N62604.AR.001325
NCBC GULFPORT
5090.3a

WORK PLAN BENCH-SCALE SOIL/SEDIMENT TREATABILITY STUDY, SITE 8 HERBICIDE ORANGE STUDY AREA NCBC GULFPORT MS
10/1/2000
TETRA TECH

Work Plan
Bench-Scale Soil/Sediment Treatability Study

Site 8
Herbicide Orange Study Area

at

Naval Construction Battalion Center

Gulfport, Mississippi

Southern Division
Naval Facilities Engineering Command
Contract Number N62467-94-D-0888
Contract Task Order 0143

October 2000

WORK PLAN
FOR
BENCH-SCALE SOIL/SEDIMENT TREATABILITY STUDY

SITE 8
HERBICIDE ORANGE STUDY AREA

NAVAL CONSTRUCTION BATTALION CENTER
GULFPORT, MISSISSIPPI

COMPREHENSIVE LONG-TERM
ENVIRONMENTAL ACTION NAVY (CLEAN) CONTRACT

Submitted to:
Southern Division
Naval Facilities Engineering Command
2155 Eagle Drive
North Charleston, South Carolina 29406

Submitted by:
Tetra Tech NUS, Inc.
661 Andersen Drive
Foster Plaza 7
Pittsburgh, Pennsylvania 15220

CONTRACT NUMBER N62467-94-D-0888
CONTRACT TASK ORDER 0143

OCTOBER 2000

PREPARED UNDER THE SUPERVISION OF:

for ROBERT FISHER
TASK ORDER MANAGER
TETRA TECH NUS, INC.
TALLAHASSEE, FLORIDA

APPROVED FOR SUBMITTAL BY:

DEBBIE WROBLEWSKI
PROGRAM MANAGER
TETRA TECH NUS, INC.
PITTSBURGH, PENNSYLVANIA

TABLE OF CONTENTS

FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

AASHO	American Association of State Highway Officials
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CKD	cement kiln dust
CLEAN	Comprehensive Long-Term Environmental Action Navy
CTO	Contract Task Order
DOT	U.S. Department of Transportation
HO	Herbicide Orange
H20	Highway 20
MSDEQ	Mississippi Department of Environmental Quality
µg/kg	microgram per kilogram
NCBC	Naval Construction Battalion Center
ng/kg	nanogram per kilogram
SOUTHDIVNAVFACENGCOM	Southern Division Naval Facility Engineering Command
SRT	sediment recovery trap
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TtNUS	Tetra Tech NUS, Inc.
USAF	U.S. Air Force

Site 8 is also currently used to store construction debris and dioxin-contaminated sediment excavated from ditches as part of removal actions conducted during the widening of 28th Street in 1995 and the 1997 upgrading of the sediment recovery trap (SRT) system located in the on-base drainage ditches.

The currently proposed remedial approach for the contaminated soil and sediment is to excavate dioxin-contaminated soil from Sites 8B and 8C and sediment from on-base drainage ditches and off-base swampland and to consolidate the excavated material on Site 8A with the incineration ash, construction debris, and existing dioxin-contaminated sediment on Site 8. The consolidated material would then be capped and the capped area used as a parking and storage area for heavy construction equipment. Based upon a soil/sediment dioxin concentration criterion of 50 nanograms per kilogram (ng/kg), the currently estimated volumes of the materials to be consolidated on Site 8A are as follows [Harding Lawson Associates (HLA), 2000]:

Material	Estimated Volume (cubic yards)
Site 8A Incinerated Soil Ash	21,000
Site 8A Construction Debris	600
On-Base Ditches Contaminated Sediment	24,000
Off-Base Swamp Contaminated Sediment	13,000
Total	**58,600**

Figures 1-2 and 1-3 show the approximate areal extent of the on-base and off-base contaminated media, respectively.

1.3 TEST OBJECTIVES

The purpose of this bench-scale treatability study is to determine whether the materials identified in Section 1.2 can be excavated and placed on Site 8A in such a manner that the consolidated material will be suitable to support a structural cap. The area to receive the structural cap will ultimately be used for the parking and storage of heavy construction equipment. It was assumed that the structural cap would be designed to support Highway 20 (H20) loading, as defined by the American Association of State Highway Officials (AASHO, 1973). The consolidated material must therefore have sufficient strength to support the structural cap and H20 loading. To determine this, the consolidated material will be evaluated for compaction and strength characteristics during this treatability study.

This page intentionally left blank.

1.0 INTRODUCTION

1.1 SCOPE AND PURPOSE

This Bench-Scale Soil/Sediment Treatability Study Work Plan for Naval Construction Battalion Center (NCBC) Gulfport, Site 8, Herbicide Orange Study Area (Site 8) has been prepared by Tetra Tech NUS, Inc. (TtNUS) for the Southern Division Naval Facilities Engineering Command (SOUTHDIVNAVFACENGCOM) under the Navy Comprehensive Long-Term Environmental Action Navy (CLEAN) Program, Contract Number N62467-94-D-0888, Contract Task Order (CTO) 0143. The purpose of this Work Plan is to define the objectives of the soil and sediment stabilization bench-scale treatability study and provide a detailed description of planned testing activities.

1.2 SITE HISTORY AND PROJECT BACKGROUND

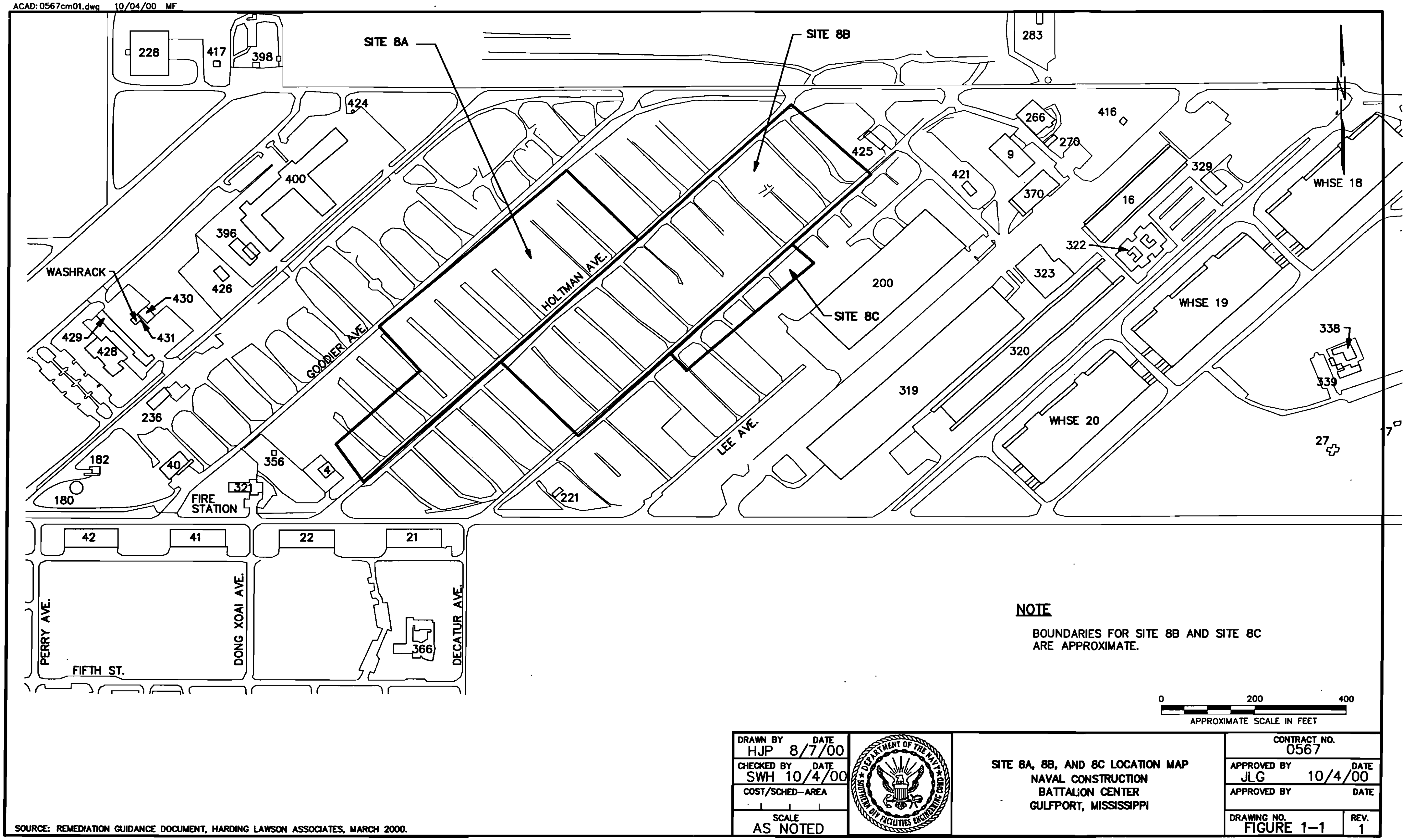
Site 8 occupies approximately 30 acres in the north central section of NCBC Gulfport. From 1968 to 1977, the site was used by the U.S. Air Force (USAF) for the storage of approximately 850,000 gallons of Herbicide Orange (HO) in 55-gallon drums. It was originally believed that only 12 acres of the site, designated as Site 8A, had been used for HO storage, but two additional storage areas were later identified, including 17-acre Site 8B and 1-acre Site 8C. Figure 1-1 shows the location of Sites 8A, 8B, and 8C.

The main chemical of concern at the site is 2,3,7,8-tetrachlorodibenzo-p-dioxin, or TCDD, which is a manufacturing impurity of the HO. In this document, TCDD and the other dioxins found in HO will be collectively referred to as "dioxin."

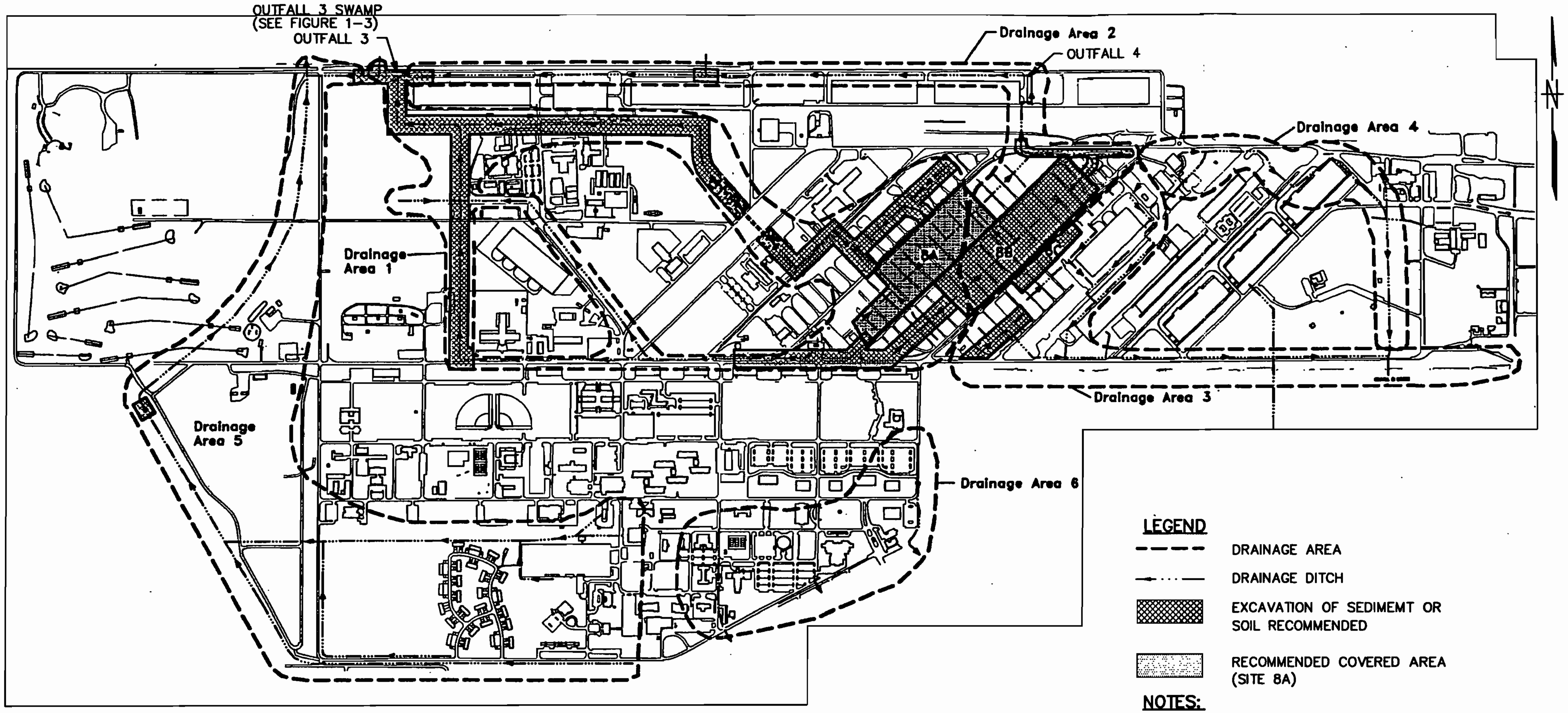
In 1977, the USAF disposed of the entire HO inventory by high-temperature incineration at sea. From 1987 to 1988, a quantity of dioxin-contaminated soil was treated on site by high-temperature incineration and the resulting ash were stored on Site 8A. This ash meets the dioxin delisting concentration criterion of 1.0 microgram per kilogram (µg/kg) set by the Mississippi Department of Environmental Quality (MSDEQ, 1997).

As a result of the spills and leaks that occurred during the years of HO storage, dioxin has migrated from Site 8 to the system of on-base ditches which drains surface runoff from the site and to the off-base swampland located across 28th Street from Outfall 3. Since dioxin has an affinity for soil and is not readily water soluble, this migration has primarily occurred through the erosion and transportation of contaminated soil from the site and deposition in the sediment of the on-base ditches and off-base swampland.

This page intentionally left blank.



