United States
Department of
Agriculture

Soil
Conservation
Service

Soil Mechanics Training Series

Basic Soil Properties

Module 5 - Compaction

Part C - Compaction of Gravelly Soils

Study Guide

ENG-SOIL MECHANICS TRAINING SERIES--

BASIC SOIL PROPERTIES

MODULE 5 - COMPACTION

PART C

COMPACTION OF 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 reviewers have helped make this training series one that will provide basic knowledge and skills to employees in soil mechanics.

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

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

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INTRODUCTION

This is Part C of Module 5 - Compaction of 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 C has three 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 C 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.

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 C you will be able to:

1. State which ASTM compaction test method is applicable for soils that have given gravel contents.

2. Explain conceptually the differences between the three ASTM compaction test methods.

3. Define each of the terms in the rock correction equations.
   Use the equations to solve simple problems from given compaction data and gradation data.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 2 - COMPACTION TESTS WITH GRAVEL INCLUDED

When soils to be used in an earth fill contain significant amounts of gravel, the engineering properties of the soil are likely to be appreciably different from similar soils that do not have gravel. Usually, 5 percent or more by dry weight of gravel particles are considered significant. The dry unit weight of a soil containing gravel will be higher than a similar, non-gravelly soil, and the water content will be less.

In the design of a project to be constructed with gravelly soils, the engineering properties of the compacted soil should be based on shear strength, consolidation, and permeability tests performed on samples that contain similar amounts of gravel as the proposed borrow soils. To obtain preliminary design densities and water contents for these engineering property tests, you must have compaction test data on samples that contain the proper amount of gravel particles. If soils to be tested have oversize particles which are not included in the compaction test specimens, then rock correction equations may be used to theoretically consider the effect of the excluded oversize particles on the density and water content of the soil.

Several standard test methods are available for testing soils that have small gravel particles. However, standard tests are not available for samples that have more than 30 percent by dry weight of particles larger than the 3/4 inch sieve. (Soils with less than 70 percent passing the 3/4 inch sieve.)

Another need for compaction test procedures which incorporate gravels, or particles larger than the number 4 sieve, is in construction quality control of compacted fills. Compaction tests which include proper amount of gravel more closely model the compacted fill and the degree of compaction of the completed fill can be more reliably assessed if comparison to the proper test method is made. Again, if gravel particles larger than permitted in standard procedures are present, rock correction equations may be useful for determining the theoretical combined density and water content of the compaction test specimens and the excluded oversize materials. These equations and their use are illustrated later in this module.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 3 - SELECTION OF TEST METHOD

Different standardized compaction test methods are used depending on the gravel content of the sample being tested, as you learned in Activity 3 of Part B, of this module.

In Part B, test methods for compaction of soils containing less than 20 percent gravel size particles were covered. This Part of the Module covers compaction test procedures for soils that contain more than 20 percent gravel.

You should recall that standard methods are not available for soils that have less than 70 percent of the sample finer than the 3/4 inch sieve. Also, remember that to perform compaction tests on soils that have less than 12 percent fines is difficult. Such soils should be tested using procedures covered in Part D of this Module.

Soils that contain less than 80 percent fines should be tested by ASTM Test Methods B or C. Method B procedures are used for soils that have less than 80 percent fines (particles smaller than the number 4 sieve) and 80 percent or more finer than the 3/8 inch sieve.

Soils that have less than 80 percent fines and less than 80 percent finer than the 3/8 inch sieve are tested by Method C procedures.

The selection of the proper Test Method applies to tests performed using either Standard (ASTM D 698) or Modified (ASTM D 1557) energy levels.

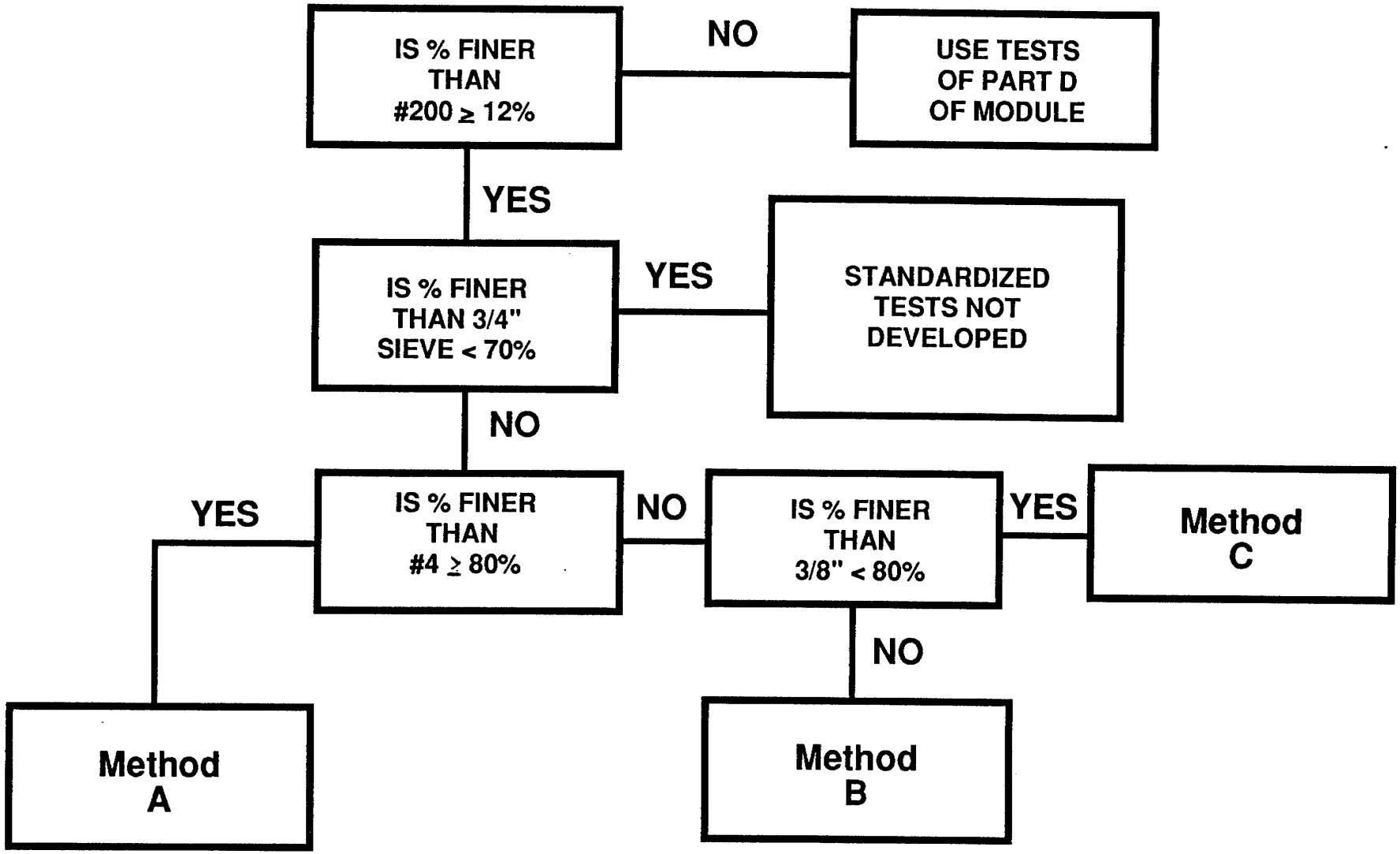
A summary of the criteria for selection of Test Method is as follows:

