United States
Department of
Agriculture

Soil
Conservation
Service

Soil Mechanics Training Series

Basic Soil Properties

Module 5 - Compaction

Part B - Compaction of Non-gravelly Soils

Study Guide

ENG-SOIL MECHANICS TRAINING SERIES--

BASIC SOIL PROPERTIES

MODULE 5 - COMPACTION

PART B

COMPACTION OF NON-GRAVELLY SOILS

STUDY GUIDE

National Employee Development Staff
Soil Conservation Service
United States Department of Agriculture
December 1988

PREFACE

The design and development of this training series are the results of concerted efforts by practicing engineers in the SCS. The contributions of many technical and procedural reviews have helped make this training series one that will provide basic knowledge and skills to employees in soil mechanics.

The training series is designed to be a self-study and self-paced training program.

The training series, or a part of the series, may be used as refresher training. Upon completion of the training series, participants should have reached the ASK Level 3, perform with supervision. The modules for the training series will be released as they are developed.

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INTRODUCTION

This is Part B of Module 5 - Compaction of Non-gravelly Soils of the ENG-Soil Mechanics Training Series-Basic Soil Properties. Module 5 consists of five parts, Parts A to E. Each part has its own study guide and slide/tape presentation. The parts of the module are:

Part A - Introduction, Definitions, and Concepts
Part B - Compaction of Non-gravelly Soils
Part C - Compaction of Gravelly Soils
Part D - Compaction of Clean, Coarse-grained Soils
Part E - Evaluation of Compaction Data and Specifications

Soil Mechanics Level I contains Modules 1 through 3:

Module 1 - Unified Soil Classification System
Module 2 - AASHTO
Module 3 - USDA Textural Soil Classification

The modules in the ENG-Soil Mechanics Training Series--Basic Soil Properties are:

Module 4 - Volume-Weight Relations
Module 5 - Compaction
Module 6 - Effective Stress Principal
Module 7 - Qualitative Engineering Behavior by USCS Class
Module 8 - Estimated Soil Properties Table
Module 9 - Qualitative Embankment Design

INSTRUCTIONS

During the presentation you will be asked to STOP the machine and do activities in your Study Guide. These activities offer a variety of learning experiences and give you feedback on your ability to accomplish the related module objectives.

Part B has six objectives to be accomplished. If you have difficulty with a specific area, study, re-study, and, if necessary, get someone to help you. DO NOT continue until you can complete each objective.

You should complete Part B as follows:

1. Read the objectives.
2. Run the slide/audio cassette, stopping it when you need to work in the Study Guide.
3. Study and review all references.
4. Activity 8 requires you to perform a compaction test. You must coordinate this Activity with your Training Officer and Technical Leader.

If you have difficulty in a specific area, contact your State Engineering Staff, through your supervisor.

CONTENTS OF PACKAGE

1 slide tray
1 audio cassette
1 Study Guide

ACTIVITY 1 - OBJECTIVES

At the completion of Part B you will be able to:

1. From a list, define the important terms associated with the procedures and equipment used in performing the compaction test.

2. Describe how compaction test results are affected by soil gradation and plasticity characteristics.

3. Describe the effects of different energy levels on compaction test results.

4. Using example data, compute and plot results of a compaction test and determine values of maximum dry density and optimum water content.

5. Explain conceptually from memory the purpose of laboratory and field compaction tests. Explain how compaction tests are used in design and quality control of earth fills.

6. Using field equipment and a soil sample provided, perform a compaction test by standard procedures.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 2 - COMPACTION THEORY INTRODUCTION

R. R. Proctor, an engineer in California, developed many of the important concepts relating to compaction in the 1930's. He was one of the first to recognize how important water content was to the resulting dry unit weight of compacted soil.

Three primary variables determine the compacted dry unit weight of a soil mass. These variables are:

1. The soil being compacted. Each soil has unique compaction characteristics. If one uses the same energy and water content to compact several soils, different dry unit weights will result.

2. The water content at which the soil is compacted. If the same soil is compacted using a uniform energy and the water content of several specimens is varied, then the resulting dry unit weight of the specimens will vary. This is the most common statement of the principal of compaction.

3. The amount and type of energy. If one compacts several specimens of soil at the same water contents and varies the energy used to compact them, then resultant dry unit weights of the specimens will vary.

Proctor developed a test apparatus that would apply a standard energy to a soil as it is compacted. By eliminating energy as a variable, the relationship between water content and compacted dry unit weight of a soil can be studied. By performing a series of tests on soil specimens at several water contents using a standard energy application to compact the specimens, a graphical relationship between water content and compacted dry unit weight can be developed for that soil and that energy. Two levels of energy are commonly used. They are discussed in detail later in the module.

The plotted data relating dry unit weight and water content is called a compaction curve or Proctor curve. Values of water content are plotted on the horizontal axis and values of dry unit weight are plotted on the vertical axis. Compaction curves typically have a parabolic shape with a peak value of dry unit weight occurring at some value of water content.

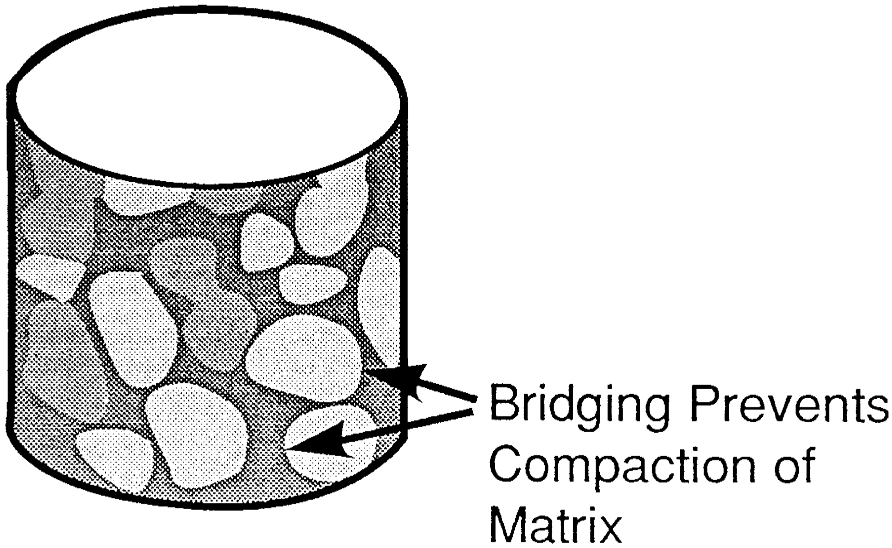
Compaction tests are difficult to perform on relatively clean, coarse-grained soils because of their inability to retain water. Testing a series of specimens at varying water contents is problematic because the soils will not retain added water. Sometimes, a single value of compacted dry unit weight is obtained for some arbitrary water content using the standardized energy application, but rarely can be a meaningful curve be developed. A "rule-of-thumb" used is that soils that have less than 12 percent finer than the number 200 sieve are difficult to test using Proctor's procedures.

To perform compaction tests on soils that have a significant percentage of large gravel-size particles is also problematic. A testing apparatus that would accomodate large gravel particles would be quite large, and standardized equipment has not been developed for such soils. Soils that have over 30 percent of particles larger than 3/4 inch cannot be tested using standardized compaction test procedures. Study Figure 2.1, page 4.

START THE TAPE WHEN YOU HAVE FINISHED

Figure 2.1

COMPACTION TESTS NOT APPLICABLE FOR SOILS WITH >30% LARGER THAN 3/4"



<u>ACTIVITY 3</u> - DETERMINATION OF PROPER ASTM TEST METHOD

The selection of the proper test method for compaction tests is based on the gradation of the soil to be tested. These guidelines apply to ASTM Test D 698, called the "standard" compaction test, and to ASTM Test D 1557, often called the "modified" test. Each of these tests uses a different amount of energy to compact soils.

The information required on a soil's gradation are the percent passing the 3/4 inch sieve, the 3/8 inch sieve, the number 4 sieve, and the number 200 sieve.

Remember that ordinarily, compaction tests are not performed on soils that have less than 12 percent finer than the number 200 sieve. Soils that have a low fines content do not readily retain moisture in their pores, and it is difficult to obtain a series of test specimens at successively higher water contents.

Because of limitations on the size of laboratory equipment, standardized test methods are not presently available for soils that have more than 30 percent of particles larger than 3/4 inch.

The two standardized ASTM compaction tests, D 698 and D 1557, have 3 variations that can be used. These are referred to as Methods A, B, and C. The differences in the test methods are in the size of particles included in the test specimens and the size of mold in which the soil is compacted.

Tests performed by Method A are covered in this portion of Module 5, Part B. Tests performed using Methods B and C are covered in the next part of the Module, Part C.

The flow chart shown on page 9 is useful for determining which ASTM variation should be used for a particular soil. Carefully examine the chart, and then follow these example uses of the chart.

Example 1:

A soil has 89 percent finer than use 3/4 inch sieve, 76 percent finer than the 3/8 inch sieve, 69 percent finer than number 4 sieve, and 37 percent finer than the number 200 sieve. Using the flow chart, the correct test method is C.

Example 2:

A soil has 95 percent finer than 3/4 inch sieve, 88 percent finer than 3/8 inch sieve, 82 percent finer than the number 4 sieve, and 49 percent finer than the number 200 sieve. Using the flow chart, correct test method is A.

CONTINUE TO NEXT PAGE

ACTIVITY 3 - Continued

Selection of Proper ASTM Test Method:

Given the gradations of each of the following soils, use the flow chart on page 9 to determine which ASTM test variation, or Method should be used to perform a compaction test on that soil. Complete the column listing the proper method.

Soil Number	Percent Finer By Dry Weight #200	#4	3/8"	3/4"	ASTM Test Method
1	42	73	82	93	
2	8	69	76	89	
3	78	98	100	100	
4	27	49	56	67	
5	22	70	74	79	

WHEN YOU HAVE COMPLETED THE ACTIVITY, REVIEW THE ANSWERS PROVIDED ON PAGE 8

ACTIVITY 3 - Solution

Soil 1:

Method B is the correct Test Method to use for a compaction test on this soil.

Soil 2:

The soil has less than 12 percent finer than the number 200 sieve, so that compaction tests would be difficult to perform. Test procedures covered in Part D of this Module should be followed.

Soil 3:

Method A is the correct Test Method for this soil.

Soil 4:

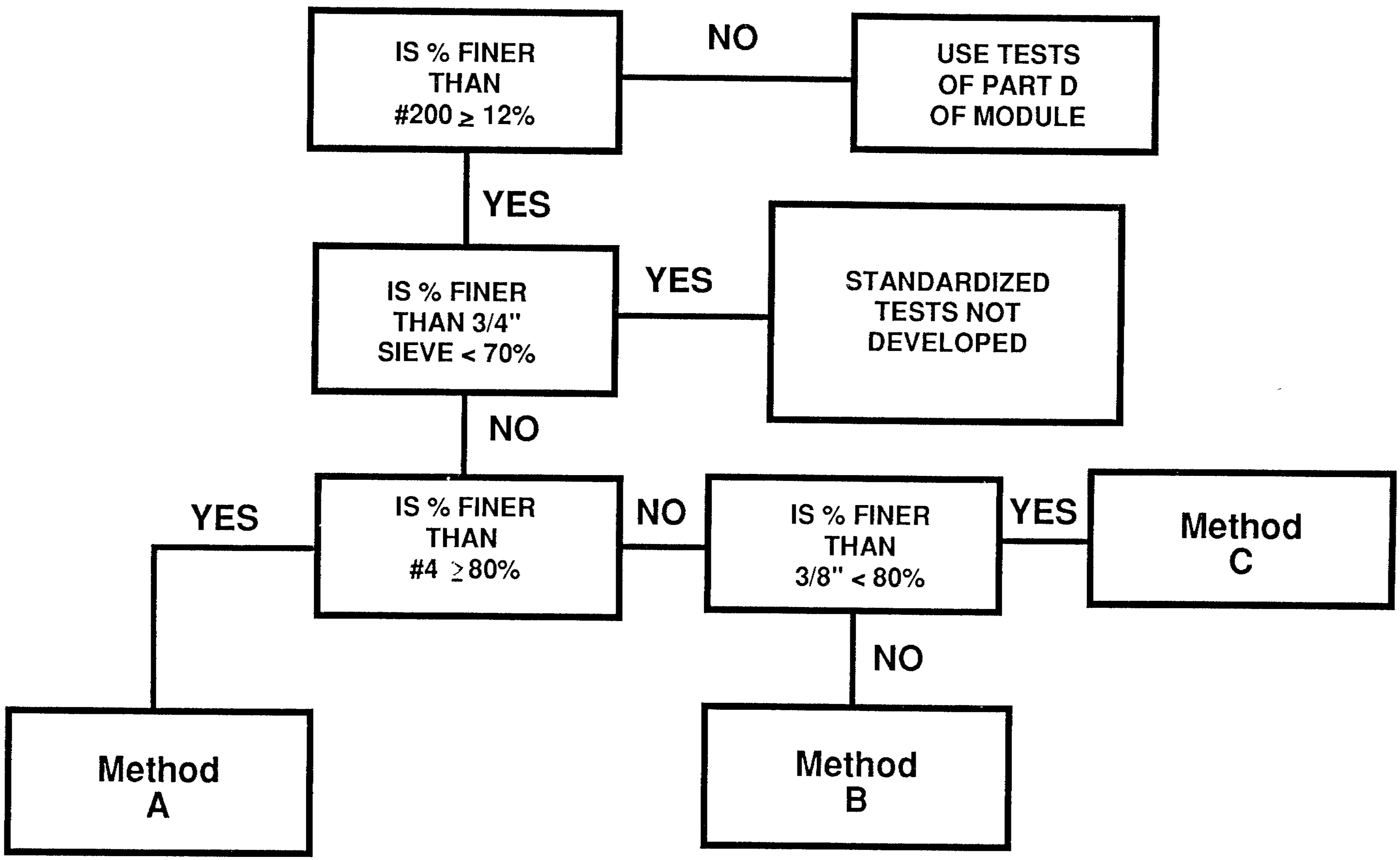
The soil has more than 30 percent of particles larger than the 3/4 inch sieve, so standard compaction test procedures do not apply. (69% or less is finer than the 3/4 inch sieve)

Soil 5:

Method C is the correct Method.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 3



IS % FINER THAN #200 ≥ 12%
NO
USE TESTS OF PART D OF MODULE
YES
IS % FINER THAN 3/4" SIEVE < 70%
YES
STANDARDIZED TESTS NOT DEVELOPED
NO
IS % FINER THAN #4 ≥ 80%
YES
Method A
NO
IS % FINER THAN 3/8" < 80%
YES
Method C
NO
Method B

ACTIVITY 4 - SUMMARY OF COMPACTION TEST PROCEDURES

This Activity introduces the standard test methods for performing compaction tests. Remember that standardized methods are not presently available for soils that have more than 30 percent by dry weight of particles larger than a 3/4 inch sieve. Also, compaction tests are difficult to perform on soils that have less than 12 percent finer than the number 200 sieve.

Two ASTM test standards are available for compaction tests of soils. The two test standards vary primarily in the amount of energy used to compact the soil samples in the test. ASTM Test D 698 is often referred to as the "standard" energy test, and Test D 1557 is referred to as the "modified" energy test. Additional details on energies used in each of these tests will be given in a later Activity.

Each of these ASTM tests has three variations that can be used to test a particular soil sample. As you learned in Activity 3, selection of the proper method depends on the gradation of the soil. The three Methods of performing compaction tests are denoted A, B, and C. Method A tests require gravel-size particles to be removed before testing. These test procedures are covered in this part of the Module. The Method B and C procedures include some gravel-sized particles in the compaction test sample, and these procedures will be covered in the next part of the Module, Part C.

In preparation for Method A compaction tests, the soil sample is screened through a number 4 sieve to remove all gravel-size particles. Corrections to test results for the density of the excluded oversize gravels may be made as detailed in part C of this module. Soils may be prepared either at their natural water contents, or they may be air-dried before processing. Some laboratories prefer to air-dry the soil before sieving because of the difficulty in sieving out gravel particles from a plastic clay matrix when the soils are at natural water content. One should realize that the compaction properties of some soils may be changed by air-drying, and these soils should be processed at natural water content. Soil samples should never be oven-dried before testing because this will almost certainly alter their properties.