FORM CADD NO. SDIV_BH.DWG - REV 0 - 1/20/98



LEGEND

– – – –	DRAINAGE AREA
–·–·–·–	DRAINAGE DITCH
(dark hatched)	EXCAVATION OF SEDIMEMT OR SOIL RECOMMENDED
(light stippled)	RECOMMENDED COVERED AREA (SITE 8A)

NOTES:

1) BOUNDARIES FOR SITE 8B AND SITE 8C ARE APPROXIMATE.
2) WIDTHS ACROSS DRAINAGE DITCHES ARE NOT TO SCALE.

0 500 1000
APPROXIMATE SCALE IN FEET

SOURCE: REMEDIATION GUIDANCE DOCUMENT, HARDING LAWSON ASSOCIATES, MARCH 2000.

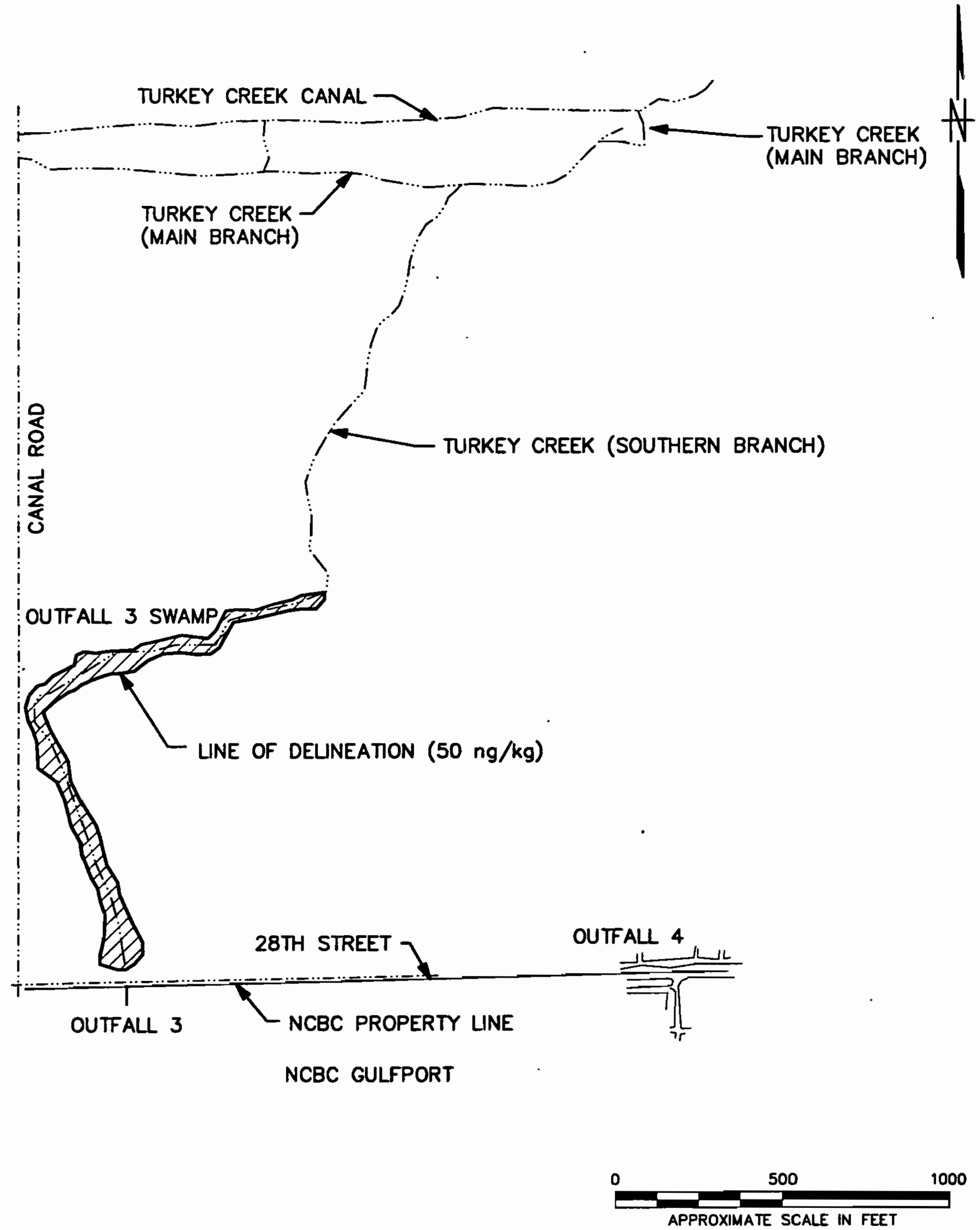
DRAWN BY HJP	DATE 8/7/00	
CHECKED BY SWH	DATE 10/4/00	
COST/SCHED-AREA		
SCALE AS NOTED		

AREAL EXTENT OF ON-BASE CONTAMINATED MEDIA
NAVAL CONSTURCTION BATTALION CENTER
GULFPORT, MISSISSIPPI

CONTRACT NO. 0567	
APPROVED BY JLG	DATE 10/4/00
APPROVED BY	DATE
DRAWING NO. FIGURE 1-2	REV. 1

FORM CADD NO. SDIV_BH.DWG - REV 0 - 1/20/98

ACAD: 0567CM02.dwg 08/07/00 HJP



SOURCE: REMEDIATION GUIDANCE DOCUMENT, HARDING LAWSON ASSOCIATES, MARCH 2000.

DRAWN BY HJP DATE 8/7/00	DEPARTMENT OF THE NAVY SOUTHERN DIV FACILITIES ENGINEERING COMD	AREAL EXTENT OF OFF-BASE CONTAMINATED MEDIA NAVAL CONSTRUCTION BATTALION CENTER GULFPORT, MISSISSIPPI	CONTRACT NO. 0567
CHECKED BY SWH DATE 10/4/00			APPROVED BY JLG DATE 10/4/00
COST/SCHED-AREA			APPROVED BY DATE
SCALE AS NOTED			DRAWING NO. FIGURE 1-3 REV. 1

FORM CADD NO. SDIV_AV.DWG - REV 0 - 1/20/98

The objectives of this bench-scale treatability study are as follows:

- Determine the compaction and strength characteristics of the anticipated material blend as defined in Section 1.2.
- Determine the extent to which the compaction and strength characteristics of the anticipated material blend as defined in Section 1.2 are deteriorated by an increase in the content of its weakest component (i.e., sediment).
- Determine the extent to which the compaction and strength characteristics of the anticipated material blend as defined in Section 1.2 are improved by the addition of binding agents.

1.4 DOCUMENT ORGANIZATION

This Work Plan has four sections. Section 1.0 provides this brief introduction. Section 2.0 describes the field sampling and collection of the materials to be tested. Section 3.0 describes bench-scale testing procedures. Section 4.0 describes test reporting procedures and provides a project schedule.

2.0 FIELD SAMPLING AND COLLECTION OF TEST MATERIALS

2.1 TEST MATERIALS QUANTITIES

Samples of the materials to be consolidated at Site 8A will be collected in quantities sufficient for performance of the tests described in Section 3.0. It is estimated that a total of approximately 140 gallons (or 1,680 pounds) of materials will be required for this purpose.

Samples of individual materials will be collected in quantities proportional to the estimated volumes of these same materials as defined in Section 1.2. Given current estimates, quantities of individual materials to be collected are as follows:

Material	Collected Quantity (gallons/pounds)
Site 8A Incinerated Soil Ash	50/600
On-Base Ditches Contaminated Sediment	60/720
Off-Base Swamp Contaminated Sediment	30/360
Total	**140/1,680**

It should be noted that the previously-mentioned Site 8A construction debris are not included in the above list. This is because these debris represent only approximately 1 percent of the total volume of materials to be placed under the cap and, based upon experience with similar projects, the structural characteristics of such debris are suitable for H20 loading.

In addition to the above-listed materials, approximately 10 gallons (or 120 pounds) of Type F fly ash will be obtained from a Gulfport area electric power generating station and approximately 10 gallons (or 120 pounds) of cement kiln dust (CKD) will also be obtained locally for use as binding agents.

2.2 SAMPLES COLLECTION PROCEDURES

The testing objectives defined in Section 1.3 are strictly of a geotechnical nature (i.e., to establish the suitability of the load-bearing characteristics of the material blend to be consolidated and determine if stabilization of that blend is required). Therefore, fulfillment of these objectives does not specifically require the use of dioxin-contaminated materials, and samples of the Sites 8B and 8C soil, on-base drainage ditches sediment, and off-base swamp sediment will be collected immediately outside of the known area(s) of contamination to provide non-contaminated materials with representative geotechnical characteristics. This will greatly facilitate sample collection and shipment of the test materials, which will not require elaborate hazardous materials manifesting.

The necessary quantities of the materials identified in Section 2.1 will be manually collected using a hand trowel or shovel. Each type of material will be collected from multiple locations (typically up to five) and field-composited to provide a representative range of site conditions. If significant free water is observed in the swamp or drainage ditch sediment, samples of these materials will be collected in such a way as to include an amount of water representative of that which would remain in the sediment if this material was removed with typical excavation equipment, such as a backhoe or dragline. Each type of composited material will be containerized separately in U.S. Department of Transportation (DOT) approved 5-gallon plastic buckets labeled to identify their contents.

3.0 TREATABILITY TESTING

3.1 MATERIALS BLENDING

Samples of the materials to be consolidated at Site 8A, as collected in the field, will be received at the TtNUS Pittsburgh testing facility. Each of the materials will first be handled in the following manner:

- Any observed free standing water will be decanted and drained.
- Off-size particles and debris will be removed by screening the material through a ¾ -inch sieve.
- The decanted and screened material will be tested for moisture content in accordance with American Society for Testing and Materials (ASTM) Method D2216-98. A copy of this ASTM test method is provided in Appendix A.

Approximately one third of all the samples will then be mixed together in the proportions defined in Section 2.1 to form 45 gallons (or approximately 560 pounds) of a homogeneous mix, hereafter referred to in this work plan as the Material Blend. This will be accomplished by using a small-scale concrete mixer.

The Material Blend will then be used for the testing described in the following sections while the remaining individual materials will be kept in reserve, either to produce additional Material Blend or to modify its composition, as may be required.

3.2 GEOTECHNICAL TESTING OF MATERIAL BLEND

Geotechnical testing will be conducted in either a two-or three-tiered fashion. First-tier tests will be performed on the Material Blend to determine its structural strength characteristics. If the strength characteristics of the Material Blend are determined to be acceptable, second-tier tests will be performed to determine to which extent an increase in sediment content would deteriorate these characteristics. If the strength characteristics of the Material Blend are determined to be non-acceptable, second-tier tests will be performed to determine if these characteristics can be made acceptable through addition of binding agents. In this latter case, third-tier tests might also be performed to determine if the addition of binding agents could also effectively counteract an increase in sediment content.

3.2.1 First-Tier Tests

The following tests will be performed on the Material Blend:

- Moisture-density relationship test (Proctor test) in accordance with ASTM Method D698-91.
- California Bearing Ratio (CBR) in accordance with ASTM Method D1883-99 (recompacted at 95% of maximum dry density as determined by ASTM Method D698-91).
- Penetrometer test (i.e., unconfined compressive strength).

Performance of these tests will be subcontracted to a specialized geotechnical testing laboratory. Copy of these ASTM test methods is provided in Appendix A.

3.2.2 Second-Tier Tests

3.2.2.1 Increased Sediment Content

The sensitivity of the first-tier tests results will be evaluated by performing second-tier tests on a Material Blend modified by adding sediments to determine the extent to which a higher proportion of the weakest component would deteriorate compaction and strength characteristics.

For this purpose, the following design mixes will be prepared to increase the sediment content of the Material Blend as follows:

Design Mix No.	Composition (%, by weight)
GFP-08-MB-02-SD15	85% Material Blend + 15% Sediment
CFP-08-MB-02-SD30	70% Material Blend + 30% Sediment

The above design mixes will then be tested for moisture-density relationship in accordance to ASTM Method D698-91 and CBR in accordance to ASTM Method D1883-99 to determine the suitability of their compaction and strength characteristics. Copy of these ASTM test methods is provided in Appendix A.

Design mixes will be prepared at the TtNUS Pittsburgh testing facility. Geotechnical testing of these mixes will be subcontracted to a specialized geotechnical testing laboratory.

3.2.2.2 Binding Agents Addition

The sensitivity of the first-tier tests results will also be evaluated by performing second-tier tests on a Material Blend modified by adding binding agents to determine the extent to which such an addition would improve compaction and strength characteristics.

Two types of binding agents have been selected for testing: CKD and Type F fly ash. These agents were selected based upon past experience with similar projects, local availability, and cost.

The following design mixes will be prepared and tested for moisture-density relationship in accordance to ASTM Method D558-96 and CBR in accordance to ASTM Method D1883-99:

Design Mix No.	Composition (%, by weight)
GFP-08-MB-02-CK05	95% Material Blend + 5% CKD
GFP-08-MB-02-CK6	90% Material Blend + 10% CKD
GFP-08-MB-02-CK15	85% Material Blend + 15% CKD
GFP-08-MB-02-FA05	95% Material Blend + 5% Fly ash
GFP-08-MB-02-FA10	90% Material Blend + 10% Fly ash
GFP-08-MB-02-FA15	85% Material Blend + 15% Fly ash

The above design mixes will be prepared at the TtNUS Pittsburgh testing facility. Geotechnical testing of these mixes will be subcontracted to a specialized geotechnical testing laboratory. A copy of these ASTM test methods is provided in Appendix A.

3.2.3 Third-Tier Tests (Optional)

As previously mentioned, third-tier tests may be performed on one or more of the binding agent design mixes described in Section 3.2.2.2. These tests would evaluate the extent to which an increase in the percentage of sediment would deteriorate the strength characteristics of the design mixes. These tests would essentially be identical to those described in Section 3.2.2.1, except that they would be performed with one or more of the design mixes defined in Section 3.2.2.2. instead of the Material Blend.

4.0 REPORTING AND SCHEDULE

4.1 REPORT

Once the analytical results from all the testing activities have been received, a letter-type report will be prepared which will include the following elements:

- Description of the field sampling test materials gathering procedures, including copies of sample custody forms.
- Description of the bench-scale testing procedures.
- Presentation of the bench-scale testing results, including geotechnical laboratory data sheets.
- Treatability study conclusions and recommendations.