Percent Finer than #200	Percent Finer than #4	Percent Finer 3/8"	Percent Finer 3/4"	ASTM Test Method
≥12	>79	---	≥70	A
≥12	<79	≥80	≥70	B
≥12	<79	<80	≥70	C
≤12	Use Methods of Part D - Compaction test procedures not applicable			

The flow chart shown in Activity 3 of Part B may also be useful in illustrating these criteria and selecting the proper test method to be used for the soil sample being examined. It is reproduced here for reference, on the following page.

CONTINUE TO PAGE 7

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
YES
IS % FINER THAN #4 ≥ 80%
NO
IS % FINER THAN 3/8" < 80%
YES
Method C
NO
Method A
Method B

ACTIVITY 3 - PROBLEM

To review your understanding of the proper selection of the ASTM Method for performing a compaction test, complete the following table. Use the gradation data provided for each sample and use the flow chart provided to determine the appropriate test method.

Soil No.	Percent Finer 3"	3/4"	1/2"	3/8"	#4	#200	Appropriate Test Method
1	100	98	89	72	64	28	
2	98	68	43	36	29	16	
3	100	100	100	86	79	62	
4	100	82	73	62	49	31	
5	100	100	100	100	98	10	

AFTER COMPLETING THE ACTIVITY, CHECK YOUR ANSWERS ON THE FOLLOWING PAGE

ACTIVITY 3 - SOLUTION

Soil No.	Percent Passing 3"	3/4"	1/2"	3/8"	#4	#200	Appropriate Test Method
1	100	98	89	72	64	28	C
2	98	68	43	36	29	16	Standard tests N/A
3	100	100	100	86	79	62	B
4	100	82	73	62	49	31	C
5	100	100	100	100	98	10	Compaction tests may be difficult to perform

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 4 - METHOD B COMPACTION TESTS

ASTM Test Method B is used for those soils that have less than 80 percent finer than the #4 sieve and 80 percent or more finer than the 3/8 inch sieve.

To prepare soil for Method B tests, the sample is first sieved through a 3/8 inch sieve. If the sample has more than 5 percent plus 3/8 inch size gravel content, the Method B test values will be corrected by equations shown later in the module. Corrections are not necessary if the sample has less than 5 percent larger than the 3/8 inch sieve. The soil to be tested should not have been air-dried before testing if it contains fines that are affected by air-drying. Soils should never be oven-dried before testing.

After sieving out the particles larger than 3/8 inch, four to five specimens are prepared at water contents about 1-1/2 to 2 percent apart in water content. The range of water contents selected is based on experience and feel of the sample. The specimens are then allowed to "cure" an appropriate length of time before compaction. ASTM standards specify the minimum length of curing time depending on the classification of the soil being tested as follows:

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

The compaction test for Test Method B uses the same equipment and procedures as you learned for Test Method A in Part B of this Module. The mold volume is about 1/30 a cubic foot. A value for dry unit weight and water content is determined after compaction of each specimen and a curve is drawn showing the relationship between dry unit weight and water content. The peak of the curve defines the maximum dry unit weight and the optimum water content of the sample for that test method.

The effect of the inclusion of the small gravel particles in Test Method B is to increase the values of dry unit weight and decrease the values of optimum water content, compared to a test of similar soil that does not have the gravel particles.

Typical test results are shown on the following page for a sample tested using Test Method B compared to the same sample tested using Test Method A. The only difference in the two tests is the inclusion of gravel particles smaller than 3/8 inch and larger than the #4 sieve in the Method B test. The Method A test is on soil smaller than a #4 sieve.

Compaction tests may be performed by Method B using both of the standardized energies - Standard and Modified. Details are given in the ASTM Test Method descriptions D 698 and D 1557.

START THE TAPE WHEN YOU HAVE STUDIED FIGURE 4.1 ON PAGE 10

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FILE CODE ENG-22

ACTIVITY 4

LABORATORY NO _____

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

PROJECT and STATE
Figure 4.1 - Typical Compaction Test Results for Method A and Method B Tests

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

CLASSIFICATION CH LL 60 PI 40

MAX. PARTICLE SIZE INCLUDED IN TEST _____ "

