United States
Department of
Agriculture

Soil
Conservation
Service

# Soil Mechanics Training Series

# Basic Soil Properties

## Module 5 - Compaction

## Part D - Compaction of Clean, Coarse-grained Soils

Study Guide

# ENG-SOIL MECHANICS TRAINING SERIES--

## BASIC SOIL PROPERTIES

## MODULE 5 - COMPACTION

## PART D

## COMPACTION OF CLEAN, COARSE-GRAINED SOILS

## STUDY GUIDE

National Employee Development Staff
Soil Conservation Service
United States Department of Agriculture
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## 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 D of Module 5 - Compaction of Clean, Coarse-grained 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 D 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 D 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 D, you will be able to:

1. From a list of terms, define the terms associated with index density and relative density.

2. Identify the equipment and procedures used for performing index density tests in the laboratory and field.

3. Estimate values for index densities based on soil classification and gradation data.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 2 - INTRODUCTION

Acceptable engineering characteristics are attained at different dry unit weights for different compacted kinds of soil. Although an SP soil might be well compacted and relatively dense at a dry unit weight of 100 pcf, this might represent loose fill material of a GW soil. For this reason, fill placement must be specified in terms of a reference density test when kinds of soil are variable on a site.

As you learned in previous parts of this Module, compaction tests are quite useful in control and specification of densities in soil that has more than 12 percent fines. Performing compaction tests is difficult on soil that has less than about 12 percent fines. The low fines content of the soil results in a rather free-draining character. Water is not readily retained in the pores. When this kind of soil is compacted in a compaction test mold, water in the soil may drain out the bottom of the sample. Obtaining more than 1 or 2 specimens is difficult with differing water contents from which a compaction curve could be plotted. Even though a complete curve may not be developed, however, a value of dry unit weight resulting from the application of standard compactive energy may be of interest. This is especially true for soil that has between 5 percent and 12 percent fines content.

Tests other than compaction tests are used for assessing the compaction characteristics of these kinds of soils. The specific test procedures are covered later in the module.

Tests used for clean, coarse-grained soil determine values for minimum and maximum index densities for the soils. Practical design densities usually are somewhere between these extreme values. These tests may also form the basis for field quality control.

You may want to review Activity 6 of Part A of this Module that covers the general compaction characteristics of these soil groups.

The Unified Soil Classification System classifications to which these concepts apply are:

GRAVELS - GP GP-GM GP-GC GW GW-GM GW-GC

SANDS - SP SP-SM SP-SC SW SW-SM SW-SC

These soils may be naturally occurring soils in a borrow area, or they may be filters or drain system materials.

Note that density is often used interchangeably with unit weight in these discussions. You should recall from other Parts of this Module that density is actually an expression of the mass of an object per unit volume whereas unit weight is an expression of the weight of an object per unit volume. The weight of an object is equal to its mass times the gravity constant. Because the gravity constant varies slightly over the earth's surface, there is a minor difference in the two values, but for practical purposes, the terms may be used interchangeably.

START THE PLAYER WHEN YOU HAVE FINISHED

## ACTIVITY 3 - MINIMUM INDEX DENSITY TEST

One of the tests used to evaluate compaction characteristics of relatively clean coarse-grained soil is the minimum index density test. Detailed test methods are contained in ASTM Test Method D 4254. This discussion is a summary of important points in the procedure, but you should refer to the ASTM standard for detail adequate to perform the test.

Minimum index density is defined as the reference dry density of a soil in the loosest state of compactness at which it can be placed using a standard laboratory procedure that prevents bulking and minimizes particle segregation. From the definition, the value of minimum index density should not be regarded as an absolute value of the minimum density to which a particular soil could occur. If a soil were deposited in a manner such that bulking of the soil and particle segregation could occur, then a lower value of density might result. Bulking is the creation of a loose structure in a sand or gravel caused by capillary stresses in the moist material. It results in a loose structure. Segregation is the separation of coarser fragments from finer fragments in a sample caused by dropping the sample from too great a height during placement.

Soil for a minimum index density test is first oven dried at 110 degrees Centigrade (± 5 degrees) and then processed to remove any weakly cemented aggregates. The amount of sample needed to perform the test depends on the maximum particle size in the sample. About 75 pounds of sample are required for soil that has maximum particle sizes larger than the 3/4 inch sieve; 25 pounds of sample are needed for soil that has a maximum particle size smaller than the 3/4 inch sieve. Only the portion of a soil sample finer than 3 inches is used in these test methods.

A representative sample must be used for performing the test. Representative samples are usually obtained using sample splitters or the technique of quartering.

CONTINUE TO THE NEXT PAGE

ACTIVITY 3 - Continued

The minimum index density test is performed by carefully pouring the soil into a cylindrical mold of known volume. The soil is allowed to drop only from a specified height, using specified pouring devices and procedures. The size of mold and the type of pouring device are selected based on the maximum particle size in the soil, according to the following table:

| Maximum particle size | Required size of sample (pounds) | Placement device used in minimum density test | Nominal size of mold (volume - cubic foot) |
|---|---|---|---|
| 3" | 75 | Shovel or extra large scoop | 0.5 |
| 1-1/2" | 75 | Scoop | 0.5 |
| 3/4" | 25 | Scoop | 0.1 |
| 3/8" | 25 | Pouring device with 1" diameter | 0.1 |
| #4 sieve | 25 | Pouring device with 1/2" diameter spout | 0.1 |

The mold is filled by pouring the prepared sample carefully into the mold with the required pouring device using a spiralling movement of the device over the surface of the sample. The free fall of the soil is kept to a maximum of about 1/2 inch or just high enough to maintain continuous flow of the sample without the spout contacting the already deposited soil.

The mold is overfilled slightly (1/2" to 1" above the top of the mold). The excess soil is then carefully screed off with a straightedge to avoid any vibration or jarring of the mold. Do not jar the mold while pouring the sample into the mold or when screeding off the excess soil, because any jarring of the mold will cause an increase in the density of the soil.

Next, the weight of the mold and soil is determined. The volume of the mold and its weight should have been determined previously. Knowing the weight of soil and volume of the mold, the density of the soil at its minimum index state may be determined.

The test is usually repeated until several trials are obtained with results within 1 percent of one another to insure accuracy.

CONTINUE TO THE NEXT PAGE

ACTIVITY 3 - Continued

Example

A soil classifies as an SP soil. It has 100 percent finer than the #4 sieve. The minimum density test is performed using a mold that has a volume of 0.10034 cubic foot and a pouring device that has a spout having a diameter of 1/2 inch. The wei of the mold and soil is 16.96 pounds; the weight of the mold alone is 8.14 pounds. The minimum index density is calculated as follows:

$$\text{Minimum Index Density} = \frac{\text{(Weight of Soil + Mold)-(Weight of Mold)}}{\text{Volume of Mold}}$$

$$= \frac{16.96-8.14}{0.10034}$$

$$= 87.9 \text{ pounds per cubic foot}$$

Problem:

Given the gradation of the following soils, determine the mold size and pouring device to use for a minimum index density test on each soil. (The maximum particle size is the smallest sieve size that 100 percent of the sample passes.)

| Soil No. | #200 | Percent finer #4 | 3/8" | 1/2" | 3/4" | 1-1/2" | 3" | Mold size and pouring device |
|---|---|---|---|---|---|---|---|---|
| 1 | 8 | 98 | 100 | 100 | 100 | 100 | 100 | |
| 2 | 3 | 52 | 64 | 72 | 88 | 92 | 100 | |
| 3 | 4 | 72 | 79 | 89 | 100 | 100 | 100 | |

WHEN YOU HAVE COMPLETED THE ACTIVITY, CHECK YOUR ANSWERS ON THE FOLLOWING PAGE

ACTIVITY 3 - Solution

Soil 1 - The sample has a maximum particle size of 3/8 inch. At least 25 pounds of oven-dried sample is required for the test. A mold that has a volume of about 0.1 cubic foot should be used with a pouring device with a spout having a 1 inch diameter.

