

**FM 5-472  
NAVFAC MO 330  
AFJMAN 32-1221(I)**

***Materials Testing***

***DEPARTMENT  
OF THE  
ARMY***

DISTRIBUTION RESTRICTION: Approved for  
public release; distribution is unlimited

Change 2

Headquarters  
Department of the Army  
Washington, DC, 1 July 2001

## Materials Testing

1. Change FM 5-472, 27 October 1999, as follows:

Remove Old Pages

2-55 through 2-58  
2-83 and 2-84  
2-103 and 2-104  
4-21 through 4-24  
4-29 and 4-31  
A-1

Insert New Pages

2-55 through 2-58  
2-83 and 2-84  
2-103 and 2-104  
4-21 through 4-24  
4-29 through 4-31  
A-1

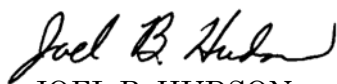
2. A bar (|) marks new or changed material.
3. File this transmittal sheet in front of the publication.

DISTRIBUTION RESTRICTION: Approved for public release; distribution is unlimited.

By Order of the Secretary of the Army:

ERIC K. SHINSEKI  
General, United States Army  
Chief of Staff

Official:



JOEL B. HUDSON  
Administrative Assistant to the  
Secretary of the Army  
0119105

DISTRIBUTION:

*Active Army, Army National Guard, and US Army Reserve:* To be distributed in accordance with the initial distribution number 110133, requirements for FM 5-472.

Change 1

Headquarters  
Department of the Army  
Washington, DC, 29 December 2000

## Materials Testing

1. Change FM 5-472, 27 October 1999, as follows:

Remove Old Pages

2-65 and 2-66  
2-77 and 2-78  
2-81 and 2-82  
2-87 and 2-88

Insert New Pages

2-65 and 2-66  
2-77 and 2-78  
2-81 and 2-82  
2-87 and 2-88


2. A bar (b) marks new or changed material.
3. File this transmittal sheet in front of the publication.

DISTRIBUTION RESTRICTION: Approved for public release; distribution is unlimited.

By Order of the Secretary of the Army:

ERIC K. SHINSEKI  
General, United States Army  
Chief of Staff

Official:



JOEL B. HUDSON  
Administrative Assistant to the  
Secretary of the Army  
0031907

DISTRIBUTION:

*Active Army, Army National Guard, and US Army Reserve:* To be distributed in accordance with the initial distribution number 110133, requirements for FM 5-472.

## Foreword

This publication may be used by the US Army, US Navy, and US Air Force during training, exercises, and contingency operations.

JOHN N. ABRAMS  
General USA  
Commanding General  
United States Army Training  
and Doctrine Command

LOUIS M. SMITH  
Rear Admiral, CEC, US Navy  
Commander, Naval Facilities  
Engineering Command

MICHAEL E. RYAN  
General, USAF  
Chief of Staff

# MATERIALS TESTING

## Table of Contents

	Page
<b>Preface</b> .....	ix
<b>Chapter 1. Materials Testing Overview</b> .....	1-1
Materials Tests.....	1-1
Soil Properties .....	1-2
Classifications .....	1-2
Design Requirements.....	1-2
Bitumens.....	1-2
Concrete .....	1-3
Stabilization .....	1-3
Equipment .....	1-3
Test Set, Soil (SC 6635-98-CL-E02).....	1-3
Test Set, Asphalt (SC 6635-98-CL-E03) .....	1-4
Test Set, Concrete (SC 6635-98-CL-E04) .....	1-4
Nuclear Moisture Density Gauge .....	1-4
Safety and Environmental Considerations.....	1-4
<b>Chapter 2, Soils, part 1.</b> .....	2-1
<b>Section I. Formation, Classification, and Field Identification</b> .....	2-1
Soil Formation.....	2-1
Rocks .....	2-1
Strata .....	2-2
Physical Properties .....	2-2
Grain or Particle Size .....	2-3
Grain or Particle Shape.....	2-3
Gradation .....	2-4
Density .....	2-5
Specific Gravity.....	2-5
Moisture .....	2-6

---

DISTRIBUTION RESTRICTION: Approved for public release; distribution is unlimited.

\*This publication supersedes FM 5-530, 17 August 1987.