4.2 SCHEDULE

It is anticipated that the bench-scale treatability study will be completed within 20 weeks. Anticipated project schedule is summarized as follows:

Activity	Start	End
Prepare Draft Work Plan	07/28/00	08/07/00
Submit Draft Work Plan	08/07/00	08/07/00
Navy/Air Force Review of Draft Work Plan	08/08/00	09/01/00
Prepare Final Work Plan	08/22/00	08/28/00
Submit Final Work Plan	08/28/00	08/28/00
Field Sampling and Test Materials Collection	08/22/00	08/24/00
Contaminated Materials Volumes Reassessment	08/25/00	09/14/00
Bench-Scale Testing	09/05/00	10/20/00
Prepare Draft Letter Report	10/16/00	11/03/00
Submit Draft Letter Report	11/03/00	11/03/00
Navy/Air Force Review of Draft Letter Report	11/06/00	11/27/00
Prepare Final Letter Report	11/28/00	12/12/00
Submit Final Letter Report	12/12/00	12/12/00

REFERENCES

AASHO (American Association of State Highway Officials), 1973. *Standard Specifications for Highway Bridges.* Eleventh Edition.

MSDEQ (Mississippi Department of Environmental Quality), 1997. *Agreed Order No. 3466-97.* November 5.

APPENDIX A

ASTM TEST METHODS

Standard Test Methods for Moisture-Density Relations of Soil-Cement Mixtures[1]

This standard is issued under the fixed designation D 558; 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. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

. Scope*

1.1 These test methods cover the determination of the elationship between the water content and the density of oil-cement mixtures when compacted before cement hydraion as prescribed.

1.2 A 1/30-ft³ (944-cm³) mold and a 5.5-lb (2.49-kg) ammer dropped from a height of 12 in. (304.8 kg) are used ınd two methods, depending on soil gradation, are covered, ıs follows:

	Sections
Test Method A, using soil material passing a No. 4 (4.75-mm) sieve. This method shall be used when 100 % of the soil sample passes the No. 4 (4.75-mm) sieve	5
Test Method B, using soil material passing a ¾-in. (19.0-mm) sieve. This method shall be used when part of the soil sample is retained on the No. 4 (4.75-mm) sieve. This test method may be used only on materials with 30 % or less retained on the ¾-in. (19.0-mm) sieve	6

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

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

2. Referenced Documents

2.1 *ASTM Standards:*

C 150 Specification for Portland Cement[2]

C 595 Specification for Blended Hydraulic Cements[2]

D 559 Test Methods for Wetting-and-Drying Tests of Compacted Soil-Cement Mixtures[3]

D 560 Test Methods for Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures[3]

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[3]

D 2168 Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors[3]

D 3740 Practice for the Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock Used in Engineering Design and Construction[3]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[4]

3. Significance and Use

3.1 These tests determine the optimum water content and maximum density to be used for molding soil-cement specimens in accordance with Methods D 559 and D 560.

NOTE 1—Since these tests are used in conjunction with Methods D 559 and D 560 and the criteria referenced therein, the test differs in several aspects from Test Methods D 698.

NOTE 2—The agency performing these test methods can be evaluated in accordance with Practice D 3740. Not withstanding statements on precision and bias contained in these test methods: the precision of 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 D 3740 are generally considered capable of competent and objective testing. Users of these test methods are cautioned that compliance with Practice D 3740 does not, in itself, ensure reliable testing. Reliable testing depends on many factors; Practice D 3740 provides a means of evaluating some of these factors.

4. Apparatus

4.1 *Mold*—A cylindrical metal mold having a capacity of 1/30 ± 0.0004 ft³ (944 ± 11 cm³) with an internal diameter of 4.0 ± 0.016 in. (101.60 ± 0.41 mm) and conforming to Fig. 1 to permit preparing compacted specimens of soil-cement mixtures of this size. The mold shall be provided with a detachable collar assembly approximately 2½ in. (63.5 mm) in height. The mold may be of the split type consisting of two half-round sections or section of pipe with one side split perpendicular to the pipe circumference and that can be securely locked in place to form a closed cylinder having the dimensions described above. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base (Fig. 1).

4.2 *Rammer:*

4.2.1 *Manual Rammer*—A manually operated metal rammer having a 2.0 ± 0.005-in. (50.80 ± 0.13-mm) diameter circular face and weighing 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The rammer shall be equipped with a suitable guidesleeve to control the height of drop to a free fall of 12.0

---

[1] These test methods are under the jurisdiction of ASTM Committee D-18 on Soil and Rock and are the direct responsibility of Subcommittee D18.15 on Stabilization of Additives.

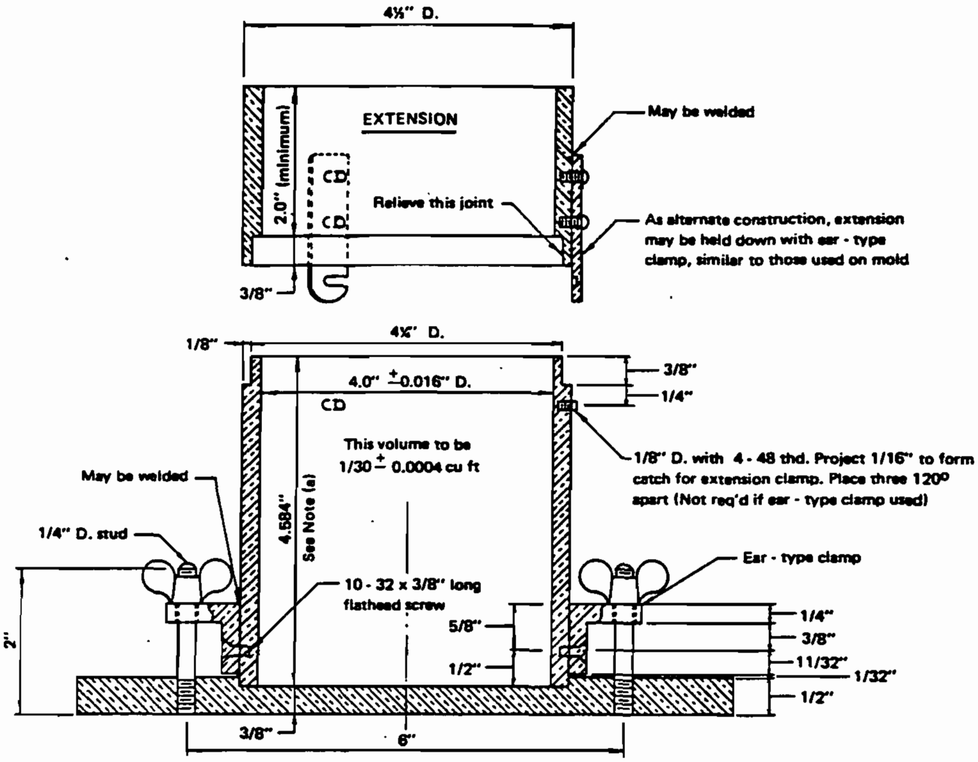
Current edition approved May 10, 1996. Published June 1996. Originally published as D 558 – 38. Last previous edition D 558 – 82 (1990)$^{\epsilon 1}$.

[2] *Annual Book of ASTM Standards*, Vols 04.01 and 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

[4] *Annual Book of ASTM Standards*, Vols 04.01, 04.06, and 14.02.

* A Summary of Changes section appears at the end of test methods.



Metric Equivalents

in.	mm
0.016	0.41
0.026	0.66
1/32	0.80
1/16	1.6
1/8	3.2
1/4	6.4
11/32	8.7
3/8	9.5
1/2	12.7
5/8	15.9
2	50.8
2 1/2	63.5
4	101.6
4 1/4	108.0
4 1/2	114.3
4.584	116.43
6	152.4
6 1/2	165.1
8	203.2
ft³	**cm³**
1/30	944
0.004	11
1/13.333	2124
0.0009	25

NOTE (a)—The tolerance on the height is governed by the allowable volume and diameter tolerances.

NOTE (b)—The methods shown for attaching the extension collar to the mold and the mold to the base plate are recommended. However, other methods are acceptable providing the attachments are equally as rigid as those shown.

FIG. 1 Cylindrical Mold

± 1/16 in. (304.8 ± 1.6 mm) above the elevation of the soil-cement. The guidesleeve shall have at least four vent holes not smaller than 3/8 in. (9.5 mm) spaced 90° apart and located with centers 3/4 ± 1/16 in. (19.0 ± 1.6 mm) from each end and shall provide sufficient clearance that free-falls of the rammer shaft and head will not be restricted.

4.2.2 *Mechanical Rammer*—A mechanically operated metal rammer having a 2.0 ± 0.005-in. (50.80 ± 0.13-mm) diameter face and a manufactured mass of 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The operating mass of the rammer shall be determined from a calibration in accordance with Method D 2168. The rammer shall be equipped with a suitable arrangement to control the height of drop to a free-fall of 12.0 ± 1/16 in. (304.8 ± 1.6 mm) above the elevation of the soil-cement.

4.2.3 *Rammer Face*—A sector face may be substituted with mechanical rammers provided the report shows that a sector face rammer was used. The sector face shall be a sector of a 4.0 ± 0.016-in. (101.60 ± 0.41-mm) diameter circle and shall have an area equal to that of the circular face rammer.

NOTE 3—The sector face rammer shall not be used to compact test specimens in accordance with Methods D 559 and D 560, unless previous tests on like soils show strength and resistance to wetting-and-drying and freezing-and-thawing of specimens compacted with this rammer are similar to that of specimens compacted with the circular face rammer.

4.3 *Sample Extruder*—A jack, lever frame, or other device adapted for the purpose of extruding compacted specimens from the mold. Not required when a split-type mold is used.

4.4 *Balances*—A balance or scale of at least 25-lb (11.3-kg) capacity sensitive to 0.01 lb (0.005 kg) and a balance of at least 1000-g capacity sensitive to 0.1 g.

4.5 *Drying Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 230 ± 9°F (110 ± 5°C) for drying water content samples.

4.6 *Straightedge*—A rigid steel straight-edge 12 in. (305 mm) in length and having one beveled edge.

4.7 *Sieves*—3-in. (75-mm), ¾-in. (19.0-mm), and No. 4 (4.75-mm) sieves conforming to the requirements of Specification E 11.

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

4.9 *Container*—A flat, round pan for moisture absorption by soil-cement mixtures, about 12 in. (305 mm) in diameter and 2 in. (50 mm) deep.

4.10 *Moisture Cans*—Suitable containers for moisture samples.

4.11 *Butcher Knife*—A butcher knife approximately 10 in. (250 mm) in length for trimming the top of the specimens.

5. Test Method A, Using Soil Material Passing a No. 4 (4.75-mm) Sieve

5.1 *Sample:*

5.1.1 Prepare the sample for testing by breaking up the soil aggregations to pass the No. 4 (4.75-mm) sieve in such a manner as to avoid reducing the natural size of the individual particles. When necessary, first dry the sample until it is friable under a trowel. Drying may be accomplished by air drying or by the use of drying apparatus such that the temperature of the sample does not exceed 140°F (60°C).

5.1.2 Select a representative sample, weighing approximately 6 lb (2.7 kg) or more, of the soil prepared as described in 5.1.1.

5.2 *Procedure:*

5.2.1 Add to the soil the required amount of cement conforming to Specification C 150 or Specification C 595. Mix the cement and soil thoroughly to a uniform color.

5.2.2 When needed, add sufficient potable water to dampen the mixture to approximately four to six percentage points below the estimated optimum water content and mix thoroughly. At this moisture content, plastic soils, tightly squeezed in the palm of the hand, will form a cast that will fracture with only slight pressure applied by the thumb and fingertips; nonplastic soils will bulk noticeably.

5.2.3 When the soil is a heavy-textured clayey material, compact the mixture of soil, cement, and water in the container to a depth of about 2 in. (50 mm) using the rammer described in 4.2 or a similar hand tamper. Cover, and allow to stand for not less than 5 min but not more than 10 min to aid dispersion of the moisture and to permit more complete absorption by the soil-cement.

5.2.4 After the absorption period, thoroughly break up the mixture, without reducing the natural size of individual particles, until it will pass a No. 4 (4.75-mm) sieve and then remix.

5.2.5 Form a specimen by compacting the prepared soil-cement mixture in the mold, with the collar attached, in three equal layers so as to give a total compacted depth of about 5 in. (130 mm). Compact each layer by 25 blows from the rammer dropping free from a height of 12 in. (304.8 mm) above the elevation of the soil-cement when a sleeve-type rammer is used, or from 12 in. (304.8 mm) above the approximate elevation of each finally compacted layer when a stationary-mounted type rammer is used. The blows shall be uniformly distributed over the surface of the layer being compacted. During compaction, the mold shall rest on a uniform, rigid foundation such as provided by a cylinder or a cube of concrete weighing not less than 200 lb (91 kg).

5.2.6 Following compaction, remove the extension collar, carefully trim the compacted mixture even with the top of the mold by means of the knife and straightedge, and weigh.

5.2.7 Multiply the mass of the compacted specimen and mold, minus the mass of the mold, by 30 (or divide by 942.95); record the result as the wet unit mass, γ_m, in pounds per cubic foot or grams per cubic centimetre, of the compacted soil-cement mixture.

5.2.8 Remove the material from the mold and slice vertically through the center. Take a representative sample of the material, weighing not less than 100 g, from the full height of one of the cut faces, weigh immediately, and dry in an oven at 230 ± 9°F (110 ± 5°C) for at least 12 h or to constant mass.

5.2.9 Calculate the water content of the sample as directed in Section 7. Record the result as the moisture content, *w*, of the compacted soil-cement mixture.

5.2.10 Thoroughly break up the remainder of the material as before until it will pass a No. 4 (4.75-mm) sieve, as judged by eye, and add all other material remaining after obtaining the moisture sample.

5.2.11 Add water in sufficient amount to increase the water content of the soil-cement mixture by one or two percentage points, mix, and repeat the procedure given in 5.2.5 to 5.2.10 for each increment of water added.

5.2.12 Continue this series of determinations until there is either a decrease or no change in the wet unit mass, γ_m, in pounds per cubic foot or grams per cubic centimetre of the compacted soil-cement mixture.

NOTE 4—This procedure has been found satisfactory in most cases. However, in instances where the soil material is fragile in character and will reduce significantly in grain size due to repeated compaction, a separate and new sample shall be used for each moisture-density determination.

NOTE 5—To minimize the effect of cement hydration, perform the test expeditiously and continuously to completion.