Soil 2 - The sample has a maximum particle size of 3 inches. At least 75 pounds of oven-dried sample is required for the test. A mold that has a volume of about 0.5 cubic foot should be used with a extra large scoop or shovel for a pouring device.

Soil 3 - The sample has a maximum particle size of 3/4 inch. At least 25 pounds of oven-dried sample is required for the test. A mold that has a volume of about 0.1 cubic foot should be used with a scoop for a pouring device.

START THE TAPE WHEN YOU HAVE FINISHED

## ACTIVITY 4 - MAXIMUM INDEX DENSITY TEST

The second test to evaluate compaction characteristics of relatively clean, coarse-grained soils is the maximum index density test. Detailed test methods are contained in ASTM Test Method D 4253. This discussion is a summary of the important points in the procedure, but you should refer to the ASTM standard for detail adequate for actually performing the test.

Maximum index density is defined as the reference dry density of a soil in the densest state of compactness that can be attained using a standard laboratory procedure that minimizes particle segregation and breakdown. From the definition, the value of maximum index density should not be regarded as an absolute value of the maximum density at which a particular soil could occur. If a soil were densified by other means than the test procedure, higher densities could be attainable.

This test may be performed on a sample of soil which was used for the minimum index test, or a separate specimen may be prepared for this test. A sample should be used that will result in a value of minimum index density within the 1 percent tolerance mentioned for that procedure. The requirements for sample size and mold volume are the same as those for the minimum index density test and are not repeated here.

Several test methods are used for performing the maximum index density test. The differences in the methods involve whether the sample is vibrated in a wet or dry state, and what type of vibrating table is used, as detailed below.

The test is performed by placing either oven-dried or wet soil in a mold, applying a surcharge weight that exerts a surface pressure of 2 pounds per square inch on the soil, and then vertically vibrating the mold, soil, and surcharge. An electromagnetic, eccentric, or cam-driven vibrating table operating at about 60 Hertz (cycles per second) for 8 minutes is used to vibrate the sample and apparatus. The maximum index density is obtained by dividing the oven-dried weight of the densified soil by its densified volume. The densified volume of the sample is obtained by measurements of the vibrated height of the sample times the area of the mold.

The most common method for performing the test is using oven-dried soil and an electromagnetic vibrating table. Both the dry and wet methods should be used on a new job, because occasionally the wet method will result in significantly higher values of maximum index density than the dry method. On soil that has between 5 percent and 12 percent fines, impact compaction tests (ASTM D 698 or D 1557) may be useful in evaluating what is an appropriate value of maximum index density.

Some soil may experience significant degradation or breakdown of sand and gravel particles during the test. This may be evaluated by performing a gradation analysis before and after performing the maximum index density test.

CONTINUE TO NEXT PAGE

ACTIVITY 4 - Continued

Example

The sample used in the example for Activity 3 was subjected to a maximum index density test. The densified volume of the sample was determined to be 0.08345 cubic foot. What is the maximum index density of the sample?

Solution

The maximum index dry density is equal to the weight of dry soil in the mold divided by the vibrated volume of the sample. The soil in Activity 3 had a dry weight of 16.96-8.14, or 8.82 pounds. This weight, divided by 0.08645 cubic foot is 105.7 pounds per cubic foot, the maximum index density for the sample.

CONTINUE TO THE NEXT PAGE

ACTIVITY 4 - Continued

Problem

The same soil was evaluated for maximum index density by using the wet sample preparation method. Using the same mold, which has a volume of 0.10034 cubic feet and a weight of 8.14 pounds, the mold was carefully filled with wet soil while vibrating the mold. After filling, the surcharge weight is placed on the sample and the sample vibrated additionally. The vibrated volume of the sample is determined to be 0.09243 cubic foot. The wet weight of the soil and mold is 18.48 pounds, and the measured water content of the sample is determined to be 6.2 percent. What is the maximum index density of the sample?

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

ACTIVITY 4 - Problem Solution

The following information is given:

Weight of mold + wet soil = 18.48 pounds
Weight of mold = 8.14 pounds
Volume of mold = 0.10034 cubic foot
Water content of soil = 6.2%
Vibrated volume of soil = 0.09243 cubic foot

The weight of wet soil = 18.48-8.14
= 10.34 pounds

Using the formula Dry Weight = Wet Weight/(1+w(%)/100)
= 10.34 pounds/(1+6.2%/100)
= 10.34/1.062
= 9.736 pounds

The maximum index density is the weight of dry soil divided by the vibrated volume of the soil = 9.736 pounds/0.09243 cubic foot
= 105.3 pounds per cubic foot

This indicates there was little difference in the values of maximum index density between the dry and wet methods. Subsequent testing on similar soils from this site may use the dry method.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 5 - RELATIVE DENSITY

Results of the minimum and maximum index density tests are used in several ways by designers and construction inspection personnel in projects where clean, coarse-grained soil is compacted in a fill. The kind of soil may form the entire fill in some projects, and in other situations, the clean coarse-grained material may be a filter or drain section in an embankment or surrounding a concrete structure.

In any case, these tests are performed for the same reasons that the compaction test is performed on soil that has more than 12 percent fines. If laboratory tests for shear strength, consolidation, or permeability are desired, a value for placement dry density must be assumed so that the tests may be performed at that density. If satisfactory properties are obtained at these densities, then the project may be designed and placement of the soil specified at comparable densities to ensure the fill is constructed to a degree of compactness similar to that tested in the laboratory. These concepts are summarized in the flow chart on Figure 5.1, p. 20. Review the information before continuing.

Samples of proposed fill material are obtained usually in the site investigation of a project. The number of samples needed is a function of the yardage of soil represented and the variability of the deposits. The size of sample needed depends on the maximum particle size of the sample. Recall that about 75 pounds of sample are needed for tests on soil that has larger particles, and sample sizes of 25 pounds are adequate for samples that have no large gravels.

After performing minimum and maximum index density tests, a designer must decide at what intermediate density he wishes to assume the fill should be compacted. One approach is to assume the soil is placed at some arbitrary percent of the maximum index density, such as 90 or 95 percent of maximum index density.

A more common assumption is based on the concept of relative density. Relative density is defined as the ratio, expressed as a percentage, of the difference between the maximum index void ratio and a given value of void ratio; to the difference between its maximum and minimum index void ratios.