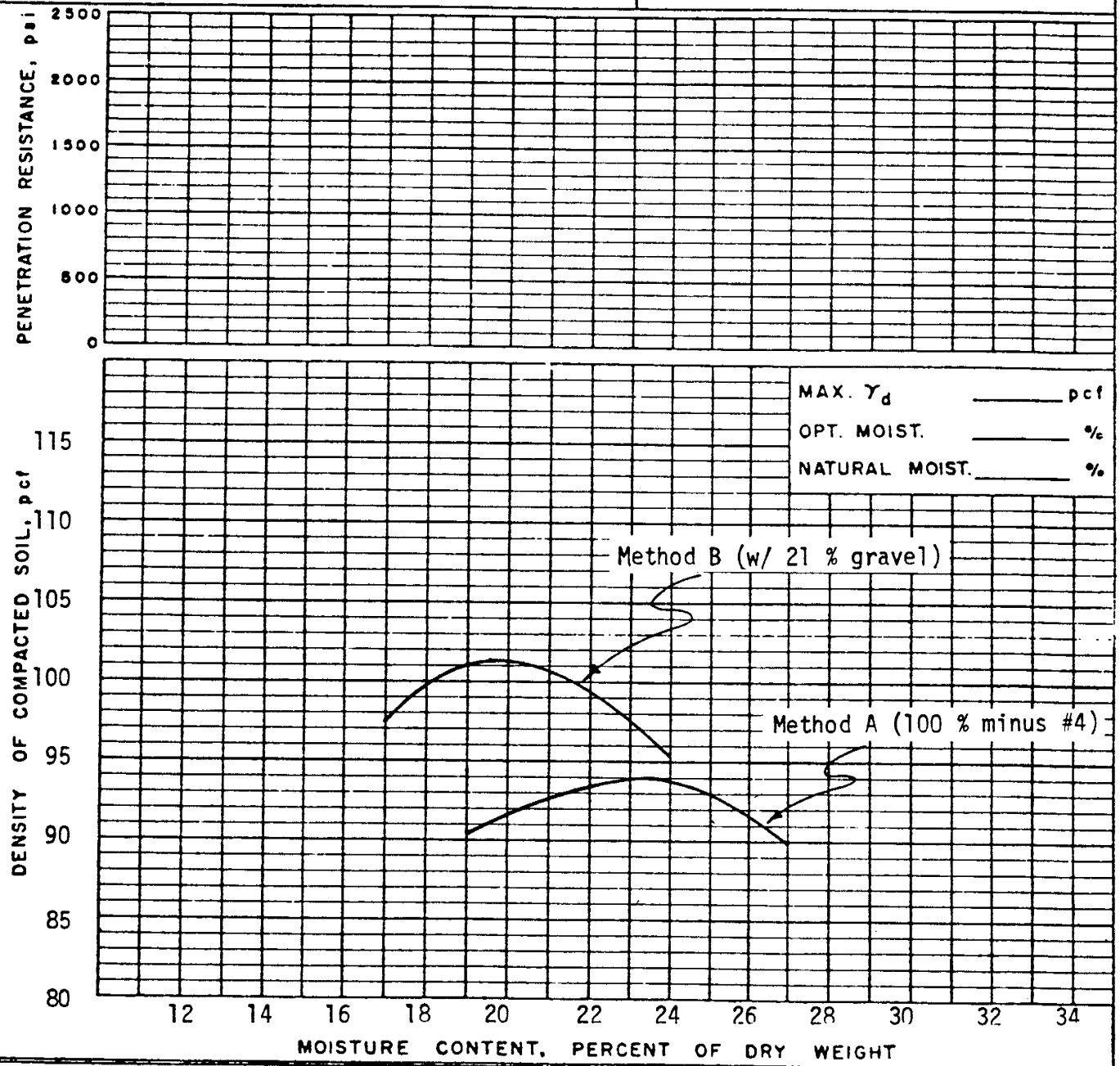
SPECIFIC GRAVITY (G_s) { MINUS NO. 4 2.66 / PLUS NO. 4 123.2 (pcf)

CURVE NO. 1 OF 1

STD. (ASTM D-698) ☒; METHOD A&B

MOD. (ASTM D-1557) ☐; METHOD _____

OTHER TEST ☐ (SEE REMARKS)



REMARKS

ACTIVITY 5 - METHOD C COMPACTION TESTS

ASTM Test Method C is used for those soils that have less than 80 percent finer than the #4 sieve and less than 80 percent finer than the 3/8 inch sieve.

Soils to be tested by Method C are first sieved through a 3/4 inch sieve. The soil should not be air-dried before testing if the soil has properties that are altered by air-drying. Soils should never be oven-dried before testing.

If the gravel particles in the Method C test are shales or other types of gravels that could be degradable in a compaction test, assess the degree of breakdown of the gravel by determining the gradation of the sample after compaction as well as before compaction. These types of gravels probably should not be air-dried prior to testing.

The next step in performing a compaction test using Method C is to prepare four to five specimens that have successively higher water contents. Base the range of water contents selected on experience and feel of the sample. The specimens are then allowed to "cure" an appropriate length of time before performing the test. Samples that have plastic fines may need to be cured as much as 40 hours. ASTM test methods have specific curing requirements depending on the sample's classification as follows:

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

The compaction test for Test Method C differs in several important respects from Test Methods A and B. Method C uses a 6-inch diameter mold, which has a volume of about 1/13.33 cubic foot. Because a constant energy source is the purpose of the test, and a larger volume of soil is compacted in this Test Method, the number of times the hammer is dropped must be altered to achieve the same energy application per cubic foot of compacted soils.

In Test Method C, each layer is compacted with 56 drops of the hammer. Compare this to the 25 drops of the hammer for the tests that use a 4-inch mold using Standard and Modified energies.

A value of dry unit weight and water content is measured for each specimen tested. A curve is then drawn showing the relationship between dry unit weight and water content. The peak of the curve defines the maximum dry unit weight and optimum water content of the sample tested.

CONTINUE TO NEXT PAGE

The gravel included in the Method C test specimens results in higher values of dry unit weight and lower values of optimum water content than Method A tests on the same soils. The purpose of using Method C tests is to attempt to more closely model borrow soils' densities and water contents when they contain significant quantities of gravels.

Typical test results are shown on the following page for a sample tested using Test Method C compared to the same sample tested using Test Method A. The only difference in the two samples is the inclusion of gravel particles in the Method C test.

Compaction tests may be performed using Method C procedures for either Standard (ASTM D 698) or Modified (ASTM D 1557) energies. You should refer to the actual ASTM test standards for details that are adequate for actually performing these tests. Equipment is available for performing these tests in field as well as laboratory situations.

If the sample from which the test soil was selected contained oversize particles which were screened out in preparation for the test, corrections for density and water content may be desirable. Since oversize particles excluded from the compaction test are usually more dense and lower in water content than the compaction specimen, the corrected test results will usually have a higher value of maximum dry unit weight and a lower value of optimum water content.