For the test, after sieving, four to five specimens are separated, each weighing about 5 pounds (air-dry weight), and then are moistened to water contents about 1-1/2 or 2 percent apart. Selection of the water contents for the specimens requires judgement and experience. Higher water contents are used for plastic, fine-grained soils than are used for lower plasticity and sandier soils. If one uses poor judgement in selecting the water contents of the prepared specimens, additional specimens may be prepared to complete the test. Occasionally, as many as eight specimens are used when poor judgement is used in preparing the initial four to five specimens. See Figure 4.5, p. 21.

Each of the prepared specimens is then allowed to "cure" in a moisture-proof container for a specified period. The curing time required is based on the Unified Soil Classification System class of the soil being tested. Curing allows the water added to the soil to equilibrate, or to become equally distributed throughout the sample.

CONTINUE TO THE NEXT PAGE

ACTIVITY 4 - Continued

The length of curing time required is specified as follows in ASTM procedures:

Unified Soil Classification Group	Minimum Curing Time (hours)
SM, GM	3
ML, CL, OL, GC, SC	16 (overnight)
MH, CH, OH	40

Each specimen is then compacted into a circular mold. The soil is compacted by dropping a hammer of specified weight from a specified height for a specified number of times. Several "lifts" are used to fill the mold with compacted soil. Details on hammer weights, height of drop, number of blows of the hammer per lift, and number of lifts of soil used to fill the mold are given in a later Activity. These details determine the amount of energy used to compact the soil, with ASTM Tests 698 and 1557, using different amounts of energy.

The volume of the mold into which the soil is compacted and the weight of the mold are carefully determined before testing. These values are needed to compute the compacted density of each specimen. Method A tests use a mold that has a diameter of about 4" and a volume of about 1/30 a cubic foot.

The moist unit weight of each compacted specimen is determined by weighing the specimen and the mold into which it has been compacted, subtracting the weight of the mold, and then dividing by the volume of the mold, with the following equation:

$$\text{Moist Unit Weight} = \frac{(\text{Weight of Mold + Soil}) - (\text{Weight of Mold})}{\text{Volume of Mold}}$$

Units of pounds per cubic foot or kilograms per cubic meter are used to measure moist unit weight. The system used depends on the devices used to weigh the samples and measure the volume of the mold.

The water content of each specimen is determined by drying a representative portion in an oven to a constant weight. The oven is usually set to 110 degrees Centigrade. However, soils that contain hydrated minerals, such as gypsum, must be dried at temperatures that will not drive off hydrated water, usually 60 degrees Centigrade.

The dry unit weight of each specimen may then be calculated from the following equation:

$$\text{Dry Unit Weight} = \frac{\text{Moist Unit Weight}}{(1 + (\text{water content }\%/100))}$$

If the proper range of water contents was selected for the preparation of the test specimens, the values of the soil's compacted dry unit weights will show an increase for the first several specimens, and then at higher water contents, the value will decrease.

CONTINUE TO THE NEXT PAGE

ACTIVITY 4 - Continued

With the data obtained, a curve may be plotted showing the relationship between water content and dry unit weight for that soil and that energy application. Ordinarily, water content is used for the horizontal scale and dry unit weight for the vertical scale. The curve typically has a parabolic shape that has a defined peak in dry unit weight. If a peak does not occur in the plotted data, the proper range of water contents was not selected for the test specimens, and additional specimens should be prepared.

The water content at which the peak in the curve occurs is called the optimum water content. The value of dry unit weight at the peak of the curve is referred to as the maximum dry unit weight of the soil for that energy application. See Figure 4.1, p. 15.

Problem:

Problem 4.1, page 18, contains data obtained from a Method A compaction test performed on a silty clay soil classifying as CL. The test was performed using "standard" ASTM D 698, energy. The form is a laboratory worksheet used by SCS technicians to record compaction test data.

Row 1 contains the weight of the compacted soil and mold for each specimen tested.

Row 2 has the weight of the mold, or cylinder into which the soil was compacted.

Row 3, the weight of the compacted soil, is obtained by subtracting Row 2 and Row 1.

Row 4 is the moist density of the compacted specimen, obtained by dividing Row 3 by the volume of the mold.

Row 5 is the computed dry unit weight of the specimen, obtained by dividing the moist unit weight (Row 4) by 1 plus the water content expressed as a decimal (Row 9 divided by 100).

Rows 10 through 15 contain weights of water content samples taken from each compacted specimen. The wet weight of the sample plus can, the dry weight of the soil plus can, and the can weight, are used to calculate the water content, Row 9.

To complete this problem, (1) calculate the moist unit weight of each specimen. (2) Then, calculate the water content of each specimen. (3) Then, calculate the value of dry unit weight for each point. (4) When you have computed the data, prepare the blank data form provided on page 19 to plot this data. (5) Select a suitable scale for water content for the horizontal axis, and a suitable scale for dry unit weight for the horizontal axis.

CONTINUE TO THE NEXT PAGE

ACTIVITY 4 - Continued

The same scales for plotting compaction test data must be used each time data is plotted. This allows you to develop an experience based on the typical shapes of different soil types and energies used to perform the tests. SCS engineers have found the following scales to be appropriate:

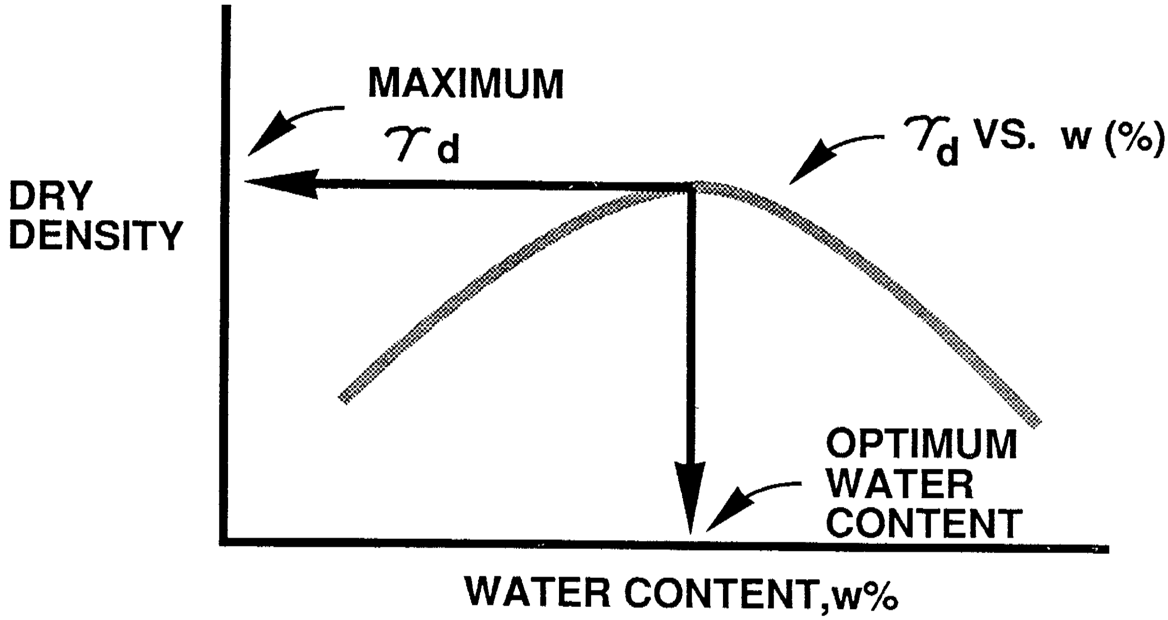
For water content - Use 1" = 4% water content

For Unit Weight - Use 1" = 10 pounds per cubic foot

Figure 4.4, p. 21 illustrates the scales suggested for use.

(6) Finally, plot the problem data on the blank form provided on page 19. The data should enable you to construct a smooth curve connecting the data points. (7) From this curve, determine the value of water content at which the peak in the curve occurs, and determine the value of maximum dry unit weight at the peak of the curve. Round your answers to the nearest 0.5 pcf for dry density and to the nearest 0.5% for water contnet.

WHEN YOU HAVE COMPLETED THE ACTIVITY, REVIEW THE ANSWERS PROVIDED ON PAGE 20



Note: γ_m curve not shown

Figure 4.1-- Typical Compaction Test Results.

CONTINUE TO THE NEXT PAGE

ACTIVITY 4 - PART B - PROBLEM 4.1

WORK SHEET FOR COMPACTION AND PENETRATION RESISTANCE DATA

Sample No.: ____________

COMPACTION DATA **(Record Weights in Pounds)**

1	Wt. of Cyl. + Soil	8.26	8.51	8.63	8.51		
2	Wt. of Cylinder	4.20	4.20	4.20	4.20		
3	Wt. of Soil = (1) - (2)						
4	Wt. per Cu. Ft. (Wet) = (3) ÷ Vol. of Cyl.						
5	Wt. per Cu. Ft. (Dry) = $\frac{(4) \times 100}{100 + (9)}$						
6	Proctor Needle Readings						
7	Size Needle (Sq.in.)						
8	Penetration (Lbs./sq. in.) Resistance = (6) ÷ (7)						

MOISTURE DETERMINATION DATA **(Record Weights in Grams)**

9	Percent Moisture = $\frac{(13)}{(15)} \times 100$						
10	Can Number	20	21	22	23		
11	Wet Wt. - Can + Soil	185.62	178.24	172.14	238.48		
12	Dry Wt. - Can + Soil	171.86	162.48	154.84	209.48		
13	Moisture Weight = (11) - (12)						
14	Weight of Can	37.62	37.78	38.30	38.50		
15	Dry Weight of Soil = (12) - (14)						

Vol. of Cyl. .03337 cu. ft.	
	Standard Proctor
	Modified AASHO
	Other ____________

PROCEDURE DATA:

Wt. of Hammer 5.5 Pounds

Drop 12 Inches

No. of Lifts 3

Completed by: ____________ Date: ____________

Computed by: ____________ Date: ____________

Checked by: ____________ Date: ____________

Recorded by: ____________ Date: ____________

Density		% H_2O
Wet	Dry	

Project ACTIVITY 4 - PROBLEM 4.1

Site MODULE 5 - PART B

SCS-ENG-352 (REV. 3-70)
FILE CODE ENG-22

LABORATORY NO ______

MATERIALS TESTING REPORT	U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	COMPACTION AND PENETRATION RESISTANCE

PROJECT and STATE: Problem 4.1

FIELD SAMPLE NO	LOCATION	DEPTH

GEOLOGIC ORIGIN	TESTED AT	APPROVED BY	DATE

CLASSIFICATION ______ LL ______ PI ______

MAX. PARTICLE SIZE INCLUDED IN TEST ______"

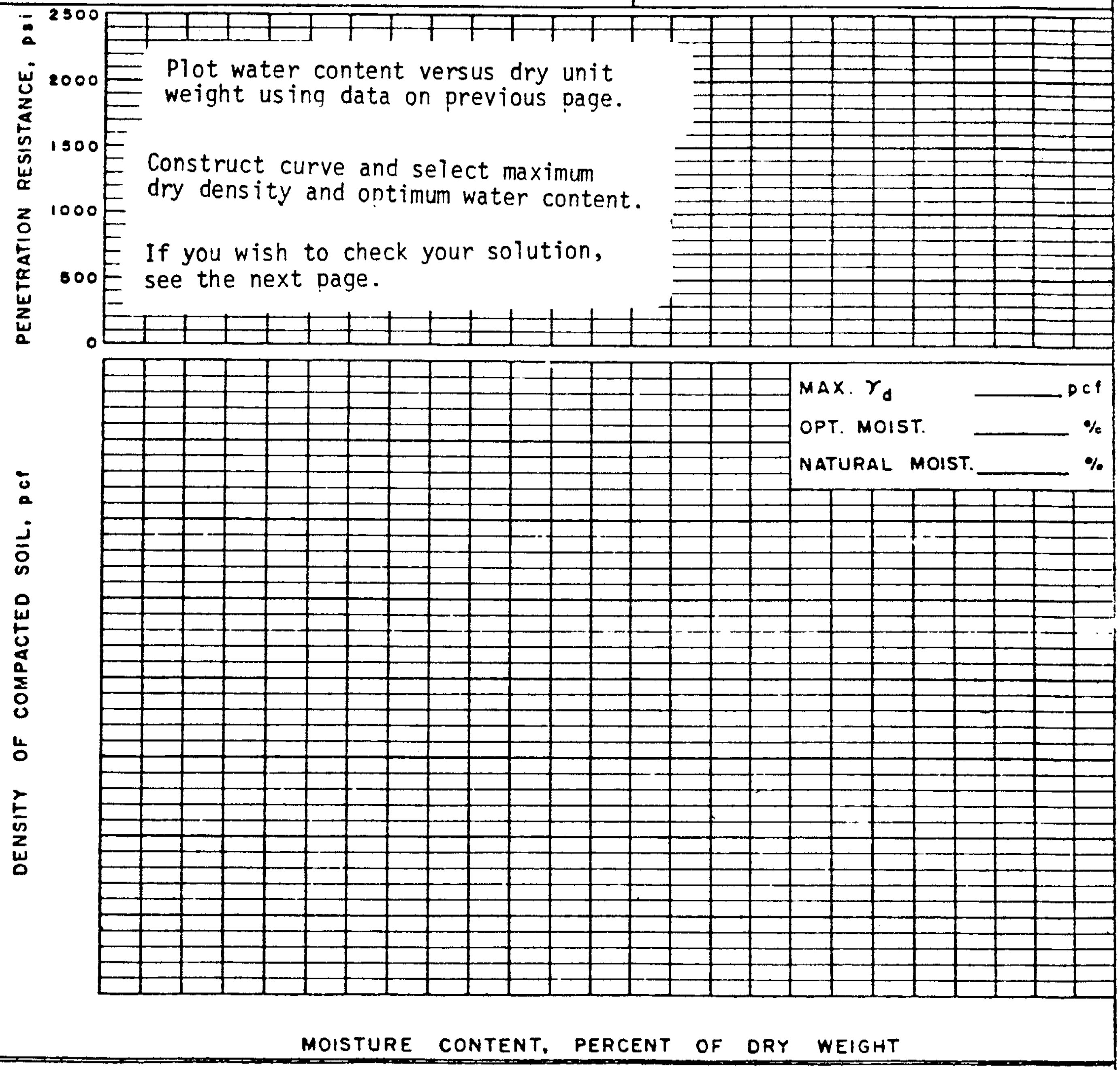
SPECIFIC GRAVITY (G_s) { MINUS NO. 4 ______ / PLUS NO. 4 ______

CURVE NO. ______ OF ______

STD. (ASTM D-698) ☐; METHOD ______

MOD. (ASTM D-1557) ☐; METHOD ______

OTHER TEST ☐ (SEE REMARKS)



Plot water content versus dry unit weight using data on previous page.

Construct curve and select maximum dry density and optimum water content.

If you wish to check your solution, see the next page.

