17):

SIEVE ANALYSIS

Sieve Size	Percentage Passing
3-in.
2-in.
1 ½-in.

HYDROMETER ANALYSIS

0.074 mm	.....
0.005 mm	.....
0.001 mm	.....

Note: 17—No. 8 (2.36-mm) and No. 50 (300-µm) sieves may be substituted for No. 10 and No. 40 sieves.

19. Keywords

19.1 grain-size; hydrometer analysis; hygroscopic moisture; particle-size; sieve analysis

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Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft³ (600 kN-m/m³))¹

This standard is issued under the fixed designation D 698; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last 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 Department of Defense.

^{ε1} NOTE—Figure 2 was editorially corrected in July 2007.

1. Scope*

1.1 These test methods cover laboratory compaction methods used to determine the relationship between molding water content and dry unit weight of soils (compaction curve) compacted in a 4 or 6-in. (101.6 or 152.4-mm) diameter mold with a 5.50-lbf (24.5-N) rammer dropped from a height of 12.0 in. (305 mm) producing a compactive effort of 12 400 ft-lbf/ft³ (600 kN-m/m³).

NOTE 1—The equipment and procedures are similar as those proposed by R. R. Proctor (*Engineering News Record*—September 7, 1933) with this one major exception: his rammer blows were applied as “12 inch firm strokes” instead of free fall, producing variable compactive effort depending on the operator, but probably in the range 15 000 to 25 000 ft-lbf/ft³ (700 to 1200 kN-m/m³). The standard effort test (see 3.1.3) is sometimes referred to as the Proctor Test.

1.1.1 Soils and soil-aggregate mixtures are to be regarded as natural occurring fine- or coarse-grained soils, or composites or mixtures of natural soils, or mixtures of natural and processed soils or aggregates such as gravel or crushed rock. Hereafter referred to as either soil or material.

1.2 These test methods apply only to soils (materials) that have 30 % or less by mass of particles retained on the ¾-in. (19.0-mm) sieve and have not been previously compacted in the laboratory; that is, do not reuse compacted soil.

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

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

1.3.1 Method A:

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

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

1.3.1.3 *Layers*—Three.

1.3.1.4 *Blows per Layer*—25.

1.3.1.5 *Usage*—May be used if 25 % or less (see Section 1.4) by mass of the material is retained on the No. 4 (4.75-mm) sieve.

1.3.1.6 *Other Usage*—If this gradation requirement cannot be met, then Method C may be used.

1.3.2 *Method B:*

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

1.3.2.2 *Material*—Passing ¾-in. (9.5-mm) sieve.

1.3.2.3 *Layers*—Three.

1.3.2.4 *Blows per Layer*—25.

1.3.2.5 *Usage*—May be used if 25 % or less (see Section 1.4) by mass of the material is retained on the ¾-in. (9.5-mm) sieve.

1.3.2.6 *Other Usage*—If this gradation requirement cannot be met, then Method C may be used.

1.3.3 *Method C:*

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

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

1.3.3.3 *Layers*—Three.

1.3.3.4 *Blows per Layer*—56.

1.3.3.5 *Usage*—May be used if 30 % or less (see Section 1.4) by mass of the material is retained on the ¾-in. (19.0-mm) sieve.

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

NOTE 2—Results have been found to vary slightly when a material is tested at the same compactive effort in different size molds, with the smaller mold size typically yielding larger values of density/unit weight (I, pp. 21+).²

1.4 If the test specimen contains more than 5 % by mass of oversize fraction (coarse fraction) and the material will not be included in the test, corrections must be made to the unit mass

¹ These Test Methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

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² The boldface numbers in parentheses refer to the list of references at the end of this standard.

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

and molding water content of the specimen or to the appropriate field-in-place density test specimen using Practice **D 4718**.

1.5 This test method will generally produce a well-defined maximum dry unit weight for non-free draining soils. If this test method is used for free-draining soils the maximum unit weight may not be well defined, and can be less than obtained using Test Methods **D 4253**.

1.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice **D 6026**, unless superseded by this standard.

1.6.1 For purposes of comparing measured or calculated value(s) with specified limits, the measured or calculated value(s) shall be rounded to the nearest decimal or significant digits in the specified limits.

1.6.2 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.

1.7 The values in inch-pound units are to be regarded as the standard. The values stated in SI units are provided for information only, except for units of mass. The units for mass are given in SI units only: g or kg.

1.7.1 It is common practice in the engineering profession to concurrently use pounds to represent both a unit of mass (lbm) and a 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. This standard has been written using the gravitational system of units when dealing with the inch-pound system. In this system, the pound (lbf) represents a unit of force (weight). However, the use of balances or scales recording pounds of mass (lbm) or the recording of density in lbm/ft³ shall not be regarded as a nonconformance with this standard.

1.8 *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

- C 127** Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
- C 136** Test Method for Sieve Analysis of Fine and Coarse Aggregates

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.

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

D 2168 Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors

D 2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

D 4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles

D 4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D 4914 Test Methods for Density of Soil and Rock in Place by the Sand Replacement Method in a Test Pit

D 5030 Test Method for Density of Soil and Rock in Place by the Water Replacement Method in a Test Pit

D 6026 Practice for Using Significant Digits in Geotechnical Data

D 6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis

E 11 Specification for Wire Cloth and Sieves for Testing Purposes

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): the Modern Metric System

3. Terminology

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

3.1.1 *molding water content, n*—the adjusted water content of a soil (material) that will be compacted/reconstituted.

3.1.2 *standard effort—in compaction testing*, the term for the 12 400 ft-lbf/ft³ (600 kN-m/m³) compactive effort applied by the equipment and methods of this test.

3.1.3 *standard maximum dry unit weight, $\gamma_{d,max}$* in lbf/ft³ (kN/m³)—*in compaction testing*, the maximum value defined by the compaction curve for a compaction test using standard effort.

3.1.4 *standard optimum water content, w_{opt}* in %—*in compaction testing*, the molding water content at which a soil can be compacted to the maximum dry unit weight using standard compactive effort.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *oversize fraction (coarse fraction), P_C* in %—the portion of total specimen not used in performing the compaction test; it may be the portion of total specimen retained on the No.

4 (4.75-mm) sieve in Method A, $\frac{3}{8}$ -in. (9.5-mm) sieve in Method B, or $\frac{3}{4}$ -in. (19.0-mm) sieve in Method C.

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

4. Summary of Test Method

4.1 A soil at a selected molding water content is placed in three layers into a mold of given dimensions, with each layer compacted by 25 or 56 blows of a 5.50-lbf (24.47-N) rammer dropped from a distance of 12.00 in. (304.8 mm), subjecting the soil to a total compactive effort of about 12 400 ft-lbf/ft³ (600 kN-m/m³). The resulting dry unit weight is determined. The procedure is repeated for a sufficient number of molding water contents to establish a relationship between the dry unit weight and the molding water content for the soil. This data, when plotted, represents a curvilinear relationship known as the compaction curve. The values of optimum water content and standard maximum dry unit weight are determined from the compaction curve.

5. Significance and Use

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

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

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

5.3.1 *Oversize Fraction*—Soils containing more than 30 % oversize fraction (material retained on the $\frac{3}{4}$ -in. (19-mm) sieve) are a problem. For such soils, there is no ASTM test method to control their compaction and very few laboratories are equipped to determine the laboratory maximum unit weight

(density) of such soils (USDI Bureau of Reclamation, Denver, CO and U.S. Army Corps of Engineers, Vicksburg, MS). Although Test Methods D 4914 and D 5030 determine the “field” dry unit weight of such soils, they are difficult and expensive to perform.

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

NOTE 3—Success in executing the compaction control of an earthwork project, especially when a method specification is used, is highly dependent upon the quality and experience of the contractor and inspector.

5.3.1.2 Another method is to apply the use of density correction factors developed by the USDI Bureau of Reclamation (2,3) and U.S. Corps of Engineers (4). These correction factors may be applied for soils containing up to about 50 to 70 % oversize fraction. Each agency uses a different term for these density correction factors. The USDI Bureau of Reclamation uses D ratio (or D -VALUE), while the U.S. Corps of Engineers uses Density Interference Coefficient (I_c).

5.3.1.3 The use of the replacement technique (Test Method D 698–78, Method D), in which the oversize fraction is replaced with a finer fraction, is inappropriate to determine the maximum dry unit weight, $\gamma_{d,max}$, of soils containing oversize fractions (4).

5.3.2 *Degradation*—Soils containing particles that degrade during compaction are a problem, especially when more degradation occurs during laboratory compaction than field compaction, as is typical. Degradation typically occurs during the compaction of a granular-residual soil or aggregate. When degradation occurs, the maximum dry-unit weight increases (1, p. 73) so that the laboratory maximum value is not representative of field conditions. Often, in these cases, the maximum dry unit weight is impossible to achieve in the field.

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

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

NOTE 4—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing/sampling/inspection, and the like. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Mold Assembly*—The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and

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

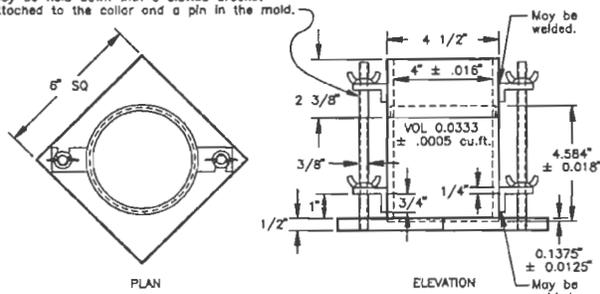


FIG. 1 4.0-in. Cylindrical Mold

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

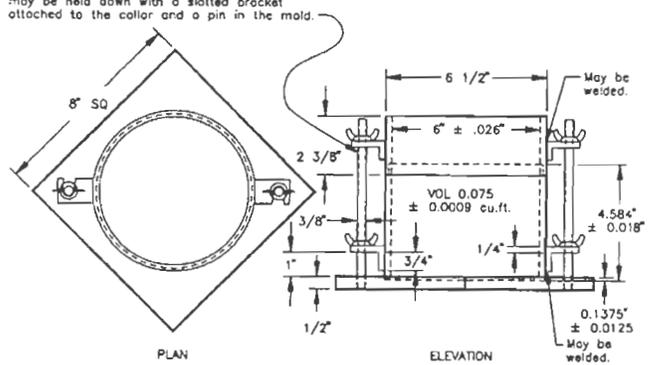


FIG. 2 6.0-in. Cylindrical Mold

dimensions indicated in 6.1.1 or 6.1.2 and Figs. 1 and 2. See also Table 1. The walls of the mold may be solid, split, or tapered. The "split" type may consist of two half-round sections, or a section of pipe split along one element, which can be securely locked together to form a cylinder meeting the requirements of this section. The "tapered" type shall have an internal diameter taper that is uniform and not more than 0.200 in./ft (16.7 mm/m) of mold height. Each mold shall have a base plate and an extension collar assembly, both made of rigid metal and constructed so they can be securely attached and easily detached from the mold. The extension collar assembly shall have a height extending above the top of the mold of at least 2.0 in. (51 mm) which may include an upper section that flares out to form a funnel, provided there is at least a 0.75 in. (19 mm) straight cylindrical section beneath it. The extension collar shall align with the inside of the mold. The bottom of the base plate and bottom of the centrally recessed area that accepts the cylindrical mold shall be planar within ±0.005 in. (±0.1 mm).

6.1.1 *Mold, 4 in.*—A mold having a 4.000 ± 0.016-in. (101.6 ± 0.4-mm) average inside diameter, a height of 4.584 ± 0.018 in. (116.4 ± 0.5 mm) and a volume of 0.0333 ± 0.0005 ft³ (943.0 ± 14 cm³). A mold assembly having the minimum required features is shown in Fig. 1.

6.1.2 *Mold, 6 in.*—A mold having a 6.000 ± 0.026-in. (152.4 ± 0.7-mm) average inside diameter, a height of 4.584 ± 0.018 in. (116.4 ± 0.5 mm), and a volume of 0.0750 ± 0.0009 ft³ (2124 ± 25 cm³). A mold assembly having the minimum required features is shown in Fig. 2.

6.2 *Rammer*—A rammer, either manually operated as described further in 6.2.1 or mechanically operated as described in 6.2.2. The rammer shall fall freely through a distance of 12.00 ± 0.05 in. (304.8 ± 1 mm) from the surface of the specimen. The weight of the rammer shall be 5.50 ± 0.02 lbf (24.47 ± 0.09 N, or mass of 2.495 ± 0.023 kg), except that the weight of the mechanical rammers may be adjusted as described in Test Methods D 2168; see Note 5. The striking face of the rammer shall be planar and circular, except as noted in 6.2.2.1, with a diameter when new of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). The rammer shall be replaced if the striking face becomes worn or bellied to the extent that the diameter exceeds 2.000 ± 0.01 in. (50.80 ± 0.25 mm).

NOTE 5—It is a common and acceptable practice to determine the weight of the rammer using either a kilogram or pound balance and

TABLE 1 Metric Equivalents for Figs. 1 and 2

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

assume 1 lbf is equivalent to 0.4536 kg, 1 lbf is equivalent to 1 lbm, or 1 N is equivalent to 0.2248 lbf or 0.1020 kg.

6.2.1 *Manual Rammer*—The rammer shall be equipped with a guide sleeve that has sufficient clearance that the free fall of the rammer shaft and head is not restricted. The guide sleeve shall have at least four vent holes at each end (eight holes total) located with centers 3/4 ± 1/16 in. (19 ± 2 mm) from each end and spaced 90 degrees apart. The minimum diameter of the vent holes shall be 3/8 in. (9.5 mm). Additional holes or slots may be incorporated in the guide sleeve.

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

6.2.2.1 Mechanical Rammer-Sector Face—The sector face shall be used with the 6-in. (152.4-mm) mold, in place of the circular face rammer. The striking face shall have the shape of a sector of a circle of radius equal to 2.90 ± 0.02 in. (73.7 ± 0.5 mm) and an area about the same as the circular face, see **6.2**. The rammer shall operate in such a manner that the vertex of the sector is positioned at the center of the specimen.

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

6.4 Balance—A Class GP5 balance meeting the requirements of Specification **D 4753** for a balance of 1-g readability. If the water content of the compacted specimens is determined using a representative portion of the specimen, rather than the whole specimen, and if the representative portion is less than 1000 g, a Class GP2 balance having a 0.1-g readability is needed in order to comply with Test Methods **D 2216** requirements for determining water content to 0.1 %.

NOTE 6—Use of a balance having an equivalent capacity and a readability of 0.002 lbm as an alternative to a class GP5 balance should not be regarded as nonconformance to this standard.

6.5 Drying Oven—Thermostatically controlled oven, capable of maintaining a uniform temperature of $230 \pm 9^\circ\text{F}$ ($110 \pm 5^\circ\text{C}$) throughout the drying chamber. These requirements typically require the use of a forced-draft type oven. Preferably the oven should be vented outside the building.

6.6 Straightedge—A stiff metal straightedge of any convenient length but not less than 10 in. (250 mm). The total length of the straightedge shall be machined straight to a tolerance of ± 0.005 in. (± 0.1 mm). The scraping edge shall be beveled if it is thicker than $\frac{1}{8}$ in. (3 mm).

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

6.8 Mixing Tools—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, spraying device (to add water evenly), and (preferably, but optional) suitable mechanical device for thoroughly mixing the subspecimen of soil with increments of water.

7. Standardization/Calibration

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

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

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

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

7.1.4 Mechanical Rammer—Verify and adjust if necessary that the mechanical rammer is in accordance with Test Method **D 2168**. In addition, the clearance between the rammer and the inside surface of the mold shall be verified in accordance with **6.2.2**.

8. Test Specimen

8.1 The minimum specimen (test fraction) mass for Methods A and B is about 16 kg, and for Method C is about 29 kg of dry soil. Therefore, the field sample should have a moist mass of at least 23 kg and 45 kg, respectively. Greater masses would be required if the oversize fraction is large (see **10.2** or **10.3**) or an additional molding water content is taken during compaction of each point (see **10.4.2.1**).

8.2 If gradation data is not available, estimate the percentage of material (by mass) retained on the No. 4 (4.75-mm), $\frac{3}{8}$ -in. (9.5-mm), or $\frac{3}{4}$ -in. (19.0-mm) sieve as appropriate for selecting Method A, B, or C, respectively. If it appears the percentage retained of interest is close to the allowable value for a given Method (A, B, or C), then either:

8.2.1 Select a Method that allows a higher percentage retained (B or C).

8.2.2 Using the Method of interest, process the specimen in accordance with **10.2** or **10.3**, this determines the percentage retained for that method. If acceptable, proceed, if not go to the next Method (B or C).

8.2.3 Determine percentage retained values by using a representative portion from the total sample, and performing a simplified or complete gradation analysis using the sieve(s) of interest and Test Method **D 6913** or **C 136**. It is only necessary to calculate the retained percentage(s) for the sieve or sieves for which information is desired.

9. Preparation of Apparatus

9.1 Select the proper compaction mold(s), collar, and base plate in accordance with the Method (A, B, or C) being used. Check that its volume is known and determined with or without base plate, free of nicks or dents, and will fit together properly.

NOTE 7—Mass requirements are given in **10.4**.

9.2 Check that the manual or mechanical rammer assembly is in good working condition and that parts are not loose or worn. Make any necessary adjustments or repairs. If adjustments or repairs are made, the rammer must be re-standardized.

10. Procedure

10.1 Soils:

10.1.1 Do not reuse soil that has been previously compacted in the laboratory. The reuse of previously compacted soil yields a significantly greater maximum dry unit weight (**1**, p. 31).

10.1.2 When using this test method for soils containing hydrated halloysite, or in which past experience indicates that results will be altered by air-drying, use the moist preparation method (see **10.2**). In referee testing, each laboratory has to use the same method of preparation, either moist (preferred) or air-dried.

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

10.2 Moist Preparation Method (preferred)—Without previously drying the sample/specimen, process it over a No. 4 (4.75-mm), $\frac{3}{8}$ -in. (9.5-mm), or $\frac{3}{4}$ -in. (19.0-mm) sieve, depending on the Method (A, B, or C) being used or required as covered in **8.2**. For additional processing details, see Test Method **D 6913**. Determine and record the mass of both the retained and passing portions (oversize fraction and test

fraction, respectively) to the nearest g. Oven dry the oversize fraction and determine and record its dry mass to the nearest g. If it appears more than 0.5 % of the total dry mass of the specimen is adhering to the oversize fraction, wash that fraction. Then determine and record its oven dry mass to the nearest g. Determine and record the water content of the processed soil (test fraction). Using that water content, determine and record the oven dry mass of the test fraction to the nearest g. Based on these oven dry masses, the percent oversize fraction, P_C , and test fraction, P_F , shall be determined and recorded, unless a gradation analysis has already been performed, see Section 11 on Calculations.

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

NOTE 8—With practice it is usually possible to visually judge a point near optimum water content. Typically, cohesive soils at the optimum water content can be squeezed into a lump that sticks together when hand pressure is released, but will break cleanly into two sections when “bent.” They tend to crumble at molding water contents dry of optimum; while, they tend to stick together in a sticky cohesive mass wet of optimum. The optimum water content is typically slightly less than the plastic limit. While for cohesionless soils, the optimum water content is typically close to zero or at the point where bleeding occurs.

10.2.2 Thoroughly mix the test fraction, then using a scoop select representative soil for each subspecimen (compaction point). Select about 2.3 kg when using Method A or B, or about 5.9 kg for Method C. Test Method D 6913 section on Specimen and Annex A2 gives additional details on obtaining representative soil using this procedure and why it is the preferred method. To obtain the subspecimen’s molding water contents selected in 10.2.1, add or remove the required amounts of water as follows. To add water, spray it into the soil during mixing; to remove water, allow the soil to dry in air at ambient temperature or in a drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). Mix the soil frequently during drying to facilitate an even water content distribution. Thoroughly mix each subspecimen to facilitate even distribution of water throughout and then place in a separate covered container to stand (cure) in accordance with Table 2 prior to compaction. For selecting a standing time, the soil may be classified using Practice D 2487, Practice D 2488 or data on other samples from the same material source. For referee testing, classification shall be by Practice D 2487.

10.3 *Dry Preparation Method*—If the sample/specimen is too damp to be friable, reduce the water content by air drying

TABLE 2 Required Standing Times of Moisturized Specimens

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

until the material is friable. Drying may be in air or by the use of drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). Thoroughly break up the aggregations in such a manner as to avoid breaking individual particles. Process the material over the appropriate sieve: No. 4 (4.75-mm), $\frac{3}{8}$ -in. (9.5-mm), or $\frac{1}{4}$ -in. (19.0-mm). When preparing the material by passing over the $\frac{1}{4}$ -in. sieve for compaction in the 6-in. mold, break up aggregations sufficiently to at least pass the $\frac{3}{8}$ -in. sieve in order to facilitate the distribution of water throughout the soil in later mixing. Determine and record the water content of the test fraction and all masses covered in 10.2, as applicable to determine the percent oversize fraction, P_C , and test fraction, P_F .

10.3.1 From the test fraction, select and prepare at least four (preferably five) subspecimens in accordance with 10.2.1 and 10.2.2, except for the following: Use either a mechanical splitting or quartering process to obtain the subspecimens. As stated in Test Method D 6913, both of these processes will yield non-uniform subspecimens compared to the moist procedure. Typically, only the addition of water to each subspecimen will be required.

10.4 *Compaction*—After standing (curing), if required, each subspecimen (compaction point) shall be compacted as follows:

10.4.1 Determine and record the mass of the mold or mold and base plate, see 10.4.7.

10.4.2 Assemble and secure the mold and collar to the base plate. Check the alignment of the inner wall of the mold and mold extension collar. Adjust if necessary. The mold shall rest, without wobbling/rocking on a uniform rigid foundation, such as provided by a cylinder or cube of concrete with a weight or mass of not less than 200-lbf or 91-kg, respectively. Secure the base plate to the rigid foundation. The method of attachment to the rigid foundation shall allow easy removal of the assembled mold, collar and base plate after compaction is completed.

10.4.2.1 During compaction, it is advantageous but not required to determine the water content of each subspecimen. This provides a check on the molding water content determined for each compaction point and the magnitude of bleeding, see 10.4.9. However, more soil will have to be selected for each subspecimen than stated in 10.2.2.

10.4.3 Compact the soil in three layers. After compaction, each layer should be approximately equal in thickness and extend into the collar. Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a fluffy or loose state, using either the manual rammer or a 2±-in. (50±-mm) diameter cylinder. Following compaction of each of the first two layers, any soil that has not been compacted; such as adjacent to the mold walls or extends above the compacted surface (up the mold walls) shall be trimmed. The trimmed soil shall be discarded. A knife or other

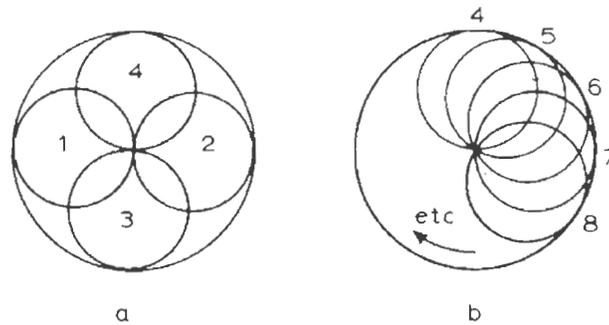


FIG. 3 Rammer Pattern for Compaction in 4 in. (101.6 mm) Mold

suitable device may be used. The total amount of soil used shall be such that the third compacted layer slightly extends into the collar, but does not extend more than approximately 1/4-in. (6-mm) above the top of the mold. If the third layer does extend above this limit, then the compaction point shall be discarded. In addition, the compaction point shall be discarded when the last blow on the rammer for the third layer results in the bottom of the rammer extending below the top of the compaction mold; unless the soil is pliable enough, that this surface can easily be forced above the top of the compaction mold during trimming (see Note 9).

10.4.4 Compact each layer with 25 blows for the 4-in. (101.6-mm) mold or with 56 blows for the 6-in. (152.4-mm) mold. The manual rammer shall be used for referee testing.

10.4.5 In operating the manual rammer, take care to avoid lifting the guide sleeve during the rammer upstroke. Hold the guide sleeve steady and within 5° of vertical. Apply the blows at a uniform rate of about 25 blows/min and in such a manner as to provide complete, uniform coverage of the specimen surface. When using a 4-in. (101.6-mm) mold and manual rammer, follow the blow pattern given in Fig. 3a and Fig. 3b; while for a mechanical rammer, follow the pattern in Fig. 3b. When using a 6-in. (152.4-mm) mold and manual rammer, follow the blow pattern given in Fig. 4 up to the 9th blow, then systematically around the mold (Fig. 3b) and in the middle; while for a mechanical rammer use a sector face and a pattern having the logic given in Fig. 3b. If the surface of the compacted soil becomes highly uneven (see Note 9), then adjust the pattern to follow the logic given in Fig. 3a or Fig. 4. This will most likely void the use of a mechanical rammer for such compaction points.

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

10.4.6 Following compaction of the last layer, remove the collar and base plate (except as noted in 10.4.7) from the mold. A knife may be used to trim the soil adjacent to the collar to loosen the soil from the collar before removal to avoid disrupting the soil below the top of the mold. In addition, to prevent/reduce soil sticking to the collar or base plate, rotate them before removal.

10.4.7 Carefully trim the compacted specimen even with the top of the mold by means of the straightedge scraped across the

top of the mold to form a plane surface even with the top of the mold. Initial trimming of the specimen above the top of the mold with a knife may prevent the soil from tearing below the top of the mold. Fill any holes in the top surface with unused or trimmed soil from the specimen, press in with the fingers, and again scrape the straightedge across the top of the mold. If gravel size particles are encountered, trim around them or remove them, whichever is the easiest and reduces the disturbance of the compacted soil. The estimated volume of particles above the surface of the compacted soil and holes in that surface shall be equal, fill in remaining holes as mentioned above. Repeat the appropriate preceding operations on the bottom of the specimen when the mold volume was determined without the base plate. For very wet or dry soils, soil or water may be lost if the base plate is removed. For these situations, leave the base plate attached to the mold. When the base plate is left attached, the volume of the mold must be calibrated with the base plate attached to the mold rather than a plastic or glass plate as noted in Annex A1, A1.4.

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

10.4.9 Remove the material from the mold. Obtain a specimen for molding water content by using either the whole specimen (preferred method) or a representative portion. When the entire specimen is used, break it up to facilitate drying. Otherwise, obtain a representative portion of the three layers, removing enough material from the specimen to report the water content to 0.1 %. The mass of the representative portion of soil shall conform to the requirements of Table 1, Method B, of Test Methods D 2216. Determine the molding water content in accordance with Test Methods D 2216.

10.5 Following compaction of the last specimen, compare the wet unit weights to ensure that a desired pattern of obtaining data on each side of the optimum water content will be attained for the dry-unit-weight compaction curve. Plotting the wet unit weight and molding water content of each compacted specimen can be an aid in making the above evaluation. If the desired pattern is not obtained, additional compacted specimens will be required. Generally, for experienced plotters of compaction curves, one compaction point wet of the optimum water content is adequate to define the maximum wet unit weight, see 11.2.

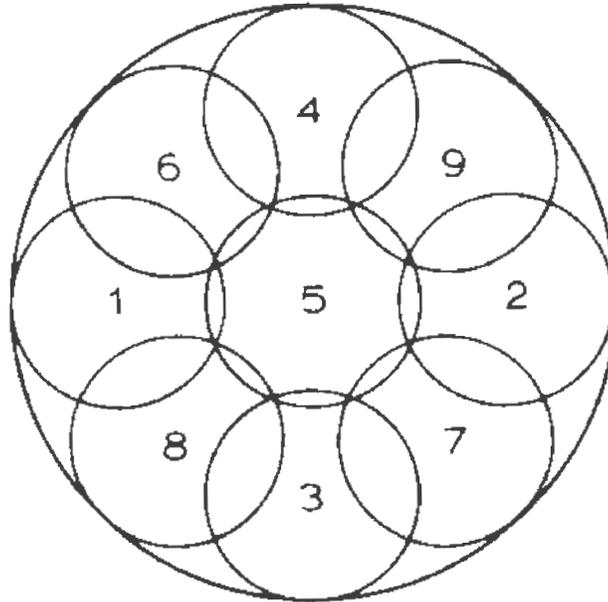


FIG. 4 Rammer Pattern for Compaction in 6 in. (152.4 mm) Mold

11. Calculations and Plotting (Compaction Curve)

11.1 *Fraction Percentages*—If gradation data from Test Method **D 6913** is not available, calculate the dry mass of the test fraction, percentage of oversize fraction and test fraction as covered below and using the data from **10.2** or **10.3**:

11.1.1 *Test Fraction*—Determine the dry mass of the test fraction as follows:

$$M_{d,tf} = \frac{M_{m,tf}}{1 + \frac{w_{tf}}{100}} \quad (1)$$

where:

- $M_{d,tf}$ = dry mass of test fraction, nearest g or 0.001 kg,
- $M_{m,tf}$ = moist mass of test fraction, nearest g or 0.001 kg, and
- w_{tf} = water content of test fraction, nearest 0.1 %.

11.1.2 *Oversize Fraction Percentage*—Determine the oversize (coarse) fraction percentage as follows:

$$P_C = \frac{M_{d,of}}{M_{d,of} + M_{d,tf}} \quad (2)$$

where:

- P_C = percentage of oversize (coarse) fraction, nearest %, and
- $M_{d,of}$ = dry mass of oversize fraction, nearest g or 0.001 kg,

11.1.3 *Test Fraction Percentage*—Determine the test (finer) fraction percentage as follows:

$$P_F = 100 - P_C \quad (3)$$

where:

- P_F = percentage of test (finer) fraction, nearest %.

11.2 *Density and Unit Weight*—Calculate the molding water content, moist density, dry density, and dry unit weight of each compacted specimen as explained below.

11.2.1 *Molding Water Content, w*—Calculate in accordance with Test Methods **D 2216** to nearest 0.1 %.

11.2.2 *Density and Unit Weights*—Calculate the moist (total) density (Eq 4), the dry density (Eq 5), and then the dry unit weight (Eq 6) as follows:

11.2.2.1 *Moist Density*:

$$\rho_m = K \times \frac{(M_t - M_{md})}{V} \quad (4)$$

where:

- ρ_m = moist density of compacted subspecimen (compaction point), four significant digits, g/cm³ or kg/m³,
- M_t = mass of moist soil in mold and mold, nearest g,
- M_{md} = mass of compaction mold, nearest g,
- V = volume of compaction mold, cm³ or m³ (see **Annex A1**), and
- K = conversion constant, depending on density units and volume units.

Use 1 for g/cm³ and volume in cm³.

Use 1000 for g/cm³ and volume in m³.

Use 0.001 for kg/cm³ and volume in m³.

Use 1000 for kg/m³ and volume in cm³.

11.2.2.2 *Dry Density*:

$$\rho_d = \frac{\rho_m}{1 + \frac{w}{100}} \quad (5)$$

where:

- ρ_d = dry density of compaction point, four significant digits, g/cm³ or kg/m³, and
- w = molding water content of compaction point, nearest 0.1 %.

11.2.2.3 *Dry Unit Weight*:

$$\gamma_d = K_1 \times \rho_d \text{ in lbf/ft}^3 \quad (6)$$

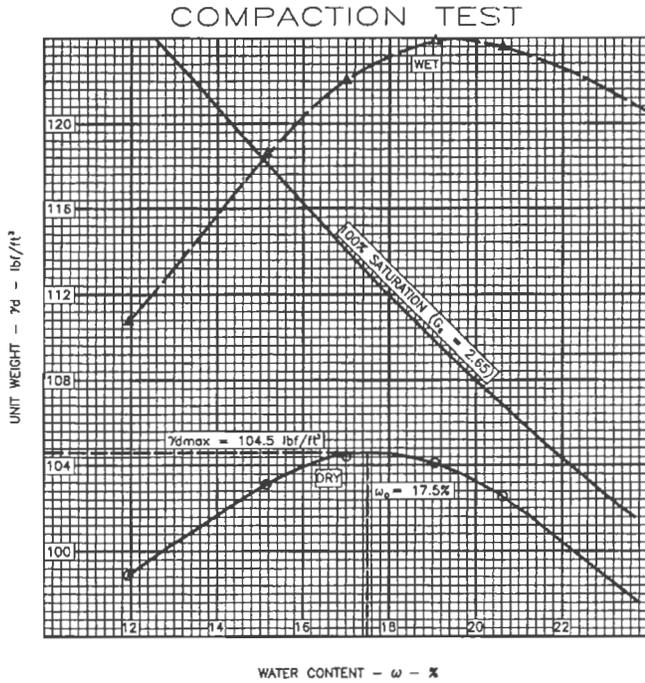


FIG. 5 Example Compaction Curve Plotting

or

$$\gamma_d = K_2 \times \rho_d \text{ in kN/m}^3 \quad (7)$$

where:

γ_d = dry unit weight of compacted specimen, four significant digits, in lb/ft^3 or kN/m^3 .

K_1 = conversion constant, depending on density units.
Use 62.428 for density in g/cm^3 , or
Use 0.062428 for density in kg/m^3 .

K_2 = conversion constant, depending on density units.
Use 9.8066 for density in g/cm^3 , or
Use 0.0098066 for density in kg/m^3 .

11.3 *Compaction Curve*—Plot the dry unit weight and molding water content values, the saturation curve (see 11.3.2), and draw the compaction curve as a smooth curve through the points (see example, Fig. 5). For each point on the compaction curve, calculate, record, and plot dry unit weight to the nearest 0.1 lb/ft^3 (0.02 kN/m^3) and molding water content to the nearest 0.1 %. From the compaction curve, determine the compaction results: optimum water content, to nearest 0.1 % and maximum dry unit weight, to the nearest 0.1 lb/ft^3 (0.02 kN/m^3). If more than 5 % by mass of oversize material was removed from the sample/specimen, calculate the corrected optimum water content and maximum dry unit weight of the total material using Practice D 4718. This correction may be made to the appropriate field in-place density test specimen rather than to the laboratory compaction results.

11.3.1 In these plots, the scale sensitivities should remain the same, that is the change in molding water content or dry unit weight per division is constant between plots. Typically, the change in dry unit weight per division is twice that of molding water content's (2 lb/ft^3 to 1 % w per major division). Therefore, any change in the shape of the compaction curve is

a result of testing different material, not the plotting scale. However, a one to one ratio should be used for soils that have a relatively flat compaction curve (see 10.2.1), such as highly plastic soils or relatively free draining ones up to the point of bleeding.

11.3.1.1 The shape of the compaction curve on the wet side on optimum should typically follow that of the saturation curve. The shape of the compaction curve on the dry side of optimum may be relatively flat or up and down when testing some soils, such as relatively free draining ones or plastic soils prepared using the moist procedure and having molding water contents close to or less than the shrinkage limit.

11.3.2 Plot the 100 % saturation curve, based on either an estimated or a measured specific gravity. Values of water content for the condition of 100 % saturation can be calculated as explained in 11.4 (see example, Fig. 5).

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

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

$$w_{sat} = \frac{(\gamma_w)(G_s) - \gamma_d}{(\gamma_d)(G_s)} \times 100 \quad (8)$$

where:

w_{sat} = water content for complete saturation, nearest 0.1 %,

γ_w = unit weight of water, 62.32 lb/ft^3 (9.789 kN/m^3) at 20°C,

γ_d = dry unit weight of soil, lb/ft^3 (kN/m^3), three significant digits, and

G_s = specific gravity of soil (estimated or measured), to nearest 0.01 value, see 11.4.1.

11.4.1 Specific gravity may be estimated for the test fraction based on test data from other soils having the same soil classification and source or experience. Otherwise, a specific gravity test (Test Method C 127, Test Method D 854, or both) is necessary.

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

12.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as described below, is covered in 1.6.

12.2 The data sheet(s)/form(s) shall contain as a minimum the following information:

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

12.2.2 Preparation method used (moist or dry).

12.2.3 As received water content if determined, nearest 1 %.

12.2.4 Standard optimum water content, $\text{Std-}w_{opt}$ to nearest 0.1 %.

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

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

^A $\gamma_{d,max}$ (pcf) = standard maximum dry unit weight in lbf/ft³ and w_{opt} (%) = standard optimum water in percent.

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

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

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

^E Both values of $\gamma_{d,max}$ and w_{opt} have to fall within values given for the selected soil type.