Oversize corrections are usually desirable when the percentage of oversize particles is greater than 5 percent. Corrections for oversize particles are not considered accurate, however, if more than about 40 percent of the proposed fill sample is oversize particles. Also, remember that standard compaction tests are not performed on soils with more than 30 percent particles larger than the 3/4 inch sieve. Corrections for oversize particles are not considered accurate, however, if more than about 40 percent of the proposed fill sample is oversize, or 30 percent, if the oversize particles are greater than 3/4 inches in diameter. Oversize correction equations are covered later in this module. To determine whether oversize corrections are appropriate, determine what percentage of the total sample was excluded from the test specimen. For Method C tests, the oversize fraction is that percent of the total sample larger than the 3/4 inch sieve.

A summary of the differences in the various test methods is shown below:

Test method (ASTM)	Volume of mold (ft^3)	Weight of hammer (pounds)	Height of drop (ft)	No. of blows per lift	Number of lifts	Maximum particle size
D 698 A	1/30	5.5	1.0	25	3	#4 sieve
D 698 B	1/30	5.5	1.0	25	3	3/8"
D 698 C	1/13.33	5.5	1.0	56	3	3/4"
D 1557 A	1/30	10.0	1.5	25	5	#4
D 1557 B	1/30	10.0	1.5	25	5	3/8"
D 1557 C	1/13.33	10.0	1.5	56	5	3/4"

START THE TAPE WHEN YOU HAVE FINISHED

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FILE CODE ENG-22

ACTIVITY 5

LABORATORY NO _____

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

PROJECT and STATE
Figure 5.1 - Typical Compaction Test Results for Method A and Method C Tests

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

CLASSIFICATION GC LL 32 PI 13

MAX. PARTICLE SIZE INCLUDED IN TEST 3/4" "

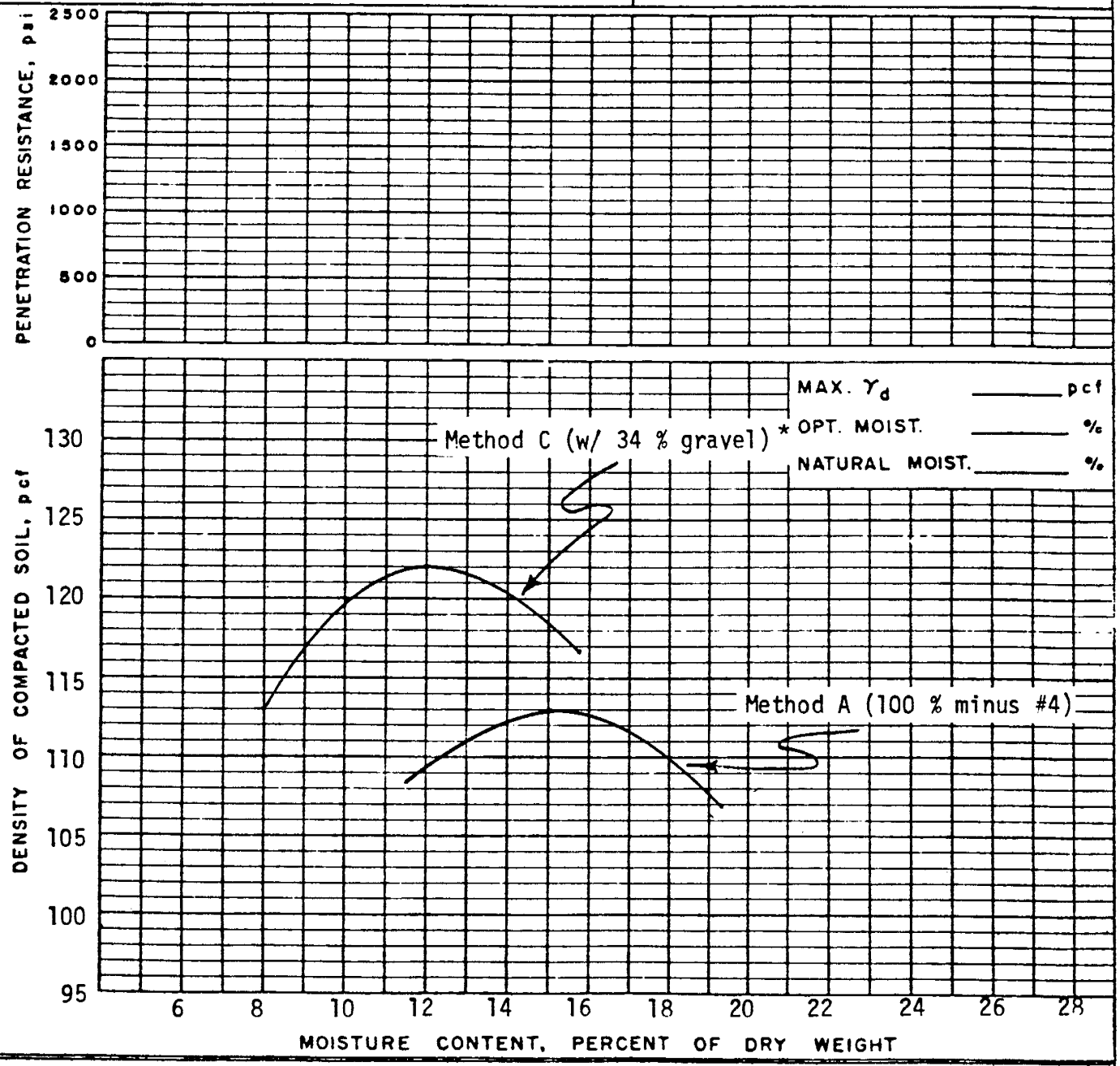
SPECIFIC GRAVITY (G_s) { MINUS NO. 4 2.69 / PLUS NO. 4 2.33

CURVE NO. 1 OF 1

STD. (ASTM D-698) ☒; METHOD A&C

MOD. (ASTM D-1557) ☐; METHOD _____

OTHER TEST ☐ (SEE REMARKS)



REMARKS * Gravel is up to 3/4" in size

ACTIVITY 6 - SUMMARY OF TEST METHOD DIFFERENCES

This Activity summarizes the differences in the three test methods for compaction. Each of the methods can be used for the standard energy tests, ASTM D 698, and the modified energy test, ASTM D 1557.

Selection of the test method to be used is based on the amount of gravel in the test specimen, as follows:

Test method	Amount of gravel (+ #4)	Size of gravel
A	<20%	Not a Factor
B	≥20%	More than 80% of sample is larger than the 3/8" sieve
C	≥20%	Less than 80% of sample is finer than 3/8" sieve

Notes: (1) Compaction tests are not usually performed if a sample has less than 12 percent fines.