6. Test Method B, Using Soil Material Passing a 3/4-in. (19.0-mm) Sieve

6.1 *Sample:*

6.1.1 Prepare the sample for testing by segregating the aggregate retained on a No. 4 (4.75-mm) sieve and breaking up the remaining soil aggregations to pass the No. 4 (4.75-mm) sieve in such a manner as to avoid reducing the natural size of individual particles. When necessary, first dry the sample until it is friable under a trowel. Drying may be accomplished by air drying or by the use of drying apparatus such that the temperature of the sample does not exceed 140°F (60°C).

6.1.2 Sieve the prepared soil over the 3-in. (75-mm) (Note 2), 3/4-in., (19.0-mm), and No. 4 (4.75-mm) sieves. Discard the material retained on the 3-in. (75-mm) sieve. Determine the percentage of material, by oven-dry mass, retained on the 3/4-in. (19.0-mm) and No. 4 sieves.

6.1.3 Saturate the aggregate passing the 3/4-in. (19.0-mm) sieve and retained on the No. 4 (4.75-mm) sieve by soaking in potable water; surface-dry the material as required for later testing.

NOTE 6—Most soil-cement construction specifications covering soil gradation limit maximum size material to 3 in. (75 mm) or less.

6.1.4 Select and maintain separate representative samples of soil passing the No. 4 (4.75-mm) sieve and of saturated, surface-dry aggregate passing the 3/4-in. (19.0-mm) sieve and retained on the No. 4 sieve so that the total sample will weigh approximately 11 lb (4.99 kg) or more. The percentage, by oven-dry mass, of aggregate passing the 3/4-in. (19.0-mm) sieve and retained on the No. 4 (4.75-mm) sieve shall be the same as the percentage passing the 3-in. (75-mm) sieve and retained on the No. 4 sieve in the original sample.

6.2 *Procedure:*

6.2.1 Add to the portion of the soil sample passing the No. 4 sieve, the amount of cement conforming to Specification C 150 or Specification C 595, required for the total sample specified in 6.1.4. Mix the cement and soil thoroughly to a uniform color.

6.2.2 When needed, add water to this soil-cement mixture and facilitate moisture dispersion as described for Method A in 5.2.2 to 5.2.4. After this preparation, add the saturated, surface-dry aggregate to the soil-cement mixture passing the No. 4 (4.75-mm) sieve and mix thoroughly.

6.2.3 Form a specimen by compacting the prepared soil-cement mixture in the mold (with the collar attached) and trim and weigh the compacted specimen as described for Method A in 5.2.5 and 5.2.6. During the trimming operation remove all particles that extend above the top level of the mold. Correct all irregularities in the surface by hand-tamping fine material into these irregularities and leveling the specimen again with the straightedge.

6.2.4 Multiply the mass of the compacted specimen and mold, minus the mass of the mold, by 30 (or divide by 942.95); record the result as the wet unit mass, γ_m, in pounds per cubic foot or grams per cubic centimetre of the compacted soil-cement mixture.

6.2.5 Remove the material from the mold and take a sample for determining the water content as described for Method A in 5.2.8 and 5.2.9 except that the moisture sample shall weigh not less than 500 g. Record the result as the water content, w, of the compacted soil-cement mixture.

6.2.6 Thoroughly break up the remainder of the materi as before until it will pass a 3/4-in. (19.0-mm) sieve and least 90 % of the soil particles smaller than a No. (4.75-mm) sieve will pass a No. 4 sieve, as judged by eye, ar add all other material remaining after obtaining the moistu sample.

6.2.7 Add sufficient water to increase the water content the soil-cement mixture by one or two percentage poin mix, and repeat the procedure described in 6.2.3 to 6.2.6 f each increment of water added. Continue this series determinations until there is either a decrease or no chan in the wet unit mass, γ_m, in pounds per cubic foot or gran per cubic centimetre of the compacted soil-cement mixtu (Notes 3 and 4).

7. Calculation

7.1 Calculate the water content and dry unit mass, γ_d, pounds per cubic foot or grams per cubic centimetre of tl compacted soil-cement mixture for each trial as follows:

$$w = [(A - B)/(B - C)] \times 100$$
$$\gamma = [\gamma_m/(w + 100)] \times 100$$

where:

w = percentage of water in the specimen,
A = mass of moisture can and wet soil-cement,
B = mass of moisture can and oven-dry soil-cement,
C = mass of moisture can,
γ_d = dry unit mass of compacted soil cement, lb/ft^3 (g/cm^3, and
γ_m = wet unit mass of compacted soil-cement, lb/ft^3 (g/cm^3.

8. Moisture-Density Relationship

8.1 The calculations in Section 7 shall be made determine the water content and corresponding dry un mass, γ_d, in pounds per cubic foot or grams per cub centimetre (density) for each of the compacted soil-ceme samples. The dry unit mass, γ_d, in pounds per cubic foot grams per cubic centimetre (densities) of the soil-ceme mixture shall be plotted as ordinates and the correspondi moisture contents as abscissas.

8.2 *Optimum Water Content,* w_o—When the densiti and corresponding moisture contents for the soil-ceme mixture have been determined and plotted as indicated 8.1 it will be found that by connecting the plotted points wi a smooth line, a curve is produced. The water conte corresponding to the peak of the curve shall be termed tl "optimum moisture content" of the soil-cement mixtu under the compaction prescribed in these methods.

8.3 *Maximum Density,* γ_{max}—The dry unit mass, γ_d, pounds per cubic foot or grams per cubic centimetre of tl soil-cement mixture at "optimum water content" shall l termed "maximum density" under the compaction pr scribed in these test methods.

9. Report

9.1 The report shall include the following:

9.1.1 Optimum water content, and

9.1.2 Maximum density.

0. Precision and Bias

10.1 *Precision*—Data are being sought by the subcom-nittee for the preparation of a statement on the precision of his test procedure. Until a statement is developed, the user nay be guided by the statement in Test Method D 698, for vhich the precision is expected to be similar.

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

11 Keywords

11.1 compaction; dry density; optimum water content; soil-cement; soil-stabilization; unit weight

SUMMARY OF CHANGES

This section identifies the principal changes to these test methods that have been incorporated since the last issue.

(1) Added new sentence at the end of Section 1.2, Test Method B, to clarify the applicable materials as required in Test Method D 698 when using a 4-in. (101.60-mm) mold.

(2) Added safety caveat in 1.4 to comply with present policy.

(3) Added Practice D 3740 as a referenced document in Section 2 to conform to the recommended D-18 practice.

(4) Added new Note 2 in Section 3 to reference Practice D 3740. Renumbered the remaining notes.

(5) Revised Section 11 on Keywords.

(6) Added new Section 12 on Summary of Changes to reflect the changes made in this revision.

(7) Changed "moisture content" to "water content" in Sections 1.1, 3.1, 4.5, 5.2.2, 5.2.9, 5.2.1.1, 6.2.5, 6.2.7, 7.1, 8.1, 8.2, 8.3, and 9 to agree with current D-18 Terminology.

Designation: D 698 – 91 (Reapproved 1998)

Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3(600 kN-m/m^3))[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.

1. Scope

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

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

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

1.2 This test method applies only to soils that have 30 % or less by weight of particles retained on the ¾-inch (19.0-mm) sieve.

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

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

1.3.1 *Procedure A*:

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

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

1.3.1.3 *Layers*—Three.

1.3.1.4 *Blows per layer*—25.

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

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

1.3.2 *Procedure B*:

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

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

1.3.2.3 *Layers*—Three.

1.3.2.4 *Blows per layer*—25.

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

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

1.3.3 *Procedure C*:

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

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

1.3.3.3 *Layers*—Three.

1.3.3.4 *Blows per layer*—56.

1.3.3.5 *Use*—Shall be used if more than 20 % by weight of the material is retained on the ⅜-in. (9.5-mm) sieve and less than 30 % by weight 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 Procedure A or B.

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

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

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

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

1.6.1 In the engineering profession it is customary practice to use, interchangeably, units representing both mass and force, unless dynamic calculations ($F = Ma$) are involved. This implicitly combines two separate systems of units, that is, the absolute system and the gravimetric system. It is scientifically

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved Nov. 19, 1991. Published January 1992.

undesirable to combine the use of two separate systems within a single standard. This test method has been written using inch-pound units (gravimetric system) where the pound (lbf) represents a unit of force. The use of mass (lbm) is for convenience of units and is not intended to convey the use is scientifically correct. Conversions are given in the SI system in accordance with Practice E 380. The use of balances or scales recording pounds of mass (lbm), or the recording of density in lbm/ft^3 should not be regarded as nonconformance with this standard.

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

2. Referenced Documents

2.1 *ASTM Standards:*

C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate[2]

C 136 Method for Sieve Analysis of Fine and Coarse Aggregate[2]

D 422 Test Method for Particle Size Analysis of Soils[3]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[3]

D 854 Test Method for Specific Gravity of Soils[3]

D 1557 Test Methods for Moisture-Density Relations of Soils and Soil Aggregate Mixtures Using 10-lb (4.54-kg.) Rammer and 18-in. (457 mm) Drop[3]

D 2168 Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors[3]

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock and Soil-Aggregate Mixtures[3]

D 2487 Test Method for Classification of Soils for Engineering Purposes[3]

D 2488 Practice for Description of Soils (Visual-Manual Procedure)[3]

D 4220 Practices for Preserving and Transporting Soil Samples[3]

D 4253 Test Methods for Maximum Index Density of Soils Using a Vibratory Table[3]

D 4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles[3]

D 4753 Specification for Evaluating, Selecting and Specifying Balances and Scales For Use in Soil and Rock Testing[3]

E 1 Specification for ASTM Thermometers[4]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[5]

E 319 Practice for the Evaluation of Single-Pan Mechanical Balances[5]

E 380 Practice for Use of the International System of Units (SI) (the Modernized Metric System)[5]

[2] *Annual Book of ASTM Standards*, Vol 04.02.
[3] *Annual Book of ASTM Standards*, Vol 04.08.
[4] *Annual Book of ASTM Standards*, Vol 14.03.
[5] *Annual Book of ASTM Standards*, Vol 14.02.

3. Terminology

3.1 *Definitions:* See Terminology D 653 for general d tions.

3.2 *Description of Terms Specific to This Standard:*

3.2.1 *oversize fraction (coarse fraction), P_c* in %- portion of total sample not used in performing the compa test; it may be the portion of total sample retained on th 4 (4.75-mm), ⅜-in. (9.5-mm), or ¾-in. (19.0-mm) sieve.

3.2.2 *standard effort*—the term for the 12,400 ft-lbf/ft kN-m/m^3) compactive effort applied by the equipment procedures of this test.

3.2.3 *standard maximum dry unit weight, γ_{dmax}* in l (kN/m^3)—the maximum value defined by the compa curve for a compaction test using standard effort.

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

3.2.5 *test fraction (finer fraction), P_F* in %—the porti the total sample used in performing the compaction test the fraction passing the No. 4 (4.75-mm) sieve in Procedu minus ⅜-in. (9.5-mm) sieve in Procedure B, or minus (19.0-mm) sieve in Procedure C.

4. Summary of Test Method

4.1 A soil at a selected water content is placed in layers into a mold of given dimensions, with each compacted by 25 or 56 blows of a 5.5-lbf (24.4-N) ra dropped from a distance of 12-in. (305-mm), subjecting th to a total compactive effort of about 12,400 ft-lbf/ft^3 kN-m/m^3). The resulting dry unit weight is determined procedure is repeated for a sufficient number of water co to establish a relationship between the dry unit weight an water content for the soil. This data, when plotted, repres curvilinear relationship known as the compaction curve values of optimum water content and standard maximur unit weight are determined from the compaction curve.

5. Significance and Use

5.1 Soil placed as engineering fill (embankments, fo tion pads, road bases) is compacted to a dense state to c satisfactory engineering properties such as, shear str compressibility, or permeability. Also, foundation soil often compacted to improve their engineering prop Laboratory compaction tests provide the basis for deterr the percent compaction and water content needed to ac the required engineering properties, and for controlling struction to assure that the required compaction and contents are achieved.

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

6. Apparatus

6.1 *Mold Assembly*—The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and dimensions indicated in 6.1.1 or 6.1.2 and Fig. 1 and Fig. 2. The walls of the mold may be solid, split, or tapered. The "split" type may consist of two half-round sections, or a section of pipe split along one element, which can be securely locked together to form a cylinder meeting the requirements of this section. The "tapered" type shall an internal diameter taper that is uniform and not more than 0.200 in./ft (16.7- mm/m) of mold height. Each mold shall have a base plate and an extension collar assembly, both made of rigid metal and constructed so they can be securely attached and easily detached from the mold. The extension collar assembly shall have a height extending above the top of the mold of at least 2.0 in. (50.8-mm) which may include an upper section that flares out to form a funnel provided there is at least a 0.75 in. (19.0-mm) straight cylindrical section beneath it. The extension collar shall align with the inside of the mold. The bottom of the base plate and bottom of the centrally recessed area that accepts the cylindrical mold shall be planar.

6.1.1 *Mold, 4 in.*—A mold having a 4.000 ± 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 ft^3 (944 ± 14 cm^3). A mold assembly having the minimum required features is shown in Fig. 1.