12.2.5 Standard maximum dry unit weight, Std- $\gamma_{d,max}$ nearest 0.1 lbf/ft³ or 0.02 kN/m³.

12.2.6 Type of rammer (manual or mechanical).

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

12.2.8 Description of sample used in test (as a minimum, color and group name and symbol), by Practice D 2488, or classification by Practice D 2487.

12.2.9 Specific gravity and method of determination, nearest 0.01 value.

12.2.10 Identification of sample used in test: for example, project number/name, location, depth, and the like.

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

12.2.12 Percentages for the fractions retained (P_c) and passing (P_f) the sieve used in Method A, B, or C, nearest 1%. In addition, if compaction data (Std- w_{opt} and Std- $\gamma_{d,max}$) are corrected for the oversize fraction, include that data.

13. Precision and Bias

13.1 *Precision*—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types are given in Tables 3 and 4. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program.⁴ In this

⁴ Research Report RR:D18-1008 contains the data and statistical analysis used to establish these precision statements and it is available from ASTM Headquarters.

TABLE 4 Summary of Single Test Results from Each Laboratory (Standard Effort Compaction)^A

(1) Number of Test Laboratories			(2) Test Value (Units)	(3) Average Value			(4) Standard Deviation			(5) Acceptable Range of Two Results		
CH CL ML			CH CL ML			CH CL ML			CH CL ML			
<i>Soil Type:</i>												
<i>Multilaboratory Results (Between-Laboratory Reproducibility):</i>												
26	26	25	$\gamma_{d,max}$ (pcf)	97.3	109.2	106.2	1.6	1.1	1.0	4.5	3.0	2.9
			w_{opt} (%)	22.6	16.4	16.7	0.9	0.7	1.0	2.4	1.8	2.9

^A See footnotes in Table 3.

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

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

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

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

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

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

ML Silt, ML, 99 % fines, LL=27, PI=4, light brown, soil had been air dried and pulverized. Local name—Vicksburg Silt

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

14. Keywords

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

ANNEX

(Mandatory Information)

A1. VOLUME OF COMPACTION MOLD

A1.1 Scope

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

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

A1.1.3 The water filling method for the 4-in. (106.5-mm) mold, when using a balance readable to nearest g, does not yield four significant figures for its volume, just three. Based on Practice **D 6026**, this limits the density/unit weight determinations previously presented from four to three significant figures. To prevent this limitation, the water filling method has been adjusted from that presented in early versions of this test method.

A1.2 Apparatus

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

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

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

A1.2.1.3 *Depth Micrometer (optional)*, having a measuring range of at least 0 to 6 in. (0 to 150 mm) and readable to at least 0.001 in. (0.02 mm).

A1.2.1.4 *Plastic or Glass Plates*—Two plastic or glass plates about 8 in. square by ¼ in. thick (200 by 200 by 6 mm).

A1.2.1.5 *Thermometer or Other Thermometric Device*, having graduation increments of 0.1°C.

A1.2.1.6 *Stopcock Grease*, or similar sealant.

A1.2.1.7 *Miscellaneous Equipment*—Bulb syringe, towels, etc.

A1.3 Precautions

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

A1.4 Procedure

A1.4.1 *Water-Filling Method*:

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

A1.4.1.2 Determine the mass of the greased mold and both plastic or glass plates to the nearest 1 g and record, M_{mp} . When the base plate is being used in lieu of the bottom plastic or glass plate, determine the mass of the mold, base plate and a single plastic or glass plate to be used on top of the mold to the nearest 1 g and record.

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

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

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

A1.4.1.6 Determine the mass of the mold, plates and water and record to the nearest 1 g, $M_{mp,w}$.

A1.4.1.7 Determine the temperature of the water in the mold to the nearest 0.1°C and record. Determine and record the density of water from the table given in Test Method **D 854** or as follows:

$$\rho_{w,c} = 1.00034038 - (7.77 \times 10^{-6}) \times T - (4.95 \times 10^{-6}) \times T^2 \quad (\text{A1.1})$$

where:

$\rho_{w,c}$ = density of water, nearest 0.00001 g/cm³, and
 T = calibration test temperature, nearest 0.1°C.

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

A1.4.1.9 Calculate the volume of water by dividing the mass of water by the density of water. Record this volume to the nearest 0.1 cm³ for the 4-in. (101.6-mm) mold or nearest 1 cm³ for the 6-in. (152.4-mm) mold. To determine the volume of the mold in m³, multiply the volume in cm³ by 1×10^{-6} . Record this volume, as prescribed.

A1.4.1.10 If the filling method is being used to determine the mold's volume and checked by linear measurement method, repeat this volume determination (**A1.4.1.3-A1.4.1.9**) and determine and record the average value, V_w , as prescribed.

A1.4.2 *Linear Measurement Method*:

A1.4.2.1 Using either the vernier caliper or the inside micrometer (preferable), measure the inside diameter (ID) of the mold 6 times at the top of the mold and 6 times at the bottom of the mold, spacing each of the six top and bottom measurements equally around the ID of the mold. Record the

values to the nearest 0.001-in. (0.02-mm). Determine and record the average ID to the nearest 0.001-in. (0.02-mm), d_{avg} . Verify that this ID is within specified tolerances, 4.000 ± 0.016 in. (101.6 ± 0.4 mm), if not discard the mold.

A1.4.2.2 Using the vernier caliper or depth micrometer (preferably), measure the inside height of the mold attached to the base plate. In these measurements, make three or more measurements equally spaced around the ID of the mold, and preferably one in the center of the mold, but not required (used the straightedge to facilitate the later measurement and correct measurement for thickness of straightedge). Record these values to the nearest 0.001-in. (0.02-mm). Determine and record the average of these height measurements to the nearest 0.001 in. (0.02 mm), h_{avg} . Verify that this height is within specified tolerances, 4.584 ± 0.018 in. (116.4 ± 0.5 mm), if not discard the mold.

A1.4.2.3 Calculate the volume of the mold to four significant digits in cm^3 as follows:

$$V_{lm} = K_3 \frac{\pi \times h_{avg} \times (d_{avg})^2}{4} \quad (\text{A1.2})$$

where:

V_{lm} = volume of mold by linear measurements, to four significant digits, cm^3 ,

K_3 = constant to convert measurements made in inch (in.) or mm,

Use 16.387 for measurements in inches.

Use 10^{-6} for measurements in mm.

π = 3.14159,

h_{avg} = average height, in. (mm), and

d_{avg} = average of the top and bottom diameters, in. (mm).

A1.4.2.4 If the volume in m^3 is required, then multiply the above value by 10^{-6} .

A1.5 Comparison of Results and Standardized Volume of Mold

A1.5.1 The volume obtained by either method should be within the volume tolerance requirements of 6.1.1 and 6.1.2, using either or cm^3 to ft^3 . To convert cm^3 to ft^3 , divide cm^3 by 28 317, record to the nearest 0.0001 ft^3 .

A1.5.2 The difference between the two methods should not exceed 0.5 % of the nominal volume of the mold, cm^3 to ft^3 .

A1.5.3 Repeat the determination of volume, which is most suspect or both if these criteria are not met.

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

A1.5.5 Use the volume of the mold determined using the water-filling or linear method, or average of both methods as the standardized volume for calculating the moist density (see 11.4). This value (V) in cm^3 or m^3 shall have four significant digits. The use of a volume in ft^3 , along with masses in lbm shall not be regarded as a nonconformance with this standard.

REFERENCES

- (1) Johnson, A. W., and Sallberg, J. R., *Factors Influencing Compaction Test Results*, Highway Research Board, Bulletin 318, Publication 967, National Academy of Sciences-National Research Council, Washington, DC, 1962.
- (2) *Earth Manual*, United States Bureau of Reclamation, Part 1, Third Edition, 1998, pp. 255-260.
- (3) *Earth Manual*, United States Bureau of Reclamation, Part 2, Third Edition, 1990, USBR 5515.
- (4) Torrey, V. H., and Donaghe, R. T., "Compaction Control of Earth-Rock Mixtures: A New Approach," *Geotechnical Testing Journal*, GTJODJ, Vol 17, No. 3, September 1994, pp. 371-386.

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last published edition (2000a^{e1}) that may impact the use of this standard.

- (1) Changed Notes 2 and 3 to text. Also, added in 1.2 that compacted soil cannot be reused, since it is such an important issue.
- (2) The amount of allowable oversize fraction increased to at least 25 % for Methods A and B.
- (3) In 1.3, simplified the description of the gradation controlling the selection of the method.
- (4) Updated the section on units.
- (5) Added reference to Test Methods D 6913 for gradation and sample/specimen processing.
- (6) In Terminology, relocated some terms to definitions and made editorial changes.
- (7) In apparatus for ovens, added the guidance that they should

be vented outside the building. In mixing tools, added a sprayer and made the mixer optional. The sector face has to be used for the 6-in. mold and the area of its face the same as the circular one. The requirement for balances was changed to conform to the latest version of Test Methods D 2216 used to determine water content.

- (8) More guidance is provided in following areas: (a) why one shall not reuse compacted soil; (b) plotting compaction curve; (c) using molding water content to check the one taken after compaction and to determine magnitude of bleeding; (d) proper pattern of rammer during compaction and what to do when the rammer causes soil to flow up the sides; (e) removing the collar and mold from base plate; (f) trimming subspecimens

containing gravel; and (g) calculating the percentages for oversize and test fractions.

(9) Section 10.4.9 was reworded to permit alternative methods for obtaining water content samples from compacted specimens and to clarify the requirements of Test Methods D 2216.

(10) Changed the title and revised the Calculations section.

(11) Updated the Report section to agree with D18.91 requirements.

(12) Updated the Annex on volume of mold to allow either water filling or linear method to determine the volume of the mold, to measure temperature to 0.1°C instead of nearest 1°C, and to use Test Methods D 854 (or equation) for density of water.

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Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer¹

This standard is issued under the fixed designation D854; 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 Department of Defense.

1. Scope*

1.1 These test methods cover the determination of the specific gravity of soil solids that pass the 4.75-mm (No. 4) sieve, by means of a water pycnometer. When the soil contains particles larger than the 4.75-mm sieve, Test Method **C127** shall be used for the soil solids retained on the 4.75-mm sieve and these test methods shall be used for the soil solids passing the 4.75-mm sieve.

1.1.1 Soil solids for these test methods do not include solids which can be altered by these methods, contaminated with a substance that prohibits the use of these methods, or are highly organic soil solids, such as fibrous matter which floats in water.

NOTE 1—The use of Test Method **D5550** may be used to determine the specific gravity of soil solids having solids which readily dissolve in water or float in water, or where it is impracticable to use water.

1.2 Two methods for performing the specific gravity are provided. The method to be used shall be specified by the requesting authority, except when testing the types of soils listed in **1.2.1**.

1.2.1 *Method A*—Procedure for Moist Specimens, described in **9.2**. This procedure is the preferred method. For organic soils; highly plastic, fine grained soils; tropical soils; and soils containing halloysite, Method A shall be used.

1.2.2 *Method B*—Procedure for Oven-Dry Specimens, described in **9.3**.

1.3 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice **D6026**.

1.3.1 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.

1.4 The values stated in SI units are to be regarded as standard. The inch-pound units given in parentheses are mathematical conversions which are provided for information purposes only and are not considered 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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:²

C127 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate

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

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

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D5550 Test Method for Specific Gravity of Soil Solids by Gas Pycnometer

D6026 Practice for Using Significant Digits in Geotechnical Data

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

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

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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.

Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions*—For definitions of technical terms used in these test methods, refer to Terminology **D653**.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *specific gravity of soil solids, G_s , n* —the ratio of the mass of a unit volume of a soil solids to the mass of the same volume of gas-free distilled water at 20°C.

4. Significance and Use

4.1 The specific gravity of a soil solids is used in calculating the phase relationships of soils, such as void ratio and degree of saturation.

4.1.1 The specific gravity of soil solids is used to calculate the density of the soil solids. This is done by multiplying its specific gravity by the density of water (at proper temperature).

4.2 The term soil solids is typically assumed to mean naturally occurring mineral particles or soil like particles that are not readily soluble in water. Therefore, the specific gravity of soil solids containing extraneous matter, such as cement, lime, and the like, water-soluble matter, such as sodium chloride, and soils containing matter with a specific gravity less than one, typically require special treatment (see **Note 1**) or a qualified definition of their specific gravity.

4.3 The balances, pycnometer sizes, and specimen masses are established to obtain test results with three significant digits.

NOTE 2—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.

5. Apparatus

5.1 *Pycnometer*—The water pycnometer shall be either a stoppered flask, stoppered iodine flask, or volumetric flask with a minimum capacity of 250 mL. The volume of the pycnometer must be 2 to 3 times greater than the volume of the soil-water mixture used during the deairing portion of the test.

5.1.1 The stoppered flask mechanically sets the volume. The stoppered iodine flask has a flared collar that allows the stopper to be placed at an angle during thermal equilibration and prevents water from spilling down the sides of the flask when the stopper is installed. The wetting the outside of the flask is undesirable because it creates changes in the thermal equilibrium. When using a stopper flask, make sure that the stopper is properly labeled to correspond to the flask.

5.2 *Balance*—A balance meeting the requirements of Guide **D4753** for a balance of 0.01 g readability. When using the 250-mL pycnometers, the balance capacity shall be at least 500 g and when using the 500-mL pycnometers, the balance capacity shall be at least 1000 g.

5.3 *Drying Oven*—Thermostatically controlled oven, capable of maintaining a uniform temperature of $110 \pm 5^\circ\text{C}$ throughout the drying chamber. These requirements usually require the use of a forced-draft oven.

5.4 *Thermometric Device*, capable of measuring the temperature range within which the test is being performed, having a readability of 0.1°C and a maximum permissible error of 0.5°C. The device must be capable of being immersed in the sample and calibration solutions to a depth ranging between 25 and 80 mm. Full immersion thermometers shall not be used. To ensure the accuracy of the thermometric device, the thermometric device shall be standardized by comparison to a NIST traceable thermometric device. The standardization shall include at least one temperature reading within the range of testing. The thermometric device shall be standardized at least once every twelve months.

5.5 *Desiccator*—A desiccator cabinet or large desiccator jar of suitable size containing silica gel or anhydrous calcium sulfate.

NOTE 3—It is preferable to use a desiccant that changes color to indicate when it needs reconstitution.

5.6 *Entrapped Air Removal Apparatus*—To remove entrapped air (deairing process), use one of the following:

5.6.1 *Hot Plate or Bunsen Burner*, capable of maintaining a temperature adequate to boil water.

5.6.2 *Vacuum System*, a vacuum pump or water aspirator, capable of producing a partial vacuum of 100 mm of mercury (Hg) or less absolute pressure. **Warning**—Mercury has been designated by EPA and many state agencies as a hazardous material that can cause central nervous system, kidney and liver damage. Mercury, or its vapor, may be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury containing products. See the applicable product Material Safety Data Sheet (MSDS) for details and EPA's website – <http://www.epa.gov/mercury/faq.htm> - for additional information. Users should be aware that selling mercury and/or mercury containing products into your state may be prohibited by state law.

NOTE 4—A partial vacuum of 100 mm Hg absolute pressure is approximately equivalent to a 660 mm (26 in.) Hg reading on vacuum gauge at sea level.

5.7 *Insulated Container*—A Styrofoam cooler and cover or equivalent container that can hold between three and six pycnometers plus a beaker (or bottle) of deaired water, and a thermometer. This is required to maintain a controlled temperature environment where changes will be uniform and gradual.

5.8 *Funnel*—A non-corrosive smooth surface funnel with a stem that extends past the calibration mark on the volumetric flask or stoppered seal on the stoppered flasks. The diameter of the stem of the funnel must be large enough that soil solids will easily pass through.

5.9 *Pycnometer Filling Tube with Lateral Vents (optional)*—A device to assist in adding deaired water to the pycnometer without disturbing the soil-water mixture. The device may be fabricated as follows. Plug a 6 to 10-mm ($\frac{1}{4}$ to $\frac{3}{8}$ in.) diameter plastic tube at one end and cut two small vents (notches) just above the plug. The vents should be perpendicular to the axis of the tube and diametrically opposed. Connect a valve to the other end of the tube and run a line to the valve from a supply of deaired water.

5.10 *Sieve*— 4.75 mm (No. 4) conforming to the requirements of Specification E11.

5.11 *Blender (optional)*—A blender with mixing blades built into the base of the mixing container.

5.12 *Miscellaneous Equipment*, such as a computer or calculator (optional), specimen dishes, and insulated gloves.

6. Reagents

6.1 *Purity of Water*—Distilled water is used in this test method. This water may be purchased and is readily available at most grocery stores; hereafter, distilled water will be referred to as water.

7. Test Specimen

7.1 The test specimen may be moist or oven-dry soil and shall be representative of the soil solids that pass the 4.75-mm (No. 4) sieve in the total sample. Table 1 gives guidelines on recommended dry soil mass versus soil type and pycnometer size.

7.1.1 Two important factors concerning the amount of soil solids being tested are as follows. First, the mass of the soil solids divided by its specific gravity will yield four-significant digits. Secondly, the mixture of soil solids and water is a slurry not a highly viscous fluid (thick paint) during the deairing process.

8. Calibration of Pycnometer

8.1 Determine the mass of the clean and dry pycnometer to the nearest 0.01 g (typically five significant digits). Repeat this determination five times. One balance should be used for all of the mass measurements. Determine and record the average and standard deviation. The standard deviation shall be less than or equal to 0.02 g. If it is greater, attempt additional measurements or use a more stable or precise balance.

8.2 Fill the pycnometer with deaired water to above or below the calibration mark depending on the type of pycnometer and laboratory preference to add or remove water.

8.2.1 It is recommended that water be removed to bring the water level to the calibration mark. The removal method reduces the chances of altering the thermal equilibrium by reducing the number of times the insulated container is opened.

8.2.2 The water must be deaired to ensure that there are no air bubbles in the water. The water may be deaired using either boiling, vacuum, combination of vacuum and heat, or a deairing device. This deaired water should not be used until it has equilibrated to room temperature. Also, this water shall be added to the pycnometer following the guidance given in 9.6.

8.3 Up to six pycnometers can be calibrated concurrently in each insulated container. Put the pycnometer(s) into a covered insulated container along with the thermometric device (or the

temperature sensing portion of the thermometric device), a beaker (or bottle) of deaired water, stopper(s) (if a stoppered pycnometer is being used), and either an eyedropper or pipette. Let the pycnometer(s) come to thermal equilibrium (for at least 3 h). The equilibrium temperature should be within 4°C of room temperature and between 15 and 30°C.

8.4 Move the insulated container near the balance or vice versa. Open the container and remove one pycnometer. Only the rim of the pycnometer shall be touched as to prevent the heat from handling changing the thermal equilibrium. Either work in the container or place the pycnometer on an insulated block (Styrofoam) while making water level adjustments.

8.4.1 If using a volumetric flask as a pycnometer, adjust the water to the calibration mark, with the bottom of the meniscus level with the mark. If water has to be added, use the thermally equilibrated water from the insulated container. If water has to be removed, use a small suction tube or paper towel. Check for and remove any water beads on the pycnometer stem or on the exterior of the flask. Measure and record the mass of pycnometer and water to the nearest 0.01 g.

8.4.2 If a stoppered flask is used, adjust the water to prevent entrapment of any air bubbles below the stopper during its placement. If water has to be added, use the thermally equilibrated water from the insulated container. Then, place the stopper in the bottle. If water has to be removed, before or after inserting the stopper, use an eyedropper. Dry the rim using a paper towel. Be sure the entire exterior of the flask is dry. Measure and record the mass of pycnometer and water to the nearest 0.01 g.

8.5 Measure and record the temperature of the water to the nearest 0.1°C using the thermometric device that has been thermally equilibrated in the insulated container. Insert the thermometric device (or the temperature sensing portion of the thermometric device) to the appropriate depth of immersion (see 5.4). Return the pycnometer to the insulated container. Repeat the measurements for all pycnometers in the container.

8.6 Readjust the water level in each pycnometer to above or below the calibration line or empty the pycnometer and fill to the above or below the calibration line. Allow the pycnometers to thermally equilibrate (for at least 3 h) in the covered insulated container. Adjust the water level to the calibration line by removing water from the pycnometer or by filling the pycnometer to the calibration mark with the thermally equilibrated deaired water from the insulated container. Measure and record the mass and temperature of the filled pycnometer.

8.6.1 Repeat the procedure in 8.6 until a total of five independent measurements of the mass of the filled pycnometer and temperature readings are obtained. The temperatures do not need to bracket any particular temperature range.

8.7 Using each of these five data points, compute the calibrated volume of each pycnometer, V_p , using the following equation:

$$V_p = \frac{(M_{pw,c} - M_p)}{\rho_{w,c}} \quad (1)$$

where:

$M_{pw,c}$ = the mass of the pycnometer and water at the calibration temperature, g,

TABLE 1 Recommended Mass for Test Specimen

Soil Type	Specimen Dry Mass (g)	Specimen Dry Mass (g)
	When Using 250 mL Pycnometer	When Using 500 mL Pycnometer
SP, SP-SM	60 ± 10	100 ± 10
SP-SC, SM, SC	45 ± 10	75 ± 10
Silt or Clay	35 ± 5	50 ± 10

M_p = the average mass of the dry pycnometer at calibration, g, and
 $\rho_{w,c}$ = the mass density of water at the calibration temperature g/mL, (Table 2).

8.8 Calculate the average and the standard deviation of the five volume determinations. The standard deviation shall be less than or equal to 0.05 mL (rounded to two decimal places). If the standard deviation is greater than 0.05 mL, the calibration procedure has too much variability and will not yield accurate specific gravity determinations. Evaluate areas of possible refinement (adjusting the volume to the calibration mark, achieving temperature equilibrium, measuring tempera-

ture, deairing method or changing to the stoppered flasks) and revise the procedure until the standard deviation is less than or equal to 0.05 mL.

9. Procedure

9.1 Pycnometer Mass—Using the same balance used to calibrate the pycnometer, verify that the mass of the pycnometer is within 0.06 g of the average calibrated mass. If it is not, re-calibrate the dry mass of the pycnometer.

9.2 Method A—Procedure for Moist Specimens:

9.2.1 Determine the water content of a portion of the sample in accordance with Test Method D2216. Using this water

TABLE 2 Density of Water and Temperature Coefficient (K) for Various Temperatures^{A,B}

Temperature (°C)	Density (g/mL) ^C	Temperature Coefficient (K)	Temperature (°C)	Density (g/mL) ^C	Temperature Coefficient (K)	Temperature (°C)	Density (g/mL) ^C	Temperature Coefficient (K)	Temperature (°C)	Density (g/mL) ^C	Temperature Coefficient (K)
15.0	0.99910	1.00090	16.0	0.99895	1.00074	17.0	0.99878	1.00057	18.0	0.99860	1.00039
.1	0.99909	1.00088	.1	0.99893	1.00072	.1	0.99876	1.00055	.1	0.99858	1.00037
.2	0.99907	1.00087	.2	0.99891	1.00071	.2	0.99874	1.00054	.2	0.99856	1.00035
.3	0.99906	1.00085	.3	0.99890	1.00069	.3	0.99872	1.00052	.3	0.99854	1.00034
.4	0.99904	1.00084	.4	0.99888	1.00067	.4	0.99871	1.00050	.4	0.99852	1.00032
.5	0.99902	1.00082	.5	0.99886	1.00066	.5	0.99869	1.00048	.5	0.99850	1.00030
.6	0.99901	1.00080	.6	0.99885	1.00064	.6	0.99867	1.00047	.6	0.99848	1.00028
.7	0.99899	1.00079	.7	0.99883	1.00062	.7	0.99865	1.00045	.7	0.99847	1.00026
.8	0.99898	1.00077	.8	0.99881	1.00061	.8	0.99863	1.00043	.8	0.99845	1.00024
.9	0.99896	1.00076	.9	0.99879	1.00059	.9	0.99862	1.00041	.9	0.99843	1.00022
19.0	0.99841	1.00020	20.0	0.99821	1.00000	21.0	0.99799	0.99979	22.0	0.99777	0.99957
.1	0.99839	1.00018	.1	0.99819	0.99998	.1	0.99797	0.99977	.1	0.99775	0.99954
.2	0.99837	1.00016	.2	0.99816	0.99996	.2	0.99795	0.99974	.2	0.99773	0.99952
.3	0.99835	1.00014	.3	0.99814	0.99994	.3	0.99793	0.99972	.3	0.99770	0.99950
.4	0.99833	1.00012	.4	0.99812	0.99992	.4	0.99791	0.99970	.4	0.99768	0.99947
.5	0.99831	1.00010	.5	0.99810	0.99990	.5	0.99789	0.99968	.5	0.99766	0.99945
.6	0.99829	1.00008	.6	0.99808	0.99987	.6	0.99786	0.99966	.6	0.99764	0.99943
.7	0.99827	1.00006	.7	0.99806	0.99985	.7	0.99784	0.99963	.7	0.99761	0.99940
.8	0.99825	1.00004	.8	0.99804	0.99983	.8	0.99782	0.99961	.8	0.99759	0.99938
.9	0.99823	1.00002	.9	0.99802	0.99981	.9	0.99780	0.99959	.9	0.99756	0.99936
23.0	0.99754	0.99933	24.0	0.99730	0.99909	25.0	0.99705	0.99884	26.0	0.99679	0.99858
.1	0.99752	0.99931	.1	0.99727	0.99907	.1	0.99702	0.99881	.1	0.99676	0.99855
.2	0.99749	0.99929	.2	0.99725	0.99904	.2	0.99700	0.99879	.2	0.99673	0.99852
.3	0.99747	0.99926	.3	0.99723	0.99902	.3	0.99697	0.99876	.3	0.99671	0.99850
.4	0.99745	0.99924	.4	0.99720	0.99899	.4	0.99694	0.99874	.4	0.99668	0.99847
.5	0.99742	0.99921	.5	0.99717	0.99897	.5	0.99692	0.99871	.5	0.99665	0.99844
.6	0.99740	0.99919	.6	0.99715	0.99894	.6	0.99689	0.99868	.6	0.99663	0.99842
.7	0.99737	0.99917	.7	0.99712	0.99892	.7	0.99687	0.99866	.7	0.99660	0.99839
.8	0.99735	0.99914	.8	0.99710	0.99889	.8	0.99684	0.99863	.8	0.99657	0.99836
.9	0.99732	0.99912	.9	0.99707	0.99887	.9	0.99681	0.99860	.9	0.99654	0.99833
27.0	0.99652	0.99831	28.0	0.99624	0.99803	29.0	0.99595	0.99774	30.0	0.99565	0.99744
.1	0.99649	0.99828	.1	0.99621	0.99800	.1	0.99592	0.99771	.1	0.99562	0.99741
.2	0.99646	0.99825	.2	0.99618	0.99797	.2	0.99589	0.99768	.2	0.99559	0.99738
.3	0.99643	0.99822	.3	0.99615	0.99794	.3	0.99586	0.99765	.3	0.99556	0.99735
.4	0.99641	0.99820	.4	0.99612	0.99791	.4	0.99583	0.99762	.4	0.99553	0.99732
.5	0.99638	0.99817	.5	0.99609	0.99788	.5	0.99580	0.99759	.5	0.99550	0.99729
.6	0.99635	0.99814	.6	0.99607	0.99785	.6	0.99577	0.99756	.6	0.99547	0.99726
.7	0.99632	0.99811	.7	0.99604	0.99783	.7	0.99574	0.99753	.7	0.99544	0.99723
.8	0.99629	0.99808	.8	0.99601	0.99780	.8	0.99571	0.99750	.8	0.99541	0.99720
.9	0.99627	0.99806	.9	0.99598	0.99777	.9	0.99568	0.99747	.9	0.99538	0.99716

^A Reference: CRC Handbook of Chemistry and Physics, David R. Lide, Editor-in-Chief, 74th Edition, 1993–1994.

^B

$$\rho_w = 1.00034038 - (7.77 \times 10^{-6}) \times T - (4.95 \times 10^{-6}) \times T^2$$

where:

ρ_w = Density of water in g/mL,
 T = the test temperature in °C, and
 K = 1⁰⁰⁰/0.9982063

^C mL = cm³.

content, calculate the range of wet masses for the specific gravity specimen in accordance with 7.1. From the sample, obtain a specimen within this range. Do not sample to obtain an exact predetermined mass.

9.2.2 To disperse the soil put about 100 mL of water into the mixing container of a blender or equivalent device. Add the soil and blend. The minimum volume of slurry that can be prepared by this equipment will typically require using a 500-mL pycnometer.

9.2.3 Using the funnel, pour the slurry into the pycnometer. Rinse any soil particles remaining on the funnel into the pycnometer using a wash/spray squirt bottle.

9.2.4 Proceed as described in 9.4.

9.3 Method B—Procedure for Oven-Dried Specimens:

9.3.1 Dry the specimen to a constant mass in an oven maintained at $110 \pm 5^\circ\text{C}$. Break up any clods of soil using a mortar and pestle. If the soil will not easily disperse after drying or has changed composition, use Test Method A. Refer to 1.2.1 for soils that require use of Test Method A.

9.3.2 Place the funnel into the pycnometer. The stem of the funnel must extend past the calibration mark or stopper seal. Spoon the soil solids directly into the funnel. Rinse any soil particles remaining on the funnel into the pycnometer using a wash/spray squirt bottle.

9.4 *Preparing the Soil Slurry*—Add water until the water level is between $\frac{1}{3}$ and $\frac{1}{2}$ of the depth of the main body of the pycnometer. Agitate the water until slurry is formed. Rinse any soil adhering to the pycnometer into the slurry.

9.4.1 If slurry is not formed, but a viscous paste, use a pycnometer having a larger volume. See 7.1.1.

NOTE 5—For some soils containing a significant fraction of organic matter, kerosene is a better wetting agent than water and may be used in place of distilled water for oven-dried specimens. If kerosene is used, the entrapped air should only be removed by use of an aspirator. Kerosene is a flammable liquid that must be used with extreme caution.

9.5 *Deairing the Soil Slurry*—Entrapped air in the soil slurry can be removed using either heat (boiling), vacuum or combining heat and vacuum.

9.5.1 When using the heat-only method (boiling), use a duration of at least 2 h after the soil-water mixture comes to a full boil. Use only enough heat to keep the slurry boiling. Agitate the slurry as necessary to prevent any soil from sticking to or drying onto the glass above the slurry surface.

9.5.2 If only a vacuum is used, the pycnometer must be continually agitated under vacuum for at least 2 h. Continually agitated means the silt/clay soil solids will remain in suspension, and the slurry is in constant motion. The vacuum must remain relatively constant and be sufficient to cause bubbling at the beginning of the deairing process.

9.5.3 If a combination of heat and vacuum are used, the pycnometers can be placed in a warm water bath (not more than 40°C) while applying the vacuum. The water level in the bath should be slightly below the water level in the pycnometer, if the pycnometer glass becomes hot, the soil will typically stick to or dry onto the glass. The duration of vacuum and heat must be at least 1 h after the initiation of boiling.

During the process, the slurry should be agitated as necessary to maintain boiling and prevent soil from drying onto the pycnometer.

9.6 *Filling the Pycnometer with Water*—Fill the pycnometer with deaired water (see 8.2.2) by introducing the water through a piece of small-diameter flexible tubing with its outlet end kept just below the surface of the slurry in the pycnometer or by using the pycnometer filling tube. If the pycnometer filling tube is used, fill the tube with water, and close the valve. Place the tube such that the drainage holes are just at the surface of the slurry. Open the valve slightly to allow the water to flow over the top of the slurry. As the clear water layer develops, raise the tube and increase the flow rate. If the added water becomes cloudy, do not add water above the calibration mark or into the stopper seal area. Add the remaining water the next day.

9.6.1 If using the stoppered iodine flask, fill the flask, such that the base of the stopper will be submerged in water. Then rest the stopper at an angle on the flared neck to prevent air entrapment under the stopper. If using a volumetric or stoppered flask, fill the flask to above or below the calibration mark depending on preference.

9.7 If heat has been used, allow the specimen to cool to approximately room temperature.

9.8 *Thermal Equilibrium*—Put the pycnometer(s) into a covered insulated container along with the thermometric device (or the temperature sensing portion of the thermometric device), a beaker (or bottle) of deaired water, stopper(s) (if a stoppered pycnometer is being used), and either an eyedropper or pipette. Keep these items in the closed container overnight to achieve thermal equilibrium.

9.9 *Pycnometer Mass Determination*—If the insulated container is not positioned near a balance, move the insulated container near the balance or vice versa. Open the container and remove the pycnometer. Only touch the rim of the pycnometer because the heat from hands can change the thermal equilibrium. Place the pycnometer on an insulated block (Styrofoam or equivalent).

9.9.1 If using a volumetric flask, adjust the water to the calibration mark following the procedure in 8.4.1.

9.9.2 If a stoppered flask is used, adjust the water to prevent entrapment of any air bubbles below the stopper during its placement. If water has to be added, use the thermally equilibrated water from the insulated container. Then, place the stopper in the bottle. If water has to be removed, before or after inserting the stopper, use an eyedropper. Dry the rim using a paper towel. Be sure the entire exterior of the flask is dry.

9.10 Measure and record the mass of pycnometer, soil, and water to the nearest 0.01 g using the same balance used for pycnometer calibration.

9.11 *Pycnometer Temperature Determination*—Measure and record the temperature of the slurry/soil-water mixture to the nearest 0.1°C using the thermometric device and method used during calibration in 8.5. This is the test temperature, T_t .

9.12 *Mass of Dry Soil*—Determine the mass of a tare or pan to the nearest 0.01 g. Transfer the soil slurry to the tare or pan. It is imperative that all of the soil be transferred. Water can be added. Dry the specimen to a constant mass in an oven

maintained at $110 \pm 5^\circ\text{C}$ and cool it in a desiccator. If the tare can be sealed so that the soil can not absorb moisture during cooling, a desiccator is not required. Measure the dry mass of soil solids plus tare to the nearest 0.01 g using the designated balance. Calculate and record the mass of dry soil solids to the nearest 0.01 g.

NOTE 6—This method has been proven to provide more consistent, repeatable results than determining the dry mass prior to testing. This is most probably due to the loss of soil solids during the de-airing phase of testing.

10. Calculation

10.1 Calculate the mass of the pycnometer and water at the test temperature as follows:

$$M_{pw,t} = M_p + (V_p \cdot \rho_{w,t}) \quad (2)$$

where:

$M_{pw,t}$ = mass of the pycnometer and water at the test temperature (T_t), g,

M_p = the average calibrated mass of the dry pycnometer, g,

V_p = the average calibrated volume of the pycnometer, mL, and

$\rho_{w,t}$ = the density of water at the test temperature (T_t), g/mL from **Table 2**.

10.2 Calculate the specific gravity at soil solids the test temperature, G_t as follows:

$$G_t = \frac{\rho_s}{\rho_{w,t}} = \frac{M_s}{(M_{pw,t} - M_p)} \quad (3)$$

where:

ρ_s = the density of the soil solids Mg/m³ or g/cm³,

$\rho_{w,t}$ = the density of water at the test temperature (T_t), from **Table 2**, g/mL or g/cm³.

M_s = the mass of the oven dry soil solids (g), and

$M_{pw,t}$ = the mass of pycnometer, water, and soil solids at the test temperature, (T_t), g.

10.3 Calculate the specific gravity of soil solids at 20°C as follows:

$$G_{20^\circ\text{C}} = K \cdot G_t \quad (4)$$

where:

K = the temperature coefficient given in **Table 2**.

10.4 For soil solids containing particles greater than the 4.75-mm (No. 4) sieve for which Test Method **C127** was used to determine the specific gravity of these particles, calculate an average specific gravity. Test Method **C127** requires the test be performed at $23 \pm 1.7^\circ\text{C}$ and does not require the specific gravity data to be corrected to 20°C. Use **10.3** to correct this measurement to 20°C. Use the following equation to calculate the average specific gravity:

$$G_{avg@20^\circ\text{C}} = \frac{1}{\frac{R}{100 \cdot G_{1@20^\circ\text{C}}} + \frac{P}{100 \cdot G_{2@20^\circ\text{C}}}} \quad (5)$$

where:

R = the percent of soil retained on the 4.75-mm sieve,

P = the percent of soil passing the 4.75-mm sieve,

$G_{1@20^\circ\text{C}}$ = the apparent specific gravity of soils retained on the 4.75-mm sieve as determined by Test Method **C127**, corrected to 20°C

$G_{2@20^\circ\text{C}}$ = the specific gravity of soil solids passing the 4.75-mm sieve as determined by these test methods (Equation 4).