(2) Standardized tests are not developed for soils that have less than 70 percent finer than the 3/4 inch sieve.

To accomodate soils that have a significant amount of larger gravel, a different size mold is used for Method C tests. To achieve the same energy application per volume of soil compacted, the number of hammer blows per lift is adjusted. The following table summarizes this.

Test method (ASTM)	Volume of mold (ft^3)	Weight of hammer (pounds)	Height of drop (ft)	No. of blows per lift	Number of lifts	Maximum particle size
D 698 A	1/30	5.5	1.0	25	3	#4 sieve
D 698 B	1/30	5.5	1.0	25	3	3/8"
D 698 C	1/13.33	5.5	1.0	56	3	3/4"
D 1557 A	1/30	10.0	1.5	25	5	#4
D 1557 B	1/30	10.0	1.5	25	5	3/8"
D 1557 C	1/13.33	10.0	1.5	56	5	3/4"

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 7 - ROCK CORRECTION EQUATIONS, UNIT WEIGHT

This Activity covers the use of the rock correction equation for dry unit weights in soils which contain an oversize fraction which is excluded from the test specimen. Oversize particles excluded may be gravels larger than the number 4 sieve in the case of Method A compaction tests, or may be larger than the 3/8 inch sieve in the case of Method B compaction tests, or gravels larger than the 3/4 inch sieve for Method C tests.

An example of one application of this procedure is as follows: A density test is performed on a compacted fill in the field. The density test may have been performed using a nuclear density gauge, a sand cone device, or another method. The soil in the compacted fill contains oversize particles which were not included in the compaction tests performed representing these soils. The rock correction equations may be used to determine the theoretical density of the soil matrix exclusive of the more dense oversize particles, so as to compare the degree of compaction of the soil matrix to the test standard. The soil at the location where the fill density test was taken will have to be sampled so that the percentage of oversize particles and their bulk specific gravity can be obtained. The density test gives the value needed for the combined soil matrix-oversize mass.

Another application of the use of the rock correction equations and this procedure is during design and engineering testing of soils for a fill project. Suppose that the proposed fill soils contain a significant amount of particles larger than the number 4 sieve. Method A compaction tests are performed on the portion of the sample smaller than the number 4 sieve. To model the shear strength of the soil as closely as possible, however, it is desired to perform shear tests on samples which include the oversize particles. By knowing the percentage of oversize particles and their bulk specific gravity, using the rock correction equations, one may estimate what the combined dry unit weight of the compaction test fraction (finer than the number 4 sieve) and the oversize particles would be. Shear test specimens containing the correct percentage of oversize particles can then be prepared compacted to this density, and the fill soils will be more closely modeled.

The mathematical equation shown below accounts for the different densities of the compaction test fraction and the oversize particles. This equation should not be used for soils with more than 40 percent oversize particles. Also, since compaction tests are not applicable for soils with more than 30 percent of particles larger than the 3/4" sieve, the equations should not be used for those soils, either. Usually, if the percentage of oversize particles is less than 5 percent, corrections are not considered necessary.

$$W_{rs} = \frac{W_s \times W_r}{(p)\ W_s + (1-p)\ W_r}$$

where,

W_{rs} = Combined dry unit weight of the test fraction and the oversize particles, pounds per cubic foot or kilograms per cubic meter

W_r = Bulk specific gravity of oversize particles (determined by ASTM Test Method C 127) (Converted to bulk unit weight. Units are pounds per cubic foot (Gm x 62.4) or kilograms per cubic meter (Gm x 1000)).

CONTINUED TO THE NEXT PAGE

ACTIVITY 7 - Continued

W_S = Dry unit weight of test fraction (For Method A tests this is the portion smaller than the #4 sieve; for Method B tests, it is the portion of a sample smaller than the 3/8 inch sieve; and for Method C tests, it is the portion smaller than the 3/4 inch sieve, pounds per cubic foot or kilograms per cubic meter.

p = Percentage of oversize particles not included in the test fraction. It is expressed as a decimal p = p(%)/100

If one knows any three terms in the equation, then you may solve for the remaining fourth unknown term. The primary use of this equation is to calculate a value for the combined dry unit weight of a test fraction and oversize particles. Use the values obtained for the dry unit weights of the test fractions from a Method A, B, or C compaction. This allows one to estimate what a compaction test result might be if the oversize particles could have been included in the test fraction.

Example: Given the following information, determine what the dry unit weight of the combined test fraction and oversize particles would theoretically be.

An ASTM D 698, Method C compaction test was performed. A maximum dry unit weight value of 132.5 pounds per cubic foot was determined. A bulk specific gravity test on the oversize particles measured a value of 2.234 (145.0 pcf). The sample had 22 percent oversize particles removed before testing.

Solution: The rock correction equation is solved by substituting the given values in the equation:

$$W_{rs} = \frac{W_S \times W_r}{(p)\ W_S + (1-p)\ W_r}$$

Substituting the known values in the equation, we have:

$$W_{rs} = \frac{132.5 \times 145.0}{(0.22)\ (132.5) + (0.78)\ (145.0)}$$

$$W_{rs} = \frac{19{,}212.5}{142.25}$$

W_{rs} = 135.1 pounds per cubic foot

Problem: A compaction test was performed using Test Method A. Only the soil fraction of the sample (the portion of the sample finer than the #4 sieve) was used. A value of maximum dry unit weight of 89.0 pounds per cubic foot was determined. In a field density test, the soil had 18 percent particles larger than the number 4 sieve, which have a bulk specific gravity of 155.0 pounds per cubic foot. What would be an estimate of the maximum dry unit weight of that soil with the gravel particles included?

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

ACTIVITY 7 - Worksheet

ACTIVITY 7 - Solution

The following information is given in the problem:

W_s = 89.0 pounds per cubic foot

W_r = 155.0 pounds per cubic foot

p = 18%, or 0.18 as a decimal substituting in the rock correction equation:

$$W_{rs} = \frac{W_s \times W_r}{p \times W_s + (1-p) \times W_r}$$

$$W_{rs} = \frac{89.0 \times 155.0}{(.18 \times 89.0) + (.82 \times 155.0)}$$

$$W_{rs} = \frac{13,795}{143.12}$$

W_{rs} = 96.4 pounds per cubic foot

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 8 - ROCK CORRECTION EQUATIONS, WATER CONTENT

This Activity covers the use of the rock correction equation for water contents in soils which contain an oversize fraction which is excluded from the test specimen. Oversize particles excluded may be gravels larger than the number 4 sieve in the case of Method A compaction tests, or may be larger than the 3/8 inch sieve in the case of Method B compaction tests, or gravels larger than the 3/4 inch sieve for Method C tests.