MAX. γ_d ______ pcf

OPT. MOIST. ______ %

NATURAL MOIST. ______ %

REMARKS

USDA-SCS-HYATTSVILLE MD 1986

ACTIVITY 4 - PART B

LABORATORY NO

MATERIALS TESTING REPORT	U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	COMPACTION AND PENETRATION RESISTANCE

PROJECT and STATE: Problem 4.1 Solution D Figure 4.3

FIELD SAMPLE NO. | LOCATION | DEPTH

GEOLOGIC ORIGIN | TESTED AT | APPROVED BY | DATE

CLASSIFICATION ______ LL ______ PI ______

MAX. PARTICLE SIZE INCLUDED IN TEST # 4 "

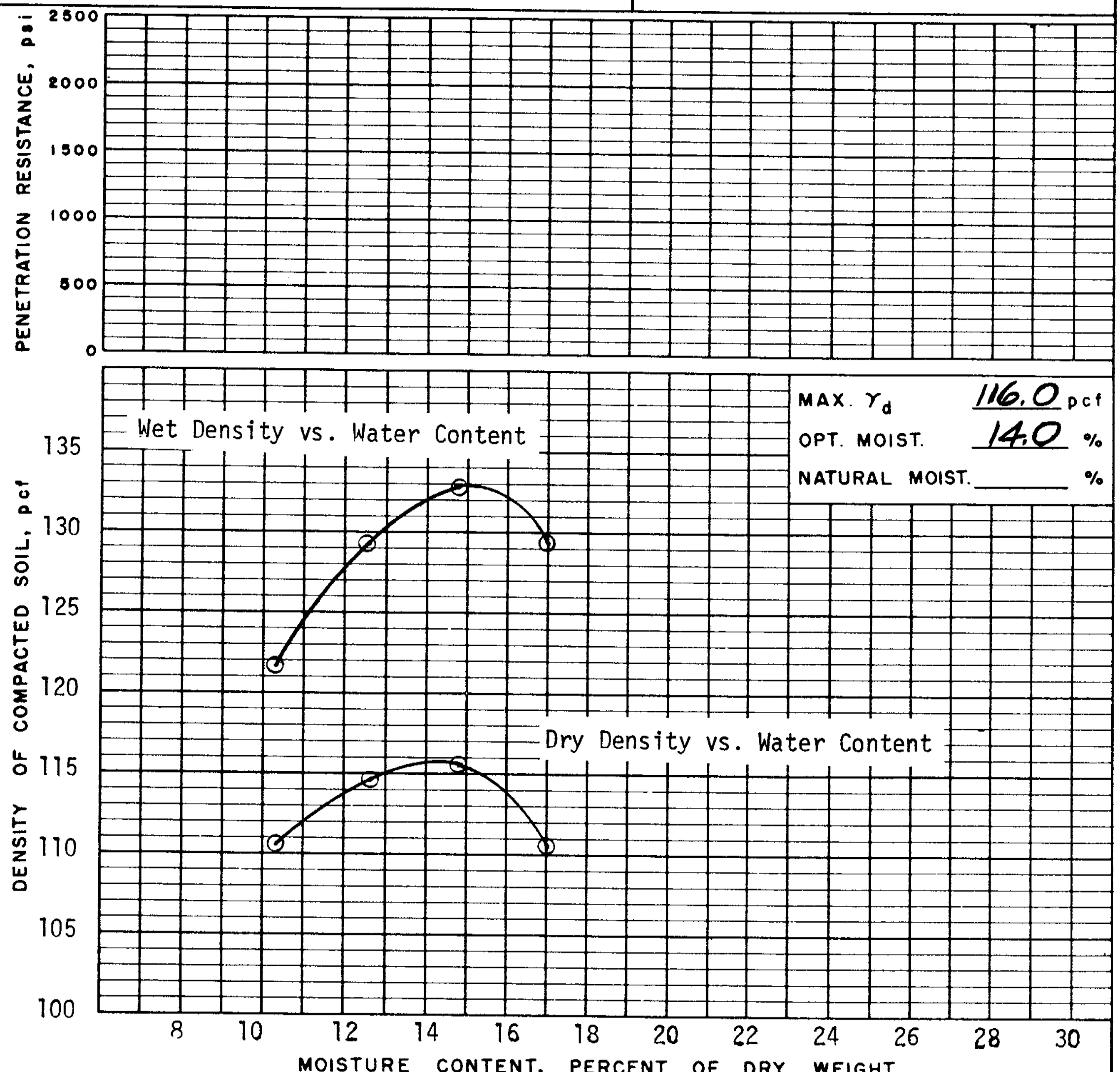
SPECIFIC GRAVITY (G_s) { MINUS NO. 4 ______ ; PLUS NO. 4 ______

CURVE NO. ______ OF ______

STD. (ASTM D-698) ☒; METHOD A

MOD. (ASTM D-1557) ☐; METHOD ______

OTHER TEST ☐ (SEE REMARKS)



MAX. γ_d 116.0 pcf

OPT. MOIST. 14.0 %

NATURAL MOIST. ______ %

REMARKS

START THE TAPE PLAYER WHEN YOU HAVE FINISHED

PROPER SCALES FOR PLOTS

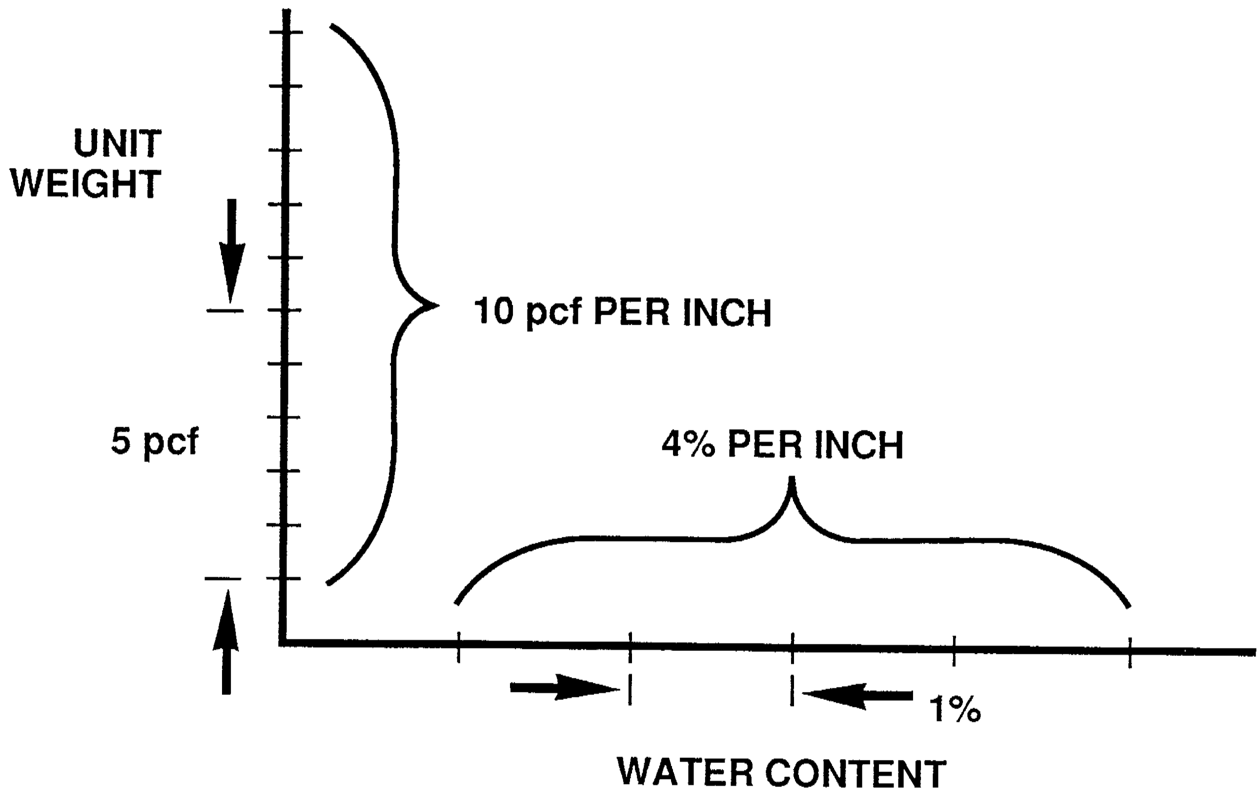


Figure 4.4

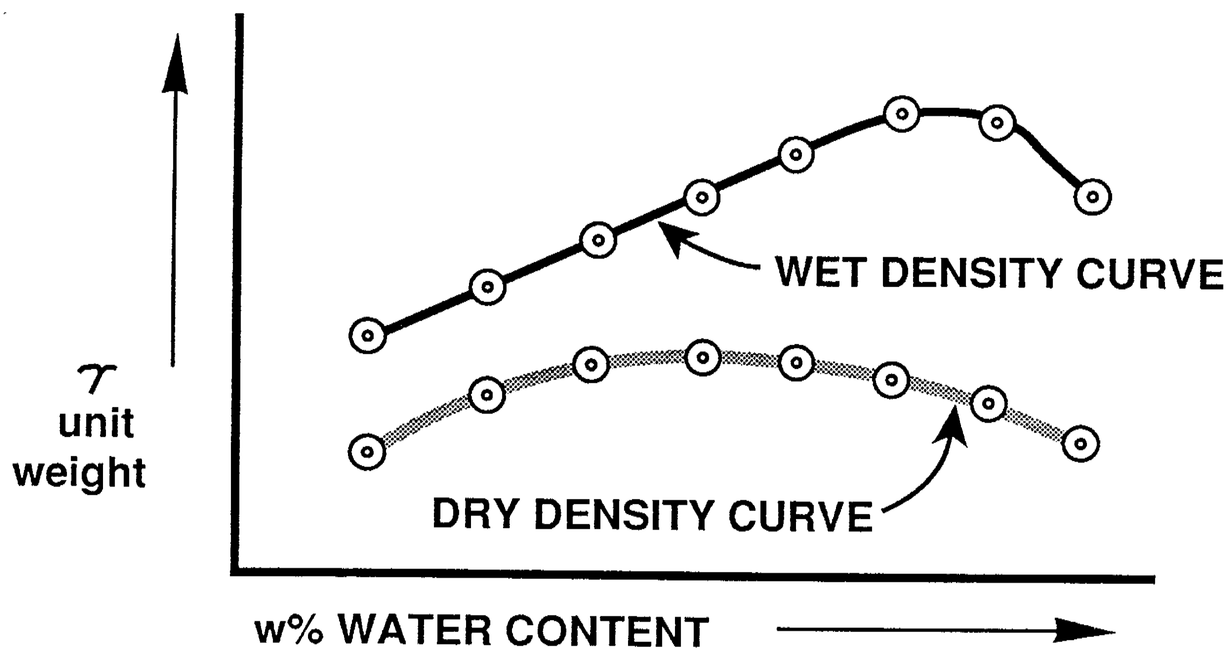


Figure 4.5--Excessive number of test points required due to low starting point

ACTIVITY 5 - STANDARDIZED ENERGY TESTS

Two different standard energy applications are commonly used to perform compaction tests. A standard test has been developed for each energy application. The standard tests are published in the American Society for Testing and Materials, ASTM, annual book of standards. Standards for testing soils are in Section 4, Volume 04.08. The more important aspects of the test procedures are summarized in this Activity and in the previous Activity. Detailed instructions necessary for one to actually perform a test are contained in the ASTM test standard, covered in a later Activity. Test methods are periodically reviewed and revised by ASTM, and you should always be sure you are using the most current one.

The first compaction test to be discussed is ASTM D 698. This is often referred to as the "standard" Proctor test. You should recall that each test standard contains three variations depending on the gradation of the soil being tested. Method A tests are covered in this part of the Module.

The equipment used to compact soils using ASTM D 698 Method A procedures is shown on Figure 5.1. This test uses a hammer weighing 5.5 pounds which is dropped a vertical distance of 12 inches a total of 25 times per lift of compacted soil. Soil is compacted into a mold that has a volume of about 1/30 of a cubic foot in three lifts.

The amount of energy applied then may be calculated as follows:

$$\frac{5.5 \text{ pounds} \times 1 \text{ foot} \times 25 \text{ blows per lift} \times 3 \text{ lifts}}{1/30 \text{ cubic foot}} = 12{,}375 \text{ foot-pounds per cubic foot}$$

ASTM Test Method D 1557 uses a hammer weighing 10 pounds that is dropped a distance of 18 inches a total of 25 times per lift of compacted soil. The mold is filled using 5 lifts of compacted soil. A mold with a volume of about 1/30 a cubic foot is used. Figure 5.2 depicts this test. This is a much higher energy application than the Standard Method covered previously. This test method is often referred to as the Modified Proctor test.

The amount of energy applied to the soil in this test is:

$$10 \text{ pounds} \times 1.5 \text{ foot} \times 25 \text{ blows per lift} \times 5 \text{ lifts}/(1/30 \text{ cubic foot}) = 56{,}250 \text{ foot-pounds/cubic foot}$$

CONTINUE TO NEXT PAGE

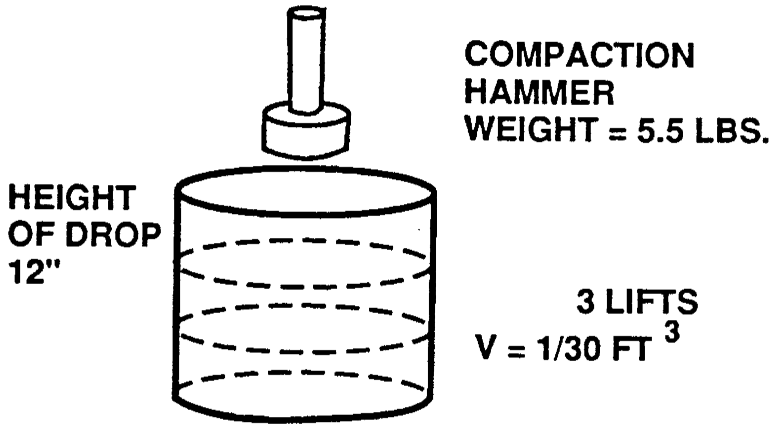
ACTIVITY 5 - Continued

The following table summarizes the test procedures and equipment used for each compaction test. Each specimen in a test is compacted using the same energy. The purpose of standardizing equipment and procedures is to obtain an energy application which is the same for each test. This enables one to examine only the influence of water content on the compacted dry unit weight of the specimens being tested.

Test Method	Hammer Weight (pounds)	Distance Dropped (ft.)	Blows/Lift	No. of Lifts	Energy (foot/pounds) cubic yards
D 698 A	5.5	1.0	25	3	12,375
D 1557 A	10.0	1.5	25	5	56,250

START THE TAPE WHEN YOU HAVE STUDIED THE FOLLOWING PAGE

STANDARD PROCTOR ENERGY APPLICATION



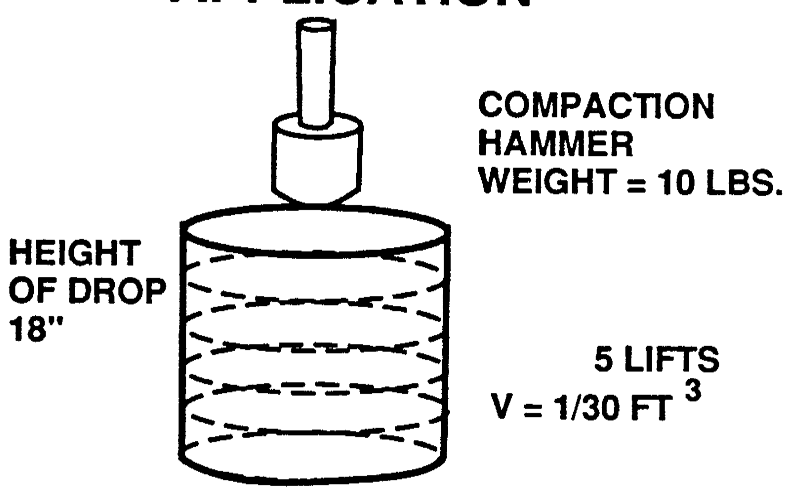
Standard Proctor Energy - ASTM D698

$$= \frac{5.5 \text{ lbs.} \times 1 \text{ ft.} \times 25 \text{ blows/lift} \times 3 \text{ lifts}}{1/30 \text{ ft.}^3}$$

$= 12{,}375$ ft. - lbs./ft.^{3}

Figure 5.1

MODIFIED PROCTOR ENERGY APPLICATION



Modified Proctor Energy - ASTM D1557

$$= \frac{10 \text{ lbs.} \times 1.5 \text{ ft.} \times 25 \text{ blows/lift} \times 5 \text{ lifts}}{1/30 \text{ ft.}^3}$$

$= 56{,}250$ ft. - lbs./ft.^{3}

Figure 5.2

ACTIVITY 6 - EFFECT OF VARYING ENERGY LEVELS ON COMPACTION TEST RESULTS

If compaction tests were performed on the same soil using different energy levels, different compaction curves would result. In general, the higher the energy used in compacting a soil, the higher will be the unit weight of the compacted soil, and the optimum water content will be lower.