	Page
Consistency.....	2-7
Organic Soil.....	2-8
Effects of Soil Characteristics.....	2-8
Soil Classification.....	2-8
Classification.....	2-9
Categories.....	2-9
Identification of Soil Groups.....	2-12
Field Identification.....	2-13
Test Equipment.....	2-14
Test Factors.....	2-14
Soil-Description Example.....	2-15
Field-Identification Tests.....	2-15
Visual Test.....	2-15
Odor Test.....	2-19
Sedimentation Test.....	2-19
Bite or Grit Test.....	2-21
Feel Test.....	2-21
Roll or Thread Test.....	2-22
Wet Shaking Test.....	2-23
Breaking or Dry-Strength Test.....	2-24
Ribbon Test.....	2-25
Shine Test.....	2-25
<b>Section II. Soil Surveys and Sampling.....</b>	<b>2-26</b>
Types of Soil Surveys.....	2-26
Hasty Survey.....	2-27
Deliberate Survey.....	2-27
Objective of a Soil Survey.....	2-27
Location, Nature, and Classification of Soil Layers.....	2-27
Condition of Soils in Place.....	2-27
Drainage Characteristics.....	2-28
Groundwater and Bedrock.....	2-28
Sources of Information.....	2-28
Intelligence Reports.....	2-28
Local Inhabitants.....	2-28
Maps.....	2-29
Aerial Photographs.....	2-30
Field Investigations.....	2-31
Sampling Methods.....	2-31
Preparing Samples.....	2-32
Recording Samples.....	2-33
Obtaining Representative Soil Samples.....	2-34
Moisture-Content Samples.....	2-38
Undisturbed Samples.....	2-38
Chunk Samples.....	2-39
Cylinder Samples.....	2-43
Quartering Samples.....	2-48
Samples Weighing Over 100 Pounds.....	2-48
Samples Weighing 25 to 100 Pounds.....	2-48
Samples Weighing Less Than 25 Pounds.....	2-50
The Soil Profile.....	2-50

	Page
Purpose.....	2-50
Equipment.....	2-51
Steps.....	2-52
<b>Section III. Moisture-Content Determination .....</b>	<b>2-54</b>
Oven-Dry Method (ASTM D 2216-90).....	2-55
Purpose.....	2-55
Equipment.....	2-55
Steps.....	2-55
Calcium-Carbide-Gas Pressure Method (AASHTO T 217-1986).....	2-57
Purpose.....	2-58
Equipment.....	2-58
Steps.....	2-58
Calculations .....	2-59
Example .....	2-59
<b>Chapter 2, Soils, part 2. ....</b>	<b>2-62</b>
<b>Section IV. Specific-Gravity-of-Solids Determination (ASTM D 854-92) .....</b>	<b>2-62</b>
Specific Gravity of Soil or Solids .....	2-62
Specific-Gravity Test.....	2-62
Purpose.....	2-63
Equipment.....	2-63
Steps.....	2-64
Apparent and Bulk Specific Gravity .....	2-69
<b>Section V. Grain-Size Analysis and Distribution</b>	
<b>(ASTM D 422-63 and ASTM 2217-85) .....</b>	<b>2-70</b>
Sieve Analysis (Mechanical Analysis).....	2-70
Purpose.....	2-71
Equipment.....	2-71
Steps.....	2-72
Hydrometer Analysis .....	2-79
Purpose.....	2-79
Equipment.....	2-79
Steps.....	2-80
Presentation of Results .....	2-87
<b>Section VI. Liquid Limit, Plastic Limit, and Plasticity Index Determination</b>	
<b>(ASTM D 4318-95a) .....</b>	<b>2-89</b>
LL Determination .....	2-90
Purpose.....	2-90
Equipment.....	2-90
Steps.....	2-92
PL Determination .....	2-98
Purpose.....	2-98
Equipment.....	2-98
Steps.....	2-98
PI Determination .....	2-100
<b>Section VII. Laboratory Compaction Characteristics of Soil Using Modified</b>	
<b>Effort (Compaction Test) (ASTM D 1557-91) .....</b>	<b>2-101</b>
Compaction Test.....	2-102
Purpose.....	2-102
Equipment.....	2-103
Steps.....	2-104