In equation form, relative density is defined as:

$$D_d\ (\%) = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

CONTINUE TO THE NEXT PAGE

where,

$D_d$ = relative density, expressed as a percentage

$e_{max}$ = maximum index void ratio. This value is calculated from the minimum index density using the formula:

$$e_{max} = \frac{\text{Specific gravity x 62.425}}{\text{Minimum index density}} - 1$$

$e_{min}$ = minimum index void ratio. This value is calculated from the maximum index density using the formula.

$$e_{min} = \frac{\text{Specific gravity x 62.425}}{\text{Maximum index density}} - 1$$

e = void ratio at which relative density is being calculated. This value is obtained from a measurement of the soil's in-place dry density from the equation:

$$e = \frac{\text{Specific gravity x 62.4}}{\text{Dry Unit Weight (pcf)}} - 1.0$$

CONTINUE TO NEXT PAGE

Note

The equations for calculating $e_{max}$ and $e_{min}$ assume that the maximum and minimum index densities are expressed in units of pounds per cubic foot. If units of kilograms per cubic meter are used for measurement of maximum and minimum index densities, then the constant 62.4 in the equation should be changed to 1000, which is the unit weight of water in the metric system.

An alternative formula expressing relative density in terms of density rather than void ratio is shown below:

$$D_d\ (\%) = \frac{D_{max}\ (D - D_{min})}{D\ (D_{max} - D_{min})} \times 100 \quad \text{or} \quad \frac{1 - \frac{D_{min}}{D}}{1 - \frac{D_{min}}{D_{max}}} \times 100$$

where,

$D_d$ (%) = relative density, expressed as a percentage

$D_{max}$ = maximum index density, pcf or Kgm

$D_{min}$ = minimum index density, pcf or Kgm

D = placement density,pcf or Kgm

Common values for relative density assumed in preliminary designs may range from 50 to 80 percent. After assumming a value for relative density, the above equations are used to calculate what the corresponding value of placement density is, as shown with the following example:

Example

A minimum and maximum index density test are performed on a sample of SP soil. Values obtained are 89.5 pounds per cubic foot and 108.5 pounds per cubic foot, respectively. What density corresponds to a relative density value of 70%?

Solution

The equation for Relative Density may be arranged as follows:

$$D = \frac{D_{min}}{1 - \frac{D_d(\%) \times (D_{max} - D_{min})}{100 \times D_{max}}} \quad \text{or} \quad \frac{D_{max}\ D_{min}}{D_{max} - \frac{D_d(\%)}{100}\ (D_{max} - D_{min})}$$

CONTINUE TO NEXT PAGE

ACTIVITY 5 - Continued

Substituting given values into this equation:

$$D = \frac{89.5}{1 - \frac{70 \times (108.5-89.5)}{100 \times 108.5}}$$

$$D = \frac{89.5}{1 - \frac{70 \times (19)}{10,850}}$$

$$= \frac{89.5}{1 - 0.12258}$$

= 102.0 pounds per cubic foot

Problem

A soil's minimum index density is 94.5 pounds per cubic foot and its maximum index density is 111.5 pounds per cubic foot. The soil has a specific gravity of 2.66. Calculate the maximum and minimum void ratios for the sample, and determine what the relative density of a compacted fill of this soil would be if an in-place density test of the fill measured a dry unit weight of 107.6 pounds per cubic foot.

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

ACTIVITY 5 - Worksheet

ACTIVITY 5 - Problem Solution

The following information is given:

$D_{max}$ = 111.5 pounds per cubic foot
$D_{min}$ = 94.5 pounds per cubic foot
$G_s$ = 2.66

1. Calculate the maximum void ratio for the sample using the equation:

$$e_{max} = \frac{\text{Specific gravity} \times 62.425}{\text{Minimum index density}} - 1$$

$$= \frac{2.66 \times 62.425}{94.5} - 1$$

$$= 1.7571 - 1$$

$$= 0.7571$$

2. Calculate the minimum void ratio for the sample using the equation:

$$e_{min} = \frac{\text{Specific gravity} \times 62.425}{\text{Maximum index density}} - 1$$

$$= \frac{2.66 \times 62.425}{111.5} - 1$$

$$= 1.4892 - 1$$

$$= 0.4892$$

3. Calculate the void ratio of the soil in the fill using the equation

$$e = \frac{\text{Specific gravity} \times 62.425}{\text{In place density}} - 1$$

$$= \frac{2.66 \times 62.425}{107.6} - 1$$

$$= 1.5432 - 1$$

$$= 0.5432$$

CONTINUE TO NEXT PAGE

ACTIVITY 5 - Problem Solution Continued

4. Calculate the value for relative density using the equation:

$$D_d\ (\%) = \frac{e_{max} - e}{e_{max} - e_{min}} *100$$

$$= \frac{0.7571 - 0.5432}{0.7571 - 0.4892} *100$$

$$= \frac{0.2139}{0.2679} \times 100$$

$$= 79.8\%$$

This would represent very well compacted soil in all likelihood.

START THE TAPE WHEN YOU HAVE FINISHED

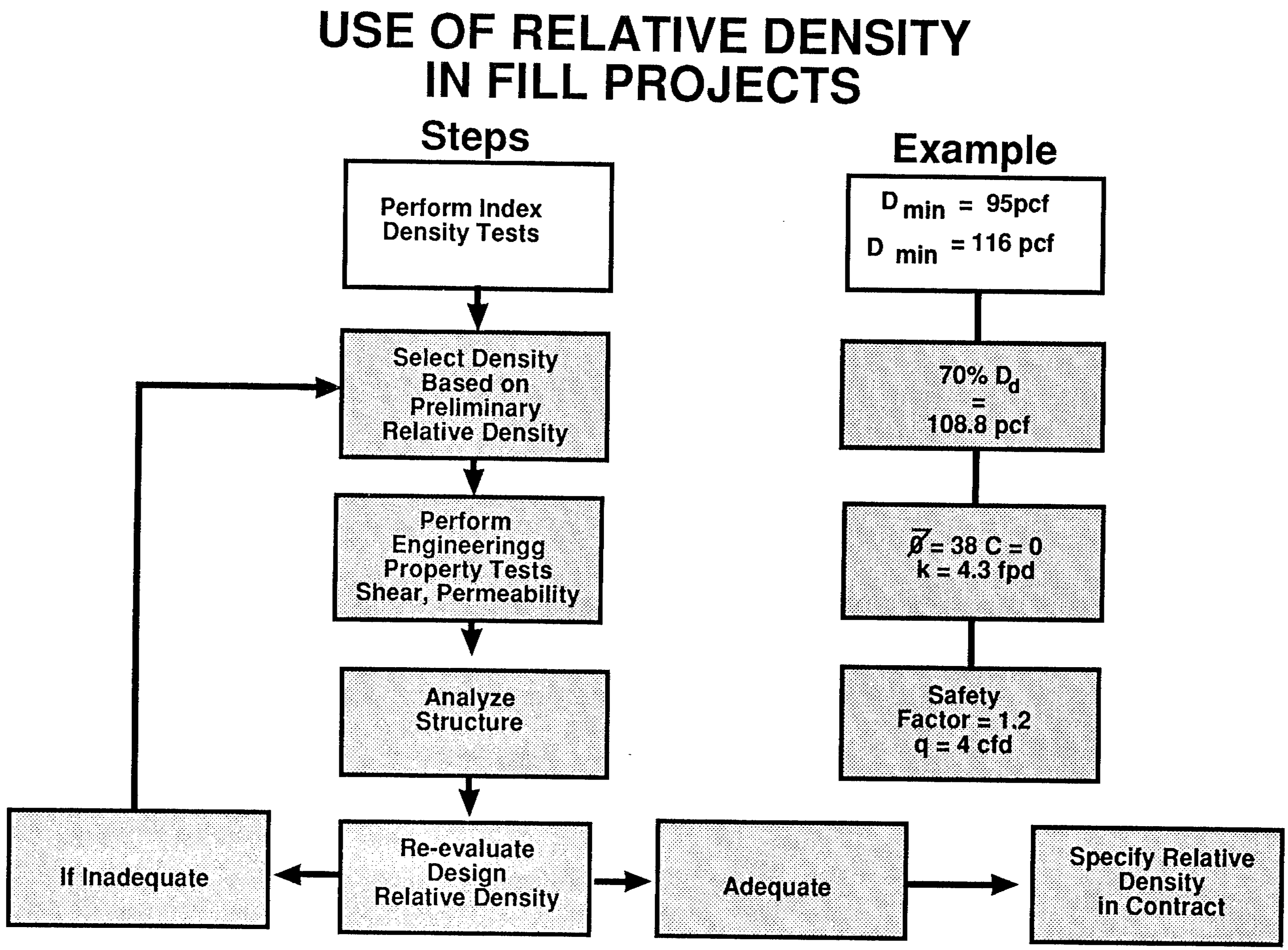
USE OF RELATIVE DENSITY
IN FILL PROJECTS
Steps
Example
Perform Index Density Tests
Select Density Based on Preliminary Relative Density
Perform Engineeringg Property Tests Shear, Permeability
Analyze Structure
Re-evaluate Design Relative Density
If Inadequate
Adequate
Specify Relative Density in Contract
D min = 95pcf
D min = 116 pcf
70% Dd = 108.8 pcf
Ø = 38 C = 0
k = 4.3 fpd
Safety Factor = 1.2
q = 4 cfd