The curves developed for the different energies have the most significant differences for plastic, fine-grained soils, and are less pronounced on less plastic, sandy soils.

One must realize that the energies used in these laboratory tests do not have a direct correlation to the energy applied to soils by field compaction equipment. The intent of this test is not to simulate field compaction characteristics. Results of the laboratory compaction test are used primarily to form the basis for the design of a compacted fill. A desirable degree of compaction can by established by testing soils at different design densities for engineering properties such as shear strength, consolidation, and permeability. The laboratory compaction test provides a uniform reference base for a given soil, and field control can then be tied to this reference base.

Typical test results for two different energy level compaction tests for several different Unified Soil Classification soil groups are shown on the following pages. Carefully examine the curves. Note the typical values for maximum dry unit weight and optimum water content obtained for each energy. Note also the typical shapes of the curves for each soil type.

For each soil, list the values of maximum dry unit weight and optimum water content obtained for each energy source by filling out the following table. (Round off values of density to the nearest 0.5 pcf and water content to the nearest 0.5%).

	Standard Energy (D 698)		Modified Energy (D 1557)	
Soil Type	Maximum Dry Unit Weight pounds/ft³	Optimum Water Content %	Maximum Dry Unit Weight pounds/ft³	Optimum Water Content %
Figure 6.1 CH				
Figure 6.2 CL				
Figure 6.3 ML				
Figure 6.4 MH				
Figure 6.5 SC				
Figure 6.6 SM				

WHEN YOU HAVE COMPLETED THE ACTIVITY, REVIEW THE ANSWERS PROVIDED ON PAGE 34

SCS-ENG-352 (REV. 3-70)
FILE CODE ENG-22

LABORATORY NO ________

MATERIALS TESTING REPORT	U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	COMPACTION AND PENETRATION RESISTANCE

PROJECT and STATE: Figure 6.1 Typical compaction test results for CH soil

FIELD SAMPLE NO.	LOCATION	DEPTH

GEOLOGIC ORIGIN	TESTED AT	APPROVED BY	DATE

CLASSIFICATION CH LL 67 PI 43

MAX. PARTICLE SIZE INCLUDED IN TEST #4 "

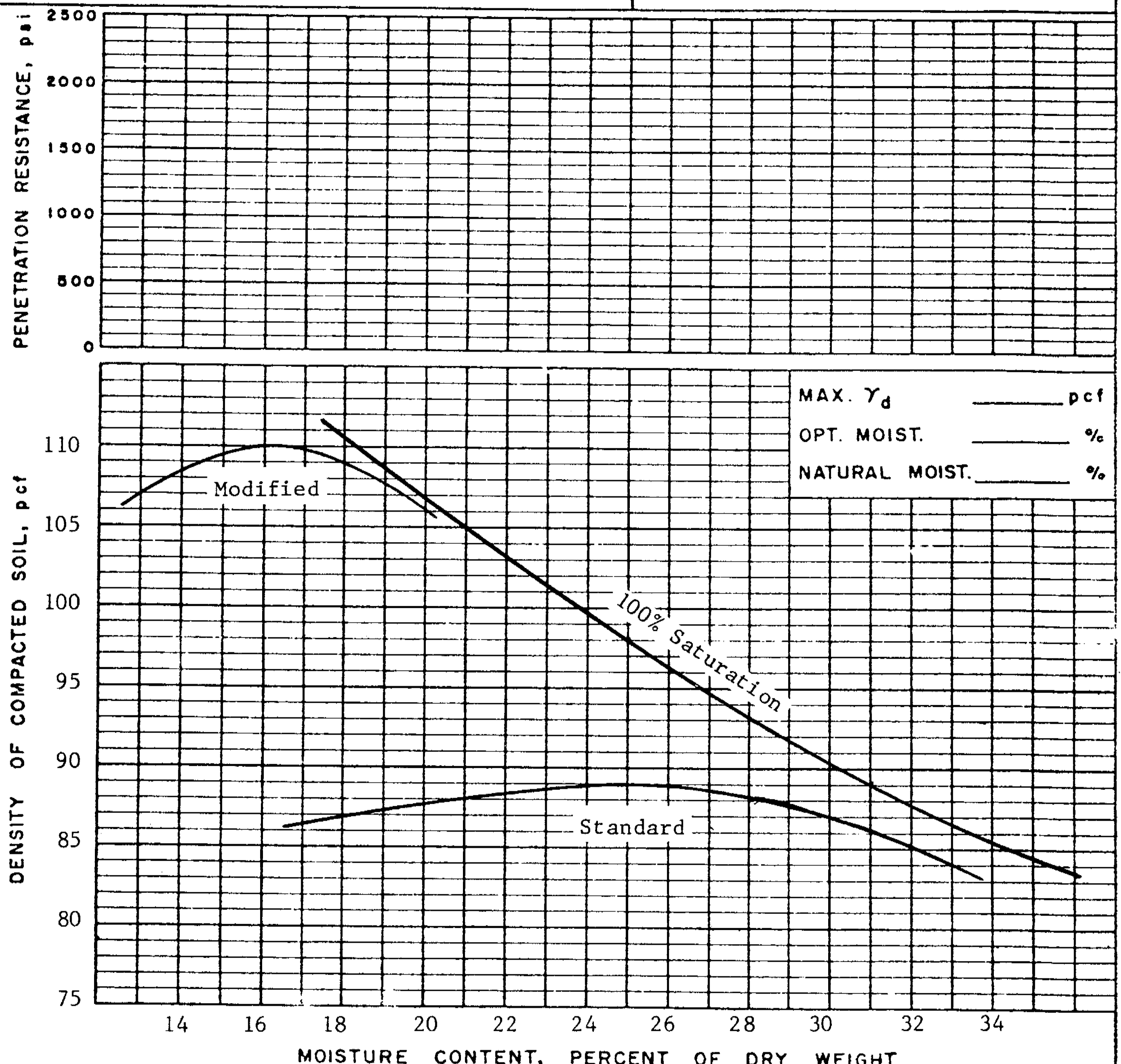
SPECIFIC GRAVITY (G_s) MINUS NO. 4 2.65; PLUS NO. 4 ________

CURVE NO. 1 OF 6

STD. (ASTM D-698) ☒; METHOD A

MOD. (ASTM D-1557) ☒; METHOD A

OTHER TEST ☐ (SEE REMARKS)



REMARKS

USDA-SCS-HYATTSVILLE MD 1966

SCS-ENG-352 (REV. 3-70)
FILE CODE ENG-22

ACTIVITY 6 - PART B

LABORATORY NO ______

MATERIALS TESTING REPORT	U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	COMPACTION AND PENETRATION RESISTANCE

PROJECT and STATE Figure 6.2 Typical compaction test results for CL soil

FIELD SAMPLE NO.	LOCATION		DEPTH
GEOLOGIC ORIGIN	TESTED AT	APPROVED BY	DATE

CLASSIFICATION CL LL 31 PI 15

MAX. PARTICLE SIZE INCLUDED IN TEST #4 "

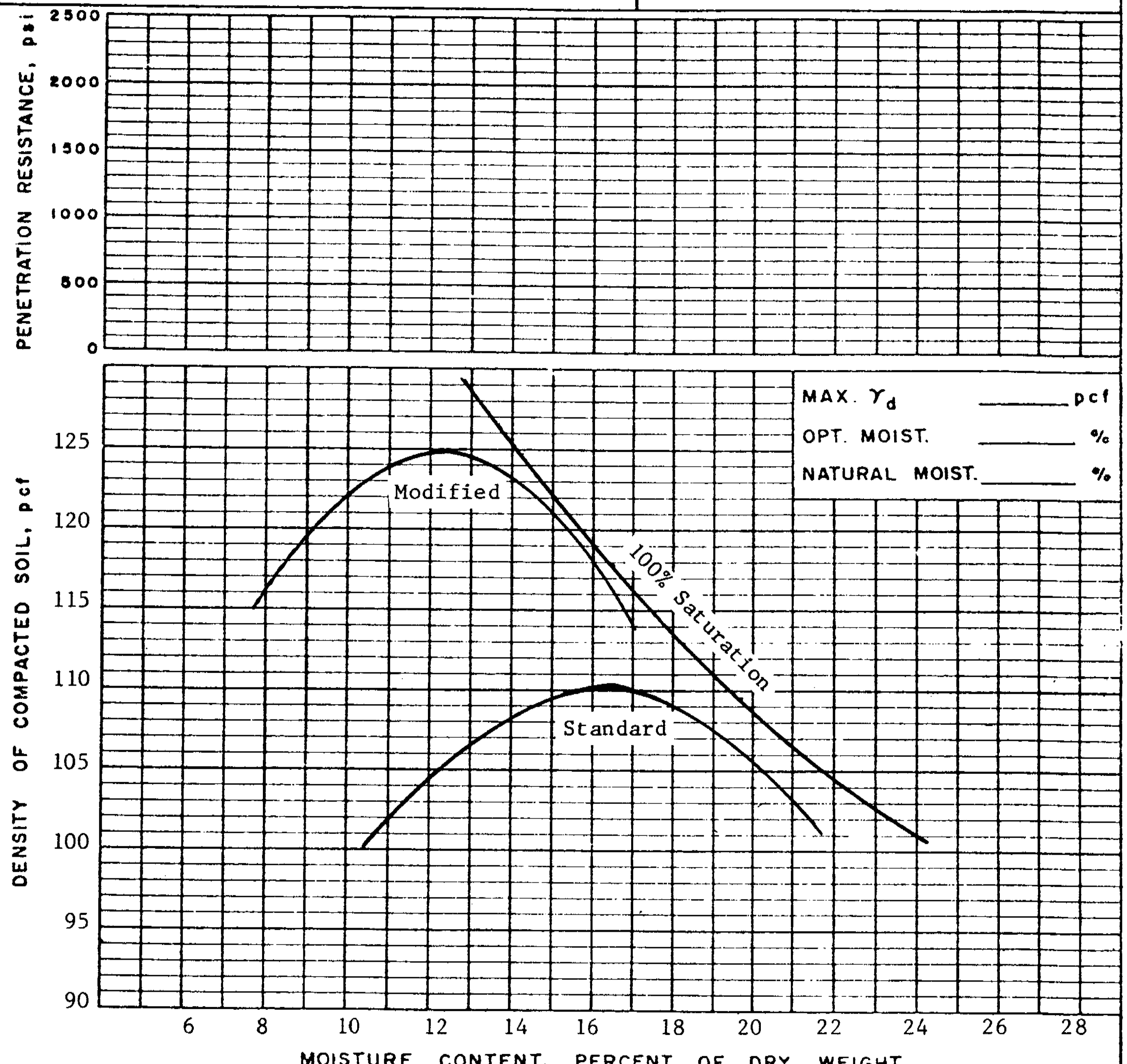
SPECIFIC GRAVITY (G_s) { MINUS NO. 4 2.66 ; PLUS NO. 4 ______

CURVE NO. 2 OF 6

STD. (ASTM D-698) ☒; METHOD A

MOD. (ASTM D-1557) ☒; METHOD A

OTHER TEST ☐ (SEE REMARKS)



MAX. γ_d ______ pcf

OPT. MOIST. ______ %

NATURAL MOIST. ______ %

REMARKS

USDA-SCS-HYATTSVILLE MD 1966

ACTIVITY 6 - PART B

LABORATORY NO ______

MATERIALS TESTING REPORT	U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	COMPACTION AND PENETRATION RESISTANCE

PROJECT and STATE: Figure 6.3 Typical compaction test results for ML soil

FIELD SAMPLE NO.	LOCATION	DEPTH

GEOLOGIC ORIGIN	TESTED AT	APPROVED BY	DATE

CLASSIFICATION ML LL - PI NP

MAX. PARTICLE SIZE INCLUDED IN TEST #4"

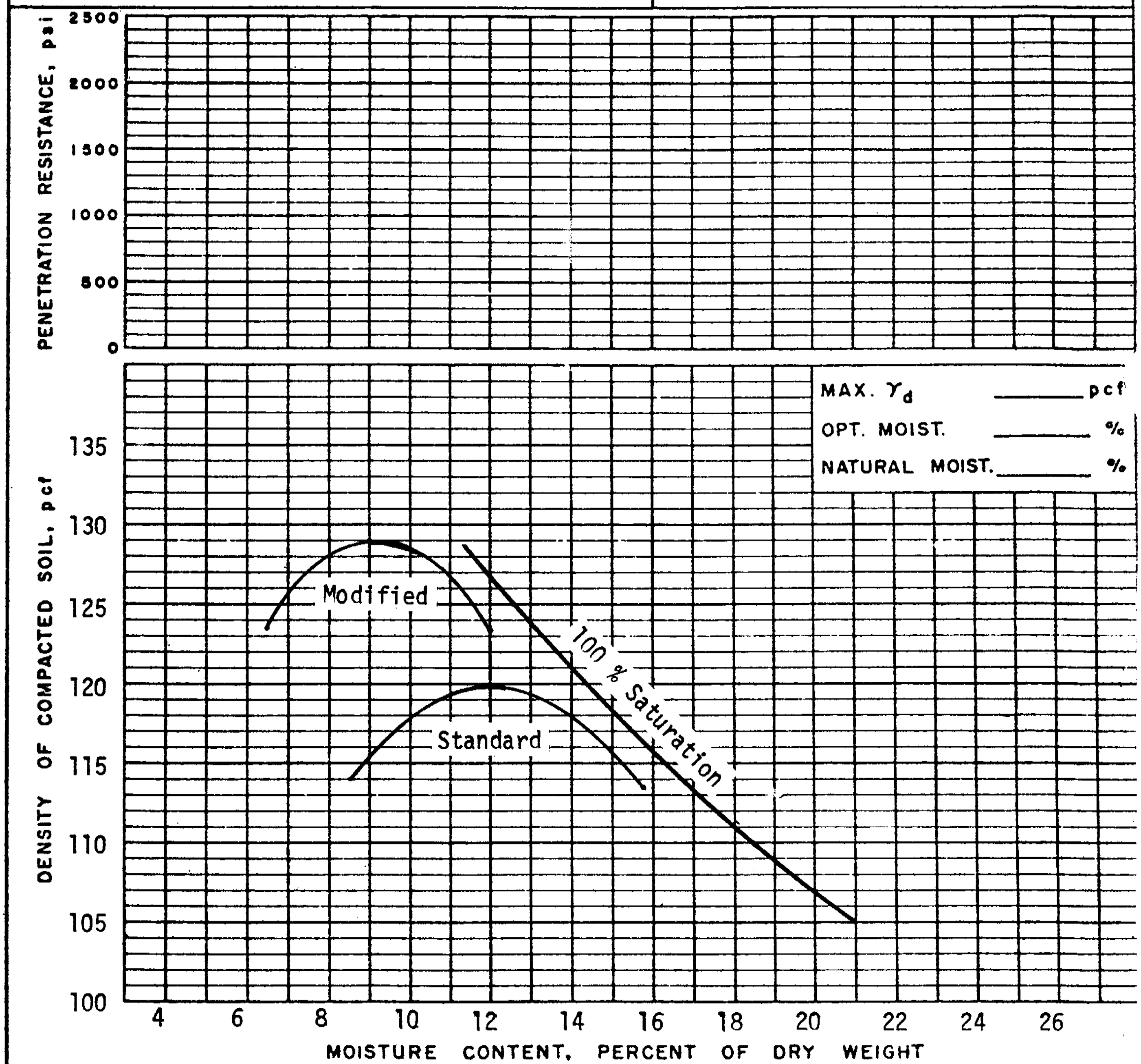
SPECIFIC GRAVITY (G_s) { MINUS NO. 4 2.68 ; PLUS NO. 4 ______ }

CURVE NO. 3 OF 6

STD. (ASTM D-698) ☒; METHOD A

MOD. (ASTM D-1557) ☒; METHOD A

OTHER TEST ☐ (SEE REMARKS)