	Page
Compaction-Test Graph—Presentation of Results.....	2-109
Compaction Curve.....	2-109
Zero Air Voids and Saturation .....	2-111
Percent Moisture.....	2-112
Percent Compaction.....	2-112
Compaction-Specification Block.....	2-112
Effect of Water on Density.....	2-113
Effect of Different Compactive Efforts on Density.....	2-114
Effect of Different Types of Soils on Density.....	2-115
Compaction Equipment.....	2-115
Other Compactive Efforts .....	2-116
<b>Section VIII. In-Place Density Determination.....</b>	<b>2-116</b>
Sand-Cone or Sand-Displacement Method (ASTM D 1556-90) .....	2-117
Purpose .....	2-118
Equipment.....	2-118
Steps .....	2-119
Nuclear Moisture-and-Density Tester.....	2-123
Water-Displacement Method .....	2-124
<b>Section IX. CBR Tests .....</b>	<b>2-124</b>
CBR of Laboratory-Compacted Soils (ASTM D 1883-94).....	2-125
Purpose .....	2-125
Equipment.....	2-125
Steps .....	2-127
Undisturbed Sample Testing.....	2-135
In-Place Field CBR Testing.....	2-135
Presentation and Analysis of CBR Data .....	2-135
Test Program for Nonswelling Soils.....	2-135
Test Program for Swelling or Expansive Soils .....	2-146
Test Program for Free-Draining Soils .....	2-151
<b>Section X. Technical Soils Report .....</b>	<b>2-153</b>
Soils Tests Required .....	2-153
Purpose of the Report .....	2-153
Organization and Scope of the Tests.....	2-154
Soils Technical Report.....	2-155
Purpose .....	2-156
Equipment.....	2-156
Outline.....	2-156
<b>Chapter 3. Bituminous Mixtures .....</b>	<b>3-1</b>
<b>Section I. Bituminous Pavements/Surfaces.....</b>	<b>3-1</b>
Aggregates.....	3-1
Bituminous Materials.....	3-1
Asphalts.....	3-2
Tars.....	3-6
Characteristics and Uses of Bitumens .....	3-7
Safety Precautions .....	3-7
Advantages and Disadvantages .....	3-11
<b>Section II. Sampling Materials.....</b>	<b>3-12</b>
Bituminous Materials Sampling (ASTM D 140-88).....	3-12
Liquid Materials.....	3-12



	Page
Solid and Semisolid Materials .....	3-12
Aggregate Sampling (ASTM D 75-87).....	3-12
Stone From Ledges and Quarries.....	3-13
Natural Deposits of Sand and Gravel.....	3-13
Stockpiles .....	3-14
Commercial Aggregates .....	3-14
<b>Section III. Field Identification .....</b>	<b>3-14</b>
Bitumen Field-Identification Tests.....	3-14
Asphalts and Tars.....	3-16
Asphalt Cement and Cutbacks .....	3-16
Asphaltic-Cutback Tests .....	3-16
Asphalt-Emulsion (Anionic) Tests .....	3-18
Road-Tar Tests.....	3-18
Aggregate Identification and Selection.....	3-19
Shape and Roughness.....	3-19
Hardness and Durability.....	3-19
Cleanliness.....	3-20
Hydrophobicity.....	3-20
Gradation .....	3-21
Particle Size .....	3-21
<b>Section IV. Bitumen Testing.....</b>	<b>3-22</b>
Specific-Gravity Test (ASTMs C 127-88 and C 128-93) .....	3-22
Flash-Point and Fire-Point Tests.....	3-24
Flash Point and Fire Point by Cleveland Open Cup .....	3-24
Flash Point by Tag Open Cup (ASTM D 4552-87).....	3-25
Penetration Test (ASTM D 5-86).....	3-27
Equipment.....	3-27
Steps.....	3-27
Results.....	3-29
Ductility Test.....	3-29
Softening-Point Test .....	3-30
Viscosity Tests.....	3-30
Saybolt-Furor Test (ASTM D 244-89).....	3-30
Kinematic-Viscosity Test (ASTM D 2170-85) .....	3-30
Solubility Test (ASTM D 2042-81) .....	3-30
Spot Test.....	3-31
Thin-Film Oven Test (ASTM D 1754-87).....	3-31
<b>Section V. Aggregate and Filler Testing .....</b>	<b>3-31</b>
Sieve Analysis .....	3-32
Mineral Filler (ASTM D 242-85).....	3-32
Fine and Coarse Aggregate (Washed) (ASTMs D 1073-88, D 448-86, and D 692-88) ...	3-32
Specific Gravity .....	3-32
Apparent Specific Gravity of Coarse Aggregate .....	3-33
Apparent Specific Gravity of Fine Aggregate (Calibrated Flask).....	3-34
Apparent Specific Gravity of Fine Aggregate (Uncalibrated Flask).....	3-36
Specific Gravity of Bulk-Impregnated Aggregate.....	3-37
Specific Gravity of Mineral Filler .....	3-39
Los Angeles Abrasion Test.....	3-39
<b>Section VI. Bituminous-Mix Design .....</b>	<b>3-40</b>
Hot-Mix Design Considerations .....	3-40