6.1.2 *Mold, 6 in.*—A mold having a 6.000 ± 0.026-in. (152.4 ± 0.7-mm) average inside diameter, a height of 4.584 ± 0.018-in. (116.4 ± 0.5-mm), and a volume of 0.075 ± 0.0009 ft^3 (2124 ± 25 cm^3). 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 ± 0.05-in. (304.8 ± 1.3-mm) from the surface of the specimen. The mass of the rammer shall be 5.5 ± 0.02-lbm (2.5 ± 0.01-kg), except that the mass 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

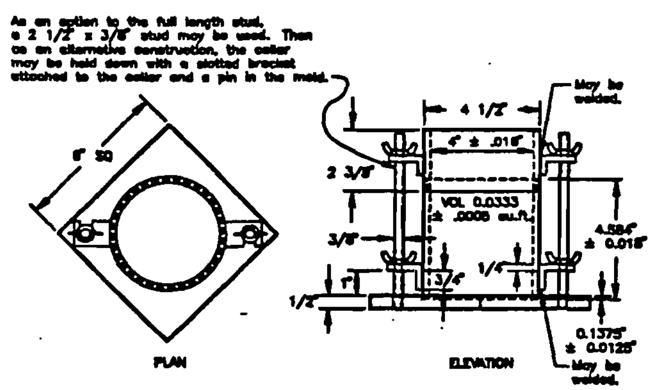


FIG. 1 4.0-In. Cylindrical Mold

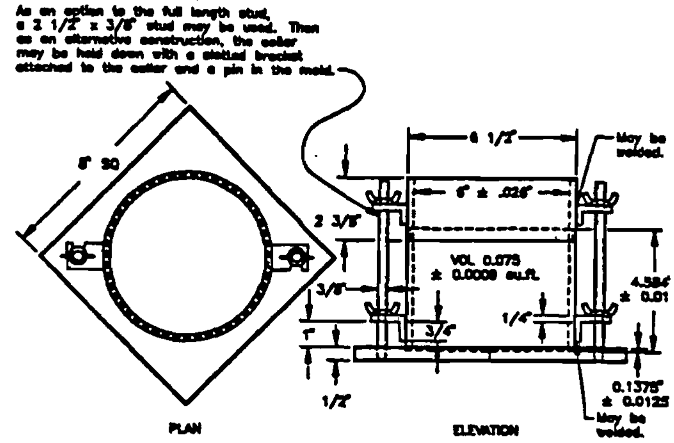


FIG. 2 6.0-In. Cylindrical Mold

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

6.2.1 *Manual Rammer*—The rammer shall be equipped with a guide sleeve that has sufficient clearance that the free fall of the rammer shaft and head is not restricted. The guide sleeve shall have at least four vent holes at each end (eight holes total) located with centers ¾ ± 1/16-in. (19.0 ± 1.6-mm) from each end and spaced 90 degrees apart. The minimum diameter of the vent holes shall be ⅜-in. (9.5-mm). Additional holes or slots may be incorporated in the guide sleeve.

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

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

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

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

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

6.6 *Straightedge*—A stiff metal straightedge of any convenient length but not less than 10-in. (254-mm). The total length of the straightedge shall be machined straight to a tolerance of

±0.005-in. (±0.1-mm). The scraping edge shall be beveled if it is thicker than ⅛-in. (3-mm).

6.7 *Sieves*—¾-in. (19.0-mm), ⅜-in. (9.5-mm), and No. 4 (4.75-mm), conforming to the requirements of Specification E 11.

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

7. Calibration

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

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

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

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

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

8. Test Sample

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

8.2 Determine the percentage of material retained on the No. 4 (4.75-mm), ⅜-in. (9.5-mm), or ¾-in. (19.0-mm) sieve as appropriate for choosing Procedure A, B, or C. Make this determination by separating out a representative portion from the total sample and determining the percentages passing the sieves of interest by Test Methods D 422 or Method C 136. It is only necessary to calculate percentages for the sieve or sieves for which information is desired.

9. Preparation of Apparatus

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

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

10. Procedure

10.1 *Soils*:

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

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

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

10.2 *Moist Preparation Method (preferred)*—Without viously drying the sample, pass it through a No. 4 (4.75-m ⅜-in. (9.5-mm), or ¾-in. (19.0-mm) sieve, depending on procedure (A, B, or C) being used. Determine the water con of the processed soil.

10.2.1 Prepare at least four (preferably five) specim having water contents such that they bracket the estim optimum water content. A specimen having a water con close to optimum should be prepared first by trial addition water and mixing (see Note 6). Select water contents for rest of the specimens to provide at least two specimens wet two specimens dry of optimum, and water contents varying about 2 %. At least two water contents are necessary on the and dry side of optimum to accurately define the dry weight compaction curve (see 10.5). Some soils with very optimum water content or a relatively flat compaction c may require larger water content increments to obtain a defined maximum dry unit weight. Water content increm should not exceed 4 %.

NOTE 6—With practice it is usually possible to visually judge a near optimum water content. Typically, soil at optimum water conten be squeezed into a lump that sticks together when hand pressu released, but will break cleanly into two sections when "bent". At contents dry of optimum soils tend to crumble; wet of optimum soils to stick together in a sticky cohesive mass. Optimum water conte typically slightly less than the plastic limit.

10.2.2 Use approximately 5-lbm (2.3-kg) of the sieved for each specimen to be compacted using Procedure A or 13-lbm (5.9-kg) using Procedure C. To obtain the speci water contents selected in 10.2.1, add or remove the requ amounts of water as follows: to add water, spray it into the during mixing; to remove water, allow the soil to dry in a ambient temperature or in a drying apparatus such that temperature of the sample does not exceed 140°F (60°C). the soil frequently during drying to maintain an even w content distribution. Thoroughly mix each specimen to en even distribution of water throughout and then place separate covered container and allow to stand in accord with Table 1 prior to compaction. For the purpose of selec a standing time, the soil may be classified using Test Me D 2487, Practice D 2488 or data on other samples from same material source. For referee testing, classification sha by Test Method D 2487.

10.3 *Dry Preparation Method*—If the sample is too dan be friable, reduce the water content by air drying until material is friable. Drying may be in air or by the use of dr apparatus such that the temperature of the sample does exceed 140°F (60°C). Thoroughly break up the aggregatio such a manner as to avoid breaking individual particles.

TABLE 1 Required Standing Times of Moisturized Specim

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

TABLE 2 Metric Equivalents for Figs. 1 and 2

in.	mm
0.016	0.41
0.026	0.66
0.032	0.81
0.028	0.71
½	12.70
2½	63.50
2⅝	66.70
4	101.60
4½	114.30
4.584	116.43
4¾	120.60
6	152.40
6½	165.10
6⅝	168.30
6¾	171.40
8¼	209.60
ft³	cm³
1/30 (0.0333)	943
0.0005	14
(0.0750)	2,124
0.0011	31

the material through the appropriate sieve: No. 4 (4.75-mm), ⅜-in. (9.5-mm), or ¾-in. (19.0-mm). When preparing the material by passing over the ¾-in. sieve for compaction in the 6-in. mold, break up aggregations sufficiently to at least pass the ⅜-in. sieve in order to facilitate the distribution of water throughout the soil in later mixing.

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

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

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

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

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

10.4.3 Compact the specimen in three layers. After compaction, each layer should be approximately equal in thickness. Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a fluffy or loose state, using either the manual compaction rammer or a 2-in. (5-mm) diameter cylinder. Following compaction of each of the first two layers, any soil adjacent to the mold walls that has not been compacted or extends above the compacted surface shall be trimmed. The trimmed soil may be included with the additional soil for the next layer. A knife or other suitable device may be used. The total amount of soil used shall be such that the third compacted layer slighly extends into the collar, but does not exceed ¼-in. (6-mm) above the top of the mold. If the third layer does extend above the top of the mold by more than ¼-in. (6-mm), the specimen shall be discarded. The specimen shall be discarded when the last blow on the rammer for the third layer results in the bottom of the rammer extending below the top of the compaction mold.

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

NOTE 7—When compacting specimens wetter than optimum water content, uneven compacted surfaces can occur and operator judgement is required as to the average height of the specimen.

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

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

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

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

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

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

11. Calculation

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

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

NOTE 8—The 100 % saturation curve is an aid in drawing the compaction curve. For soils containing more than approximately 10 % fines at water contents well above optimum, the two curves generally become roughly parallel with the wet side of the compaction curve between 92 % to 95 % saturation. Theoretically, the compaction curve cannot plot to the right of the 100 % saturation curve. If it does, there is an error in specific gravity, in measurements, in calculations, in test procedures, or in plotting.

NOTE 9—The 100 % saturation curve is sometimes referred to as the zero air voids curve or the complete saturation curve.

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

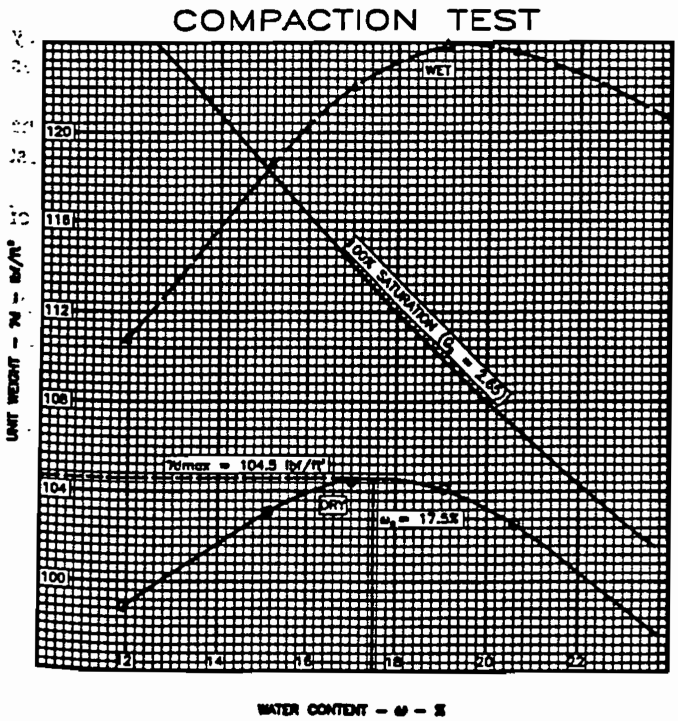


FIG. 3 Example Compaction Curve Plotting

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

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

where:

ρ_m = moist density of compacted specimen, Mg/m^3,
M_t = mass of moist specimen and mold, kg,
M_{md} = mass of compaction mold, kg, and
V = volume of compaction mold, m^3(see Annex A1)

$$\rho_d = \rho_m/(1 + w/100)$$

where:

ρ_d = dry density of compacted specimen, Mg/m^3, and
w = water content,% .

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

or

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

where:

γ_d = dry unit weight of compacted specimen.

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

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

where:

w_{sat} = water content for complete saturation, %,
γ_w = unit weight of water, 62.43 lbf/ft^3 (9.807 kn/m^3),
γ_d = dry unit weight of soil, and
G_s = specific gravity of soil.

NOTE 10—Specific gravity may be estimated for the test specimer the basis of test data from other samples of the same soil classification source. Otherwise, a specific gravity test (Test Method C 127, Test Met D 854, or both) is necessary.

12. Report

12.1 The report shall contain the following information

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

12.1.2 Preparation method used (moist or dry).

12.1.3 As received water content if determined.

12.1.4 Standard optimum water content, to the nea 0.5 %.

12.1.5 Standard maximum dry unit weight, to the nea 0.5 lbf/ft^3.

12.1.6 Description of rammer (manual or mechanical).

12.1.7 Soil sieve data when applicable for determinatio procedure (A, B, or C) used.

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

12.1.9 Specific gravity and method of determination.

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

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

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

13. Precision and Bias

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

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

14. Keywords

14.1 NT—impact compaction using standard effort; RT—density; RT—moisture-density curves; RT—proctor test; UF—compaction characteristics; UF—soil compaction; USE—laboratory tests

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 a water-filled method and checked by a linear-measurement method.

A1.2 Apparatus

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

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

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

A1.2.1.3 *Plastic or Glass Plates*—Two plastic or glass plates approximately 8 in. square by ¼ in. thick (200 by 200 mm by 6 mm).

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

A1.2.1.5 *Stopcock grease* or similar sealant.

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

A1.3 Precautions

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

A1.4 Procedure

A1.4.1 *Water-Filling Method*:

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

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

A1.4.1.3 Place the mold and the bottom 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 0.01-lbm (1-g).

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

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

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

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

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 Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, Ohio.

top of the mold and 6 times at the bottom of the mold, spacing each of the six top and bottom measurements equally around the circumference of the mold. Record the values to the nearest 0.001-in. (0.02-mm).

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

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

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

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

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

where:

V = volume of mold, ft^3 (cm^3),
h = average height, in. (mm),
d_t = average top diameter, in. (mm),
d_b = average bottom diameter, in. (mm),
$1/1728$ = constant to convert in^3 to ft^3, and
$1/10^3$ = constant to convert mm^3 to cm^3.

A1.5 Comparison of Results

A1.5.1 The volume obtained by either method should within the volume tolerance requirements of 6.1.1 and 6.1.

A1.5.2 The difference between the two methods should ı exceed 0.5 % of the nominal volume of the mold.

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

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

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

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils[1]

This standard is issued under the fixed designation D 1883; 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 test method covers the determination of the CBR (California Bearing Ratio) of pavement subgrade, subbase, and base/course materials from laboratory compacted specimens. The test method is primarily intended for but not limited to, evaluating the strength of cohesive materials having maximum particle sizes less than ¾ in. (19 mm).

NOTE 1—The agency performing this test can be evaluated in accordance with Practice D 3740.
Not withstanding statements on precision and bias contained in this Standard: The precision of this test method is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies which meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing. Users of this method are cautioned that compliance with Practice D 3740 does not in itself assure reliable testing. Reliable testing depends on many factors; Practice D 3740 provides a means of evaluating some of those factors.

1.2 When materials having maximum particle sizes greater than ¾ in. (19 mm) are to be tested, this test method provides for modifying the gradation of the material so that the material used for tests all passes the ¾-in. sieve while the total gravel (+No. 4 to 3 in.) fraction remains the same. While traditionally this method of specimen preparation has been used to avoid the error inherent in testing materials containing large particles in the CBR test apparatus, the modified material may have significantly different strength properties than the original material. However, a large experience base has developed using this test method for materials for which the gradation has been modified, and satisfactory design methods are in use based on the results of tests using this procedure.

1.3 Past practice has shown that CBR results for those materials having substantial percentages of particles retained on the No. 4 sieve are more variable than for finer materials. Consequently, more trials may be required for these materials to establish a reliable CBR.

1.4 This test method provides for the determination of the CBR of a material at optimum water content or a range of water content from a specified compaction test and a specified dry unit weight. The dry unit weight is usually given as a percentage of maximum dry unit weight from the compaction tests of Test Methods D 698 or D 1557.

1.5 The agency requesting the test shall specify the water content or range of water content and the dry unit weight for which the CBR is desired.

1.6 Unless specified otherwise by the requesting agency, or unless it has been shown to have no effect on test results for the material being tested, all specimens shall be soaked prior to penetration.

1.7 For the determination of CBR of field compacted materials, see Test Method D 4429.

1.8 The values stated in inch-pound units are to be regarded as the standard. The SI equivalents shown in parentheses may be approximate.