Figure 5.1

ACTIVITY 6 - ESTIMATING INDEX DENSITY VALUES

To obtain values for minimum and maximum index densities is frequently difficult particularly in a construction project that has no field laboratory. Testing may not be justified for smaller projects. Empirical estimates of values of minimum and maximum index densities may be useful in these cases. This Activity presents two methods for estimating relative density parameters.

Method 1

The first method is one developed by the U.S. Army Corps of Engineers. Values of minimum and maximum index densities are estimated based on the percent finer than the number 16 sieve in a soil. The equations are based on correlations from a large number of tests. The equations do not consider other factors such as angularity of particles, whether the soil is well-graded or poorly graded, or what differences might occur because of specific gravity values. As you would with any correlation, you should know the limitations and lack of precision of such estimates. However, for a preliminary estimate, or where no other means is available for obtaining a reasonable estimate, the equations are useful.

Estimates for minimum and maximum index densities are given by the equations:

Minimum Index Density = 125.5 - 0.36 x P

Maximum Index Density = 132.9 - 0.27 x P

where,

Minimum and Maximum Index Densities are expressed in pounds per cubic foot, and

P = the percent of the sample finer than the Number 16 sieve

These equations are taken from the Corps of Engineers Engineering Manual EM-1110-2-1911, p. 5-34. They should not be used for gravelly soils.

Method 2

Another empirical tool for evaluating relative density is shown on Figure 6.1. This chart is taken from an article of the American Society of Civil Engineers titled Liquefaction Problems in Geotechnical Engineering, 1976, page 164, authored by N. C. Donovan and S. Singh. Relative density is read from the chart by entering the chart with a value for a soil's dry unit weight and soil type. The chart may also be used to estimate a value for dry unit weight if you know the relative density and kind of soil. This chart was developed in conjunction with the Alaska pipeline design. The same precautions on the use of such a correlation as disscussed previously should be regarded when using such a chart. Other important factors are not included in the chart, and individual variations may be large.

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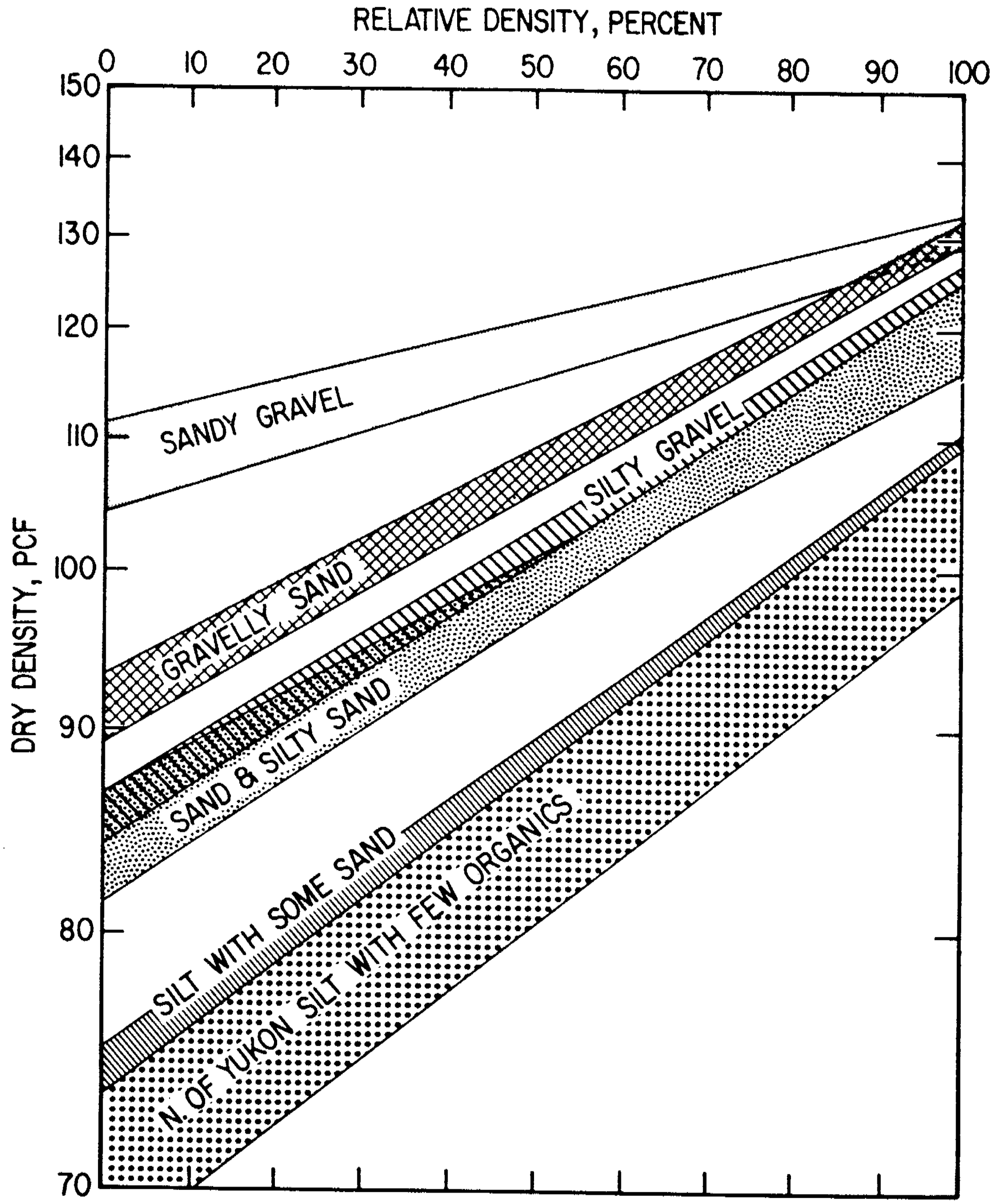



Reference: Donovan, N.C. and S. Singh, "Liquefaction Criteria for the Trans-Alaska Pipeline", Liquefaction Problems in Geotechnical Engineering, A.S.C.E., 1976, p. 164.