An example of one application of this procedure is as follows: A water content test is performed on a compacted fill in the field. The water content test may have been performed using a nuclear density gauge, or other acceptable procedures. The soil in the compacted fill contains oversize particles which were not included in the compaction tests performed representing these soils. The rock correction equations may be used to determine the theoretical water content of the soil matrix exclusive of the drier oversize particles, so as to compare the water content to optimum water content for the soil. The soil at the location where the fill water content test was taken will have to be sampled so that the percentage of oversize particles and their percent absorption value can be obtained.

Another application of the use of the rock correction equations and this procedure is during design and engineering testing of soils for a fill project. Suppose that the proposed fill soils contain a significant amount of particles larger than the number 4 sieve. Method A compaction tests are performed on the portion of the sample smaller than the number 4 sieve. To model the consolidation properties of the soil as closely as possible, however, it is desired to perform consolidation tests on samples which include the oversize particles. By knowing the percentage of oversize particles and their percent absorption, using the rock correction equations, one may estimate what the combined water content of the compaction test fraction (finer than the number 4 sieve) and the oversize particles would be. Consolidation test specimens can then be prepared containing the correct percentage of oversize particles, compacted to this water content, and the fill soils will be more closely modeled.

The mathematical equation shown below accounts for the different water contents of the compaction test fraction and the oversize particles. This equation should not be used for cases where the percentage of oversize particles exceeds 40 percent in any case, and should not be used when over 30 percent of oversize particles are greater than 3/4 inches in size. Usually, if the percentage of oversize particles is less than 5 percent, corrections are not considered necessary.

$$w(\%)rs = w(\%)s \times (1-p) + w(\%)r \times p$$

where,

$w(\%)rs$ = water content of combined test fraction and oversize particles, as a percentage

CONTINUE TO THE NEXT PAGE

ACTIVITY 8 - Continued

w(%)s = water content of the test fraction, as a percentage

w(%)r = water content of oversize particles, also referred to as percent absorption, as a percentage. This value is obtained in performing an apparent specific gravity test (ASTM C 127) on the oversize particles.

p = percent of sample excluded from test fraction, expressed as a decimal - [p = p(%)/100]

CONTINUE TO THE NEXT PAGE

ACTIVITY 8 - Continued

Example 1: A compaction test performed using test method C obtained a value of dry unit weight of 122.5 pounds per cubic foot and an optimum water content of 13.5 percent. The test specimen excluded 15 percent gravel particles larger than the 3/4 inch sieve. The oversize gravels had a water content, or percent absorption of 4.2 percent. Find the theoretical optimum water content of the combined Method C test material and the oversize particles.

The following information is given:

$$w(\%)s = 13.5\%$$

$$w(\%)r = 4.2\%$$

$$p = .15$$

To solve for w(%)rs, the values are substituted as follows:

$$w(\%)rs = ws(\%) \times (1-p) + w(\%)\ r \times p$$

$$w(\%)rs = 13.5 \times (1-0.15) + 4.2 \times 0.15$$

$$= 13.5 \times 0.85 + 0.63$$

$$= 12.1\%$$

CONTINUE TO THE NEXT PAGE

ACTIVITY 8 - Continued

Problem: A compaction test was performed on a sample using Test Method A, on the minus #4, or soil, fraction of the sample. A value of 22.5 percent was obtained for optimum water content. Estimate the optimum water content of the soil combined with 15 percent gravel, where the gravel particles have a percent absorption value of 3.2 percent.

WHEN YOU HAVE COMPLETED THE ACTIVITY,
REVIEW THE ANSWERS PROVIDED ON PAGE 26

ACTIVITY 8 - Worksheet

ACTIVITY 8 - Solution

The following information is given:

$$w(\%)s = 22.5\%$$

$$w(\%)r = 3.2\%$$

$$p = .15$$

Substituting in the water content correction formula:

$$w(\%)rs = w(\%)s \times (1-p) + w(\%)r \times p$$

$$= 22.5 \times (1-.15) + 3.2 \times .15$$

$$= 22.5 \times .85 + .48$$

$$= 19.125 + .48$$

$$= 19.6\%$$

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 9 - REVIEW PROBLEMS

To see whether you have met the objectives of the Module, complete the following questions:

A. Label each of the following statements as true or false (T/F)

1. Compaction tests are performed on specimens containing gravel particles only by Standard (ASTM D 698) energy methods. _____

2. Standard test procedures are not presently available for soils containing more than 30 percent by weight of particles larger than 3/8 inches. _____

3. The value of maximum dry unit weight from a compaction test on a sample with no gravel will be lower than the value obtained on a test of the same soil with gravel included. _____

4. Compaction tests are difficult to perform and obtain meaningful test results if a soil contains less than 12 percent finer than the number 200 sieve. _____

5. The rock correction equations may be used to estimate test results for a Method C compaction test if one knows values obtained in a Method A test and has values for specific gravity of gravel particles and knows the percent of gravel. _____

6. In Method B tests, a 6" diameter mold with a volume of 1/13.33 cubic foot is used. _____

7. The number of hammer blows per lift is different between Method A and Method C tests. _____

CONTINUE TO THE NEXT PAGE

B. Determine which ASTM Test Method should be used to perform a compaction test on each of the soils with gradations shown:

Soil Number	Percent Finer Than #200	#4	3/8"	1/2"	3/4"	1"	3"	Test Method
1	46	65	73	81	85	95	100	
2	58	72	82	93	98	100	100	
3	39	82	88	92	96	99	100	
4	68	78	88	92	97	100	100	
5	27	56	67	69	72	85	98	

C. Problem: An ASTM D 1557 Test Method C compaction test was performed on a sample. The sample had 15% oversize gravels removed before testing. The oversize particles have a specific gravity of 138.5 pounds per cubic feet and a percent absorption value of 9.8 percent. The Method C test resulted in a maximum dry unit weight value of 127.5 pounds per cubic feet and an optimum water content of 14.5 percent.