1.9 *This standard does not purport to address all of the safety problems, 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:*

D 422 Test Method for Particle-Size Analysis of Soils[2]
D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]
D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))[2]
D 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))[2]
D 2168 Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors[2]
D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[2]
D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[2]
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

Current edition approved Feb. 10, 1999. Published May 1999. Originally published as D 1883 – 61T. Last previous edition D 1883 – 94.

[2] *Annual Book of ASTM Standards*, Vol 04.08.

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

D 3740 Practice for Minimum Requirements of Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[2]

D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[2]

D 4429 Test Method for CBR (California Bearing Ratios) of Soils in Place[2]

3. Summary of Test Method

3.1 For tests performed on materials compacted to one water content, three specimens are prepared. The specimens are compacted using three different compactive efforts to obtain unit weights both above and below the desired unit weight. After allowing specimens to take on water by soaking, or other specified treatment such as curing, each specimen is subjected to penetration by a cylindrical rod. Results of stress (load) versus penetration depth are plotted to determine the CBR for each specimen. The CBR at the specified density is determined from a graph of CBR versus dry unit weight.

3.2 For tests in which the result is to be determined for a water content range, a series of specimens at each of three compactive efforts are prepared over the range of water content of interest. The compactive efforts are chosen to produce unit weights above and below the desired unit weight. After allowing the specimens to take on water by soaking, or other specified treatment such as curing, each specimen is penetrated. Results are plotted to obtain the CBR for each specimen. A plot of CBR versus unit weight for each water content is made to determine the minimum CBR for the water content range of interest.

4. Significance and Use

4.1 This test method is used to evaluate the potential strength of subgrade, subbase, and base course material, including recycled materials for use in road and airfield pavements. The CBR value obtained in this test forms an integral part of several flexible pavement design methods.

4.2 For applications where the effect of compaction water content on CBR is small, such as cohesionless, coarse-grained materials, or where an allowance is made for the effect of differing compaction water contents in the design procedure, the CBR may be determined at the optimum water content of a specified compaction effort. The dry unit weight specified is normally the minimum percent compaction allowed by the using agency's field compaction specification.

4.3 For applications where the effect of compaction water content on CBR is unknown or where it is desired to account for its effect, the CBR is determined for a range of water content, usually the range of water content permitted for field compaction by using agency's field compaction specification.

4.4 The criteria for test specimen preparation of self cementing (and other) materials which gain strength with time must be based on a geotechnical engineering evaluation. As directed by the engineer, self cementing materials shall be properly cured until bearing ratios representing long term service conditions can be measured.

5. Apparatus

5.1 *Loading Machine*—The loading machine shall be equipped with a movable head or base that travels at a unif (not pulsating) rate of 0.05 in. (1.27 mm)/min for use in for the penetration piston into the specimen. The machine shal equipped with a load-indicating device that can be read t lbf (44 N) or less. The minimum capacity of the loa machine shall be based on the requirements indicated in T 1.

5.2 *Mold*—The mold shall be a rigid metal cylinder wit inside diameter of 6 ± 0.026 in. (152.4 ± 0.66 mm) a height of 7 ± 0.018 in. (177.8 ± 0.46 mm). It shall be prov with a metal extension collar at least 2.0 in. (50.8 mm height and a metal base plate having at least twenty e 1⁄16-in. (1.59-mm) diameter holes uniformly spaced over plate within the inside circumference of the mold. W assembled with spacer disc in place in the bottom of the m the mold shall have an internal volume (excluding exten collar) of 0.075 ± 0.0009 ft (2124 ± 25 cm). Fig. 1 sho satisfactory mold design. A calibration procedure shoul used to confirm the actual volume of the mold with the sp disk inserted. Suitable calibrations are contained in Methods D 698 and D 1557.

5.3 *Spacer Disk*—A circular metal spacer disc (see Fi having a minimum outside diameter of 5 15⁄16 in. (150.8 but no greater than will allow the spacer to easily slip int mold. The spacer disc shall be 2.416± 0.005 in. (61.3 0.127 mm) in height.

5.4 *Rammer*—A rammer as specified in either Test Met D 698 or D 1557 except that if a mechanical rammer is us must be equipped with a circular foot, and when so equi must provide a means for distributing the rammer b uniformly over the surface of the soil when compacting 6-in. (152.4-mm) diameter mold. The mechanical rammer be calibrated and adjusted in accordance with Test Me D 2168.

5.5 *Expansion-Measuring Apparatus*— An adjustable stem and perforated metal plate, similar in configuration t shown in Fig. 1. The perforated plate shall be 5⅞ to 5 15⁄ (149.23 to 150.81 mm) in diameter and have at least fort 1⁄16-in. (1.59-mm) diameter holes uniformly spaced ove plate. A metal tripod to support the dial gage for measurir amount of swell during soaking is also required.

5.6 *Weights*—One or two annular metal weights hav total mass of 4.54 ± 0.02 kg and slotted metal weights having masses of 2.27 ± 0.02 kg. The annular weight sh 5⅞ to 5 15⁄16 in. (149.23 to 150.81 mm) in diameter and have a center hole of approximately 2⅛in. (53.98 mm).

5.7 *Penetration Piston*—A metal piston 1.954 ± 0.0 (49.63 ± 0.13 mm) in diameter and not less than 4 in. (mm) long (see Fig. 1). If, from an operational standpoin advantageous to use a piston of greater length, the l piston may be used.

5.8 *Gages*—Two dial gages reading to 0.001 in. (0.02

TABLE 1 Minimum Load Capacity

Maximum Measurable CBR	Minimum Load Capacity (lbf)	(kN)
20	2500	11.2
50	5000	22.3
>50	10 000	44.5

TABLE 2 Metric Equivalents

Inch-Pound Units, in.	Metric Equivalent, mm	Inch-Pound Units, in.	Metric Equivalent, mm	Inch-Pound Units, in.	Metric Equivalent, mm
0.003	0.076	19/32	15.08	3 1/2	88.90
0.005	0.127	5/8	15.88	3 3/4	95.25
0.135	3.43	3/4	19.10	4 1/4	108.0
0.201	5.11	15/16	23.81	4 1/2	114.3
0.4375	11.11	1	25.40	4 3/4	120.7
0.4378	11.12	1 1/8	28.58	5 7/8	149.2
0.510	12.95	1 1/4	31.8	5 15/16	150.8
0.633	16.08	1 3/8	34.9	6	152.0
1.370	34.60	1 1/2	38.10	6 7/32	158.0
1.375	34.93	1 3/4	44.5	6 1/2	165.1
1.954	49.63	1 13/16	46.04	7	177.8
2.416	61.37	1 15/16	49.21	7 1/2	190.1
1/16	1.59	2	50.80	8 3/8	212.7
7/32	5.56	2 1/8	53.98	8 1/2	215.9
1/4	6.35	2 1/5	55.9	9 3/8	238.1
3/8	9.53	2 1/4	57.2	14 1/4	362.0
7/16	11.11	2 1/2	63.50	18	457.2
15/32	11.91	2 3/4	69.85	32 1/4	719.2
1/2	12.70	2 31/32	75.41	36 5/8	930.3
17/32	13.49	3	76.20	39	990.6

Inch-Pound Units, lb	Metric Equivalent, kg	Inch-Pound Units, psi	Metric Equivalent, MPa
0.04	0.02	200	1.4
0.05	0.02	400	2.8
0.12	0.05	600	4.1
0.59	0.27	800	5.5
0.71	0.32	1000	6.9
0.75	0.34	1200	8.3
3.20	1.45	1400	9.7
5.00	2.27		
10.00	4.54		

with a range of 0.200 minimum.

5.9 *Miscellaneous Apparatus*—Other general apparatus such as a mixing bowl, straightedge, scales, soaking tank or pan, oven, fast filtering high wet strength filter paper, dishes, and 2-in., 3/4-in. and No. 4 sieves.

6. Sample

6.1 The sample shall be handled and specimen(s) for compaction shall be prepared in accordance with the procedures given in Test Methods D 698 or D 1557 for compaction in a 6-in. (152.4-mm) mold except as follows:

6.1.1 If all material passes a 3/4-in. (19-mm) sieve, the entire gradation shall be used for preparing specimens for compaction without modification. If there is material retained on the 3/4-in. (19-mm) sieve, the material retained on the 3/4-in. (19-mm) sieve shall be removed and replaced by an equal amount of material passing the 3/4-in. (19-mm) sieve and retained on the No. 4 sieve obtained by separation from portions of the sample not otherwise used for testing.

7. Test Specimens

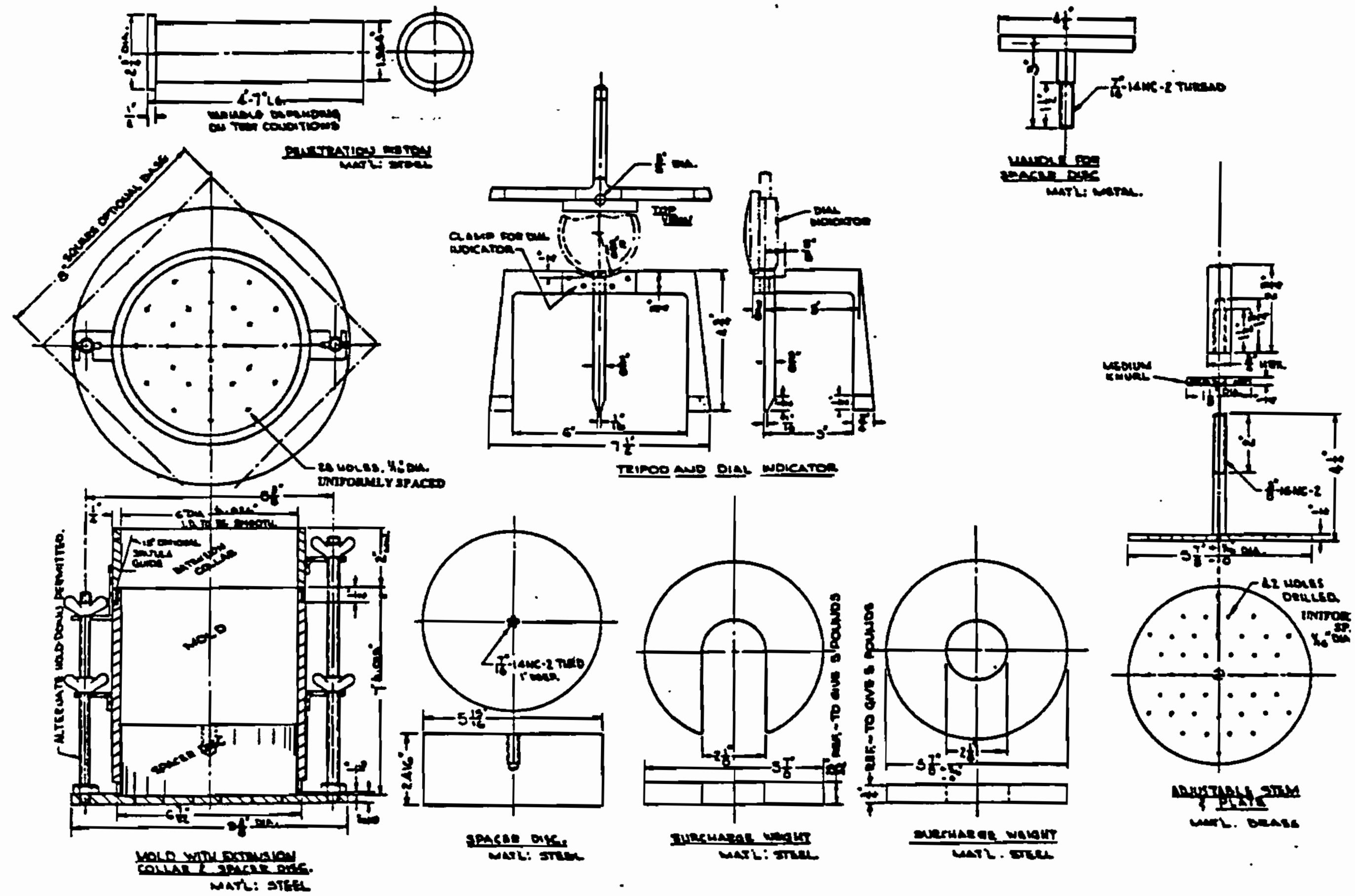
7.1 *Bearing Ratio at Optimum Water Content Only*—Using material prepared as described in 6.1, conduct a control compaction test with a sufficient number of test specimens to definitely establish the optimum water content for the soil using the compaction method specified, either Test Methods D 698 or D 1557. A previously performed compaction test on the same material may be substituted for the compaction test just described, provided that if the sample contains material retained on the 3/4-in. (19-mm) sieve, soil prepared as described in 6.1 is used (Note 1).

NOTE 2—Maximum dry unit weight obtained from a compaction test performed in a 4-in. (101.6-mm) diameter mold may be slightly greater than the maximum dry unit weight obtained from compaction in the 6-in. (152.4-mm) compaction mold or CBR mold.

7.1.1 For cases where the CBR is desired at 100 % maximum dry unit weight and optimum water content, compact a specimen using the specified compaction procedure, either Test Methods D 698 or D 1557, from soil prepared to within ±0.5 percentage point of optimum water content in accordance with Test Method D 2216.

NOTE 3—Where the maximum dry unit weight was determined from compaction in the 4-in. (101.6-mm) mold, it may be necessary to compact specimens as described in 7.1.2, using 75 blows per layer or some other value sufficient to produce a specimen having a density equal to or greater than that required.

7.1.2 Where the CBR is desired at optimum water content and some percentage of maximum dry unit weight, compact three specimens from soil prepared to within ±0.5 percentage point of optimum water content and using the specified compaction but using a different number of blows per layer for each specimen. The number of blows per layer shall be varied as necessary to prepare specimens having unit weights above and below the desired value. Typically, if the CBR for soil at 95 % of maximum dry unit is desired, specimens compacted using 56, 25, and 10 blows per layer is satisfactory. Penetration shall be performed on each of these specimens.



NOTE 1—See Table 2 for metric equivalents.