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

11.1 The method used to specify how data are recorded on the test data sheets or forms, as given below, is the industry standard, and are representative of the significant digits that should be retained. These requirements do not consider in situ material variation, use of the data, special purpose studies, or any considerations for the user's objectives. It is common practice to increase or reduce significant digits of reported data commensurate with these considerations. It is beyond the scope of the standard to consider significant digits used in analysis methods for engineering design.

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

11.2.1 Identification of the soil (material) being tested, such as boring number, sample number, depth, and test number.

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

11.2.3 Percent of soil particles passing the 4.75-mm (No. 4) sieve.

11.2.4 If any soil or material was excluded from the test specimen, describe the excluded material.

11.2.5 Method used (Method A or Method B).

11.2.6 All mass measurements (to the nearest 0.01 g).

11.2.7 Test temperature (to the nearest 0.1°C).

11.2.8 Specific gravity at 20°C (G , G_s , $G_{20^\circ\text{C}}$) to the nearest 0.01. If desired, values to the nearest 0.001 may be recorded.

11.2.9 Average specific gravity at 20°C (G_{ave} or $G_{avg@20^\circ\text{C}}$) to the nearest 0.01, if applicable. (See **10.4**).

12. Precision and Bias

12.1 *Precision*—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types using Method A (except the soil was air dried) is given in **Tables 3 and 4**. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program.³ In this program, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single test laboratory). A description of the soils tested is given in **12.1.4**. The precision estimates may vary with soil type and method used (Method A or B). Judgement is required when applying these estimates to another soil or method.

12.1.1 The data in **Table 3** are based on three replicate tests performed by each triplicate test laboratory on each soil type. The single operator and multilaboratory standard deviation shown in **Table 3**, Column 4 were obtained in accordance with Practice **E691**, which recommends each testing laboratory perform a minimum of three replicate tests. Results of two

³ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: RR:D18-1009.

TABLE 3 Summary of Test Results from Triplicate Test Laboratories (Specific Gravity)

(1) Soil Type	(2) Number of Triplicate Test Labs	(3) Average Value ^A	(4) Standard Deviation ^B	(5) Acceptable Range of Two Results ^C
<i>Single-Operator Results (Within- Laboratory Repeatability):</i>				
CH	14	2.717	0.009	0.03
CL	13	2.670	0.006	0.02
ML	14	2.725	0.006	0.02
SP	14	2.658	0.006	0.02
<i>Multilaboratory Results (Between- Laboratory Reproducibility):</i>				
CH	14	2.717	0.028	0.08
CL	13	2.670	0.022	0.06
ML	14	2.725	0.022	0.06
SP	14	2.658	0.008	0.02

^A The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice **D6026**, the standard deviation and acceptable range of results cannot have more decimal places than the input data.

^B Standard deviation is calculated in accordance with Practice **E691** and is referred to as the 1s limit.

^C Acceptable range of two results is referred to as the d2s limit. It is calculated as $1.960\sqrt{2}$ 1s, as defined by Practice **E177**. The difference between two properly conducted tests should not exceed this limit. The number of significant digits/decimal places presented is equal to that prescribed by these test methods or Practice **D6026**. In addition, the value presented can have the same number of decimal places as the standard deviation, even if that result has more significant digits than the standard deviation.

TABLE 4 Summary of Single Test Result from Each Laboratory (Specific Gravity)^A

(1) Soil Type	(2) Number of Test Laboratories	(3) Average Value	(4) Standard Deviation	(5) Acceptable Range of Two Results
<i>Multilaboratory Results (Single-Test Performed by Each Laboratory):</i>				
CH	18	2.715	0.027	0.08
CL	18	2.673	0.018	0.05
ML	18	2.726	0.022	0.06
SP	18	2.660	0.007	0.02

^A See footnotes in **Table 3**.

properly conducted tests performed by the same operator on the same material, using the same equipment, and in the shortest practical period of time should not differ by more than the single-operator d2s limits shown in **Table 3**, Column 5. For definition of d2s see Footnote C in **Table 3**. Results of two properly conducted tests performed by different operators and on different days should not differ by more than the multilaboratory d2s limits shown in **Table 3**, Column 5.

12.1.2 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 data in **Table 4** are based upon the first test result from the triplicate test laboratories and the single test results from the other laboratories. Results of two properly conducted tests performed by two different laboratories with different operators using different equipment and on different days should not vary by more than the d2s limits shown in **Table 4**, Column 5. The results in **Tables 3 and 4** are dissimilar because the data sets are different.

12.1.3 **Table 3** presents a rigorous interpretation of triplicate test data in accordance with Practice **E691** from prequalified laboratories. **Table 4** is derived from test data that represents common practice.

12.1.4 *Soil Type*—Based on the multilaboratory test 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.

CH—Fat clay, CH, 99 % fines, LL=60, PI=39, grayish brown, soil had been air dried and pulverized. Local name—Vicksburg Buckshot Clay
 CL—Lean clay, CL, 89 % fines, LL=33, PI=13, gray, soil had been air dried and pulverized. Local name—Annapolis Clay
 ML—Silt, ML, 99 % fines, LL=27, PI=4, light brown, soil had been air dried and pulverized. Local name—Vicksburg Silt
 SP—Poorly graded sand; SP, 20 % coarse sand, 48 % medium sand, 30 % fine sand, 2 % fines, yellowish brown. Local name—Frederick sand

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

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (06^{e1}) that may impact the use of this standard.

- (1) Subsections **5.4**, **8.3**, **8.5**, **8.6**, **9.8**, and **9.11** were changed to permit the use of standardized non-mercury thermometers.
- (2) Subsection **8.6** was changed and subsection **8.6.1** was added to clarify the pycnometer calibration procedure.

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Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass¹

This standard is issued under the fixed designation D2216; 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 Department of Defense.

1. Scope*

1.1 These test methods cover the laboratory determination of the water (moisture) content by mass of soil, rock, and similar materials where the reduction in mass by drying is due to loss of water except as noted in 1.4, 1.5, and 1.7. For simplicity, the word “material” shall refer to soil, rock or aggregate whichever is most applicable.

1.2 Some disciplines, such as soil science, need to determine water content on the basis of volume. Such determinations are beyond the scope of this test method.

1.3 The water content of a material is defined in 3.2.1.

1.4 The term “solid material” as used in geotechnical engineering is typically assumed to mean naturally occurring mineral particles of soil and rock that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement etc.) may require special treatment or a qualified definition of water content. In addition, some organic materials may be decomposed by oven drying at the standard drying temperature for this method (110°C). Materials containing gypsum (calcium sulfate dihydrate) or other compounds having significant amounts of hydrated water may present a special problem as this material slowly dehydrates at the standard drying temperature (110°C) and at very low relative humidity, forming a compound (such as calcium sulfate hemihydrate) that is not normally present in natural materials except in some desert soils. In order to reduce the degree of dehydration of gypsum in those materials containing gypsum or to reduce decomposition in highly/fibrous organic soils, it may be desirable to dry the materials at 60°C or in a desiccator at room temperature. Thus, when a drying temperature is used which is different from the standard drying temperature as defined by this test method, the resulting water content may be different from the standard water content determined at the standard drying temperature of 110°C.

NOTE 1—Test Method D2974 provides an alternate procedure for

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.

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determining water content of peat materials.

1.5 Materials containing water with substantial amounts of soluble solids (such as salt in the case of marine sediments) when tested by this method will give a mass of solids that includes the previously soluble dissolved solids. These materials require special treatment to remove or account for the presence of precipitated solids in the dry mass of the specimen, or a qualified definition of water content must be used. For example, see Test Method D4542 regarding information on marine sediments.

1.6 This test standard requires several hours for proper drying of the water content specimen. Test Methods D4643, D4944 and D4959 provide less time-consuming processes for determining water content. See Gilbert² for details on the background of Test Method D4643.

1.7 Two test methods are provided in this standard. The methods differ in the significant digits reported 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.

1.7.1 *Method A*—The water content by mass is recorded to the nearest 1 %. For cases of dispute, Method A is the referee method.

1.7.2 *Method B*—The water content by mass is recorded to the nearest 0.1 %.

1.8 This standard requires the drying of material in an oven. If the material being dried is contaminated with certain chemicals, health and safety hazards can exist. Therefore, this standard should not be used in determining the water content of contaminated soils unless adequate health and safety precautions are taken.

1.9 *Units*—The values stated in SI units shall be regarded as standard excluding the Alternative Sieve Sizes listed in Table 1. No other units of measurement are included in this test method.

1.10 Refer to Practice D6026 for guidance concerning the use of significant figures that shall determine whether Method, A or B is required. This is especially important if the water content will be used to calculate other relationships such as

² Gilbert, P.A., “Computer Controlled Microwave Oven System for Rapid Water Content Determination.” Tech. Report GL-88-21. Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, MS, November 1988.

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

TABLE 1 Minimum Requirements for Mass of Test Specimen, and Balance Readability^A

Maximum Particle Size (100 % Passing)		Method A Water Content Recorded to ± 1 %		Method B Water Content Recorded to ± 0.1 %	
SI Unit Sieve Size	Alternative Sieve Size	Specimen Mass	Balance Readability (g)	Specimen Mass (g)	Balance Readability (g)
75.0 mm	3 in.	5 kg	10	50 kg	10
37.5 mm	1-1/2 in.	1 kg	10	10 kg	10
19.0 mm	3/4 in.	250 g	1	2.5 kg	1
9.5 mm	3/8 in.	50 g	0.1	500 g	0.1
4.75 mm	No. 4	20 g	0.1	100 g	0.1
2.00 mm	No. 10	20 g	0.1	20 g	0.01

^AIf water content data is to be used to calculate other relationships, such as moist or dry mass, wet or dry unit weight or total or dry density, then specimen mass up to 200 g must be determined using a balance accurate to 0.01 g.

moist mass to dry mass or vice versa, wet unit weight to dry unit weight or vice versa, and total density to dry density or vice versa. For example, if four significant digits are required in any of the above calculations, then the water content must be recorded to the nearest 0.1 %. This occurs since 1 plus the water content (not in percent) will have four significant digits regardless of what the value of the water content is; that is, 1 plus 0.1/100 = 1.001, a value with four significant digits. While, if three significant digits are acceptable, then the water content can be recorded to the nearest 1 %.

1.11 *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
- D2974** Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic 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** Practices for Preserving and Transporting Soil Samples
- D4318** Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
- D4542** Test Method for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer
- D4643** Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating
- D4753** Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
- D4944** Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester

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.

- D4959** Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating
- D5079** Practices for Preserving and Transporting Rock Core Samples
- D6026** Practice for Using Significant Digits in Geotechnical Data
- D7263** Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens
- E145** Specification for Gravity-Convection and Forced-Ventilation Ovens

3. Terminology

3.1 Refer to Terminology **D653** for standard definitions of terms.

3.2 Definitions:

3.2.1 *water content by mass (of a material)*—the ratio of the mass of water contained in the pore spaces of soil or rock material, to the solid mass of particles in that material, expressed as a percentage. A standard temperature of $110 \pm 5^\circ\text{C}$ is used to determine these masses.

3.3 Definitions of Terms Specific to This Standard:

3.3.1 *constant dry mass (of a material)*—the state that a water content specimen has attained when further heating causes, or would cause, less than 1 % or 0.1 % additional loss in mass for Method A or B respectively. The time required to obtain constant dry mass will vary depending on numerous factors. The influence of these factors generally can be established by good judgement, and experience with the materials being tested and the apparatus being used.

4. Summary of Test Method

4.1 A test specimen is dried in an oven at a temperature of $110 \pm 5^\circ\text{C}$ to a constant mass. The loss of mass due to drying is considered to be water. The water content is calculated using the mass of water and the mass of the dry specimen.

5. Significance and Use

5.1 For many materials, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and its index properties.

5.2 The water content of a material is used in expressing the phase relationships of air, water, and solids in a given volume of material.

5.3 In fine-grained (cohesive) soils, the consistency of a given soil type depends on its water content. The water content

of a soil, along with its liquid and plastic limits as determined by Test Method **D4318**, is used to express its relative consistency or liquidity index.

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 ensure reliable results. Reliable results depend on many factors: Practice **D3740** provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Drying Oven*—Vented, thermostatically-controlled, preferably of the forced-draft type, meeting the requirements of Specification **E145** and capable of maintaining a uniform temperature of $110 \pm 5^\circ\text{C}$ throughout the drying chamber.

6.2 *Balances*—All balances must meet the requirements of Specification **D4753** and this section. A Class GP1 balance of 0.01 g readability is required for specimens having a mass of up to 200 g (excluding mass of specimen container) and a Class GP2 balance of 0.1 g readability is required for specimens having a mass over 200 g. However, the balance used may be controlled by the number of significant digits needed (see **I.10**).

6.3 *Specimen 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. Unless a desiccator is used, containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g; while for specimens having a mass greater than about 200 g, containers without lids may be used (see **Note 3**). One uniquely numbered (identified) container or number-matched container and lid combination as required is needed for each water content determination.

NOTE 3—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial mass determination, and to prevent absorption of moisture from the atmosphere following drying and before final mass determination.

6.4 *Desiccator (Optional)*—A desiccator cabinet or large desiccator jar of suitable size containing silica gel or anhydrous calcium sulfate. It is preferable to use a desiccant that changes color when it needs to be reconstituted.

NOTE 4—Anhydrous calcium sulfate is sold under the trade name Drierite.

6.5 *Container Handling Apparatus*, heat resistant gloves, tongs, or suitable holder for moving and handling hot containers after drying.

6.6 *Miscellaneous*, knives, spatulas, scoops, quartering cloth, wire saws, etc., as required.

7. Samples

7.1 Soil samples shall be preserved and transported in accordance with Practice **D4220** Section 8 Groups B, C, or D soils. Rock samples shall be preserved and transported in accordance with Practice **D5079** section 7.5.2, Special Care Rock. Keep the samples that are stored prior to testing in non-corrodible airtight containers at a temperature between

approximately 3 and 30°C and in an area that prevents direct contact with sunlight. Disturbed samples in jars or other containers shall be stored in such a way as to minimize moisture condensation on the insides of the containers.

7.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corrodible containers (such as thin-walled steel tubes, paint cans, etc.) or plastic sample bags are used.

8. Test Specimen

8.1 For water contents being determined in conjunction with another ASTM method, the specimen mass requirement stated in that method shall be used if one is provided. If no minimum specimen mass is provided in that method then the values given below shall apply. See Howard⁴ for background data for the values listed.

8.2 The minimum specimen mass of moist material selected to be representative of the total sample is based on visual maximum particle size in the sample and the Method (Method A or B) used to record the data. Minimum specimen mass and balance readability shall be in accordance with **Table 1**.

8.3 Using a test specimen smaller than the minimum indicated in **8.2** requires discretion, though it may be adequate for the purposes of the test. Any specimen used not meeting these requirements shall be noted on the test data forms or test data sheets.

8.4 When working with a small (less than 200 g) specimen containing a relatively large gravel particle, it is appropriate not to include this particle in the test specimen. However, any discarded material shall be described and noted on the test data form/sheet.

8.5 For those samples consisting entirely of intact rock or gravel-size aggregate, the minimum specimen mass shall be 500 g. Representative portions of the sample may be broken into smaller particles. The particle size is dictated by the specimen mass, the container volume and the balance being used to determine constant mass, see **10.4**. Specimen masses as small as 200 g may be tested if water contents of only two significant digits are acceptable.

9. Test Specimen Selection

9.1 When the test specimen is a portion of a larger amount of material, the specimen must be selected to be representative of the water condition of the entire amount of material. The manner in which the test specimen is selected depends on the purpose and application of the test, type of material being tested, the water condition, and the type of sample (from another test, bag, block, etc.).

9.2 For disturbed samples such as trimmings, bag samples, etc: obtain the test specimen by one of the following methods (listed in order of preference):

9.2.1 If the material is such that it can be manipulated and handled without significant moisture loss and segregation, the material should be mixed thoroughly. Select a representative

⁴ Howard, A. K., "Minimum Test Specimen Mass for Moisture Content Determination." *Geotechnical Testing Journal*, ASTM., Vol. 12, No. 1, March 1989, pp. 39-44.

portion using a scoop of a size that no more than a few scoopfuls are required to obtain the proper size of specimen defined in 8.2. Combine all the portions for the test specimen.

9.2.2 If the material is such that it cannot be thoroughly mixed or mixed and sampled by a scoop, form a stockpile of the material, mixing as much as possible. Take at least five portions of material at random locations using a sampling tube, shovel, scoop, trowel, or similar device appropriate to the maximum particle size present in the material. Combine all the portions for the test specimen.

9.2.3 If the material or conditions are such that a stockpile cannot be formed, take as many portions of the material as practical, using random locations that will best represent the moisture condition. Combine all the portions for the test specimen.

9.3 Intact samples such as block, tube, split barrel, etc. obtain the test specimen by one of the following methods depending on the purpose and potential use of the sample:

9.3.1 Using a knife, wire saw, or other sharp cutting device, trim the outside portion of the sample a sufficient distance to see if the material is layered, and to remove material that appears more dry or more wet than the main portion of the sample. If the existence of layering is questionable, slice the sample in half. If the material is layered, see 9.3.3.

9.3.2 If the material is not layered, obtain the specimen meeting the mass requirements in 8.2 by: (1) taking all or one-half of the interval being tested; (2) trimming a representative slice from the interval being tested; or (3) trimming the exposed surface of one-half or from the interval being tested.

NOTE: 5—Migration of moisture in some cohesionless soils may require that the entire sample be tested.

9.3.3 If a layered material (or more than one material type is encountered), select an average specimen, or individual specimens, or both. Specimens must be properly identified as to location, or what they represent, and appropriate remarks entered on the test data forms or test data sheets.

10. Procedure

10.1 Determine and record the mass of the clean and dry specimen container and its lid, if used along with its identification number.

10.2 Select representative test specimens in accordance with Section 9.

10.3 Place the moist test specimen in the container and, if used, set the lid securely in position. Determine the mass of the container and moist specimen using a balance (see 8.2 and Table 1) selected on the basis of the specimen mass or required significant digits. Record this value.

NOTE: 6—To assist in the oven drying of large test specimens, they should be placed in containers having a large surface area (such as pans) and the material broken up into smaller aggregations.

10.4 Remove the lid (if used) and place the container with the moist specimen in the drying oven. Dry the specimen to a constant mass. Maintain the drying oven at $110 \pm 5^\circ\text{C}$ unless otherwise specified (see 1.4). The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors. The influence of these factors generally can be established by good

judgment and experience with the materials being tested and the apparatus being used.

10.4.1 In most cases, drying a test specimen overnight (about 12 to 16 h) is sufficient, especially when using forced draft ovens. In cases where there is doubt concerning the adequacy of drying to a constant dry mass, see 3.3.1 and check for additional loss in mass with additional oven drying over an adequate time period. A minimum time period of two hours should be used, increasing the drying time with increasing specimen mass. A rapid check to see if a relatively large specimen (> than about 100 g of material) is dry: place a small strip of torn paper on top of the material while it is in the oven or just upon removal from the oven. If the paper strip curls the material is **not** dry and requires additional drying time. Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

10.4.2 Since some dry materials may absorb moisture from drying specimens that still retain moisture, dried specimens shall be removed before placing moist specimens in the same oven; unless they are being dried overnight.

10.5 After the specimen has dried to constant mass, remove the container from the oven (and replace the lid if used). Allow the specimen and container to cool to room temperature 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 heat transmission or both. Determine the mass of the container and oven-dried specimen using the same type/capacity balance used in 10.3. Record this value. Tight fitting lids shall be used if it appears that the specimen is absorbing moisture from the air prior to determination of its dry mass.

10.5.1 Cooling in a desiccator is acceptable in place of tight fitting lids since it greatly reduces absorption of moisture from the atmosphere during cooling.

10.6 A copy of a sample data sheet is shown in Appendix X1. Any data sheet can be used, provided the form contains all the required data.

11. Calculation

11.1 Calculate the water content of the material as follows:

$$w = [(M_{cms} - M_{cds}) / (M_{cds} - M_c)] \times 100 = (M_w / M_s) \times 100 \quad (1)$$

where:

w = water content, %,

M_{cms} = mass of container and moist specimen, g,

M_{cds} = mass of container and oven dry specimen, g,

M_c = mass of container, g,

M_w = mass of water ($M_w = M_{cms} - M_{cds}$), g, and

M_s = mass of oven dry specimen ($M_s = M_{cds} - M_c$), g.

12. Report: Test Data Form/Sheet

12.1 The method used to specify how data are recorded on the test data sheets or forms, as given below, is the industry standard, and are representative of the significant digits that should be retained. These requirements do not consider in situ material variation, use of the data, special purpose studies, or any considerations for the user's objectives. It is common practice to increase or reduce significant digits of reported data commensurate with these considerations. It is beyond the scope

of the standard to consider significant digits used in analysis method for engineering design.

12.1.1 Test data forms or test data sheets shall include the following:

12.1.2 Identification of the sample (material) being tested, such as boring number, sample number, test number, container number etc.

12.1.3 Water content of the specimen to the nearest 1 % for Method A or 0.1 % for Method B, as appropriate based on the minimum mass of the specimen. If this method is used in concert with another method, the water content of the specimen should be reported to the value required by the test method for which the water content is being determined. Refer to Practice [D6026](#) for guidance concerning significant digits, especially if the value obtained from this test method is to be used to calculate other relationships such as unit weight or density. For instance, if it is desired to express dry unit weight, as determined by [D7263](#) to the nearest 0.1 lbf/f³ (0.02 kN/m³), it may be necessary to use a balance with a greater readability or use a larger specimen mass to obtain the required significant digits the mass of water so that the water content can be determined to the required significant digits. Also, the significant digits in Practice [D6026](#) may need to be increased when calculating phase relationships requiring four significant digits.

12.1.4 Indicate if test specimen had a mass less than the minimum indicated in [8.2](#).

12.1.5 Indicate if test specimen contained more than one material type (layered, etc.).

12.1.6 Indicate the drying temperature if different from $110 \pm 5^{\circ}\text{C}$.

12.1.7 Indicate if any material (size and amount) was excluded from the test specimen.

12.2 When reporting water content in tables, figures, etc., any data not meeting the requirements of this test method shall be noted, such as not meeting the mass, balance, or temperature requirements or a portion of the material is excluded from the test specimen.

13. Precision and Bias

13.1 *Statements on Precision*⁵:

13.1.1 *Precision*—Test data on precision is not presented due to the nature of the soil or rock materials tested by this test method. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation.

13.1.2 Subcommittee D18.03 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

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

14. Keywords

14.1 aggregate; consistency; index property; laboratory; moisture analysis; moisture content; soil; water content

⁵ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D13-1108.

APPENDIX

(Nonmandatory Information)

X1. WATER CONTENT OF SOIL AND ROCK SAMPLE DATA SHEET

Project Name: _____		Project Number: _____			
		Test Method: <u> X </u>	Method A		
		_____	Method B		
Laboratory Number	04-725-S	04-726-S	04-727-S		
Boring Number	B-1	B-2	B-2		
Field Number	SPT-1	SPT-2	SPT-2a		
Container / Lid Number	725	726	727		
Container Mass, g M_c	770.1	731.7	770.6		
Container+Moist Specimen Mass, g M_{cms}	1895.3	2008.4	1827.9		
Date / Time In Oven	8/20/2004 0700	8/20/2004 0700	8/20/2004 0700		
Initial Container+Oven Dry Specimen Mass, g	1721.4	1872.1	1707.6		
Date / Time Out of Oven	8/20/2004 1200	8/20/2004 1200	8/20/2004 1200		
Secondary Container+Oven Dry Specimen Mass, g	1721.4	1801.2	1660.8		
Date / Time Out of Oven	--	8/20/2004 1600	8/20/2004 1600		
Final Container+Oven Dry Specimen Mass, g, $M_{c ds}$	1721.4	1801.2	1660.8		
Date / Time Out of Oven	--	8/21/2004 0700	8/21/2004 0700		
Mass of Water, g, $M_w = M_{cms} - M_{c ds}$	173.9	207.2	167.1		
Mass of Solids, g, $M_s = M_{c ds} - M_c$	951.3	1069.5	890.2		
Water Content, %, $w = (M_w/M_s) \times 100$	18	19	19		
Unified Soil Classification Group Symbol (Visual)	GC	GC	GC		
Bold Approximate Maximum Grain Size (Visual)	3 in., 1½ in., ¾ in., ¾ in., #4, #10, < #10	3 in., 1½ in., ¾ in., ¾ in., #4, #10, < #10	3 in., 1½ in., ¾ in., ¾ in., #4, #10, < #10	3 in., 1½ in., ¾ in., ¾ in., #4, #10, < #10	3 in., 1½ in., ¾ in., ¾ in., #4, #10, < #10
Oven Temperature if Other Than 110°C	--	--	--		
Remarks: _____					

Tested By: _____		Date: _____		Checked By: _____	
Dry Mass By: _____		Date: _____		Spot Checked: _____	
Calculated By: _____		Date: _____		Reviewed By: _____	

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to these test methods since the last issue, D2216–05, that may impact the use of these test methods. (Approved July 1, 2010)

- (1) Replaced “has to” with “must” in **1.10**.
- (2) Added the “heat resistant” to “gloves” in **6.5**.
- (3) Replaced “reduce” with “minimize” in **7.1**.
- (4) Added “or required significant digits” in **10.3**.
- (5) Revised **10.4.1** to clarify the process of obtaining and checking to determine if a specimen had reached constant mass.
- (6) Added “that still retain moisture” in **10.4.2**.
- (7) Replaced “its being heated” with “heat transmission” in **10.5**.
- (8) Added “as determined by **D7263**” in **12.1.3**.
- (9) Added Footnote A to **Table 1** reflecting balance requirements outlined in **6.2**.

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Standard Practices for Preserving and Transporting Soil Samples¹

This standard is issued under the fixed designation D 4220; 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 approval. 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 Department of Defense.

1. Scope*

1.1 These practices cover procedures for preserving soil samples immediately after they are obtained in the field and accompanying procedures for transporting and handling the samples.

1.2 *Limitations*—These practices are not intended to address requirements applicable to transporting of soil samples known or suspected to contain hazardous materials.

1.3 *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. See Section 7.*

2. Referenced Documents

2.1 ASTM Standards:²

D 420 Guide to Site Characterization for Engineering Design and Construction Purposes

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 1452 Practice for Soil Investigation and Sampling by Auger Borings

D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils

D 1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

D 3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils

D 4564 Test Method for Density of Soil in Place by the Sleeve Method

D 4700 Guide for Soil Sampling from the Vadose Zone

3. Terminology

3.1 Terminology in these practices is in accordance with Terminology **D 653**.

4. Summary of Practices

4.1 The various procedures are given under four groupings as follows:

4.1.1 *Group A*—Samples for which only general visual identification is necessary.

4.1.2 *Group B*—Samples for which only water content and classification tests, proctor and relative density, or profile logging is required, and bulk samples that will be remolded or compacted into specimens for swell pressure, percent swell, consolidation, permeability, shear testing, CBR, stabilimeter, etc.

4.1.3 *Group C*—Intact, naturally formed or field fabricated, samples for density determinations; or for swell pressure, percent swell, consolidation, permeability testing and shear testing with or without stress-strain and volume change measurements, to include dynamic and cyclic testing.

4.1.4 *Group D*—Samples that are fragile or highly sensitive for which tests in Group C are required.

4.2 The procedure(s) to be used should be included in the project specifications or defined by the designated responsible person.

5. Significance and Use

5.1 Use of the various procedures recommended in these practices is dependent on the type of samples obtained (Practice **D 420**), the type of testing and engineering properties required, the fragility and sensitivity of the soil, and the

¹ These practices are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Evaluations.

Current edition approved July 1, 2007. Published August 2007. Originally approved in 1983. Last previous edition approved in 2000 as D 4220 – 95 (2000).

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.

climatic conditions. In all cases, the primary purpose is to preserve the desired inherent conditions.

5.2 The procedures presented in these practices were primarily developed for soil samples that are to be tested for engineering properties, however, they may be applicable for samples of soil and other materials obtained for other purposes.

6. Apparatus

6.1 The type of materials and containers needed depend upon the conditions and requirements listed under the four groupings A to D in Section 4, and also on the climate and transporting mode and distance.

6.1.1 *Sealing Wax*, includes microcrystalline wax, paraffin, beeswax, ceresine, carnaubawax, or combinations thereof.

6.1.2 *Metal Disks*, about 1/16 in. (about 2 mm) thick and having a diameter slightly less than the inside diameter of the tube, liner, or ring and to be used in union with wax or caps and tape, or both.

6.1.3 *Wood Disks*, prewaxed, 1 in. (25 mm) thick and having a diameter slightly less than the inside diameter of the liner or tube.

6.1.4 *Tape*, either waterproof plastic, adhesive friction, or duct tape.

6.1.5 *Cheesecloth*, to be used in union with wax in alternative layers.

6.1.6 *Caps*, either plastic, rubber or metal, to be placed over the end of thin-walled tubes (Practice [D 1587](#)), liners and rings (Practice [D 3550](#)), in union with tape or wax.

6.1.7 *O'ring (Sealing End Caps)*, used to seal the ends of samples within thin-walled tubes, by mechanically expanding an O'ring against the tube wall.

NOTE 1—Plastic expandable end caps are preferred. Metal expandable end caps seal equally well; however, long-term storage may cause corrosion problems.

6.1.8 *Jars*, wide mouthed, with rubber-ringed lids or lids lined with a coated paper seal and of a size to comfortably receive the sample, commonly 1/2 pt (250 mL), 1 pt (500 mL) and quart-sized (1000 mL).

6.1.9 *Bag*, either plastic, burlap with liner, burlap or cloth type (Practice [D 1452](#)).

6.1.10 *Packing Material*, to protect against vibration and shock.

6.1.11 *Insulation*, either granule (bead), sheet or foam type, to resist temperature change of soil or to prevent freezing.

6.1.12 *Sample Cube Boxes*, for transporting cube (block) samples. Constructed with 1/2 to 3/4 in. (13 to 19 mm) thick plywood (marine type).

6.1.13 *Cylindrical Sample Containers*, somewhat larger in dimension than the thin-walled tube or liner samples, such as cylindrical frozen food cartons.

6.1.14 *Shipping Containers*, either box or cylindrical type and of proper construction to protect against vibration, shock, and the elements, to the degree required.

NOTE 2—The length, girth and weight restrictions for commercial transportation must be considered.

6.1.15 *Identification Material*—This includes the necessary writing pens, tags, and labels to properly identify the sample(s).

7. Precautions

7.1 Special instructions, descriptions, and marking of containers must accompany any sample that may include radioactive, chemical, toxic, or other contaminant material.

7.2 Interstate transportation containment, storage, and disposal of soil samples obtained from certain areas within the United States and the transportation of foreign soils into or through the United States are subject to regulations established by the U.S. Department of Agriculture, Animal, and Plant Health Service, Plant Protection and Quarantine Programs, and possibly to regulations of other federal, state, or local agencies.

7.2.1 Samples shipped by way of common carrier or U.S. Postal Service must comply with the Department of Transportation Hazardous Materials Regulation, 49CFR Part 172.

7.3 Sample traceability records (see [Fig. 1](#)) are encouraged and should be required for suspected contaminated samples.

7.3.1 The possession of all samples must be traceable, from collection to shipment to laboratory to disposition, and should be handled by as few persons as possible.

7.3.2 The sample collector(s) should be responsible for initiating the sample traceability record; recording the project, sample identification and location, sample type, date, and the number and types of containers.

7.3.3 A separate traceability record shall accompany each shipment.

7.3.4 When transferring the possession of samples the person(s) relinquishing and receiving the samples shall sign, date, record the time, and check for completeness of the traceability record.

8. Procedure

8.1 *All Samples*—Properly identify samples with tags, labels, and markings prior to transporting them as follows:

8.1.1 Job name or number, or both,

8.1.2 Sampling date,

8.1.3 Sample/boring number and location,

8.1.4 Depth or elevation, or both,

8.1.5 Sample orientation,

8.1.6 Special shipping or laboratory handling instructions, or both, including sampling orientation, and

8.1.7 Penetration test data, if applicable (Test Method [D 1586](#)).

8.1.8 Subdivided samples must be identified while maintaining association to the original sample.

8.1.9 If required, sample traceability record.

8.2 *Group A*—Transport samples in any type of container by way of available transportation. If transported commercially, the container need only meet the minimum requirements of the transporting agency and any other requirements necessary to assure against sample loss.

8.3 *Group B*:

8.3.1 Preserve and transport these samples in sealed, moistureproof containers. All containers shall be of sufficient thickness and strength to ensure against breakage and moisture loss. The container types include: plastic bags or pails, glass or plastic (provided they are waterproof) jars, thin walled tubes, liners, and rings. Wrap cylindrical and cube samples in suitable

8.3.8.2 *Cylindrical and Cube Samples Wrapped in Cheesecloth and Wax*, shall be sealed with a minimum of three layers of each, placed alternatively.

8.3.8.3 *Carton Samples (Frozen Food Cartons)*—Samples placed in these containers must be situated so that wax can be poured completely around the sample. The wax should fill the void between the sample and container wall. The wax should be sufficiently warm to flow, but not so hot that it penetrates the pores of the soil. Generally, the samples should be wrapped in plastic or foil before being surrounded with wax.

8.4 Group C:

8.4.1 Preserve and seal these samples in containers as covered in 8.3. In addition, they must be protected against vibration and shock, and protected from extreme heat or cold.

8.4.2 Samples transported by the sampling or testing agency personnel on seats of automobiles and trucks need only be placed in cardboard boxes, or similar containers into which the sealed samples fit snugly, preventing bumping, rolling, dropping, etc.

8.4.3 For all other methods of transporting samples, including automobile trunk, bus, parcel services, truck, boat, air, etc., place the sealed samples in wood, metal, or other type of suitable shipping containers that provide cushioning or insulation, or both, for each sample and container. Avoid transporting by any agency whose handling of containers is suspect.

8.4.4 The cushioning material (sawdust, rubber, polystyrene, urethane foam, or material with similar resiliency) should completely encase each sample. The cushioning between the samples and walls of the shipping containers should have a minimum thickness of 1 in. (25 mm). A minimum thickness of 2 in. (50 mm) shall be provided on the container floor.

8.4.5 When required, the samples should be shipped in the same orientation in which they were sampled. Otherwise, special conditions shall be provided such as freezing, controlled drainage, or sufficient confinement, or a combination thereof, to maintain sample integrity.

8.5 Group D:

8.5.1 The requirements of 8.4 must be met, in addition to the following:

8.5.1.1 Samples should be handled in the same orientation in which they were sampled, including during transportation or shipping, with appropriate markings on the shipping container.

8.5.1.2 For all modes of private or commercial transportation, the loading, transporting and unloading of the shipment containers should be supervised as much as possible by a qualified person.

NOTE 5—A qualified person may be an engineer, geologist, soil scientist, soils technician or responsible person designated by the project manager.

8.6 *Shipping Containers* (see **Figs. 2-7** for typical containers):

8.6.1 The following features should be included in the design of the shipping container for Groups C and D.

8.6.1.1 It should be reuseable,

8.6.1.2 It should be constructed so that the samples can be maintained, at all times, in the same position as when sampled or packed, or both.

8.6.1.3 It should include sufficient packing material to cushion or isolate, or both, the tubes from the adverse effect of vibration and shock, and

8.6.1.4 It should include sufficient insulating material to prevent freezing, sublimation and thawing, or undesirable temperature changes.

8.6.2 *Wood Shipping Containers*:

8.6.2.1 Wood is preferred over metal. Outdoor (marine) plywood having a thickness of ½ and ¾ in. (13 to 19 mm) may be used. The top (cover) should be hinged and latched, or fastened with screws.

8.6.2.2 The cushioning requirements are given in 8.4.4.

8.6.2.3 For protection against freezing or extreme temperature variation, the entire shipping container should be lined with a minimum insulation thickness of 2 in. (50 mm).

8.6.3 *Metal Shipping Containers*—The metal shipping containers must incorporate cushioning and insulation material to minimum thicknesses in accordance with 8.6.2, although slightly greater thicknesses would be appropriate. Alternatively, the cushion effect could be achieved with a spring suspension system, or any other means that would provide similar protection.