REMARKS

ACTIVITY 6 - PART B

LABORATORY NO ______

MATERIALS TESTING REPORT	U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	COMPACTION AND PENETRATION RESISTANCE

PROJECT and STATE: Figure 6.4 Typical compaction test results for MH soil

FIELD SAMPLE NO.	LOCATION		DEPTH
GEOLOGIC ORIGIN	TESTED AT	APPROVED BY	DATE

CLASSIFICATION MH LL 76 PI 32

MAX. PARTICLE SIZE INCLUDED IN TEST #4 "

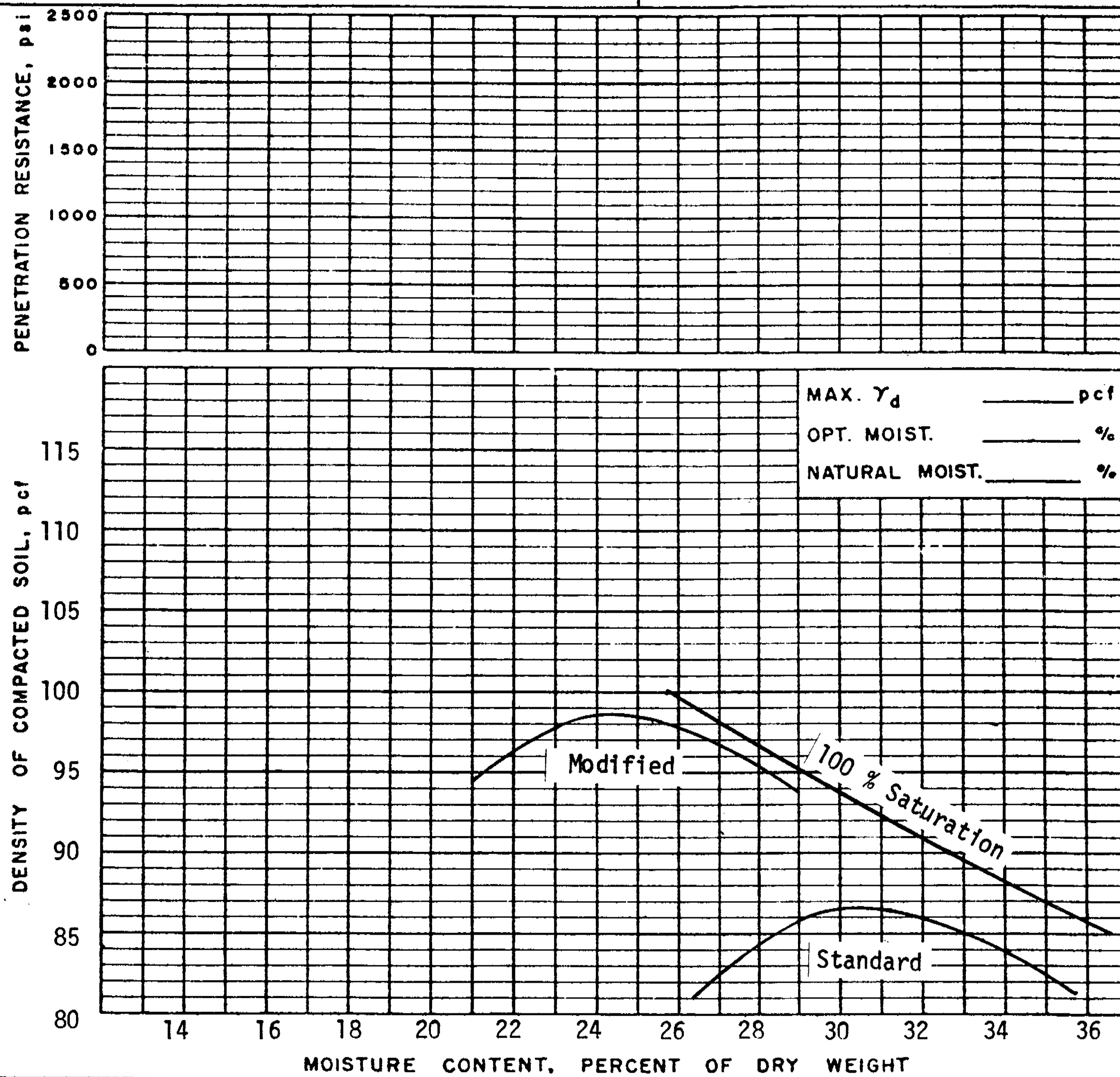
SPECIFIC GRAVITY (G_s) { MINUS NO. 4 2.72 / PLUS NO. 4 ______

CURVE NO. 4 OF 6

STD. (ASTM D-698) ☒; METHOD A

MOD. (ASTM D-1557) ☒; METHOD A

OTHER TEST ☐ (SEE REMARKS)



REMARKS

SCS-ENG-352 (REV. 3-70)
FILE CODE ENG-22

ACTIVITY 6 - PART B

LABORATORY NO ______

MATERIALS TESTING REPORT	U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	COMPACTION AND PENETRATION RESISTANCE

PROJECT and STATE: Figure 6.5 Typical compaction test results for SC soil

FIELD SAMPLE NO.	LOCATION		DEPTH
GEOLOGIC ORIGIN	TESTED AT	APPROVED BY	DATE

CLASSIFICATION SC LL 31 PI 12

MAX. PARTICLE SIZE INCLUDED IN TEST #4 "

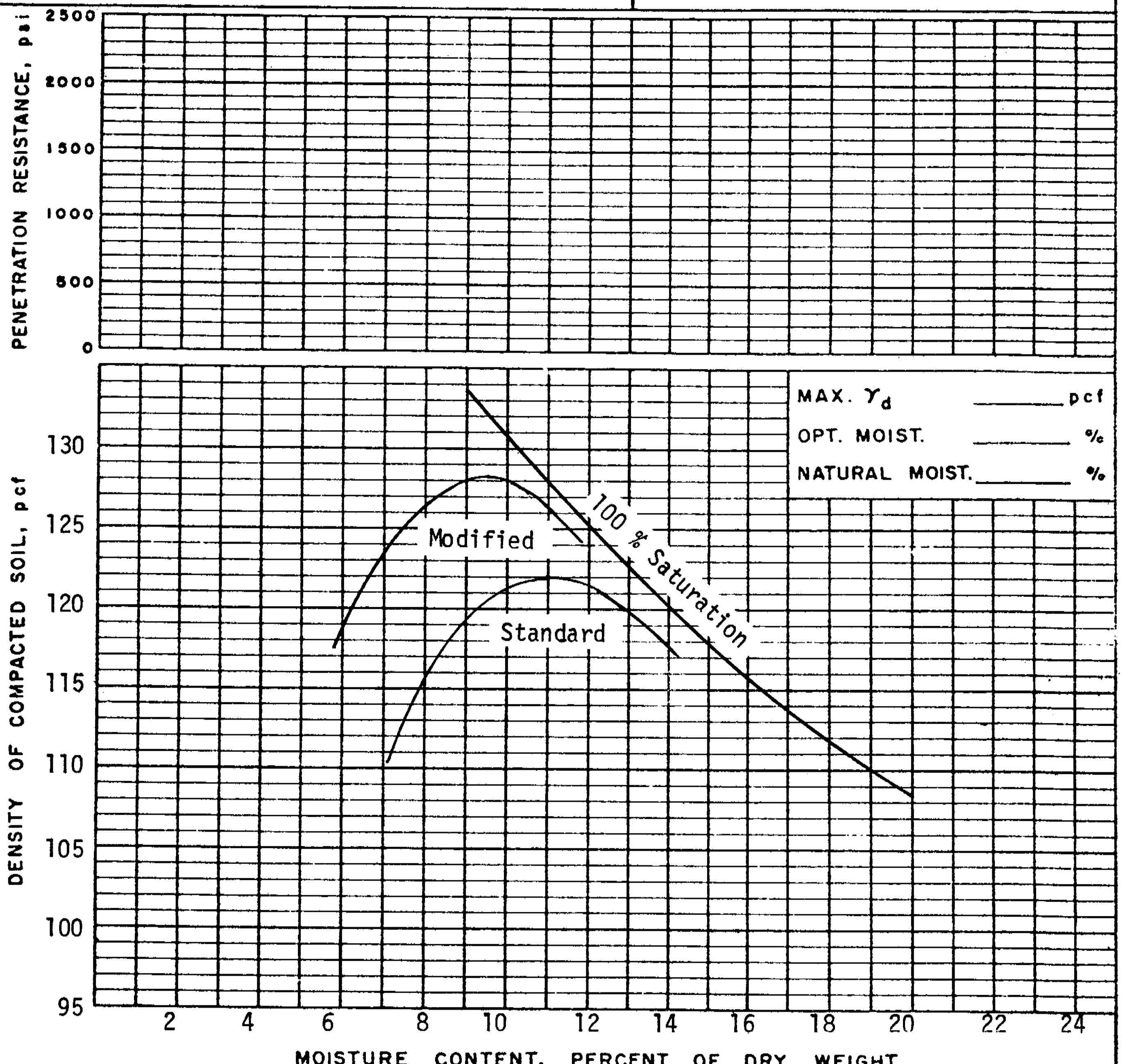
SPECIFIC GRAVITY (G_s) MINUS NO. 4 2.66; PLUS NO. 4 ______

CURVE NO. 5 OF 6

STD. (ASTM D-698) ☒; METHOD A

MOD. (ASTM D-1557) ☒; METHOD A

OTHER TEST ☐ (SEE REMARKS)



REMARKS

USDA-SCS-HYATTSVILLE MD. 1966

SCS-ENG-352 (REV. 3-70)
FILE CODE ENG-22

ACTIVITY 6 -- PART B

LABORATORY NO ______

MATERIALS TESTING REPORT	U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	COMPACTION AND PENETRATION RESISTANCE

PROJECT and STATE: Figure 6.6 Typical compaction test results for SM soil

FIELD SAMPLE NO.	LOCATION		DEPTH
GEOLOGIC ORIGIN	TESTED AT	APPROVED BY	DATE

CLASSIFICATION SM LL 17 PI 1

CURVE NO. 6 OF 6

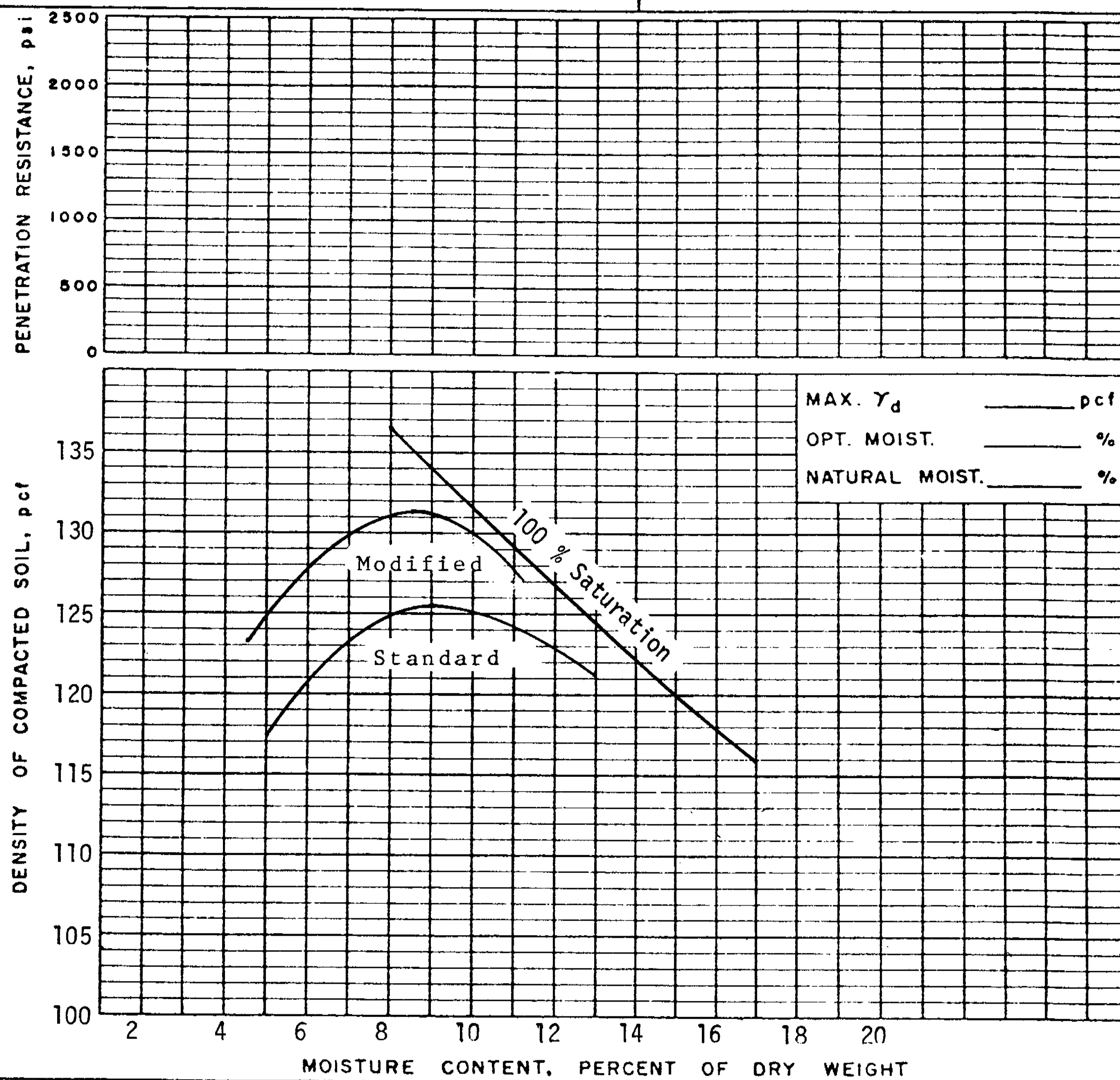
MAX. PARTICLE SIZE INCLUDED IN TEST #4 "

STD. (ASTM D-698) ☒; METHOD A

SPECIFIC GRAVITY (G_s) { MINUS NO. 4 2.66 ; PLUS NO. 4 ______ }

MOD. (ASTM D-1557) ☒; METHOD A

OTHER TEST ☐ (SEE REMARKS)



REMARKS

USDA-SCS-HYATTSVILLE MD. 1966

ACTIVITY 6 - PROBLEM SOLUTION

Soil Type	Standard Energy (D 698) Maximum Dry Unit Weight pounds/ft³	Standard Energy (D 698) Optimum Water Content (%)	Modified Energy (D 1557) Maximum Dry Unit Weight pounds/ft³	Modified Energy (D 1557) Optimum Water Content (%)
CH	89.0	25.0	110.0	16.0
CL	110.5	16.5	125.0	12.5
ML	120.0	12.0	129.0	9.0
MH	86.5	30.5	98.5	24.5
SC	122.0	11.0	128.5	9.5
SM	125.5	9.0	131.5	8.5

Study Figures 6.7, 6.8, and 6.9, before you continue.