Find the theoretical maximum dry unit weight and optimum water content of the sample if the oversize particles were included in the specimen.

D. Match the definition on the left with the proper symbol on the right. Terms are from the Rock Correction Equations.

1. Specific gravity of oversize particles in test, in pcf.	A. W_s
2. Percent of oversize particles excluded from test, in percent.	B. $w(\%)_r$
3. Dry unit weight of test fraction, pcf.	C. W_{rs}
4. Percent absorption of oversize fraction, percent.	D. $w(\%)_s$
5. Theoretical combined density of test fraction and oversize fraction, pcf.	E. $w(\%)_{rs}$
6. Water content of test fraction, percent.	F. W_r
7. Theoretical water content of combined test fraction and oversize particles, percent.	G. p

WRITE YOUR ANSWERS ON THE WORKSHEET ON THE FOLLOWING PAGE

AFTER COMPLETING THE ACTIVITY, CHECK YOUR ANSWERS ON THE FOLLOWING PAGE

ACTIVITY 9 - PROBLEM SOLUTION

A. True/false questions:

1. F
2. F
3. T
4. T
5. T (if oversize % is less than 30)
6. F
7. T

B. Selection of Test Method Problems:

Soil 1 - Method C
Soil 2 - Method B
Soil 3 - Method A
Soil 4 - Method B
Soil 5 - Method C

C. Numerical Problem Solution:

The following information is given in the problem:

W_s = 127.5 pounds per cubic foot
W_r = 138.5 pounds per cubic foot
p = 15%/100 = 0.15
w(%)s = 14.5%
w(%)r = 9.8%

Find W_{rs}, w (%) rs

$$W_{rs} = \frac{W_s \times W_r}{p \times W_s + (1-p) \times W_r}$$

$$= \frac{127.5 \times 138.5}{(0.15 \times 127.5) + (0.85 \times 138.5)}$$

$$= \frac{17{,}658.75}{136.85}$$

= 129.0 pounds per cubic foot

Solving for water content:

$$w(\%)rs = w(\%)s \times (1-p) + w(\%)r \times p$$

$$w = 14.5 \times (0.85) + 9.8 \times 0.15$$

= 13.8%

CONTINUE TO THE NEXT PAGE

The estimated combined density of the Method C and the oversize particles is 129.0 pcf, and the combined water content is theoretically 13.8 percent. These estimated values could then be used as target values for a fill constructed using the oversize particles with the Method C test specimen soil.

D. Matching Questions

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

START THE TAPE WHEN YOU HAVE FINISHED

APPENDIX

SCS Logo

ENG - SOIL MECHANICS TRAINING SERIES--
BASIC SOIL PROPERTIES
MODULE 5 - COMPACTION
PART C

1 COMPACTION OF GRAVELLY SOILS

-

Part C of Module 5 covers the compaction test procedures used for soils that have more than twelve percent fines and contain less than 80% fines. It also covers procedures for obtaining corrected values for water content and dry unit weight when soils that have more than five percent oversize particles excluded from the test specimen are tested by
2 methods of Part B of the Module.

-

At the completion of Part C, you will be able to meet the following objectives:

1. State which ASTM Compaction test method is applicable to
3 soils with varying gravel contents.

-

2. Explain conceptually the difference in the three test
4 methods for performing compaction tests.

-

3. Define each term in the rock correction equations.
5 Use the equations to solve simple problems.

-

ACTIVITY 1
6 These objectives are shown in Activity 1, Part C, of your Study Guide. Stop the tape before continuing.

-

Three methods are used in performing compaction tests using either standard or modified energies. These are called Method A, Method B, and Method C.

In Part B of Module 5 you learned that soils that have 80 percent or more fines are tested by sieving the sample through the number four sieve before testing. This procedure is referred to as Method A in ASTM test procedures D 698 and D 1557.

If samples tested by Method A have more than five percent gravel content, correction equations are used to determine the theoretical maximum dry density and optimum water content for the total sample.

7

-

ACTIVITY 2

To predict the engineering behavior of soils that have less than 80 percent fines, other standard compaction test procedures must be used. A general discussion on the importance of using these other test methods in earth fill design is given in Part C, Activity 2. Stop the tape and review that Activity before proceeding.

8

-

Two compaction test methods are used when samples contain less than 80 percent fines. However, standard methods are not available for performing compaction tests when samples contain more than 30 percent by dry weight of particles larger than the three-fourths inch sieve. (70% or less is finer than the three-fourths inch sieve).

9

-

Method B is used when a sample has less than 80 percent fines, and it has 80 percent or more finer than the three-eighths inch sieve.

10

-

Method C is used when samples have less than 80 percent fines and less than 80 percent finer than the three-eighths inch sieve. Remember, standard procedures are not available if 70 percent or less of the sample is finer than the three-fourths inch sieve.

11

-

ACTIVITY 3

Part B, Activity 3, of your Study Guide contains a flow chart with the criteria for selection of the appropriate compaction test method. Activity 3 also gives review problems. Stop the tape and complete Activity 3 before continuing.

12

-

Method B test procedures will be discussed first. Soils are prepared for method B tests by sieving the sample through a three-eighths inch sieve. The soil may be air-dried before sieving if its properties are not significantly changed by air-drying.

If the sample has over five percent but less than twenty percent of gravel larger than the three-eighths inch sieve, test results should be corrected for oversize content using procedures discussed later in this Module. If the sample contains five percent or less larger than the three-eighths inch sieve, no corrections are necessary.

13

-

Method B uses the same size mold and the same energy application as used in the Method A tests covered in Part B of the Module. Method B tests may be performed using either of the two standardized energies, Standard (ASTM 698), or Modified (ASTM D 1557) energies.

14

-

After preparing a series of four to five specimens at successively higher water contents, values are obtained for wet unit weight, water content, and dry unit weight after compaction of each specimen, just as you learned for Method A tests in Part B of this Module.

15

-

The data is plotted the same way as you learned for Method A tests. Values for maximum dry unit weight and optimum water content are obtained from the curve and reported as test
16 results.

-

Values for dry unit weight on tests performed using Method B will be higher than tests performed using Method A if the same soils are tested. Method B includes gravel size particles that are generally more dense than a corresponding
17 volume of minus number four material.