8.6.4 *Styrene Shipping Containers*—Bulk styrene with slots cut to the dimensions of the sample tube or liner. A protective outer box of plywood or reinforced cardboard is recommended.

8.6.5 *Other Containers*—Containers constructed with laminated fiberboard, plastic or reinforced cardboard outer walls, and properly lined, may also be used.

9. Reporting

9.1 The data obtained in the field shall be recorded and should include the following:

9.1.1 Job name or number, or both,

9.1.2 Sampling date(s),

9.1.3 Sample/boring number(s) and location(s),

9.1.4 Depth(s) or elevation(s), or both,

9.1.5 Sample orientation,

9.1.6 Groundwater observation, if any.

9.1.7 Method of sampling, and penetration test data, if applicable,

9.1.8 Sample dimensions,

9.1.9 Soil description (Practice **D 2488**),

9.1.10 Names of technician/crewman, engineer, project chief, etc.,

9.1.11 Comments regarding contaminated or possible contaminated samples.

9.1.12 If used, a copy of traceability records.

9.1.13 Weather conditions, and

9.1.14 General remarks.

10. Precision and Bias

10.1 This practice provides qualitative and general information only. Therefore, a precision and bias statement is not applicable.

11. Keywords

11.1 preservation; soil samples; transportation

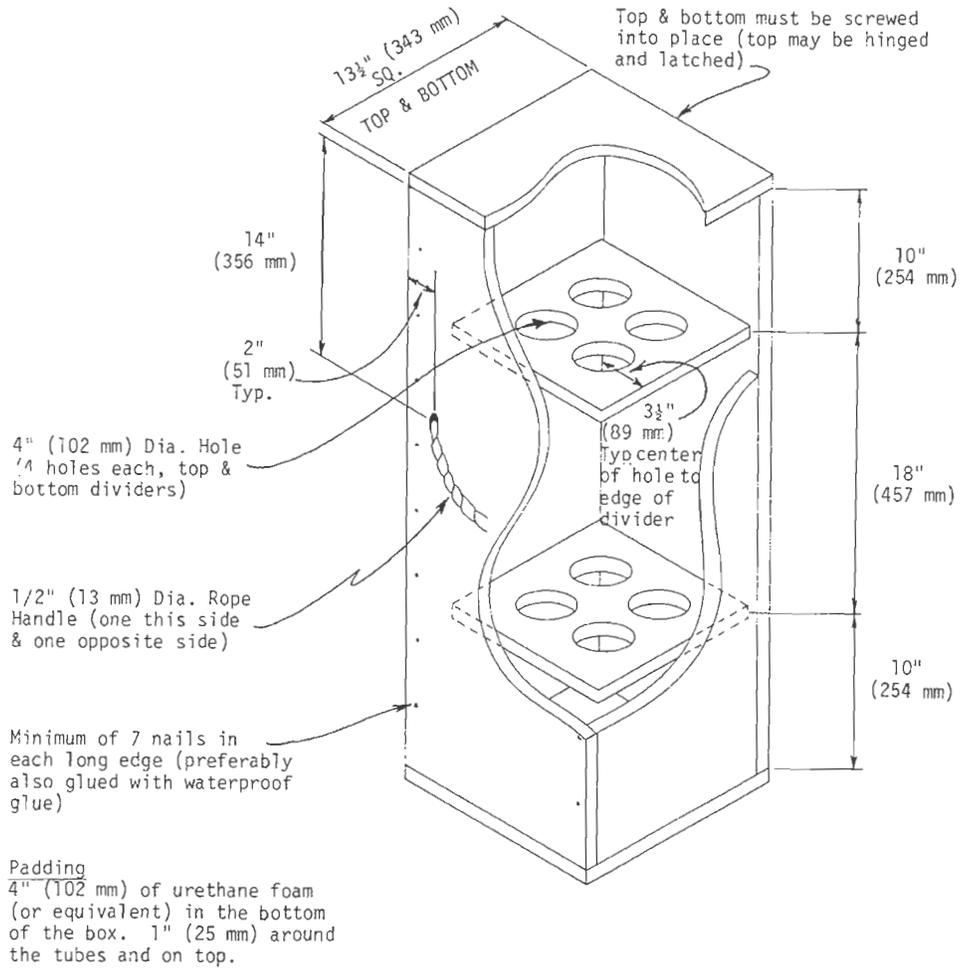
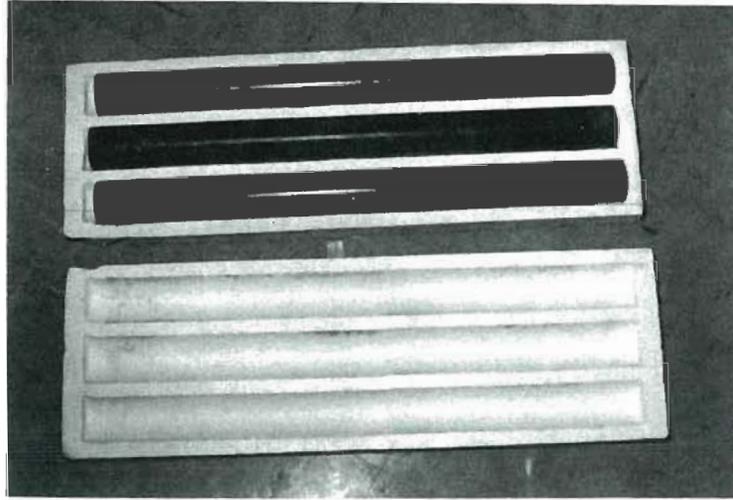
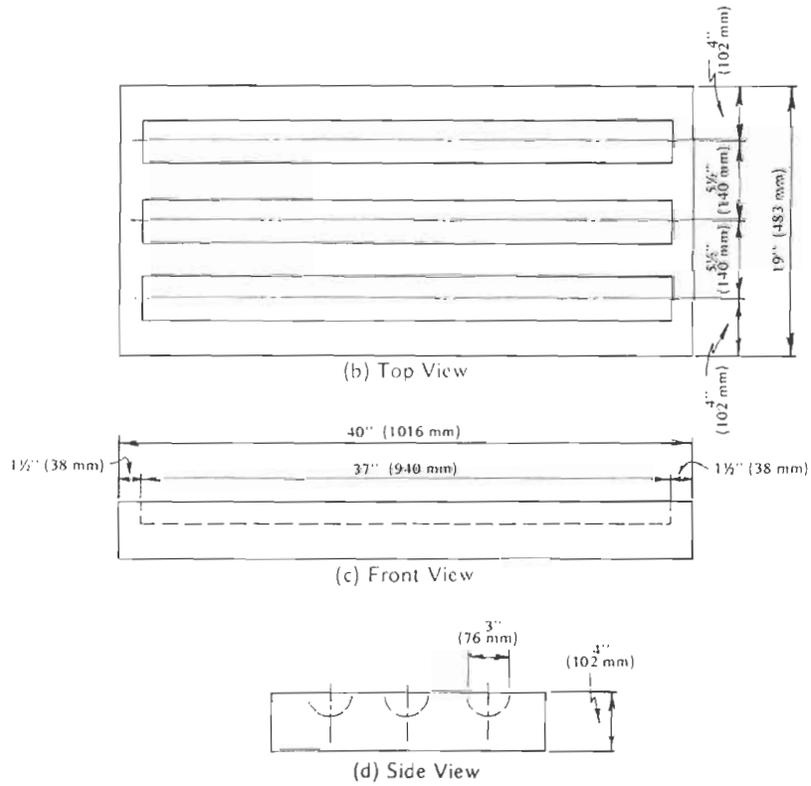


FIG. 2 Shipping Box for 3-in. (76-mm) Thin-Walled Tubes

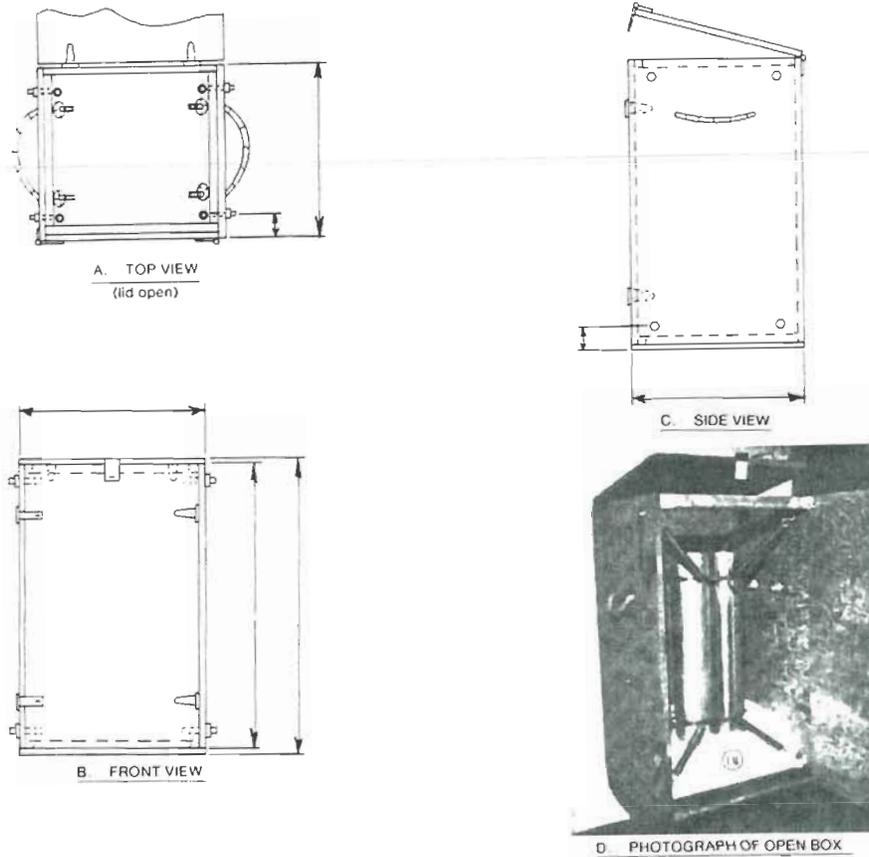


(a) Photo of Open Box For 5" (127 mm) Tubes



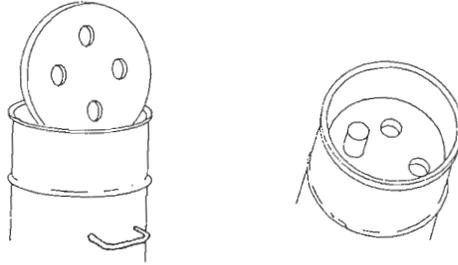
NOTE 1—Top and bottom halves are identical.

FIG. 3 Styrene Shipping Container for 3-in. (76-mm) Thin-Walled Tubes

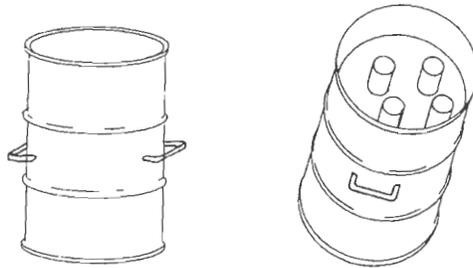


BILL OF MATERIALS			
Item No.	Description of Item	Quantity	Item No. Description of Item Quantity
1	Plywood, 4 ft by 8 ft by 3/4 in. (1220 mm by 2440 mm by 19.1 mm) exterior, Grade AC	1 Sheet	13 Rope, nylon, 1/2-in. (12.7-mm) diameter, solid braided 5 ft (1524 mm)
2	Hinge, strap, 4 in. (102 mm), heavy duty with screws	4 Each	14 Cushioning Material, expanded polystyrene foam 10 ft ³ (0.28 m ³)
3	Hasp, hinged, 4 1/2 in. (114 mm), with screws	3 Each	Notes— (a) All wooden components can be sawed from one sheet of plywood.
4	Screw, Wood, Steel, Flathead, No. 10 by 1 3/4 in. (44.5 mm)	72 Each	(b) This shipping box will accommodate approximately three 3-in. (76-mm) diameter tubes or two 5-in (127-mm) diameter tubes up to 30 in. (762 mm) in length. For longer tubes the inside height of the box must be a minimum of 6-in. (152 mm) greater than the length of the tube.
5	Bolt, Machine, 3/8 in. (9.5 mm), with nut to secure hasps	3 Each	(c) All joints to be glued and fastened with screws.
6	Washer, flat, 3/8 in. (9.5 mm)	3 Each	(d) Stencil all sides as follows (See Views B and C).
7	Eye Bolt, 1/2 by 2 in. (6.4 mm by 51 mm), zinc-plated, with nut	8 Each	TO PROTECT FROM FREEZING
8	Washer, flat, 1/4 in. (6.4 mm), for hasp bolt	8 Each	(e) After suspending samples as indicated above, all void space must be filled with a suitable resilient packing material.
9	S Hooks, 2 in. (51 mm), open, zinc-plated	8 Each	
10	Clamp, adjustable, hose, steel, worm screw adjustment	2 Each	
11	Spring, expansion	8 Each	
12	Adhesive, woodworking	1 lb (454 g)	

FIG. 4 Suspension System Container for Thin-Walled Tubes



(a) 55-gallon (0.21 m³) oil barrels with sections of styrofoam insulation; welded handles on each side.



(b) Same as (a) showing barrel ready for shipment. Steel lids bolted on to provide tight seal.

NOTE 1—Two in. (51 mm) of foam rubber covers 2 in. of styrofoam at the base. One in. (25 mm) of foam rubber overlays the top of the tubes, and the remaining space to the lid is filled with styrofoam.

FIG. 5 Shipping Barrel for Thin-Walled Tubes

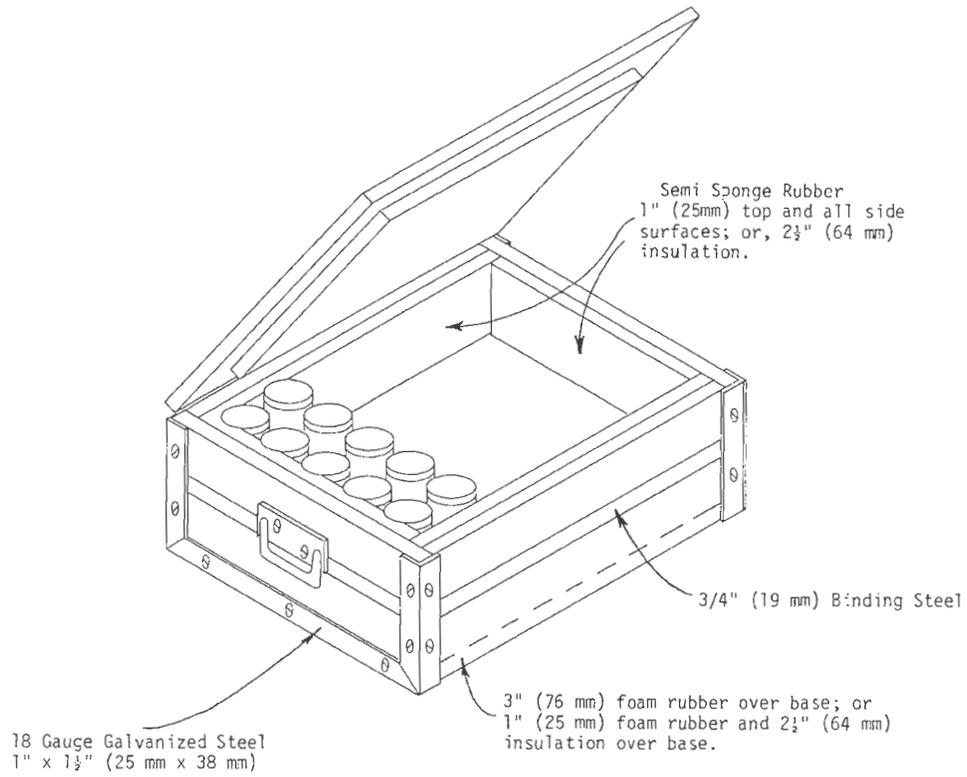
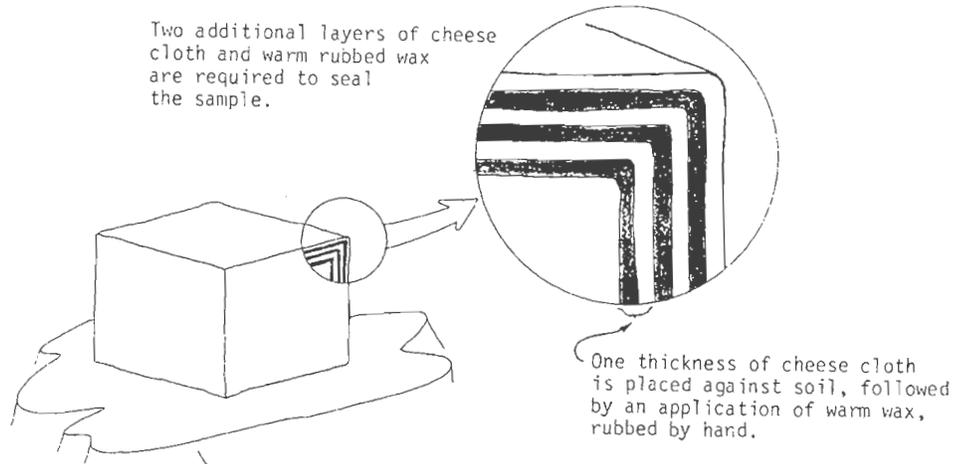
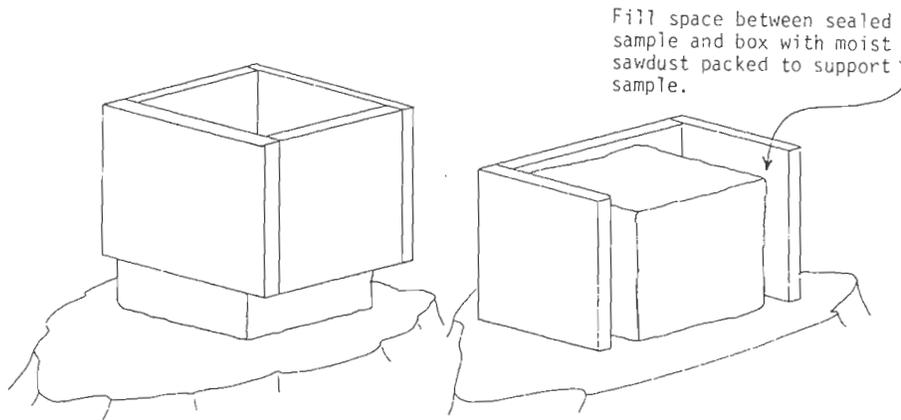


FIG. 6 Shipping Box for Liner (Short Tube) or Ring Samples



A. METHOD FOR SEALING HAND-CUT UNDISTURBED SAMPLES



B. ENCASE EASILY DISTURBED SAMPLES IN BOX PRIOR TO CUTTING

Box constructed with 1/2"-3/4" (13 - 19 mm) exterior plywood.

FIG. 7 Preparing and Packaging a Block Sample

SUMMARY OF CHANGES

This section identifies the location of changes to these practices that have been incorporated since the last issue. Committee D-18 has highlighted those changes that affect the technical interpretation or use of these practices.

- (1) Section 11 was added since the last revision.
- (2) Section 2 was expanded since the last revision.

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Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils¹

This standard is issued under the fixed designation D4318; 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 Department of Defense.

1. Scope*

1.1 These test methods cover the determination of the liquid limit, plastic limit, and the plasticity index of soils as defined in Section 3 on Terminology.

1.2 Two methods for preparing test specimens are provided as follows: *Wet preparation method*, as described in 10.1. *Dry preparation method*, as described in 10.2. The method to be used shall be specified by the requesting authority. If no method is specified, use the wet preparation method.

1.2.1 The liquid and plastic limits of many soils that have been allowed to dry before testing may be considerably different from values obtained on non-dried samples. If the liquid and plastic limits of soils are used to correlate or estimate the engineering behavior of soils in their natural moist state, samples should not be permitted to dry before testing unless data on dried samples are specifically desired.

1.3 Two methods for determining the liquid limit are provided as follows: *Method A*, Multipoint test as described in Sections 11 and 12. *Method B*, One-point test as described in Sections 13 and 14. The method to be used shall be specified by the requesting authority. If no method is specified, use Method A.

1.3.1 The multipoint liquid limit method is generally more precise than the one-point method. It is recommended that the multipoint method be used in cases where test results may be subject to dispute, or where greater precision is required.

1.3.2 Because the one-point method requires the operator to judge when the test specimen is approximately at its liquid limit, it is particularly not recommended for use by inexperienced operators.

1.3.3 The correlation on which the calculations of the one-point method are based may not be valid for certain soils, such as organic soils or soils from a marine environment. It is

strongly recommended that the liquid limit of these soils be determined by the multipoint method.

1.4 The plastic limit test is performed on material prepared for the liquid limit test.

1.5 The liquid limit and plastic limit of soils (along with the shrinkage limit) are often collectively referred to as the Atterberg limits. These limits distinguished the boundaries of the several consistency states of plastic soils.

1.6 The composition and concentration of soluble salts in a soil affect the values of the liquid and plastic limits as well as the water content values of soils (see Method D4542). Special consideration should therefore be given to soils from a marine environment or other sources where high soluble salt concentrations may be present. The degree to which the salts present in these soils are diluted or concentrated must be given careful consideration.

1.7 The methods described herein are performed only on that portion of a soil that passes the 425- μm (No. 40) sieve. Therefore, the relative contribution of this portion of the soil to the properties of the sample as a whole must be considered when using these tests to evaluate properties of a soil.

1.8 The values stated in SI units are to be regarded as the standard, except as noted below. The values given in parentheses are for information only.

1.8.1 The standard units for the resilience tester covered in Annex A1 are inch-pound, not SI. The SI values given are for information only.

1.9 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.9.1 For purposes of comparing a measured or calculated value(s) with specified limits, the measured or calculated value(s) shall be rounded to the nearest decimal or significant digits in the specified limits.

1.9.2 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 do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the

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

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

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.

1.10 *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.*

2. Referenced Documents

2.1 ASTM Standards:²

- C702** Practice for Reducing Samples of Aggregate to Testing Size
- D75** Practice for Sampling Aggregates
- D420** Guide to Site Characterization for Engineering Design and Construction Purposes
- D653** Terminology Relating to Soil, Rock, and Contained Fluids
- D1241** Specification for Materials for Soil-Aggregate Subbase, Base, and Surface Courses
- 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)
- D3282** Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- D3740** Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
- D4542** Test Method for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer
- 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
- 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 Definitions:

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

3.1.2 *Atterberg Limits*—Originally, six “limits of consistency” of fine-grained soils were defined by Albert Atterberg: the upper limit of viscous flow, the liquid limit, the sticky limit, the cohesion limit, the plastic limit, and the shrinkage limit. In

current engineering usage, the term usually refers only to the liquid limit, plastic limit, and in some references, the shrinkage limit.

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

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

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

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

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

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

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

3.1.9 *activity number (A)*—the ratio of (1) the plasticity index of a soil to (2) the percent by mass of particles having an equivalent diameter smaller than 2 μm .

4. Summary of Test Method

4.1 The specimen is processed to remove any material retained on a 425- μm (No. 40) sieve. The liquid limit is determined by performing trials in which a portion of the specimen is spread in a brass cup, divided in two by a grooving tool, and then allowed to flow together from the shocks caused by repeatedly dropping the cup in a standard mechanical device. The multipoint liquid limit, Method A, requires three or more trials over a range of water contents to be performed and the data from the trials plotted or calculated to make a relationship from which the liquid limit is determined. The one-point liquid limit, Method B, uses the data from two trials at one water content multiplied by a correction factor to determine the liquid limit.

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

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

5. Significance and Use

5.1 These test methods are used as an integral part of several engineering classification systems to characterize the fine-grained fractions of soils (see Practices **D2487** and **D3282**) and to specify the fine-grained fraction of construction materials (see Specification **D1241**). The liquid limit, plastic limit, and plasticity index of soils are also used extensively, either individually or together, with other soil properties to correlate

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.

with engineering behavior such as compressibility, hydraulic conductivity (permeability), compactibility, shrink-swell, and shear strength.

5.2 The liquid and plastic limits of a soil and its water content can be used to express its relative consistency or liquidity index. In addition, the plasticity index and the percentage finer than 2- μ m particle size can be used to determine its activity number.

5.3 These methods are sometimes used to evaluate the weathering characteristics of clay-shale materials. When subjected to repeated wetting and drying cycles, the liquid limits of these materials tend to increase. The amount of increase is considered to be a measure of a shale's susceptibility to weathering.

5.4 The liquid limit of a soil containing substantial amounts of organic matter decreases dramatically when the soil is oven-dried before testing. Comparison of the liquid limit of a sample before and after oven-drying can therefore be used as a qualitative measure of organic matter content of a soil (see Practice D2487).

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, generally, are 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 Liquid Limit Device—A mechanical device consisting of a brass cup suspended from a carriage designed to control its

drop onto the surface of a block of resilient material that serves as the base of the device. Fig. 1 shows the essential features and critical dimensions of the device. The device may be operated by either a hand crank or electric motor.

6.1.1 Base—A block of material having a resilience rebound of at least 77 % but no more than 90 %. Conduct resilience tests on the finished base with the feet attached. Details for measuring the resilience of the base are given in Annex A1.

6.1.2 Rubber Feet, supporting the base, designed to provide dynamic isolation of the base from the work surface.

6.1.3 Cup, brass, with a mass, including cup hanger, of 185 to 215 g.

6.1.4 Cam—Designed to raise the cup smoothly and continuously to its maximum height, over a distance of at least 180° of cam rotation, without developing an upward or downward velocity of the cup when the cam follower leaves the cam. (The preferred cam motion is a uniformly accelerated lift curve.)

NOTE 2—The cam and follower design in Fig. 1 is for uniformly accelerated (parabolic) motion after contact and assures that the cup has no velocity at drop off. Other cam designs also provide this feature and may be used. However, if the cam-follower lift pattern is not known, zero velocity at drop off can be assured by carefully filing or machining the cam and follower so that the cup height remains constant over the last 20 to 45° of cam rotation.

6.1.5 Carriage, constructed in a way that allows convenient but secure adjustment of the height-of-drop of the cup to 10 mm (0.394 in.), and designed such that the cup and cup hanger assembly is only attached to the carriage by means of a

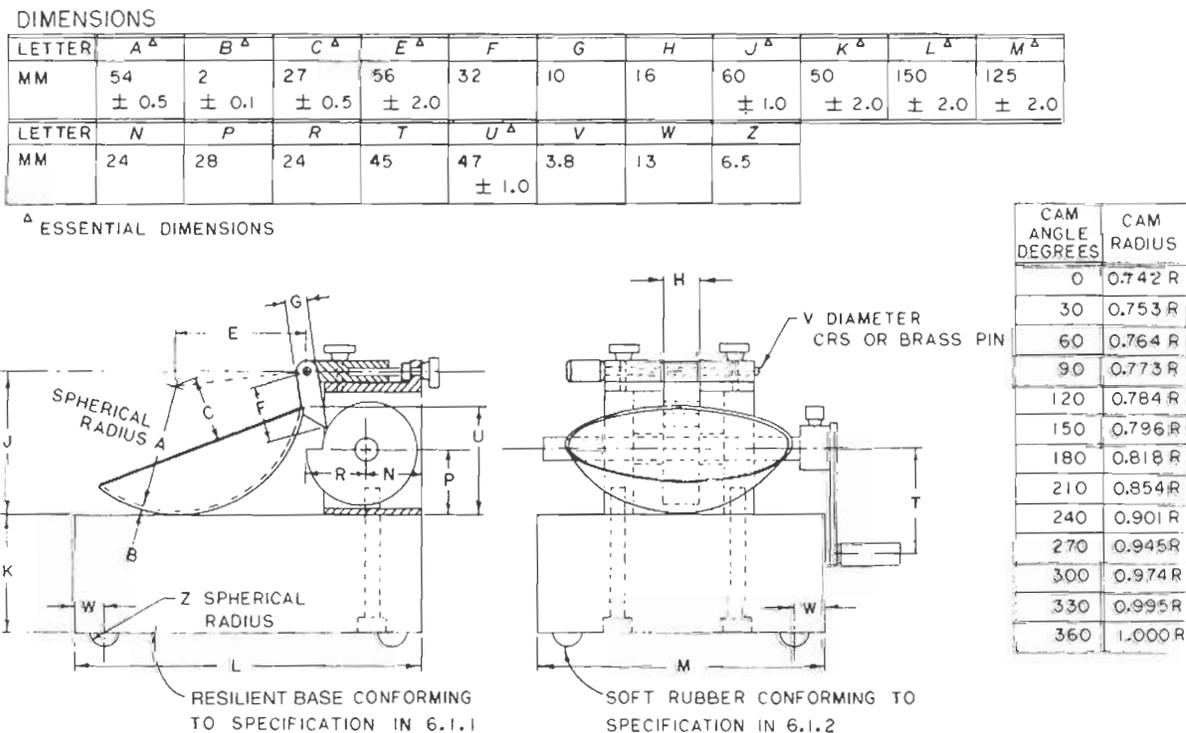


FIG. 1 Hand-Operated Liquid Limit Device

removable pin. See Fig. 2 for definition and determination of the height-of-drop of the cup.

6.1.6 *Motor Drive (Optional)*—As an alternative to the hand crank shown in Fig. 1, the device may be equipped with a motor to turn the cam. Such a motor must turn the cam at 2 ± 0.1 revolutions per second and must be isolated from the rest of the device by rubber mounts or in some other way that prevents vibration from the motor being transmitted to the rest of the apparatus. It must be equipped with an ON-OFF switch and a means of conveniently positioning the cam for height-of-drop adjustments. The results obtained using a motor-driven device must not differ from those obtained using a manually operated device.

6.2 *Flat Grooving Tool*—A tool made of plastic or noncorroding-metal having the dimensions shown in Fig. 3. The design of the tool may vary as long as the essential dimensions are maintained. The tool may, but need not, incorporate the gauge for adjusting the height-of-drop of the liquid limit device.

NOTE 3—Prior to the adoption of this test method, a curved grooving tool was specified as part of the apparatus for performing the liquid limit test. The curved tool is not considered to be as accurate as the flat tool described in 6.2 since it does not control the depth of the soil in the liquid limit cup. However, there are some data which indicate that typically the liquid limit is slightly increased when the flat tool is used instead of the curved tool.

6.3 *Gauge*—A metal gauge block for adjusting the height-of-drop of the cup, having the dimensions shown in Fig. 4. The design of the tool may vary provided the gauge will rest securely on the base without being susceptible to rocking, and the edge which contacts the cup during adjustment is straight, at least 10 mm ($\frac{3}{8}$ in.) wide, and without bevel or radius.

6.4 *Water Content Containers*—Small corrosion-resistant containers with snug-fitting lids for water content specimens. Aluminum or stainless steel cans 2.5 cm (1 in.) high by 5 cm (2 in.) in diameter are appropriate.

6.5 *Balance*, conforming to Specification D4753, Class GPI (readability of 0.01 g).

6.6 *Mixing and Storage Container*—A container to mix the soil specimen (material) and store the prepared material. During mixing and storage, the container shall not contaminate the material in any way, and prevent moisture loss during storage. A porcelain, glass, or plastic dish about 11.4 cm ($4\frac{1}{2}$

in.) in diameter and a plastic bag large enough to enclose the dish and be folded over is adequate.

6.7 *Plastic Limit*:

6.7.1 *Ground Glass Plate*—A ground glass plate of sufficient size for rolling plastic limit threads.

6.7.2 *Plastic Limit-Rolling Device (optional)*—A device made of acrylic conforming to the dimensions shown in Fig. 5.^{3,4} The type of unglazed paper attached to the top and bottom plate (see 16.2.2) shall be such that it does not add foreign matter (fibers, paper fragments, etc.) to the soil during the rolling process.

6.8 *Spatula*—A spatula or pill knife having a blade about 2 cm ($\frac{3}{4}$ in.) wide, and about 10 to 13 cm (3 to 4 in.) long.

6.9 *Sieve(s)*—A 200-mm (8-in.) diameter, 425- μ m (No. 40) sieve conforming to the requirements of Specification E11 and having a rim at least 5 cm (2 in.) above the mesh. A 2.00-mm (No. 10) sieve meeting the same requirements may also be needed.

6.10 *Wash Bottle*, or similar container for adding controlled amounts of water to soil and washing fines from coarse particles.

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

6.12 *Washing Pan*, round, flat-bottomed, at least 7.6 cm (3 in.) deep, and slightly larger at the bottom than a 20.3-cm (8-in.) diameter sieve.

7. Reagents and Materials

7.1 *Purity of Water*—Where distilled water is referred to in this test method, either distilled or demineralized water may be used. See Note 7 covering the use of tap water.

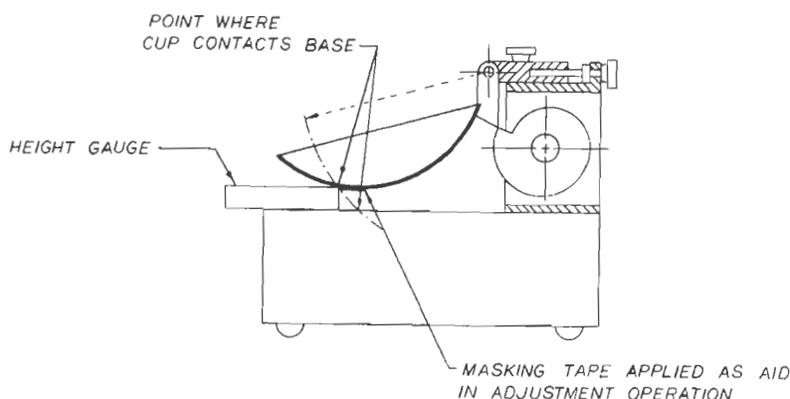


FIG. 2 Calibration for Height-of-Drop

³ The plastic limit-rolling device is covered by a patent (U.S. Patent No. 5,027,660).⁷ Interested parties are invited to submit information regarding the identification of an alternative(s) to this patented item to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible subcommittee, which you may attend.

⁴ Bobrowski, L. J., Jr. and Griekspoor, D. M., "Determination of the Plastic Limit of a Soil by Means of a Rolling Device." *Geotechnical Testing Journal*, GTJODJ, Vol 15, No. 3, September 1992, pp. 284-287.

DIMENSIONS

LETTER	A ^Δ	B ^Δ	C ^Δ	D ^Δ	E ^Δ	F ^Δ
MM	2 ± 0.1	11 ± 0.2	40 ± 0.5	8 ± 0.1	50 ± 0.5	2 ± 0.1
LETTER	G	H	J	K ^Δ	L ^Δ	N
MM	10 MINIMUM	13	60	10 ± 0.05	60 DEG ± 1 DEG	20

^Δ ESSENTIAL DIMENSIONS

[□] BACK AT LEAST 15 MM FROM TIP

NOTE : DIMENSION A SHOULD BE 1.9-2.0 AND DIMENSION D SHOULD BE 8.0-8.1 WHEN NEW TO ALLOW FOR ADEQUATE SERVICE LIFE

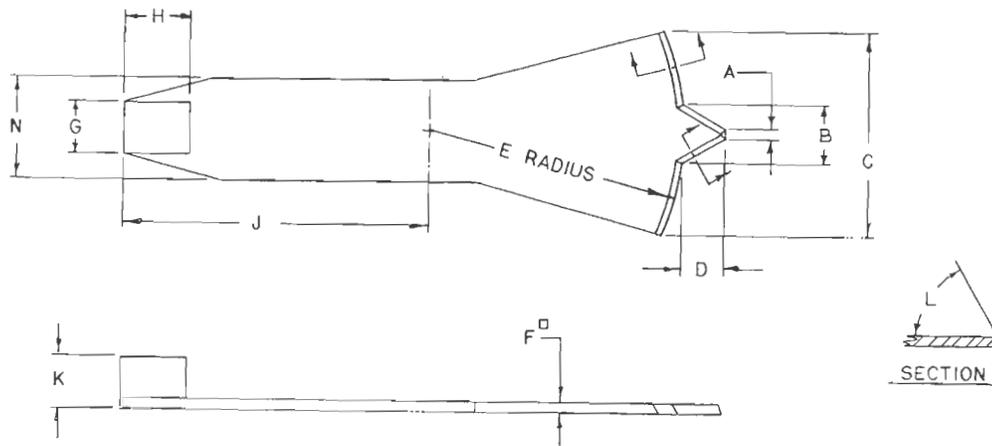
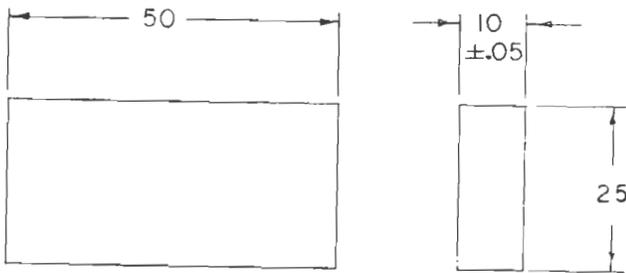


FIG. 3 Grooving Tool (Optional Height-of-Drop Gauge Attached)



DIMENSIONS IN MILLIMETRES

FIG. 4 Height-of-Drop Gauge

8. Sampling and Specimen

8.1 Samples may be taken from any location that satisfies testing needs. However, Practices C702, D75, and D420 should be used as guides for selecting and preserving samples from various types of sampling operations. Samples in which specimens will be prepared using the wet-preparation method (10.1) must be kept at their as-sampled water content prior to preparation.