START THE TAPE WHEN YOU HAVE FINISHED

Figure 6.7

TYPICAL COMPACTION TEST RESULTS LESS PLASTIC, SANDY SOILS

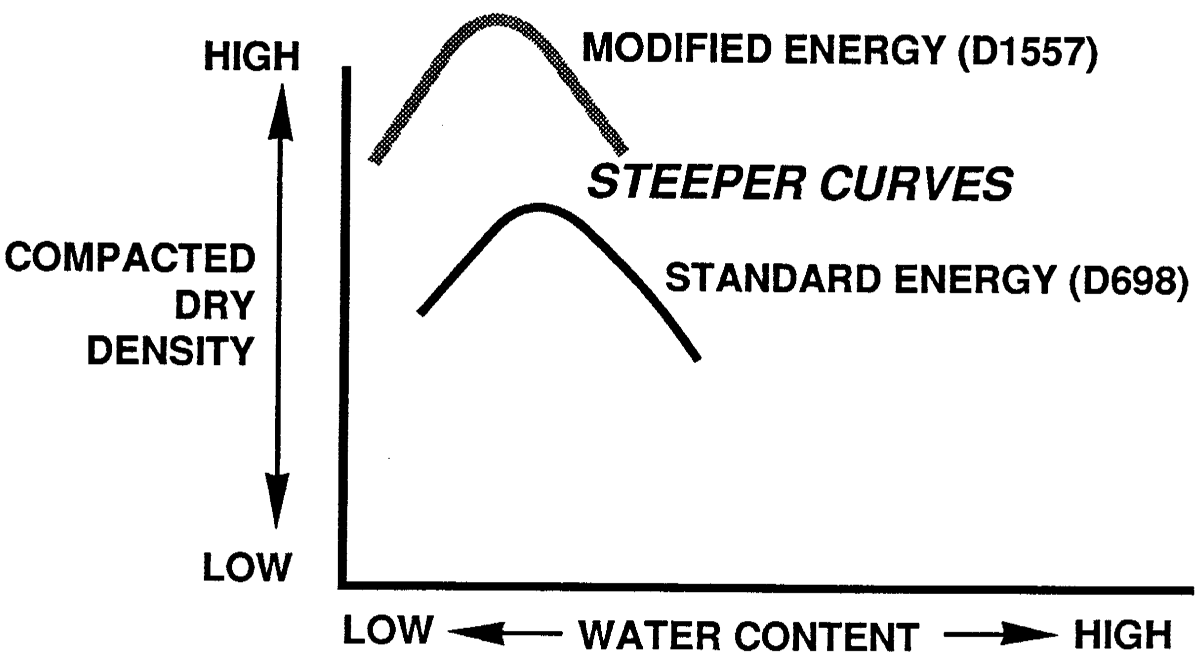


Figure 6.8

COMPACTION TEST RESULTS

Actual construction equipment may apply higher energies than standard laboratory compaction tests

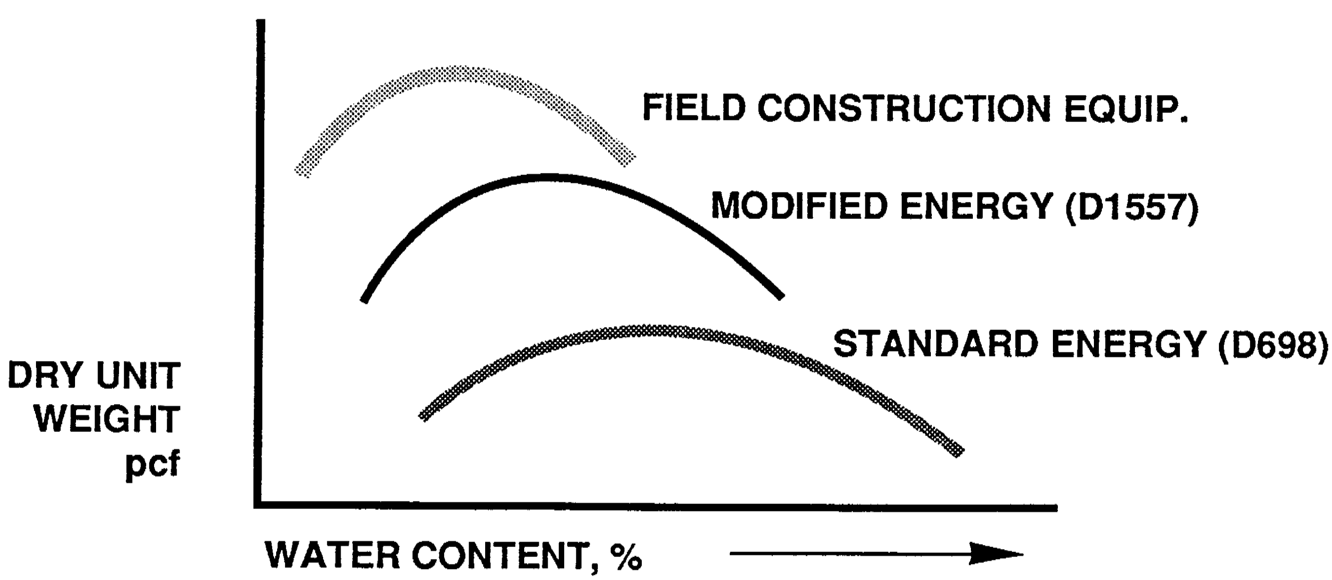
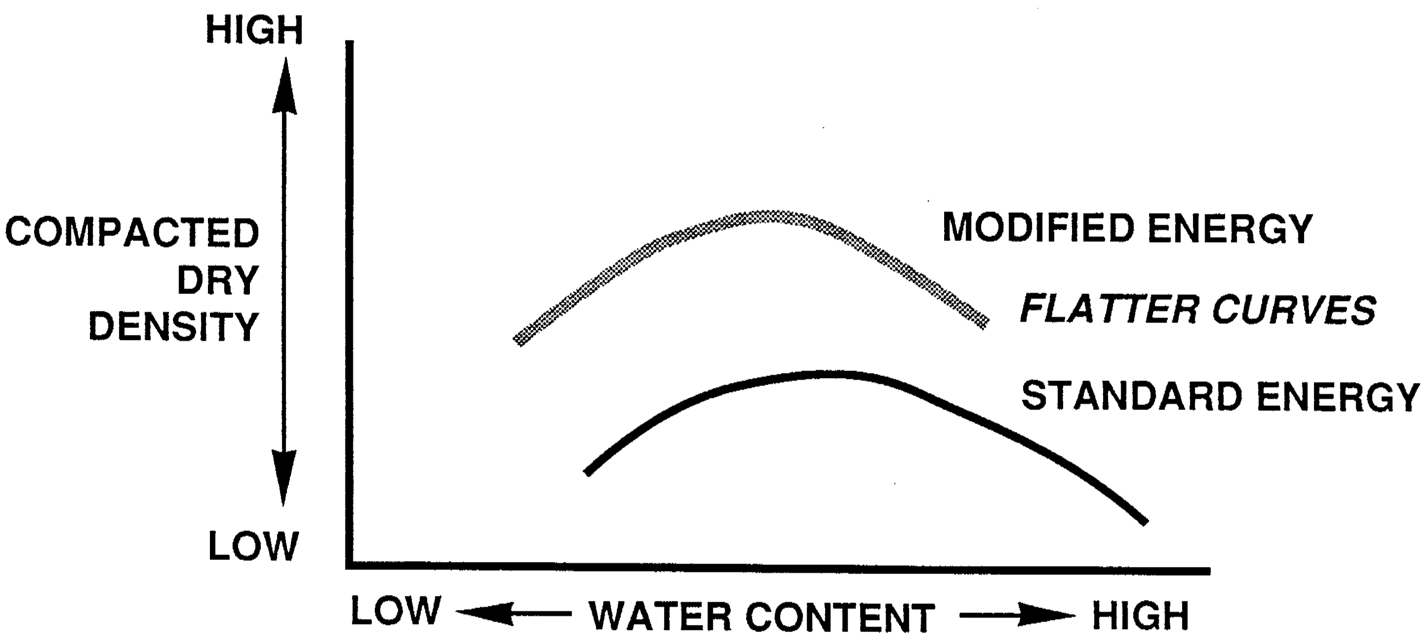


Figure 6.9

TYPICAL COMPACTION TEST FOR PLASTIC FINE - GRAINED SOILS



ACTIVITY 7 - USE OF COMPACTION TEST IN DESIGN AND CONSTRUCTION

The use of the compaction test in the design of an earth fill and in the quality control of the constructed fill are discussed in this Activity. One must understand the purpose for performing this test in the laboratory as part of the design process and the subsequent use of the test during construction for quality control and contract compliance.

Soil samples for a proposed fill construction are usually obtained during the site investigation for a project. The number of samples required depends on the uniformity of the borrow source soils and the anticipated yardage of fill required. Very few samples may be required if a small fill is to be constructed using soils from a uniform deposit of similar soils. A large number of samples may be needed to represent a large earth fill constructed from borrow sources with widely varying kinds of soils. One rule-of-thumb that has been used is that a sample should be obtained if it is likely that the soil type will represent over 10 percent of the completed fill.

The size of sample obtained is critical if adequate quantities are to be available for performing the necessary laboratory tests. The following table gives recommended sample sizes needed for laboratory testing of proposed borrow soils. The table is based on a needed dry weight, and wet samples should be larger.

Estimated Gradation of Soil	Minimum Sample Size, Pounds
less than 10% gravel	25
10% to 50% gravel	50
more than 50% gravel	150

Compaction tests may not be required on all samples submitted to a laboratory for testing. Samples may be grouped on the basis of Unified Classification, Atterberg limit data, gradation, and geologic origin. Representative samples from each group may then be tested. Usually, soils with similar gradation and Atterberg limit data that have similar geological origin will have similar compaction characteristics.

The compaction test standard used is usually based on an organization's experience and precedence. The Soil Conservation Service usually bases its designs upon compaction tests performed using the ASTM D 698, or Standard, compaction test. Many highway departments use the Modified Proctor (ASTM D 1557) method for compaction tests in their designs because a higher density is used for highway subbases.

After performing compaction tests on representative samples, the designer then selects an arbitrary percentage of the maximum dry unit weight as the preliminary basis for the design.

CONTINUE TO THE NEXT PAGE

In Soil Conservation Service projects a preliminary design often assumes soils to be placed at 95 percent of their maximum Standard dry unit weight. Using this value of dry unit weight, then, engineering tests such as shear strength, consolidation, permeability, and shrink swell tests are performed in the soils laboratory. Tests may also be performed at several different water contents. These test results and various analyses are used to determine if the preliminary design placement densities and water contents are satisfactory.

If an acceptable design results, the final design will then include specifications for placement of the fill soils at these design percentages of the reference compaction test method within the range of water contents selected. If analyses indicate that soil engineering properties are unsatisfactory at the preliminary design densities and water contents, then a higher value of design density may be assumed, perhaps 100 percent of maximum Standard Proctor density. Additional tests and analyses are then performed to determine whether satisfactory engineering properties result from the revised design densities and water contents.

As mentioned, water content is usually as important a consideration as design densities. Remember that a number of tradeoffs must be considered. Placement wet of optimum will usually result in a more flexibile product with lower swell properties, but there is some sacrifice in shear strength, and compressibility may be higher. Design placement water contents are usually referenced to optimum water content. A typical design would be to place soils at water contents from 1 percent dry of optimum to 3 percent wet of optimum. On many small Soil Conservation Service projects where shear strength is a minor consideration, placement is specified as any water content equal to optimum water content or higher. This results in good flexibility.

On projects where embankments are to be constructed that are greater than about 50 feet in height of plastic, fine-grained soils, an upper limit is often placed on placement water contents. This is necessary to prevent the development of internal pore pressures during construction. If allowed to develop, these pressures can adversely affect the stability of the embankment. Methods are available for calculating the probable development of these pore pressures for each placement water content and dry unit weight in the preliminary design.

Each kind of soil representative of a significant zone of the fill is usually tested to determine acceptable placement densities and water content range. Ordinarily, all of the soils in a fill are specified to be placed at the same degree of compaction. On some projects, some fine-grained soils may need to be placed at higher percentages of maximum dry unit weight than other, less plastic soils to obtain a similar engineering quality.

The approach of specifying a percentage of maximum dry unit weight and a water content range referenced to optimum water content from compaction tests is necessary when different kinds of soil are on a site. Specifying a single value of dry unit weight or water content for all the soils in a fill is not desirable when different kinds of soil are available with which to construct the fill. A compacted dry unit weight of 100 pounds per cubic feet might be

CONTINUE TO THE NEXT PAGE

quite adequate for a plastic clay soil, but be inadequate for a less plastic, sandy soil. By referencing the required density to a standard test method, quality control is possible even though different soils may be encountered during construction than were sampled for design. A placement water content of 24 percent might be desirable for a plastic clay, but impractical to obtain for a silty sand. Specifying water contents in terms of each soil's optimum water content is the only practical method of obtaining uniformity in fill materials.

During construction of a fill, one must ensure that soils are compacted to the same degree and at the designed water content as was assumed during design of the project. Tests of the compacted fill are performed to determine what are the dry unit weight and water contents. These values are then compared to the compaction test curve and the construction specifications for that soil. If the compacted soil in the fill is determined to have been placed at a dry unit weight at least as high as specified, and the water content is within the range specified, then the portion of the fill represented by that test is regarded as acceptable. If tests indicate that the soils are not compacted adequately, or that the water contents are not within the specified range, then some change in equipment type or methods of operation is usually necessary. Fill that has been improperly compacted must be removed and re-compacted to the required specifications.

Compaction tests must be performed in the field during construction because it is difficult to determine whether the same soils were tested in the laboratory as are used to construct the fill. One must not assume that laboratory compaction tests adequately represent all available fill soils and to rely solely on the laboratory test results for quality control. Factors that may cause samples submitted during design to be unrepresentative of the constructed fill include: (1) obtaining samples from auger borings, (2) mixing of soil deposits by construction equipment, (3) use of borrow areas which were not investigated.

Study Figures 7.1 and 7.2 before you continue.

START THE PLAYER WHEN YOU HAVE FINISHED

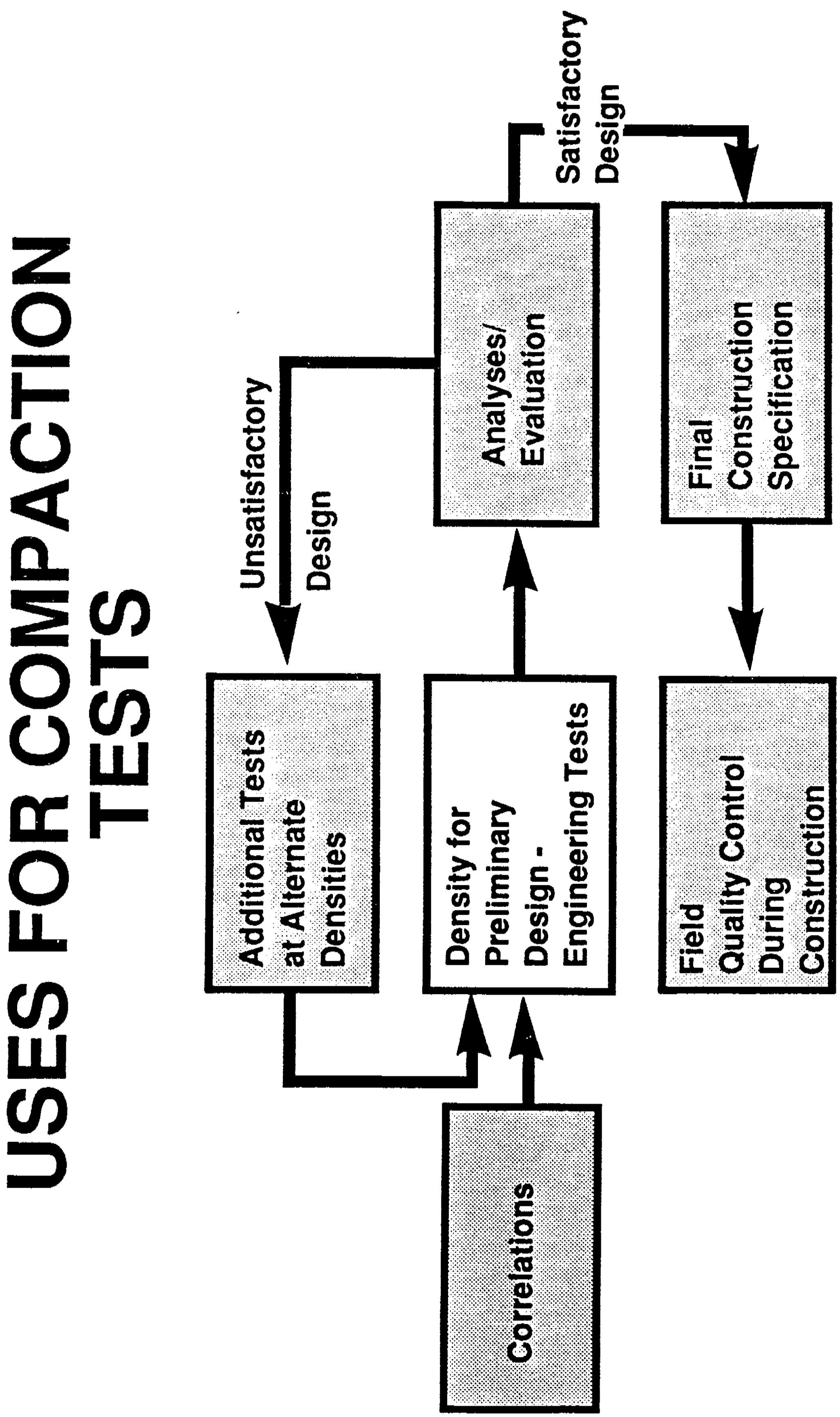
Figure 7.1

USES OF COMPACTION TESTS
CORRELATIONS

Soil No.	% Finer Than .005 mm	% Finer Than #200	Liquid Limit	Plastic Limit	γ_d max pcf	w_{opt} %
1	32	69	32	14	110.5	14.5
2	63	96	62	41	89.5	24.5
3	18	73	- -	NP	121.5	10.5
4	29	75	33	15	111.5	14.0
5	59	86	59	38	90.5	23.5

Soils 2 and 5 are similar

Figure 7.2


USES FOR COMPACTION TESTS
Correlations
Additional Tests at Alternate Densities
Density for Preliminary Design - Engineering Tests
Unsatisfactory Design
Analyses/ Evaluation
Satisfactory Design
Final Construction Specification
Field Quality Control During Construction

ACTIVITY 8 - PERFORMING A COMPACTION TEST

In Activity 8 you will perform a complete compaction test using ASTM Test procedure D 698 Method A. You will be furnished the necessary equipment and suitable soil sample for testing. A copy of the D 698 Standard Test Method is included as a supplement to this Manual. You should insert this Standard into the provided plastic envelope, because information will be lost by using a three-hole-punch on it. A detailed video tape instruction is shown at the time you take Activity 8, by the Technical Facilitator.