**RELATIONSHIP BETWEEN DRY DENSITY AND RELATIVE DENSITY FOR SOILS ALONG PIPELINE ROUTE**

Figure 6.1

Example Problem

A soil has 79 percent finer than the #16 sieve. The soil is a well graded sand with no gravel. An in-place density test was made in a fill constructed of the soil, and a measured value of 106.0 pounds per cubic foot was reported as the dry unit weight of the compacted fill. What is the relative density of the fill? Estimate by both methods.

Method 1

Minimum Index Density = 125.5 - 0.36 x P
= 125.5 - 0.36 x 79
= 125.5 - 28.44
= 97.06 pounds per cubic foot

Maximum Index Density = 132.9 - 0.27 x P
= 132.9 - 0.27 x 79
= 132.9 - 21.33
= 111.57 pounds per cubic foot

Using the value given of 106.0 pcf for in-place density, D:

$$D_d\ (\%) = \frac{D_{max}\ (D - D_{min})}{D\ (D_{max} - D_{min})} \times 100$$

$$= \frac{111.57\ (106.0 - 97.06)}{106.0\ (111.57 - 97.06)} \times 100$$

$$= \frac{997.44}{1{,}538.06} \times 100$$

$$= 65\%$$

Method 2

Entering Figure 6.1 with an in-place dry unit weight of 106.0 pounds per cubic foot, read horizontally to the band for sand and silty sand. Read upwards to the relative density scale, and detemine that the in-place soil has a relative density of between 62 percent and 72 percent or an average of about 67 percent. This agrees closely with the estimate of the Corps of Engineers Method.

CONTINUE TO THE NEXT PAGE

## Problem

ASTM standard gradation C-33 is often specified for a fine filter or drain material. This gradation is a standard gradation used in manufacture of concrete. On a hypothetical construction project, it is considered desirable to place this drain material at a relative density of 70 percent. The standard gradation for this filter is shown on Figure 6.2. Estimate by both methods what a desirable range in the value of compacted density would be for this material with the given information. You should obtain two estimates; one estimate for the finest gradation curve shown and one for the coarsest gradation curve shown on Figure 6.2. The equations used for calculating density from known values of relative density and index densities is shown on page 15. Note that this problem soil would correspond to the sand/silty sand band on Figure 6.1.

AFTER COMPLETING THE ACTIVITY, CHECK THE SOLUTION ON PAGE 26

U.S. Department of Agriculture
Soil Conservation Service

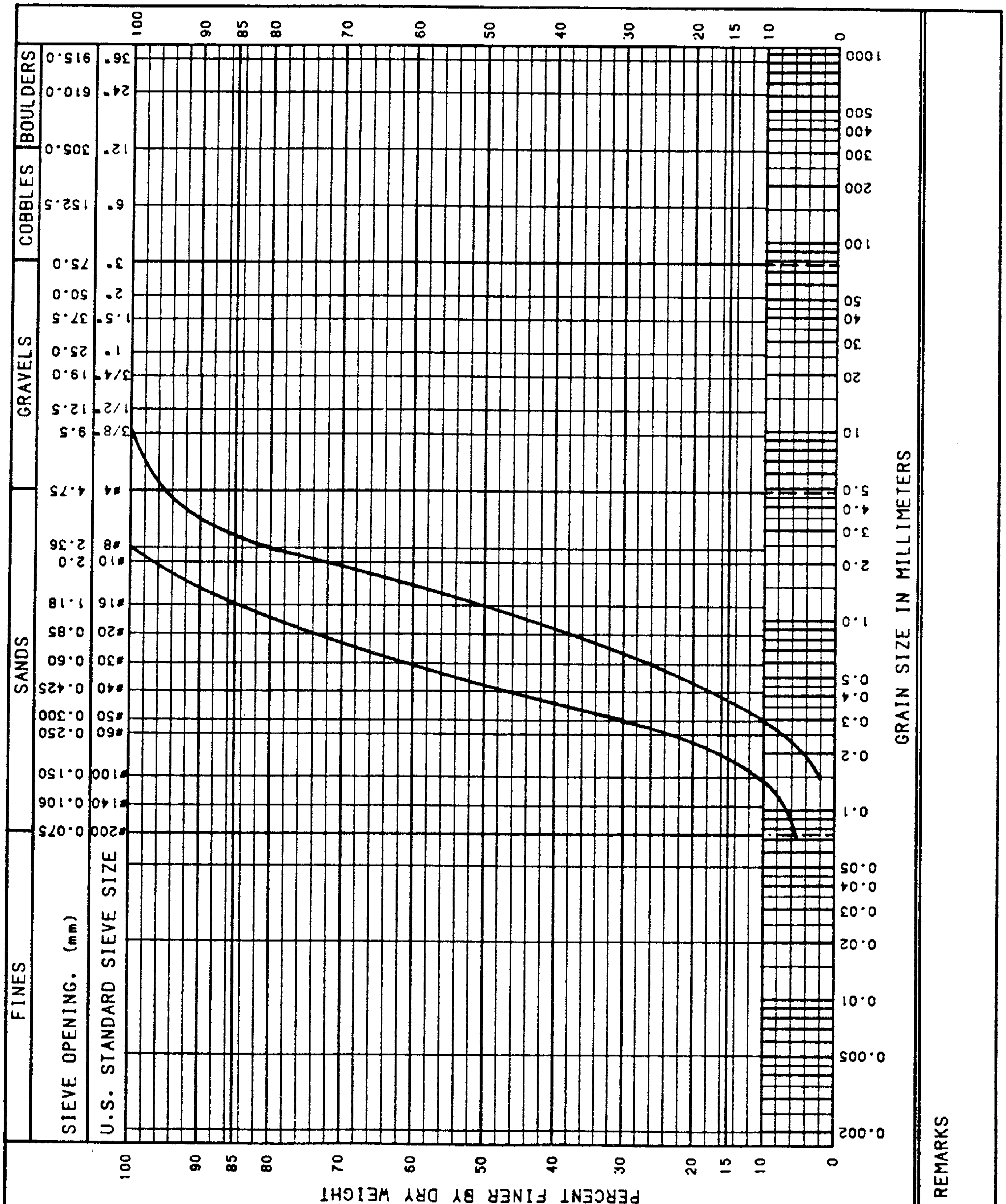
SCS-ENG-130
2-85

GRAIN SIZE ANALYSIS FOR

ACTIVITY 6 - Figure 6.2
(Specify)

Project and state PROBLEM

Designed at ______ By ______ Date ______



ACTIVITY 6 - Solution

Using the given gradation curve, the range of permissible materials has a percent finer than the #16 sieve of between 50 and 85 percent.

Method A (Corps of Engineers)

Determine minimum and maximum values of index densities for the lower value of percent finer than the #16 sieve.