8.1.1 Where sampling operations have preserved the natural stratification of a sample, the various strata must be kept separated and tests performed on the particular stratum of interest with as little contamination as possible from other strata. Where a mixture of materials will be used in construc-

tion, combine the various components in such proportions that the resultant sample represents the actual construction case.

8.1.2 Where data from these test methods are to be used for correlation with other laboratory or field test data, use the same material as used for those tests where possible.

8.2 Specimen—Obtain a representative portion from the total sample sufficient to provide 150 to 200 g of material passing the 425- μ m (No. 40) sieve. Free flowing samples (materials) may be reduced by the methods of quartering or splitting. Non-free flowing or cohesive materials shall be mixed thoroughly in a pan with a spatula or scoop and a representative portion scooped from the total mass by making one or more sweeps with a scoop through the mixed mass.

9. Calibration of Apparatus

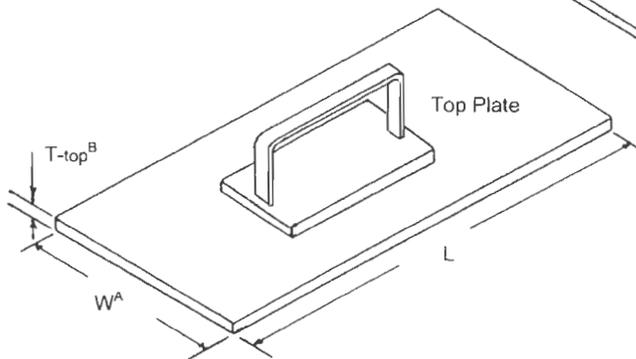
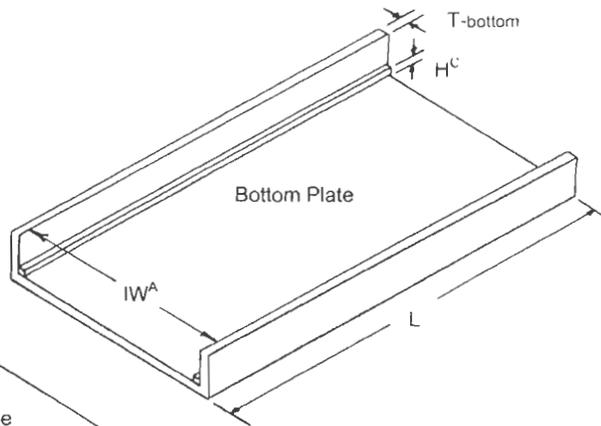
9.1 Inspection of Wear:

9.1.1 Liquid Limit Device—Determine that the liquid limit device is clean and in good working order. Check the following specific points.

9.1.1.1 Wear of Base—The spot on the base where the cup makes contact should be worn no greater than 10 mm ($\frac{3}{8}$ in.) in diameter. If the wear spot is greater than this, the base can be machined to remove the worn spot provided the resurfacing does not make the base thinner than specified in 6.1 and the other dimensional relationships are maintained.

Dimensions:

IW—100 mm (4 in.), more or less
 L—200 mm (8 in.), more or less
 T-top—10 to 15 mm (3/8 to 1/2 in.) or thicker, see Note B
 T-bottom—5 mm (1/4 in.) or thicker
 H—Is the height of the slide rails. It shall equal 3.2 mm (1/8 in.) plus the total thickness of the unglazed paper that is not in contact with the top or bottom surface of the slide rails. The tolerance on this height is $\pm 1/4$ mm ($\pm 1/100$ in.), see Note C.
 W—See Note A.


FIG. 5 Plastic Limit-Rolling Device

Figure 4 Notes:

- (A) The tolerance between the width of the top plate (W) and the inside width of the bottom plate (IW) shall be such that the top plate slides freely on the rails without wobbling.
- (B) The top plate shall be rigid enough so that the thickness of the rolled threads is within the tolerances given for the rail height (H).
- (C) The width of the slide rails shall be between 3 and 6 mm (1/8 and 1/4 in.).

9.1.1.2 *Wear of Cup*—Replace the cup when the grooving tool has worn a depression in the cup 0.1 mm (0.004 in.) deep or when the rim of the cup has been reduced to half its original thickness. Verify that the cup is firmly attached to the cup hanger.

9.1.1.3 *Wear of Cup Hanger*—Verify that the cup hanger pivot does not bind and is not worn to an extent that allows more than 3 mm (1/8 in.) side-to-side movement of the lowest point on the rim.

9.1.1.4 *Wear of Cam*—The cam shall not be worn to an extent that the cup drops before the cup hanger (cam follower) loses contact with the cam.

9.1.1.5 *Rubber Feet*—The feet should prevent the base from bouncing or sliding on the work surface. Replace rubber feet that become hard, cracked, or brittle from age.

9.1.2 *Grooving Tools*—Inspect grooving tools for wear on a frequent and regular basis. The rapidity of wear depends on the material from which the tool is made, and the types of soils being tested. Soils containing a large proportion of fine sand particles may cause rapid wear of grooving tools; therefore, when testing these materials, tools should be inspected more frequently than for other soils.

NOTE 4—The width of the tip of grooving tools is conveniently checked using a pocket-sized measuring magnifier equipped with a millimeter scale. Magnifiers of this type are available from most laboratory supply companies. The depth of the tip of grooving tools can be checked using the depth-measuring feature of vernier calipers.

9.2 *Adjustment of Height-of-Drop*—Adjust the height-of-drop of the cup so that the point on the cup that comes in contact with the base rises to a height of 10 ± 0.2 mm. See Fig. 2 for proper location of the gauge relative to the cup during adjustment.

NOTE 5—A convenient procedure for adjusting the height-of-drop is as

follows: place a piece of masking tape across the outside bottom of the cup parallel with the axis of the cup hanger pivot. The edge of the tape away from the cup hanger should bisect the spot on the cup that contacts the base. For new cups, placing a piece of carbon paper on the base and allowing the cup to drop several times will mark the contact spot. Attach the cup to the device and turn the crank until the cup is raised to its maximum height. Slide the height gauge under the cup from the front, and observe whether the gauge contacts the cup or the tape. (See Fig. 2.) If the tape and cup are both simultaneously contacted, the height-of-drop is ready to be checked. If not, adjust the cup until simultaneous contact is made. Check adjustment by turning the crank at 2 revolutions per second while holding the gauge in position against the tape and cup. If a faint ringing or clicking sound is heard without the cup rising from the gauge, the adjustment is correct. If no ringing is heard or if the cup rises from the gauge, readjust the height-of-drop. If the cup rocks on the gauge during this checking operation, the cam follower pivot is excessively worn and the worn parts should be replaced. Always remove tape after completion of adjustment operation.

10. Preparation of Test Specimen

10.1 *Wet Preparation Method*—Except where the dry method of specimen preparation is specified (10.2), prepare the specimen for testing as described in the following sections.

10.1.1 *Material Passes the 425- μ m (No. 40) Sieve:*

10.1.1.1 Determine by visual and manual methods that the specimen from 8.2 has little or no material retained on a 425- μ m (No. 40) sieve. If this is the case, prepare 150 to 200 g of material by mixing thoroughly with distilled or demineralized water on the glass plate or mixing dish using the spatula. If desired, soak the material in a mixing/storage dish with a small amount of water to soften the material before the start of mixing. If using Method A, adjust the water content of the material to bring it to a consistency that would require about 25 to 35 blows of the liquid limit device to close the groove (Note 6). For Method B, the number of blows should be between about 20 and 30 blows.

10.1.1.2 If, during mixing, a small percentage of material is encountered that would be retained on a 425- μm (No. 40) sieve, remove these particles by hand (if possible). If it is impractical to remove the coarser material by hand, remove small percentages (less than about 15 %) of coarser material by working the material (having the above consistency) through a 425- μm sieve. During this procedure, use a piece of rubber sheeting, rubber stopper, or other convenient device provided the procedure does not distort the sieve or degrade material that would be retained if the washing method described in 10.1.2 were used. If larger percentages of coarse material are encountered during mixing, or it is considered impractical to remove the coarser material by the procedures just described, wash the sample as described in 10.1.2. When the coarse particles found during mixing are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425- μm sieve, but remove by hand or by washing.

10.1.1.3 Place the prepared material in the mixing/storage dish, check its consistency (adjust if required), cover to prevent loss of moisture, and allow to stand (cure) for at least 16 h (overnight). After the standing period and immediately before starting the test, thoroughly remix the soil.

NOTE 6—The time taken to adequately mix a soil will vary greatly, depending on the plasticity and initial water content. Initial mixing times of more than 30 min may be needed for stiff, fat clays.

10.1.2 Material Containing Particles Retained on a 425- μm (No. 40) Sieve:

10.1.2.1 Place the specimen (see 8.2) in a pan or dish and add sufficient water to cover the material. Allow the material to soak until all lumps have softened and the fines no longer adhere to the surfaces of the coarse particles (**Note 7**).

NOTE 7—In some cases, the cations of salts present in tap water will exchange with the natural cations in the soil and significantly alter the test results if tap water is used in the soaking and washing operations. Unless it is known that such cations are not present in the tap water, distilled or demineralized water should be used. As a general rule, water containing more than 100 mg/L of dissolved solids should not be used for either the soaking or washing operations.

10.1.2.2 When the material contains a large percentage of particles retained on the 425- μm (No. 40) sieve, perform the following washing operation in increments, washing no more than 0.5 kg (1 lb) of material at one time. Place the 425- μm sieve in the bottom of the clean pan. Transfer, without any loss of material, the soil-water mixture onto the sieve. If gravel or coarse sand particles are present, rinse as many of these as possible with small quantities of water from a wash bottle, and discard. Alternatively, transfer the soil-water mixture over a 2.00-mm (No. 10) sieve nested atop the 425- μm sieve, rinse the fine material through and remove the 2.00-mm sieve. After washing and removing as much of the coarser material as possible, add sufficient water to the pan to bring the level to about 13 mm ($\frac{1}{2}$ in.) above the surface of the 425- μm sieve. Agitate the slurry by stirring with the fingers while raising and lowering the sieve in the pan and swirling the suspension so that fine material is washed from the coarser particles. Disaggregate fine soil lumps that have not slaked by gently rubbing them over the sieve with the fingertips. Complete the washing operation by raising the sieve above the water surface and

rinsing the material retained with a small amount of clean water. Discard material retained on the 425- μm sieve.

10.1.2.3 Reduce the water content of the material passing the 425- μm (No. 40) sieve until it approaches the liquid limit. Reduction of water content may be accomplished by one or a combination of the following methods: (a) exposing to air currents at room temperature, (b) exposing to warm air currents from a source such as an electric hair dryer, (c) decanting clear water from surface of the suspension, (d) filtering in a Büchner funnel or using filter candles, or (e) draining in a colander or plaster of Paris dish lined with high retentivity,⁵ high wet-strength filter paper. If a plaster of Paris dish is used, take care that the dish never becomes sufficiently saturated that it fails to absorb water into its surface. Thoroughly dry dish between uses. During evaporation and cooling, stir the material often enough to prevent over-drying of the fringes and soil pinnacles on the surface of the mixture. For materials containing soluble salts, use a method of water reduction (a or b) that will not eliminate the soluble salts from the test specimen.

10.1.2.4 If applicable, remove the material retained on the filter paper. Thoroughly mix this material or the above material on the glass plate or in the mixing dish using the spatula. Adjust the water content of the mixture, if necessary, by adding small increments of distilled or demineralized water or by allowing the mixture to dry at room temperature while mixing on the glass plate. If using Method A, the material should be at a water content that would require about 25 to 35 blows of the liquid limit device to close the groove. For Method B, the number of blows should be between about 20 and 30. Put, if necessary, the mixed material in the storage dish, cover to prevent loss of moisture, and allow to stand (cure) for at least 16 h. After the standing period and immediately before starting the test, thoroughly remix the specimen.

10.2 Dry Preparation Method:

10.2.1 Dry the specimen from 8.2 at room temperature or in an oven at a temperature not exceeding 60°C until the soil clods will pulverize readily. Disaggregation is expedited if the material is not allowed to completely dry. However, the material should have a dry appearance when pulverized.

10.2.2 Pulverize the material in a mortar with a rubber-tipped pestle or in some other way that does not cause breakdown of individual particles. When the coarse particles found during pulverization are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425- μm (No. 40) sieve, but remove by hand or other suitable means, such as washing. If a washing procedure is used, follow 10.1.2.1-10.1.2.4.

10.2.3 Separate the material on a 425- μm (No. 40) sieve, shaking the sieve by hand to assure thorough separation of the finer fraction. Return the material retained on the 425- μm sieve to the pulverizing apparatus and repeat the pulverizing and sieving operations. Stop this procedure when most of the fine material has been disaggregated and material retained on the 425- μm sieve consists of individual particles.

⁵ S and S 595 filter paper available in 320-mm circles has proven satisfactory. 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.

10.2.4 Place material retained on the 425- μm (No. 40) sieve after the final pulverizing operations in a dish and soak in a small amount of water. Stir this mixture and transfer it to a 425- μm sieve, catching the water and any suspended fines in the washing pan. Pour this suspension into a dish containing the dry soil previously sieved through the 425- μm sieve. Discard material retained on the 425- μm sieve.

10.2.5 Proceed as described in 10.1.2.3 and 10.1.2.4.

MULTIPOINT LIQUID LIMIT—METHOD A

11. Procedure

11.1 Thoroughly remix the specimen (soil) in its mixing dish, and, if necessary, adjust its water content until the consistency requires about 25 to 35 blows of the liquid limit device to close the groove. Using a spatula, place a portion(s) of the prepared soil in the cup of the liquid limit device at the point where the cup rests on the base, squeeze it down, and spread it into the cup to a depth of about 10 mm at its deepest point, tapering to form an approximately horizontal surface. Take care to eliminate air bubbles from the soil pat, but form the pat with as few strokes as possible. Keep the unused soil in the mixing/storage dish. Cover the dish with a wet towel (or use other means) to retain the moisture in the soil.

11.2 Form a groove in the soil pat by drawing the tool, beveled edge forward, through the soil on a line joining the highest point to the lowest point on the rim of the cup. When cutting the groove, hold the grooving tool against the surface of the cup and draw in an arc, maintaining the tool perpendicular to the surface of the cup throughout its movement. See Fig. 6. In soils where a groove cannot be made in one stroke without

tearing the soil, cut the groove with several strokes of the grooving tool. Alternatively, cut the groove to slightly less than required dimensions with a spatula and use the grooving tool to bring the groove to final dimensions. Exercise extreme care to prevent sliding the soil pat relative to the surface of the cup.

11.3 Verify that no crumbs of soil are present on the base or the underside of the cup. Lift and drop the cup by turning the crank at a rate of 1.9 to 2.1 drops per second until the two halves of the soil pat come in contact at the bottom of the groove along a distance of 13 mm (1/2 in.). See Fig. 7 and Fig. 8. The base of the machine shall not be held with the hand, or hands, while the crank is turned.

Note: 8—Use of a scale is recommended to verify that the groove has closed 13 mm (1/2 in.).

11.4 Verify that an air bubble has not caused premature closing of the groove by observing that both sides of the groove have flowed together with approximately the same shape. If a bubble has caused premature closing of the groove, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving operation and repeat 11.1-11.3. If the soil slides on the surface of the cup, repeat 11.1-11.3 at a higher water content. If, after several trials at successively higher water contents, the soil pat continues to slide in the cup or if the number of blows required to close the groove is always less than 25, record that the liquid limit could not be determined, and report the soil as nonplastic without performing the plastic limit test.

11.5 Record the number of drops, *N*, required to close the groove. Remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right

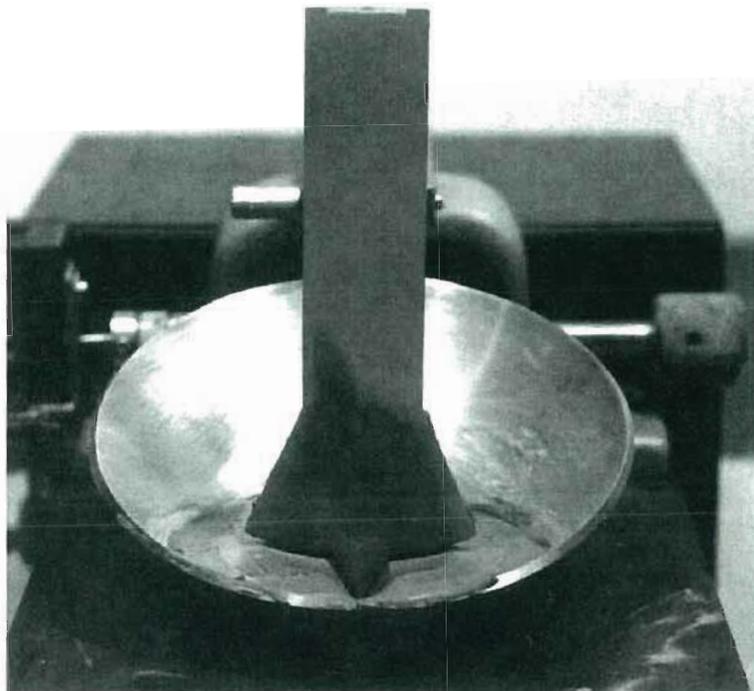


FIG. 6 Example of Grooving Tool Placed in a Properly Grooved Soil Pat

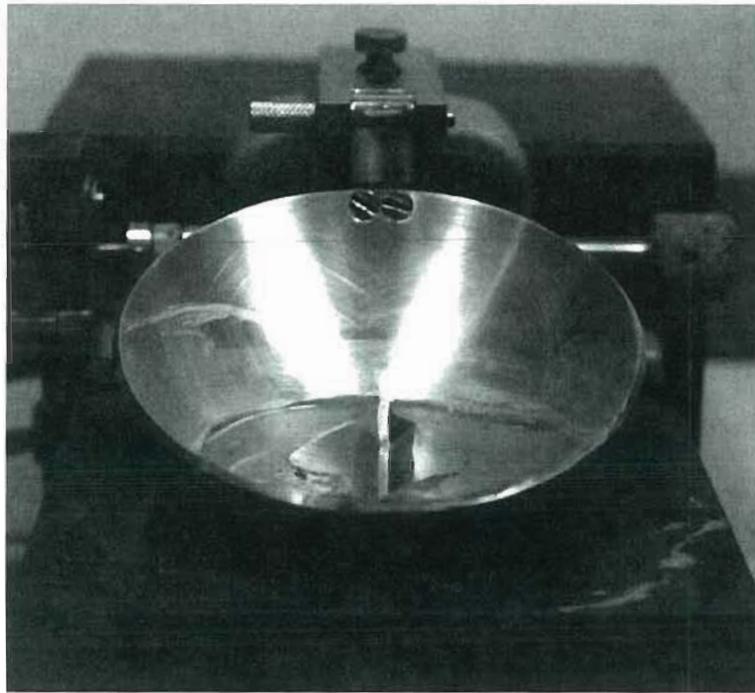


FIG. 7 Grooved Soil Pat in Liquid Limit Device

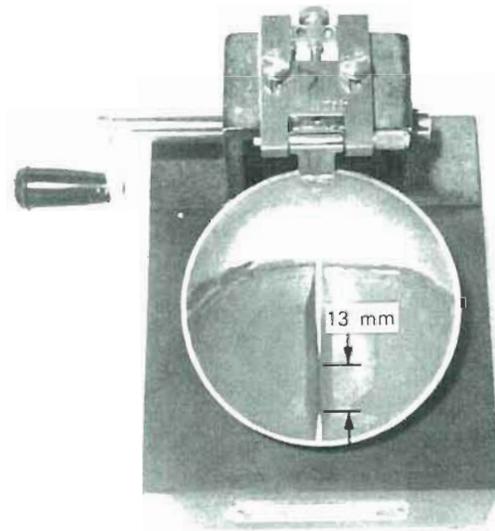


FIG. 8 Soil Pat After Groove Has Closed

angles to the groove and including that portion of the groove in which the soil flowed together, place in a container of known mass, and cover.

11.6 Return the soil remaining in the cup to the dish. Wash and dry the cup and grooving tool and reattach the cup to the carriage in preparation for the next trial.

11.7 Remix the entire soil specimen in the dish adding distilled water to increase the water content of the soil and

decrease the number of blows required to close the groove. Repeat 11.1-11.6 for at least two additional trials producing successively lower numbers of blows to close the groove. One of the trials shall be for a closure requiring 25 to 35 blows, one for closure between 20 and 30 blows, and one trial for a closure requiring 15 to 25 blows.

11.8 Determine the water content, W^1 , of the soil specimen from each trial in accordance with Test Method D2216.

11.8.1 Determination of initial masses (container plus moist soil) should be performed immediately after completion of the test. If the test is to be interrupted for more than about 15 minutes, determine the mass of the water content specimens already obtained at the time of the interruption.

12. Calculation

12.1 Plot the relationship between the water content, W^i , and the corresponding number of drops, N , of the cup on a semilogarithmic graph with the water content as ordinates on the arithmetical scale, and the number of drops as abscissas on a logarithmic scale. Draw the best straight line through the three or more plotted points.

12.2 Take the water content corresponding to the intersection of the line with the 25-drop abscissa as the liquid limit of the soil and round to the nearest whole number. Computational methods may be substituted for the graphical method for fitting a straight line to the data and determining the liquid limit.

ONE-POINT LIQUID LIMIT—METHOD B

13. Procedure

13.1 Proceed as described in 11.1-11.5 except that the number of blows required to close the groove shall be 20 to 30. If less than 20 or more than 30 blows are required, adjust the water content of the soil and repeat the procedure.

13.2 Immediately after removing a water content specimen as described in 11.5, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving and water content sampling processes.

13.2.1 As an alternative to reforming the soil in the brass cup after removing the water content specimen, the soil remaining in the cup can be removed from the cup, remixed with the soil in the mixing container and a new specimen placed in the cup as described in 11.1.

13.3 Repeat 11.2-11.5

13.4 If the second closing of the groove requires the same number of drops or no more than two drops difference, secure another water content specimen. If the difference of the number of drops between the first and second closings of the groove is greater than two, remix the entire specimen and repeat the procedure, beginning at 13.1, until two successive closures having the same number of drops or no more than two drops difference are obtained.

NOTE 9—Excessive drying or inadequate mixing will cause the number of blows to vary.

13.5 Determine water contents of the two specimens in accordance with 11.8.

14. Calculation

14.1 Determine the liquid limit for each water content specimen using one of the following equations:

$$LL^i = W^i \cdot \left(\frac{N}{25}\right)^{0.121}$$

or

$$LL^i = k \cdot W^i$$

where:

LL^i = one point liquid limit for given trial, %,

N = number of blows causing closure of the groove for given trial,

W^i = water content for given trial, %, and

k = factor given in Table 1.

14.1.1 The liquid limit, LL , is the average of the two trial liquid-limit values, to the nearest whole number (without the percent designation).

14.2 If the difference between the two trial liquid-limit values is greater than one percentage point, repeat the test as described in 13.1 through 14.1.1.

PLASTIC LIMIT

15. Preparation of Test Specimen

15.1 Select a 20-g or more portion of soil from the material prepared for the liquid limit test; either, after the second mixing before the test, or from the soil remaining after completion of the liquid limit test. Reduce the water content of the soil to a consistency at which it can be rolled without sticking to the hands by spreading or mixing continuously on the glass plate or in the mixing/storage dish. The drying process may be accelerated by exposing the soil to the air current from an electric fan, or by blotting with paper, that does not add any fiber to the soil. Paper such as hard surface paper toweling or high wet-strength filter paper is adequate.

16. Procedure

16.1 From this plastic-limit specimen, select a 1.5 to 2.0 g portion. Form the selected portion into an ellipsoidal mass.

16.2 Roll the soil mass by one of the following methods (hand or rolling device):

16.2.1 *Hand Method*—Roll the mass between the palm or fingers and the ground-glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length (see Note 10). The thread shall be further deformed on each stroke so that its diameter reaches 3.2 mm ($1/8$ in.), taking no more than 2 min (see Note 11). The amount of hand or finger pressure required will vary greatly according to the soil being tested, that is, the required pressure typically increases with increasing plasticity. Fragile soils of low plasticity are best rolled under the outer edge of the palm or at the base of the thumb.

TABLE 1 Factors for Obtaining Liquid Limit from Water Content and Number of Drops Causing Closure of Groove

N (Number of Drops)	k (Factor for Liquid Limit)
20	0.973
21	0.979
22	0.985
23	0.990
24	0.995
25	1.000
26	1.005
27	1.009
28	1.014
29	1.018
30	1.022

NOTE 10—A normal rate of rolling for most soils should be 80 to 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position. This rate of rolling may have to be decreased for very fragile soils.

NOTE 11—A 3.2-mm (1/8-in.) diameter rod or tube is useful for frequent comparison with the soil thread to ascertain when the thread has reached the proper diameter.

16.2.2 *Rolling Device Method*—Attach smooth unglazed paper to both the top and bottom plates of the plastic limit-rolling device. Place the soil mass on the bottom plate at the midpoint between the slide rails. Place the top plate in contact with the soil mass(es). Simultaneously apply a slight downward force and back and forth motion to the top plate so that the top plate comes into contact with the side rails within 2 min (see Notes 10 and 12). During this rolling process, the end(s) the soil thread(s) shall not contact the side rail(s). If this occurs, roll a smaller mass of soil (even if it is less than that mentioned in Section 16.1).

NOTE 12—In most cases, two soil masses (threads) can be rolled simultaneously in the plastic limit-rolling device.

16.3 When the diameter of the thread becomes 3.2 mm, break the thread into several pieces. Squeeze the pieces together, knead between the thumb and first finger of each hand, reform into an ellipsoidal mass, and re-roll. Continue this alternate rolling to a thread 3.2 mm in diameter, gathering together, kneading and re-rolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a 3.2-mm diameter thread (see Fig. 9). It has no significance if the thread breaks into threads of shorter length. Roll each of these shorter threads to 3.2 mm in diameter. The only requirement for continuing the test is that

these threads can be reformed into an ellipsoidal mass and rolled out again. The operator shall at no time attempt to produce failure at exactly 3.2-mm diameter by allowing the thread to reach 3.2 mm, then reducing the rate of rolling or the hand pressure, or both, while continuing the rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal mass nearer to the required 3.2-mm final diameter. If crumbling occurs when the thread has a diameter greater than 3.2 mm, this shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread 3.2 mm in diameter. Crumbling of the thread will manifest itself differently with the various types of soil. Some soils fall apart in numerous small aggregations of particles, others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally, the thread falls apart in many small platy particles. Fat clay soils require much pressure to deform the thread, particularly as they approach the plastic limit. With these soils, the thread breaks into a series of barrel-shaped segments about 3.2 to 9.5 mm (1/8 to 3/8 in.) in length.

16.4 Gather the portions of the crumbled thread together and place in a container of known mass. Immediately cover the container.

16.5 Select another 1.5 to 2.0-g portion of soil from the plastic-limit specimen and repeat the operations described in 16.1 and 16.2 until the container has at least 6 g of soil.



FIG. 9 Lean Clay Soil at the Plastic Limit

16.6 Repeat **16.1-16.5** to make another container holding at least 6 g of soil. Determine the water content of the soil contained in the containers in accordance with Test Method **D2216**. See **11.8.1**.

17. Calculation

17.1 Compute the average of the two water contents (trial plastic limits) and round to the nearest whole number. This value is the plastic limit, *PL*. Repeat the test if the difference between the two trial plastic limits is greater than the acceptable range for two results listed in **Table 2** for single-operator precision, that is, 1.4 percentage points; i.e., (2.8×0.5) .

PLASTICITY INDEX

18. Calculation

18.1 Calculate the plasticity index as follows:

$$PI = LL - PL$$

where:

LL = liquid limit (whole number), and

PL = plastic limit (whole number).

18.1.1 Both *LL* and *PL* are whole numbers. If either the liquid limit or plastic limit could not be determined, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

19. Report: Test Data Sheet(s)/Form(s)

19.1 The terminology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in **1.9**.

19.2 Record as a minimum the following information:

19.2.1 Sample/specimen identifying information, such as project name, project number, boring number, depth (m or ft).

19.2.2 Description of sample, such as approximate maximum grain size, estimate of the percentage of sample retained on the 425- μ m (No. 40) sieve, as-received water content.

19.2.3 Details of specimen preparation, such as wet or dry (air-dried or oven-dried), method of removing particles larger than the 425- μ m (No. 40) sieve.

19.2.4 Any special specimen selection process used, such as removal of sand lenses from an intact (undisturbed) sample.

19.2.5 Equipment used, such as hand rolled or mechanical rolling device for plastic limit, manual or mechanical liquid limit device, metal or plastic grooving tool.

19.2.6 Liquid limit, plastic limit, and plasticity index to the nearest whole number, omitting the percent designation. If the liquid limit or plastic limit tests could not be performed, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

19.2.7 Procedure by which liquid limit was performed, if it differs from the multipoint method.

20. Precision and Bias

20.1 *Precision*—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types are given in **Tables 2 and 3**. In performing these test methods, Method A and the Wet Preparation Method (except soil was air-dried) were used.

20.1.1 These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program.⁶ In this program, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single-test laboratory). A description of the soils tested is given in **20.1.5**. The precision estimates vary with soil type and method(s) used. Judgment is required when applying these estimates to another soil and method used (Method A or B, or Wet or Dry Preparation Method).

20.1.2 The data in **Table 2** are based on three replicate tests performed by each triplicate test laboratory on each soil type. The single operator and multilaboratory standard deviation shown in **Table 2**, Column 4, were obtained in accordance with Practice **E691**, which recommends each testing laboratory perform a minimum of three replicate tests. Results of two properly conducted tests performed by the same operator on

⁶ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D18-1013.

TABLE 2 Summary of Test Results from Triplicate Test Laboratories (Atterberg Limits)

(1) Soil Type	(2) Number of Triplicate Test Laboratories			(3) Average Value ^A (Percentage Points)			(4) Standard Deviation ^B (Percentage Points)			(5) Acceptable Range of Two Results ^C (Percentage Points)		
	LL	PL	PI	Type Test			LL	PI	LL	PL	PI	
				LL	PL	PI						
	<i>Single-Operator Results (Within-Laboratory Repeatability)</i>											
CH	13	13	13	59.8	20.6	39.2	0.7	0.5	0.8	2	1	2
CL	14	13	13	33.4	19.9	13.6	0.3	0.4	0.5	1	1	1
ML	12	11	11	27.4	23.4 ^D	4.1 ^D	0.5	0.3	0.6	2	1	2
	<i>Multilaboratory Results (Between-Laboratory Reproducibility)</i>											
CH	13	13	13	59.8	20.6	39.2	1.3	2.0	2.5	4	6	7
CL	14	13	13	33.4	19.9	13.6	1.0	1.2	1.7	3	3	5
ML	12	11	11	27.4	23.4 ^D	4.1 ^D	1.3	0.9	1.9	4	3	5

^A The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice **D6026**, the standard deviation and acceptable range of results can not have more decimal places than the input data.

^B Standard deviation is calculated in accordance with Practice **E691**, and is referred to as the 1s limit.

^C Acceptable range of two results is referred to as the d2s limit. It is calculated as $-1.960 \cdot \sqrt{2} \cdot 1s$, as defined by Practice **E177**. The difference between two properly conducted tests should not exceed this limit. The number of significant digits/decimal places presented is equal to that prescribed by this test method or Practice **D6026**. In addition, the value presented can have the same number of decimal places as the standard deviation, even if that result has more significant digits than the standard deviation.

^D For the ML soil, 2 out of 14 triplicate test laboratories reported the soil as nonplastic.

TABLE 3 Summary of Single-Test Result from Each Laboratory (Atterberg Limits)^A

(1) Soil Type	(2) Number of Test Laboratories	(3) Average Value (Percentage Points)			(4) Standard Deviation (Percentage Points)			(5) Acceptable Range of Two Results (Percentage Points)		
		LL	PL	PI	LL	PL	PI	LL	PL	PI
CH	24	59.9	20.4	39.5	2.1	2.7	3.1	6	7	9
CL	24	33.3	19.9	13.4	0.8	1.3	1.6	2	4	4
ML	18	27.1	23.2 ^B	3.9 ^B	1.3	1.2	1.8	4	3	5

^A For column footnotes, see Table 3.

^B For the ML soil, 6 out of 24 laboratories reported the soil as nonplastic.

the same material, using the same equipment, and in the shortest practical period of time should not differ by more than the single-operator d_{2s} limits shown in Table 2, Column 5. For definition of d_{2s} see Footnote C in Table 2. Results of two properly conducted tests performed by different operators and on different days should not differ by more than the multilaboratory d_{2s} limits shown in Table 2, Column 5.

20.1.3 In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test on each soil type. This is common practice in the design and construction industry. The data for each soil type in Table 3 are based upon the first test results from the triplicate test laboratories

and the single test results from the other laboratories. Results of two properly conducted tests performed by two different laboratories with different operators using different equipment and on different days should not vary by more than the d_{2s} limits shown in Table 3, Column 5. The results in Table 2 and Table 3 are dissimilar because the data sets are different.

20.1.4 Table 2 presents a rigorous interpretation of triplicate test data in accordance with Practice E691 from pre-qualified laboratories. Table 3 is derived from test data that represents common practice.

20.1.5 *Soil Types*—Based on the multilaboratory test results, the soils used in the program are described below in accordance with Practice D2487. In addition, the local names of the soils are given.

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

20.2 *Bias*—There is no acceptable reference value for these test methods; therefore, bias cannot be determined.

21. Keywords

21.1 activity; Atterberg limits; liquid limit; plasticity index; plastic limit

ANNEX

(Mandatory Information)

A1. Resilience Tester

A1.1 A device for measuring the resilience of liquid limit device bases is shown in Fig. A1.1. The device consists of a clear acrylic plastic tube and cap, a 5/16-in. diameter steel ball, and a small bar magnet. The cylinder may be cemented to the cap or threaded as shown. The small bar magnet is held in the recess of the cap and the steel ball is fixed into the recess in the underside of the cap with the bar magnet. The cylinder is then turned upright and placed on the top surface of the base to be

tested. Holding the tube lightly against the liquid limit device base with one hand, release the ball by pulling the magnet out of the cap. Use the scale markings on the outside of the cylinder to determine the highest point reached by the bottom of the ball. Repeat the drop at least three times, placing the tester in a different location for each drop. Tests should be conducted at room temperature.