Data forms for recording the test data as you perform the test are attached to this Activity on following pages. Also included is a blank Form SCS-352 which you should use to plot the completed test. Retain this test data and plotted compaction curve for use in Part E of this Module, Evaluation of Compaction Test Data.

This Activity will require you to coordinate with your Technical Facilitator in your state or NTC to determine a suitable time and location for completing the Activity. You may wish to complete Activity 9 and the rest of the Module if there is a considerable delay before you are able to schedule Activity 8. However, you should complete this activity no later than 6 months after completing the rest of the Module. You cannot receive credit for completing this Module until you complete this Activity.

WHEN YOU HAVE COMPLETED STUDYING THIS INFORMATION PROCEED WITH THE MODULE

SCS-ENG-359
REV. 6-71

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

WORK SHEET FOR COMPACTION AND PENETRATION RESISTANCE DATA

Sample No.: ____________

COMPACTION DATA (Record Weights in Pounds)

1	Wt. of Cyl. + Soil						
2	Wt. of Cylinder						
3	Wt. of Soil = (1) - (2)						
4	Wt. per Cu. Ft. (Wet) = (3) ÷ Vol. of Cyl.						
5	Wt. per Cu. Ft. (Dry) = $\frac{(4) \times 100}{100 + (9)}$						
6	Proctor Needle Readings						
7	Size Needle (Sq.in.)						
8	Penetration (Lbs./sq. in.) Resistance = (6) ÷ (7)						

MOISTURE DETERMINATION DATA (Record Weights in Grams)

9	Percent Moisture = $\frac{(13)}{(15)} \times 100$						
10	Can Number						
11	Wet Wt. - Can + Soil						
12	Dry Wt. - Can + Soil						
13	Moisture Weight = (11) - (12)						
14	Weight of Can						
15	Dry Weight of Soil = (12) - (14)						

Vol. of Cyl. _______ cu. ft.	
	Standard Proctor
	Modified AASHO
	Other __________

PROCEDURE DATA:

Wt. of Hammer __________ Pounds

Drop __________ Inches

No. of Lifts __________

Completed by: __________ Date: __________

Computed by: __________ Date: __________

Checked by: __________ Date: __________

Recorded by: __________ Date: __________

Density		% H_2O
Wet	Dry	

Project ______________________________

Site ______________________________

59M-81

SCS-ENG-352 (REV. 3-70)
FILE CODE ENG-22

LABORATORY NO ________

MATERIALS TESTING REPORT	U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	COMPACTION AND PENETRATION RESISTANCE

PROJECT and STATE

FIELD SAMPLE NO	LOCATION	DEPTH

GEOLOGIC ORIGIN	TESTED AT	APPROVED BY	DATE

CLASSIFICATION ________ LL ____ PI ____

MAX. PARTICLE SIZE INCLUDED IN TEST ________"

SPECIFIC GRAVITY (G_s) { MINUS NO. 4 ________ / PLUS NO. 4 ________

CURVE NO. ________ OF ________

STD. (ASTM D-698) ☐; METHOD ________

MOD. (ASTM D-1557) ☐; METHOD ________

OTHER TEST ☐ (SEE REMARKS)

PENETRATION RESISTANCE, psi

2500
2000
1500
1000
500
0

DENSITY OF COMPACTED SOIL, pcf

MAX. γ_d ________ pcf

OPT. MOIST. ________ %

NATURAL MOIST. ________ %

MOISTURE CONTENT, PERCENT OF DRY WEIGHT

REMARKS

USDA-SCS-HYATTSVILLE MD 1966

ACTIVITY 9 - TEST FOR OBJECTIVES

To test your understanding of the material in Part B and the completion of the desired objectives, complete the following questions:

Match the terms on the left with the correct definition on the right:

1. Mold_____	A. 12,375 foot-pounds/cubic foot
2. Modified Energy _____	B. Peak value from compaction curve
3. Compaction Curve _____	C. Container used to hold compacted soil in the compaction test
4. Maximum Dry Unit Weight _____	D. Typical shape of a compaction curve
5. Optimum Water Content _____	E. To cure or evenly distribute moisture within a compaction sample
6. Standard Energy _____	F. Curve showing relationship between dry unit weight and water content
7. Parabolic _____	G. Water content at which compaction curve peaks
8. Equilibrate _____	H. 56,250 foot-pounds/cubic foot

Label the following statements as true or false (T/F)

1. The maximum dry unit weight from a modified compaction test on a CH soil will probably be much lower than the maximum dry unit weight from a standard compaction test on the same soil. _____
2. Compaction tests should not be attempted on clean, coarse-grained soils. _____
3. The hammer weight in a Standard compaction test is 10 pounds. _____
4. The optimum water content from a Modified compaction test will usually be lower than that from a Standard compaction test. _____
5. A compacted dry unit weight of 80 pounds per cubic foot would probably be quite high for an SM soil. _____
6. The compaction curve for a Standard test on a CH soil will usually have a very sharp peak at the optimum water content. _____
7. Field compaction tests are not necessary if laboratory compaction tests have been performed. _____
8. Compacting soils to dry unit weights higher than 100 percent of their maximum dry unit weight obtained in a Standard compaction test is possible. _____

CONTINUE TO THE NEXT PAGE

ACTIVITY 9 - Continued

9. Modified energy is about equal to 4 times Standard energy. _____

Fill in the blanks in the following statements:

1. A common assumed design on compacted fills in SCS projects is ______ percent of maximum Standard dry unit weight.

2. The ________________ compaction test is often used for design of highway projects.

3. The volume of the mold used in the compaction test for soils that have no gravel particles is about ______________ cubic foot.

4. In the Modified compaction test, ________ lifts are used to fill the compaction mold.

5. Standard test methods are published by a national organization with the abbreviation ____________ which stands for ______________________________ ____.

6. In preparing specimens for a compaction test, water must be allowed to ________________ in the soil before performing the test.

7. Usually ____________ to ___________ specimens are needed to develop a compaction curve.

8. Plastic soils will have a ________________ optimum water content and a __________________ maximum dry unit weight than slightly plastic soils.

9. In preparation for Method A compaction tests, soils are first screened through a ____________________ sieve.

10. The test method that uses 12,375 foot-pounds per cubic foot is also called the _________________________ method.

11. Complete the following table.

Test Method	Size Mold	Hammer Weight	Drop Ht.	No. Blows Per Lift	No. Lifts	Maximum Particle Size	Maximum Gravel Content
ASTM D 698 A							
ASTM D 1557 A							

12. An earth fill is being constructed of a CL soil on which a standard (ASTM D 698 Method A) compaction test has been performed. Design and construction specifications require the soil to be placed at dry densities of 95.0 percent of maximum dry density at water contents in the range of 1% dry of optimum to 3% wet of optimum. The compaction test for the soil is shown on page 53.

A test on the compacted fill resulted in a measured dry density value of 103.9 pcf and a water content of 16.3%. Is the fill acceptable?

WHEN YOU HAVE COMPLETED THE ACTIVITY, REVIEW THE ANSWERS PROVIDED ON PAGE 50

ACTIVITY 9 - PART B

LABORATORY NO ______

MATERIALS TESTING REPORT	U. S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	COMPACTION AND PENETRATION RESISTANCE

PROJECT and STATE
Figure 9.1 Compaction test results for CL soil

FIELD SAMPLE NO	LOCATION	DEPTH

GEOLOGIC ORIGIN	TESTED AT	APPROVED BY	DATE

CLASSIFICATION CL LL 31 PI 15

MAX. PARTICLE SIZE INCLUDED IN TEST #4"

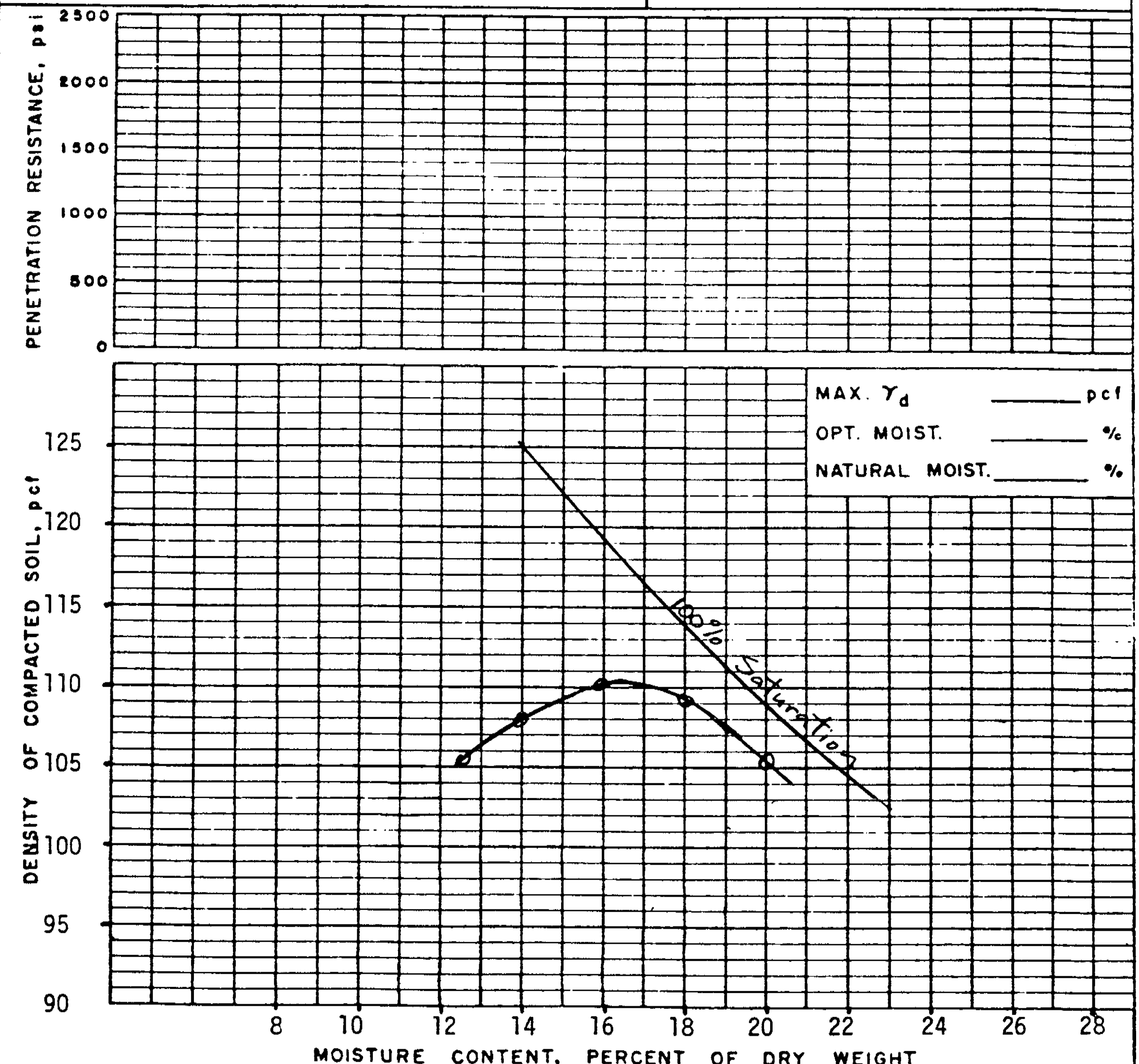
SPECIFIC GRAVITY (G_s) { MINUS NO. 4 2.66 ; PLUS NO. 4 ______ }

CURVE NO. 2 OF 6

STD. (ASTM D-698) ☒; METHOD A

MOD. (ASTM D-1557) ☐; METHOD ______

OTHER TEST ☐ (SEE REMARKS)



REMARKS

ACTIVITY 9 - Solution to Problems

Matching terms:

1. C 5. G
2. H 6. A
3. F 7. D
4. B 8. E

True/False statements:

1. F 6. F
2. T 7. F
3. F 8. T
4. T 9. T
5. F

Fill in blanks:

1. 95
2. Modified (ASTM D 1557)
3. 1/30
4. 5
5. ASTM, American Society for Testing and Materials
6. equilibrate or cure
7. 4 to 5
8. higher, lower
9. number 4
10. Standard or ASTM D698 Method A

11.

Test Method	Size Mold (ft^3)	Hammer Weight (lbs.)	Drop (in.)	No. Blows/ Lift	No. Lifts	Maximum Particle Size	Maximum Gravel Content
ASTM D 698 A	1/30	5.5	12	25	3	#4	20
ASTM D 1557 A	1/30	10	18	25	5	#4	20

12. The plotted compaction curve has a maximum dry density of 110.5 pcf and an optimum water content of 16.5%.

    The fill density of 103.9 pcf is equal to

    $$\frac{103.9}{110.5} \times 100 = 94.0\% \text{ of maximum}$$

    The water content is -0.2 dry of optimum and is acceptable.

    Because the fill dry density is not equal to or greater than 95% of the compaction curve maximum dry density, the fill is not acceptable.

APPENDIX

1 ENG-SOIL MECHANICS TRAINING SERIES--
BASIC SOIL PROPERTIES
MODULE 5 - COMPACTION
PART B
COMPACTION OF NON-GRAVELLY SOILS

-

Part B of Module 5 covers standard compaction tests for soils that have low gravel content and more than 12 percent fines. Major topics include the history of the development of the
2 compaction test and standard procedures for performing a test.

-

At the completion of Part B, you will be able to complete the following objectives:

Objective 1:

From a list, define the important terms associated with the
3 procedures and equipment used in performing compaction tests.

-

Objective 2:

4 Describe how compaction test results are affected by soil gradation and plasticity characteristics.

-

Objective 3:

Describe the effects of different energy levels on compaction
5 test results.

-

Objective 4:

Using example data, compute and plot results of a compaction test and determine values of maximum dry density and optimum
6 water content.

-

Objective 5:

Explain the purpose of laboratory and field compaction tests.
Explain how compaction tests are used in design and quality
7 control of earth fills.

-

Objective 6:

8 Using field equipment and a soil sample provided, perform a
compaction test by standard procedures.

-

Activity 1 These objectives are listed in your Study Guide, Activity
9 1. Stop the tape and review that Activity before continuing.

-

The important principles of soil compaction theory were first
stated by R. R. Proctor, in the 1930's. He first recognized
that the dry unit weight of a compacted soil varied with the
amount of energy used to compact the soil and the water
10 content at which the soil was compacted.