	Page
Steps .....	3-40
Variables.....	3-41
Blends .....	3-41
Optimum Bitumen Content .....	3-41
Gyratory Test Method.....	3-41
Marshall Test Method (ASTM D 1559-89).....	3-46
Surface-Area Method .....	3-59
Job-Mix Formula .....	3-60
<b>Section VII. Plant Control</b> .....	<b>3-64</b>
Plant Types .....	3-64
High-Type Bituminous Paving Plant.....	3-64
Intermediate-Type Plants.....	3-66
Initiating Plant Production.....	3-66
Sieve Analysis .....	3-66
Mix Redesign.....	3-66
Controlling Plant Production.....	3-66
Gyratory Test Control.....	3-67
Marshall Test Control.....	3-68
Plant-Control Execution .....	3-69
Centrifugal-Extraction Method (ASTM D 2172-88) .....	3-69
Purpose .....	3-69
Equipment .....	3-69
Steps .....	3-70
Calculations.....	3-72
Sieve Analysis of Aggregate .....	3-72
Testing Tar or Tar-Rubber Mixes .....	3-72
Density Tests .....	3-72
Expediting the Design.....	3-74
<b>Chapter 4. Concrete</b> .....	<b>4-1</b>
<b>Section I. Characteristics and Identification</b> .....	<b>4-1</b>
Description and Components .....	4-1
Cement.....	4-1
Air-Entrained Cement .....	4-2
Water .....	4-3
Aggregates .....	4-3
Properties of Concrete .....	4-4
Strength.....	4-4
Durability .....	4-5
Watertightness.....	4-5
Workability.....	4-6
Consistency.....	4-6
Uniformity .....	4-6
Concrete Curing.....	4-6
Temperature.....	4-6
Moisture.....	4-7
Concrete Admixtures .....	4-7
Accelerators .....	4-8
Retarders .....	4-8
Air-Entraining Agents .....	4-8

	Page
Water Reducers (Plasticizers).....	4-9
<b>Section II. Aggregate Testing</b> .....	4-9
Stockpile Sampling (ASTM D 75-87) .....	4-10
Gradation Determination .....	4-10
Apparatus, Test Procedures, and Calculations.....	4-11
Material Finer Than 0.75 Millimeters (No. 200 Sieve) .....	4-11
Fineness Modulus.....	4-13
Tests for Specific Gravity, Absorption, and Surface Moisture .....	4-13
Specific Gravity and Absorption of Coarse Aggregate (ASTM C 127-88).....	4-13
Specific Gravity of Fine Aggregate (ASTM C 128-93) .....	4-15
Coarse- and Fine-Aggregate Absorption .....	4-16
Surface Moisture.....	4-17
<b>Section III. Fresh-Concrete Tests</b> .....	4-17
Slump Test (ASTM C 143-90a).....	4-18
Equipment.....	4-18
Steps.....	4-18
Supplementary Test Procedure .....	4-20
Air-Content Test (ASTM 231-97) .....	4-20
Equipment.....	4-20
Steps.....	4-21
<b>Section IV. Flexural-Strength Test (Modulus of Rupture)</b> .....	4-21
Test Beams .....	4-21
Forming the Beams (ASTM C 192-90a) .....	4-21
Taking the Specimens .....	4-22
Curing the Beams.....	4-22
Flexural-Strength Test (ASTM C 78-94) .....	4-22
Equipment.....	4-22
Steps.....	4-22
<b>Section V. Compressive-Strength Test</b> .....	4-25
Casting a Concrete Cylinder.....	4-25
Equipment.....	4-25
Steps.....	4-26
Number of Specimens.....	4-27
Curing and Storing Cylinders .....	4-27
Capping Cylinders.....	4-28
Determining Compressive Strength of a Cylindrical Specimen (ASTM C 39-96) .....	4-28
Equipment.....	4-28
Steps.....	4-29
<b>Chapter 5. Soil Stabilization</b> .....	5-1
<b>Section I. Mechanics of Soil Stabilization and Modification</b> .....	5-1
Stabilization .....	5-1
Uses of Stabilization.....	5-1
Methods of Stabilization.....	5-2
Modification.....	5-3
<b>Section II. Stabilizing Agents</b> .....	5-3
Types of Stabilizers .....	5-3
Cement .....	5-3
Lime.....	5-4
Fly Ash .....	5-4