CLEAR PLASTIC (SUCH AS ACRYLIC)
CAP AND TUBE

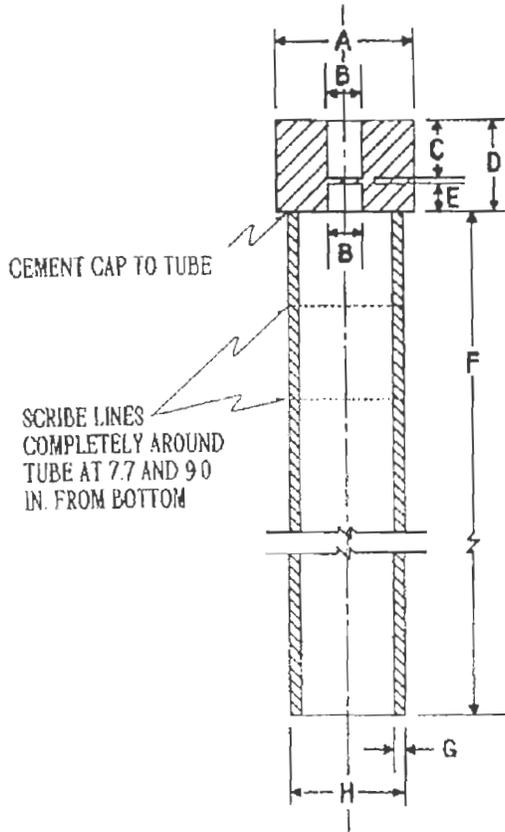


TABLE OF MEASUREMENTS

DIMENSION	DESCRIPTION	ENGLISH, in.	SI, mm
A	DIAM. OF CAP	1 1/2	38.10
B	DIAM. OF HOLE	3/8	9.52
C	DEPTH OF HOLE	10/16	15.88
D	HEIGHT OF CAP	1	25.40
E	DEPTH OF HOLE	5/16	7.94
F	LENGTH OF TUBE	10	254.00
G	WALL THICKNESS	1/8	3.18
H	O.D. OF TUBE	1 1/4	31.75

FIG. A1.1 Resilience Tester

APPENDIX

X1. Sample Data Sheet

X1.1 See Fig. X1.1.

Laboratory Name: Example Project Name: Example Project Number: Example
 Soil Type: CH-1 Boring Number: N/A Depth (m or ft): N/A
 Initial Visual Description: CH, brown, highly plastic clay
 Sample Number: N/A

INITIAL VISUAL USCS GROUP SYMBOL:	CH
-----------------------------------	----

SPECIMEN PREPARATION			
Wet:	<input checked="" type="checkbox"/>	Washed on #40 Sieve	<input type="checkbox"/>
Dry (Air):	<input type="checkbox"/>	Dry Sieved on #40 Sieve	<input type="checkbox"/>
Dry (Oven):	<input type="checkbox"/>	Mechanically Pushed Through #40 Sieve	<input type="checkbox"/>
Mixed on Glass Plate and Removed Medium Plus Sand Particles			<input checked="" type="checkbox"/>
Mixing Water: Distilled	<input checked="" type="checkbox"/>	Demineralized:	<input type="checkbox"/>
		Other:	<input type="checkbox"/>

TESTING EQUIPMENT USED		
Plastic Limit:	Hand Rolled	<input checked="" type="checkbox"/>
	Mechanical Rolling Device	<input type="checkbox"/>
Liquid Limit:	Manual	<input checked="" type="checkbox"/>
	Mechanical	<input type="checkbox"/>
Apparatus No. ()	Metal	<input type="checkbox"/>
Casagrande/ASTM	Metal	<input type="checkbox"/>
Grooving Tool:	Plastic	<input checked="" type="checkbox"/>

AS-RECEIVED WATER CONTENT (OVEN DRIED)

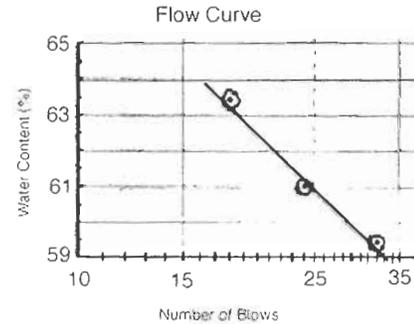
Container No.	example	example	
Mass Moist Soil + Container, M1 (g)	n/a	n/a	
Mass Dry Soil + Container, M2 (g)			
Mass Container, M3 (g)			Average
WATER CONTENT, w, (%)			
Circle Approximate Max. Grain Size in Sample 3" 1-1/2" 3/4" 3/8" #4 #10 < #10			

PLASTIC LIMIT

Container No.	151	s-110	
Mass Moist Soil + Container, M1 (g)	24.44	23.75	
Mass Dry Soil + Container, M2 (g)	22.96	22.13	
Mass Container, M3 (g)	16.76	15.32	Average
WATER CONTENT, w, (%)			23.9

LIQUID LIMIT

Container No.	147	232	152		
Mass Moist Soil + Container, M1 (g)	35.24	37.73	35.88		
Mass Dry Soil + Container, M2 (g)	28.52	30.50	28.46		
Mass Container, M3 (g)	17.13	18.55	16.75		
WATER CONTENT, w, (%)			59.3	61.0	63.4
NUMBER OF BLOWS, N			32	24	18
LIQUID LIMIT, ASTM SINGLE POINT			n/a	n/a	n/a
					Average



LINEAR REGRESSION ANALYSIS	
w at N = 25 Blows	
Coef. Of Determination, r ²	

Recommended range of Blow Count for Multiple Point Method A: SUMMARY

15 to 25, 25 to 30, and 25 to 35

Recommended range of Blow Count for Single Point Method B:

20 to 30

w_o or w = ((M1-M2)/(M2-M3))x100

LL = Water Content at N=25 blows, from Flow Curve

LL by Single Point = w x (N/25)0.121

PI = LL - PL

LI = (w_o-PL) / (LL - PL)

TEST METHOD	A	X	B		Wet	%	Dry
AS-RECEIVED WATER CONTENT, w, (%)							
							n/a
LIQUID LIMIT, LL							
							61
PLASTIC LIMIT, PL							
							24
PLASTICITY INDEX, PI							
							37
LIQUIDITY INDEX, LI							
							n/a
PERCENTAGE POINTS ABOVE/BELOW A-LINE							
							n/a
PLASTICITY CHART CLASSIFICATION							
							CH

PREPARED BY: _____ DATE: _____ DRY MASS BY: _____ CHECKED BY: _____
 TESTED BY: _____ DATE: _____ CALCULATED BY: _____ SPOT CHECKED BY: _____
 REVIEWED BY: _____

FIG. X1.1 Sample Data Sheet

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D4318 - 05) that may impact the use of this standard. (Approved January 15, 2010.)

- (1) Corrected 1.6 to reference D4542 and added D4542 to Referenced Documents in Section 2.
- (2) In 1.8 and 1.8.1, clarified use of SI units.
- (3) Added 1.9 referencing D6026 and the use of significant digits and renumbered 1.9 as 1.10.
- (4) In 6.1 and 6.1.1 reworded the requirements for the composition of the base and removed the word "rubber." "Rubber" was also removed from the label in Fig. 1.
- (5) In 6.1.2 removed the Durometer hardness requirement for the rubber feet.
- (6) In 6.7.1 removed the dimensional requirements for the Ground Glass Plate.
- (7) In 9.1.1.5 added guidance for replacement of rubber feet.
- (8) In 11.1 changed "cup" to "dish" for consistency.
- (9) In 11.3 added instruction that the base shall not be held during testing.
- (10) In 13.2 to 13.5 clarified the instructions to allow two alternative test procedures.
- (11) Section 19 was updated to comply with the D18.91 Special Memorandum on Report Section.

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Standard Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles¹

This standard is issued under the fixed designation D 4718; 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 Department of Defense.

1. Scope

1.1 This practice presents a procedure for calculating the unit weights and water contents of soils containing oversize particles when the data are known for the soil fraction with the oversize particles removed.

1.2 The practice also can be used to calculate the unit weights and water contents of soil fractions when the data are known for the total soil sample containing oversize particles.

1.3 This practice is based on tests performed on soils and soil-rock mixtures in which the portion considered oversize is that fraction of the material retained on the No. 4 sieve. Based on these tests, this practice is applicable to soils and soil-rock mixtures in which up to 40 % of the material is retained on the No. 4 sieve. The practice also is considered valid when the oversize fraction is that portion retained on some other sieve, such as the $\frac{3}{4}$ -in. sieve, but the limiting percentage of oversize particles for which the correction is valid may be lower. However, the practice is considered valid for materials having up to 30 % oversize particles when the oversize fraction is that portion retained on the $\frac{3}{4}$ -in. sieve.

1.4 The factor controlling the maximum permissible percentage of oversize particles is whether interference between the oversize particles affects the unit weight of the finer fraction. For some gradations, this interference may begin to occur at lower percentages of oversize particles, so the limiting percentage must be lower for these materials to avoid inaccuracies in the computed correction. The person or agency using this practice shall determine whether a lower percentage is to be used.

1.5 This practice may be applied to soils with any percentage of oversize particles subject to the limitations given in 1.3 and 1.4. However, the correction may not be of practical significance for soils with only small percentages of oversize particles. The person or agency specifying this practice shall specify a minimum percentage of oversize particles below

which the practice need not be applied. If a minimum percentage is not specified, 5 % shall be used.

1.6 This practice may not be applicable to soil-rock mixtures which degrade under field compaction.

1.7 *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.*

2. Referenced Documents

2.1 ASTM Standards:²

- C 127** Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
- D 698** Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft³ (600 kN-m/m³))
- D 1556** Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method
- D 1557** Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2,700 kN-m/m³))
- D 2167** Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method
- D 2216** Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
- D 2922** Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)³
- D 3017** Test Method for Water Content of Soil and Rock in

¹ This practice 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 Sept. 1, 2007. Published September 2007. Originally approved in 1987. Last previous edition approved in 2001 as D 4718 – 87 (2001).

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 Withdrawn.

Place by Nuclear Methods (Shallow Depth)

D 4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

E 11 Specification for Wire Cloth and Sieves for Testing Purposes

3. Significance and Use

3.1 Compaction tests on soils performed in accordance with Test Methods **D 698**, **D 1557**, and **D 4253** place limitations on the maximum size of particles that may be used in the test. If a soil contains cobbles or gravel, or both, test options may be selected which result in particles retained on a specific sieve being discarded (for example the No. 4 (4.75-mm) or the 3/4-in. (19-mm) or other appropriate size), and the test performed on the finer fraction. The unit weight–water content relations determined by the tests reflect the characteristics of the actual material tested, and not the characteristics of the total soil material from which the test specimen was obtained.

3.2 It is common engineering practice to use laboratory compaction tests for the design, specification, and construction control of soils used in earth construction. If a soil used in construction contains large particles, and only the finer fraction is used for laboratory tests, some method of correcting the laboratory test results to reflect the characteristics of the total soil is needed. This practice provides a mathematical equation for correcting the unit weight and water content of the tested finer fraction of a soil, to determine the unit weight and water content of the total soil.

3.3 Similarly, this practice provides a means for correcting the unit weight and water content of field compacted samples of the total soil, so that values can be compared with those for a laboratory compacted finer fraction.

NOTE 1—When this practice is used for construction control, the using agency should specify whether the maximum unit weight value used for reference is the unit weight including oversize fraction or the unit weight of the finer fraction. Calculated values of percent compaction based on this correction practice will vary depending on which unit weight value is used for reference.

4. Procedure

4.1 *Correction of Unit Weight and Water Content for Total Sample:*

4.1.1 Prepare the sample from which compaction test specimens are to be taken in accordance with provisions of Test Methods **D 698**, **D 1557**, or **D 4253**. Determine the mass of the moist fine fraction of the sample and the mass of the moist oversize (plus No. 4 or plus 3/4-in., or other appropriate size) fraction of the total sample. If Test Methods **D 4253** is used, the correction for water content does not apply. Determine the water content of each of the two fractions in accordance with Method **D 2216**. Calculate the mass of the dry finer fraction and the dry oversize fraction as follows:

$$M_D = M_M / (1 + w) \quad (1)$$

where:

M_D = mass of the dry material (finer or oversize fraction), g.

M_M = mass of the moist material (finer or oversize fraction), g, and
 w = water content of the respective finer or oversize fractions expressed as a decimal.

4.1.2 Calculate the percentage of the finer fraction and of the oversize fraction of the sample by dry weight as follows:

$$P_F = 100 M_{DF} / (M_{DF} + M_{DC}) \quad (2)$$

and

$$P_C = 100 M_{DC} / (M_{DF} + M_{DC}) \quad (3)$$

where:

P_F = percent of finer fraction by weight,
 P_C = percent of oversize fraction by weight,
 M_{DF} = mass of dry finer fraction, and
 M_{DC} = mass of dry oversize fraction.

4.1.3 Determine the bulk specific gravity (G_M) of the oversize fraction as set forth in Test Method **C 127**.

4.1.4 Calculate the corrected water content and corrected dry unit weight of the total material (combined finer and oversize fractions), as follows:

$$C_w = (w_F P_F + w_C P_C) \quad (4)$$

where:

C_w = corrected water content of combined and oversize fractions,
 w_F = water content of finer fraction expressed as a decimal,
 w_C = water content of oversize fraction expressed as a decimal,

and

$$C\delta_D = 100 \delta_F G_M \delta_w / (\delta_F P_C + G_M \delta_w P_F) \quad (5)$$

where:

$C\delta_D$ = corrected unit dry weight of the total material (combined finer and oversize fractions),
 G_M = bulk specific gravity,
 δ_F = dry unit weight of the finer fraction, and
 δ_w = unit weight of water (62.42 lbf/ft³ or 9.802 kN/m³).

4.2 *Correction of Unit Weight and Water Content for Finer Fraction of a Soil Sample:*

4.2.1 When it is desired to compare the unit weight and water content of a field-compacted soil containing oversize particles with the results of laboratory compaction tests on the finer fraction, the following procedure may be used:

4.2.1.1 A sample of the total material is obtained in the field at the desired test location in conjunction with a unit dry weight (δ_D) and water content (w) determination by methods such as Test Methods **D 1556**, **D 2167**, or **D 2922** and **D 3017** combined. Since this practice is usually used for materials containing coarse gravel and cobble size particles, special care should be taken to assure that the volume of material sampled is adequate to accurately represent the material in the field at the test location.

4.2.1.2 Remove the oversize particles (plus No. 4 or 3/4-in., or other appropriate size) from the field sample and determine the percentage of oversize particles in the total sample. If, in the laboratory testing of the materials, the bulk specific gravity

and the water content of the oversize particles have been determined, these values may be used in the calculations. Otherwise, it will be necessary to determine the bulk specific gravity by Test Method **C 127**.

4.2.1.3 Calculate the water content of the finer fraction of the field sample as follows:

$$w_F = (100 w - w_C P_C) / P_F \quad (6)$$

4.2.1.4 Calculate the dry unit weight of the finer fraction of the field sample as follows:

$$\delta_F = \delta_{1j} G_M \delta_w P_F / (100 G_M \delta_w - \delta_{1j} P_C) \quad (7)$$

5. Report

5.1 The report shall contain the following:

5.1.1 The identification of the sample.

5.1.2 The method used in compacting the sample.

5.1.3 The method used to obtain the field sample (as appropriate).

5.1.4 The sieve size used to separate the oversize particles.

5.1.5 The percentage by weight of oversize particles.

5.1.6 The value of bulk specific gravity, G_M , used in the calculations.

5.1.7 For laboratory compacted samples, the dry unit weight and water content of the finer fraction, and the corrected value for the total sample.

5.1.8 For samples obtained in the field, the dry unit weight and water content of the total sample, and the corrected value for the finer fraction.

6. Keywords

6.1 oversize particles; unit weight; water content

APPENDIX

(Nonmandatory Information)

X1. RATIONALE

X1.1 The calculations to correct the unit weight and water content of soil samples containing oversize particles are based on the premise that the percentage of such particles is small enough that they do not interfere with the compaction of the finer fraction during the compaction process. Thus, the finer fraction of the soil will achieve the same unit weight and water content with the oversize particles absent as with them present. The equation used for the calculation of unit weight is based on the work of Ziegler.⁴

X1.2 Tests conducted by the Bureau of Reclamation^{5, 6} and

the Waterways Experiment Station⁷ indicate that the limiting oversize particle (plus No. 4 sieve) content may be as high as 40 %. It is necessary in evaluating such studies to ensure that the gradation of the finer fraction does not change as the oversize particle content changes. The upper limit of oversize particles in this practice has been set at 40 % of the plus No. 4 material and 30 % of the plus ¾-in. material.

X1.3 It is assumed that in a moist, compacted sample of soil containing oversize particles, those oversize particles absorb moisture from the surrounding medium. The maximum water content that the oversize particles can achieve approaches as a limit the percent absorption of the oversize fraction, as measured by Test Method **C 127**. The water content of the oversize fraction also may be measured directly by Method **D 2216**.

⁴ Ziegler, E. J. "Effect of Materials Retained on the No. 4 Sieve on the Compaction Test of Soil." *Proceedings, Highway Research Board*, Vol. 28, 1948, pp 409-414.

⁵ Merriam, J. "Research on Compaction Control Testing for Gravelly Soils." *Earth Research Program Report EM662*, U.S. Bureau of Reclamation, Denver, CO, August 1963.

⁶ Holtz, W. G., and Lowitz, C. A., "Compaction Characteristics of Gravelly Soils." *U.S. Bureau of Reclamation Earth Laboratory Report No. 509*, Denver, CO, September 1957.

⁷ Donaghe, R. T., and Townsend, F. C., "Compaction Characteristics of Earth-Rock Mixtures." Report 2 "Blended Material." Misc. Paper S-73-25, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MI, August 1975.

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Standard Test Method for Water Content and Density of Soil in Place by Time Domain Reflectometry (TDR)¹

This standard is issued under the fixed designation D 6780; 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 may be used to determine the water content of soils and the in-place density of soils using a TDR apparatus.

1.2 This test method applies to soils that have 30 % or less by weight of their particles retained on the 19.0-mm (¾-in.) sieve.

1.3 This test method is suitable for use as a means of acceptance for compacted fill or embankments.

1.4 This test method may not be suitable for organic and highly plastic soils.

1.5 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.5.1 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.

1.6 Two alternative procedures are provided.

1.6.1 *Procedure A* involves two tests in the field, an in-place test and a test in a mold containing material excavated from the in-place test location. The apparent dielectric constant is determined in both tests.

1.6.2 *Procedure B* involves only an in-place test by incorporating a bulk electrical conductivity in addition to the apparent dielectric constant.

1.7 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. For additional information consult ASTM SI 10

1.8 *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 appro-*

prate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 *ASTM Standards:*²

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 698 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures, Using 5.5 lb (2.49 kg) Rammer and 12-in. (305-mm) Drop

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil and Rock Testing

D 6026 Practice for Using Significant Digits in Geotechnical Data

D 6565 Test Method for Determination of Water (Moisture) Content of Soil by the Time Domain Reflectometry Method

E 1 Specification for ASTM Thermometers

SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System

3. Terminology

3.1 *Definitions*—Refer to Terminology D 653 for standard definitions of terms.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apparent dielectric constant, K_{insitu} , K_{mold}* —the squared ratio of the velocity of light in air to the apparent velocity of electromagnetic wave propagation in the soil measured by a TDR apparatus in place and in the cylindrical mold, respectively.

3.2.2 *apparent length, l_a* —on a plot of electromagnetic wave signal versus scaled distance measured by a TDR

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

Current edition approved May 1, 2005. Published June 2005. Originally approved in 2002. Last previous edition approved in 2002 as D 6780 – 02.

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.

apparatus as shown in Fig. 1, it is the horizontal distance between the point on the waveform due to the reflection from the surface of the soil where the probe is inserted into the soil to the point on the waveform due to the reflection from the end of the probe.

3.2.3 *bulk electrical conductivity, EC_b* —electrical conductivity is a measure of how well a material accommodates the transport of electric charge. Its SI derived unit is Siemens per meter (S/m). As an electromagnetic wave propagates along TDR probed buried in soil, the signal energy is attenuated in proportion to the electrical conductivity along the travel path. Determination of bulk electrical conductivity is illustrated in Fig. 1.

3.2.4 *coaxial head, CH^3* —a device that forms a transition from the coaxial cable connected to the TDR apparatus to the Multiple Rod Probe or to a Cylindrical Mold Probe.

3.2.5 *cylindrical mold probe, CMP^3* —a probe formed by a cylindrical metal mold as the outer conductor having a non-metallic end plate, filled with compacted soil, and with an inner conductor consisting of a rod driven into the soil along the axis of the mold.

3.2.6 *multiple rod probe, MRP^3* —a probe formed by driving four rods of equal length into the soil in a pattern where three of the rods define the outer conductor of a “coaxial cable” and one of the rods is the inner conductor.

3.2.7 *probe length, L* —the length of the TDR probe that is below the surface of the soil.

3.2.8 *scaled distance, l* —the product of the velocity of light in air and electromagnetic wave travel time in the soil divided by two.

3.2.9 *TDR internal resistance, R_s* —the internal resistance of the TDR’s pulse generator (generally 50 ohms).

3.2.10 *voltage source, V_s* —the source voltage and equal to twice the step voltage generated by the TDR.

3.2.11 *voltage, long term, V_f* —the long term voltage as illustrated in Fig. 1.

4. Summary of Test Method

4.1 *Procedure A*—The dielectric constant of the soil in-place is determined using a multiple rod probe (MRP), a coaxial head (CH), and TDR apparatus. The soil at the location of the insitu measurement is then excavated and compacted in a mold. By measurement of the mass of the mold and soil and with the mass and volume of the mold known, the wet density of the soil in the mold is determined. A rod driven into the soil along the axis of the mold creates a cylindrical mold probe (CMP). Using the same coaxial head (CH), an adapter ring, and the TDR apparatus the dielectric constant of the soil in the mold is measured. The water content of the soil in the mold is determined using a correlation between the dielectric constant, moisture content and soil density. The correlation requires two constants that are somewhat soil specific. It is assumed that the water content of the soil in place is the same as the water content in the mold. The density of the soil in place is determined from the density of the soil in the mold and the dielectric constants measured in the mold and in place.

4.2 *Procedure B*—The apparent dielectric constant and the bulk electrical conductivity of the soil in-place is determined using a multiple rod probe (MRP), a coaxial head (CH), and TDR apparatus. The water content and density of the soil in-place are determined from the measured apparent dielectric constant, the bulk electrical conductivity and six constants. The six soil constants are soil and in-place pore fluid dependent. The six soil constants are determined in conjunction with laboratory compaction procedures using specified compaction

³ The apparatus is covered by patents. Interested parties are invited to submit information regarding the identification of alternative(s) to this patented item to the ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

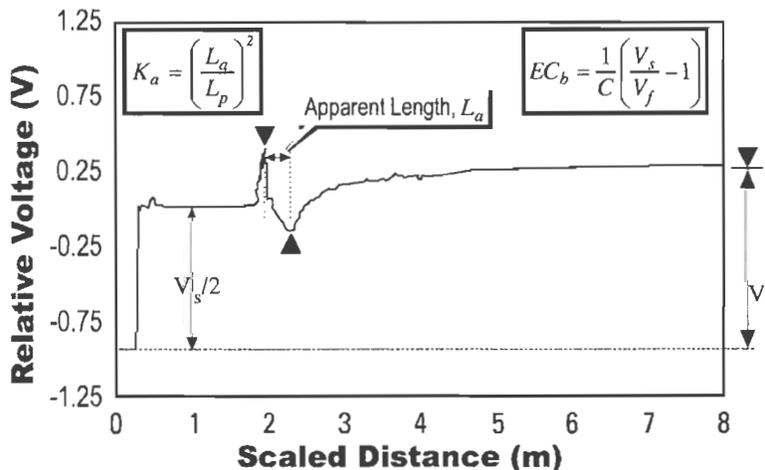


Figure 1. Typical TDR Waveform for Soil Showing Measurements to Obtain Apparent Dielectric Constant, K_a , and Bulk D.C. Electrical Conductivity, EC_b .

FIG. 1 Typical TDR Waveform for Soil Showing Measurements to Obtain Apparent Dielectric Constant, K_a , and Bulk D.C. Electrical Conductivity, EC_b

procedures, for example, Test Method **D 698**, and by taking measurements of the apparent dielectric constant and the bulk electrical conductivity for each compaction point.

5. Significance and Use

5.1 This test method can be used to determine the density and water content of naturally occurring soils and of soils placed during the construction of earth embankments, road fills, and structural backfills.

5.2 Time domain reflectometry (TDR) measures the apparent dielectric constant (Procedure A) and both the apparent dielectric constant and the bulk electrical conductivity (Procedure B) of soil. The apparent dielectric constant is affected significantly by the water content and density of soil, and to a lesser extent by the chemical composition of soil and pore water, and by temperature. The bulk electrical conductivity is affected significantly by the water content, density, and the chemical composition of the in-place pore water, and to a lesser extent the chemical composition of the soil solids. This test method measures the gravimetric water content and makes use of a different relationship between the electrical properties and water content from Test Method **D 6565** which measures the volumetric water content.

5.3 Soil and pore water characteristics are accounted for in Procedure A with two calibration constants and for Procedure B with six calibration constants. The soil constants for Procedure A are determined for a given soil by performing compaction tests in a special mold as described in **Annex A2**. The six soil constants for Procedure B are determined in conjunction with compaction testing in accordance with specified compaction procedures, for example, Test Method **D 698** as described in **Annex A3**. Both Procedures A and B use Test Method **D 2216** to determine the water contents.

5.4 When following Procedure A, the water content is the average value over the length of the cylindrical mold and the density is the average value over the length of the multiple-rod probe embedded in the soil. When following Procedure B, the water content and density is the average values over the length of the multiple-rod embedded in the soil.

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 **D 3740** are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice **D 3740** does not in itself assure reliable results. Reliable results depend on many factors; Practice **D 3740** provides a means of evaluating some of those factors.

6. Interferences

6.1 Quality and accuracy of the test results significantly depend on soil having contact with the inner conductor of the probes. To assist this, when installing the rods of the MRP, the rod that forms the inner conductor must be the last rod installed. If in the installation process, the rod hits upon a large particle that causes it to drift from vertical alignment, all rods should be removed and the test conducted in a new location at least 0.2-m (8-in.) from the previous test location.

6.2 The quality of the signal read by the TDR apparatus depends on having clean contacts between the CH and the

MRP and the CMP. The contacting surfaces should be wiped with a clean cloth prior to placing the CH on the MRP and the CMP. Once placed, observe the signal on the TDR apparatus. If the characteristic signal is not present, the CH may have to be slightly rotated about its axis to make better contact.

6.3 This test method only applies to non-frozen soil. The apparent dielectric constant is slightly temperature dependent for soils and depends on soil type. For soil temperatures between 15°C and 25°C (59°F and 77°F), no temperature corrections are needed for most soils. A simple temperature adjustment for water content determination is part of the test method.

7. Apparatus

7.1 *TDR Apparatus*, a Metallic Time Domain Reflectometer with a scaled length resolution of at least 2.4-mm (0.10-in.) (this corresponds approximately to a time between data points less than or equal to sixteen picoseconds (16×10^{-12} s)). A portable computer with a communication port to the TDR is suggested for controlling the apparatus, acquiring and saving the data, and for making the calculations as the test proceeds.

7.2 Multiple Rod Probe (MRP)³ with Coaxial Head (CH)³

7.2.1 The MRP consists of four common steel spikes, typically 250-mm (10-in.) in length and uniform diameters of 9.5-mm ($\frac{3}{8}$ -in.). (Other length spikes, but with the same diameter, may be used but in no case should they have lengths less than 150-mm (6-in.). For lengths longer than 250-mm (10-in.), drift in the alignment of the spikes and loss of reflected signal from the end of the MRP may occur.)

7.2.2 A MRP guide template (see **Fig. 2**) is used to guide the spikes as they are driven into the soil. The template must allow for its removal after the spikes are driven and before a TDR measurement is made. (The radius from the central spike to the outer spikes must be within the range of 5 to 7.5 times the diameter of the central spike.)

7.2.3 The Coaxial Head (CH)³ (see **Fig. 3**) forms a transition from the coaxial cable coming from the TDR apparatus to the MRP.

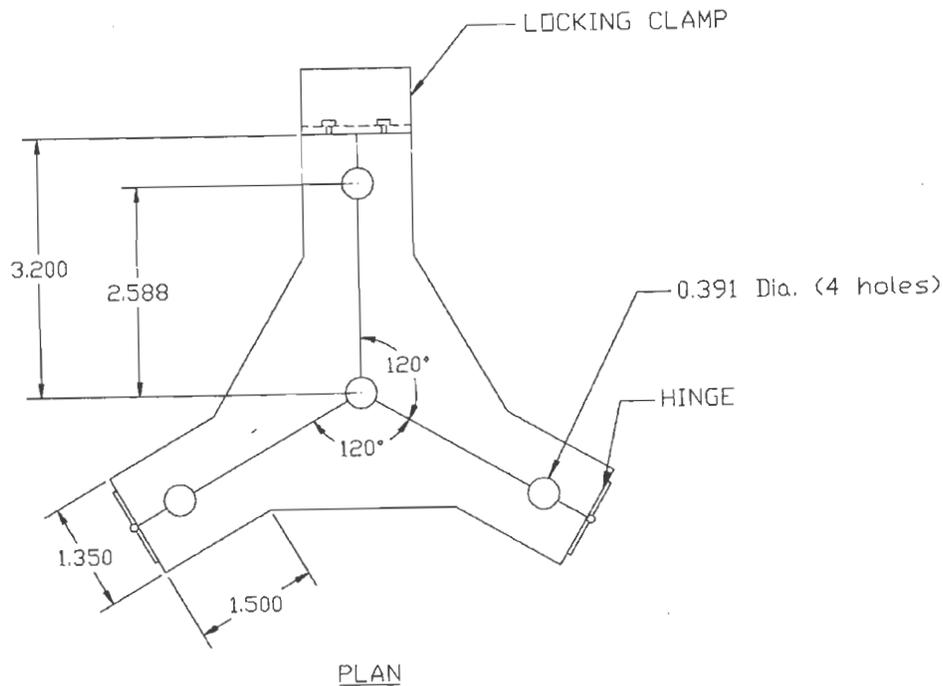
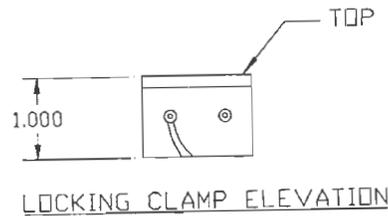
7.3 *Cylindrical Mold Probe (CMP)³*, the CMP consists of a cylindrical mold, a guide template, a central rod, and a ring collar. Details for these items are shown in **Fig. 4**.

7.3.1 The central rod is a stainless steel rod with a diameter of 8.0-mm ($\frac{5}{16}$ -in.) and a length of 264-mm (10.4-in.) in length.

7.4 *Balances or Scales*, meeting Specification GP10 of Specification **D 4753** to determine the mass of the soil and the cylindrical mold. A battery-operated balance or scale having a minimum capacity of 10 kg is suitable when an apparatus with the dimension given in **Fig. 3** is used.

7.5 *Driving Tools*, a brass-headed hammer for driving spikes for the MRP and the central rod into the cylindrical mold. A resin-headed hammer also may be used for driving the central rod into the cylindrical mold. (Use of these hammers prevents peening of the driving end of the steel rods from repeated use.)

7.6 *Tamping Rod*, an aluminum rod with flat ends, a diameter of 37-mm (1.5-in.), and a length of 380-mm (15-in.). Other tamping devices which provide a relatively uniformly compacted specimen also may be used.



Note: All dimensions are in inches.
See Table 1 for tolerances and metric equivalents.

FIG. 2 MRP Guide Template

TABLE 1 Metric Equivalents for Dimensions in Fig. 2

(in.)	Tol. (in.)	(mm)	Tol. (mm)
0.391	± 0.002	10.00	± 0.05
1.000	± 0.005	25.00	± 0.15
1.350	± 0.015	34.30	± 0.40
1.500	± 0.015	38.00	± 0.40
2.588	± 0.005	65.70	± 0.13
3.200	± 0.020	80.00	± 0.50

7.7 *Thermometer*, 0 to 50°C range, 0.5°C graduations, conforming to requirements of Specification E 1.

7.8 *Vernier or Dial Caliper*, having a measuring range of at least 0 to 250-mm (0 to 10-in.) and readable to at least 0.02-mm (0.001-in.).

7.9 *Miscellaneous Tools*, a battery-powered hand drill with a spare battery and charger and with a 25-mm (1-in.) diameter auger bit (alternatively, a small pick will work), straight edge for smoothing the surface of the soil for the in-place test and for smoothing the surface of the soil in the cylindrical mold, pliers for removing the spikes and central rod, small scoop or

spoon for removal of the loosened soil and for placement in the cylindrical mold, and a brush for removing excess soil from around the base of the cylindrical mold prior to determining its mass.

8. Preparation of Apparatus

8.1 Charge or replace, as appropriate batteries in the TDR apparatus, the hand drill, and the balance.

9. Calibration and Standardization

9.1 Determine the average length of the spikes that will penetrate into the soil surface in the in-place test, L_{insitu} , m (in.), by inserting each spike into the MRP guide template and measuring the length that each spike protrudes from the template when fully inserted. All measured lengths should be equal within 0.5-mm (0.020-in.).

9.2 Determine the volume of the cylindrical mold, V_{mold} , m³ (in.³), in accordance with Annex A1.

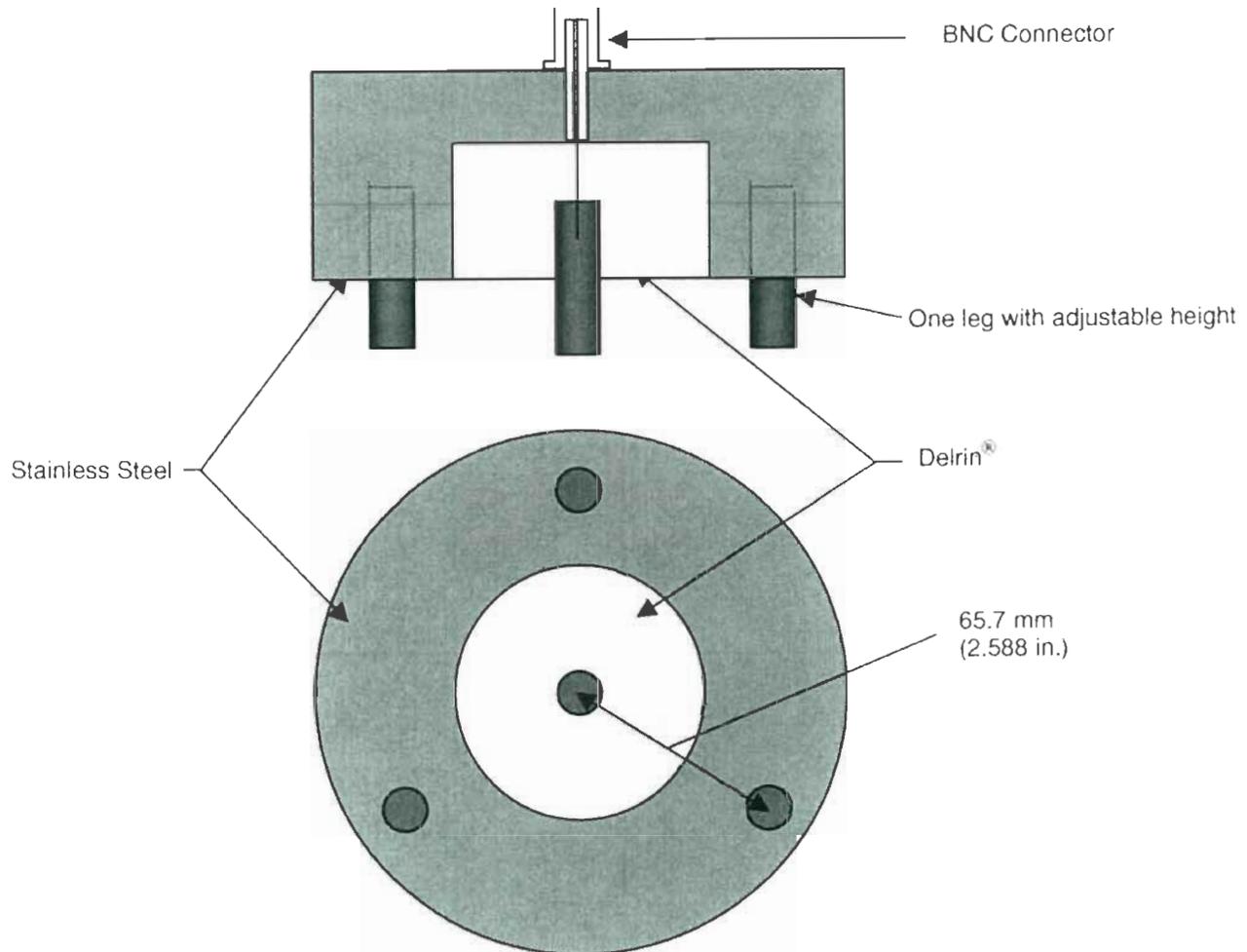


FIG. 3 Coaxial Head (CH)

9.3 Determine the mass of the empty and clean cylindrical mold including the base, but without the ring collar, M_2 , kg (lbf), by placing on a calibrated balance.