-

Proctor designed and built an apparatus that could deliver a
standardized energy while compacting a soil. By eliminating
the variable of energy, then the relationship between
compaction water content and dry unit weight can be examined
11 separately.

-

Proctor discovered that for any given soil, a unique
relationship exists between water content and compacted
12 density, for a given energy application.

-

13

As a "rule-of-thumb", soils with less than 12 percent fines are difficult to test using Proctor's test procedures. Tests on these relatively clean, coarse-grained soils will be covered in a later part of this Module. Standard procedures are also not available for soils that have a high percentage of large gravel-size particles.

Activity 2

14

Activity 2, in your Study Guide summarizes the main points covered in this introduction to compaction. Stop the tape and review this Activity before continuing.

ASTM

15

The procedures used to perform compaction tests, and the terminology associated with the tests will now be covered. Standard test procedures are established by the American Society for Testing and Materials. The organization publishes standard test methods for soils and other materials. These test standards are necessary so that all laboratories follow the same procedures.

D 698
D 1557

16

Two standardized energy levels are commonly used to perform compaction tests. Details on the tests are covered later in the Module. The two standardized tests are referred to by their ASTM designations, tests D 698 and D 1557.

Method A
B
C

17

Within each of these standardized tests, there are variations of procedures. These variations depend on the gradation of the soil to be tested. Each ASTM compaction test procedure has three variations, referred to as Methods A, B, and C.

Method Used Depends On:
% FINER THAN
#4
3/8"
3/4"
#200

18

To determine the proper variation to be used, you must first determine the gradation of the soil to be tested. Data required include the percent passing the three-quarter inch, the three-eighths inch, the number four, and the number 200 sieves. Gravel particles larger than three-quarters inch are not used in normal compaction tests.

Activity 3 19	The flow chart shown in Activity 3 is useful for determining which of the test variations should be used for performing a compaction test. The activity also contains example soil gradation data and problems on use of the flow chart to select the proper test method. Stop the tape and complete the Activity before continuing.
Method A Tests 20	This Part of Module 5, Part B, will cover tests performed by Method A of the ASTM procedures. As you have seen, test method A applies to soils that have 20 percent or less gravel content. Test methods B and C apply to soils with more than 20 percent gravel. These test methods will be covered in the next part of this Module, Part C.
Standard Procedures Not Available For Soils With < 12% Fines Or > 30% Plus 3/4" 21	Remember from the previous Activity that standard compaction test procedures are not available for soils with less than 12 percent fines or more than 30 percent of particles larger than three-fourths inch.
Remove Gravel Rock Corrections Used If % Gravel Is > 5% 22	To perform a Method A test using either test procedure ASTM D 698 or D 1557, a soil sample is first processed through a number four sieve to remove any gravel sized particles. If a sample has more than five percent gravel, corrections may be made to test results as covered in Part C of the module. No corrections are necessary if the sample has five percent percent or less gravel.
Air-Drying May Affect Test Results On Some Unusual Soils 23	Many soils may be air-dried to facilitate sieving out any gravel present, but some unusual soils may be drastically affected by air-drying. Those soils should not be air-dried prior to testing. The test requires about 25 pounds of soil on a dry weight basis.

epare 4 To 5 Specimens
At Successively Higher
Water Contents
Initial Water Content Of
Series Of Specimens
24

In preparation for performing a compaction test, a series of 4, or preferably, 5 samples of soil are prepared at successively higher water contents. The water contents used are selected as follows. The initial water content, or the water content of the first specimen, is obtained by either adding or removing water from the prepared sample.

Soil Forms Ball
When Squeezed
25

The water content of the initial sample in the series of prepared samples should be that at which the soil will just form a coherent mass or ball when squeezed.

4 To 5 Pounds Of Soil
Needed For Each Test
Specimen
26

Usually, from four to five pounds of moist soil are required for each prepared specimen. This amount needed varies with the soil type and water contents used.

Water Contents Should
Be 1-1/2% Apart
27

Specimens at successively higher water contents are prepared by adding water so that the water content of the specimens are spaced about one and one-half to two percentage points apart. Each specimen is placed in an airtight container for curing.

Curing Period From
3 To 40 Hours
28

The curing period required is based on the plasticity of the soil, and varies from 3 to 40 hours. Curing of water content is required to permit thorough wetting of all soil particles.

Specimen Compacted Into
Mold With Hammer
29

After the samples are cured, the first specimen to be tested is compacted into a cylindrical mold. Compaction of the soil results from dropping a hammer of standard weight and dimensions a specified distance for the required number of times. Several lifts of soil are used to completely fill the mold. The weight of hammer, height of drop, number of blows of the hammer, and number of lifts of soil required to fill the mold are variables in the two standard tests, D 698 and D 1557.

Photo Of Mold 30	Method A tests use a mold with a diameter of about 4 inches, which has a volume of about one-thirtieth of a cubic foot. The volume of the mold is carefully determined before testing, and its weight also predetermined. -
Photo 31	After compacting the soil into the mold using specified procedures, the excess soil is carefully removed. -
Photo 32	The mold and compacted moist soil are then weighed. -
Equation For Moist Unit Weight 33	Using the equation shown, the wet unit weight of the compacted specimen is calculated. Units commonly used for wet unit weight are pounds per cubic feet or kilograms per cubic meter. -
Photo 34	A representative portion of the soil in the mold is obtained and the water content is determined by drying in an oven, usually overnight. -
Photo 35	Soil is dried in an oven set to the proper temperature - usually 110 degrees Centigrade. Soils with hydrated minerals, such as gypsum, must be dried at a lower temperature to prevent driving off hydrated water. Usually, sixty degrees Centigrade oven temperature is used for those soils. -
Dry Unit Weight Equation 36	If the wet unit weight and the water content of the compacted soil is known, then a dry unit weight may be calculated by the equation shown: -

;urve With 1 Point Shown	37	The values of dry unit weight and water content represent one point on the compaction curve that is being developed by the test.
Curve With 5 Points Shown	38	The remaining specimens are then compacted using the same procedures. Values for wet unit weight, water content, and dry unit weight are obtained for each specimen. By plotting values of dry unit weight versus water content, a compaction curve is developed for the soil and energy level used in the test. As you will see, this curve is unique for every soil and energy level used.
Test Showing Excessive Number of Points Due To Low Initial Water Content	39	To develop a complete test, specimens must be tested at successively higher water contents until a decrease in wet unit weight occurs. If good judgement is used in selecting a starting water content, four or five specimens will develop a good curve. If poor judgement is exercised, the test may be re-run, or additional test specimens may be prepared at higher, or lower, water contents.
Typical Curve	40	The plotted curves of dry unit weight versus water content typically have a parabolic shape as shown. Depending on the scales used to plot the data, and the kind of soil being tested, the curves may be quite flat or quite steep.
Illustrated Scales	41	Using the same scale is important for dry unit weight and water content each time you plot the data. This will allow you to develop an experience base for the typical curve shapes of different soil types. The scales shown here have been found by SCS engineers to be satisfactory for most tests.

Maximum Dry Unit Weight Optimum Water Curve 42	This is a typical compaction test curve. Several terms are defined from the curve. The peak value of dry unit weight is called the maximum dry unit weight. It may be reported in pounds per cubic foot or kilograms per cubic meter. The water content at which this peak occurs is called optimum water content.
	-
Wet Unit Weight Versus Water Content Used For Some Field Applications 43	Although wet density versus water content may be plotted as well as dry unit weight, the plot of wet unit weight is used only for special applications in field control, and its use is not covered here.
	-
Activity 4 44	Activity 4 of your Study Guide has example test data for a compaction test performed on a soil with gravel removed - Test Method A, using ASTM D 698, procedures. Using the test data, compute and plot values of dry unit weight and water content and plot the test data. Determine the value of maximum dry unit weight and optimum water content for the soil tested. Stop The Tape And Complete The Activity.
	-
ASTM D 698 Method A Illustration Of Hammer Weight Height Of Drop Blows Per Lift Lifts To Fill Mold 45	Next, details on the standard energy tests are covered. The first to be discussed is ASTM D 698, commonly referred to as "standard" energy. This test uses a hammer weighing five and one-half pounds that is dropped a distance of twelve inches for 25 drops per lift of soil compacted in the mold. The mold is compacted in 3 equal lifts. Using the equation shown, the energy applied in compacting the soil is 12,375 foot-pounds per cubic foot of soil.
	-
D 698 Used or Design of Most SCS Structures 46	ASTM D 698 compaction tests are most commonly used in design of SCS structures. For some applications, one may want to know the relationship between dry weight and water content for a higher level of energy application. The ASTM test for a higher energy is ASTM D 1557, also called the "Modified" compaction test.
	-

ASTM D 1557 Weight of Hammer Height of Drop Blows per lift Lifts to Fill Mold 47	In the ASTM D 1557 test, 56,250 foot-pounds of energy per cubic foot are applied to each specimen in the test. A hammer weighing ten pounds is used. It is dropped a distance of 18 inches a total of 25 times per lift, with 5 lifts of soil used to fill the mold.
	-
Activity 5 48	Activity 5 summarizes the two standardized energies used for compaction tests. Stop the tape and review the activity.
	-
Index Property 49	The compaction test curve developed for a particular soil and energy level used is essentially an index property of the soil tested, just as are Atterberg limits and gradation. Each soil tested has unique values and curve shapes.
	-
Compaction Curves For CH Soil For Both D 698 Method A and D 1557 Method A 50	A soil's maximum dry unit weight will be higher for a Modified test compared to a Standard test because of the higher energy used. ASTM D 1557 compaction test curves will also typically have a lower optimum water content than D 698 tests. These compaction tests are for a CH soil using both test energy levels on the same soil. Note the drastic differences in the values of maximum dry unit weight and optimum water content.
	-
Other Energy Tests California Compaction Test 51	Other energy levels have been used for performing compaction tests by some engineering organizations. These test methods are not completely standardized at present and infrequently used in the SCS. Therefore, they are not discussed in this Module. One example is the "California" compaction test, which uses 20,300 foot-pounds per cubic foot of energy.
	-

Effect of Plasticity on Test Results

52

The values obtained for maximum dry unit weight and optimum water content vary with the type of soil being tested and the energy used. Fine-grained, plastic soils have relatively low values of maximum dry unit weight and high values for optimum water content for a given energy.

-

Effect of Plasticity on Test Results

53

Sandier soils and soils that have less plasticity, have higher values of maximum dry unit weight and lower values of optimum water content for a given energy.

-

Curve Shape Depends

54

The shape of the compaction curve also depends on the kind of soil tested and the energy applied during the test.

Typically, fine grained, plastic soils will have a broad, very flat curve. Less plastic soils or sandier soils will have a steeper curve with a more pronounced peak. Higher energies usually produce a curve with a more pronounced peak than lower energies.

-

ACTIVITY 6

55

Activity 6 shows typical values for compaction test results for selected Unified Soil Classification groups. Only the Unified Classes to which procedures of this Part of the Module apply are covered. Stop the tape and complete Activity 6.

-

Higher Energies Result In Higher Unit Weights and Lower Optimum Contents

56

Heavy construction equipment and intensive processing of earth fills often result in compacted soil that has dry unit weights greater than those given by standard laboratory tests. The illustration shows a compaction curve obtained by compacting samples of soil in an earth fill with large equipment at several water contents. Note that this curve has a higher value of maximum dry unit weight than the standardized laboratory compaction tests. The field equipment has applied more energy than the laboratory tests. Note also that optimum water content is lower for the higher energy application.

-

No Absolute Value for Dry Unit Weight - Depends On Amount and Type of Energy
57

This should help you realize that a given soil does not have an absolute value of maximum dry unit weight or optimum water content. Values depend on the energy used to compact the soil. Maximum dry density and optimum water content are relative terms for a particular energy.

-

Purposes of Compaction Tests
58

The uses and purposes of compaction testing will now be covered. Some uses are:

1. Correlating soils.
2. Preliminary design densities for engineering property tests.
3. Construction specifications.
4. Quality control of constructed fills.

-

Correlations
59

Compaction test values, together with other index properties such as gradation and Atterberg limits may be useful for grouping soils for correlation purposes. Soils 2 and 5 of the soils shown are very similar based on index properties shown.

-

Uses of Correlation
60

Correlations are helpful in grouping similar soils that are expected to have similar engineering behavior properties. This reduces the number of complex property tests needed, simplifies analyses, and reduces the testing cost for a site design.

-

Preliminary Design Densities and Water Contents
61

Compaction tests furnish preliminary design values for dry unit weight and water content that are used in assigning laboratory tests such as shear strength, consolidation, permeability, and shrink-swell. A designer usually assumes that soil for a proposed fill be placed at some percentage of its maximum dry unit weight at water contents within a prescribed water content range.

Common Preliminary Design Assumes Compaction to 95% of Maximum D 698 Density
62

Commonly, in SCS designs, a preliminary design assumes that soils will be compacted to 95 percent of maximum dry unit weight at water contents of optimum water content or higher, referenced to the ASTM D 698 compaction test.

-

Design Density Re-Evaluated After Analyses
63

If subsequent testing and analysis indicates that the preliminary design is inadequate, additional engineering property tests may be performed at higher densities or other water contents.

-

Highway Construction Designs Commonly Referenced to Modify Compaction Tests D 1557
64

Some applications, particularly highway construction using plastic, fine-grained soils, routinely use ASTM D 1557 compaction as the reference test for design. A higher design unit weight results, which produces more rigid soil more suitable for highway sub-bases. Typical preliminary designs for these applications are for dry unit weights equal to 90 percent to 95 percent of maximum D 1557 dry unit weight.

-

Satisfactory Design Specified for Construction
65

The degree of compaction and range of water content that produce the desired engineering properties for the soils on a particular site will then form the basis for the design of a site. A construction contract can be written requiring that all fill soils will be placed at the designed percentage of maximum dry unit weight within the range of specified water contents.

-

66

Using the compaction test as a reference for specifying fill placement unit weights and water contents is necessary because of the variability of soils on most sites. If one could be assured that all of the soils to be used in a fill were exactly alike, then a designer could specify only a single value for dry unit weight and water content which would produce an acceptable fill.

-

For instance, a placement dry unit weight of 100 pounds per cubic foot would probably be excellent for a plastic clay, but would be very low for a slightly plastic silt. Placement at twenty percent water content might be acceptable for a plastic CH soil, but would be a very wet placement water
67 content for a slightly plastic ML soil.

Compaction tests are also used in quality control of earth fills during construction. By performing tests to determine what are the dry unit weights of the completed fill, and comparing them to the compaction curves and design requirements for those soils, quality control of the earth fill is accomplished. Quality control of earth fills is
68 covered in Module 11 of this series.

Activity 7 Activity 7 covers the main points just covered.
69 Stop the tape and review the Activity before continuing.

Activity 8 Activity 8 requires you to actually perform a compaction test using test Method ASTM D 698 Method A. Your Technical leader will furnish you with the necessary equipment and a suitable soil sample. Carefully study the test procedures given in Activity 8 of your Study Guide, and complete the test. When you have completed this exercise, resume the tape at the next
70 slide.

Let's review the objectives of Part B of this Module.

Objective 1 was to define the important terms used in describing the procedures and equipment used in performing
71 the compaction test.

-

Objective 2 was to describe how compaction test results are
72 affected by soil gradation and plasticity characteristics.

-

Objective 3 was to describe the effects of different energy
73 levels on compaction test results.

-

Objective 4 was to compute and plot results of a compaction test and determine values of maximum dry density and optimum
74 water content using example test data furnished.

-

Objective 5 was to explain conceptually from memory the purpose of laboratory and field compaction tests and explain how compaction tests are used in design and quality control
75 of earth fills.

-

Objective 6 was to perform a compaction test using standard procedures and equipment furnished on a sample of soil furnished, and determine accurate values of maximum dry unit
76 weight and optimum water content.

-

To test your completion of the objectives of this part of the
77 Module, complete Activity 9 in your Study Guide. Stop the tape and complete the Activity.

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You are now ready to continue to Part C of the Module covering compaction tests of soils with more than twenty per
78 cent gravel.

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