Minimum Index Density = 125.5 - 0.36 x P
= 125.5 - 0.36 x 50
= 107.5 pounds per cubic foot

Maximum Index Density = 132.9 - 0.27 x P
= 132.9 - 0.27 x 50
= 119.4 pounds per cubic foot

The density corresponding to 70 percent relative density may be calculated from the equation.

$$D = \frac{D_{min}}{1 - \frac{D_d(\%) \times (D_{max} - D_{min})}{100 \times D_{max}}}$$

$$D = \frac{107.5}{1 - \frac{70 \times (119.4-107.5)}{100 \times 119.4}}$$

= 115.6 pounds per cubic foot

Using the same procedure for the maximum shown value of percent finer than the #16 sieve of 85, then

Minimum Index Density = 125.5 - 0.36 x P
= 125.5 - 0.36 x 85
= 94.9 pounds per cubic foot

Maximum Index Density = 132.9 - 0.27 x P
= 132.9 - 0.27 x 85
= 109.95 pounds per cubic foot

CONTINUE TO NEXT PAGE

ACTIVITY 6 - Solution Continued

$$D = \frac{D_{min}}{1 - \frac{D_d(\%) \times (D_{max} - D_{min})}{100 \times D_{max}}}$$

$$D = \frac{94.9}{1 - \frac{70 \times (109.95-94.9)}{100 \times 109.95}}$$

= 105.0 pounds per cubic foot

The range of estimated dry densities corresponding to 70 percent relative density by this method is then from 105.0 to 115.6 pounds per cubic foot.

Using Method 2, the chart should be read from a relative density value of 70 percent at the top of the chart downwards to the band shown for sand and silty sand, then read horizontally to the dry density scale - A range of dry densities of from about 104.0 to 109.0 pounds per cubic foot. This shows good agreement between the two methods for estimating.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 7 - EXAMPLES OF EQUIPMENT SPECIFICATIONS

On some projects, to perform index density tests may be impractical in the design and construction of a fill project where relatively clean, coarse-grained soil is used. Performing field density tests in this kind of soil is also difficult, especially when the soil contains significant gravel content. In these cases, to specify the type of equipment and mode of operation may be preferable to control the placement of the soil. These specifications should be based on previous favorable experience with placement of similar soil.

SCS specifications often include a paragraph requiring that these soil types be thoroughly wet during compaction to reduce the bulking tendencies of moist sands, and ensure good compaction.

Examples of this type of specification are shown below. The first specification shown is one used for placement of drain fill. These materials are clean sands and gravels.

Example specification 1. Fill shall be placed uniformly in layers not more than 12 inches deep before compaction. The material shall be placed in a manner to avoid segration of particles sizes. Each layer shall be compacted by at least 2 passes, over the entire surface, of a steel-drum vibrating roller weighing not less than 5 tons and exerting a vertical vibrating force of not less than 20,000 pounds at least 1,200 times per minute.

Example specification 2. Fill shall be placed uniformly in layers not more than 12 inches deep before compaction. The material shall be placed in a manner to avoid segregation of particle sizes. Each layer shall be compacted by at least 2 passes, over the entire surface, of a pneumatic-tired roller exerting a pressure of not less than 75 pounds per square inch. A pass is defined as at least one complete coverage of the roller wheel, tire or drum over the entire surface of the layer.

Example specification 3. Fill shall be placed uniformly in layers not more than 12 inches deep before compaction. The material shall be placed in a manner to avoid segregation of particle sizes. Each layer shall be compacted by at least 4 passes, over the entire surface, of the track of a crawler-type tractor weighing not less than 20 tons.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 8 - TEST OF OBJECTIVES

To test your understanding of the material in Part D of this Module and to see whether the objectives have been met, complete the following questions:

Match the term on the left with the appropriate definition on the right:

1. Minimum void ratio _____
2. Surcharge weight _____
3. 60 Hertz _____
4. Relative density _____
5. 0.1 cubic foot mold _____
6. Unified Soil Classifications for which minimum and maximum index density tests do not apply _____
7. Unified Soil Classifications for which minimum and maximum index density tests apply _____
8. Most efficient method of compacting clean, coarse-grained soils _____
9. Method of Maximum Index Density Test likely to result in highest values _____
10. ASTM Test Method Designations for Minimum and Maximum Index Density Tests _____
11. Maximum void ratio _____
12. 0.5 cubic foot mold _____

A. CH, ML, SC, GC

B. Mold size for samples with maximum particles sizes less than 3/4"

C. Void ratio corresponding to maximum index density

D. D 4254 and D 4253

E. Frequenty of vibration of table on maximum index test

F. Exerts pressure of 2 pounds per square inch

G. Mold size for samples with particles larger than 3/4"

H. Void ratio corresponding to minimum index density

I. GP, SP, GP-GM, SP-SM

J. Vibratory

K. $\frac{e_{max} - e}{e - e_{min}} \times 100$

L. Wet method

CONTINUE TO NEXT PAGE

ACTIVITY 8 - Continued

The soil with gradation shown on Figure. 8.1 will be the primary fill material for a building foundation. Preliminary design estimates are that the soil should be placed at a relative density of 80 percent.

1. What size mold and type of pouring device should be used for the minimum and maximum index density tests?

2. Give an estimate of the minimum and maximum index densities for the sample, and state what value of dry density corresponds to 80 percent relative density based on these estimates.

WHEN YOU HAVE COMPLETED THE TEST, CHECK YOUR ANSWERS ON THE PAGE 34

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Soil Conservation Service

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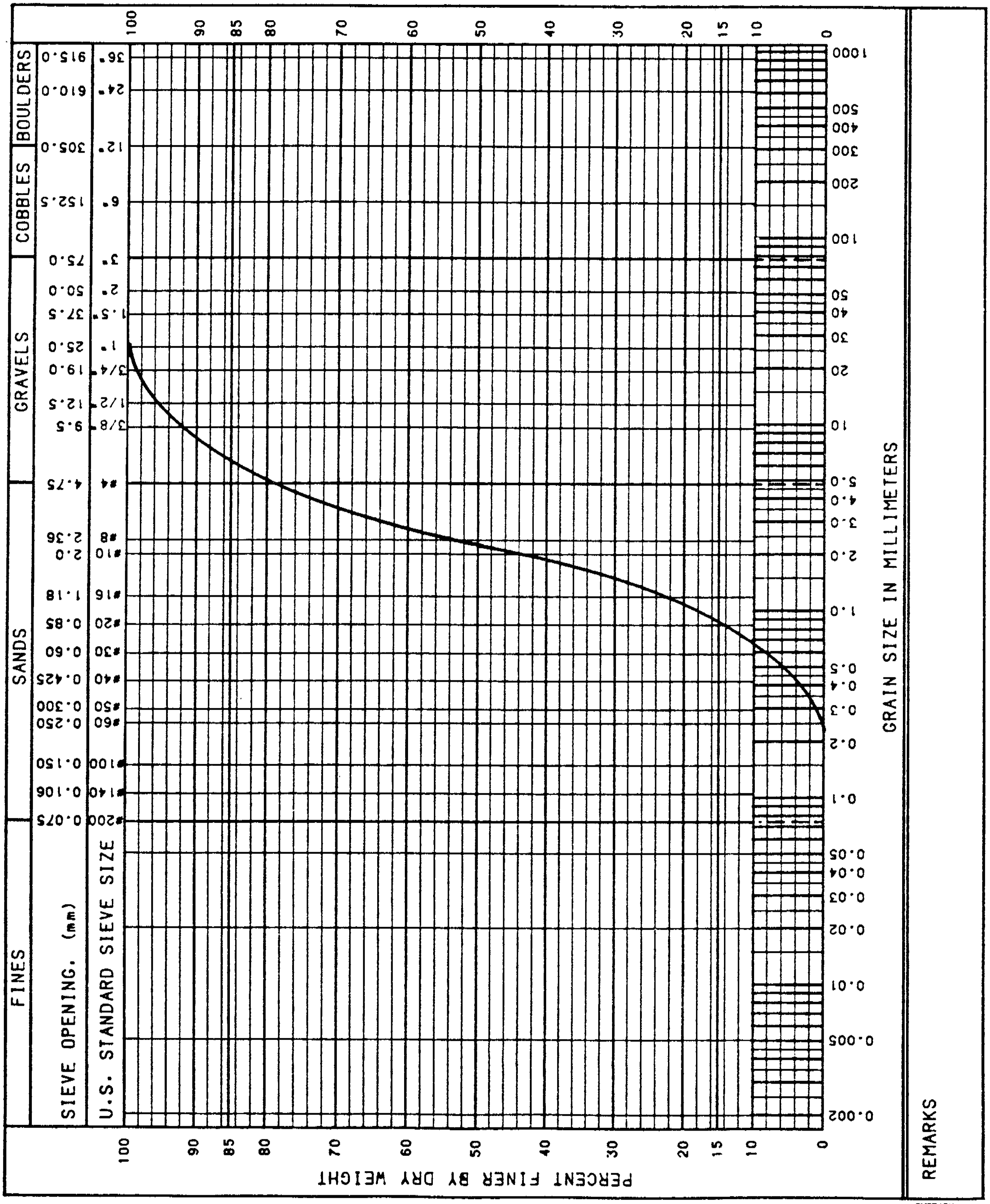
GRAIN SIZE ANALYSIS FOR