FIG. 1 Bearing Ratio Test Apparatus

7.2 *Bearing Ratio for a Range of Water Content*—Prepare specimens in a manner similar to that described in 7.1 except that each specimen used to develop the compaction curve shall be penetrated. In addition, the complete water content-unit weight relation for the 25-blow and 10-blow per layer compactions shall be developed and each test specimen compacted shall be penetrated. Perform all compaction in the CBR mold. In cases where the specified unit weight is at or near 100 % maximum dry unit weight, it will be necessary to include a compactive effort greater than 56-blows per layer (Note 3).

NOTE 4—A semilog log plot of dry unit weight versus compactive effort usually gives a straight line relation when compactive effort in ft-lb/ft^3 is plotted on the log scale. This type of plot is useful in establishing the compactive effort and number of blows per layer needed to bracket the specified dry unit weight and water content range.

7.2.1 If the sample is to be soaked, take a representative sample of the material, for the determination of moisture, at the beginning of compaction and another sample of the remaining material after compaction. Use Test Method D 2216 to determine the moisture content. If the sample is not to be soaked, take a moisture content sample in accordance with Test Methods D 698 or D 1557 if the average moisture content is desired.

7.2.2 Clamp the mold (with extension collar attached) to the base plate with the hole for the extraction handle facing down. Insert the spacer disk over the base plate and place a disk of filter paper on top of the spacer disk. Compact the soil-w mixture into the mold in accordance with 7.1, 7.1.1, or 7.

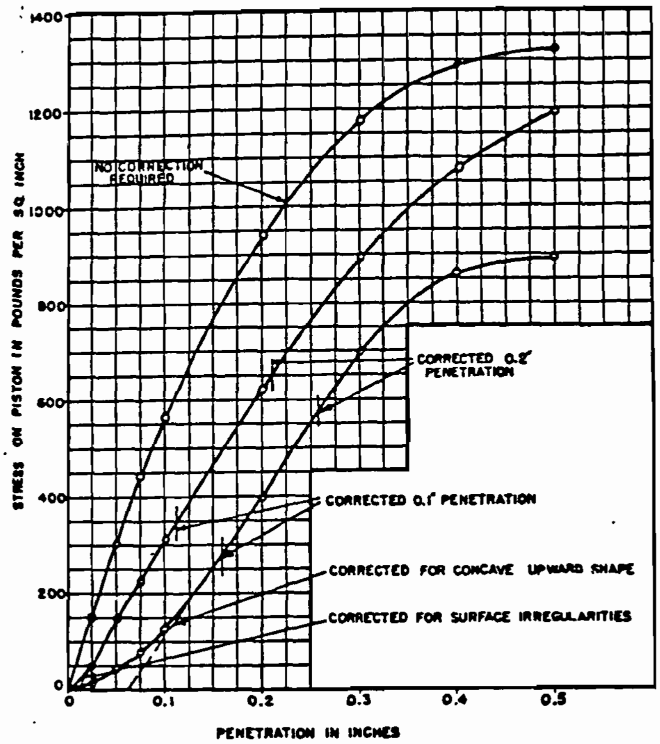
7.2.3 Remove the extension collar and carefully trim compacted soil even with the top of the mold by means straightedge. Patch with smaller size material any holes may have developed in the surface by the removal of cc material. Remove the perforated base plate and spacer weigh, and record the mass of the mold plus compacted Place a disk of coarse filter paper on the perforated base p invert the mold and compacted soil, and clamp the perfo base plate to the mold with compacted soil in contact wit filter paper.

7.2.4 Place the surcharge weights on the perforated and adjustable stem assembly and carefully lower ont compacted soil specimen in the mold. Apply a surcharge to the weight of the base material and pavement within 2. (5 lb), but in no case shall the total weight used be less 4.54 kg (10 lb). If no pavement weight is specified, use 4.5 Immerse the mold and weights in water allowing free acc water to the top and bottom of the specimen. Take i measurements for swell and allow the specimen to soak f h. Maintain a constant water level during this period. A sh immersion period is permissible for fine grained soi granular soils that take up moisture readily, if tests show the shorter period does not affect the results. At the end h, take final swell measurements and calculate the swel percentage of the initial height of the specimen.

7.2.5 Remove the free water and allow the specimen to drain downward for 15 min. Take care not to disturb the surface of the specimen during the removal of the water. It may be necessary to tilt the specimen in order to remove the surface water. Remove the weights, perforated plate, and filter paper, and determine and record the mass.

8. Procedure for Bearing Test

8.1 Place a surcharge of weights on the specimen sufficient to produce an intensity of loading equal to the weight of the base material. If no pavement weight is specified, use 4.54 kg mass. If the specimen has been soaked previously, the surcharge shall be equal to that used during the soaking period. To prevent upheaval of soil into the hole of the surcharge weights, place the 2.27 kg annular weight on the soil surface prior to seating the penetration piston, after which place the remainder of the surcharge weights.



NOTE 1—See Table 2 for metric equivalents.

FIG. 2 Correction of Load-Penetration Curves

8.2 Seat the penetration piston with the smallest possible load, but in no case in excess of 10 lbf (44 N). Set both the stress and penetration gages to zero. This initial load is required to ensure satisfactory seating of the piston and shall be considered as the zero load when determining the load penetration relation. Anchor the strain gage to the load measuring device, if possible; in no case attach it to the testing machines support bars (legs).

NOTE 5—At high loads the supports may torque and affect the reading of the penetration gage. Checking the depth of piston penetration is one means of checking for erroneous strain indications.

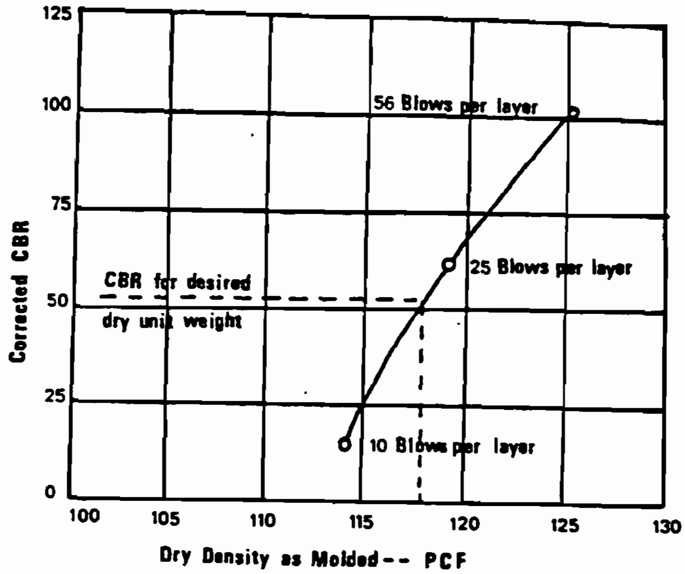


FIG. 3 Dry Density Versus CBR

8.3 Apply the load on the penetration piston so that the rate of penetration is approximately 0.05 in. (1.27 mm)/min. Record the load readings at penetrations of 0.025 in. (0.64 mm), 0.050 in. (1.27 mm), 0.075 in. (1.91 mm), 0.100 in. (2.54 mm), 0.125 in. (3.18 mm), 0.150 in. (3.81 mm), 0.175 in. (4.45 mm), 0.200 in. (5.08 mm), 0.300 in. (7.62 mm), 0.400 in. (10.16 mm) and 0.500 in. (12.70 mm). Note the maximum load and penetration if it occurs for a penetration of less than 0.500 in. (12.70 mm). With manually operated loading devices, it may be necessary to take load readings at closer intervals to control the rate of penetration. Measure the depth of piston penetration into the soil by putting a ruler into the indentation and measuring the difference from the top of the soil to the bottom of the indentation. If the depth does not closely match the depth of penetration gage, determine the cause and test a new sample.

8.4 Remove the soil from the mold and determine the moisture content of the top 1-in. (25.4-mm) layer. Take a moisture content sample in accordance with Test Methods D 698 or D 1557 if the average moisture content is desired. Each moisture content sample shall weigh not less than 100 g for fine-grained soils nor less than 500 g for granular soils.

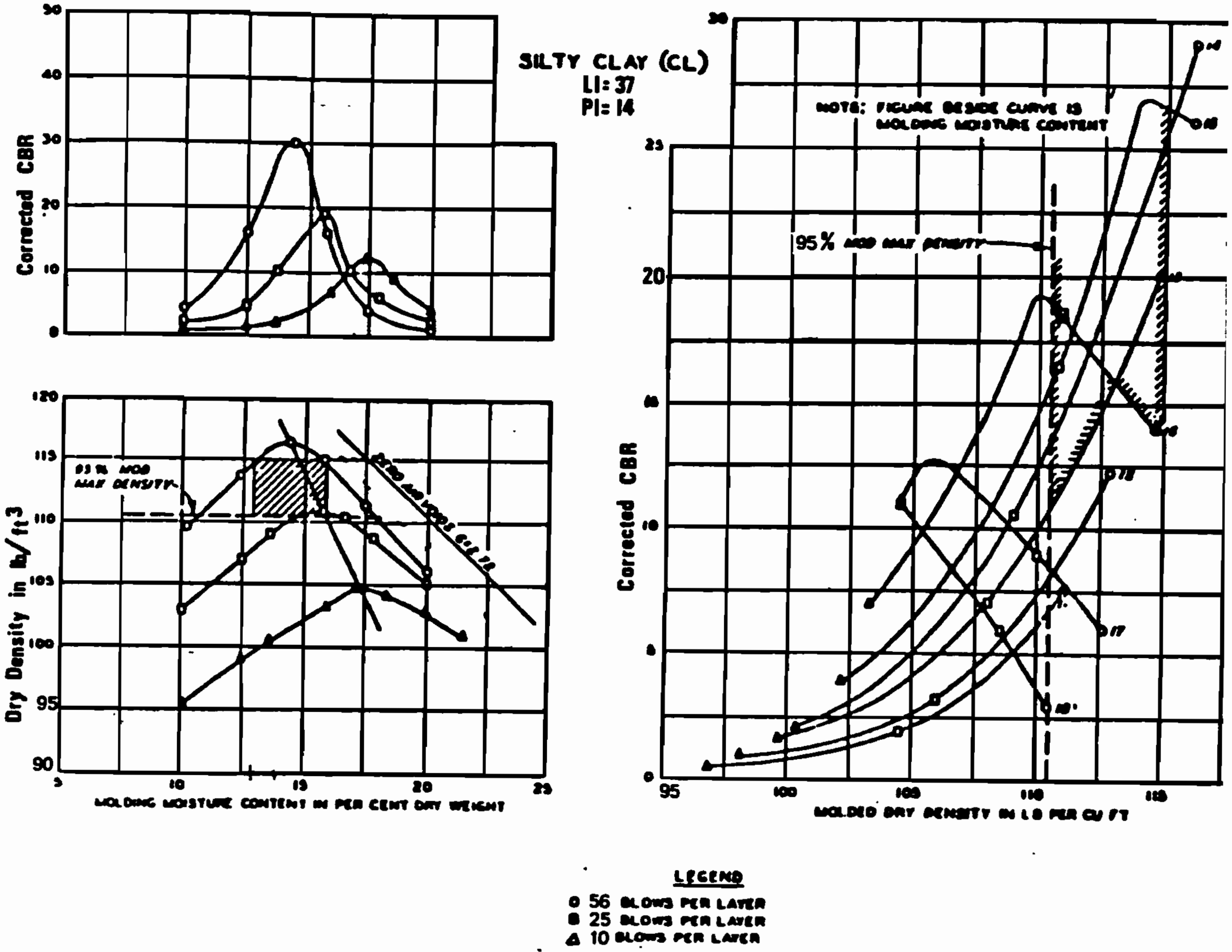
NOTE 6—The load readings at penetrations of over 0.300 in. (7.6 mm) may be omitted if the testing machine's capacity has been reached.

9. Calculation

9.1 *Load-Penetration Curve*—Calculate the penetration stress in pounds per square inch or megapascals and plot the stress-penetration curve. In some instances, the stresspenetration curve may be concave upward initially, because of surface irregularities or other causes, and in such cases the zero point shall be adjusted as shown in Fig. 2.

NOTE 7—Fig. 2 should be used as an example of correction of load-penetration curves only. It is not meant to imply that the 0.2-in. penetration is always more than the 0.1-in. penetration.

9.2 *Bearing Ratio*—Using corrected stress values taken from the stress penetration curve for 0.100 in. (2.54 mm) and



NOTE 1—Surcharge = 50 lb soaking and penetration. All samples soaked top and bottom four days. All samples compacted in 5 layers, 10-lb 18-in. drop in CBR mold.

FIG. 4 Determining CBR for Water Content Range and Minimum Dry Unit Weight

0.200 in. (5.08 mm) penetrations, calculate the bearing ratios for each by dividing the corrected stresses by the standard stresses of 1000 psi (6.9 MPa) and 1500 psi (10.3 MPa) respectively, and multiplying by 100. Also, calculate the bearing ratios for the maximum stress, if the penetration is less than 0.200 in. (5.08 mm) interpolating the standard stress. The bearing ratio reported for the soil is normally the one at 0.100 in. (2.54 mm) penetration. When the ratio at 0.200 in. (5.08 mm) penetration is greater, rerun the test. If the check test gives a similar result, use the bearing ratio at 0.200 in. (5.08 mm) penetration.

NOTE 8—If bearing ratio values at penetrations of 0.300 (7.62 mm), 0.400 (10.16 mm) and 0.500 in. (12.7 mm) are desired, the corrected stress values of these penetrations should be divided by the standard stresses of 1900 psi (13.1 MPa), 2300 psi (15.9 MPa), 2600 psi (17.9 MPa), respectively, and multiplied by 100.

9.3 *Design CBR for One Water Content Only*—Using the data obtained from the three specimens, plot the CBR versus molded dry unit weight relation as illustrated in Fig. 3. Determine the design CBR at the percentage of the maximum dry unit weight requested.

9.4 *Design CBR for Water Content Range*— Plot t from the tests at the three compactive efforts as shown 4. The data plotted as shown represents the response of over the range of water content specified. Select the C reporting as the lowest CBR within the specified water range having a dry unit weight between the specified m and the dry unit weight produced by compaction wi water content range.