-

Part C, Activity 4 has a summary of procedures for performing
ACTIVITY 4 compaction tests by Method B. The activity shows example data for two samples tested using both Method A and B. Stop
18 the tape and complete the Activity, before continuing.

-

Soils to be tested using Method C procedures are first sieved through a three-fourths inch sieve. Remember that samples that have more than 30 percent larger than the three-fourths inch sieve are not tested with standard compaction test procedures.

If the sample contains between six percent and 30 percent larger than the three-fourths inch sieve, the maximum dry unit weight and optimum water content obtained using Method C may be corrected for the oversize particles using the procedures discussed later on in this Part of the Module. If the sample contains five percent or less larger than the three-fourths inch sieve, no corrections are necessary.
19 Corrected values represent the <u>total</u> sample.

-

A larger mold, six inches in diameter, is used for the Method C test procedure. This is necessary because of the larger size particles included in the sample tested. The mold has a volume of about two and one-fourth times the volume of the
20 mold used for Method A and B tests.

-

To achieve the same compactive energy per volume of soil, the hammer must be dropped a larger number of times per lift. Method C uses 56 blows of the hammer per lift as compared to the 25 blows per lift used for Methods A and B using both

21 Standard or Modified energies.

-

The size of particles included in the test, the mold size, and the number of blows per lift are the major differences in the test procedures in comparing Method C tests to Methods A

22 and B.

-

ACTIVITY 5

Part C, Activity 5 in your Study Guide summarizes test procedures and test equipment used for Method C tests and shows examples for soils tested using both Method A and Method C. The soils in the example are the same except for gravel included in the two tests. Stop and study that

23 Activity now.

-

In summary, three methods are used in performing compaction tests using either standard or modified energies. These

24 methods are called Method A, Method B, and Method C.

-

Selection of the method to use is based on the gravel content of the sample being tested.

Method A tests have no gravel in the test specimen. Method B tests have less than 80 percent fines and 80 percent or more is finer than the three-eighths inch sieve. Method C tests have less than 80 percent and less than 80 percent is finer

25 than a three eighths inch sieve.

-

26 Standardized methods are not available for soils that have more than 30 percent of particles larger than the three-fourths inch sieve.

-

27 The mold size used and numbers of blows per lift are variables in the three test methods, together with the size of particles used in the test.

-

28 Activity 6 summarizes the differences in the three test methods. Stop the tape and study the Activity before continuing.

-

The use of the rock correction equations will now be discussed. These equations are useful when a soil is composed of a mixture of soil and gravel.

29 Because hard gravel size particles cannot be compacted, the only densification that can result in a soil-gravel mixture is due to rearrangement of the gravel particles and compaction of the finer particles in the sample. The portion of a soil-gravel mixture in the test specimen that is finer than the specified sieve used is often referred to as the matrix in the sample.

-

Use of the rock correction equations enables one to separate the unit weight and water content of the matrix in a sample from that of the gravel excluded from the matrix in the sample.

30 The equations are useful both in design and quality control during construction of earth fills constructed with gravelly soils.

-

Slide with Rock
`orrection Equation
31

This theoretical equation calculates the combined dry unit weight of a soil-gravel mixture. It is quite accurate for oversize gravel contents less than about forty percent.

-

Highlight term WRS
in Equation
32

Let's examine the definition of each term in the equation. The term W-sub-RS is the combined dry unit weight of the compacted soil and rock, or gravel.

-

Highlight term WS
in Equation
33

The term W-sub-S is the dry unit weight of the test fraction. The test fraction may be the portion of the sample finer than the number four sieve in the case of Method A tests, or the portion of the sample finer than the three-eighths inch sieve in the case of Method B tests, or the portion of the sample finer than the three-fourths inch sieve in the case of Method C tests.

-

lighlight term WR
in Equation
34

The term W-sub-R is the specific gravity of the oversize particles. This value is obtained from a laboratory test. This term is also abbreviated as G-sub-m, the bulk surface dry specific gravity of the oversize particles. This value should be in the same units used to express dry unit weight, either pounds per cubic foot or kilograms per cubic meter. Remember that specific gravity is the ratio of the unit weight of a substance to that of water. To convert to pounds per cubic foot, multiply by 62.4. To convert to kilograms per cubic meter, multiply by 1000.

-

Highlight term P
in Equation
35

P is the percentage of oversize material, or the percentage of particles not included in the test. It is expressed as a decimal. Again, for Method A tests, the P would be the percentage of particles larger than the number 4 sieve. For Method B, it would be the percentage larger than the three eights inch sieve. And, for Method C tests, it is the percentage larger than the three-fourths inch sieve.

-

36

If you know any three of the terms in this equation, you may solve for the remaining unknown term.

-

Activity 7

37

Part C, Activity 7 in your Study Guide contains more detail on the use of this equation and has examples and problems on its use. Stop the tape and complete that Activity before continuing.

-

w_{RS} (%) = (w_S (%) * (1-p) + w_R (%) * p)/100

38

This equation is used to calculate the water content of a mixture of a test matrix and oversize particles.

-

Highlight term w_{RS} in Equation

39

The terms are defined as follows:
w-sub-RS is the water content of the combined test fraction and oversize particles. The water content is expressed as a percentage.

-

Highlight term W_S

40

w-sub-S is the water content of the test matrix. It is also expressed as a percentage. Often, calculations will be made using optimum water content from the compaction test for this value.

-

Highlight term w_R in equation

41

w-sub-R is the water content, or percent absorption, of the oversize material in the sample. Percent absorption values are obtained in the laboratory bulk specific gravity test for gravels.

-

42

p is the percent of oversize particles in the sample tested. It is expressed as a decimal in the equation.

-

Activity 8

43 Activity 8 has examples and problems on the use of the water content correction equations. Stop the tape and complete that Activity before continuing.

-

44 Let's review the objectives of Part C of the Module. Objective 1 was to state which of the three ASTM test methods is applicable depending on the gravel content of the soil being tested.

-

45 Objective 2 was to explain the differences in the test methods used in performing compaction tests.

-

46 Objective 3 was to define each term in the rock correction equations for density and water content, and to use the rock correction equations to solve simple problems.

-

Activity 9

47 To test your completion of the objectives of Part C, complete Activity 9 in your Study Guide.

-

48 You are now ready to proceed to Part D of this Module covering test procedures for soils with less than twelve percent fines.

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