9.4 Determine the length of the central rod for insertion into the compaction mold, $L_{central\ rod}$, m (in.).

9.5 Calibration Constants:

9.5.1 Procedure A—Determine the values of a and b for the soils to be tested in the field by procedures in Annex A2.

9.5.2 Procedure B—Determine the values a , b , c , d , f , and g for the soils to be tested in the field by procedures in Annex A3.

10. Procedure

10.1 The following is applicable for Procedures A and B:

10.1.1 Prepare the surface at the test location so that it is plane and level.

10.1.2 Seat the MRP guide template on the plane surface.

10.1.3 Drive the outer spikes through the guide holes so that the bottom surfaces of the spike heads touch the template. Drive the central spike last. (See Fig. 5.)

10.1.4 Remove the template as shown in Fig. 6. Check that all spikes are driven properly without any air gap around the spikes where they penetrate the soil.

10.1.5 Connect the coaxial cable to the CH and the TDR device. Turn on the device.

10.1.6 Wipe the top surfaces of the spike heads and ends of the studs on the CH and place the CH on the spikes, centering the CH on the heads of all the spikes as shown in Fig. 7.

10.1.7 Determine and record the apparent length, l_{insitu} , m (in.) with the TDR equipment.⁴

10.1.8 When following Procedure B, determine and record the source voltage, V_s , and the long term voltage, V_p , from the TDR waveform⁵ as illustrated in Fig. 1.

10.1.9 Remove the spikes.

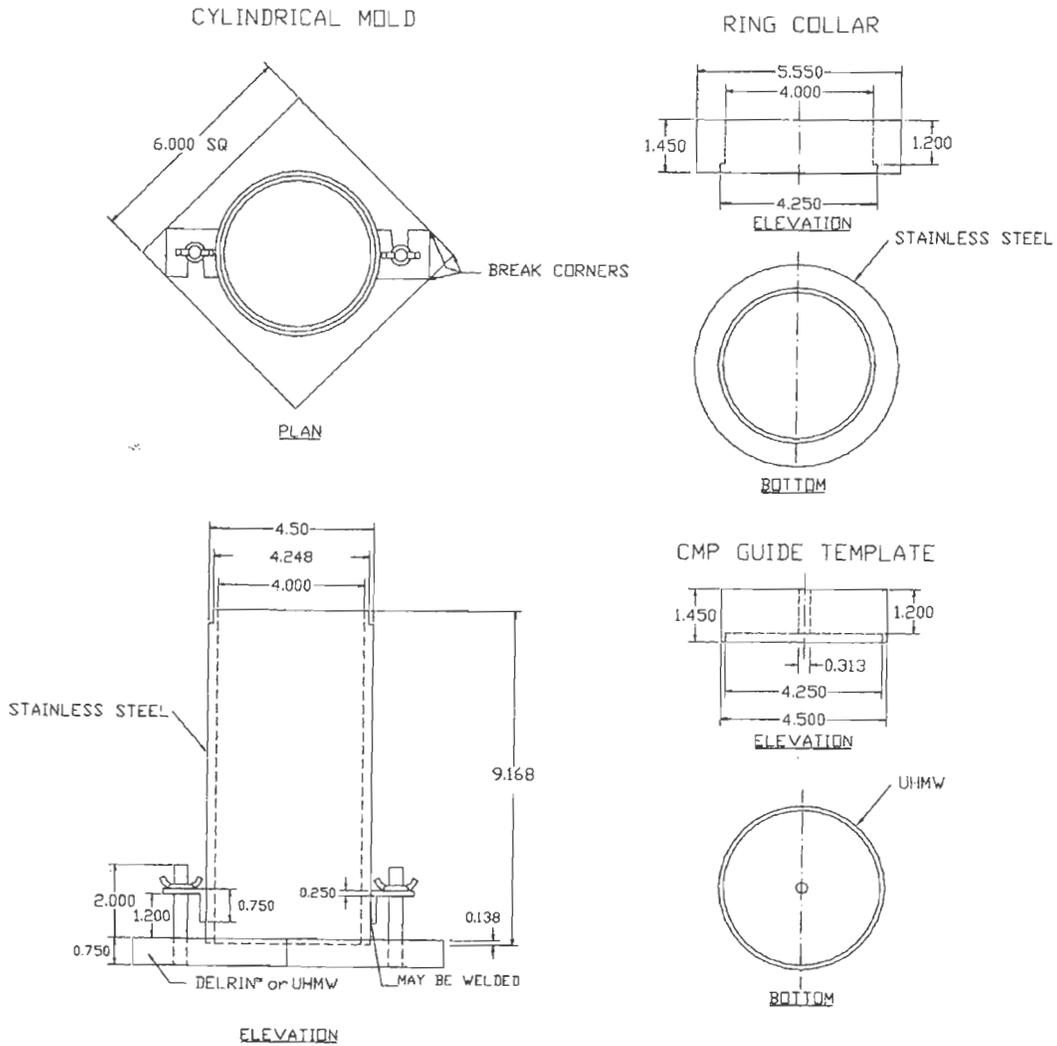
10.2 For Procedure A, do the following:

10.2.1 Measure the apparent length in the cylindrical mold.

10.2.2 Assemble and secure the cylindrical mold to the base plate and attach the ring collar.

⁴ Automated procedures for doing this are usually contained in a program on the portable computer. Algorithms for various procedures are discussed by Baker and Allmaras (1990), Feng et al. (1998), Heimovaara and Bouten (1990), and Wraith, J. M., and Or, D., (1999).

⁵ Background for making these measurements are provided by Yu and Drnevich (2004).



Note: All dimensions are in inches. See Table 2 for metric equivalents and tolerances.

FIG. 4 Cylindrical Mold, Ring Collar, and Guide Template

TABLE 2 Metric Equivalents for Dimensions in Fig. 4

(in.)	Tol. (in.)	(mm)	Tol. (mm)
0.138	± 0.005	3.50	± 0.13
0.250	± 0.005	6.30	± 0.13
0.313	+ 0.002, - 0.000	7.88	+ 0.05, - 0.00
0.750	± 0.010	18.90	± 0.25
1.000	± 0.010	25.00	± 0.25
1.200	± 0.002	30.24	± 0.05
1.450	± 0.005	36.54	± 0.13
2.000	± 0.020	50.00	± 0.50
4.000	± 0.016	100.00	± 0.40
4.248	+ 0.000, - 0.003	107.90	+ 0.00, - 0.08
4.250	+ 0.003, - 0.000	107.95	+ 0.08, - 0.00
4.500	± 0.020	115.00	± 0.50
5.500	± 0.020	140.00	± 0.50
6.000	± 0.020	150.00	± 0.50
9.168	± 0.020	231.00	± 0.50



FIG. 5 Driving Spikes Through Template

10.2.3 With the use of the power drill or other suitable digging implement, excavate the soil from the between the

holes left by the outer rods of the MRP and to a depth corresponding to the rod penetration and place the soil into the



FIG. 6 Removal of Template After Driving Spikes

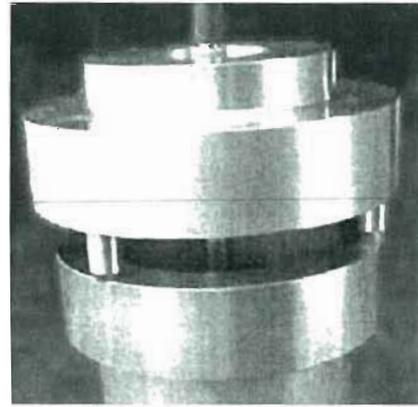


FIG. 8 Coaxial Head on Ring Collar



FIG. 7 Placement of Coaxial Head on Spikes

cylindrical mold in 6 uniform lifts applying 10 blows per lift using the aluminum-tamping rod or other suitable tamping device. Soil should be taken uniformly over the entire depth of in-place measurement and placed directly and quickly into the cylindrical mold to minimize moisture loss. Remove the ring collar and strike the surface level with the straight edge after compaction. Remove any spilled soil from around the exterior of the base plate with the brush.

10.2.4 Make sure the balance is leveled, measure and record the mass of the soil-filled cylindrical mold including the base plate, M_1 , kg (lb).

10.2.5 Clean the shoulder at the top of the mold and mount the cylindrical mold guide template on to the cylindrical mold.

10.2.6 Using the brass-headed or resin-headed hammer, drive the central rod through the guide hole into the soil until the top of rod is flush with the template.

10.2.7 Remove the guide template from the cylindrical mold.

10.2.8 Determine and record the length of the central rod above the soil surface, $L_{rod\ exposed}$, m (in.).

10.2.9 Clean the shoulder at the top of the mold and place the ring collar on the cylindrical mold. Rotate the ring back and forth on the mold to facilitate good electrical contact.

10.2.10 Wipe the top surface of the ring collar, the central rod and the ends of studs of the CH and then place the CH on the ring collar, centering the central stud on the central rod as shown in Fig. 8.

10.2.11 Determine and record the apparent length, l_{mold} , m, with the TDR device.⁴

10.2.12 Remove the central rod from the mold.

10.2.13 If the soil is a cohesive soil and if the temperature of the soil is estimated to be outside the range of 15 to 25°C (59 to 77°F), insert a metal thermometer into the hole created by the central rod, wait until the temperature stabilizes, and record the temperature, °C.

10.2.14 Remove the soil from the cylindrical mold.

11. Calculation or Interpretation of Results

11.1 Calculate the apparent dielectric constant of the soil in place as follows:

$$K_{insitu} = \left(\frac{(l_a)_{insitu}}{L_{insitu}} \right)^2 \quad (1)$$

where:

K_{insitu} = apparent dielectric constant of the soil in place,
 $(l_a)_{insitu}$ = measured apparent length insitu, m (in.), and
 L_{insitu} = length of the spikes inserted into the soil, m (in.).

11.2 Procedure A:

11.2.1 Calculate the dielectric constant of the soil in the mold as follows:

$$K_{mold} = \left(\frac{(l_a)_{mold}}{L_{mold}} \right)^2 \quad (2)$$

where:

K_{mold} = apparent dielectric constant of soil in the mold,
 $(l_a)_{mold}$ = measured apparent length in the mold, m (in.), and
 L_{mold} = length of the rod inserted into the soil in the mold, m (in.)
 = $L_{central\ rod} - L_{rod\ exposed}$

11.2.2 Calculate the wet density of the soil in mold as follows:

$$\rho_{t,mold} = \frac{M_1 - M_2}{V_{mold}} \quad (3)$$

where:

$\rho_{t,mold}$ = wet density of the soil in the mold, kg/m³ (lb/ft³),

M_1 = mass of the soil-filled mold, and base plate, kg (lbf),
 M_2 = mass of the empty mold and base plate, kg (lbf),
 V_{mold} = volume of the mold, m³ (ft³).

11.2.3 Calculate the Apparent Dielectric Constant of the soil in the mold at 20°C from:

$$K_{mold,20^\circ C} = K_{mold,T^\circ C} \times TCF \quad (4)$$

where:

TCF = Temperature Correction Factor.
 $= 0.97 + 0.0015 T_{mold,T^\circ C}$ for cohesionless soils, 4°C ≤ $T_{mold,T^\circ C}$ ≤ 40°C
 $= 1.10 - 0.005 T_{mold,T^\circ C}$ for cohesive soils, 4°C ≤ $T_{mold,T^\circ C}$ ≤ 40°C.

11.2.4 Calculate the water content of the soil in the mold and in place as follows:

$$w_{insitu} = w_{mold} = \frac{\sqrt{K_{mold,20^\circ C}} - \frac{a\rho_{L,mold}}{\rho_w}}{b\rho_{L,mold} - \sqrt{K_{mold,20^\circ C}}} \times 100 \quad (5)$$

where:

w_{mold} = water content of the soil in the mold, %,
 w_{insitu} = water content of the soil in place, %,
 ρ_w = density of water = 1000 kg/m³ (62.4 lbf/ft³),
 a = calibration constant, (see [Annex A2](#)), and
 b = calibration constant, (see [Annex A2](#)).

11.2.5 Calculate the in place dry density of the soil as follows:

$$\rho_{d,insitu} = \frac{\sqrt{K_{insitu}}}{\sqrt{K_{mold}}} \times \frac{\rho_{L,mold}}{1 + \frac{w_{mold}}{100}} \quad (6)$$

where:

$\rho_{d,insitu}$ = dry density of the soil in place, kg/m³ (lbf/ft³).

11.3 Procedure B:

11.3.1 Calculate the Bulk Electrical Conductivity using voltages from the insitu TDR waveform obtained in [11.1](#) from:

$$EC_b = \frac{1}{C} \left(\frac{V_s}{V_f} - 1 \right) \quad (7)$$

where:

EC_b = bulk electrical conductivity, S/m,
 V_s = source voltage and equal to twice the step voltage (see [Fig. 1](#)),
 V_f = long term voltage level (see [Fig. 1](#)), and
 C = constant related to probe configuration, and for a coaxial probe, calculated from:

$$C = \left(\frac{2\pi L_{insitu} R_s}{\ln\left(\frac{d_o}{d_i}\right)} \right) \quad (8)$$

where:

L_{insitu} = length of the TDR probe that is below the surface of the soil,
 R_s = internal resistance of the TDR's pulse generator,
 d_o = outer conductor diameter, and
 d_i = inner conductor diameter.

11.3.2 Correct the Apparent Dielectric Constant calculated in [11.1](#) at 20°C from:

$$K_{insitu,20^\circ C} = K_{insitu,T^\circ C} \times TCF \quad (9)$$

where:

TCF = Temperature Correction Factor
 $= 0.97 + 0.0015 \times T_{insitu,T^\circ C}$ for cohesionless soils, 4°C ≤ $T_{insitu,T^\circ C}$ ≤ 40°C
 $= 1.10 - 0.005 \times T_{insitu,T^\circ C}$ for cohesive soils, 4°C ≤ $T_{insitu,T^\circ C}$ ≤ 40°C.

11.3.3 Calculate the water content of the soil in place as follows:

$$w_{insitu} = \frac{c\sqrt{K_{adj}} - a\sqrt{EC_{b,adj}}}{b\sqrt{EC_{b,adj}} - d\sqrt{K_{adj}}} \quad (10)$$

where:

w_{insitu} = water content of the soil in place, %
 $= K_{adj} = K_{insitu,20^\circ C}$ (11)
 $= EC_{b,adj} = (f + g\sqrt{K_{adj}})^2$ (12)
 $a, b, c, d, f,$ and g = calibration constants, (see [Annex A3](#)).

11.3.4 Calculate the in place dry density of the soil as follows:

$$\rho_{d,insitu} = \frac{d\sqrt{K_{adj}} - b\sqrt{EC_{b,adj}}}{ad - cb} \quad (13)$$

where:

$\rho_{d,insitu}$ = dry density of the soil in place, kg/m³ (lbf/ft³).

12. Report

12.1 The report shall include the following:

- 12.1.1 Procedure used (A or B).
- 12.1.2 Test site identification.
- 12.1.3 Date and time of test.
- 12.1.4 Name of the operator(s).
- 12.1.5 Visual description of the material tested.
- 12.1.6 Make, model and serial number of the TDR apparatus.
- 12.1.7 Average length of the spikes that penetrated into the soil surface in the in-place test, L_{insitu} , m (in.).
- 12.2 The report shall include the following for Procedure A:
 - 12.2.1 Volume of the cylindrical mold, V_{mold} , m³ (ft³).
 - 12.2.2 Length of the central rod, $L_{central\ rod}$, m (in.), the length of the central rod exposed, $L_{rod\ exposed}$, m (in.), and inserted length of the central rod in the mold, L_{mold} , m (in.).
 - 12.2.3 Temperature of the soil in the mold, $T_{mold, T^\circ C}$.
 - 12.2.4 Values of apparent dielectric constant for the in-place test, K_{insitu} , and the test in the mold, K_{mold} .
 - 12.2.5 Water content in percent, w , from Eq 5.
 - 12.2.6 Dry density of the soil in place, $\rho_{d,insitu}$, kg/m³ (lbf/ft³) from Eq 6.
 - 12.2.7 Calibration constants a and b .
 - 12.2.8 Other comments as appropriate.
- 12.3 The report shall include the following for Procedure B:
 - 12.3.1 Temperature of the soil in place, $T_{insitu, T^\circ C}$.
 - 12.3.2 Value of the apparent dielectric constant for the in place test, K_{insitu} .
 - 12.3.3 Value of the bulk electrical conductivity, $EC_{b,insitu}$.
 - 12.3.4 Water content in percent, w , from Eq 10.
 - 12.3.5 Dry density of the soil in place, $\rho_{d,insitu}$ from Eq 13.
 - 12.3.6 Calibration constants $a, b, c, d, f,$ and g .
 - 12.3.7 Other comments as appropriate.

13. Precision and Bias

13.1 *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. The Subcommittee (D18.08) is seeking any data from the users of this test method that might be used to make a limited statement on precision.

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

NOTE 2—Guidance is available in Ref 7 for determining test variability for a given soil from laboratory tests simulating field tests.

14. Keywords

14.1 compaction test; construction control; density; dielectric constant; electrical permittivity; electromagnetic waves; field control; field tests; inspection; moisture content; quality control; soil compaction; soil density; time domain reflectometry; water content

ANNEXES

(Mandatory Information)

A1. VOLUME OF CYLINDRICAL MOLD

A1.1 Scope

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

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

A1.2 Apparatus

A1.2.1 In addition to the apparatus listed in Section 7 the following items are required:

A1.2.1.1 *Vernier or Dial Caliper*, having a measuring range of at least 0 to 250-mm (0 to 10-in.) and readable to at least 0.02-mm (0.001-in.).

A1.2.1.2 *Inside Micrometer*, having a measuring range of at least 100 to 150-mm (4 to 5-in.) and readable to at least 0.02-mm (0.001-in.).

A1.2.1.3 *Plastic or Glass Plates*, two plastic or glass plates approximately 200 by 200 by 6-mm thick (8 by 8 by ¼-in. thick).

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

A1.2.1.5 *Stopcock Grease*, or similar sealant.

A1.2.1.6 *Miscellaneous Equipment*, bulb syringe, towels, etc.

A1.3 Precautions

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

A1.4 Procedure

A1.4.1 Water-Filling Method:

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

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

single plastic or glass plate to be used on top of the mold to the nearest 1-g (0.01-lbm) and record.

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

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

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

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

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

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

A1.4.1.9 Calculate the volume of water by dividing the mass of water by the density of water and record to the nearest 1 cm³ (0.0001 ft³).

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

A1.4.2 Linear Measurement Method:

A1.4.2.1 Using either the vernier caliper or the inside micrometer, measure the diameter of the mold 6 times at the top of the mold and 6 times at the bottom of the mold, spacing

TABLE A1.1 Density of Water^A

Temperature, °C (°F)	Density of Water, g/ml
18 (64.4)	0.99862
19 (66.2)	0.99843
20 (68.0)	0.99823
21 (69.8)	0.99802
22 (71.6)	0.99779
23 (73.4)	0.99756
24 (75.2)	0.99733
25 (77.0)	0.99707
26 (78.8)	0.99681

^A Values other than shown may be obtained by referring to the Handbook of

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

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

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

A1.4.2.4 Calculate the volume of the mold and record to the nearest 1 cm³ (0.0001 ft³) as follows:

$$V = \frac{\pi(d_t + d_b)^2 h}{16} \times \left(\frac{1 \text{ ft}^3}{1728 \text{ in.}^3} \right) \text{ (inch-pound system)} \quad (\text{A1.1})$$

$$V = \frac{\pi(d_t + d_b)^2 h}{16} \times \left(\frac{1 \text{ m}^3}{10^9 \text{ mm}^3} \right) \text{ (SI system)} \quad (\text{A1.2})$$

where:

V = volume of mold, m³ (ft³),

h = average height, mm (in.),
 d_t = average top diameter, mm (in.), and
 d_b = average bottom diameter, mm (in.).

A1.5 Comparison of Results

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

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

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

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

A1.5.5 Use the volume of the mold determined using the water-filling method as the assigned volume value for calculating the wet density (see 11.3).

A2. DETERMINATION OF PARAMETERS a AND b

A2.1 Scope

A2.1.1 This annex describes the procedure for determining the soil specific parameters a and b for use in Eq 5 of Section 11.

A2.1.2 The determination requires that five tests at different water contents be performed using the cylindrical mold probe.

A2.2 Apparatus

A2.2.1 See items 7.1, 7.2.3, 7.5, and 7.8.

A2.2.2 *Guide Template*, similar to that shown on Fig. 4, but modified to conform to user's 4-in. compaction mold.

A2.2.3 *Ring Collar*, similar to that shown on Fig. 4, but modified to conform to user's 4-in. compaction mold.

A2.2.4 *Mold, 4-in.*—See 6.1 of Test Method D 698.

NOTE: A2.1—Molds from most manufacturers are made from mild steel and zinc plated to resist rust. With age and corrosion these plated steel molds may interfere with the TDR's electrical signal. The user may wish to consider using mold bodies constructed of series 303 stainless steel.

A2.2.5 *Non-conductive Base Plate*, a non-conductive base plate made of UHMW or Delrin[®] similar to that shown on Fig. 4, but modified to conform to user's 4-in. compaction mold.

A2.2.6 *Central Rod*, a stainless steel central rod with a diameter of 8-mm (⁵/₁₆-in.) and a length of 147-mm (5.791-in.).

A2.2.7 See 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, and 6.8 of Test Method D 698.

A2.3 Precautions

A2.3.1 Perform this method in an area where the ambient temperatures and the temperature of the soil are within the range of 15 to 25°C (59 to 77°F).

A2.4 Procedure

A2.4.1 Obtain a representative sample of soil from the site where in-place testing has been conducted or from the borrow

area planned as a source of material. The sample should be of sufficient mass for at least five compaction specimens, typically about 20-kg (44-lb). More material may be required if ancillary testing is planned such as particle size analysis.

A2.4.2 Air-dry the soil sample.

A2.4.3 Thoroughly break up the soil clumps in such a manner as to avoid breaking individual particles. Pass the material through a No. 4 (4.75-mm) sieve.

A2.4.4 Prepare five specimens having water contents such that they bracket the estimated field water content and vary by about 2 %. Preparation procedure should be as specified in section 10.2 or 10.3 of Test Methods D 698.

A2.4.5 Determine the volume of the cylindrical mold in accordance with Annex A1.

A2.4.6 Determine and record the mass of the cylindrical mold and base plate, and the length of the central rod.

A2.4.7 Assemble and secure the cylindrical mold and ring collar to the base plate.

A2.4.8 *Compaction*—After curing, if required, each specimen shall be compacted in accordance 10.4.1 through 10.4.7 of Test Method D 698.

A2.4.9 Remove the ring collar and strike the surface level with the straight edge after compaction. Remove any soil from around the exterior of the base plate with the brush.

A2.4.10 Do procedures 10.2.3-10.2.14.

A2.4.11 Remove the soil from the cylindrical mold. Obtain a portion of the sample for water content determination by slicing the compacted specimen axially through the center and removing at least 0.500 kg (1 lb) of soil from the cut faces. Obtain the water content in accordance with Test Method D 2216.

A2.4.12 Repeat A2.4.6 to A2.4.9 for each soil specimen.

A2.5 Calculation

A2.5.1 For each of the soil specimens, calculate the dielectric constant of soil in the cylindrical mold (K_{mold}) using Eq 2.

A2.5.2 Calculate water content, $w_{oven\ dry}$, in accordance with Test Method **D 2216**.

A2.5.3 Calculate the wet density of the soil in the cylindrical mold using Eq 3.

A2.5.4 Calculate the dry density of the soil in the cylindrical mold as follows:

$$\rho_d = \frac{\rho_t}{1 + \frac{w_{oven\ dry}}{100}} \quad (A2.1)$$

where:

ρ_d = dry density of the soil in the cylindrical mold, kg/m^3 (lb/ft^3),

ρ_t = wet density of the soil in the cylindrical mold, kg/m^3 (lb/ft^3), and

$w_{oven\ dry}$ = oven dry water content from step **A2.5.2**, %.

A2.5.5 Plot for determining calibration coefficients a and b :

$$\text{Plot } \sqrt{K_{mold}} \frac{\rho_w}{\rho_d} \text{ vs. } w_{oven\ dry} \quad (A2.2)$$

where:

K_{mold} = dielectric constant of soil in the cylindrical mold,

ρ_d = dry density of the soil in the cylindrical mold, kg/m^3 (lb/ft^3), from Eq A2.1,

ρ_w = density of water = 1000 kg/m^3 ($62.4 \text{ lb}/\text{ft}^3$), and

$w_{oven\ dry}$ = oven dry water content, %, from step **A2.4.2**.

A2.5.6 Determine calibration coefficients a and b from plot in **A2.5.5** where:

a = zero intercept of the best-fit straight line, and

b = slope of the best-fit straight line.

NOTE: A2.2—Values of a typically are between 0.7 and 1.8 and values of b are typically between 7.5 and 11 for commonly encountered natural soils.

A3. DETERMINATION OF PARAMETERS a , b , c , d , f , AND g

A3.1 Scope

A3.1.1 This annex describes the procedure for determining the soil specific parameters a , b , c , d , f , and g for use in Eq **10-13** of Section **11**.

A3.1.2 The determination requires that five tests at different water content be performed using a 4-in. diameter mold similar that described in Test Method **D 698**. Procedure A or B.

A3.2 Apparatus

A3.2.1 See items **7.1**, **7.2.3**, **7.5**, and **7.8**.

A3.2.2 *Guide Template*, similar to that shown on **Fig. 4**, but modified to conform to user's 4-in. compaction mold.

A3.2.3 *Ring Collar*, similar to that shown on **Fig. 4**, but modified to conform to user's 4-in. compaction mold.

A3.2.4 *Mold, 4-in.*—See 6.1 of Test Method **D 698**.

NOTE: A3.1—Molds from most manufacturers are made from mild steel and zinc plated to resist rust. With age and corrosion these plated steel molds may interfere with the TDR's electrical signal. The user may wish to consider using mold bodies constructed of series 303 stainless steel.

A3.2.5 *Non-conductive Base Plate*, a non-conductive base plate made of UHMW or Delrin[®] similar to that shown on **Fig. 4**, but modified to conform to user's 4-in. compaction mold.

A3.2.6 *Central Rod*, a stainless steel central rod with a diameter of 8-mm ($\frac{5}{16}$ -in.) and a length of 147-mm (5.791-in.).

A3.2.7 See 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, and 6.8 Test Method **D 698**.

A3.3 Precautions

A3.3.1 Perform this method in an area where the ambient temperatures and the temperature of the test soil are within the range of 15 to 25°C (59 to 77°F).

A3.4 Procedure

A3.4.1 Obtain a representative sample of soil from the site where in-place testing has been conducted or from the borrow

area planned as a source of material. The sample should be of sufficient mass for at least five compaction specimens, typically about 20-kg (44-lb). More material may be required if ancillary testing is planned such as particle size analysis.

A3.4.2 Air-dry the soil sample.

A3.4.3 Thoroughly break up the soil clumps in such a manner as to avoid breaking individual particles. Pass the material through a No. 4 (4.75-mm) sieve.

A3.4.4 Prepare five specimens having water contents such that they bracket the estimated field water content and the optimum water content. Incrementally increase the water content from driest compaction point by about 2%. Preparation procedures should be as specified in section 10.2 or 10.3 of Test Method **D 698**.

A3.4.5 Determine the volume of the 4-in. cylindrical mold in accordance with **Annex A1**.

A3.4.6 Determine and record the mass of the cylindrical mold and base plate, and the length of the central rod.

A3.4.7 Assemble and secure the cylindrical mold and collar to the base plate.

A3.4.8 *Compaction*—After curing, if required, each specimen shall be compacted in accordance 10.4.1 through 10.4.7 of Test Method **D 698**.

A3.4.9 Determine and record the mass of the specimen and mold to the nearest gram. When the base plate is left attached, determine and record the mass of the specimen, mold and base plate to the nearest gram.

A3.4.10 Do procedure **10.2.3-10.2.14**.

A3.4.11 Remove the soil from the cylindrical mold. Obtain a portion of the sample for water content determination by slicing the compacted specimen axially through the center and removing at least 0.5 kg (1 lb) of soil from the cut faces. Obtain the water content in accordance with Test Method **D 2216**.

A3.4.12 Repeat **A3.4.6** to **A3.4.11** for each soil specimen.

A3.5 Calculations

A3.5.1 For each of the soil specimens, calculate the dielectric constant of soil in the cylindrical mold (K_{mold}) using Eq 2 and the bulk electrical conductivity of soil in the cylindrical mold ($EC_{b,mold}$) using Eq 7 and Eq 8.

A3.5.2 Do calculations [A2.5.2-A2.5.6](#).

A3.5.3 Plot for obtaining calibration coefficients c and d :

$$\text{Plot } \sqrt{EC_{b,mold}} \frac{\rho_w}{\rho_d} \text{ vs. } w_{oven-dry} \quad (\text{A3.1})$$

where:

$EC_{b,mold}$ = bulk electrical conductivity of soil in the cylindrical mold, s/m.

A3.5.4 Determine calibration coefficients c and d from plot [A3.5.3](#) where:

c = zero intercept of the best-fit straight line, and
 d = slope of the best-fit straight line.

A3.5.5 Calculate the calibration coefficients f and g as follows:

$$\text{Plot } \sqrt{EC_{b,mold}} \text{ vs. } \sqrt{K_{a,mold}} \quad (\text{A3.2})$$

A3.5.6 Determine calibration coefficients f and g from plot in [A3.5.5](#) where:

f = zero intercept of the best-fit straight line, and
 g = slope of the best-fit straight line.

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SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D 6780 – 02) that may impact the use of this standard.

- (1) The field testing procedure and test apparatus for Procedure B is similar to Procedure A, but omits the steps of excavating the soil, compacting it in a mold, and running a second TDR test on the soil in the mold.
- (2) [Annex A3](#) has been modified to explicitly allow the use of the 4.0-in Standard Compaction mold and hammer in determining calibration factors a and b .

- (3) Reporting requirements have been changed to provide information on the procedure used ([12.1.1](#)) and measured items associated with Procedure B (all items in [12.3](#)).
- (4) [Annex A3](#) has been added for guidance in determining calibration constants a , b , c , d , f , and g that are associated with Procedure B.

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Standard Test Method for In-Place Density and Water Content of Soil and Soil- Aggregate by Nuclear Methods (Shallow Depth)¹

This standard is issued under the fixed designation D6938; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

1. Scope*

1.1 This test method describes the procedures for measuring in-place density and moisture of soil and soil-aggregate by use of nuclear equipment. The density of the material may be measured by direct transmission, backscatter, or backscatter/air-gap ratio methods. Measurements for water (moisture) content are taken at the surface in backscatter mode regardless of the mode being used for density. It is the intent of this subcommittee that this standard replace D2922 and D3017.

1.1.1 For limitations see Section 5 on Interferences.

1.2 The total or wet density of soil and soil-aggregate is measured by the attenuation of gamma radiation where, in direct transmission, the source is placed at a known depth up to 300 mm (12 in.) and the detector (s) remains on the surface (some gauges may reverse this orientation); or in backscatter or backscatter/air-gap the source and detector(s) both remain on the surface.

1.2.1 The density of the test sample in mass per unit volume is calculated by comparing the detected rate of gamma radiation with previously established calibration data.

1.2.2 The dry density of the test sample is obtained by subtracting the water mass per unit volume from the test sample wet density (Section II). Most gauges display this value directly.

1.3 The gauge is calibrated to read the water mass per unit volume of soil or soil-aggregate. When divided by the density of water and then multiplied by 100, the water mass per unit volume is equivalent to the volumetric water content. The water mass per unit volume is determined by the thermalizing or slowing of fast neutrons by hydrogen, a component of water. The neutron source and the thermal neutron detector are both located at the surface of the material being tested. The water content most prevalent in engineering and construction activities is known as the gravimetric water content, w , and is the ratio of the mass of the water in pore spaces to the total mass of solids, expressed as a percentage.

1.4 Two alternative procedures are provided.

1.4.1 *Procedure A* describes the direct transmission method in which the gamma source rod extends through the base of the gauge into a pre-formed hole to a desired depth. The direct transmission is the preferred method.

1.4.2 *Procedure B* involves the use of a dedicated backscatter gauge or the source rod in the backscatter position. This places the gamma and neutron sources and the detectors in the same plane.

1.5 *SI Units*—The values stated in SI units are to be regarded as the standard. The values in inch-pound units (ft – lb units) are provided for information only.

1.6 All observed and calculated values shall conform to the guide for significant digits and rounding established in Practice D6026.

1.6.1 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.

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

2. Referenced Documents

2.1 *ASTM Standards*:²

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/ft³ (600 kN-m/m³))

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

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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.

- D1556** Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method
- D1557** Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³(2,700 kN-m/m³))
- D2167** Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method
- D2487** Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- D2488** Practice for Description and Identification of Soils (Visual-Manual Procedure)
- D2216** Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
- D2937** Test Method for Density of Soil in Place by the Drive-Cylinder Method
- D3740** Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
- D4253** Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
- D4254** Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density
- D4643** Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating
- D4718** Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles
- D4944** Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester
- D4959** Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating
- D6026** Practice for Using Significant Digits in Geotechnical Data
- D7013** Guide for Nuclear Surface Moisture and Density Gauge Calibration Facility Setup

3. Terminology

3.1 *Definitions*: See Terminology **D653** for general definitions.

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *nuclear gauge*—a device containing one or more radioactive sources used to measure certain properties of soil and soil-aggregates.

3.2.2 *wet density*—same as bulk density (as defined in Terminology **D653**): the total mass (solids plus water) per total volume of soil or soil-aggregate.

3.2.3 *dry density*—same as density of dry soil or rock (as defined in Terminology **D653**): the mass of solid particles per the total volume of soil or soil-aggregate.

3.2.4 *gamma (radiation) source*—a sealed source of radioactive material that emits gamma radiation as it decays.

3.2.5 *neutron (radiation) source*—a sealed source of radioactive material that emits neutron radiation as it decays.

3.2.6 *Compton scattering*—the interaction between a gamma ray (photon) and an orbital electron where the gamma ray loses energy and rebounds in a different direction.

3.2.7 *detector*—a device to detect and measure radiation.

3.2.8 *probe*—a metal rod attached to a nuclear gauge in which a radioactive source or a detector is housed. The rod can

be lowered to specified depths for testing. Probes containing only a radioactive source are commonly referred to as “Source Rods.”

3.2.9 *thermalization*—the process of “slowing down” fast neutrons by collisions with light-weight atoms, such as hydrogen.

3.2.10 *water content*—the ratio of the mass of water contained in the pore spaces of soil or soil-aggregate, to the solid mass of particles in that material, expressed as a percentage (*this is sometimes referred to in some scientific fields as gravimetric water content to differentiate it from volumetric water content*).

3.2.11 *volumetric water content*—the volume of water as a percent of the total volume of soil or rock material.

3.2.12 *test count, n*—the measured output of a detector for a specific type of radiation for a given test.

3.2.13 *prepared blocks*—blocks prepared of soil, solid rock, concrete, and engineered materials, that have characteristics of various degrees of reproducible uniformity.

4. Significance and Use

4.1 The test method described is useful as a rapid, nondestructive technique for in-place measurements of wet density and water content of soil and soil-aggregate and the determination of dry density.

4.2 The test method is used for quality control and acceptance testing of compacted soil and soil-aggregate mixtures as used in construction and also for research and development. The nondestructive nature allows repetitive measurements at a single test location and statistical analysis of the results.

4.3 *Density*—The fundamental assumptions inherent in the methods are that Compton scattering is the dominant interaction and that the material is homogeneous.

4.4 *Water Content*—The fundamental assumptions inherent in the test method are that the hydrogen ions present in the soil or soil-aggregate are in the form of water as defined by the water content derived from Test Methods **D2216**, and that the material is homogeneous. (See **5.2**)

Note 1—The quality of the result produced by this standard test method 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, and the like. 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. Interferences

5.1 *In-Place Density Interferences*

5.1.1 Measurements may be affected by the chemical composition of the material being tested.

5.1.2 Measurements may be affected by non-homogeneous soils and surface texture (see **10.2**).

5.1.3 Measurements in the Backscatter Mode are influenced more by the density and water content of the material in close proximity to the surface.