ACTIVITY 8 - Figure 8.1
(Specify)

Project and state PROBLEM

Designed at ______ By ______ Date ______



ACTIVITY 8 - PROBLEM SOLUTIONS

Matching questions:

| | | | |
|---|---|---|---|
| 1. | C | 7. | I |
| 2. | F | 8. | J |
| 3. | E | 9. | L |
| 4. | K | 10. | D |
| 5. | B | 11. | H |
| 6. | A | 12. | G |

Answers for given soil gradation:

1. The soil has a maximum particle size of 1". The table in Activity 3 shows that a 75 pound sample is required, using a scoop fill a mold with a volume of 0.5 cubic foot.

2. Using the Corps of Engineers equation for estimating minimum and maximum index densities, with a percent finer than the #16 sieve read, from the gradation curve of 22 percent, as follows:

Minimum Index Density = 125.5 - 0.36 x P
= 125.5 - 0.36 x 22
= 117.6 pounds per cubic foot

Maximum Index Density = 132.9 - 0.27 x P
= 132.9 - 0.27 x 22
= 127.0 pounds per cubic foot

ACTIVITY 8 - Continued

Substitute known values in the following equation from Activity 6:

$$D = \frac{D_{min}}{1 - \frac{D_d(\%) \times (D_{max} - D_{min})}{100 \times D_{max}}}$$

$$D = \frac{117.6}{1 - \frac{80 \times (127.0-117.6)}{100 \times 127.0}}$$

$$D = \frac{117.6}{1 - 0.0592}$$

D = 125 pcf

Using the chart shown in Activity 6, with the kind of soil being a slightly gravelly, clean sand, entering the chart with a relative density value of 80 percent, read an in-place density of 120.0 pcf.

THIS COMPLETES ACTIVITY 8 AND COMPLETES PART D OF THE MODULE
YOU SHOULD NOW CONTINUE WITH PART E OF THE MODULE

# APPENDIX

SCS Logo

1 ENG-SOIL MECHANICS TRAINING SERIES--
BASIC SOIL PROPERTIES
MODULE 5 - COMPACTION
PART D
COMPACTION OF CLEAN, COARSE-GRAINED SOILS

-

Part D of Module 5 covers the laboratory and field tests used to control placement of relatively clean, coarse-grained
2 soils in a compacted fill.

-

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

1. From a list, define the terms associated with
3 index density and relative density.

-

2. Identify the equipment and procedures used for performing
4 index density tests in the laboratory and field.

-

3. Estimate values for index densities based on soil
5 classification and gradation data.

-

ACTIVITY 1 These objectives are listed in Activity 1, Part D, of your
6 Study Guide. Stop the tape and review the Activity before continuing.

-

You should recall from Part A of this Module that compaction tests are not recommended for coarse-grained soils that have less than about 12 percent of the sample finer than the number 200 sieve, or for soils that have more than 30 percent
7 by weight of particles larger than three-fourths inch.

-

Because soils that have less than 12 percent fines have a limited water holding capability, performing compaction tests are difficult on these soils. In a compaction test on this kind of soil, the curve obtained will likely be quite flat, and not useful for determining maximum dry unit weight or optimum water content values.

The Unified Soil Groups shown are those that have less than
8 12 percent fines.

-

Performing one compaction trial at some arbitrary water content may occasionally be useful to compare values of dry unit weight obtained with other procedures mentioned in this
9 Part of the Module.

-

Soils that have more than 30 percent of particles larger than the three-fourths inch sieve are also difficult to test. Large gravel particles interfere with the compaction procedure in the small standard size molds used. Compaction test methods for these very gravelly soils are in development
10 but have not yet been standardized.

-

Alternative laboratory tests are used to obtain reference densities for relatively clean, coarse-grained soils. The tests are called the maximum index densities and minimum index density tests. The ASTM designations are D 4253 and D
11 4254, respectively. These will be covered in detail.

-

Let's review some of the main points on compacting these soils that were covered in Part A of this module.

The most effective means of compacting or densifying these
12 soils is vibration.

-

These soils may be most effectively compacted at low or very high water contents. Flooding is often used to ensure good
13 compaction and prevent bulking.

-

These soils may be placed and compacted in thicker lifts in
14 the field than soils that have higher fines contents.

-

The reasons for compacting these soils are to improve the engineering properties, increase shear strength, and decrease compressibility. Although permeability may be reduced, these soils have relatively high permeabilities due
15 to their low fines content.

-

When relatively clean coarse-grained soils are used in a fill, a designer must base the design on engineering parameters obtained from laboratory tests or correlations. To perform laboratory tests or to use correlations available, one must know at what density the soils will be placed in the fill.

By performing a maximum index density test and a minimum index density test on the soils, the designer may select a design density somewhere between these two test densities. Engineering property tests or correlations may then be based on this design density. Note that density is used interchangeably with the term unit weight in these
16 discussions.

-

ACTIVITY 2 Activity 2 summarizes the main points discussed in this
17 introduction. Stop the tape and review the Activity before continuing.

-

The minimum index density test will be discussed first. Detailed test procedures are given in ASTM D 4254. You should realize that it is outside the scope of this Module to give enough detail for actually performing the tests. You
18 should refer to the ASTM standards for this detail.

-

The minimum index density is defined as the reference dry density of a soil in the loosest state of compactness at which it can be placed using a standard laboratory procedure
19 that prevents bulking and minimizes particle segregation.

-

Bulking is the creation of a loose structure in a sand or gravel caused by capillary stresses in the moist material. Proper preparation of the samples for the test will minimize
20 this problem.

-

Segregation is the separation of coarser fragments from finer
fragments in a sample caused by dropping the sample from
too great a height during placement. Use of proper
21 procedures and equipment will minimize this problem.

-

Different sizes of test equipment and test procedures are
used depending on the maximum particle size of the sample to
be tested. Soils that have a maximum particle size of 3/4
inch are tested in a small mold and soils that have larger
22 gravels are tested in a larger mold.