	Page
Bituminous .....	5-4
Combination .....	5-4
Time Requirements for Testing .....	5-4
Stabilizer Selection .....	5-5
Equipment .....	5-5
Steps .....	5-5
Soil Stabilization in Frost Areas.....	5-6
Limitations .....	5-6
Construction Cutoff.....	5-7
Weather .....	5-7
Pick-and-Click Tests.....	5-7
Wet-Dry and Freeze-Thaw Tests .....	5-7
Preparation.....	5-8
Wet-Dry Test Procedure .....	5-8
Freeze-Thaw Test Procedure.....	5-8
Calculations and Criteria .....	5-8
Modified Mix Design for Sandy Soils.....	5-10
Soils with No Material Retained on the No. 4 Sieve.....	5-11
Soils with Material Retained on the No. 4 Sieve.....	5-13
<b>Appendix A. Metric Conversion Chart .....</b>	<b>A-1</b>
<b>Appendix B. The Unified Soil Classification System .....</b>	<b>B-1</b>
Basis of the USCS.....	B-1
Purpose and Scope .....	B-1
Definitions of Soil Components .....	B-2
The Classification System.....	B-2
Soil Groups and Group Symbols .....	B-4
Identification of Soil Groups.....	B-8
Laboratory Identification.....	B-9
Major Soil Groups .....	B-9
Characteristics of Soil Groups Pertaining to Embankments and Foundations.....	B-15
Features on the Soils-Classification Sheet .....	B-15
Graphical Presentation of Soils Data.....	B-22
Characteristics of Soil Groups Pertaining to Roads and Airfields.....	B-23
Features on the Soils-Classification Sheet .....	B-23
Graphical Presentation of Soils Data.....	B-26
<b>Glossary .....</b>	<b>Glossary-1</b>
<b>References.....</b>	<b>References-1</b>
<b>Index.....</b>	<b>Index-1</b>

## Preface

Field Manual (FM) 5-472 provides the technical information necessary for military personnel to obtain samples and perform engineering tests and calculations on soils, bituminous paving mixtures, and concrete. These tests and calculations are required to achieve proper design with these materials and adequate control over their use in military construction.

This manual covers soils, aggregates, bituminous cements, bituminous paving mixtures, portland-cement concrete, and stabilized soil including stabilizing agents such as bitumens, cements, lime, fly ash, and chemical modifiers. The manual gives detailed instructions for taking adequate representative test samples and step-by-step procedures for making physical-properties tests and for recording, calculating, and evaluating test results. The manual explains methods for designing bituminous paving mixtures and for stabilizing soil. It also gives the procedures and tests required to control the manufacture of these mixtures. The manual describes the tools and equipment for performing these tests and contains general instructions for the care, calibration, and use of test equipment.

FM 5-472 is adopted for use by Navy personnel. Certain tests and procedures prescribed differ in principle or method and are more detailed than counterpart tests currently required by the Navy for new construction at Navy installations, including those in forward areas. Although this manual provides general guidance for materials and soils testing, the design of new structures and facilities will be based on the results obtained from methods and procedures outlined in Naval Facilities Engineering Command Design Manual (NAVFAC DM)-7.1 and NAVFAC DM-7.2. When methods and procedures prescribed by the Navy differ from those in this manual, the Navy's methods will take precedence.

The test procedures and terminology used in this manual conform to the latest methods and specifications of the American Society for Testing and Materials (ASTM), the American Concrete Institute (ACI), and the Portland Cement Association (PCA).

The tests listed in this manual also apply to arctic construction. However, cold-weather effects present different problems and additional tests will be required for correct evaluation of the materials. These additional tests and the considerations associated with arctic construction are in Technical Manual (TM) 5-349.

Appendix A contains an English-to-metric measurement conversion chart.

The proponent of this publication is HQ TRADOC. Send comments and recommendations on Department of the Army (DA) Form 2028 directly to Commander, USAES, ATTN: ATSE-TD-D, Fort Leonard Wood, Missouri 65473-6650.

Unless this publication states otherwise, masculine nouns and pronouns do not refer exclusively to men.