5.1.4 Measurements in the Direct Transmission mode are an average of the density from the bottom of the probe in the soil or soil aggregate back up to the surface of the gauge.

5.1.5 Oversize particles or large voids in the source-detector path may cause higher or lower density measurements. Where lack of uniformity in the soil due to layering, aggregate or voids is suspected, the test site should be excavated and visually examined to determine if the test material is representative of the in-situ material in general and if an oversize correction is required in accordance with Practice D4718.

5.1.6 The measured volume is approximately 0.0028 m³ (0.10 ft³) for the Backscatter Mode and 0.0057 m³ (0.20 ft³) for the Direct Transmission Mode when the test depth is 150 mm (6 in.). The actual measured volume is indeterminate and varies with the apparatus and the density of the material.

5.1.7 Other radioactive sources must not be within 9 m (30 ft.) of equipment in operation.

5.2 *In-Place Water (Moisture) Content Interferences*

5.2.1 The chemical composition of the material being tested can affect the measurement and adjustments may be necessary (see Section 10.6). Hydrogen in forms other than water and carbon will cause measurements in excess of the true value. Some chemical elements such as boron, chlorine, and cadmium will cause measurements lower than the true value.

5.2.2 The water content measured by this test method is not necessarily the average water content within the volume of the sample involved in the measurement. Since this measurement is by backscatter in all cases, the value is biased by the water content of the material closest to the surface. The volume of soil and soil-aggregate represented in the measurement is indeterminate and will vary with the water content of the material. In general, the greater the water content of the material, the smaller the volume involved in the measurement. Approximately 50 % of the typical measurement results from the water content of the upper 50 to 75 mm (2 to 3 in.).

5.2.3 Other neutron sources must not be within 9 m (30 ft) of equipment in operation.

6. Apparatus

6.1 *Nuclear Density / Moisture Gauge*—While exact details of construction of the apparatus may vary, the system shall consist of:

6.1.1 *Gamma Source*—A sealed source of high-energy gamma radiation such as cesium or radium.

6.1.2 *Gamma Detector*—Any type of gamma detector such as a Geiger-Mueller tube(s).

6.1.3 *Fast Neutron Source*—A sealed mixture of a radioactive material such as americium, radium and a target material such as beryllium, or a neutron emitter such as californium-252.

6.1.4 *Slow Neutron Detector*—Any type of slow neutron detector such as boron trifluoride or helium-3 proportional counter.

6.2 *Reference Standard*—A block of material used for checking instrument operation, correction of source decay, and to establish conditions for a reproducible reference count rate.

6.3 *Site Preparation Device*—A plate, straightedge, or other suitable leveling tool that may be used for planing the test site

to the required smoothness, and in the Direct Transmission Method, guiding the drive pin to prepare a perpendicular hole.

6.4 *Drive Pin*—A pin of slightly larger diameter than the probe in the Direct Transmission Instrument used to prepare a hole in the test site for inserting the probe.

6.4.1 *Drive Pin Guide*—A fixture that keeps the drive pin perpendicular to the test site. Generally part of the site preparation device.

6.5 *Hammer*—Heavy enough to drive the pin to the required depth without undue distortion of the hole.

6.6 *Drive Pin Extractor*—A tool that may be used to remove the drive pin in a vertical direction so that the pin will not distort the hole in the extraction process.

6.7 *Slide Hammer*, with a drive pin attached, may also be used both to prepare a hole in the material to be tested and to extract the pin without distortion to the hole.

7. Hazards

7.1 These gauges utilize radioactive materials that may be hazardous to the health of the users unless proper precautions are taken. Users of these gauges must become familiar with applicable safety procedures and government regulations.

7.2 Effective user instructions, together with routine safety procedures and knowledge of and compliance with Regulatory Requirements, are a mandatory part of the operation and storage of these gauges.

8. Calibration

8.1 Calibration of the gauge will be in accordance with Annex A1 and Annex A2.

8.2 For further reference on gauge calibration, see Guide D7013, Standard Guide for Nuclear Surface Moisture and Density Gauge Calibration Facility Setup.

9. Standardization

9.1 Nuclear moisture density gauges are subject to long-term aging of the radioactive sources, which may change the relationship between count rates and the material density and water content. To correct for this aging effect, gauges are calibrated as a ratio of the measurement count rate to a count rate made on a reference standard or to an air-gap count (for the backscatter/air-gap ratio method).

9.2 Standardization of the gauge shall be performed at the start of each day's use, and a record of these data should be retained for the amount of time required to ensure compliance with either subsection 9.2.2 or 9.2.3, whichever is applicable. Perform the standardization with the gauge located at least 9 m (30 ft) away from other nuclear moisture density gauges and clear of large masses of water or other items which can affect the reference count rates.

9.2.1 Turn on the gauge and allow for stabilization according to the manufacturer's recommendations.

9.2.2 Using the reference standard, take a reading that is at least four times the duration of a normal measurement period (where a normal measurement period is typically one minute) to constitute one standardization check. Use the procedure recommended by the gauge manufacturer to establish the compliance of the standard measurement to the accepted range.

Without specific recommendations from the gauge manufacturer, use the procedure in 9.2.3.

9.2.3 If the values of the current standardization counts are outside the limits set by Eq 1 and Eq 2, repeat the standardization check. If the second standardization check satisfies Eq 1 and Eq 2, the gauge is considered in satisfactory operating condition.

$$0.99(N_{dc})e^{\frac{-\ln(2)t}{T_{d(1/2)}}} \leq N_{d0} \leq 1.01(N_{dc})e^{\frac{-\ln(2)t}{T_{d(1/2)}}} \quad (1)$$

and

$$0.98(N_{mc})e^{\frac{-\ln(2)t}{T_{m(1/2)}}} \leq N_{m0} \leq 1.02(N_{mc})e^{\frac{-\ln(2)t}{T_{m(1/2)}}} \quad (2)$$

where:

- $T_{d(1/2)}$ = the half-life of the isotope that is used for the density determination in the gauge. For example, for ^{137}Cs , the radioactive isotope most commonly used for density determination in these gauges, $T_{d(1/2)}$, is 11 023 days,
- $T_{m(1/2)}$ = the half-life of the isotope that is used for the water content determination in the gauge. For example, for ^{241}Am , the radioactive isotope in Am:Be, the radioactive source most commonly used for water content determination in these gauges, $T_{m(1/2)}$, is 157 788 days,
- N_{dc} = the density system standardization count acquired at the time of the last calibration or verification,
- N_{mc} = the moisture system standardization count acquired at the time of the last calibration or verification,
- N_{d0} = the current density system standardization count,
- N_{m0} = the current moisture system standardization count,
- t = the time that has elapsed between the current standardization test and the date of the last calibration or verification. The units selected for t , $T_{d(1/2)}$, and $T_{m(1/2)}$ should be consistent, that is, if $T_{d(1/2)}$ is expressed in days, then t should also be expressed in days,
- $\ln(2)$ = the natural logarithm of 2, which has a value of approximately 0.69315,
- e = the inverse of the natural logarithm function, which has a value of approximately 2.71828.

9.2.4 If for any reason the measured density or moisture becomes suspect during the day's use, perform another standardization check.

9.3 Example—A nuclear gauge containing a ^{137}Cs source for density determination (half-life = 11 023 days) and an ^{241}Am :Be source for moisture determination (half-life = 157 788 days) is calibrated on March 1 of a specific year. At the time of calibration, the density standard count was 2800 counts per minute (prescaled), and the moisture standard count was 720 counts per minute (prescaled). According to Eq 1 and Eq 2 from Section 9.2.3, what is the allowed range of standard counts for November 1 of the same year?

9.3.1 For this example, a total of 245 days have elapsed between the date of calibration or verification (March 1) and the date of the gauge standardization (November 1). Therefore:

$t = 245$ days

$T_{d(1/2)} = 11\,023$ days

$T_{m(1/2)} = 157\,788$ days

$N_{dc} = 2800$ counts

$N_{mc} = 720$ counts

9.3.2 According to Eq 1, therefore, the lower limit for the density standard count taken on November 1, denoted by N_{d0} , is:

$$0.99(N_{dc})e^{\frac{-\ln(2)t}{T_{d(1/2)}}} = 0.99(2800)e^{\frac{-\ln(2) \cdot 245}{11\,023}} = 2772e^{-0.01541} = 2730 \text{ counts}$$

9.3.3 Likewise, the upper limit for the density standard count taken on November 1, denoted by N_{d0} , is:

$$1.01(N_{dc})e^{\frac{-\ln(2)t}{T_{d(1/2)}}} = 1.01(2800)e^{\frac{-\ln(2) \cdot 245}{11\,023}} = 2828e^{-0.01541} = 2785 \text{ counts}$$

9.3.4 Therefore, the density standard count acquired on November 1 should lie somewhere between 2730 and 2785 counts, or $2730 \leq N_{d0} \leq 2785$. According to Eq 2, the lower limit for the moisture standard count taken on November 1, denoted by N_{m0} , is:

$$0.98(N_{mc})e^{\frac{-\ln(2)t}{T_{m(1/2)}}} = 0.98(720)e^{\frac{-\ln(2) \cdot 245}{157\,788}} = 706e^{-0.00108} = 705 \text{ counts}$$

9.3.5 Likewise, the upper limit for the moisture standard count taken on November 1, denoted by N_{m0} , is:

$$1.02(N_{mc})e^{\frac{-\ln(2)t}{T_{m(1/2)}}} = 1.02(720)e^{\frac{-\ln(2) \cdot 245}{157\,788}} = 734e^{-0.00108} = 733 \text{ counts}$$

9.3.6 Therefore, the moisture standard count acquired on November 1 should lie somewhere between 705 and 733 counts, or $705 \leq N_{m0} \leq 733$.

10. Procedure

10.1 When possible, select a test location where the gauge will be placed at least 600 mm (24.0 in) away from any object sitting on or projecting above the surface of the test location, when the presence of this object has the potential to modify gauge response. Any time a measurement must be made at a specific location and the aforementioned clearance cannot be achieved, such as in a trench, follow the gauge manufacturer's correction procedure(s).

10.2 Prepare the test site in the following manner:

10.2.1 Remove all loose and disturbed material and additional material as necessary to expose the true surface of the material to be tested.

10.2.2 Prepare an area sufficient in size to accommodate the gauge by grading or scraping the area to a smooth condition so as to obtain maximum contact between the gauge and material being tested.

10.2.3 The depth of the maximum void beneath the gauge shall not exceed 3 mm ($1/8$ in.). Use native fines or fine sand to fill the voids and smooth the surface with a rigid straight edge or other suitable tool. The depth of the filler should not exceed approximately 3 mm ($1/8$ in.).

10.2.4 The placement of the gauge on the surface of the material to be tested is critical to accurate density measurements. The optimum condition is total contact between the bottom surface of the gauge and the surface of the material being tested. The total area filled should not exceed approximately 10 percent of the bottom area of the gauge.

10.3 Turn on and allow the gauge to stabilize (warm up) according to the manufacturer's recommendations (see Section 9.2.1).

10.4 *Procedure A - The Direct Transmission Procedure:*

10.4.1 Select a test location where the gauge in test position will be at least 150 mm (6 in.) away from any vertical projection

10.4.2 Make a hole perpendicular to the prepared surface using the rod guide and drive pin. The hole should be a minimum of 50 mm (2 inches) deeper than the desired measurement depth and of an alignment that insertion of the probe will not cause the gauge to tilt from the plane of the prepared area.

10.4.3 Mark the test area to allow the placement of the gauge over the test site and to align the source rod to the hole. Follow the manufacturer's recommendations if applicable.

10.4.4 Remove the hole-forming device carefully to prevent the distortion of the hole, damage to the surface, or loose material to fall into the hole.

NOTE 2—Care must be taken in the preparation of the access hole in uniform cohesionless granular soils. Measurements can be affected by damage to the density of surrounding materials when forming the hole.

10.4.5 Place the gauge on the material to be tested, ensuring maximum surface contact as described previously in 10.2.4.

10.4.6 Lower the probe into the hole to the desired test depth. Pull the gauge gently toward the back, or detector end, so that the back side of the probe is in intimate contact with the side of the hole in the gamma measurement path.

NOTE 3—As a safety measure, it is recommended that a probe containing radioactive sources not be extended out of its shielded position prior to placing it into the test site. When possible, align the gauge so as to allow placing the probe directly into the test hole from the shielded position.

10.4.7 Keep all other radioactive sources at least 9 m (30 feet) away from the gauge to avoid any effect on the measurement.

10.4.8 If the gauge is so equipped, set the depth selector to the same depth as the probe.

10.4.9 Secure and record one or more one-minute density and water content readings. Read the in-place wet density directly or determine one by use of the calibration curve or table previously established.

10.4.10 Read the water content directly or determine the water content by use of the calibration curve or table previously established.

10.5 *Procedure B - The Backscatter or Backscatter/Air-Gap Ratio Procedure:*

10.5.1 Seat the gauge firmly (see Note 2).

10.5.2 Keep all other radioactive sources at least 9m (30 ft) away from the gauge to avoid affecting the measurement.

10.5.3 Set the gauge into the Backscatter (BS) position.

10.5.4 Secure and record one or more set(s) of one-minute density and water content readings. When using the

backscatter/air-gap ratio mode, follow the manufacturer's instructions regarding gauge setup. Take the same number of readings for the normal measurement period in the air-gap position as in the standard backscatter position. Calculate the air-gap ratio by dividing the counts per minute obtained in the air-gap position by the counts per minute obtained in the standard position. Many gauges have built-in provisions for automatically calculating the air-gap ratio and wet density.

10.5.5 Read the in-place wet density or determine one by use of the calibration curve or table previously established.

10.5.6 Read the water content or determine one by use of the calibration curve or previously established table (see Section 10.6).

10.6 *Water Content Correction and Oversize Particle Correction*

10.6.1 For proper use of the gauge and accurate values of both water content and dry density, both of these corrections need to be made when applicable.

Prior to using the gauge-derived water content on any new material, the value should be verified by comparison to another ASTM method such as Test Methods D2216, D4643, D4944, or D4959. As part of a user developed procedure, occasional samples should be taken from beneath the gauge and comparison testing done to confirm gauge-derived water content values. All gauge manufacturers have a procedure for correcting the gauge-derived water content values.

10.6.2 When oversize particles are present, the gauge can be rotated about the axis of the probe to obtain additional readings as a check. When there is any uncertainty as to the presence of these particles it is advisable to sample the material beneath the gauge to verify the presence and the relative proportion of the oversize particles. A rock correction can then be made for both water content and wet density by the method in Practice D4718.

10.6.3 When sampling for water content correction or oversize particle correction, the sample should be taken from a zone directly under the gauge. The size of the zone is approximately 200 mm (8 in.) in diameter and a depth equal to the depth setting of the probe when using the direct transmission mode; or approximately 75 mm (3 in.) in depth when using the backscatter mode.

11. Calculation of Results

11.1 *Determine the Wet Density*

11.1.1 On most gauges read the value directly in kg/m³ (lbm/ft³). If the density reading is in "counts", determine the in-place wet density by use of this reading and the previously established calibration curve or table for density.

11.1.2 Record the density to the nearest 1 kg/m³ (0.1 lbm/ft³).

11.2 *Water Content*

11.2.1 Use the gauge reading for w if the gauge converts to that value.

11.2.2 If the gauge determines water mass per unit volume in kg/m³ (lbm / ft³), calculate w using the formula:

$$w = \frac{M_w \times 100}{P_d} \quad (3)$$

or,

$$w = \frac{M_m \times 100}{\rho - M_m} \quad (4)$$

where:

- w = water content
- ρ_d = dry density in kg/m^3 or (lbm/ft^3) ,
- ρ = wet density in kg/m^3 or (lbm/ft^3) , and
- M_m = water mass per unit volume in kg/m^3 or (lbm/ft^3)

11.2.3 If the water content reading was in “counts,” determine the water mass per unit volume by use of this reading and previously established calibration curve or table. Then convert to gravimetric water content as per 11.2.2.

11.2.4 Record water content to the nearest 0.1 %.

11.3 Determine the Dry Density of the soil by one of the following methods:

11.3.1 If the water content is obtained by nuclear methods, use the gauge readings directly for dry density in kg/m^3 (lbm/ft^3). The value can also be calculated from:

$$\rho_d = \rho - M_m \quad (5)$$

11.3.2 If the water content is to be determined from a sample of soil taken as prescribed in (10.6.3), follow the procedures and perform the calculations of the chosen Test Method (D2216, D4643, D4944, or D4959).

11.3.3 With a water content value from 11.3.2 calculate the dry density from:

$$\rho_d = \frac{100 \times \rho}{100 + w} \quad (6)$$

11.3.4 Report the dry density to the nearest 1 kg/m^3 (0.1 lbm/ft^3).

11.4 Determine the Percent Compaction:

11.4.1 It may be desired to express the in-place dry density as a percentage of a laboratory density such as Test Methods D698, D1557, D4253, or D4254. This relationship can be calculated by dividing the in-place dry density by the laboratory maximum dry density and multiplying by 100. Procedures for calculating relative density are provided in Test Method D4254 which requires that Test Method D4253 also be performed. Corrections for oversize material, if required, should be performed in accordance with Practice D4718.

12. Report: Test Data Sheet(s)/Form(s)/Final Report(s)

12.1 The Field Data Records shall include, as a minimum, the following:

- 12.1.1 Test Number or Test Identification.
- 12.1.2 Location of test (for example, Station number or GPS or Coordinates or other identifiable information).
- 12.1.3 Visual description of material tested.
- 12.1.4 Lift number or elevation or depth.
- 12.1.5 Name of the operator(s).
- 12.1.6 Make, model and serial number of the test gauge.
- 12.1.7 Test mode, Method A (direct transmission and test depth), or Method B (backscatter, backscatter/air-gap),
- 12.1.8 Standardization and adjustment data for the date of the tests.
- 12.1.9 Any corrections made in the reported values and reasons for these corrections (that is, over-sized particles, water content).

12.1.10 Maximum laboratory density value in kg/m^3 or lbm/ft^3 .

12.1.11 Dry density in kg/m^3 or lbm/ft^3 .

12.1.12 Wet density in kg/m^3 or lbm/ft^3 .

12.1.13 Water content in percent.

12.1.14 Percent Compaction.

12.2 Final Report (minimum required information):

12.2.1 Test Number.

12.2.2 Gauge Serial number.

12.2.3 Location of test (for example, Station number or GPS or Coordinates or other identifiable information).

12.2.4 Lift number or elevation or depth.

12.2.5 Moisture (Water) content as a percent.

12.2.6 Maximum laboratory density value in kg/m^3 or lbm/ft^3 .

12.2.7 Dry Density result in kg/m^3 or lbm/ft^3 .

12.2.8 Percent Compaction.

12.2.9 Name of Operator(s).

13. Precision and Bias

13.1 Precision:

13.1.1 Precision: Wet Density—Criteria for judging the acceptability of wet density test results obtained by this test method are given in Table 1.³ The values given are based upon an interlaboratory study in which five test sites containing soils, with wet densities as shown in column two were tested by eight different nuclear gauges and operators. The wet density of each test site was measured three times by each device.

13.1.2 Precision: Water Mass Per Unit Volume—Criteria for judging the acceptability of the water mass per unit volume results obtained by this test method are given in Table 2. The values given are based upon an inter-laboratory study in which five test sites containing soils with water mass per unit volume as shown in column two were tested by eight different nuclear gauges and operators. The water mass per unit volume of each test site was measured three times by each device.

13.1.3 Precision: Water Content—Criteria for judging the acceptability of the water content results obtained by this test method are given in Table 3. The values given are based upon an inter-laboratory study in which five test sites containing soils, with water content as shown in column two were tested by eight different nuclear gauges and operators. The water content of each test site was measured three times by each device.

13.2 Bias:

13.2.1 There are no accepted reference values for these test methods, therefore, bias cannot be determined

14. Keywords

14.1 Compaction test; acceptance testing; construction control; quality control; field density; in-place density; wet density; water content; dry density; nuclear methods, nuclear gauge

³ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR-D18-1004.

TABLE 1 Results of Statistical Analysis (Wet Density)^A

Direct Transmission:					
Material ^B	Average kg/m ³ or (lbm/ft ³)	Repeatability Standard Deviation kg/m ³ or (lbm/ft ³)	Reproducibility Standard Deviation kg/m ³ or (lbm/ft ³)	95 % Repeatability Limit on the Difference Between Two Test Results kg/m ³ or (lbm/ft ³) ^C	95 % Reproducibility Limit on the Difference Between Two Test Results kg/m ³ or (lbm/ft ³) ^C
ML	2084 (130.1)	7.4 (0.46)	12.3 (0.77)	21 (1.3)	34 (2.1)
CL	1837 (114.7)	5.4 (0.34)	10.6 (0.66)	15 (0.9)	30 (1.9)
SP	1937 (120.9)	4.2 (0.26)	11.0 (0.68)	12 (0.7)	31 (1.9)
Backscatter:					
Material ^B	Average kg/m ³ or (lbm/ft ³)	Repeatability Standard Deviation kg/m ³ or (lbm/ft ³)	Reproducibility Standard Deviation kg/m ³ or (lbm/ft ³)	95 % Repeatability Limit on the Difference Between Two Test Results kg/m ³ or (lbm/ft ³) ^C	95 % Reproducibility Limit on the Difference Between Two Test Results kg/m ³ or (lbm/ft ³) ^C
ML	1997 (124.6)	16.0 (1.00)	32.0 (2.00)	45 (2.8)	90 (5.6)

^AThe data used to establish this precision statement are contained in a Research Report available from ASTM Headquarters.³

^BMaterials are distinguished by soil types. For definitions of soil types see Practices [D2487](#) and [D2488](#).

^CTwo separate readings at a singular site with constant gauge orientation and settings.

TABLE 2 Results of Statistical Analysis (Water Mass Per Unit Volume)^A

Material ^B	Average kg/m ³ or (lbm/ft ³)	Repeatability Standard Deviation kg/m ³ or (lbm/ft ³)	Reproducibility Standard Deviation kg/m ³ or (lbm/ft ³)	95 % Repeatability Limit on the Difference Between Two Test Results kg/m ³ or (lbm/ft ³) ^C	95 % Reproducibility Limit on the Difference Between Two Test Results kg/m ³ or (lbm/ft ³) ^C
ML	313 (19.6)	5.7 (0.36)	8.1 (0.50)	16 (1.0)	23 (1.4)
CL	193 (12.1)	6.1 (0.38)	8.5 (0.53)	17 (1.1)	24 (1.5)
SP	320 (20.0)	4.3 (0.27)	10.3 (0.64)	12 (0.7)	29 (1.8)

^AThe data used to establish this precision statement are contained in a Research Report available from ASTM Headquarters.³

^BMaterials are distinguished by soil types. For definitions of soil types see Practices [D2487](#) and [D2488](#).

^CTwo separate readings at a singular site with constant gauge orientation and settings.

TABLE 3 Results of Statistical Analysis (% Water Content)^A

Material ^B	Average %	Repeatability Standard Deviation %	Reproducibility Standard Deviation %	95 % Repeatability Limit on the Difference Between Two Test Results % ^C	95 % Reproducibility Limit on the Difference Between Two Test Results % ^C
ML	17.7	0.39	0.59	1.1	1.7
CL	11.8	0.40	0.58	1.1	1.6
SP	19.8	0.32	0.81	0.9	2.3

^AThe data used to establish this precision statement are contained in a Research Report available from ASTM Headquarters.³

^BMaterials are distinguished by soil types. For definitions of soil types see Practices [D2487](#) and [D2488](#).

^CTwo separate readings at a singular site with constant gauge orientation and settings.

ANNEXES

(Mandatory Information)

A1. WET DENSITY CALIBRATION & VERIFICATION

A1.1 Calibration: Gauges shall be calibrated initially and after any repairs that can affect the gauge geometry or the existing calibration. To be within specified tolerances by procedures described in [A1.2](#), calibration curves, tables, or equivalent coefficients shall be verified, at periods not to exceed 12 months. At any time these tolerances cannot be met, the gauge shall be calibrated to establish new calibration curves, tables, or equivalent coefficients. If the owner does not

establish a verification procedure, the gauge shall be calibrated at a period not to exceed 12 months.

A1.1.1 Gauge Calibration Response shall be within ± 16 kg/m³ (± 1.0 lbm/ft³) on the block(s) on which the gauge was calibrated. This calibration may be done by the manufacturer, the user, or an independent vendor. Nuclear gauge response is influenced by the chemical composition of measured materials.

This response must be taken into account in establishing the block density. The method used for calibration shall be capable of generating a general curve covering the entire density range of the materials to be tested in the field. The density of the block(s) shall be determined in such a manner that the estimated standard deviation of the measurement results shall not exceed 0.2 % of the measured block density.

A1.1.2 Reestablish or verify the density of the block(s) used to calibrate or verify calibrations at a period not to exceed 5 years. The density values of the established block(s) of materials that have the potential for changes over time in density or moisture content, such as soil, concrete, or solid rock, shall be reestablished or verified at periods not exceeding 12 months.

NOTE: A1.1—Changes in background conditions or locations of blocks used for gauge calibrations or verification of calibrations can impact measurements on those blocks. Care must be taken to ensure uniform conditions when performing gauge calibrations or verifying gauge calibrations.

A1.1.3 Sufficient data shall be taken on each density block to ensure a gauge count precision of at least one-half the gauge count precision required for field use assuming field use measurement of one minute duration and four-minute duration used for calibration, or an equivalent relationship. The data may be presented in the form of a graph, table, equation coefficients, or stored in the gauge, to allow converting the count rate data to density.

A1.1.4 The method and test procedures used in establishing the calibration count rate data shall be the same as those used for obtaining the field count rate data.

A1.1.5 The material type, actual density, or established density of each calibration block used to establish or verify the gauge calibration shall be stated as part of the calibration data for each measurement depth. If the actual or established block density varies with measurement depth, then the density data for each measurement depth shall be stated as part of the calibration.

A1.1.6 The calibration blocks should be sufficient in size so that the count rate will not change if the block is enlarged in any dimension.

NOTE: A1.2—Minimum surface dimensions of approximately 610 mm by 430 mm (24 × 17 inches), have proven satisfactory. For the backscatter method a minimum depth of 230 mm (9 inches) is adequate; while for the direct transmission method the depth should be at least 50 mm (2 inches) deeper than the deepest rod penetration depth. A larger surface area should

be considered for the backscatter/air-gap method. For blocks with widths or lengths smaller than the sizes specified, follow the block manufacturer's recommendations for proper installation and use.

The most successful blocks that have been established for calibration have been made of magnesium, aluminum, aluminum/magnesium, granite, and limestone. These blocks have been used in combination with each other, with historical curve information, and with other prepared block(s) to produce accurate and reliable calibration.

A1.2 *Verification:* The method used for verification should be capable of confirming the accuracy of the general calibration curve representing the density range of the materials to be tested in the field. The verification process and the resulting tolerances obtained over the depths at which the gauge will be used, shall be formally recorded and documented. If this verification process indicates a variance beyond the specified tolerances, the gauge shall be calibrated

A1.2.1 Gauge verification response shall be within $\pm 32 \text{ kg/m}^3 (\pm 2.0 \text{ lbm/ft}^3)$ on block(s) of established density at each calibration depth.

A1.2.2 Using the procedure described in either **A3.1.1** or **A3.1.2**, ensure a gauge count precision of at least one-half the gauge count precision required for field use, assuming field use measurement of one-minute duration and four-minute duration are used for calibration, or an equivalent relationship.

A1.2.3 The gauge calibration may be verified on calibration block(s) which were used for calibration of the gauge, or prepared blocks.

A1.2.4 Prepared block(s) of soil, solid rock, concrete, and engineered block(s) that have characteristics of reproducible uniformity may be used, but care must be taken to establish density values and to minimize changes in density and water content over time.

A1.2.5 Density values of prepared block(s) shall be determined in such a manner that the estimated standard deviation of the measurement results shall not exceed 0.5 % of the measured block density value.

A1.2.6 Reestablish or verify density values for prepared block(s) of soil, solid rock, or concrete that have the potential of changes over time in density or moisture content at periods not exceeding 12 months.

A1.2.7 The method used to establish or verify the block(s) density values shall be stated as part of the verification data.

A1.2.8 All gauges shall be verified or calibrated at a minimum frequency of 12 months.

A2. WATER CONTENT CALIBRATION and VERIFICATION

A2.1 *Calibration:* Gauges shall be calibrated initially and after any repairs that can affect the gauge geometry or the existing calibration. Calibration curves, tables, or equivalent coefficients shall be verified at periods, not exceeding 12 months, to be within specified tolerances by procedures described in **A2.2**. At any time these tolerances cannot be met, the gauge shall be calibrated to establish new calibration curves, tables, or equivalent coefficients. If the owner does not estab-

lish a verification procedure, the gauge shall be calibrated at a period not to exceed 12 months.

A2.1.1 Gauge Calibration Response shall be within $16 \text{ kg/m}^3 (1 \text{ lbm/ft}^3)$ on the block(s) on which the gauge was calibrated. This calibration may be done by the gauge manufacturer, the user, or an independent vendor. The block(s) used for calibration should be capable of generating a general curve

covering the entire water content range of the materials to be tested in the field. The calibration curve can be established using counts and water contents of standard blocks, previous factory curve information, or historical data. Due to the effect of chemical composition, the calibration supplied by the manufacturer with the gauge will not be applicable to all materials. It shall be accurate for silica and water; therefore, the calibration must be verified and adjusted, if necessary, in accordance with section **A2.2**.

A2.1.2 Reestablish or verify the assigned water content of blocks used to calibrate or verify calibrations at periods which shall be recommended by the block manufacturer. The water content values of blocks prepared of materials that have the potential of changes over time in density or moisture content, such as soil, concrete, or solid rock, shall be reestablished or verified at periods not exceeding 12 months.

A2.1.3 All calibration blocks should be sufficient in size so that the count rate will not change if the block is enlarged in any dimension.

Note: A2.1—Dimensions of approximately 610 mm long by 460 mm wide by 200 mm deep (approximately 24 by 18 by 8 inches) have proven satisfactory. For blocks with width or length smaller than the sizes specified, follow block manufacturer's recommendations for proper installation and use.

A2.1.4 Prepare a homogeneous block of hydrogenous materials having an equivalent water mass per unit volume value determined by comparison (using a nuclear instrument) with a saturated silica sand standard prepared in accordance with **A2.1.3**. Metallic blocks used for wet density calibration such as magnesium or aluminum are a convenient zero water mass per unit volume block. A block of alternating sheets of aluminum or magnesium and polyethylene is convenient for a high water mass per unit volume block.

A2.1.5 Prepare containers of compacted material with a water content determined by oven dry (Test Method **D2216**) and a wet density calculated from the mass of the material and the inside dimensions of the container. The water mass per unit volume may be calculated as follows:

$$M_m = \frac{\rho \times w}{100 + w} \quad (\text{A2.1})$$

Where:

M_m = water mass per unit volume, kg/m³ or lbm/ft³,

w = water content, percent of dry mass, and

ρ = wet (total) density, kg/m³ or lbm/ft³.

A3. GAUGE PRECISION

A3.1 Gauge precision is defined as the change in density or water mass per unit volume that occurs corresponding to a one standard deviation change in the count due to the random decay of the radioactive source. The density of the material and time period of the count must be stated.

Calculate using the methods in either **A3.1.1** or **A3.1.2**. For wet density, use a material having a density of 2000 ± 80 kg/m³ (125.0 ± 5.0 lbm/ft³). Typical values of P are < 10

A2.1.6 Where neither of the previous calibration standards are available, the gauge may be calibrated by using a minimum of three selected test sites in an area of a compaction project where material has been placed at several different water contents. The test sites shall represent the range of water contents over which the calibration is to be used. At least three replicate nuclear measurements shall be made at each test site. The density at each site shall be verified by measurements with calibrated equipment in accordance with the procedures described in this standard, Test Methods **D1556**, **D2167**, or **D2937**. The water content of the material at each of the test sites shall be determined using Test Method **D2216**. Use the mean value of the replicate readings as the calibration point value for each test site.

A2.2 **Verification:** The method used for verification should be capable of confirming the accuracy of the general calibration curve representing the water content of the materials to be tested in the field. The verification process and resultant tolerances obtained shall be formally recorded and documented. If the verification process indicates a variance beyond the specified tolerances, new calibration curves, tables, or equivalent coefficients shall be established.

A2.2.1 Verify an existing calibration by taking sufficient number of counts on one or more blocks of established water content to ensure the accuracy of the existing calibration within ± 16 kg/m³ or (± 1 lbm/ft³). The water content block(s) should be prepared in accordance with section **A2.1.4** and **A2.1.5**.

A2.2.2 Sufficient data shall be taken to ensure a gauge count precision of at least one half the gauge count precision required for field use assuming field use measurement of one minute duration and four minute duration used for calibration, or an equivalent relationship.

A2.2.3 Calibration block(s) used to establish calibration parameters and prepared blocks can be used to verify calibration.

A2.2.4 Prepared block(s) that have characteristics of reproducible uniformity can be used, but care must be taken to minimize changes in density and water content over time.

A2.2.5 The established water content of the block(s) used for verification of the gauge shall be stated as part of the verification data.

A2.2.6 All gauges shall be verified or calibrated at a minimum frequency of 12 months.

kg/m³ (0.6 lbm/ft³) in backscatter or backscatter/air-gap; and < 5 kg/m³ (0.3 lbm/ft³) for direct transmission measured at a 15 cm (6 in) depth. Use a water mass per unit volume value of 160 ± 10 kg/m³ (10.0 ± 0.6 lbm/ft³) for determining slope and count rates. The value of P is typically less than 4.8 kg/m³ (0.3 lbm/ft³).

A3.1.1 *Gauge Precision - Slope Method*

Determine the gauge precision of the system, P , from the slope of the calibration curve, S , and the standard deviation, σ , of the signals (detected gamma rays or detected neutrons) in counts per minute (cpm), as follows:

$$P = \sigma/S \quad (\text{A3.1})$$

where:

P = precision

σ = standard deviation, cpm

S = slope, cpm/kg/m³ or cpm/lbm/ft³

NOTE A3.1—Displayed gauge counts may be scaled. Contact the manufacturer to obtain the appropriate pre-scale factor.

A3.1.2 Gauge Precision – Repetitive Method

Determine the standard deviation of a minimum of 20 repetitive readings of one minute each, without moving the gauge-between readings. Calculate the standard-deviation of the resulting readings. This is the gauge precision.

A4. FIELD MOISTURE CONTENT ADJUSTMENTS

A4.1 The calibration should be checked prior to performing tests on materials that are distinctly different from material types previously used in obtaining or adjusting the calibration. Sample materials may be selected by either **A2.1.5** or **A2.1.6**. The amount of water shall be within $\pm 2\%$ of the water content established as optimum for compaction for these materials. Determine the water content w . A microwave oven or direct heater may be utilized for drying materials that are not sensitive to combustion of organic material, in addition to the method listed in **A2.1.6**. A minimum of three comparisons is recommended and the mean of the observed differences used as the correction factor.

A4.2 Container(s) of compacted material taken from the test site shall be prepared in accordance with **A2.1.5**.

A4.3 Test site(s) or the compacted material shall be selected in accordance with the procedures in **A2.1.6**.

A4.4 The method and test procedures used in obtaining the count rate to establish the error must be the same as those used for measuring the water content of the material to be tested.

A4.5 The mean value of the difference between the moisture content of the test samples as determined in **A2.1.5** or **A2.1.6** and the values measured with the gauge shall be used as a correction to measurements made in the field. Many gauges utilizing a microprocessor have provision to input a correction factor that is established by the relative values of water content as a percentage of dry density, thus eliminating the need to determine the difference in mass units of water.

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue, D6938–08a, that may impact the use of this standard. (Approved May 1, 2010)

(1) Revised Section **13** Precision and Bias to include a table of single-operator and multi-laboratory precision values for the measurement quantity water mass per unit volume. Revised significant digits in this section for consistency with Practice E29.

(2) Added new **Table 2** and renumbered subsequent tables.

(3) Revised **Table 1** and **Table 3** for consistency with Practice E691.

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