-

Photo The minimum index test procedure involves placing a prepared
sample carefully by prescribed procedures into a mold of
known volume. The test procedures are designed to attain the
loosest state of density possible for that gradation of soil.
However, an absolute minimum density is not implied, because
23 other methods could result in slightly lower density.

-

The most common method of performing the test is to use a
Photo pouring device such as the one shown. The mold is filled
with the soil slowly and with a minimum of disturbance of the
soil as it is poured into the mold. Care is taken not to
drop the soil from any height that would cause higher
24 densities and cause segregation.

-

After carefully filling the mold, the surface of the soil is
screeded with a straight edge so that the resulting soil
Photo volume will be precisely known. By weighing the mold that
has the soil in it, and knowing the volume of the mold from
prior calibrations, one may calculate the density or dry unit
25 weight of the soil in a minimum index density state.

-

The size of mold and the pouring device used depends on the
gradation of the sample being tested. A one-tenth cubic foot
mold is used for sands, and a one-half cubic foot mold is
used for samples that have gravel. Oven-dry soil is used to
eliminate any bulking that might be caused by moisture in
26 the sample.

-

ACTIVITY 3 Activity 3, Part D, of your Study Guide has more detailed
descriptions of the minimum index density test procedures and
has examples and problems. Stop the tape and complete the
27 Activity.

-

The maximum index density test is performed by procedures
28 listed in ASTM D 4253.

-

The maximum index density is defined as the reference dry
density of a soil in the densest state of compactness that
can be attained using a standard laboratory procedure
29 that minimizes particle segregation and breakdown.

-

The maximum index density test may be performed on either
oven-dried or wet soil. The soil is placed in the same mold
Photo as used in the minimum index density test. The soil is
placed carefully in the mold to minimize segregation. Often,
the sample used for the minimum index density test is used to
30 perform this test procedure, if oven-dry soil is being tested.

-

A surcharge weight is then placed on the surface of the soil
in the mold. The weight applies a pressure of 2 pounds per
square inch. A sleeve holds the surcharge in alignment.
31

-

The sample and apparatus are then bolted to a vibratory table
that has the capability of vibrating at 50 to 60 Hertz. The
sample is then vibrated for eight to ten minutes. Hertz
32 units are cycles per second.

-

The vibration of the table and the presence of the surcharge
weight densifies the sample. The final density is termed the
maximum index density. By carefully measuring the height of
the vibrated sample after removing the surcharge weight, and
knowing the weight of sample with which the test was started
and the volume of the mold, a value of maximum index density
33 may be calculated.

-

Care must be exercised in interpreting results of tests on samples that may experience breakdown of particles during the test because this will result in an increase in density.

Repeatability of results depends on careful calibration of equipment and strict adherence to test procedures.

Test results should always state (1) the maximum size of particles in the soil tested, (2) whether the sample tested
34 was oven-dry or wet, and (3) what size of mold was used for the test.

-

ACTIVITY 4 Activity 4 has details on procedures for performing the maximum index density test. Stop the tape and complete
35 the Activity.

-

A designer may select a preliminary design density based upon the results of these two tests. Usually, a density is selected somewhere between the minimum and maximum index test values. Two ways are used to specify these design densities, as follows:

1. A design density may be expressed as some percentage of the maximum index density, such as 90 percent of maximum index density.

2. A relative density may be specified. Relative density is
36 defined as follows:

-

$$D_r\ (\%) = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

Relative density is the ratio, expressed as a percentage, of the difference between the maximum index void ratio and any given void ratio to the difference between its maximum and minimum index void ratios, by the equation shown. Recall from Module 4 that void ratio is calculated from the specific
37 gravity and the dry density of a sample.

-

$$D_r\ (\%) = \frac{D_{max}\ (D - D_{min})}{D(D_{max} - D_{min})} \times 100$$

Because density is directly related to void ratio, an alternative equation may be derived. This equation shows relative density in terms of a given density and the minimum and maximum index densities, rather than in terms of void ratios. Typical values for relative density selected for preliminary design are from 50 to 80 percent relative
38 density.

-

ACTIVITY 5

Activity 5, Part D, of your Study Guide reviews relative terminology and has examples and problems on relative density calculations. Stop the tape and complete that Activity.

39

Clean and dual classified coarse-grained soils are somewhat rare in nature. Beach sands and some desert soils are examples of clean coarse-grained soils. Consequently, few fills containing large quantities of clean or dual classifications of coarse-grained soils are constructed. Relative density most frequently applies to the placement and control of the density of drain and filter materials. These materials have usually been processed and washed to remove
40 most of the fines.

ESTIMATES OF MINIMUM AND MAXIMUM INDEX DENSITIES

Correlations have been developed from a large number of tests that can be used to obtain an estimate of minimum and maximum index densities. The correlations are based on gradation of soils. The correlations shown are based on the percent of the sample finer than the number 16 size sieve.
41 They were developed by the U.S. Army Corps of Engineers.

Correlations should be used with caution because they do not consider important variables such as specific gravity of the particles and shape of the particles. Samples of the same gradation but with differing angularity of particles will have significantly differing values of reference densities.

Correlations may be useful for preliminary estimates of relative density values, and for cases where extensive
42 laboratory testing is not justified.

ACTIVITY 6

Activity 6, of your Study Guide covers correlations for estimating values of index densities for clean coarse-grained
43 soils. Stop the tape and complete the Activity.

Relative density and index density tests are used as follows in the design of an earth fill:

First, index density tests are performed on representative
44 soils to be used in the fill.

45 Then, a design relative density is arbitrarily selected. Often, 70 percent relative density is assumed.

-

46 Engineering property tests such as shear strength and permeability tests are then performed at a dry density corresponding to the preliminary design density. The flow charts shows parameters that might be obtained in tests on a soil.

-

47 Using engineering test values obtained, the structure is analyzed for stability or seepage problems.

-

48 If the resulting design is judged inadequate, other design densities may be assumed and the process repeated until an acceptable fill is indicated. If the design is adequate, the relative density assumed will be used to write construction specifications.

-

49 After a design is based on a relative density value, then construction specifications may be written requiring the coarse-grained soils to be placed at the required reference densities. Just as with compaction, using a reference density rather than some single value of density is preferable when materials are expected to be variable. Field tests must be performed if different soils are encountered.

-

50 These index density tests are difficult to perform in the field. Consequently, using relative density specifications for earth fill quality control is unusual in the Soil Conservation Service. A more common approach is to specify an acceptable density value based on laboratory tests or correlations, or to specify the equipment type, lift thickness, and minimum number of passes of the equipment, based on previous favorable experience.

-

51 Usually, specifications also require thorough wetting of clean fine sands to prevent bulking and ensure good compaction. Filters and drains may be composed of these soil types.

-

ACTIVITY 7 Examples of construction specifications for placing coarse-grained soils with less than 12 percent fines are shown in Activity 7, of your Study Guide. Stop the tape
52 and review the Activity.

-

Let's review the objectives of Part D. Objective 1 was to define the terms associated with index density and relative
53 density.

-

Objective 2 was to identify the equipment and procedures used
54 for performing index density tests in the laboratory and field.

-

Objective 3 was to estimate values for index densities based
55 on soil classification and gradation data.

-

ACTIVITY 8 Activity 8, Part D, tests your completion of these
56 objectives. Stop the tape and complete the Activity.

-

That completes Part D of Module 5. You are now ready to
57 proceed to Part E.