10. Report

10.1 The report shall include the following:

10.1.1 Method used for preparation and compac specimen: Test Methods D 698 or D 1557, or othe description.

10.1.2 Condition of sample (unsoaked or soaked).

10.1.3 Dry density (unit weight) of sample before s kg/m^3 (lb/ft^3).

10.1.4 Dry density (unit weight) of sample after kg/m^3 (lb/ft^3).

10.1.5 Moisture content of sample in percent:

10.1.5.1 Before compaction.

10.1.5.2 After compaction.
10.1.5.3 Top 1-in (25.4-mm) layer after soaking.
10.1.5.4 Average after soaking.
10.1.6 Swell (percentage of initial height).
10.1.7 Bearing ratio of sample (unsoaked or soaked), percent.
10.1.8 Surcharge amount.
10.1.9 Any special sample preparation and testing procedures (for example: for self cementing materials).
10.1.10 Sample identification (location, boring number, etc.).
10.1.11 Any pertinent testing done to identify the sample such as: soil classifications per Test Method D 2487, visual classification per Practice D 2488, Atterberg limits per Test Method D 4318, gradation per Method D 422 etc.
10.1.12 The percent material retained on the ln[]-in. (19-mm) sieve for those cases where scalping and replacement is used.

11. Precision and Bias

11.1 No available methods provide absolute values for the soil bearing strength derived by this test method; therefore, there is no meaningful way to obtain an evaluation of bias.

11.2 At present, sufficient data for determining the precision of this test method has not been gathered. Users are encouraged to submit data to the subcommittee for inclusion in the statement. One user, based on seven repetitions, has developed a IS % of 8.2 % (compacted per Test Method D 698) and 5.9 % (compacted per Test Method D 1557). See Appendix X1 for the data used.

12. Keywords

12.1 This standard is indexed under the following terms:

California Bearing Ratio	Used For, Narrower Term
Pavement Subgrade	Used For, Narrower Term
Subgrade	Related Term, Broader Term
Pavement Subbase	Used For, Narrower Term
Subbase	Used For, Broader Term
Pavement Base Course	Used For, Narrower Term
Base Course	Used For, Broader Term
Strength of Soil	Used For
Pavement Design	Used For, Narrower Term
Acceptance Tests	Used For
Bearing Capacity	Used For
Materials Evaluations	Used For
Bearing Ratio	Used For, Broader Term
Load Penetration Curve	Used For
Design	Used For, Broader Term
Earthfill	Related To
Cohesive Soils	Used For
Compressive Strength	Used For
Flexible Pavements	Used For
Foundation Investigations	Used For
Soil Tests	Used For

APPENDIX

(Nonmandatory Information)

X1. Compactive Effort

STANDARD (D698) CBR			MODIFIED (D1557) CBR		
(x)	(x-x)	(x-x) 2	(x)	(x-x)	(x-x) 2
16.7	.5	.25	77.0	3	9
16.7	1.5	2.25	70.2	3.8	14.44
18.2	1.0	1	80.8	6.8	46.24
18.2	1.0	1	68.2	5.8	33.64
18.8	1.6	2.56	76.7	2.7	7.29
19.3	2.1	4.41	71.7	2.3	5.29
17.9	0.7	.49	73.3	0.7	.49
x =124.8	(x-x) 2	11.96	x =517.9	(x-x) 2	116.39
x = 17.2			x = 74.0		

S = 11.96 / 6   S = 116.39 / 6 = 19.39

IS (one sigma) = 1.41   IS = 4.4

IS % = 1.41 / 17.2 X 100 = 8.2%   IS % = 4.4 / 74 x 100 = 5.9%

D2S % = 22.6%   D2S % = 16.7%

NOTES:
- All Material passed the #10 sieve
- Over 90% of all material passed the #40 sieve
- Method A of AASHTO T99 & T180 used
- Unit weights were 110 PCF ± (D698) and 122 PCF ± (D1557)
- 7 test repetitions
- The above data is from one user
- The (IS) and (D2S) limits represent the limits as described in ASTM Practice C670.

FIG. X1.1 Compactive Effort

SUMMARY OF CHANGES

(*1*) Terminology D 653 was added to Section 2.
(*2*) Wording in Fig. 1 was changed from "equally spaced" to "uniformly spaced" to match the wording in the text.
(*3*) Section 5.1 was revised and a new Table 1 was added. Table 2 is the former Table 1.
(*4*) This Summary of Changes section has been added.

Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass[1]

This standard is issued under the fixed designation D 2216; 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 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" hereinafter also refers to either soil or rock, 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, and the like) 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 humidities, forming a compound (calcium sulfate hemihydrate) which 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 organic soils, it may be desirable to dry these 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 standard water content determined at the standard drying temperature.

NOTE 1—Test Methods D 2974 provides an alternate procedure for 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 which includes the previously soluble 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 Noorany[2] regarding information on marine soils.

1.6 This test method requires several hours for proper drying of the water content specimen. Test Method D 4643 provides for drying of the test specimen in a microwave oven which is a shorter process. Also see Gilbert[3] for details on the background of this test method.

1.7 This standard requires the drying of material in an oven at high temperatures. 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.

1.8 *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:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]

D 2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils[4]

D 4220 Practice for Preserving and Transporting Soil Samples[4]

D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[4]

D 4643 Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method[4]

D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil and Rock Testing[4]

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved Feb. 10, 1998. Published January 1999. Originally published as D 2216 – 63 T. Last previous edition D 2216 – 92.

[2] Noorany, I., "Phase Relations in Marine Soils", Journal of Geotechnical Engineering, ASCE, Vol. 110, No. 4, April 1984, pp. 539–543.

[3] 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.

[4] *Annual Book of ASTM Standards*, Vol 04.08.

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

D 6026 Guide for Using Significant Digits in Calculating and Reporting Geotechnical Test Data[5]

E 145 Specification for Gravity-Convection And Forced-Ventilation Ovens[6]

3. Terminology

3.1 Refer to Terminology D 653 for standard definitions of terms.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *water content (of a material)*—the ratio expressed as a percent of the mass of "pore" or "free" water in a given mass of material to the mass of the solid material. A standard temperature of 110° ± 5°C is used to determine these masses.

4. Summary of Test Method

4.1 A test specimen is dried in an oven at a temperature of 110° ± 5°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 D 4318, is used to express its relative consistency or liquidity index.

6. Apparatus

6.1 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, meeting the requirements of Specification E 145 and capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber.

6.2 *Balances*—All balances must meet the requirements of Specification D 4753 and this section. A Class GP1 balance of 0.01g readability is required for specimens having a mass of up to 200 g (excluding mass of specimen container) and a Class GP2 balance of 0.1g 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 8.2.1 and 12.1.2).

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 dessicator 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 7). One container is needed for each water content determination.

NOTE 2—The purpose of close-fitting lids is to prevent loss of moisi from specimens before initial mass determination and to prevent abs tion of moisture from the atmosphere following drying and before f mass determination.

6.4 *Desiccator*—A desiccator cabinet or large desiccator of suitable size containing silica gel or anhydrous calci sulfate. It is preferable to use a desiccant which changes cc to indicate it needs reconstitution. See 10.5.

NOTE 3—Anhydrous calcium sulfate is sold under the trade n Drierite.

6.5 *Container Handling Apparatus*, gloves, tongs, or s able holder for moving and handling hot containers a drying.

6.6 *Miscellaneous*, knives, spatulas, scoops, quarte: cloth, sample splitters, etc, as required.

7. Samples

7.1 Samples shall be preserved and transported in ac dance with Practice 4220 Groups B, C, or D soils. Keep samples that are stored prior to testing in noncorrodible air containers at a temperature between approximately 3 and 3 and in an area that prevents direct contact with sunl Disturbed samples in jars or other containers shall be store such a way as to prevent or minimize moisture condensatio the insides of the containers.

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

8. Test Specimen

8.1 For water contents being determined in conjunction another ASTM method, the specimen mass requirement s in that method shall be used if one is provided. If no mini specimen mass is provided in that method then the values ; below shall apply. See Howard[7] for background data fc values listed.

8.2 The minimum mass of moist material selected representative of the total sample shall be in accordance the following:

Maximum particle size (100 % passing)	Standard Sieve Size	Recommended minimum mass of moist test specimen for water content reported to ±0.1 %	Recommen minimum ma moist test s imen for w content rep to ±1 %
2 mm or less	No. 10	20 g	20 g[A]
4.75 mm	No. 4	100 g	20 g[A]
9.5 mm	⅜-in.	500 g	50 g
19.0 mm	¾-in.	2.5 kg	250 g
37.5 mm	1½ in.	10 kg	1 kg
75.0 mm	3-in.	50 kg	5 kg

[A]To be representative not less than 20 g shall be used.

8.2.1 The minimum mass used may have to be increa obtain the needed significant digits for the mass of water reporting water contents to the nearest 0.1 % or as indic 12.1.2.

[5] *Annual Book of ASTM Standards*, Vol 04.09.
[6] *Annual Book of ASTM Standards*, Vol 14.02.

[7] Howard, A. K., "Minimum Test Specimen Mass for Moisture Conte mination", *Geotechnical Testing Journal*, A.S.T.M., Vol. 12, No. 1, March 39-44.

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 200g) 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 forms or test data sheets.

8.5 For those samples consisting entirely of intact rock, the minimum specimen mass shall be 500 g. Representative portions of the sample may be broken into smaller particles, depending on the sample's size, the container and balance being used and to facilitate drying to constant mass, see 10.4. Specimen sizes 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, and the likes.)

9.2 For disturbed samples such as trimmings, bag samples, and the like, 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 and then select a representative 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.

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, and the like, 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 4—Migration of moisture in some cohesionless soils may require that the full section be sampled.

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).

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 material using a balance (see 6.2) selected on the basis of the specimen mass. Record this value.

NOTE 5—To prevent mixing of specimens and yielding of incorrect results, all containers, and lids if used, should be numbered and the container numbers shall be recorded on the laboratory data sheets. The lid numbers should match the container numbers to eliminate confusion.

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 moist material in the drying oven. Dry the material to a constant mass. Maintain the drying oven at 110 ± 5°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.

NOTE 7—In most cases, drying a test specimen overnight (about 12 to 16 h) is sufficient. In cases where there is doubt concerning the adequacy of drying, drying should be continued until the change in mass after two successive periods (greater than 1 h) of drying is an insignificant amount (less than about 0.1 %). Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

NOTE 8—Since some dry materials may absorb moisture from moist specimens, dried specimens should be removed before placing moist specimens in the same oven. However, this would not be applicable if the previously dried specimens will remain in the drying oven for an additional time period of about 16 h.

10.5 After the material has dried to constant mass remove the container from the oven (and replace the lid if used). Allow the material and container to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents and/or its being heated. Determine the mass of the container and oven-dried material 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.

NOTE 9—Cooling in a desiccator is acceptable in place of tight fitting lids since it greatly reduces absorption of moisture from the atmosphere during cooling especially for containers without tight fitting lids.

11. Calculation

11.1 Calculate the water content of the material as follows:

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

where:

w = water content, %,
M_{cws} = mass of container and wet specimen, g,
M_{cs} = mass of container and oven dry specimen, g,
M_c = mass of container, g,
M_w = mass of water ($M_w = M_{cws} - M_{cds}$), g, and
M_s = mass of solid particles ($M_s = M_{cds} - M_c$), g.

12. Report

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

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

12.1.2 Water content of the specimen to the nearest 1 % or 0.1 %, as appropriate based on the minimum sample used. 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 Guide D 6026 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 to the nearest 0.1 lbf/f^3(0.02 kN/m^3), 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 Guide D 6026 may need to be increased when calculating phase relationships requiring four significant digits.

12.1.3 Indicate if test specimen had a mass less than the minimum indicated in 8.2.

12.1.4 Indicate if test specimen contained more thar material type (layered, etc.).

12.1.5 Indicate the temperature of drying if different 110 ± 5°C.

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

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

13. Precision and Bias

13.1 *Statement on Bias*—There is no accepted refe value for this test method; therefore, bias cannot be c mined.

13.2 *Statements on Precision*:

13.2.1 *Single-Operator Precision (Repeatability)*— single-operator coefficient of variation has been found to b percent. Therefore, results of two properly conducted tes the same operator with the same equipment should n considered suspect unless they differ by more than 7.8 pe of their mean.[8]

13.2.2 *Multilaboratory Precision (Reproducibility)*[9]— multilaboratory coefficient of variation has been found t 5.0 percent. Therefore, results of two properly conducted by different operators using different equipment should n considered suspect unless they differ by more than 14.0 pe of their mean.

14. Keywords

14.1 consistency; index property; laboratory; moi analysis; moisture content; soil aggregate; water content

[8] These numbers represent the (1s) and (d2s) limits as described in Prac 670.

[9] These numbers represent the (1s %) and (d2s %) limits as described in P C 670.

SUMMARY OF CHANGES

Committee D-18 has identified the location of selected changes to this standard since the last issue. (D 2216-92) that may impact the use of this standard.

(*1*) Title was changed to emphasize that mass is the basis for the standard.

(*2*) Section 1.1 was revised to clarify "similar materials".

(*3*) New 1.2 was added to explain a limitation in scope. The other sections were renumbered as appropriate.

(*4*) An information reference was included in 1.5.

(*5*) An information reference was included in 1.6

(*6*) A new ASTM referenced document was included in 2.1.

(*7*) New Footnotes 2, 3, and 5 were added and identified. Other footnotes were renumbered where necessary for sequential identification.

(*8*) Information concerning balances was added in 6.2

(*9*) Section 6.3 was revised to clarify the use of close-fitting lids, and a reference to Note 8 was added.

(*10*) In 6.4, "anhydrous calcium phosphate" was change "anyhydrous calcium sulfate" to correct an error and to a with Note 3.

(*11*) A typo in 8.1 was corrected from "before" to "below" a footnoted reference was added for information.

(*12*) A portion of 8.2 was deleted for clarity.

(*13*) A new 8.2.1 was added to clarify minimum mass req ments.

(*14*) Sections 8.3, 8.4, 9.3.3, and 12.1 were change substitute "test data form/sheet" for "report".

(*15*) Footnote seven was identified.

(*16*) Section 9.2.1 was revised to improve clarity and int

(*17*) The word "possible" was changed to "practical" in 9

(18) Section 9.3.1 and 9.3.2 were revised to improve clarity and for practicality.
(19) A reference to Guide D 6026 was added in 12.1.2.
(20) Footnotes 8 and 9 were added to 13.2.1 and 13.2.2, respectively. These were inadvertently omitted from the 1992 version. These explanations provide clarity and information to the user.
(21) A Summary of Changes was added to reflect D-18's policy.